Thinking in Diagrams

A textbook about diagrammatic thinking, with a diagram lab in it, covering the systems and feedback family of diagrams.

Online, with a lab for each exercise: thinking-in-diagrams.aryehnielsen.com

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Part I — Framing

What Is a Diagram For?

All six diagram types Part I · Framing · Chapter 1 of 12 · the opening chapter

What does a diagram show that a paragraph doesn't? A diagram puts every *cause* of a quantity at that quantity, shows a circle that a paragraph's order hides, and, with dashed lines, shows *which* effects its author judges less supported.

Empty shops on the high street

The spring newsletter of a market town's traders opened with this paragraph:

> Since the council raised parking charges, fewer people come into town. The council's own footfall counter shows visitors down by a fifth over two years, and our own figures show takings per shop falling with them, month by month. Seven shops have closed, and every owner gave falling takings as the reason. Every empty shop gives people one less reason to come, so fewer still come. Some blame online shopping, but people shopped online before the charges went up.

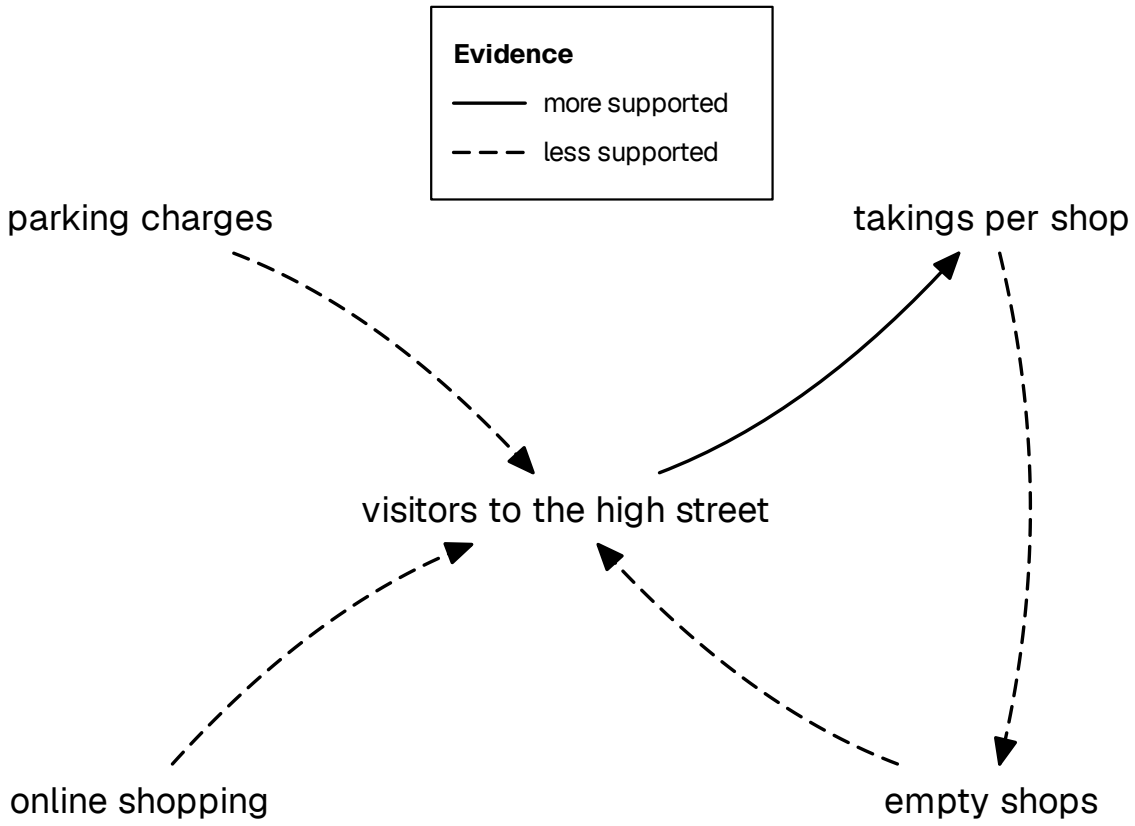
What the notation expresses

Variables

A **variable** is a quantity that can rise or fall, named as a noun phrase: *visitors to the high street*, *takings per shop*. An action is not a variable: *shoppers stay away* names something that happens, and *visitors to the high street* names what rises or falls when it does. The test for a name is in chapter 4 (chapter 4, Variables).

Effects

An **effect** is a line with an arrowhead from one variable to another: a change in the first changes the second. *Takings per shop* → *empty shops*: as takings fall, shops close.



Every figure in the chapter is the start of a causal loop diagram, whose effects gain a polarity, + or –, for which way the change runs: by the upgrade (chapter 3, Causal claims) in chapter 3, where a direction has been measured, and on every effect in chapter 4 (chapter 4, Polarity).

Evidence coding

Evidence coding shows the author's judgment of how well supported each effect is as a causal mechanism: in a diagram with a dashed effect, a solid effect is one the author judges *more supported*, and a dashed one *less supported*, a hypothesis. A dashed line means nothing else in this book.

Support comes in kinds, some stronger than others: a comparison of places where the first variable changed with places where it didn't; a count of the second changing alongside the first; an explanation of how the first changes the second; testimony; a hunch. Where the line between solid and dashed falls is the author's decision: one author draws solid only what a comparison supports, another anything better than a hunch, and a reader can question either.

The traders draw theirs at a count. They counted takings falling with visitors, month by month, and draw *visitors → takings* solid; the owners' reasons for closing are testimony, and *takings → empty shops* is dashed, though a trader who took the owners at their word could draw it solid.

A variable counted alone supports no effect. The footfall counter measures *visitors to the high street*, down by a fifth, but nobody counted visitors *alongside* a change in the charges, in online shopping or in empty shops, so the traders dash those three effects too.

A diagram with no dashed effect carries no coding: its solid effects are its author's claims, their support unrecorded.

CHECK YOUR UNDERSTANDING

A neighbour is sure the new streetlights on her road have cut burglaries there, and draws streetlights on the road → burglaries on the road as a solid effect. Which of these would give her the strongest grounds for drawing it solid?

a Burglaries on her road counted for a year before the lights went in and a year after

b The police count showing twelve burglaries on her road this year

c Her twenty years on the road, and how sure she is

Feedback: Answers, chapter 1

The legend

The **legend** is a box listing the codings a diagram uses; any diagram with a dashed effect must have one. Its evidence entry shows a solid line for *more supported* and a dashed line for *less supported*. It also lists any viewpoint tags (chapter 5, Viewpoint tags), chapter 5's small boxes naming who stresses an effect.

The drawing and the paragraph

The paragraph runs from the charges to the shops; the drawing shows four things its order hides:

- **A circle.** *Fewer still come* leads back to the first variable: *visitors → takings → empty shops → visitors* is a closed path, in chapter 4 a loop (chapter 4, Loops).
- **Two causes at one variable.** Parking charges and online shopping both end at *visitors to the high street*. The traders blame one and dismiss the other, on the same evidence: none.
- **Causes with nothing into them.** Nothing drawn changes the charges or online shopping.
- **Where the traders draw the line.** Of the circle's three effects, only *visitors → takings* is solid.

In the paragraph, what bears on visitors is spread over three sentences; in the drawing, it is the three lines ending at *visitors*. A diagram puts at one place what is used together, and shows what a paragraph leaves to be worked out (Larkin and Simon, 1987).

Reading someone else's diagram

Of each effect, solid or dashed, ask what changes; whether a change in the first changes the second, or only comes before it; and how anyone knows. Of the coding, ask where the author drew the line between solid and dashed, and whether you would draw it there: a solid effect is its author's judgment, not proof that one change causes the other. Of the whole, ask what is missing: a cause nobody drew, or an effect that would close another circle.

The lab's checks test structure, never whether an effect holds: a check counting dashed effects passes a diagram with the *wrong* ones dashed.

CHECK YOUR UNDERSTANDING

A florist draws roadworks on her street → customers a day as a solid effect: her till shows customers fell by a third the week the roadworks began. Which question about that effect has her till left open?

a Whether the roadworks changed her customers, or only came before the fall

b What changes

c Whether customers fell

Feedback: Answers, chapter 1

The bad diagram

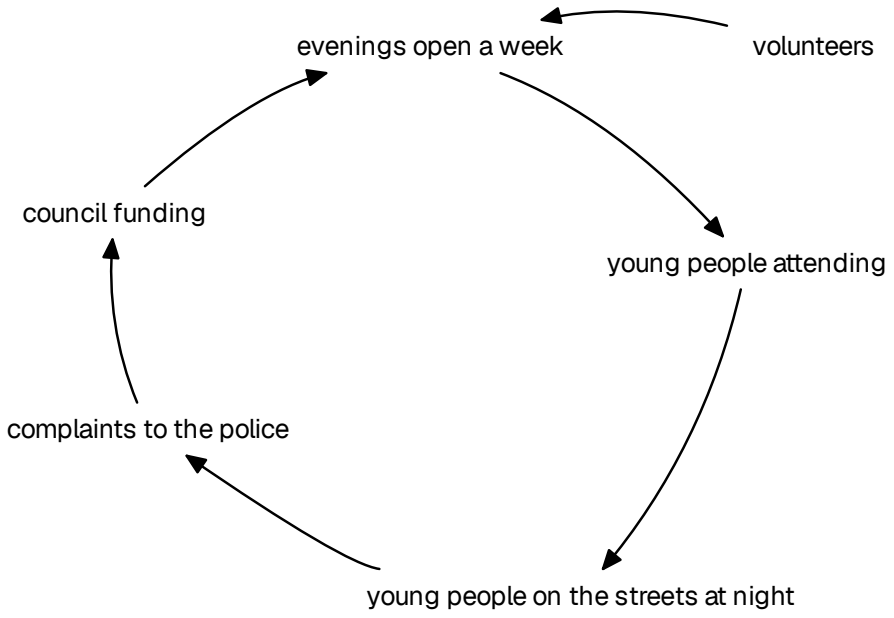
What's wrong with this diagram, from a youth club's bid to the council for another year's funding?



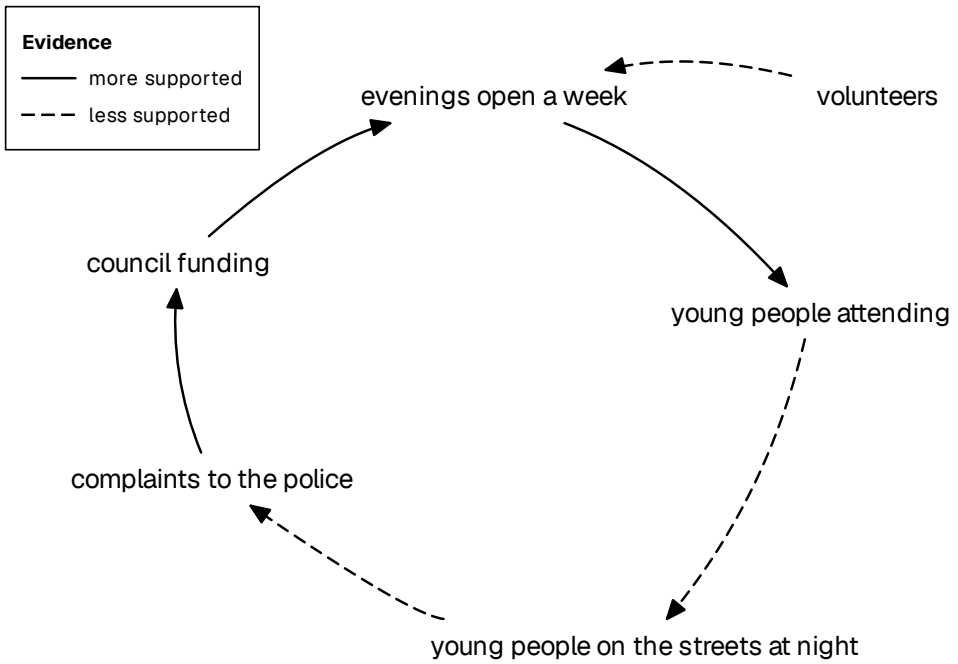
Every effect is solid, and three rest on counts: the club's sign-in sheets count attendance by evening, the council publishes its youth grant each year beside complaints to the police in the club's area, and the club's accounts show how many evenings the grant pays for. That attending keeps young people off the streets at night, that fewer on the streets means fewer complaints, and that more volunteers would open more evenings are the club's beliefs. The club draws no line between counts and beliefs, so a reader can't tell the sign-in sheets from a belief about the streets at night.

The corrected diagram

Bad diagram



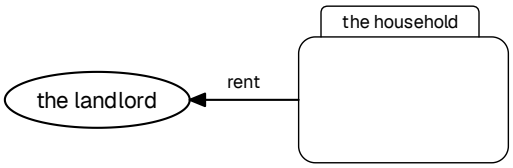
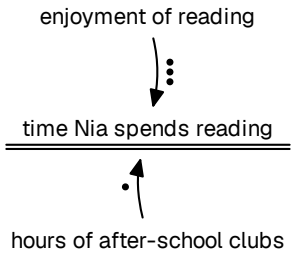
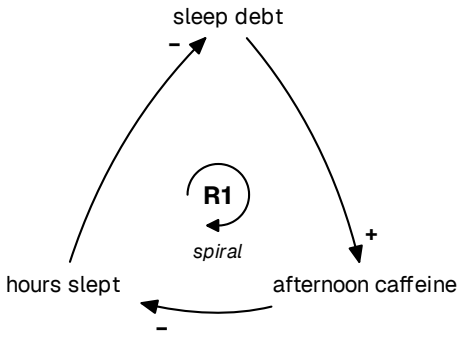
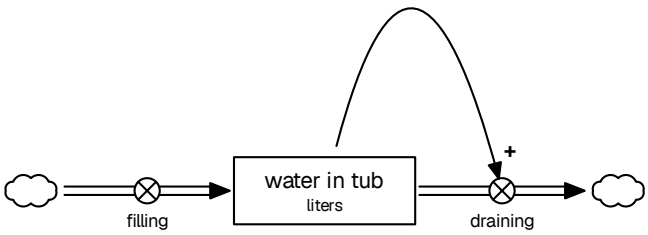
Corrected diagram

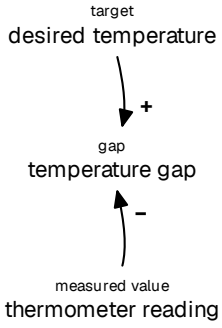
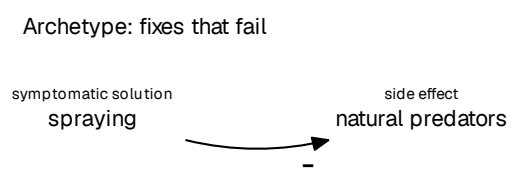


Labels unchanged. 3 effects dashed as less supported: young people attending → young people on the streets at night, young people on the streets at night → complaints to the police and volunteers → evenings open a week; legend switched on.

A count of young people on the streets near the club, on nights it opens and nights it doesn't, would give the club grounds to draw *young people attending → young people on the streets at night* solid.

The central diagram types

Type	Adds to variables and effects	Chapters
system context map (chapter 2, What the notation expresses) 	A named boundary, the parties outside it in ovals, and named exchanges crossing it, in place of variables and effects	2
influence map (chapter 3, What the notation expresses) 	Influence claims, effects with no polarity; weight in dots; one central outcome; clusters	3
causal loop diagram (chapter 4, What the notation expresses) 	A polarity on every effect; loops; delays; boundaries and external drivers	4–5
stock & flow diagram (chapter 6, What the notation expresses) 	Stocks, the flows that fill and drain them, clouds, and signals carrying readings to flows and to other variables	6–7

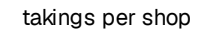
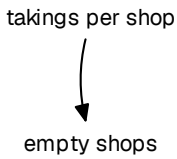
Type	Adds to variables and effects	Chapters
feedback control diagram (chapter 8, What the notation expresses) 	A role written above each variable that plays one, over the causal loop diagram's marks, its effects called signals; where the controlled variable accumulates, a stock and its flows	8–9
system archetype (chapter 10, What the notation expresses) 	A declared archetype and roles, over the causal loop diagram's marks	10–11

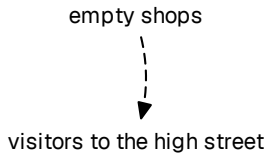
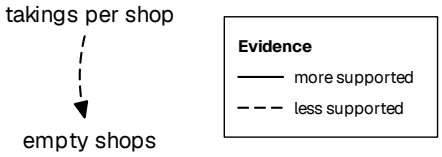
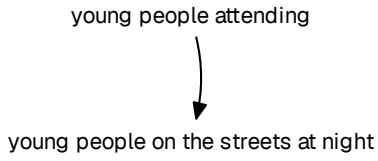
Which type to draw for which question is in chapter 12 (chapter 12, What each type answers). You draw each exercise as one type in the lab, with only the marks you need for it.

What stays informal

One claim, or several that don't meet, go in a sentence: *the charges keep shoppers away*. Causes with no effects between them go in a list. The chapter's figures show no direction, amount or timing; each is drawn from a later chapter on. Each type's case for a sentence instead is in chapter 12 (chapter 12, When not to draw).

Notation moves

Notation move	When	What it shows	Example
Name a variable 		What rises or falls	*takings per shop*, not *shops lose money*
Draw an effect 	A change in one quantity changes another	What changes what	*takings per shop* → *empty shops*

Notation move	When	What it shows	Example
Dash a hypothesis	You judge the effect less supported	Where you drew the line between more and less supported	*empty shops → visitors to the high street*
			
Add a legend	An effect is dashed	The codings in use	*Evidence: more supported, less supported*
			
Ask how they know	You read someone else's diagram	What supports each effect, and where the author drew the line	*young people attending → young people on the streets at night*
			

Common misreading

Read one way, a solid effect is proven everywhere. Its support was gathered *somewhere*, under some conditions: induced traffic, solid on chapter 5's road (chapter 5, Evidence coding), was found across American cities (Duranton and Turner, 2011), and a town of another shape may differ.

Read the other way, a dashed effect is false, or minor. It is less supported, not less important: the high street's dashed *empty shops → visitors* closes the circle.

The strongest objection

Evidence comes in degrees, and the coding has two: an effect counted in one town and one counted in twenty are drawn with the same solid line. The IPCC's authors grade evidence as *limited*, *medium* or *robust*, agreement as *low*, *medium* or *high*, and an outcome's likelihood in seven steps, from *virtually certain* to *exceptionally unlikely* (Mastrandrea and others, 2010).

With the coding, each effect carries one answer, which side of its author's line it falls on, readable at a glance. Where the line falls, and the degrees on either side of it, go in the sources and the prose beside the drawing, where the IPCC's authors put theirs: a *traceable account* of each finding's evidence, in the text.

Check your understanding

CHECK YOUR UNDERSTANDING

A theatre company's report to its funders has a diagram of nine variables and twelve effects, every effect solid, and no legend. What can a reader tell from it about the evidence for each effect?

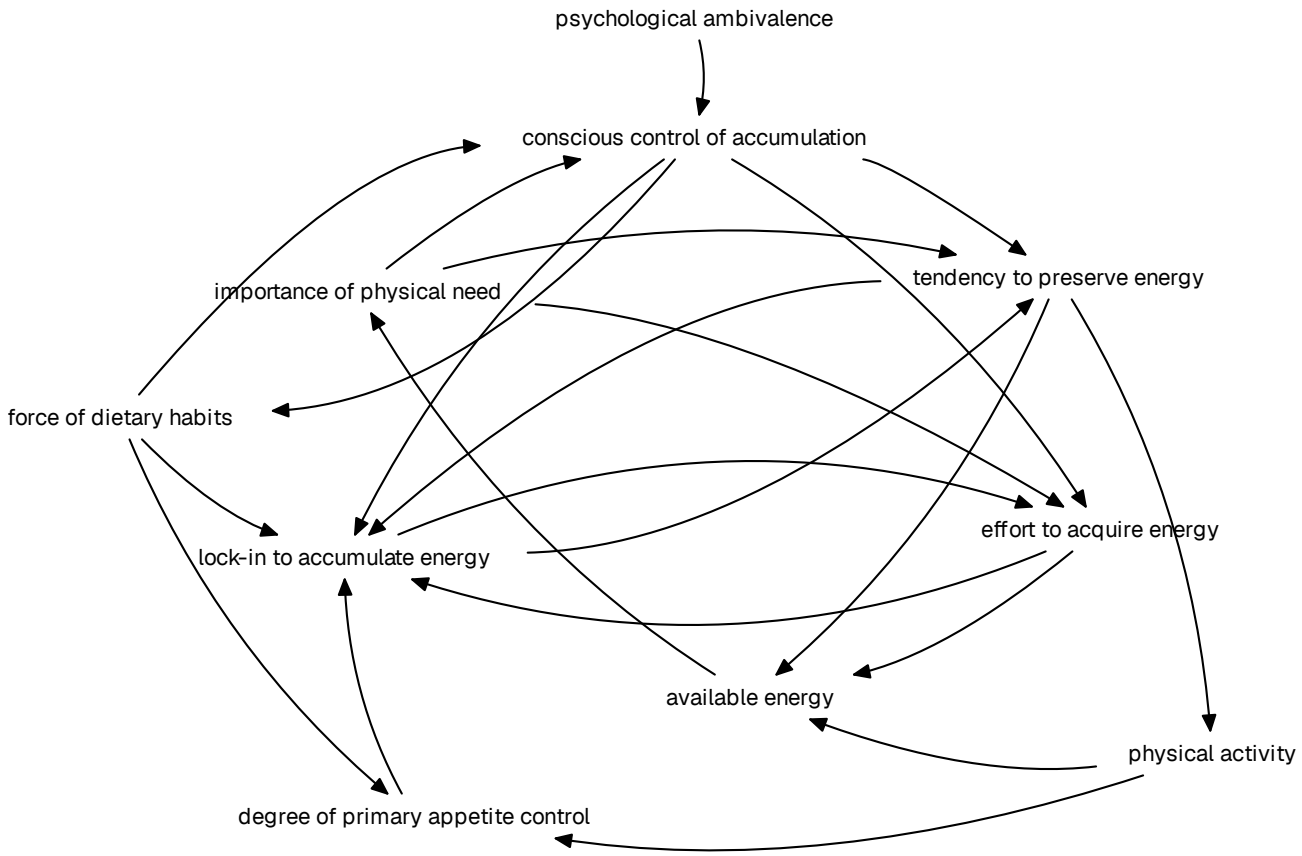
a Every effect is well supported

b Every effect is a hypothesis

c Nothing: each effect's evidence has to be asked about

Feedback: Answers, chapter 1

Foresight's obesity system engine, redrawn



Redrawn from Philippe Vandenbroeck, Jo Goossens and Marshall Clemens, Tackling Obesities: Future Choices – Obesity System Atlas (Foresight, Government Office for Science, 2007)
assets.publishing.service.gov.uk/media/5a7b8811ed915d4147620fb2/07-1177-obesity-system-atlas.pdf, Map 19, System Engine + 4 Key Variables.
Contains public sector information licensed under the Open Government Licence v3.0
www.nationalarchives.gov.uk/doc/open-government-licence/version/3/.

Map 19's ten variables, of about 110 in the whole map, and the 22 effects among them; its solid arrows, marking a positive influence, and its dotted lines ending in a square, marking a negative one, all drawn solid with an arrowhead and no polarity; its colors and the thick bands marking the engine left out; its names lowercased, two shortened.

QUESTION 1 OF 3

Which of these effects could a study support by counting the change in the second variable alongside a change in the first?

a Psychological ambivalence → conscious control of accumulation.

b Physical activity → available energy.

c Every effect, since each is drawn with an arrowhead.

QUESTION 2 OF 3

In the source, twelve of these effects are dotted lines ending in a square. What did that line mean there, and why are those effects drawn solid here?

a That the effect was less supported, as a dash means here.

b A weaker effect than a solid line.

c A negative influence, the second variable moving opposite to the first; here a dash means less supported, a hypothesis, so they are drawn solid, with no polarity.

QUESTION 3 OF 3

No effect here is dashed. Which of the solid effects did the atlas's authors judge more supported?

a Nobody can tell from the lines: a diagram with no dashed effect carries no coding.

b All of them: a solid effect is more supported.

c None of them: with no legend, a solid effect is a hypothesis.

Feedback: Answers, chapter 1

Exercises

Passing the checks means meeting the brief, not being right.

DF 01 Greta's morning drawing

A paragraph drawn

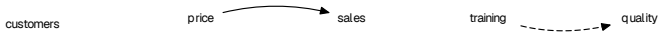
Reasoning ●○○○○ 1 of 5 Polish ●○○○○ 1 of 5

Greta draws for twenty minutes before work each morning and keeps a log. After three months she wrote in it: “I time one sketch every morning, and it now takes me five minutes, down from nine. My times fell fastest in the weeks I drew longest, and not at all in the fortnight I was ill and barely drew. Beside each sketch I mark from one to five how much I enjoyed the session, and the mornings I sketched fastest are the ones I marked highest. On those mornings I keep going past twenty minutes, and the log shows it. I started an online course in January, and I think its lessons have made me faster too, but I've kept no count of the lessons beside my times.”

The brief

- [ ] Draw four variables.
- [ ] Draw an effect wherever Greta writes that one quantity changes another.
- [ ] Code the one effect with the weakest support as a hypothesis, so it is drawn dashed.
- [ ] Each name is a quantity that can rise or fall: minutes drawn each morning, not draws every morning.
- [ ] The effects close a circle.

Your palette



variable effect evidence coding

Draw here

In the lab, with the brief’s structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/framing/what-is-a-diagram-for/#exercise-what-is-a-diagram-for-01

DF 02 Esther's grandchildren's visits

Two readings of one calendar

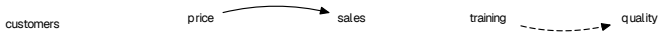
Reasoning ●●○○○ 2 of 5 Polish ●○○○○ 1 of 5

Esther marks each visit from her grandchildren on her kitchen calendar. “Until my son's family moved two hours' drive away, they came every month. Since the move they've come four times a year, and the calendar shows the drop from the first month after it. Last spring the eldest took a Saturday job at a bakery, and I think that keeps them all away now, though I haven't compared the calendar with her shifts. And I think the less often the children come, the less they want to come, and the less they want to, the less often they come. I haven't asked them.” Her son agrees that the drive cut the visits, and says it alone explains them.

The brief

- [ ] Draw four variables.
- [ ] Draw an effect wherever Esther or her son says one quantity changes another.
- [ ] Code the three effects with the weakest support as hypotheses, so they are drawn dashed.
- [ ] Each name is a quantity that can rise or fall: visits a year, not the grandchildren visit.
- [ ] Esther and her son disagree only about dashed effects.

Your palette



variable effect evidence coding

Draw here

In the lab, with the brief’s structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/framing/what-is-a-diagram-for/#exercise-what-is-a-diagram-for-02

DF 03 Hedgehogs in Britain's countryside

Sorting a report's evidence

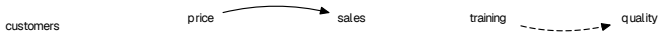
Reasoning ●●○○○ 2 of 5 Polish ●●○○○ 2 of 5

A county wildlife trust's newsletter sums up the report The State of Britain's Hedgehogs 2022 for its members. “Surveys show rural hedgehogs down by between a third and three-quarters in twenty years. Fewer are found dead on roads too, perhaps three-quarters fewer since 1990, though traffic has grown: with fewer hedgehogs about, fewer are killed. Whether road deaths are behind the decline, the report's authors call unclear. Badgers eat hedgehogs and compete with them for earthworms and beetle larvae, and the authors call it likely that badgers reduce hedgehog numbers where there are many of them. Studies show that wide, grassy field margins hold more earthworms and ground beetles; whether hedgehogs are fewer where their prey is scarcer is among the questions the authors list as still being studied. Researchers found that on arable land hedgehogs seek out village gardens to feed and are densest there, and a small hole at the foot of a fence opens one garden to the next.”

The brief

- [ ] Draw at least five variables.
- [ ] Draw an effect wherever the report's authors find or suspect that one quantity changes another.
- [ ] Code at least two effects as hypotheses, so they are drawn dashed.
- [ ] Each name is a quantity that can rise or fall: hedgehogs killed on roads each year, not roadkill.
- [ ] An effect is solid where you judge its support strong enough; when the authors call an effect likely, that is testimony, weaker than a count.

Your palette



variable effect evidence coding

Draw here

In the lab, with the brief’s structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/framing/what-is-a-diagram-for/#exercise-what-is-a-diagram-for-03

DF 04 Objects in orbit

A circle closed by a model

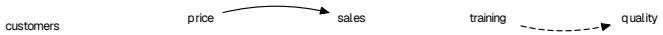
Reasoning ●●●○○ 3 of 5 Polish ●●○○○ 2 of 5

Notes from ESA's Space Environment Report 2026 and NASA's Orbital Debris Quarterly News. Launches add satellites to orbit, and 2025 had the most launches yet counted. Satellites leave orbit at the end of their life, brought down or left to fall: 1,200 intact satellites and rocket stages re-entered the atmosphere in 2025. On 10 February 2009 the working satellite Iridium 33 and the disused Cosmos 2251 collided at more than 11 km a second; both broke apart, and by the end of March 823 of their larger fragments had been catalogued. More fragments come from satellites and rocket stages that break apart without a collision, which ESA counts as the largest source of fragments today. Accidental collisions are few: Iridium 33 and Cosmos 2251 was the fourth known, and the first between two intact spacecraft. That more satellites and fragments in orbit bring more collisions, enough to set off a cascade of them over the coming centuries, comes from models: Donald Kessler and Burton Cour-Palais's in 1978, and ESA's now.

The brief

- [ ] Draw at least five variables, with satellites in orbit and fragments in orbit apart.
- [ ] Draw an effect wherever one quantity in the notes changes another.
- [ ] Code the two effects that come from models, not counts, as hypotheses, so they are drawn dashed.
- [ ] Each name is a quantity that can rise or fall: collisions each year, not a collision.
- [ ] The two dashed effects, from satellites and fragments in orbit to collisions, come from models, not counts, and close the circles.

Your palette



variable effect evidence coding

Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/framing/what-is-a-diagram-for/#exercise-what-is-a-diagram-for-04

CS 01 Kelsham Primary School: the head teacher's letter

Counts and beliefs in one letter

Reasoning ●●○○○ 2 of 5 Polish ●●○○○ 2 of 5

In October 2026 Ruth Okafor, head teacher of Kelsham Primary School, wrote to parents. “We have 88 pupils on roll this October, against 126 in October 2020. This September 9 children started with us and 16 left, Year 6 among them. The county council's records show each September's starters falling with the births in our villages four years before. Each October's count sets our funding, £4,800 a pupil: when the roll fell to 108 in 2023, it paid for four teachers, not five, and Years 3 and 4 became one class. With 88 pupils in four classes, our classes are small. Some of you tell us that mixed-age classes are why families have moved to Brayford Primary School, and others that small classes are why you stay. Nobody has counted either.”

The brief

- [ ] Draw at least six variables, with the children starting each September and the pupils leaving each year apart.
- [ ] Draw an effect wherever Ruth Okafor writes that one quantity changes another.
- [ ] Code the two effects with the weakest support, the reasons parents give, as hypotheses, so they are drawn dashed.
- [ ] Each name is a quantity that can rise or fall: pupils leaving each year, not families move.
- [ ] An effect is solid where you judge a count by the school or the county council supports it.

Your palette



variable effect evidence coding

Draw here

In the lab, with the brief’s structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/framing/what-is-a-diagram-for/#exercise-case-01

Sources

- Jill H. Larkin and Herbert A. Simon, “Why a Diagram Is (Sometimes) Worth Ten Thousand Words” doi.org/10.1111/j.1551-6708.1987.tb00863.x, *Cognitive Science* 11, no. 1 (1987): 65–99, on diagrams that hold at one location what an inference uses, and make explicit what sentences leave implicit.
- Michael D. Mastrandrea and others, *Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties* www.ipcc.ch/site/assets/uploads/2017/08/AR5_Uncertainty_Guidance_Note.pdf (IPCC, 2010), on grading evidence, agreement and likelihood in words, with a traceable account in the text.
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- Donald J. Kessler and Burton G. Cour-Palais, “Collision Frequency of Artificial Satellites: The Creation of a Debris Belt” doi.org/10.1029/JA083iA06p02637, *Journal of Geophysical Research* 83, no. A6 (1978), for DF 04.

Drawing the Boundary

System context maps Part I · Framing · Chapter 2 of 12 · the one chapter on system context maps

What is inside the system you're responsible for? A system context map shows a named boundary around that system, the parties outside it that it deals with, and each thing that crosses between them, by name.

Signals you need this diagram

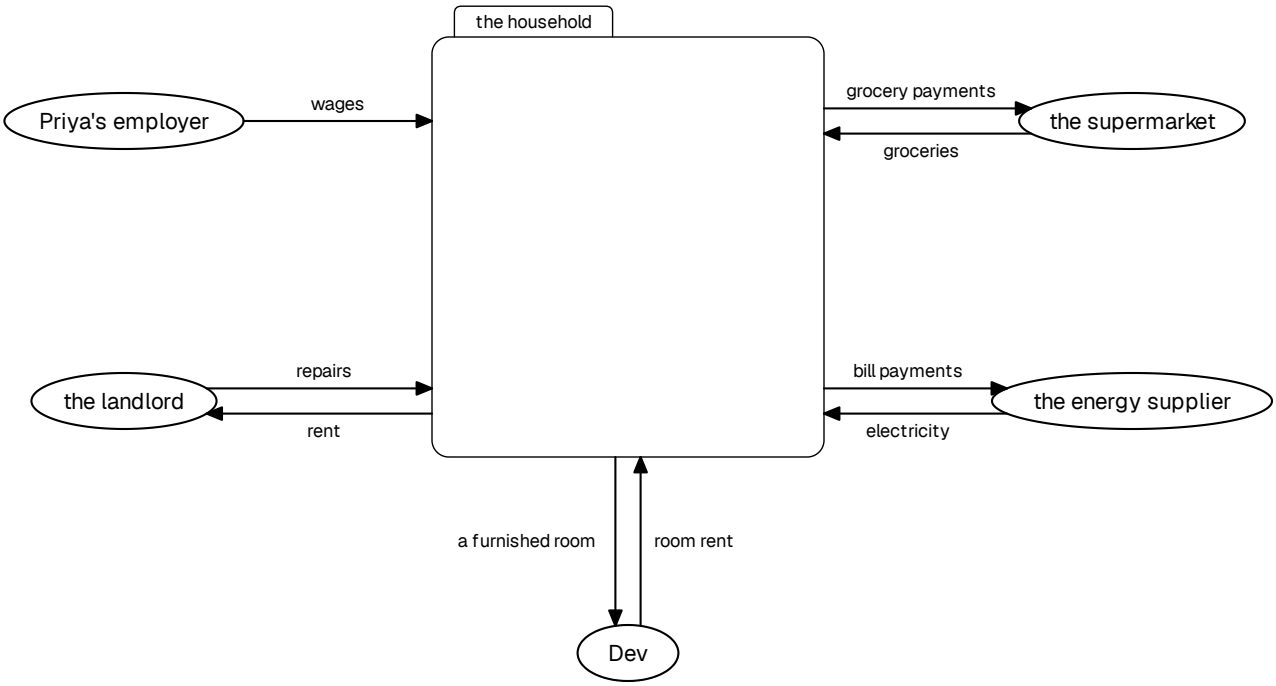
- People disagree about whose job something is.
- Something arrives that nobody expected to deal with: a bill, a request, a complaint.
- A new job, project or household starts, and nobody has listed who it deals with.
- A party outside is spoken of as if it were run from inside.
- A problem passes from one part to another, each saying it belongs elsewhere.

A household with a lodger

Priya and Sam rent a house with their ten-year-old daughter. Sam's nephew Dev rents their spare room, furnished, and buys and cooks his own food. Sam shops and cooks for the family; Priya pays the rent and the bills.

Each month Priya's wages arrive from her employer, and the household pays the landlord rent, the supermarket for groceries and the energy supplier for electricity. Dev pays the household rent for his room.

In January the boiler fails. Dev asks Sam when his room will be warm again; Sam phones the landlord, who sends a plumber three days later. The household owes Dev a warm room, and depends on the landlord to provide one.



What the notation expresses

The boundary

A **boundary** is a thin, solid, rounded outline drawn around the system, with a tab carrying the system's name. It marks what the map explains. What sits outside, the map doesn't explain: it shows what the landlord gives the household and receives from it, not how the landlord runs a business.

Every boundary has a name, since drawing one means saying which system it bounds: here, *the household*. A boundary is never dashed: in this book a dashed line means a hypothesis.

External entities

An **external entity** is a party outside the boundary that the system exchanges something with: a person, an organization or, at the scale of a planet, the Sun. It's drawn as its name in an oval. A party appears because something crosses between it and the system; one with nothing crossing is left off.

The system runs what is inside its boundary and only exchanges with what is outside. Dev lives in the house, but he pays for his room and runs his own meals, so he's an external entity; the daughter, whose room and meals the household provides, is inside.

An external entity isn't a variable: nothing on a system context map rises or falls.

CHECK YOUR UNDERSTANDING

Dev stops paying rent. Sam's sister asks the household to take him in as one of the family, and from then on he eats its meals and shares its money and chores. Is Dev still an external entity?

a Yes: he's a nephew, not one of Priya and Sam's children

b No: the household now runs his meals and money, so he's inside the boundary, with no oval

c Yes: he still sleeps in the spare room

d Yes, drawn as an oval inside the boundary

Feedback: Answers, chapter 2

Exchanges

An **exchange** is one named thing crossing the boundary between the system and an external entity: *wages*, *rent*, *electricity*. It's drawn as a solid line with one arrowhead, joining an oval to the boundary, with its name beside its middle. One exchange carries one thing: *rent and repairs* is two exchanges. A line without a name shows *that* something crosses, not what.

Direction

An exchange's **direction** runs from the party that gives to the party that receives. The household gives the landlord rent and receives repairs: two exchanges, pointing opposite ways.

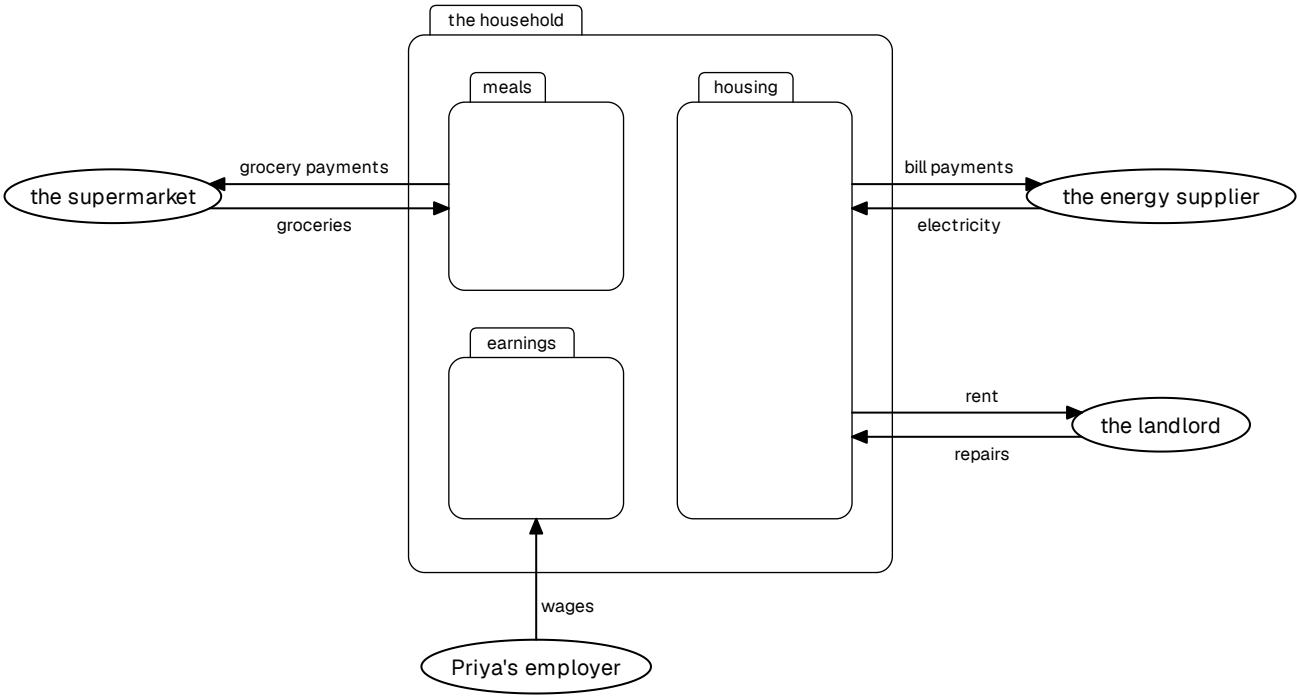
The exchanges leaving the boundary are what the system answers for to others, such as Dev's furnished room; those arriving are what it depends on, such as the landlord's repairs.

Nested boundaries

A **nested boundary** is a boundary inside another, naming a part of the system. Nesting is read from position: a boundary drawn wholly inside another is its part. Two boundaries either nest or stay apart; overlapping ones

leave it unclear which part a thing belongs to.

A part is named for what it does, not for who does it: *meals*, not *Sam*. If Priya takes over the cooking, the part stays.



Owners

An exchange's **owner** is the boundary it reaches. With parts drawn, each exchange reaches the part that handles it: groceries and grocery payments reach *meals*, wages reach *earnings*, and rent, repairs, electricity and bill payments reach *housing*. When the boiler fails, chasing the landlord's repairs falls to *housing*. An exchange drawn to the outer boundary belongs to the system as a whole.

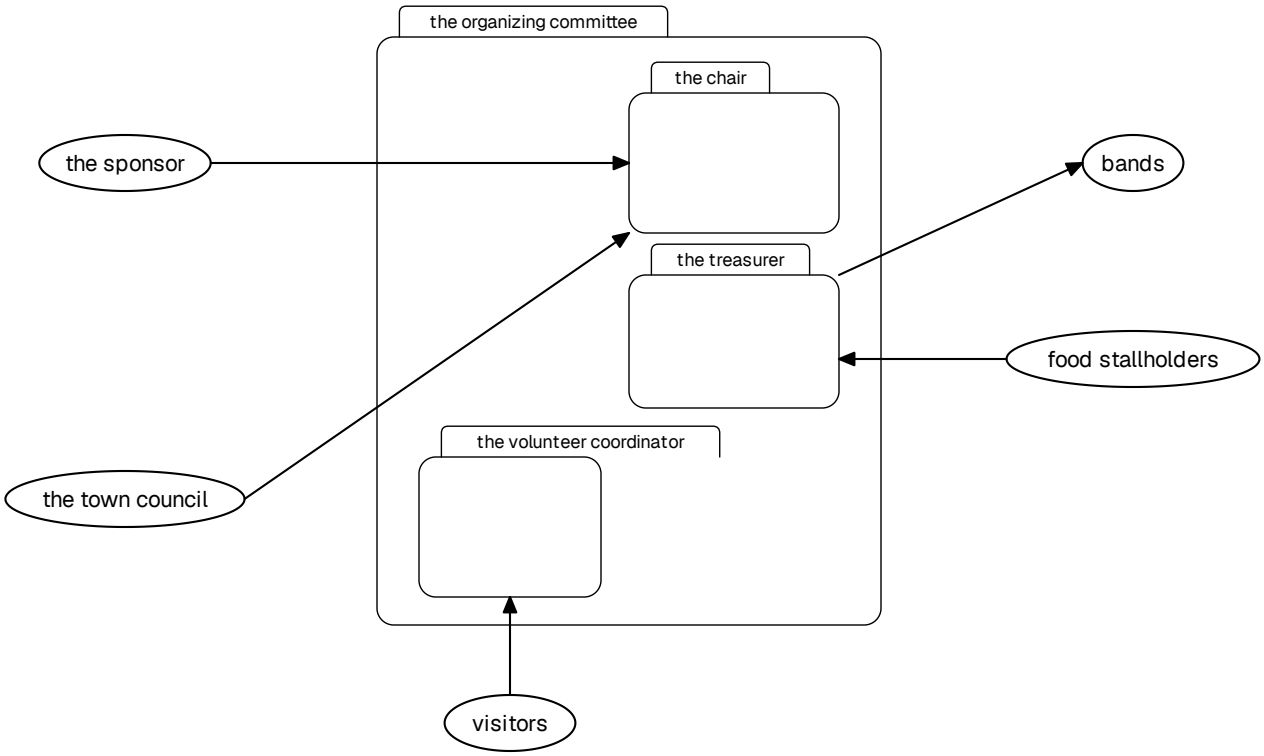
What stays informal

With one or two parties, a sentence does what the map would: *the household pays the landlord rent and gets repairs*. When a reader needs only who the system deals with, not what crosses, as on a list of emergency phone numbers, a list of parties does it.

The map shows no amounts and no timing: not how much the rent is, nor when it's due. Nor does it show causes, such as why the electricity bill rose; influence maps and causal loop diagrams, from chapter 3, show those. What passes between parts, such as *earnings* paying for *meals*, stays in a sentence.

The bad diagram

What's wrong with this map of a volunteer-run festival?



Its boundary is *the organizing committee*, with nested boundaries for the chair, the treasurer and the volunteer coordinator: an organization chart, showing who sits on the committee, not what the festival runs. Its five exchanges have no names and each runs one way only, so the map shows that the town council, the sponsor, bands, food stallholders and visitors deal with someone, not what they give or receive. The lab's check reports:

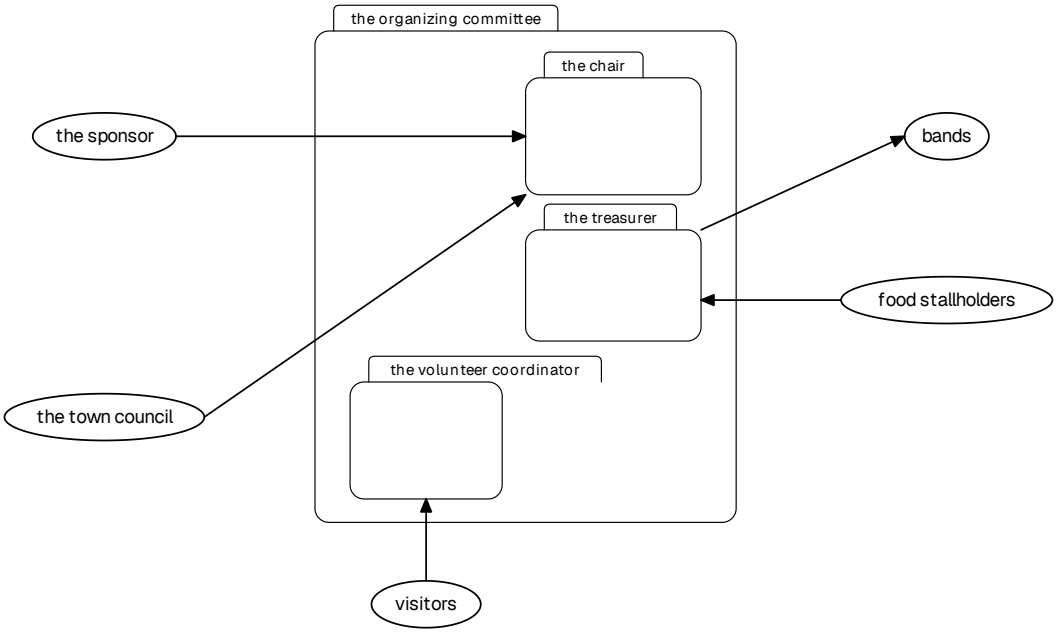
> 5 of 5 exchanges have no name yet: from the town council to the chair; from the treasurer to bands; from food stallholders to the treasurer; from visitors to the volunteer coordinator; from the sponsor to the chair. Name the one thing each carries.

The lab checks names, not what a boundary is drawn around: the committee's map with every exchange named would pass.

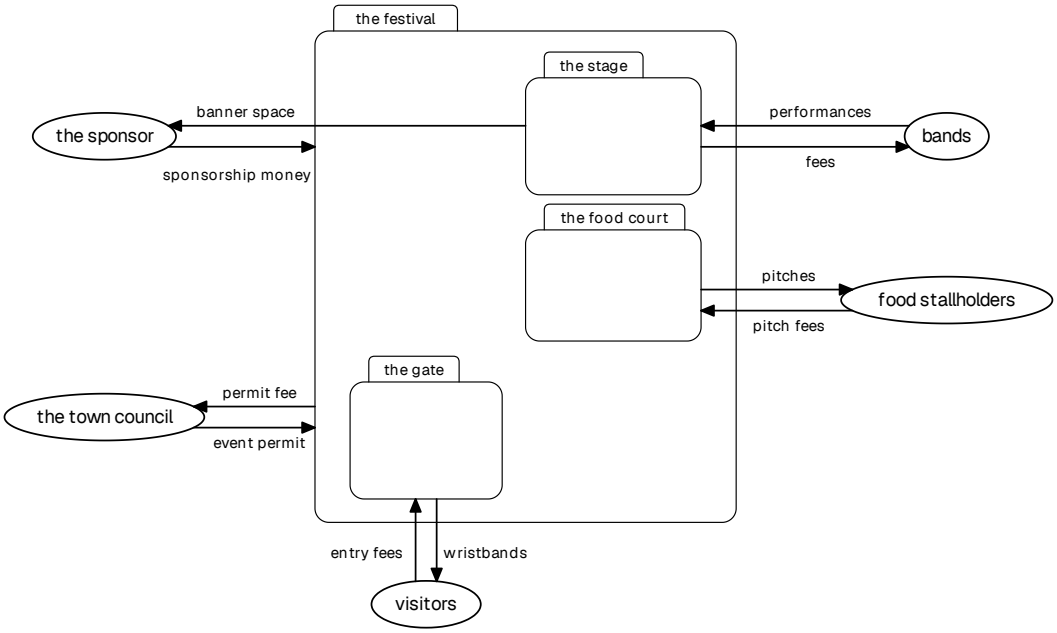
The corrected diagram

Corrected, the boundary is *the festival*, with parts for what it runs: *the stage*, *the food court* and *the gate*. The same five parties exchange named things both ways, each with the part that handles it: bands give the stage performances and receive fees; visitors give the gate entry fees and receive wristbands. The council's event permit and the sponsor's money reach the festival as a whole.

Bad diagram



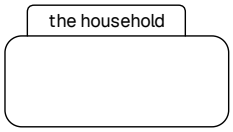
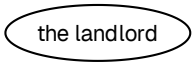
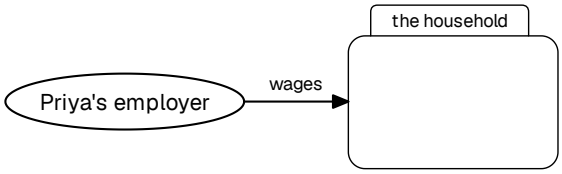
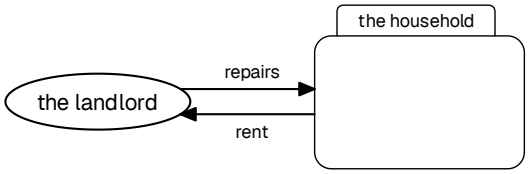
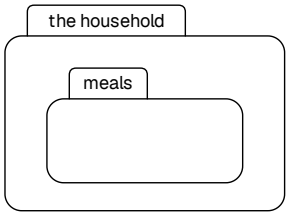
Corrected diagram



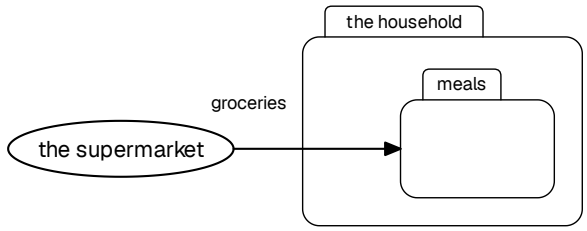
Labels unchanged. Boundaries: 4 renamed. Exchanges: 5 added, 5 named, 3 given another owner.

A new treasurer leaves the corrected map unchanged; a second stage would add a part.

Notation moves

Notation move	When	What it shows	Example
Draw a boundary and name it 	You can name the system you're responsible for	What the system is	*the household*
Place an external entity 	A party gives to the system or receives from it	Who the system deals with	*the landlord*
Draw an exchange and name it 	Something crosses between the system and a party	One thing crossing, and which way	*wages*, from Priya's employer
Draw the exchange back 	Something crosses the other way	What the system gives as well as what it receives	*rent* out, *repairs* in
Draw a nested boundary 	Different parts of the system handle different exchanges	A part of the system	*meals*

Notation move	When	What it shows	Example
Draw an exchange to its part	Parts are drawn	The exchange's owner	*groceries* to *meals*



Check your understanding

CHECK YOUR UNDERSTANDING

Ana, who lives down the street, starts minding the daughter after school, and the household pays her each week. On the map with the parts meals, earnings and housing, how are these drawn?

a One exchange, childminding, between Ana and the household

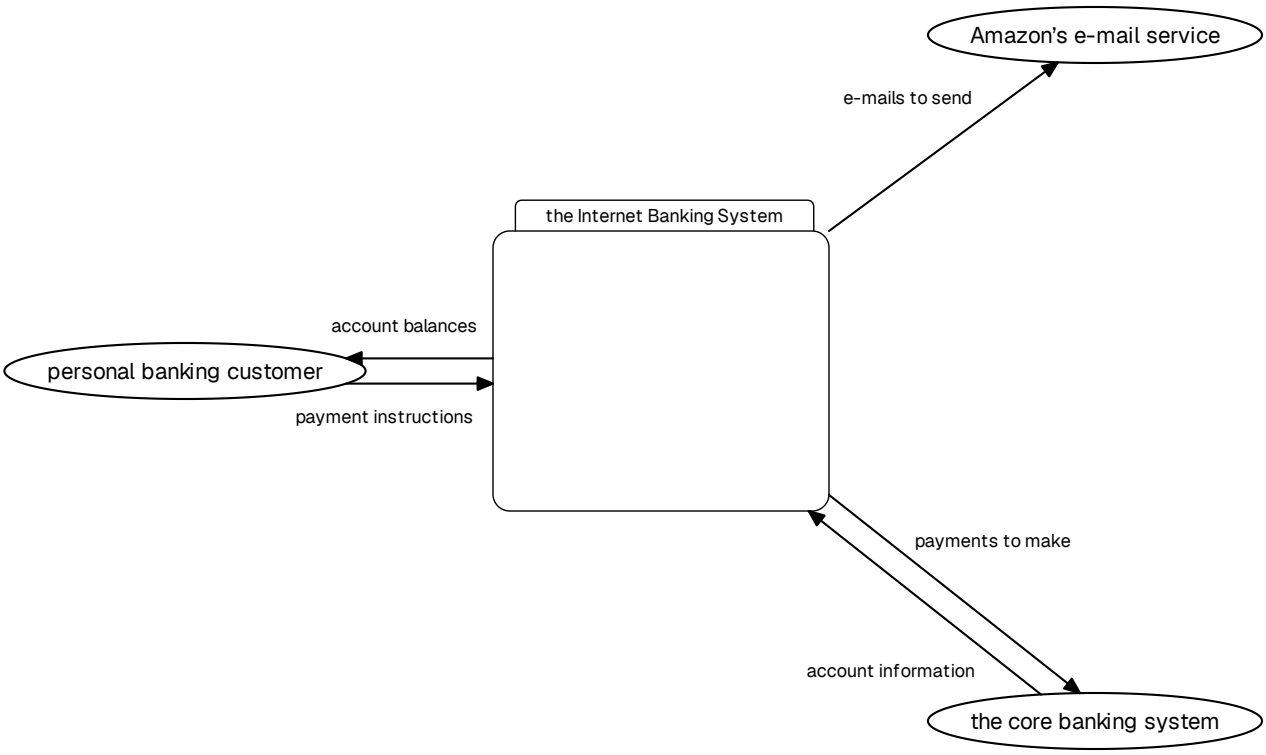
b A new nested boundary, childcare, with childminding running into it from Ana and fees running out to her

c Fees out of earnings, since earnings receives the wages

d A nested boundary named Ana, inside the household

Feedback: Answers, chapter 2

The Internet Banking System, redrawn



Redrawn from Simon Brown, "System context diagram", The C4 model (c4model.com) c4model.com/diagrams/system-context, the system context diagram of the Internet Banking System. CC BY 4.0 creativecommons.org/licenses/by/4.0/.

The system's box drawn as the boundary and the other three boxes as external entities; each dashed line, which points from a party to what it relies on, drawn as solid exchanges named for what crosses, one for each thing it carries, pointing from the party that gives; the e-mail service's name shortened; colors and descriptions left out; the e-mail service's line to the customer, between two parties outside, left out.

QUESTION 1 OF 3

Which parties sit outside the boundary?

a None: the source's figure has every party in a box, as it has the system.

b Only the personal banking customer: the other two are software, as the system is.

c All three: the customer, Amazon's e-mail service and the core banking system.

QUESTION 2 OF 3

The source's figure has four lines. Which one is no exchange on this map, and so is left out?

a The customer → the system, since the customer also receives from the system.

b Amazon's e-mail service → the customer, labeled Sends e-mails to.

c The system → Amazon's e-mail service, since an e-mail is information, not a thing given.

QUESTION 3 OF 3

The core banking system belongs to the same bank as the Internet Banking System. With the boundary drawn around the bank instead, what changes?

a Nothing: the core banking system is a separate piece of software either way.

b The customer moves inside too, as a customer of the bank.

c The core banking system moves inside, and account information and payments to make no longer cross the boundary.

Feedback: Answers, chapter 2

Exercises

Passing the checks means meeting the brief, not being right.

SC 01 A first term away from home

One boundary and the parties outside it

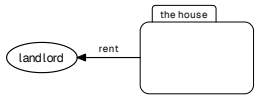
Reasoning ●○○○○ 1 of 5 Polish ●○○○○ 1 of 5

Maya starts a geology degree at a university three hundred miles from home. The university gives lectures, sets essays and returns them with grades. Her parents send her an allowance each month. She works two evening shifts a week at a café, which pays her wages, and borrows books from the city library. Draw her studies as the system, with the parties they exchange with outside it. Leave out her housemates and the friends she makes in lectures.

The brief

- [ ] Draw one boundary around Maya's studies.
- [ ] Place four to six external entities outside it.
- [ ] Draw at least four exchanges.
- [ ] Each external entity is a party that gives or receives something, not a feeling or a task.

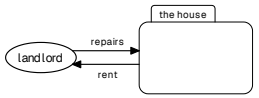
Your palette



boundary



external entity



exchange

Draw here

SC 02 Earth

One boundary, at the largest scale

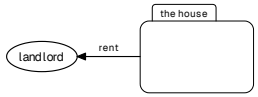
Reasoning ●○○○○ 1 of 5 Polish ●●○○○ 2 of 5

Sunlight reaches Earth from the Sun. Earth reflects part of that sunlight back out to space and radiates heat to space. A trickle of meteoric dust falls in from space, and light gases such as hydrogen escape from the top of the atmosphere. Draw Earth as the system, with what crosses between it and the parties outside it.

The brief

- [ ] Draw one boundary: Earth.
- [ ] Place two external entities outside it.
- [ ] Draw at least four exchanges.
- [ ] Show at least one external entity that both gives to Earth and receives from it.
- [ ] The names show which crossings are energy and which are matter.

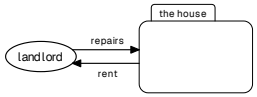
Your palette



boundary



external entity



exchange

Draw here

SC 03 A shared house

Named exchanges in both directions

Reasoning ●●○○○ 2 of 5 Polish ●●○○○ 2 of 5

Five students share a rented terraced house for their second year. They pay the landlord rent each month and send him a fault report when something breaks, and he sends a plumber or an electrician to make the repair. An energy supplier provides gas and electricity, and the students pay it by monthly direct debit. The council collects council tax, empties the bins each Tuesday and issues a parking permit for the one car they share. The neighbours take in the students' parcels, and the students feed the neighbours' cat when the neighbours are away. Draw the household as the system, with the parties it exchanges with outside it.

The brief

- [ ] Draw one boundary around the household.
- [ ] Place at least four external entities outside it.
- [ ] Show at least three external entities that both give to the household and receive from it.
- [ ] Each exchange names one thing: rent and repairs is two exchanges.

Your palette



boundary external entity exchange

Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/framing/drawing-the-boundary/#exercise-system-context-03

SC 04 A national blood service

Named exchanges in both directions, across a nation

Reasoning ●●○○○ 2 of 5 Polish ●●●○○ 3 of 5

A national blood service collects blood from volunteer donors at sessions across the country. It tests every donation and writes to any donor whose blood shows an infection. It separates the blood into red cells and platelets and delivers both to hospitals, which order what they need each day and pay for each unit. The health ministry funds the service and receives its annual report. The regulator licenses the service and receives a report of every serious incident, such as a transfusion given to the wrong patient. Research laboratories receive donations unfit for transfusion as research samples and send back their study results. Draw the service as the system, with the parties it exchanges with outside it.

The brief

- [ ] Draw one boundary around the blood service.
- [ ] Place at least five external entities outside it.
- [ ] Show at least four external entities that both give to the service and receive from it.
- [ ] Draw at least eight exchanges.
- [ ] Donors sit outside the boundary: the service exchanges with them and doesn't run them.

Your palette



boundary external entity exchange

Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/framing/drawing-the-boundary/#exercise-system-context-04

SC 05 A community garden

Nested boundaries and owners

Reasoning ●●●○○ 3 of 5 Polish ●●●○○ 3 of 5

Linden Street garden is a community garden on a former car park, divided into growing beds, compost bays and a tool shed. The water supplier pipes water to the growing beds, and the vegetables grown there go to the food bank each Saturday. A café on the corner brings its food scraps to the compost bays, and the parks department delivers fallen leaves there each autumn and collects finished compost for its flower beds. Neighbours bring their grass cuttings to the compost bays and borrow tools from the tool shed. Draw the garden as the system, divided into its parts, with each exchange reaching the part that handles it.

The brief

- [ ] Draw at least two nested boundaries inside the garden, one for each part.
- [ ] Place at least five external entities outside the garden.
- [ ] Draw each exchange to the part that handles it.
- [ ] Each part is named for what it does, not for who works in it.

Your palette



boundary external entity exchange

Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/framing/drawing-the-boundary/#exercise-system-context-05

CS 02 Kelsham Primary School and the parties it deals with

Exchanges both ways, and a party that only receives

Reasoning ●●○○○ 2 of 5 Polish ●●○○○ 2 of 5

Before the governors meet the county council, Tom Hale asks them to list what Kelsham Primary School exchanges with each party it deals with. Families send their children as pupils and tell the school what they think of it, and the school sends them a report on each child every term. The county council pays the school its funding and receives the count each October, and David Brennan, its officer for school places, sends a forecast of starters. Dale Coaches sends the school bus timetable, and the school sends it the list of children on the bus. When a child moves to Brayford Primary School, the school sends the child's records there. Larkfield Homes, the builder of the 60 homes at Mill Lane, sends the dates its first homes will be lived in, and the school sends leaflets for its buyers. Draw the school as the system, with the parties it exchanges with outside it.

The brief

- [ ] Draw one boundary around the school.
- [ ] Place at least five external entities outside it.
- [ ] Show at least four external entities that both give to the school and receive from it.
- [ ] Each exchange names one thing: funding and the forecast of starters are two exchanges.
- [ ] Leave off what passes between two parties outside the school, such as the county council's payments to Dale Coaches.

Your palette



boundary external entity exchange

Draw here

Sources

- Tom DeMarco, *Structured Analysis and System Specification* (Yourdon Press, 1978), on structured analysis's top-level diagram: the whole system drawn as one process among the parties outside it.
- Edward Yourdon, *Modern Structured Analysis* (Yourdon Press, 1989), on the environmental model, the part of structured analysis that draws a system's surroundings.
- Simon Brown, *The C4 model: System context diagram* c4model.com/diagrams/system-context, on the C4 model's top level: a software system drawn as one box among the people and other systems it deals with.
- Donella H. Meadows, *Thinking in Systems: A Primer* (Chelsea Green, 2008), chapter 4, on boundaries as choices made afresh for each problem.
- John D. Sterman, *Business Dynamics: Systems Thinking and Modeling for a Complex World* (Irwin/McGraw-Hill, 2000), chapter 3, on the model boundary chart, which lists what a model treats as inside, as outside, and leaves out.
- Rebecca Lindsey, "Climate and Earth's Energy Budget" science.nasa.gov/earth/earth-observatory/climate-and-earths-energy-budget (NASA Earth Observatory, 2009), on the sunlight Earth receives and the reflected sunlight and heat it sends to space: SC 02's situation.

Surfacing Influences

Influence maps Part I · Framing · Chapter 3 of 12 · the one chapter on influence maps

Which things affect an outcome, before you know how each changes it? An influence map shows the variables that bear on one outcome, and which bears on which, without saying which way each acts. A claim gets a direction only where its effect has been measured.

Signals you need this diagram

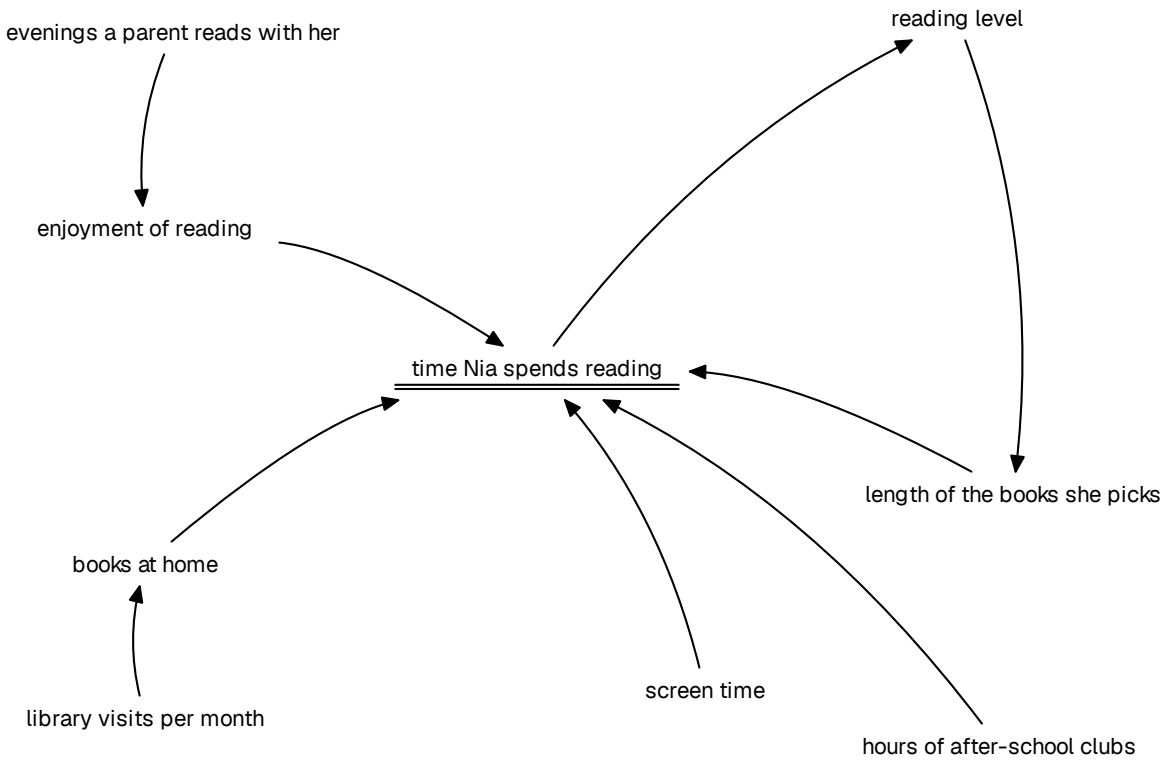
- Many things bear on one outcome, and nobody knows which way most of them act.
- A list of causes keeps growing, with no order to it.
- People argue over which way something pushes before anyone has counted it.
- Some effects have been measured and others only suspected, and a causal loop diagram would show them alike.

Nia’s reading for pleasure

Nia is ten, and her parents would like her to read more for pleasure. Asked what bears on the time she spends reading, they list how well she reads, the length of the books she picks, how much she enjoys reading, the books at home, their visits to the library, her screen time, her after-school clubs, and the evenings one of them reads with her.

Her school’s reading log holds the minutes she reads each day and each book she finishes; her teacher’s assessments give her reading level each term. Over a year the two measured three effects: in terms when she logged more minutes, her level rose further; as her level rose, she picked longer books; and with a longer book on the go, she logged more minutes a day. Nothing records the rest of the list.

Her parents rank her enjoyment highest, her screen time and the length of her books next, and the books at home and her clubs lowest.



What the notation expresses

The central outcome

The **central outcome** is the one variable the map is drawn around: here, *time Nia spends reading*. Its name is double-underlined. A map has exactly one; a second outcome gets a map of its own.

Like every variable, it is a quantity that can rise or fall: *time Nia spends reading*, not *Nia reads*.

Influence claims

An **influence claim** says that one variable bears on another, without saying which way. More screen time might mean less reading or, with books on a tablet, more. It is drawn as a solid line with an arrowhead and no + or −, from the variable that bears to the one it bears on.

Two variables that bear on each other take two claims, one each way.

Direct and indirect influences

A **direct influence** is a claim ending at the central outcome: *screen time → time Nia spends reading*. An **indirect influence** ends at another variable and reaches the outcome through it: *library visits per month* reaches *time Nia spends reading* through *books at home*.

From every variable, a path of claims runs to the central outcome. A variable with no path there either gets the claim it lacks or comes off the map.

Clusters

A **cluster** holds two or more variables that share something, under a label naming what they share: *books to hand* holds *books at home* and *library visits per month*. It is drawn as four corner brackets, the label inside the top-left one. A variable belongs to the cluster whose brackets it sits within.

Clusters neither nest nor overlap, and the central outcome sits in none. With no continuous outline, a cluster can't be read as a boundary (chapter 2, The boundary), which marks what a model explains.

Weight

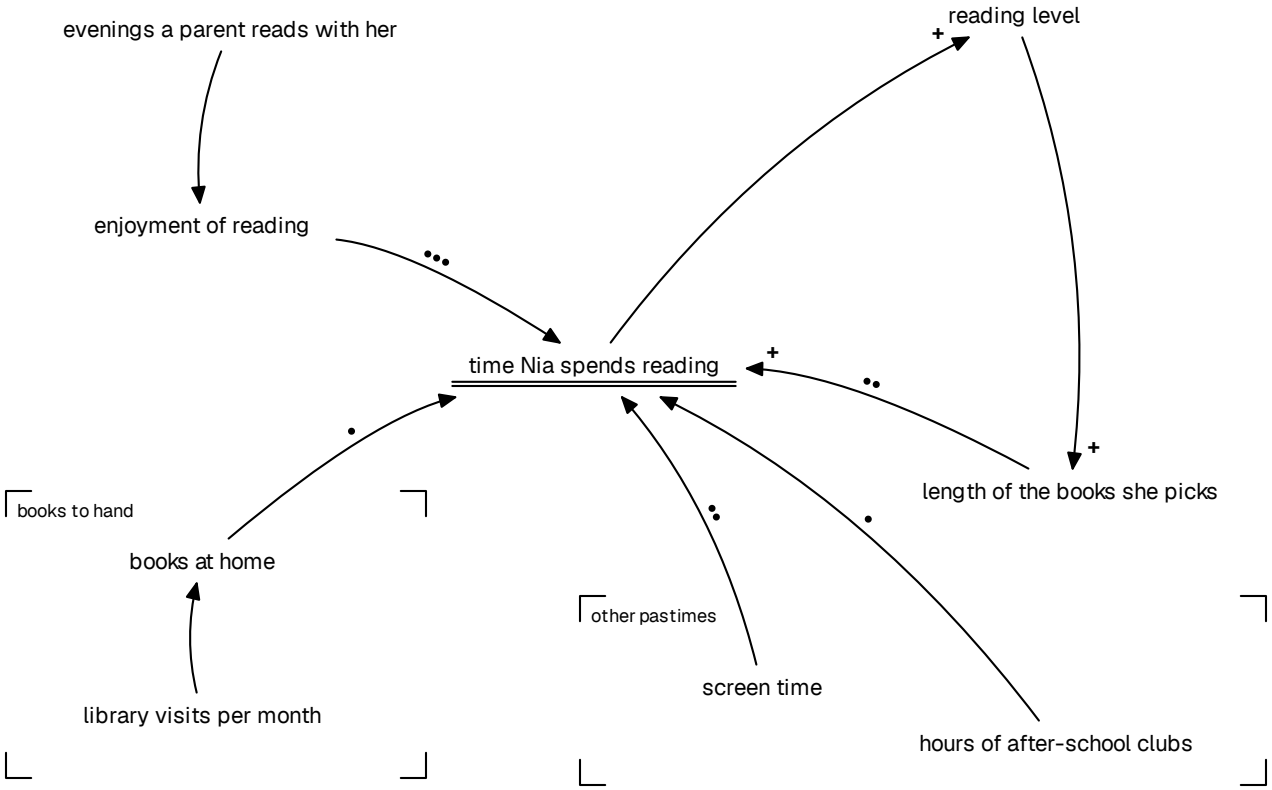
Weight is an influence's relative importance, where influences are ranked: one, two or three dots beside the middle of the claim's line. Nia's parents rank her enjoyment highest, so its claim carries three dots, and her clubs' claim one.

Weight says how much, not which way or how sure. Every line is drawn alike: a thicker one means nothing.

Causal claims

A **causal claim** says which way a change runs, by its **polarity**: + when the two variables move in the same direction, – when they move in opposite directions. Giving an influence claim a polarity is an **upgrade**; the claim keeps its ends and its weight. Taking the polarity off makes it an influence claim again.

Upgrade a claim where you can say how you know its direction. The reading log and the assessments measured three effects, each +, so those three claims are upgraded. Enjoyment, weighted highest, stays an influence claim: nothing measured it.



CHECK YOUR UNDERSTANDING

A bakery's till records show that it sells more loaves on market days, and fewer in the weeks after each rise in the price of a loaf. The owner believes her new window display brings in customers, but nobody has counted them. On a map around loaves sold per day, which influence claims can be upgraded?

a Market days per week, with a +, and the price of a loaf, with a −; the window display stays an influence claim

b All three: the owner knows her shop

c Only the window display, with a +: the owner put it there to bring customers in

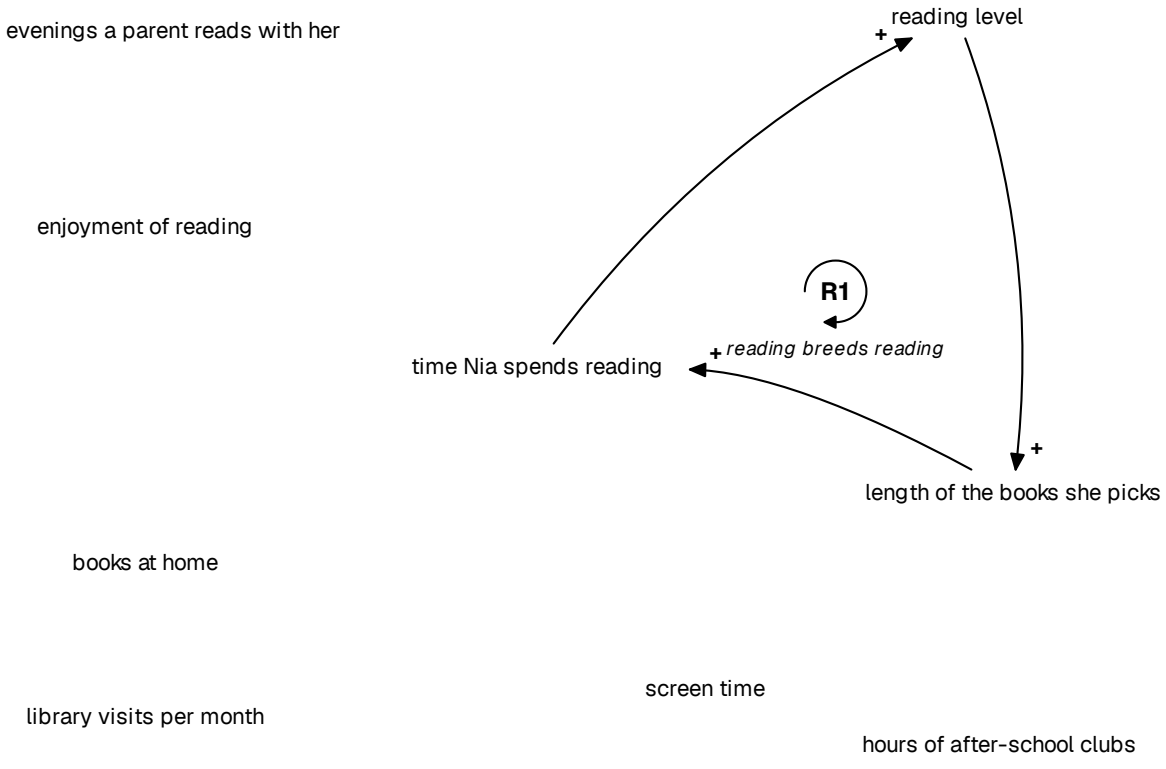
d None: an influence map holds no causal claims

Feedback: Answers, chapter 3

Conversion to a causal loop diagram

A **conversion** carries an influence map into a new causal loop diagram. The variables and the causal claims carry over; the influence claims, weights, clusters and the central outcome's double underline are left behind. An influence claim isn't carried over without a polarity: in a causal loop diagram, an effect without one is unfinished.

Nia's three causal claims close a path: more minutes, a higher level, longer books, more minutes. Declared in the causal loop diagram, the path is a loop. It has no – effects, so by the parity rule (chapter 4, The parity rule) it is a reinforcing loop: a change in any of the three comes back around in the same direction.



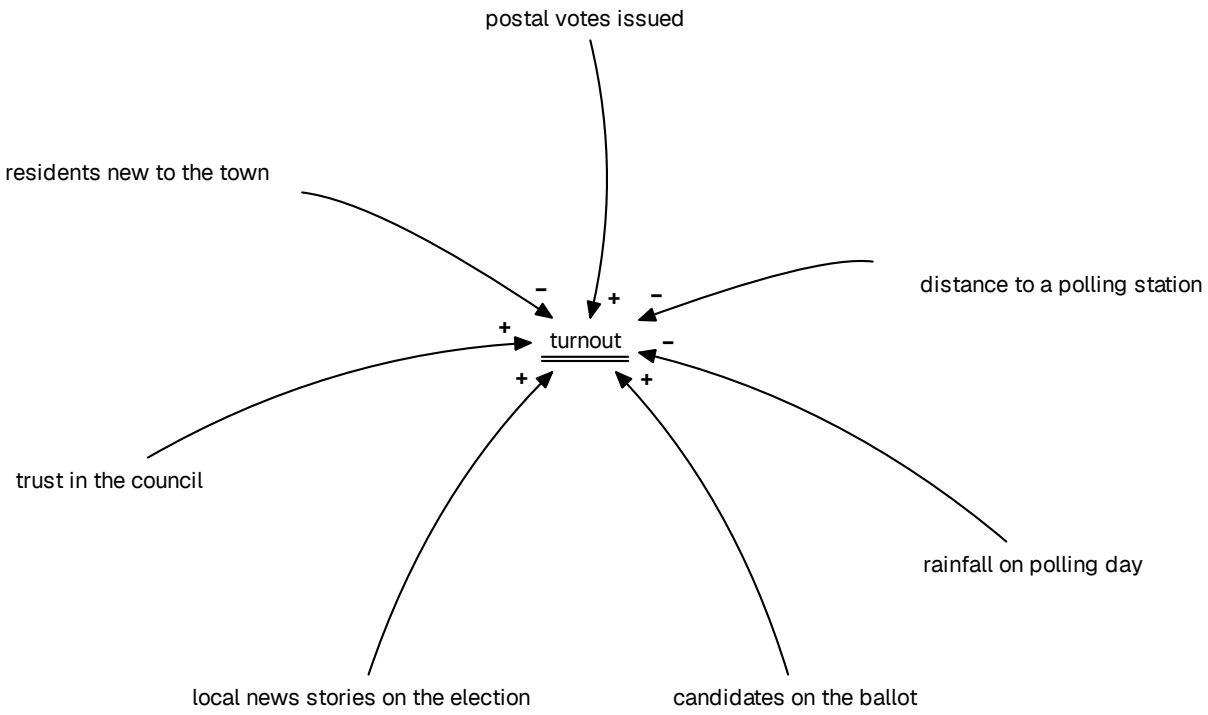
What stays informal

With a few influences, each acting on the outcome and none on another, a list of variables does what the map would. With one influence in question, a sentence does: *Nia's parents think screen time cuts into her reading*.

The map shows no amounts and no timing: not how many minutes screen time takes, nor when.

The bad diagram

What's wrong with this map of turnout in a town's local election?



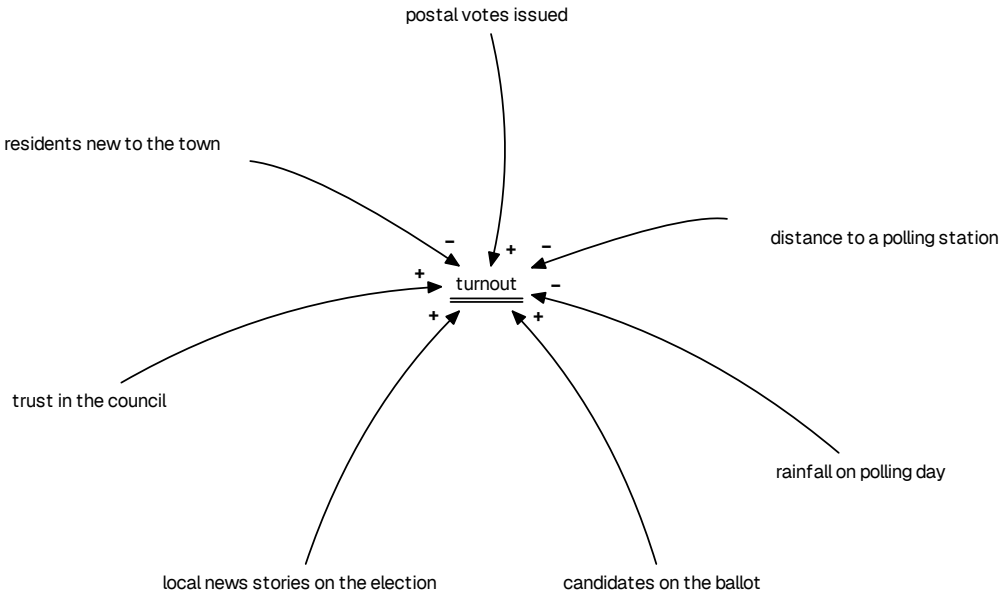
Every claim carries a + or –. The council's ward records measured only two effects: more postal votes issued, higher turnout; a longer distance to a polling station, lower turnout. The other five polarities, on rainfall, candidates, news stories, trust in the council and newcomers, are guesses drawn as findings. Converted, the map would carry all seven into a causal loop diagram.

The lab's checks test structure, not evidence: they report this map only under a brief requiring at least one influence claim.

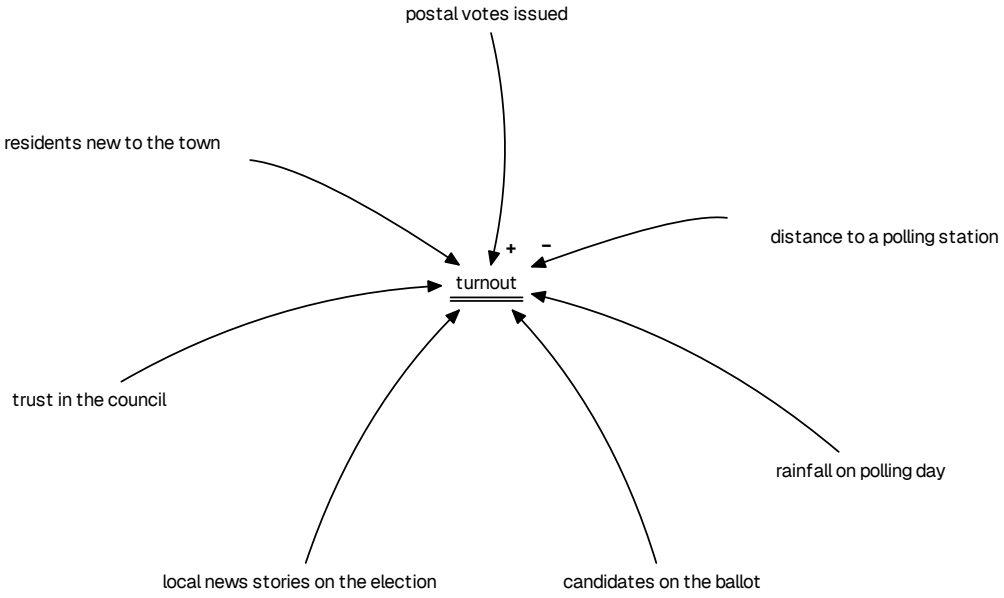
The corrected diagram

Corrected, the two measured claims keep their polarities and the other five are influence claims: the same variables and the same claims, with five fewer polarities.

Bad diagram



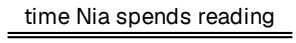
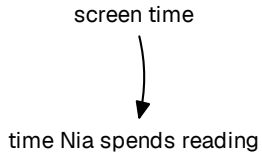
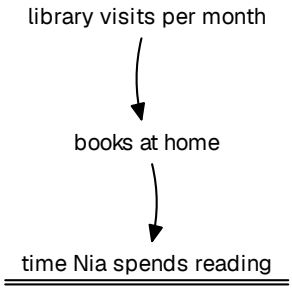
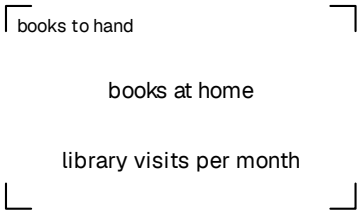
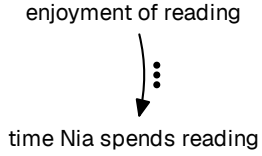
Corrected diagram



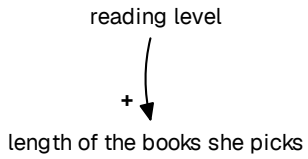
Labels unchanged. Claims: 5 returned to influence claims.

A count of turnout on wet and dry polling days, ward by ward, would let a third claim be upgraded.

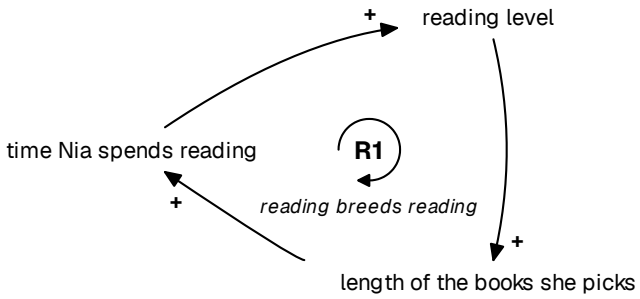
Notation moves

Notation move	When	What it shows	Example
Mark the central outcome 	You can name the one quantity in question	What the map is drawn around	*time Nia spends reading*
Draw an influence claim 	One variable bears on another, its direction unmeasured	That it bears, not which way	*screen time → time Nia spends reading*
Draw an indirect influence 	A variable acts on the outcome through another	The path by which it reaches the outcome	*library visits per month → books at home*
Draw a cluster and label it 	Several variables share something	What they share	*books to hand*
Give a claim a weight 	Influences are ranked	Relative importance	three dots on *enjoyment of reading*

Notation move	When	What it shows	Example
Upgrade a claim with + or −	Something measured the effect	Which way the change runs	*reading level* → *length of the books she picks*, +



Convert to a causal loop diagram	Causal claims close a path	The loop, to declare and read there	`R1` *reading breeds reading*



Check your understanding

CHECK YOUR UNDERSTANDING

An influence map of an allotment has the central outcome crop yield. Water per week → crop yield and crop yield → seed saved are causal claims, each +. Seed saved → crop yield and compost spread → crop yield are influence claims. Converted to a causal loop diagram, what loop can be declared there?

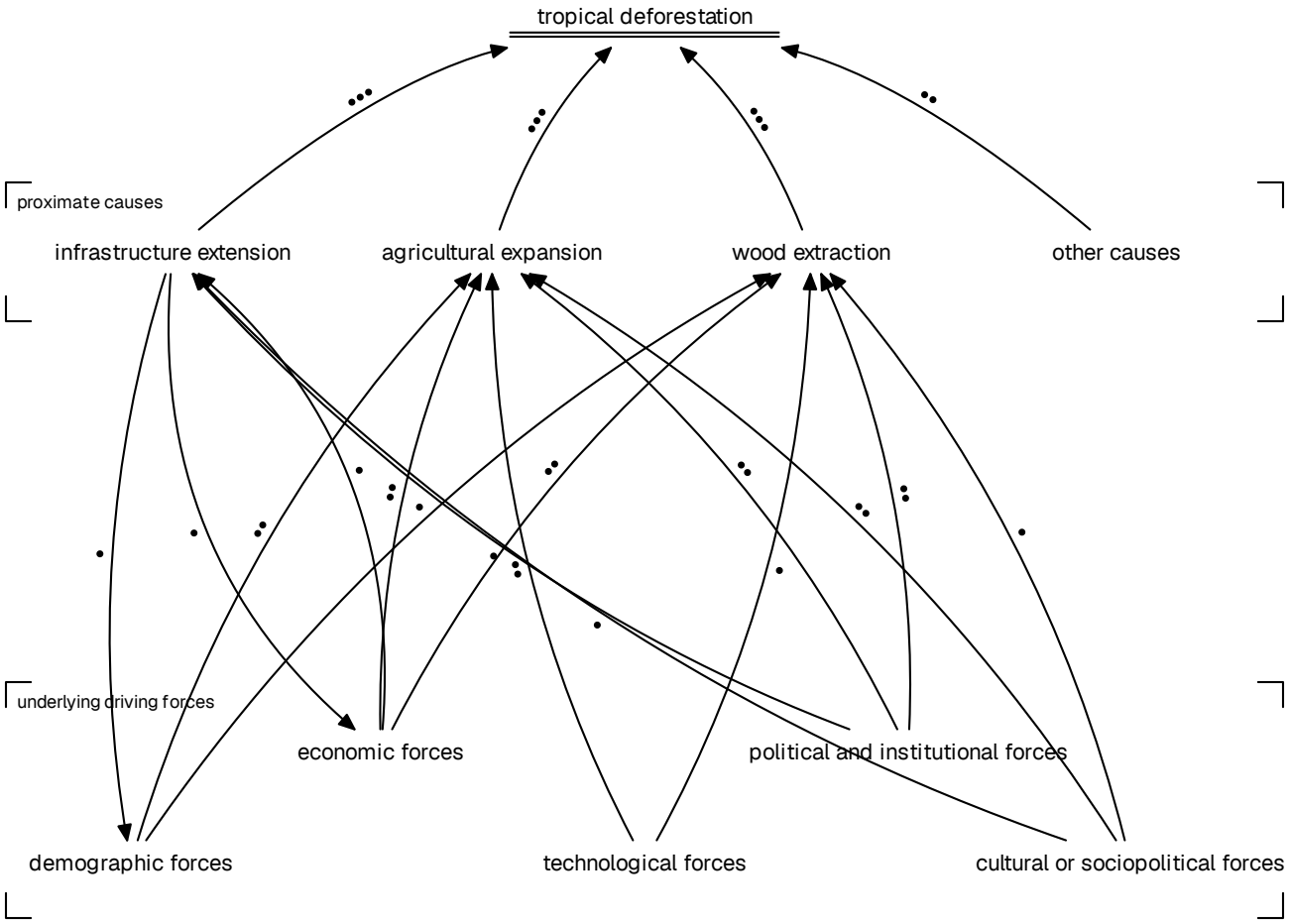
a None

b One reinforcing loop: crop yield → seed saved → crop yield

c Two: one through seed saved and one through compost spread

Feedback: Answers, chapter 3

Causes of tropical deforestation, redrawn



Redrawn from Helmut J. Geist and Eric F. Lambin, "Proximate Causes and Underlying Driving Forces of Tropical Deforestation", BioScience 52(2), 143–150 (2002) academic.oup.com/bioscience/article/52/2/143-150/341135, Figure 2. © 2002 American Institute of Biological Sciences; its structure and short labels only.

Tropical deforestation, named in the figure's title, added as the central outcome, with a claim from each of the four proximate causes; the two tiers drawn as clusters, the five underlying names ending in forces, as the source names their tier, and the last proximate cause named other causes; each line's width, the share of the 152 cases, drawn as one dot (under a third), two or three (over two thirds); the two dashed lines labeled Feedback drawn solid; the lines within each tier, the colors and the percentages left out.

QUESTION 1 OF 3

The source's figure has no box for deforestation. Why does the redrawing add tropical deforestation, double-underlined?

a It is the quantity in question, named in the figure's title, and every path of claims ends there.

b It marks the result of agricultural expansion, the cause found most often.

c Every influence map has a variable that no claim leaves.

QUESTION 2 OF 3

Which variables share a cluster with wood extraction?

a Economic forces and political and institutional forces, which bear on it in the most cases.

b Tropical deforestation, which it bears on directly.

c Infrastructure extension, agricultural expansion and other causes.

QUESTION 3 OF 3

Which claim could be upgraded with a polarity, from what the source's authors report?

a Agricultural expansion → tropical deforestation, whose three dots mark it found in 96% of the cases.

b None: an influence map's claims carry no polarity.

c Infrastructure extension → economic forces, +, one of the source's two dashed lines labeled Feedback.

Feedback: Answers, chapter 3

Exercises

Passing the checks means meeting the brief, not being right.

IM 01 Cycling to work through the winter

A central outcome and its direct influences

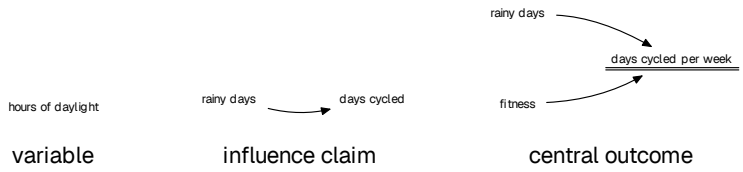
Reasoning ●○○○○ 1 of 5 Polish ●○○○○ 1 of 5

Tomás rides nine kilometres to work and takes the bus on the days he doesn't. From October he counts the days he rides each week. The hours of daylight fall through the autumn, and the rainy days per week rise. The council is putting street lights along his route, so the length of lit route grows month by month. His office has two showers, and on busy mornings fewer are free when he arrives. His fitness, built up over the summer, makes the ride quicker. The bus fare went up in September. Nobody has measured how much any of these moves the days he rides.

The brief

- [ ] Draw at least four direct influences on days cycled per week.
- [ ] Draw no indirect influences: each influence claim ends at days cycled per week.
- [ ] Each variable is a quantity that can rise or fall: hours of daylight, not the dark.

Your palette



Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/framing/surfacing-influences/#exercise-influence-map-01

IM 02 World food prices

Influences that reach the central outcome through another variable

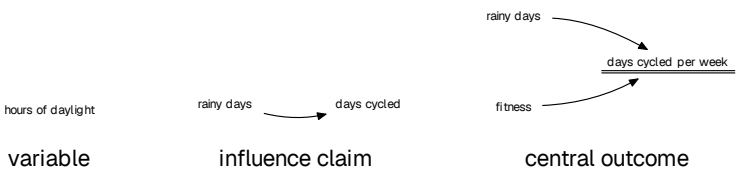
Reasoning ●○○○○ 1 of 5 Polish ●●○○○ 2 of 5

The FAO food price index tracks what the world pays for cereals, vegetable oils, dairy, meat and sugar. The size of the world's grain harvest sets how much is on sale, and the area in drought across growing regions cuts the harvest. Farmers spread less fertilizer when its cost climbs, and the grain harvest falls with it. Fertilizer is made and shipped with fossil fuels, so its cost follows the oil price, which also sets what it costs to move and process food. A dear barrel makes ethanol and biodiesel pay, and biofuel demand takes maize and vegetable oil off the food market. When a harvest fails, some governments ban grain exports, and the more grain under export bans, the fewer cargoes importers can bid for. The area in drought and fertilizer cost act on the index only through the grain harvest; the oil price acts on it straight and through fertilizer cost and biofuel demand.

The brief

- [ ] Draw at least four direct influences on the world food price index.
- [ ] Draw at least three indirect influences.
- [ ] Each indirect influence reaches the index through the variable it acts on.

Your palette



Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/framing/surfacing-influences/#exercise-influence-map-02

IM 03 An amateur football team's season

Clusters, each labeled for what its variables share

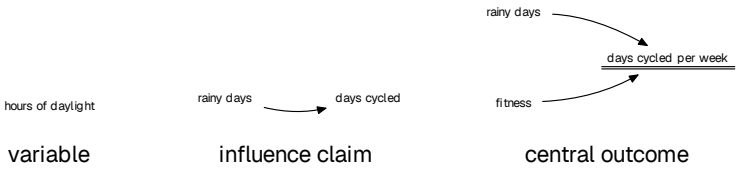
Reasoning ●●○○○ 2 of 5 Polish ●●○○○ 2 of 5

The Rovers, an amateur team, play on Sunday mornings in a county league, and their season is counted in league points. The squad size was twenty-two in September; players leaving for work or university cut it through the winter. Training attendance on Wednesday nights runs from eight to eighteen, and the players who come keep their match fitness. The players injured each week, mostly with pulled hamstrings, are fewer when match fitness is high. The coach spends half of each session on how the back four hold their line, and the training time on tactics shows in clean sheets. Team morale shows in how hard the players run in the last twenty minutes of a match, and players with low morale leave. The players at post-match socials in the clubhouse keep the team's morale up. Nobody at the club has measured how much any of these moves the points.

The brief

- [ ] Draw at least three clusters.
- [ ] Put every variable but league points in a cluster.
- [ ] Draw at least three direct influences on league points.
- [ ] Each cluster's label names what its variables share.

Your palette



variable influence claim central outcome



cluster

Draw here

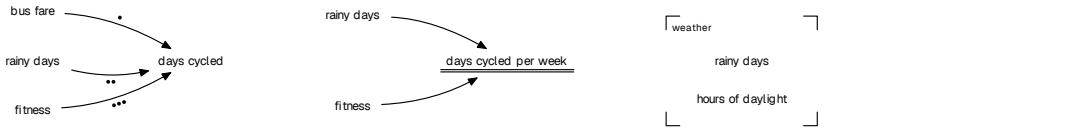
In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/framing/surfacing-influences/#exercise-influence-map-03

IM 04 Algal blooms in a lake

Your palette



variable polarity influence claim



weight central outcome cluster

IM 04 Algal blooms in a lake

Weight, and upgrading only the influences that were measured

Reasoning ●●○○○ 2 of 5 Polish ●●●○○ 3 of 5

Lake Esk supplies drinking water to three towns, and most Augusts its surface turns green with algae. The lake authority counts the weeks of algal bloom each summer. Over ten years it has measured three things that rise and fall with them: phosphorus in farm runoff, sewage overflows per year from the towns' treatment works, and summer water temperature. Farm runoff carries about two-thirds of the phosphorus that reaches the lake, and sewage overflows most of the rest; the three warmest summers had the longest blooms. Fertilizer spread on the fields around the lake feeds the runoff, and heavy rainstorms, a few each summer, wash it into the streams. Anglers blame the shrinking area of reed beds along the shore, and boat operators blame the number of summer visitors. The authority has measured neither.

The brief

- [ ] Give each direct influence on weeks of algal bloom each summer a weight.
- [ ] Upgrade exactly three influences, giving each a + or −.
- [ ] Leave at least two influences without a + or −.
- [ ] Each causal claim is one the authority measured; every other claim stays an influence claim.

Your palette

On the page before this sheet.

Draw here

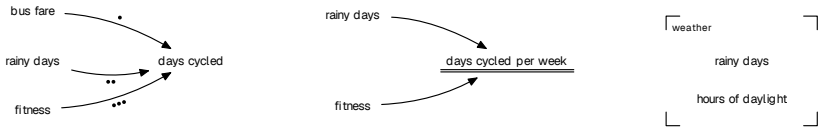
In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/framing/surfacing-influences/#exercise-influence-map-04

IM 05 An open-source project's contributors

Your palette



variable polarity influence claim



weight central outcome cluster

IM 05 An open-source project's contributors

Upgrades that close a path of causal claims, read as a causal loop diagram

Reasoning ●●●○○ 3 of 5 Polish ●●●○○ 3 of 5

Ledger is an open-source library that reads spreadsheet files, and its maintainers count its active contributors each month. Six years of the project's records show three things. Releases made while more contributors are active carry more fixes. More fixes per release bring more users, as the package registry counts them. More users bring more active contributors, since most first contributions come from someone who hit a bug in their own work. The three run in a circle: active contributors, fixes per release, users, and back to active contributors. The maintainers believe newcomers stay when their first change is reviewed within a week, when the documentation pages explain how the code is laid out, and when issues are labeled for newcomers. Donations, about four thousand dollars a year, pay a maintainer for a few hours each week, most of them spent on review. None of these has been measured.

The brief

- [ ] Upgrade the influences the project's records show until they close a path of causal claims.
- [ ] Keep at least two influence claims.
- [ ] Draw at least two clusters.
- [ ] Every causal claim is one the project's records show.

Your palette

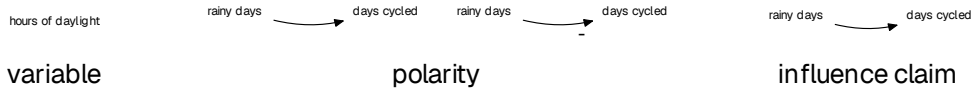
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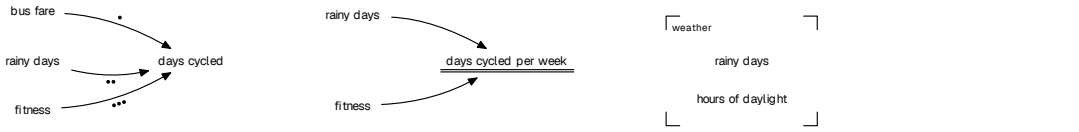
In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/framing/surfacing-influences/#exercise-influence-map-05

CS 03 Kelsham Primary School: what decides where a child starts

Your palette



variable polarity influence claim



weight central outcome cluster

CS 03 Kelsham Primary School: what decides where a child starts

Upgrading only the counted claims

Reasoning ●●●○○ 3 of 5 Polish ●●●○○ 3 of 5

Tom Hale asks what decides how many children start at Kelsham Primary School each September. The county council's records, which David Brennan keeps, show the starters following the births in the villages four years before: 22 births in 2016 and 19 starters in 2020, 13 births in 2022 and 9 starters in 2026. The school's records show that when its teachers fell from five to four in 2023, Years 3 and 4 became one class, and that its classes shrink with its roll: 88 pupils in four classes now. Ruth Okafor hears from parents that mixed-age classes send families to Brayford Primary School and that small classes keep them. Helen Marsh, Brayford's head teacher, says her school has spare places in most of its classes. David Brennan forecasts 0.25 children of primary school age for each new home at Mill Lane. Nobody has counted the parents' reasons, Brayford's places or the new homes against the starters.

The brief

- [ ] Draw at least four direct influences on children starting each September.
- [ ] Give each direct influence a weight.
- [ ] Upgrade exactly the three claims someone has counted, giving each a + or −.
- [ ] Leave at least three claims nobody has counted without a + or −.
- [ ] Draw at least two clusters.
- [ ] For each influence claim on the starters, name the count that would upgrade it.

Your palette

On the page before this sheet.

Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/framing/surfacing-influences/#exercise-case-03

Sources

- The Open University, *Diagramming for development 2: exploring interrelationships* www.open.edu/openlearn/digital-computing/diagramming-development-2-exploring-interrelationships/content-section-3.1 (OpenLearn), §3.1, *Influence diagram*, on influence diagrams: a snapshot of what can influence a situation, two influences that run both ways drawn as two lines, and stronger influences drawn thicker.
- Geoff Coyle, *Qualitative Modelling in System Dynamics, or What Are the Wise Limits of Quantification?* proceedings.systemdynamics.org/1999/PAPERS/KEYNOTE1.PDF, keynote to the System Dynamics Society's conference (Wellington, 1999), on influence diagrams drawn and studied without simulation, and what they are used for: a problem on one page, loops found in the diagram, and a basis for a quantified model.
- John D. Sterman, *Business Dynamics: Systems Thinking and Modeling for a Complex World* (Irwin/McGraw-Hill, 2000), chapter 5, on polarity in causal loop diagrams, with §5.2.1, *Causation versus Correlation*.
- George P. Richardson, "Problems with Causal-Loop Diagrams" doi.org/10.1002/sdr.4260020207, *System Dynamics Review* 2, no. 2 (1986), on what polarity does and doesn't mean.

Part II — Feedback

Loops That Amplify, Loops That Correct

Causal loops Part II · Feedback · Chapter 4 of 12 · the first of two chapters on causal loops

Why do some changes snowball while others settle? A causal loop diagram shows the loops a change runs around, and whether each amplifies the change or corrects it.

Signals you need this diagram

- A change seems to feed itself.
- Something keeps drifting back to where it was, however hard anyone pushes on it.
- A fix worked for a while, then stopped, or began working against you.
- An explanation's *because*s run in a circle.
- People disagree about what causes what, and arguing hasn't settled it.

A week of short nights

A deadline costs you two nights' sleep. Foggy on Wednesday afternoon, you have a coffee at three, finish the job, and lie awake until one. On Thursday, foggier, you have a double at two. By Friday the caffeine has you sleeping five hours a night.

At the weekend, noticing how tired you are, you go to bed at nine two nights running, and by midweek you're yourself again.

One change fed itself: less sleep, more coffee, less sleep. The other corrected itself: the further behind you fell, the harder you caught up, until there was nothing left to catch up on.

What the notation expresses

Variables

Every name on the diagram is a **variable**: a quantity that can rise or fall, such as *sleep debt* or *hours slept*.

That rules out actions and events. Test a name by putting *more* in front of it: *more afternoon caffeine* makes sense; *more drink coffee* doesn't. Naming a variable as an action is the bad diagram's mistake.

CHECK YOUR UNDERSTANDING

Which of these names could be a variable on a causal loop diagram?

a go to bed early

b hours slept

c the deadline

d tiredness increases

Feedback: Answers, chapter 4

Polarity

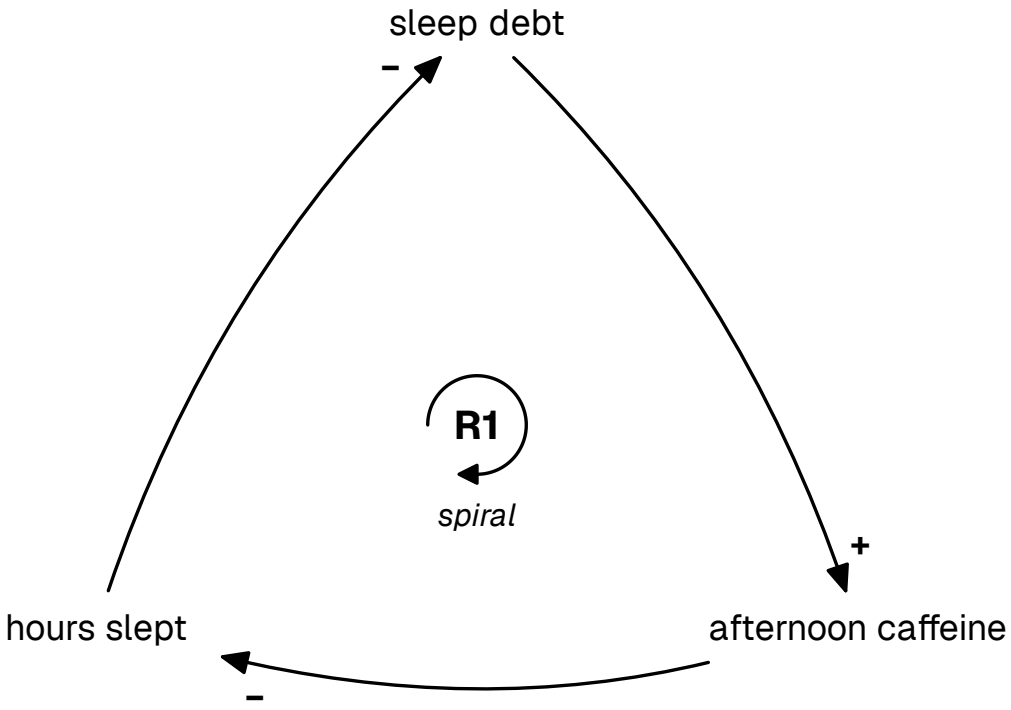
An **effect** means that a change in one variable causes a change in another; its **polarity** shows which way. A + effect means they move in the same direction: more sleep debt, more afternoon caffeine. A – effect means they move in opposite directions: more afternoon caffeine, fewer hours slept.

+ doesn't mean *good* and – doesn't mean *bad*, and neither gives size: caffeine might cost ten minutes of sleep or two hours.

In a causal loop diagram every effect carries a polarity; an influence claim (chapter 3, Influence claims), drawn in an influence map, carries none until it is upgraded to a causal claim.

Loops

Sleep debt raises afternoon caffeine, caffeine cuts hours slept, and fewer hours slept raise sleep debt. A closed path of effects like this is a **loop**. A chain shows how one thing affects another; a loop shows how a thing ends up affecting itself.



A **reinforcing loop** makes a change snowball, in whichever direction it starts: debt brings coffee and more debt, but a good night likewise brings less coffee and another good night. A **balancing loop** makes a change settle, moving a variable toward a target and opposing any push away from it: the further behind on sleep you fall, the harder you try to catch up.

Each loop's label, drawn inside it with a curved mark showing which way it circulates, is its kind and a number: `R1`, `R2` for reinforcing loops, `B1`, `B2` for balancing ones. Its name describes what it *does*, not what it's about: *spiral*, not

coffee.

The parity rule

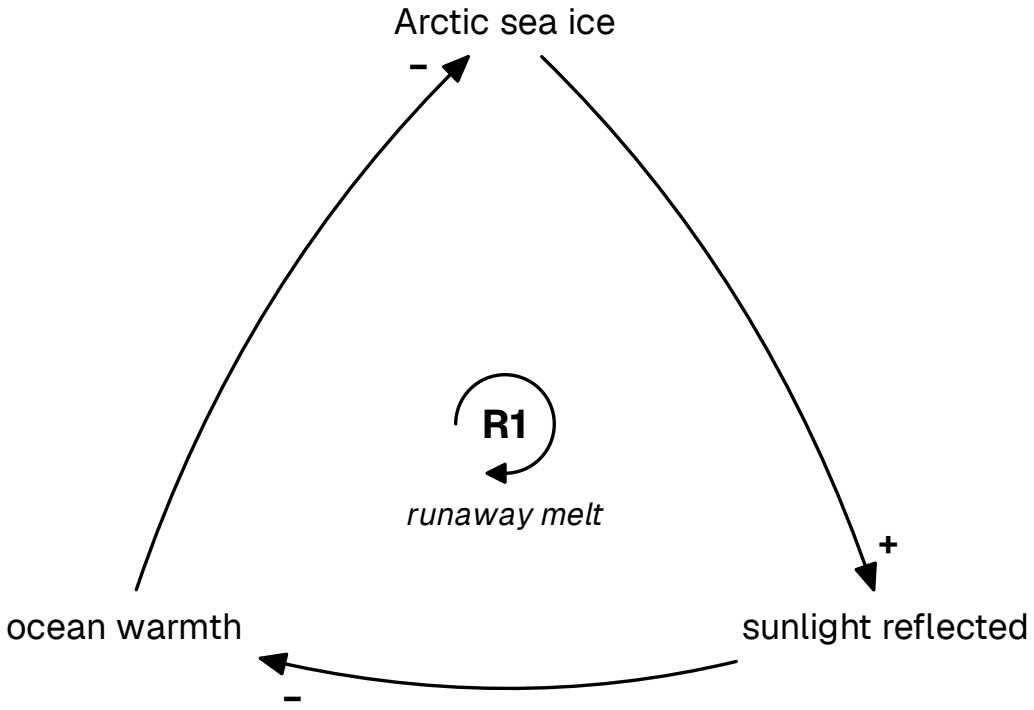
The parity rule: a loop with an even number of – effects is reinforcing, and one with an odd number is balancing. Zero counts as even.

Each – effect reverses a change passing through it. Two reversals cancel, so the change comes back pointing the way it set out, and grows; one or three leave it pointing against itself, and it shrinks.

For the spiral, the lab's check gives this working:

> R1 (spiral) has 2 – effects (afternoon caffeine → hours slept, hours slept → sleep debt): an even number, so it is reinforcing, as declared.

At planetary scale, less Arctic sea ice reflects less sunlight, so the ocean warms, and warmer water melts more ice: again two – effects, so reinforcing.



CHECK YOUR UNDERSTANDING

A loop has four effects. Three are + and one is –. What kind of loop is it?

a Reinforcing, because most of its effects are +

b Balancing

c It depends on which effect carries the –

d You can't tell without knowing what the variables are

Feedback: Answers, chapter 4

The gap

A balancing loop closes a **gap**: the difference between the value someone wants and the value they have. Here it's *sleep debt*, the sleep you need minus the sleep you get.

Draw it as its own variable, fed by the target from outside the loop. That shows the loop's target, and raises two questions about any balancing loop: who set it, and could it move?

In a feedback control diagram, the words *target*, *gap* and *measured value* (the reading the target is compared with) are written above the names of the variables in those parts, and a person chooses the target: chapter 8's target and gap (chapter 8, Target and gap).

Delays

A **delay**, two short strokes across an effect, means that the change arrives later than the cause: late enough to change what the loop does. Sleep debt builds for days before anyone acts on it, so the effect from sleep debt to early nights carries a delay, and the spiral, whose changes arrive within a day, gets a head start.

In a balancing loop with a delay, the correction continues after the gap closes; the variable overshoots its target and oscillates instead of settling.

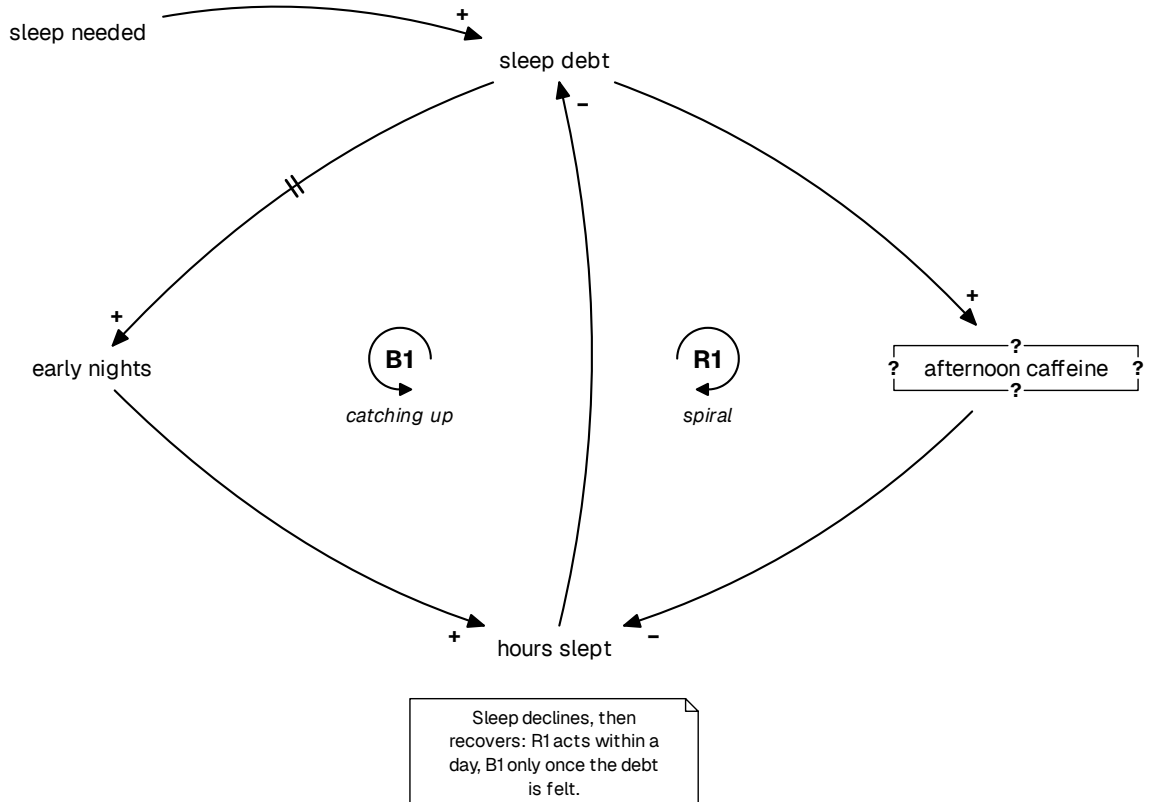
In a stock & flow diagram, a delay on a flow holds material in transit and a delay on a signal holds a reading of the material: chapter 7's material and signal delays (chapter 7, Material and signal delays).

Behavior notes

A **behavior note** names, on the diagram, the behavior you expect the structure to produce: *oscillation*, *overshoot*, *decline, then recovery*. It makes the diagram a prediction: if what happens differs, the structure you drew is missing something.

Coupled loops

Loops that share a variable are coupled: a change in one loop changes the other. In the full sleep diagram, the spiral and catching up share sleep debt, hours slept and the effect between them.



Which loop dominates depends on which is stronger at the time: early in the week, the spiral; once the debt is felt, catching up.

Leverage points

A **leverage point** is a variable proposed as the place to intervene, drawn as a box with a question mark on each side. In the sleep diagram it's *afternoon caffeine*: cutting it weakens the spiral and leaves the slow balancing loop less to correct.

It's a hypothesis, not a proven fix: someone else might propose *early nights*, arguing that noticing the debt sooner would help more. Either proposal can be tested against the diagram.

What stays informal

A causal loop diagram shows structure only, not **size**: when amounts decide the question you need numbers, which chapter 6's stocks begin to supply.

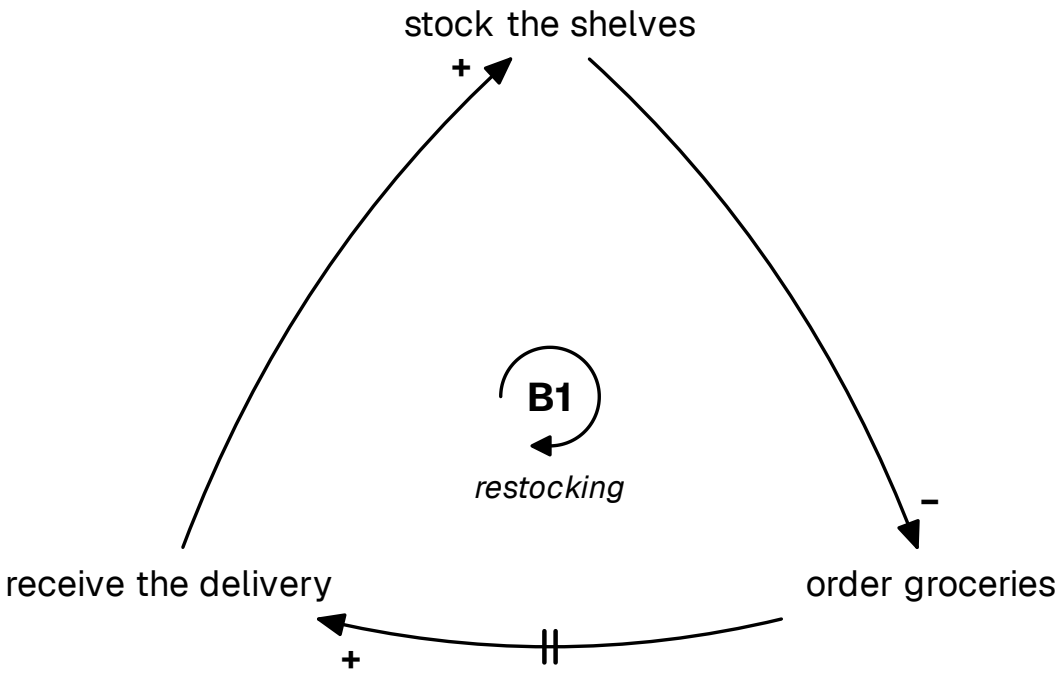
Nor does it show **sequence**: for the order in which things happen, use a numbered list. A loop diagram of a sequence is the bad diagram's mistake.

Nor **everything**: the sleep diagram leaves out stress, exercise and the deadline, keeping only the loops that explain the behavior in question.

When nothing feeds back, a sentence does the job.

The bad diagram

What's wrong with this diagram of keeping a household pantry stocked?



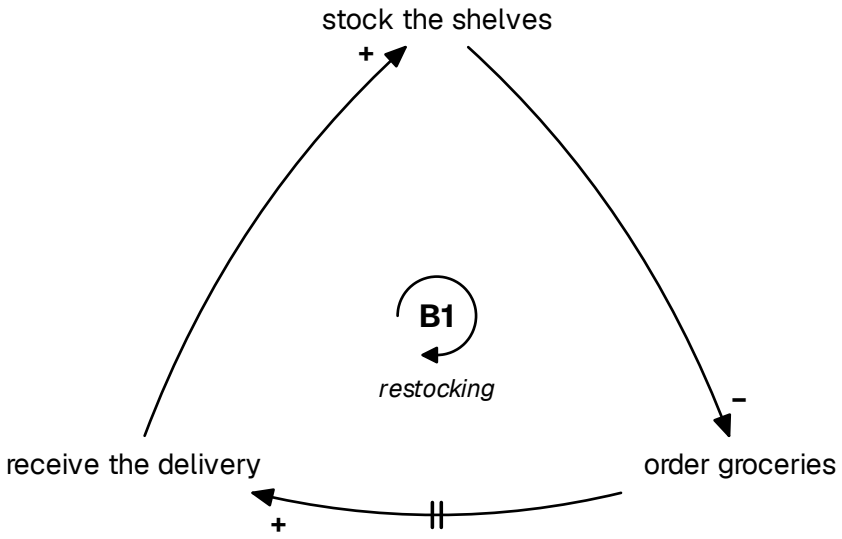
Its structure is sound: a closed loop, one – effect, labeled `B1`, a delay on the right effect. But its names, *stock the shelves*, *order groceries* and *receive the delivery*, are actions done in order and fail the *more* test, so the diagram is a to-do list bent into a circle, and its polarities mean nothing: what would *more receive the delivery* cause?

In the lab it passes every check, with a notice on each of its three names.

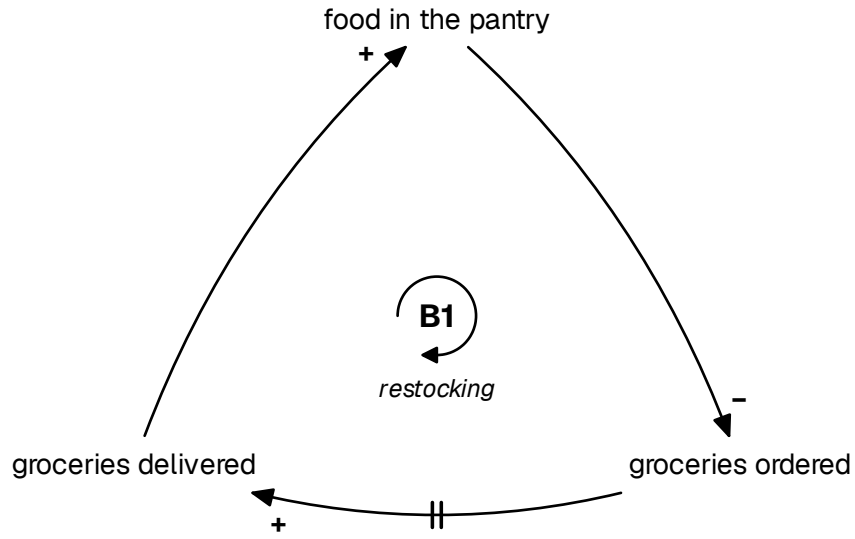
The corrected diagram

The correction keeps every effect, every polarity, the delay and the loop, and renames the three variables as quantities.

Bad diagram



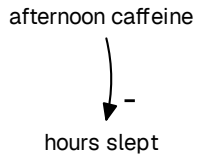
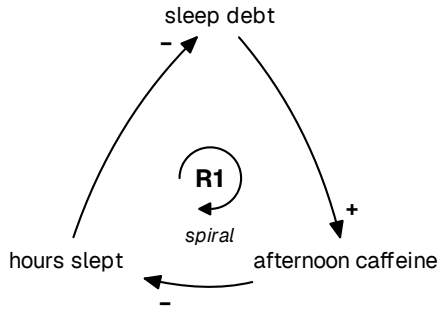
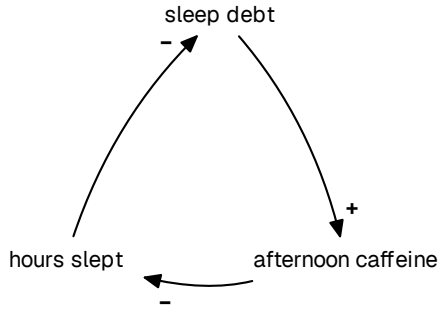
Corrected diagram

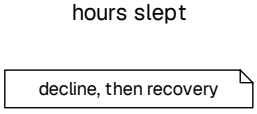
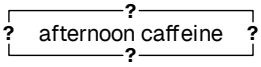


Changed: 3 labels. Effects unchanged.

Now each effect is a checkable claim: more food in the pantry, fewer groceries ordered (–); more ordered, more delivered a few days later (+, delayed); more delivered, more food in the pantry (+). One – effect, so the loop is balancing: it holds the pantry near full. With the delay: reorder before the first delivery arrives and the pantry overfills.

Notation moves

Notation move	When	What it shows	Example
Name a variable as a quantity afternoon caffeine		What rises or falls	*afternoon caffeine*, not *drink coffee*
Mark an effect + or –  		Which way each change runs	afternoon caffeine → hours slept is –
Close a loop and label it  	A chain returns to its start	How a change comes back to itself	`R1` *spiral*
Count the – effects  	Before labeling a loop	The loop's kind	two – effects, so reinforcing

Notation move	When	What it shows	Example
Draw the gap as a variable 	A balancing loop has a target	What the loop closes, and its target	*sleep debt*, fed by *sleep needed*
Mark a delay 	The change arrives late enough to alter the loop's behavior	Where a correction can overshoot	sleep debt → early nights
Add a behavior note 	You expect a pattern over time	A prediction to check	*decline, then recovery*
Propose a leverage point 	You choose where to intervene	A hypothesis to test	*afternoon caffeine*

Check your understanding

CHECK YOUR UNDERSTANDING

You're warming a pan of soup on an electric stove that takes several minutes to respond. Whenever the soup seems too cool you turn the heat up, and whenever it seems too hot you turn it down. What does the structure predict?

a A smooth rise to the temperature you want

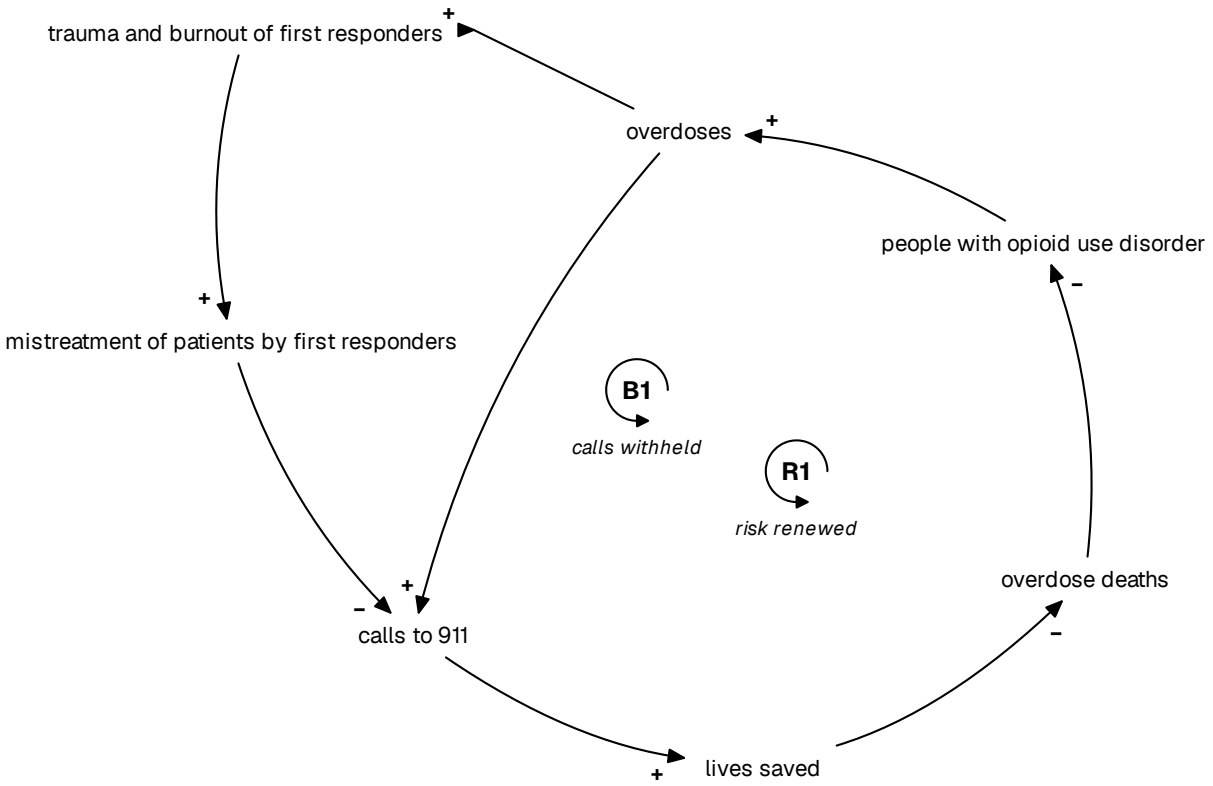
b Swings between too hot and too cool before it settles

c The soup getting hotter and hotter

d Nothing: without numbers the diagram can't predict anything

Feedback: Answers, chapter 4

Overdoses, calls to 911 and burnout, redrawn



Redrawn from Rachel L. Thompson, Nasim S. Sabounchi, Syed Shayan Ali, Robert Heimer, Gail D'Onofrio and Rebekah Heckmann, "Using qualitative system dynamics modeling to understand overdose bystander behavior in the context of Connecticut's Good Samaritan Laws and identify effective policy options", Harm Reduction Journal 21, 124 (2024) doi.org/10.1186/s12954-024-00990-3, Fig. 2, panels a and b. CC BY 4.0 creativecommons.org/licenses/by/4.0/.

Panels a and b drawn as one diagram; the heavier red lines that pick out each panel's loop drawn like every other line; Overdose, Calling 911 and Saving a Life renamed as amounts; OUD spelled out; the two names about first responders shortened; each loop named; panel c, the whole model, left out.

QUESTION 1 OF 3

R1 runs from people with opioid use disorder through overdoses, calls to 911, lives saved and overdose deaths, and back. By the parity rule, what kind of loop is it?

a Reinforcing: it has two – effects, an even number.

b Balancing: any loop with a – effect in it is balancing.

c Balancing: a call to 911 is made to bring overdose deaths down.

QUESTION 2 OF 3

B1 leaves overdoses through trauma and burnout of first responders, then mistreatment of patients, joins R1 at calls to 911 and follows it back. What kind of loop is it?

a Reinforcing: it shares four effects with R1, which is reinforcing.

b Balancing: it has three – effects, an odd number.

c Reinforcing: burnout and mistreatment both rise as overdoses rise.

QUESTION 3 OF 3

Burnout among first responders keeps growing, so mistreatment keeps more people from calling 911. Which loop comes to dominate, and what happens to overdose deaths?

a B1, and overdose deaths fall, since a balancing loop corrects the problem.

b R1, since overdoses keep rising and R1 runs through them.

c B1, and overdose deaths rise.

Feedback: Answers, chapter 4

Exercises

Passing the checks means meeting the brief, not being right.

CL 01 A riverbank cleanup that grows by word of mouth

One reinforcing loop

Reasoning ●○○○○ 1 of 5 Polish ●○○○○ 1 of 5

Neighbors meet one Saturday a month to clear litter from a city riverbank. Each cleared stretch shows from the footpath, and people who walk there talk about it. Some of them come to the next cleanup, and some of those keep coming. Show the smallest complete feedback explanation. Leave out the weather and the litter the river carries in.

The brief

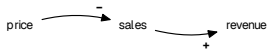
- [ ] Use exactly four variables.
- [ ] Close one loop.
- [ ] Mark every effect + or −.
- [ ] Label the loop R1.
- [ ] Give the loop a short name.

Your palette

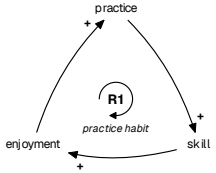
variable



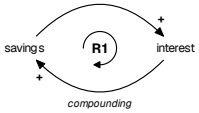
effect



polarity



loop



reinforcing loop

Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/feedback/loops-that-amplify-loops-that-correct/#exercise-causal-loop-01

CL 02 Hunger and eating

One balancing loop

Reasoning ●○○○○ 1 of 5 Polish ●●○○○ 2 of 5

When hunger rises, a person eats. Food eaten fills the stomach, and as fullness grows, hunger falls. Once hunger is low, eating stops until it returns hours later. Show this correction as feedback, not as a sequence of meals. One effect reverses direction, and the loop's kind follows from it.

The brief

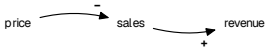
- [ ] Use three or four variables.
- [ ] Find the single – effect.
- [ ] Label the loop B1.
- [ ] Name its target-seeking behavior.

Your palette

variable



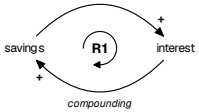
effect



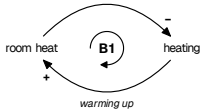
polarity



loop



reinforcing loop



balancing loop

Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/feedback/loops-that-amplify-loops-that-correct/#exercise-causal-loop-02

CL 03 A housing shortage and the building boom that overshoots it

Balancing loop with delay

Reasoning ●●○○○ 2 of 5 Polish ●●○○○ 2 of 5

A growing city has fewer homes than its households need, and rents climb. High rents lead developers to start new buildings, which take two to three years to finish. Starts continue while rents stay high, so the homes arrive together and overshoot the need. Draw the intended correction, with the delay on an effect, not in a new variable.

The brief

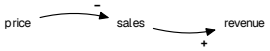
- [ ] Show the homes needed, the shortage, building starts, and the housing stock.
- [ ] Put a delay on building starts → housing stock.
- [ ] Use one behavior note.
- [ ] Name the likely behavior in it: oscillation.

Your palette

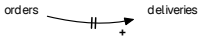
variable



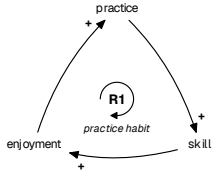
effect



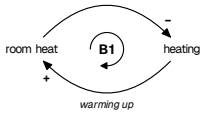
polarity



delay



loop



balancing loop



gap
drawn as an ordinary variable



behavior note

Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/feedback/loops-that-amplify-loops-that-correct/#exercise-causal-loop-03

CL 04 A friendship group that grows until gatherings feel crowded

Coupled R and B loops

Reasoning ●●○○○ 2 of 5 Polish ●●●○○ 3 of 5

A group of friends meets every Friday evening, and members invite friends of their own; some of those stay. As the group grows, the gatherings get crowded, conversations split up, and members enjoy them less and invite fewer people. Build one reinforcing loop of growth and one balancing loop of crowding around the group's size, which they share.

The brief

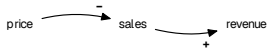
- [ ] Create one R loop.
- [ ] Create one B loop.
- [ ] Share at least one variable between them.
- [ ] Place the variables so that no two effects cross.

Your palette

variable



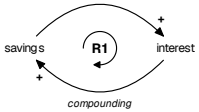
effect



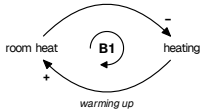
polarity



loop



reinforcing loop



balancing loop

Draw here

CL 05 Borrowing to get to the end of the month

Short-term gain, long-term erosion

Reasoning ●●●○○ 3 of 5 Polish ●●●○○ 3 of 5

A household's bills outrun its income, and it covers the month's gap with a credit card. The cash closes the gap at once. Weeks later, repayments with interest start taking money from every month, and the gap reopens wider.

The brief

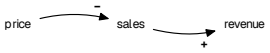
- [ ] Separate fast relief from slow consequence.
- [ ] Mark at least one delayed effect.
- [ ] Make the variable you would monitor first a leverage point.

Your palette

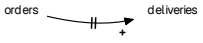
variable



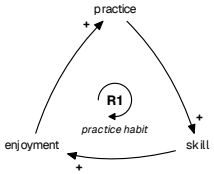
effect



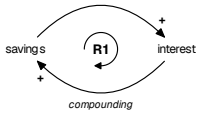
polarity



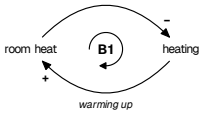
delay



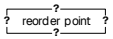
loop



reinforcing loop



balancing loop



leverage point

Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/feedback/loops-that-amplify-loops-that-correct/#exercise-causal-loop-05

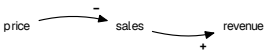
CS 04 Kelsham Primary School: funding that follows its pupils

Your palette

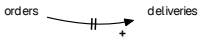
variable



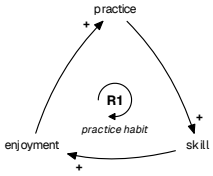
effect



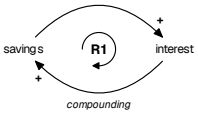
polarity



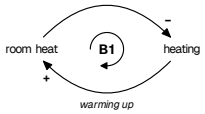
delay



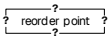
loop



reinforcing loop



balancing loop



leverage point

CS 04 Kelsham Primary School: funding that follows its pupils

Coupled loops, a delay and a leverage point

Reasoning ●●●○○ 3 of 5 Polish ●●●○○ 3 of 5

Kelsham Primary School is paid £4,800 a year for each pupil, set from the count each October and paid through the school year after it. In October 2020 it had 126 pupils in five classes. By October 2023 it had 108, the governors could pay for four teachers, and Years 3 and 4 became one class. Ruth Okafor, the head teacher, hears from some parents that mixed-age classes are why they chose Brayford Primary School, six miles away, where classes hold up to 30. Others stay because Kelsham's classes are smaller: 88 pupils in four classes in October 2026. Tom Hale, who chairs the governors, asks where the school could act. Draw both stories as loops through the pupils on roll, and mark the variable you would change first as a leverage point.

The brief

- [ ] Close one reinforcing loop through the school's funding and its teachers.
- [ ] Close one balancing loop through class size.
- [ ] Let the two loops share at least one variable.
- [ ] Mark the delay the October count makes.
- [ ] Make the variable you would change first a leverage point.
- [ ] Name each loop by what it does.

Your palette

On the page before this sheet.

Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/feedback/loops-that-amplify-loops-that-correct/#exercise-case-04

Sources

- Donella H. Meadows, *Thinking in Systems: A Primer* (Chelsea Green, 2008), chapter 1, on reinforcing and balancing loops, and chapter 2, on delays.
- Donella H. Meadows, *Leverage Points: Places to Intervene in a System* donellameadows.org/archives/leverage-points-places-to-intervene-in-a-system/ (Sustainability Institute, 1999), on leverage points.
- John D. Sterman, *Business Dynamics: Systems Thinking and Modeling for a Complex World* (Irwin/McGraw-Hill, 2000), chapter 5, on causal loop diagrams: polarity, a loop's kind, delays, and naming variables as nouns rather than actions.
- John D. Sterman, "System Dynamics Modeling: Tools for Learning in a Complex World" doi.org/10.2307/41166098, *California Management Review* 43, no. 4 (2001), a short introduction to the same ideas.
- George P. Richardson, "Problems with Causal-Loop Diagrams" doi.org/10.1002/sdr.4260020207, *System Dynamics Review* 2, no. 2 (1986), on what polarity does and doesn't mean.
- National Snow and Ice Data Center, Why sea ice matters nsidc.org/learn/parts-cryosphere/sea-ice/why-sea-ice-matters, on why melting ice speeds further melting.

Delays, External Drivers, and Competing Loops

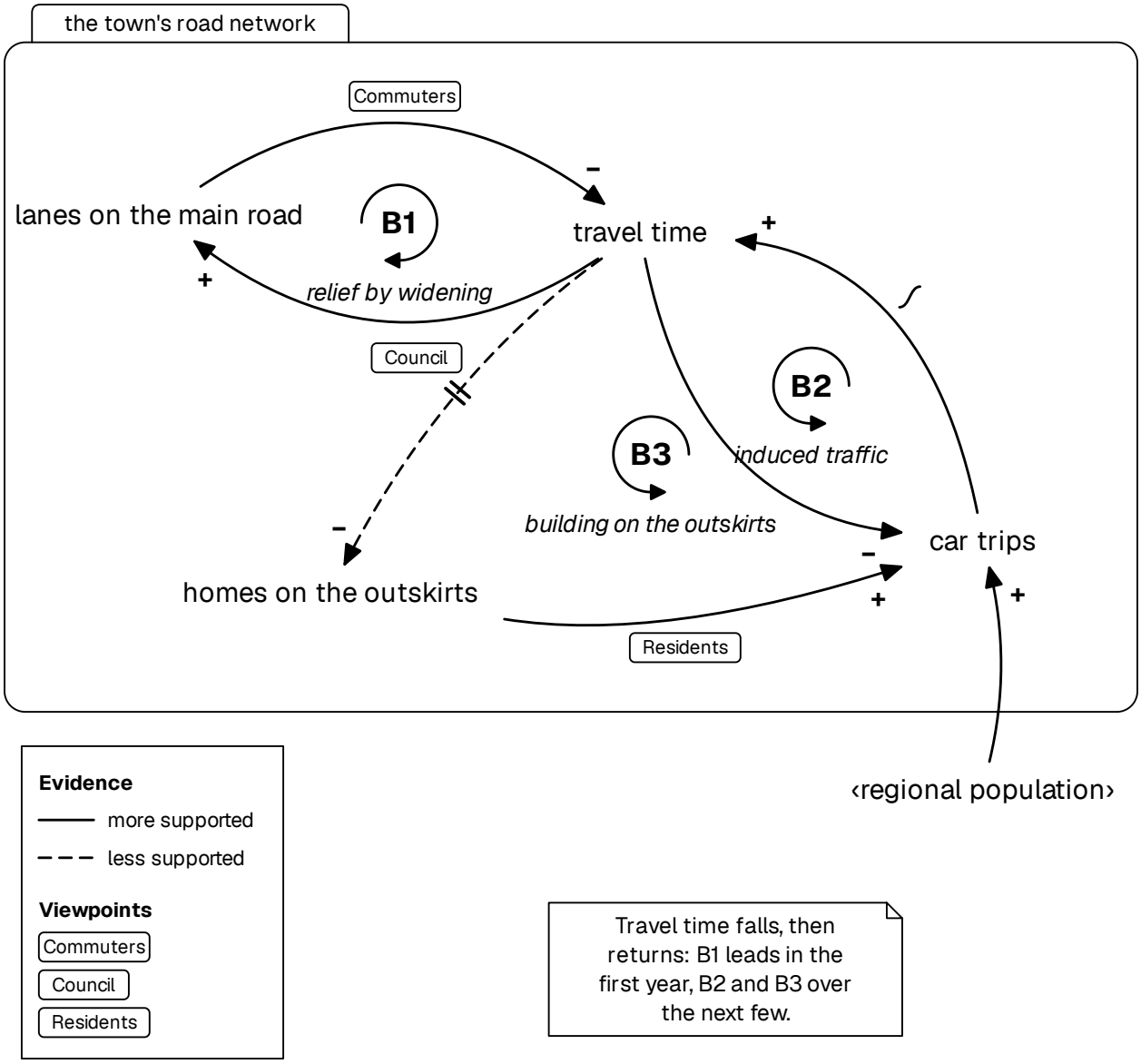
Causal loops Part II · Feedback · Chapter 5 of 12 · the second of two chapters on causal loops

Why does the obvious fix make things worse? A fix can set off loops that pull back against it, some of them after a delay. A causal loop diagram shows what those loops are, what drives them from outside, and which of them leads when.

A town widens its main road

A town’s main road jams every morning, so the council widens it from two lanes to four. For a year the drive across town takes twelve minutes instead of twenty-five.

Then the road fills. People who had taken the bus, driven at other hours or stayed home drive at rush hour. Developers build estates on the outskirts, sold on the short drive into town, and their residents drive the main road too. Meanwhile the region’s population grows, as it did before the widening. By the fifth year the drive takes twenty-five minutes again, with twice as many cars, and the council proposes six lanes.



What the notation expresses

Boundaries

A boundary (chapter 2, The boundary), a named outline with a tab, marks what the model explains. The road diagram's boundary is *the town's road network*, around the lanes, travel time, car trips and homes on the outskirts.

External drivers

An **external driver** is a variable outside every boundary that affects something inside and isn't affected back. Its name is drawn in angle brackets: *‹regional population›*. People move to the region for its jobs and housing, and nothing in the town's road network changes how many come, so regional population sits outside the boundary with one effect leaving it, into car trips.

An external entity (chapter 2, External entities) also sits outside a boundary, but it is a party, not a quantity, and exchanges run to it as well as from it; it is drawn only in system context maps, which have no variables, so the two never share a diagram.

CHECK YOUR UNDERSTANDING

In the road diagram, shorter travel times bring more homes on the outskirts, and more homes bring more car trips. Should homes on the outskirts be drawn as an external driver?

a Yes: the homes are on the outskirts, outside the town

b No: travel time affects them, so they belong inside the boundary

c Yes: developers decide what gets built, not the council

d Only once the homes outnumber the town's own

Feedback: Answers, chapter 5

Nonlinear effects

A **nonlinear effect** is weak over part of its range and sudden over another, or strong, then flat. It's drawn with a small S beside the effect's middle.

On a half-empty road, more car trips barely change travel time; near the road's capacity, each extra car adds minutes. The point where an effect turns from weak to sudden is its **threshold**: here, the road's capacity. Widening raised the threshold, so for a while more trips cost almost no time, and that drew the trips back.

Evidence coding

In a diagram with a dashed effect, solid marks an effect its author judges more supported, and dashed marks one less supported, a hypothesis; a diagram with no dashed effect carries no coding (chapter 1 (chapter 1, Evidence coding)). In the road diagram, travel time → car trips is solid: induced traffic has been counted across American cities. Travel time → homes on the outskirts is dashed: the estates may have come for the short drive or for cheap land.

Viewpoint tags

A **viewpoint tag** is a small labeled box beside an effect, naming a stakeholder who stresses that effect. The tag marks emphasis, not a different structure.

Commuters stress lanes on the main road → travel time, the drive the widening shortened. Residents along the main road stress homes on the outskirts → car trips, the traffic past their doors. The council stresses travel time → homes on the outskirts, the new estates and their taxes.

The legend

The **legend** is a box listing a diagram's codings; any diagram with a dashed effect or a viewpoint tag must have one. Its evidence entry shows a solid line for more supported and a dashed line for less supported. Its viewpoints entry lists every viewpoint tag the diagram uses.

Loop dominance

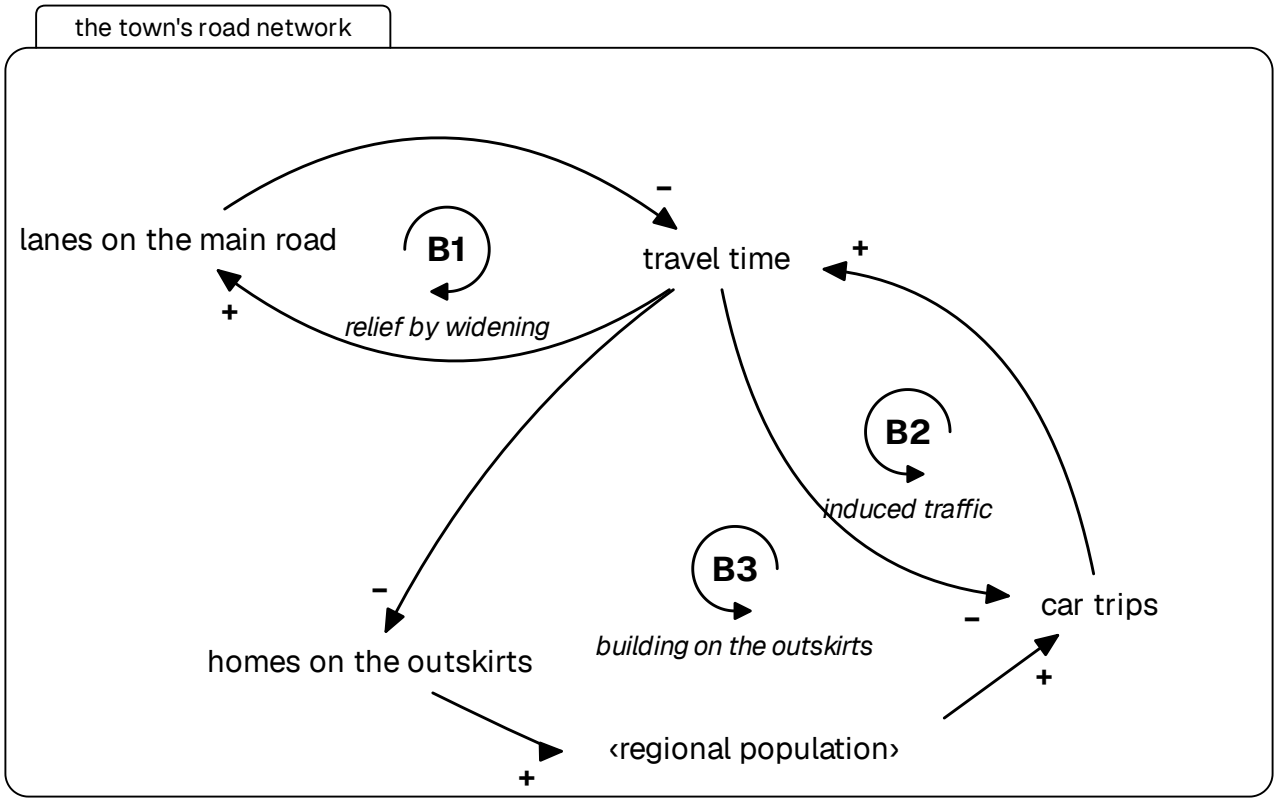
Loop dominance is which loop drives behavior at a given time. It is a reading of the structure, not a mark; the road diagram's behavior note names which loop leads first and which later.

In the first year B1, *relief by widening*, dominates: four lanes cut travel time. B2, *induced traffic*, changes travel time within months, as shorter drives draw trips back. B3, *building on the outskirts*, changes it over years, through the delay on new homes. By the fifth year B2 and B3 dominate.

All three loops are balancing, toward *different* levels: B1 moves travel time toward what the council will accept, B2 and B3 toward what motorists will put up with. A fix that a system's own loops pull back is **policy resistance**. Six lanes would set off B2 and B3 again.

The bad diagram

What's wrong with this diagram of the widened road?



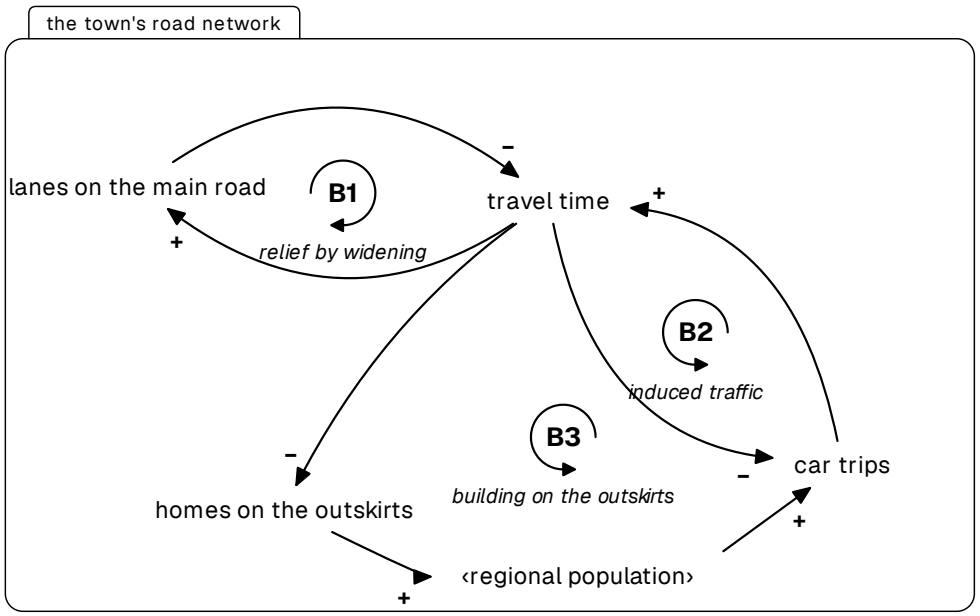
Regional population, marked external, sits inside the boundary with an effect running into it from homes on the outskirts, since new homes house new people, and B3 runs through it. The lab's check reports:

> An external driver affects the system from outside and is not affected back, but 1 effect runs into one: homes on the outskirts → regional population. Remove that effect, or bring the variable inside the system by unmarking it as an external driver.

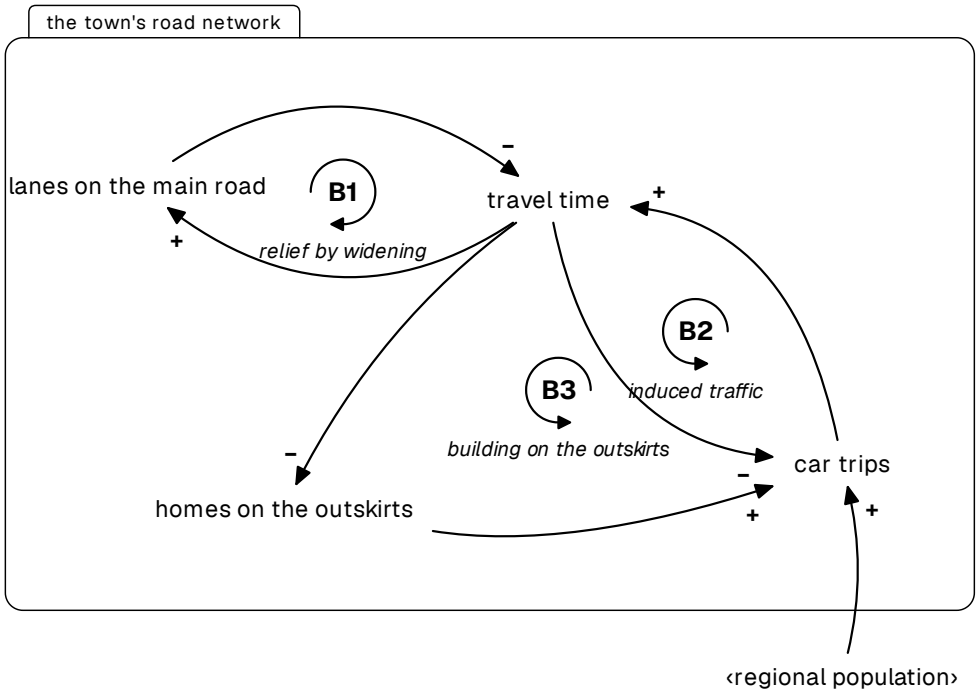
The corrected diagram

Corrected, homes on the outskirts run straight into car trips, and regional population sits outside the boundary, with its one effect leaving it.

Bad diagram



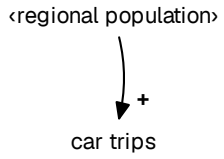
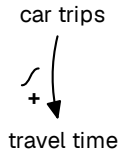
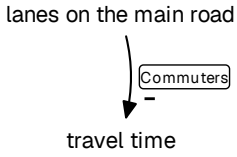
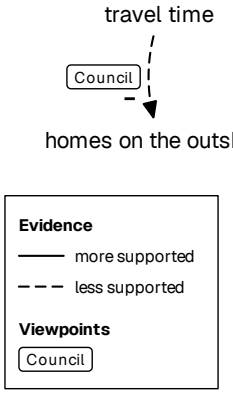
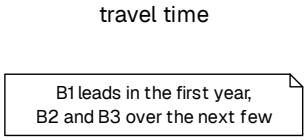
Corrected diagram



Labels unchanged. 1 variable moved outside the boundary. Effects: 1 added, 1 removed. Loops: 1 changed.

B3 now closes inside the town's road network. If the estates do draw people to the region, regional population belongs inside the boundary, unmarked.

Notation moves

Notation move	When	What it shows	Example
Mark an external driver 	A variable affects the inside and nothing inside affects it	A change the model doesn't explain	*‹regional population›* → car trips
Mark a nonlinear effect 	An effect is weak over part of its range and sudden over another	Where a threshold lies	car trips → travel time, at the road's capacity
Tag a viewpoint 	Stakeholders stress different effects	Who stresses which effect, on one structure	*Commuters* on lanes on the main road → travel time
Add a legend 	An effect is dashed or tagged	The codings in use	*Evidence*, *Viewpoints*
Name loop dominance in a behavior note 	Loops lead at different times	Which loop leads first and which later	*B1 leads in the first year, B2 and B3 over the next few*

Common misreading

Read one way, policy resistance means no fix works. The road diagram shows which loops pull widening back, and so where a fix could act on them: a charge for driving at rush hour weakens B2, so shorter drives draw fewer trips back.

Read the other way, a causal loop diagram is a set of separate effects, each judged alone. Lanes on the main road → travel time is true, and alone it means a shorter drive; the drive lengthens again through the loops it sits in.

The strongest objection

A causal loop diagram doesn't show accumulation. Homes on the outskirts pile up while drives are short and stay when drives lengthen, but a – effect from travel time can't show that, so a reader can't work out from the diagram which loop dominates when (Richardson, 1986). In experiments, business school students misjudge how the water in a bathtub changes as it flows in and drains out (Booth Sweeney and Sterman, 2000).

A behavior note is a prediction, not a derivation; stock & flow diagrams, from chapter 6, show accumulation and give numbers. Without them, the loop diagram still shows which loops exist and which way each moves travel time: widening sets off two loops against it.

Check your understanding

CHECK YOUR UNDERSTANDING

Five years after the widening, travel time is back where it was. Suppose the regional population hadn't grown at all. Which reading of the road diagram fits?

a B1 never moved travel time: widening did nothing

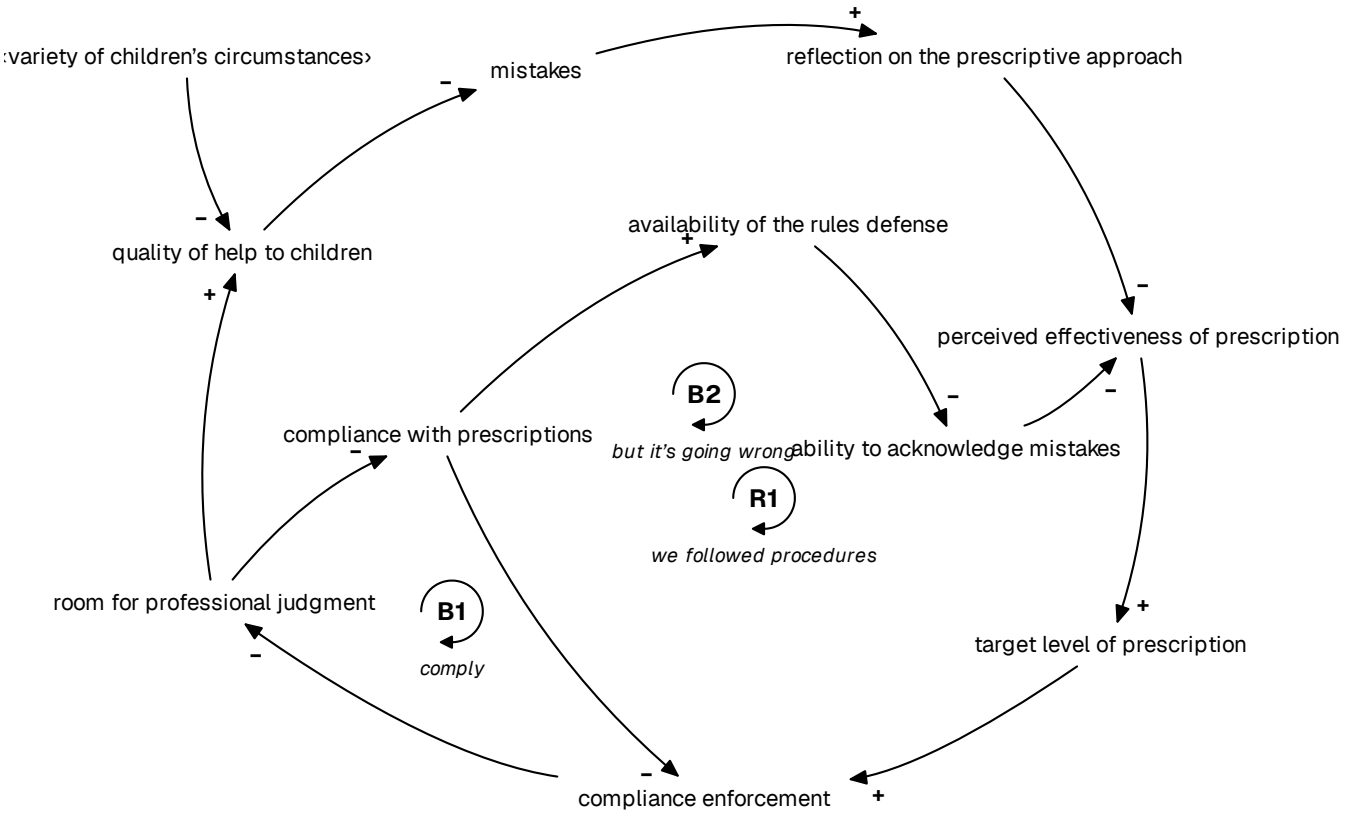
b B1 led at first; B2 and B3 led once trips and homes had grown

c A reinforcing loop formed somewhere in the town

d Travel time came back through the external driver

Feedback: Answers, chapter 5

The Munro Review's loops of compliance, redrawn



Redrawn from Eileen Munro, The Munro Review of Child Protection, Part One: A Systems Analysis (Department for Education, 2010) assets.publishing.service.gov.uk/media/5a81e8a5e5274a2e8ab567a9/TheMunroReview-Part_one.pdf, Appendix 2, the diagram on p. 52. Contains public sector information licensed under the Open Government Licence v3.0 www.nationalarchives.gov.uk/doc/open-government-licence/version/3/.

Its S (same direction) and O (opposite direction) drawn as + and –; its R labeled R1, and each loop's name lowercased, its exclamation mark dropped; nine names shortened or reworded; variety of children's circumstances marked as an external driver; its four-variable tail, from sense of satisfaction derived from work to public status of child protection workers, left out.

QUESTION 1 OF 3

Which variable is drawn as an external driver, in angle brackets, and why?

a Variety of children's circumstances: it changes the quality of help, and nothing drawn changes it.

b Target level of prescription: government sets it, from outside the profession.

c Mistakes: they arise in children's lives, outside any office.

QUESTION 2 OF 3

In the review's account, R1, we followed procedures, keeps B2, but it's going wrong, from bringing the target level of prescription down. Where do the two loops compete?

a At compliance enforcement, where B1, comply, joins them.

b At mistakes, which R1 brings down.

c At perceived effectiveness of prescription: mistakes bring it down through reflection, while the rules defense holds it up.

QUESTION 3 OF 3

No effect in the figure carries a delay. On which effect would a delay belong?

a Compliance enforcement → room for professional judgment.

b Quality of help to children → mistakes.

c Room for professional judgment → compliance with prescriptions.

Feedback: Answers, chapter 5

Exercises

Passing the checks means meeting the brief, not being right. The answer to CL 08, *a parent who finishes the homework*, has the structure of shifting the burden (chapter 10, Shifting the burden), an archetype in chapter 10.

CL 06 A food bank in a downturn

Multiple loops and a boundary

Reasoning ●●●○○ 3 of 5 Polish ●●●●○ 4 of 5

Layoffs at local employers reach a volunteer food bank months later, as families' savings run out. The food bank recruits volunteers, but the regulars give up shifts to train them, so more need goes unmet until trained volunteers take shifts weeks later. Keep layoffs outside the food bank's boundary.

The brief

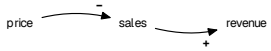
- [ ] Draw the food bank's boundary and name it.
- [ ] Include one external driver.
- [ ] Show two delays.
- [ ] Close two loops and name each one.

Your palette

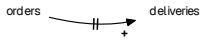
variable



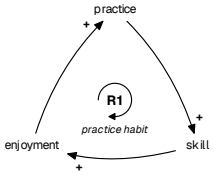
effect



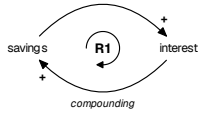
polarity



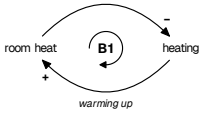
delay



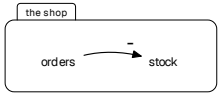
loop



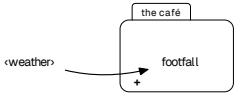
reinforcing loop



balancing loop



boundary



external driver

Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/feedback/delays-drivers-and-competing-loops/#exercise-causal-loop-06

CL 07 Antibiotics and the resistance they breed

Policy resistance

Reasoning ●●●●○ 4 of 5 Polish ●●●●○ 4 of 5

Doctors prescribe antibiotics to cure infections, and cures bring infections down. Over years, heavy use breeds resistant bacteria: treatments fail, infections spread, and prescribing rises. Drug makers might answer the failures with new antibiotics a decade later, but new antibiotics earn little, so that effect is uncertain.

The brief

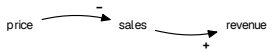
- [ ] Draw at least three loops.
- [ ] Make the loops interact by sharing variables.
- [ ] Code at least one uncertain effect as a hypothesis.
- [ ] Code an effect as a hypothesis only where you are unsure of it.
- [ ] Keep the evidence legend small and inside the canvas.

Your palette

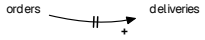
variable



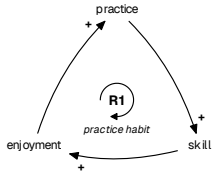
effect



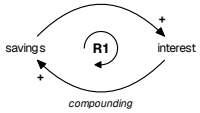
polarity



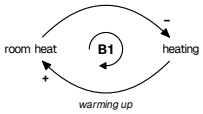
delay



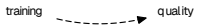
loop



reinforcing loop



balancing loop



evidence coding

Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/feedback/delays-drivers-and-competing-loops/#exercise-causal-loop-07

CL 08 A parent who finishes the homework

Shifting the burden archetype

Reasoning ●●●●○ 4 of 5 Polish ●●●●○ 4 of 5

A child stuck on homework turns to a parent, who on rushed evenings finishes it. Tonight's homework gets done, but the child comes to rely on the help and tries less, and the skill that would let the child finish alone builds only over weeks.

The brief

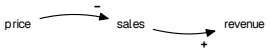
- [ ] Use the shifting-the-burden structure.
- [ ] Close two balancing loops: the quick relief and the slower fundamental response.
- [ ] Close a reinforcing loop through which the relief builds dependence.
- [ ] Show the relief crowding out the fundamental response with a – effect.
- [ ] Name every loop by behavior, not topic.
- [ ] Create a clear visual hierarchy: main story first, detail second.

Your palette

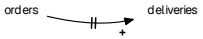
variable



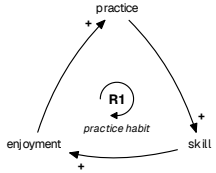
effect



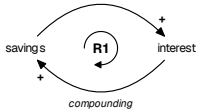
polarity



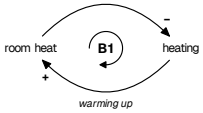
delay



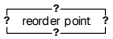
loop



reinforcing loop



balancing loop



leverage point

Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/feedback/delays-drivers-and-competing-loops/#exercise-causal-loop-08

CL 09 An old town and its visitors

Competing viewpoints and nonlinear pressure

Reasoning ●●●●● 5 of 5 Polish ●●●●● 5 of 5

Visitors to an old town fill holiday lets, and more lets draw more visitors; the council limits lets as crowding grows. Residents leave as lets replace homes and as crowding rises: slowly, then fast once summer visitors outnumber them. Local shops close, and more residents leave. Tag what residents, shopkeepers and the council each stress.

The brief

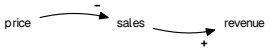
- [ ] Include two reinforcing loops: visitor growth and the loss of residents.
- [ ] Include a balancing control loop.
- [ ] Mark one threshold as a nonlinear effect.
- [ ] Tag three viewpoints without using color.

Your palette

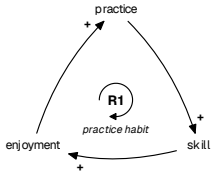
variable



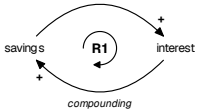
effect



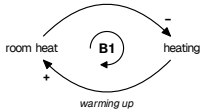
polarity



loop



reinforcing loop



balancing loop



nonlinear effect



viewpoint tag

Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/feedback/delays-drivers-and-competing-loops/#exercise-causal-loop-09

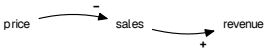
CL 10 A forest region and its fires

Your palette

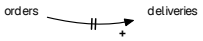
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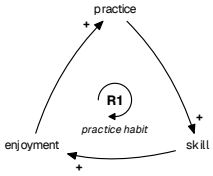
effect



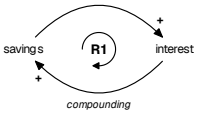
polarity



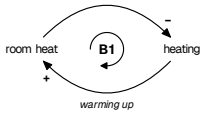
delay



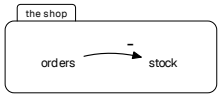
loop



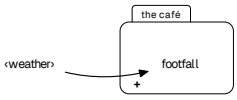
reinforcing loop



balancing loop



boundary



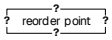
external driver



nonlinear effect



evidence coding



leverage point



behavior note



viewpoint tag

CL 10 A forest region and its fires

Publication-ready multi-loop model

Reasoning ●●●●● 5 of 5 Polish ●●●●● 5 of 5

Small fires once thinned a dry forest's undergrowth. Crews now put out small and severe fires alike, so dry fuel builds for decades and the fires that escape burn hotter. Drought years make severe fires likelier. Whether severe fires lead agencies to fund prescribed burns, which thin the fuel, is uncertain.

The brief

- [ ] Synthesize four or more named loops.
- [ ] Add drought years as an external driver, outside a named boundary.
- [ ] Use evidence coding, declared in the legend.
- [ ] Polish spacing, label placement, and reading order.

Your palette

On the page before this sheet.

Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/feedback/delays-drivers-and-competing-loops/#exercise-causal-loop-10

CS 05 Kelsham Primary School: births, new homes and two loops

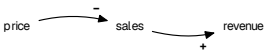
Your palette



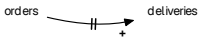
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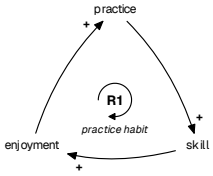
effect



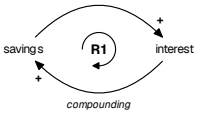
polarity



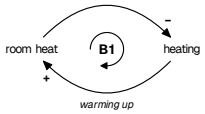
delay



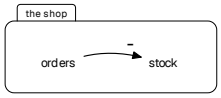
loop



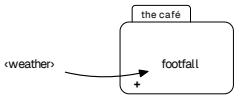
reinforcing loop



balancing loop



boundary



external driver

CS 05 Kelsham Primary School: births, new homes and two loops

External drivers, a delay of four years and competing loops

Reasoning ●●●○○ 3 of 5 Polish ●●●○○ 3 of 5

David Brennan forecasts Kelsham Primary School's starters from the births in its villages four years before. Births fell from 22 in 2016 to 11 in 2025, so the starters go on falling until 2029, whatever the school does. The first of the 60 homes at Mill Lane will be lived in from 2027, and he forecasts 0.25 children of primary school age for each, 15 children in all, joining in any year group. Inside the school, its funding still follows its pupils a school year behind each October count, and parents still weigh mixed-age classes against small ones. Draw the loops through the roll inside the school's boundary, with births and the new homes outside it.

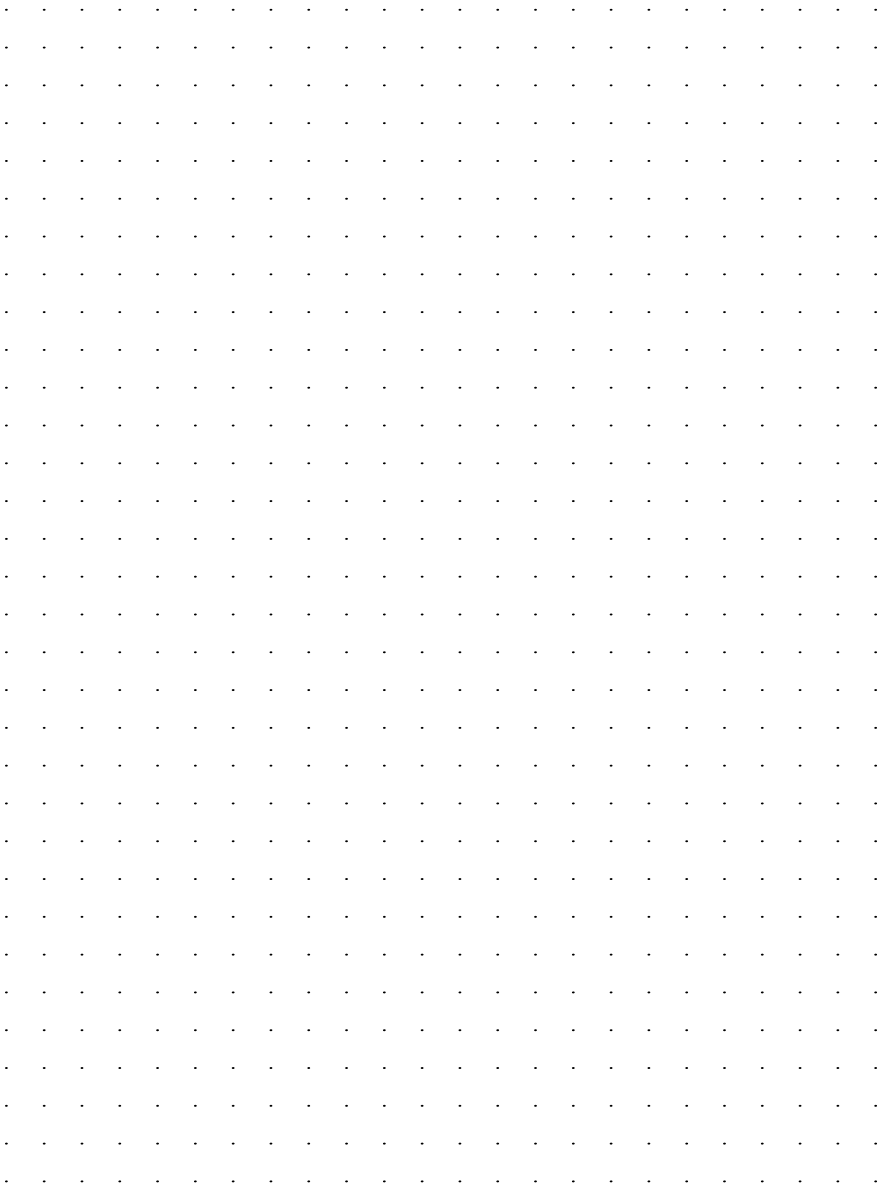
The brief

- [ ] Draw the school's boundary and name it.
- [ ] Keep births in the villages and the homes at Mill Lane outside it as external drivers.
- [ ] Mark the four years from births to starters, and the October count, as delays.
- [ ] Close one reinforcing loop through the school's funding.
- [ ] Close one balancing loop through class size.
- [ ] Let the two loops share variables, so they compete.
- [ ] Name each loop by what it does.

Your palette

On the page before this sheet.

Draw here



In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/feedback/delays-drivers-and-competing-loops/#exercise-case-05

Sources

- John D. Sterman, *Business Dynamics: Systems Thinking and Modeling for a Complex World* (Irwin/McGraw-Hill, 2000), chapter 1, on policy resistance, and chapter 5, on causal loop diagrams of road building and traffic.
- John D. Sterman, "System Dynamics Modeling: Tools for Learning in a Complex World" doi.org/10.2307/41166098, *California Management Review* 43, no. 4 (2001), on policy resistance, with road building among its examples.
- Gilles Duranton and Matthew A. Turner, "The Fundamental Law of Road Congestion: Evidence from US Cities" doi.org/10.1257/aer.101.6.2616, *American Economic Review* 101, no. 6 (2011), measuring how driving rises with new lanes.
- George P. Richardson, "Problems with Causal-Loop Diagrams" doi.org/10.1002/sdr.4260020207, *System Dynamics Review* 2, no. 2 (1986), on what loop diagrams can't show about accumulation.
- Linda Booth Sweeney and John D. Sterman, "Bathtub Dynamics: Initial Results of a Systems Thinking Inventory" doi.org/10.1002/sdr.198, *System Dynamics Review* 16, no. 4 (2000), on how people misjudge accumulation.
- Donella H. Meadows, *Thinking in Systems: A Primer* (Chelsea Green, 2008), chapter 2, on shifting dominance; chapter 4, on nonlinearities; chapter 5, on policy resistance.

Part III — Accumulation

What Accumulates

Stock & flow diagrams

Part III · Accumulation · Chapter 6 of 12 · the first of two chapters on stock & flow diagrams

What would still be there if everything stopped? A stock & flow diagram shows what accumulates, which flows fill and drain it, and which readings set how fast each flow runs.

Signals you need this diagram

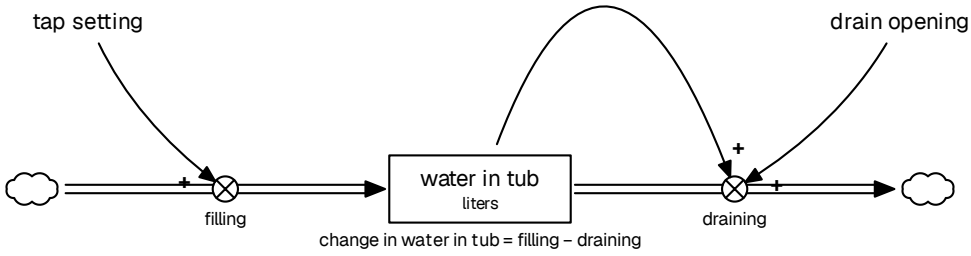
- Something builds up or runs down: savings, a backlog, a population.
- A cut in what comes in hasn't stopped the total rising.
- Something leaves one place and has to turn up in another.
- Amounts have units, and the units have to agree.

A bathtub filling and draining

With the plug in and the tap on, the water in a bathtub rises by the same amount every minute.

With the plug out, it rises more slowly as it deepens, since deeper water drains faster, until it drains as fast as it fills and holds one depth.

Turn off the tap and put the plug in: filling and draining stop, and the water is still there.

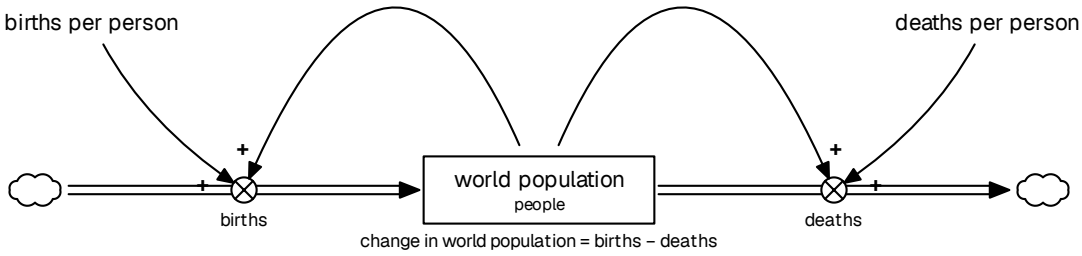


What the notation expresses

Stocks

A **stock** is a quantity that accumulates: what would still be there if every flow stopped. The water in the tub can be measured at an instant; filling and draining exist only over time. A stock changes only through its flows.

It is drawn as a box around its name, its units beneath in smaller type. The world's population is drawn the same way, filled by births and drained by deaths.



CHECK YOUR UNDERSTANDING

A phone charges overnight and runs down through the day. Which of these is a stock?

a the charge in its battery

b charging

c the screen's brightness

Feedback: Answers, chapter 6

Flows

A **flow** moves material into or out of a stock. It is drawn as a double line, its **material path**, with an arrowhead where the material goes and, at its middle, a **valve**: a small circle crossed by an X, the flow's name beside it.

A flow into a stock is one of its **inflows**, a flow out of it one of its **outflows**: *filling* is the tub's inflow, *draining* its outflow. A flow's value at an instant is its **rate**, such as 12 liters a minute.

A flow is named for what moves, *filling* or *births*, not for what sets it moving, such as *tap*.

Clouds

A **cloud**, a small unnamed scalloped outline, is where a flow's material comes from or goes to outside the model: the flow's **source** where it starts, its **sink** where it ends. The bathtub's model leaves out the water main and the sewer, so filling starts at a cloud and draining ends at one.

Each cloud ends one flow; whatever you name or count is a stock instead.

Units

Every stock has **units**: liters for the water in the tub, people for the world's population.

A diagram has one **time unit**, the unit every rate is per: the minute for the bathtub, the year for the population. A flow's units are its stock's units per time unit, so filling and draining run in liters per minute.

Transfers

A **transfer** is a flow from one stock straight into another: an outflow of the first and an inflow of the second, such as pouring from *water in bucket* into *water in tub*.

Material that leaves a stock arrives somewhere, in another stock or at a cloud: **conservation**. So both stocks of a transfer count it in the same units, liters for the bucket and the tub.

Auxiliaries

An **auxiliary** is a variable that neither accumulates nor flows, such as a setting, a capacity or a ratio, drawn as its name alone: *tap setting*, *drain opening*, or the population's *births per person*, the year's births divided by the people alive. In Stella, a modeling program, an auxiliary is a *converter*.

Signals

A **signal** is a single thin line with an arrowhead, carrying a reading of one quantity to an auxiliary or to a flow's valve; in the systems literature, an *information link*.

Tap setting → filling carries the tap's setting, not water, and has a polarity as chapter 4's effects (chapter 4, Polarity) do: +, since the further the tap is open, the faster the tub fills.

+ signals run from *water in tub* to *draining* and from *world population* to *births* and *deaths*. A signal from a stock to one of its own flows closes a loop through that stock (chapter 7 (chapter 7, Loops through stocks)).

The stock equation

A **stock equation**, one line beneath a stock's box, adds its inflows and subtracts its outflows:

```
change in water in tub = filling – draining
```

Its right-hand side is the stock's **net flow**. With filling at 12 liters a minute and draining at 8, the net flow is 4 liters a minute. In 2023 about 132 million people were born worldwide and 62 million died: a net flow of about 70 million people a year.

Auxiliaries and signals never appear in it; they change a stock only through a flow's rate. A stock with no flows reads `change in … = 0`.

Delays on flows

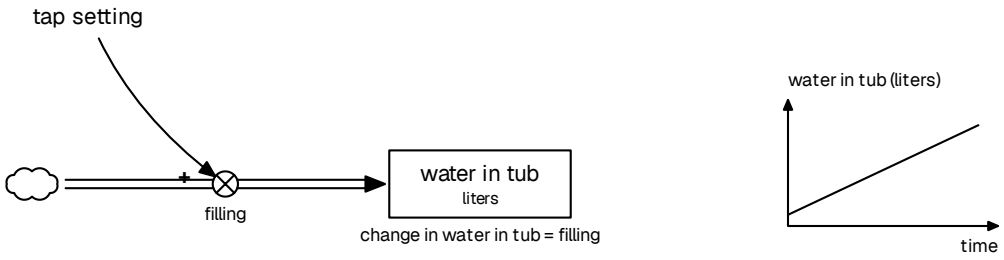
A **delay** on a flow, two short strokes across its double line, means its material arrives well after it leaves, as a change arrives late along a delayed effect (chapter 4, Delays). Grain shipped from a port reaches a mill weeks later: the flow from *grain at the port* to *grain at the mill* carries a delay, and the grain at sea is in neither stock.

Behavior-over-time graphs

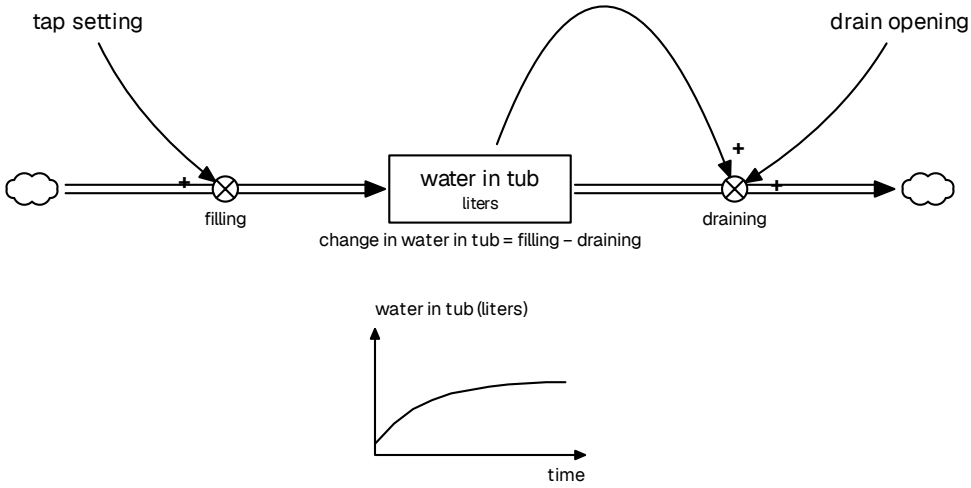
A **behavior-over-time graph** shows one stock, flow or auxiliary over time: the quantity's name (and a stock's units) on the vertical axis, *time* on the horizontal, and one line of a named shape, rising or falling. The shapes are *linear*, *exponential*, *approach* (flattening toward a value), *oscillation* (swinging around a value), *S-shaped* and *overshoot and collapse*. A graph is a prediction from the structure, made before anything is measured.

A stock's slope at any instant is its net flow: it rises while inflows exceed outflows, falls while outflows exceed inflows, and stays flat when they are equal.

With the plug in, the net flow is filling's steady rate, so the water rises in a straight line.



With the plug out, draining speeds up as the water deepens, the net flow shrinks, and the water approaches the depth at which draining equals filling.



Asked to draw the water in a bathtub from graphs of its inflow and outflow, many graduate students at MIT's business school drew a path its flows couldn't produce (Booth Sweeney and Sterman, 2000); chapter 7's *Common misreading* (chapter 7, Common misreading) gives a later study's numbers.

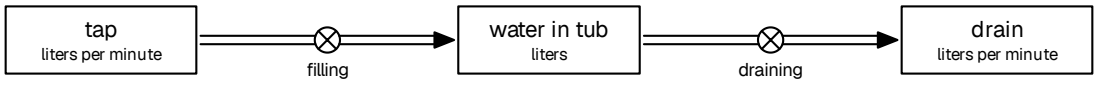
What stays informal

When nothing accumulates, or the question is only which way one quantity moves another, a sentence does: *opening the drain wider empties the tub faster*. With several such effects running in a circle, a causal loop diagram does. When the question is how much there is now, not how it changes, a list of amounts does.

The diagram holds no numbers: rates and amounts go in a sentence or a table beside it.

The bad diagram

What's wrong with this diagram of a bathtub filling from the tap and emptying down the drain?



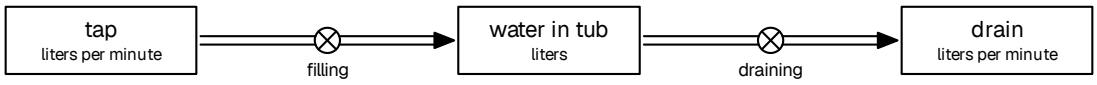
The tap, the water in the tub and the drain are three stocks in a row, joined by filling and draining. The tap is counted in liters per minute and the tub in liters, so filling's units come out as liters per minute per minute. The tap holds no water: its setting fixes how fast filling runs, as the drain's opening fixes draining. The lab's check reports:

> 2 transfers join stocks in different units: filling, from tap (liters per minute) to water in tub (liters); draining, from water in tub (liters) to drain (liters per minute). What leaves one stock arrives in the other, so both count it in the same units.

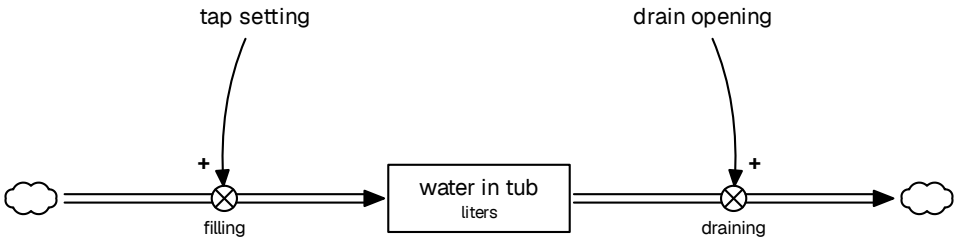
The corrected diagram

The tap and the drain become auxiliaries, *tap setting* and *drain opening*, each with a + signal to its flow's valve. Filling starts at a cloud and draining ends at one, leaving *water in tub*, in liters, the one stock, and both flows in liters per minute.

Bad diagram

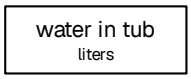
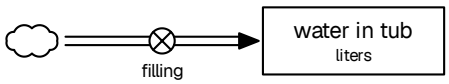
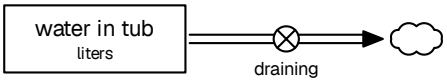
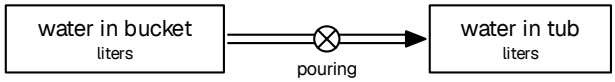
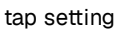
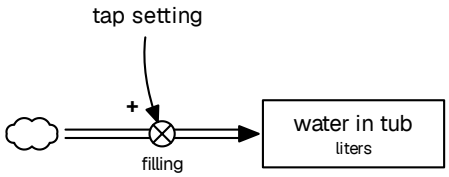


Corrected diagram

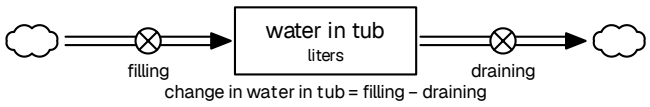


Changed: 2 labels. Stocks: 2 turned into auxiliaries. Flows: filling now starts at a cloud instead of tap, draining now ends at a cloud instead of drain. Signals: 2 added.

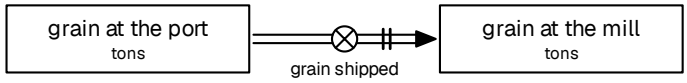
Notation moves

Notation move	When	What it shows	Example
Draw a stock, with units 	Something would remain if every flow stopped	What accumulates, in what units	*water in tub*, liters
Draw a flow 	Material moves into or out of a stock	What moves, which way	*filling*
End a flow at a cloud 	Material enters or leaves the model	Where the model stops	*draining*'s sink
Declare the time unit		What every rate is per	minute
Draw a transfer 	Material moves between stocks	Where it goes, in the same units	*water in bucket* → *water in tub*
Draw an auxiliary 	A setting, target or ratio sets a rate	What a rate depends on	*tap setting*
Draw a signal to a valve 	A reading changes a flow's rate	Which reading, which way	*tap setting* → *filling*, +

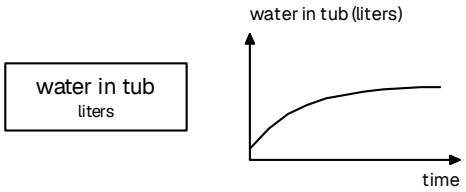
Notation move	When	What it shows	Example
Show the stock equation		The net flow	`change in water in tub = filling - draining`



Mark a delay on a flow	Material arrives well after it leaves	Material in transit	grain shipped to a mill



Draw a behavior-over-time graph		The predicted shape	*water in tub*, approach



Check your understanding

CHECK YOUR UNDERSTANDING

Emails reach Dana's inbox at 60 a day, and she answers or archives 50 a day. This week, arrivals fall to 55 a day while she still clears 50. What do the emails in her inbox do this week?

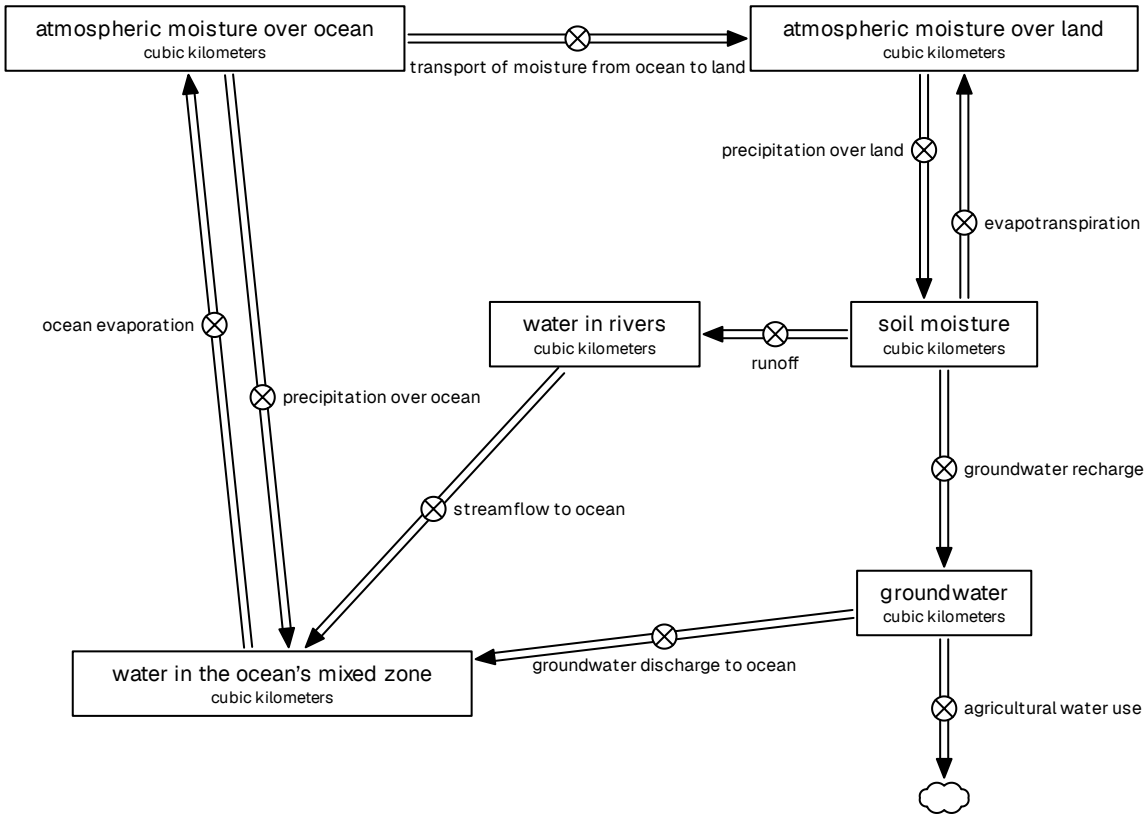
a They keep rising, by 5 a day instead of 10

b They fall, because fewer emails arrive

c They hold steady

Feedback: Answers, chapter 6

Earth's water, stored and moving, redrawn



Redrawn from U.S. Geological Survey, "The Water Cycle" (2022), also published as Hayley R. Corson-Dosch and others, The water cycle, USGS General Information Product 221 (2023) www.usgs.gov/media/images/water-cycle-png, the diagram, in English. U.S. public domain; credit: U.S. Geological Survey.

Six of its fifteen pools drawn as stocks, the ocean's mixed zone among them and its rivers named as the water in them; ten of its fluxes drawn as flows between them, each given one stock at each end, so precipitation over land ends in soil moisture; of its five kinds of human water use, agricultural water use alone, drawn from groundwater to a cloud; units added, cubic kilometers and a time unit of a year, since it gives no amounts; its pictures and colors left out.

QUESTION 1 OF 3

USGS calls each place water is stored a pool, drawn here as a stock, and each way water moves between pools a flux, drawn as a flow. Which flow is not a transfer?

a Evapotranspiration, since liquid water leaves the soil as vapor.

b Agricultural water use, which ends at a cloud.

c Transport of moisture from ocean to land, since it carries water sideways through the air rather than into or out of the ground or the sea.

QUESTION 2 OF 3

USGS gives no amounts. The redrawing counts every stock in cubic kilometers and declares the year as its time unit. In what units does ocean evaporation run?

a Cubic kilometers.

b Millimeters a year, the depth of water lost from the sea's surface.

c Cubic kilometers a year.

QUESTION 3 OF 3

Which is the stock equation of groundwater?

a change in groundwater = groundwater recharge – groundwater discharge to ocean – agricultural water use

b change in groundwater = groundwater recharge – groundwater discharge to ocean

c change in groundwater = groundwater recharge + runoff – groundwater discharge to ocean

Feedback: Answers, chapter 6

Exercises

Passing the checks means meeting the brief, not being right.

SF 01 Words a language learner knows

One stock and one inflow

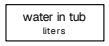
Reasoning ●○○○○ 1 of 5 Polish ●○○○○ 1 of 5

Lena is learning Portuguese from a box of flashcards. She knows about 300 words today and learns about forty new ones a week, a few each evening. Leave forgetting out: draw only the words she knows and the words she learns. Count what she knows in words, and time in weeks.

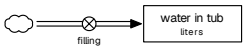
The brief

- [ ] Draw one stock: the words Lena knows.
- [ ] Fill it with one inflow.
- [ ] Draw one cloud, where the new words come from.
- [ ] Add a behavior-over-time graph of the stock, rising steadily.
- [ ] The stock is counted at an instant, in words; the flow per week, in words per week.

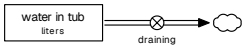
Your palette



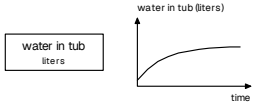
stock



flow



cloud



behavior-over-time graph

Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/accumulation/what-accumulates/#exercise-stock-and-flow-01

SF 02 Firewood at a scout camp

Inflow and outflow

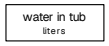
Reasoning ●○○○○ 1 of 5 Polish ●●○○○ 2 of 5

A scout patrol camps in a field for the weekend. Through Saturday afternoon the scouts gather fallen branches into a woodpile by the fire, about thirty kilograms an hour. After dark they gather about five kilograms an hour, and the campfire burns about twelve kilograms an hour. Count the wood in kilograms, and time in hours.

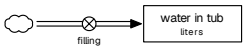
The brief

- [ ] Draw one inflow: the wood the scouts gather.
- [ ] Draw one outflow: the wood the fire burns.
- [ ] Put a cloud at each end, where the wood comes from and where it goes.
- [ ] Add a behavior-over-time graph of the stock, falling steadily.
- [ ] The graph covers the evening, after gathering slows.

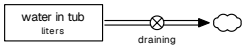
Your palette



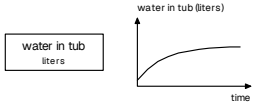
stock



flow



cloud



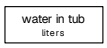
behavior-over-time graph

Draw here

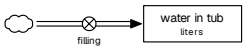
In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/accumulation/what-accumulates/#exercise-stock-and-flow-02

SF 03 Goats on a family smallholding

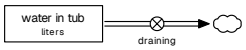
Your palette



stock

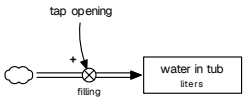


flow

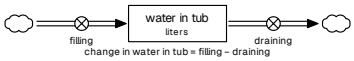


cloud

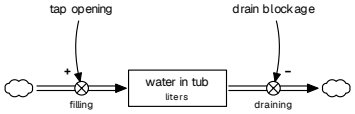
auxiliary



signal



stock equation



polarity

SF 03 Goats on a family smallholding

Net flow and equations

Reasoning ●●○○○ 2 of 5 Polish ●●○○○ 2 of 5

The Mensah family keeps goats on a smallholding: twenty at the start of the year. Each spring the herd has about one kid for every goat in it, so a bigger herd has more kids. Each year the family buys about two goats at market and sells about fifteen. Count the herd in goats, and time in years.

The brief

- [ ] Draw two inflows: kids born, and goats bought.
- [ ] Draw one outflow: goats sold.
- [ ] Add an auxiliary for the kids each goat has in a year.
- [ ] Draw a path of signals from the herd to kids born.
- [ ] Show the herd's stock equation.
- [ ] Kids born reads two signals: one from the herd, one from kids per goat per year.

Your palette

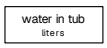
On the page before this sheet.

Draw here

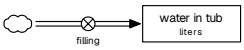
In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/accumulation/what-accumulates/#exercise-stock-and-flow-03

SF 04 Diesel for an island's power station

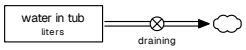
Your palette



stock

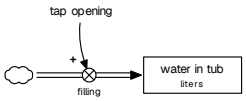


flow

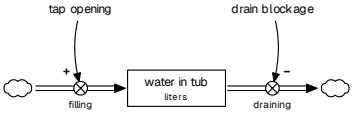


cloud

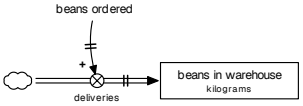
auxiliary



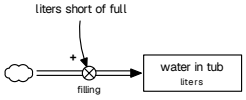
signal



polarity

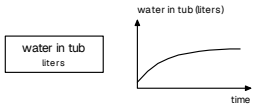


delay



gap

drawn as an ordinary variable



behavior-over-time graph

SF 04 Diesel for an island's power station

Goal seeking with a delay

Reasoning ●●○○○ 2 of 5 Polish ●●●○○ 3 of 5

The power station on a small island burns about 40 tonnes of diesel a week. Its manager aims to keep 250 tonnes in the tanks. Each week she orders 40 tonnes plus a quarter of the gap between 250 tonnes and what the tanks hold, and a tanker delivers each order four weeks after she places it. After storms kept the tankers in port, the tanks hold 100 tonnes. Count diesel in tonnes, and time in weeks.

The brief

- ☐ Draw a path of signals from the stock to the flow that refills it.
- ☐ Mark the four weeks between an order and its delivery as a material delay.
- ☐ Add a behavior-over-time graph of the stock, overshooting and swinging around a value, with a line at the desired stock.
- ☐ Orders are an auxiliary and deliveries the flow; the path from the stock to deliveries passes through the gap.

Your palette

On the page before this sheet.

Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/accumulation/what-accumulates/#exercise-stock-and-flow-04

SF 05 Bottles in a deposit-return scheme

Connected stocks and conservation

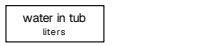
Reasoning ●●●○○ 3 of 5 Polish ●●●○○ 3 of 5

A country runs a deposit-return scheme for drink bottles. Bottlers deliver bottles to shops, where a bottle waits about two weeks on a shelf. A shopper keeps a bottle about five weeks before taking it back to a return machine; about one bottle in ten is thrown away instead. The machines are emptied twice a week, and the bottles collected for recycling. Count every stock in bottles, and time in weeks.

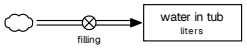
The brief

- [ ] Draw three stocks, one for each place a bottle waits: on shop shelves, with shoppers, in return machines.
- [ ] Join the stocks with transfers, so a bottle leaving one stage arrives in the next.
- [ ] Mark one material delay.
- [ ] The three stocks sit in a row in the order bottles pass through, and the delay is on the flow out of the stage where bottles wait longest.

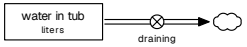
Your palette



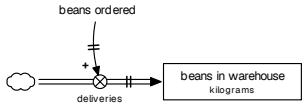
stock



flow



cloud



delay

Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/accumulation/what-accumulates/#exercise-stock-and-flow-05

CS 06 Kelsham Primary School: the roll, filled and drained

One stock, its two flows and the years of the roll

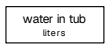
Reasoning ●●○○○ 2 of 5 Polish ●●○○○ 2 of 5

Ruth Okafor counts the pupils on roll each October: 126 in October 2020, 95 in October 2025 and 88 in October 2026. Children start in Reception each September, and pupils leave, Year 6 for secondary school and others for other schools. In the year to October 2026, 9 children started and 16 pupils left; in the year to October 2020, 19 started and 20 left. In every year between, fewer started than left. Count the roll in pupils, and time in years.

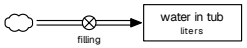
The brief

- [ ] Draw one stock: the pupils on roll, counted in pupils.
- [ ] Fill it with one inflow: the children starting each September.
- [ ] Drain it with one outflow: the pupils leaving.
- [ ] Show the roll's stock equation.
- [ ] Add a behavior-over-time graph of the roll, falling steadily.
- [ ] The stock equation balances for the year to October 2026: 95 pupils, plus 9 starters, less 16 leavers, is 88.

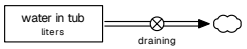
Your palette



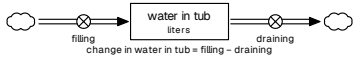
stock



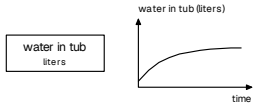
flow



cloud



stock equation



behavior-over-time graph

Draw here

Sources

- Donella H. Meadows, *Thinking in Systems: A Primer* (Chelsea Green, 2008), chapter 1, *The Basics*, on stocks, flows, clouds as sources and sinks, and the bathtub.
- John D. Sterman, *Business Dynamics: Systems Thinking and Modeling for a Complex World* (Irwin/McGraw-Hill, 2000), chapter 4, *Structure and Behavior of Dynamic Systems*, on the shapes behavior over time takes; chapter 6, *Stocks and Flows*, on the notation and on telling a stock from a flow by freezing a system in time; and chapter 7, *Dynamics of Stocks and Flows*, on reading a stock's path from its net flow.
- Linda Booth Sweeney and John D. Sterman, "Bathtub Dynamics: Initial Results of a Systems Thinking Inventory" doi.org/10.1002/sdr.198, *System Dynamics Review* 16, no. 4 (2000), on how well students with no training in system dynamics read stocks and flows.
- isee systems, *Working with Building Blocks* iseesystems.com/resources/help/v3/Content/03-BuildingModels/Working_with_building_blocks.htm (Stella help), on the parts of a model in Stella, a modeling program.
- United Nations, *World Population Prospects 2024*, through Our World in Data, *Number of births* ourworldindata.org/grapher/number-of-births-per-year and *Number of deaths* ourworldindata.org/grapher/number-of-deaths-per-year, for the world's births and deaths in 2023.

Stocks Inside Feedback

Stock & flow diagrams

Part III · Accumulation · Chapter 7 of 12 · the second of two chapters on stock & flow diagrams

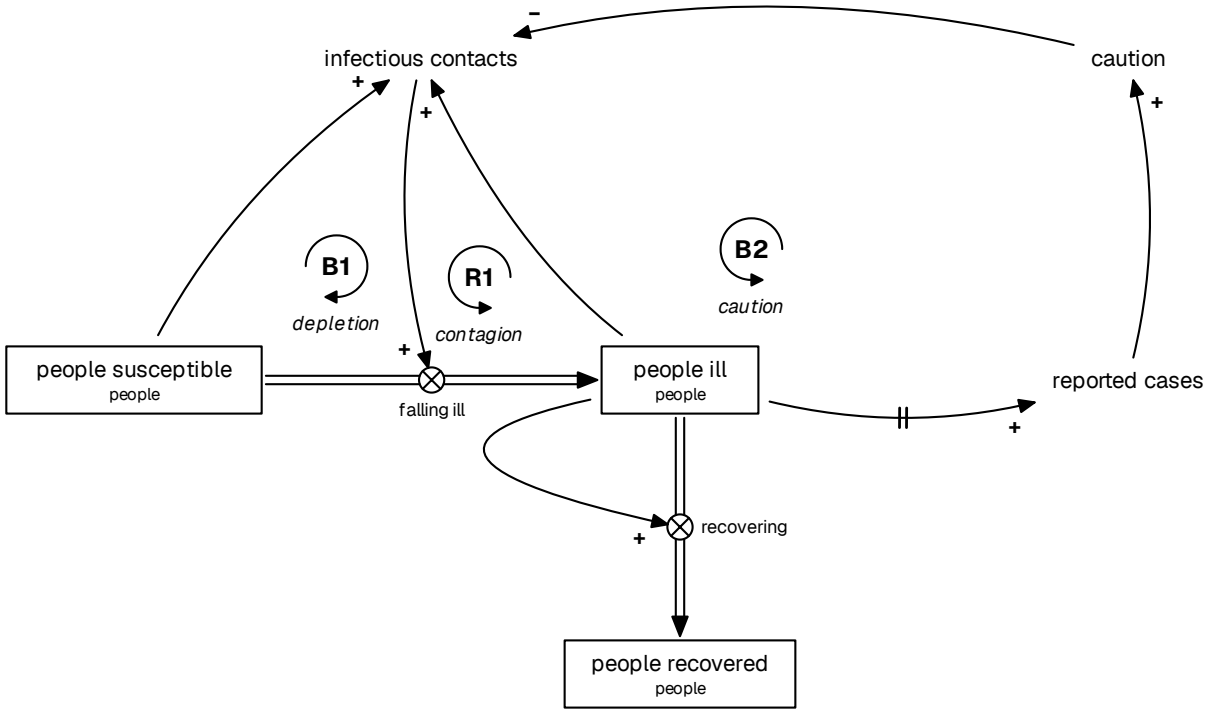
Where do things wait on their way through a system? In stocks, between the flows that fill and drain them. A stock & flow diagram with loops shows which loops pass through each stock, where material waits along a chain of stocks, and which delays hold material and which hold news of it.

A flu season in a region

A new strain of flu reaches a region of a million people, none of whom has had it. Each day people who are ill meet people who have never had it, and some of those catch it. Each person who falls ill is ill for about a week, then recovers and doesn't catch this strain again that season.

Reported cases reach the news a week after people fall ill. As the reports rise, people stay home and keep apart, and fewer fall ill.

The number of people ill rises for weeks, peaks and falls away. When the season ends, some people have never caught it.



What the notation expresses

Loops through stocks

A loop through a stock is a loop (chapter 4, Loops) whose path runs along one of the stock's flows: a signal from the stock reaches the flow's valve, directly or through auxiliaries, and the flow changes the stock. The parity rule

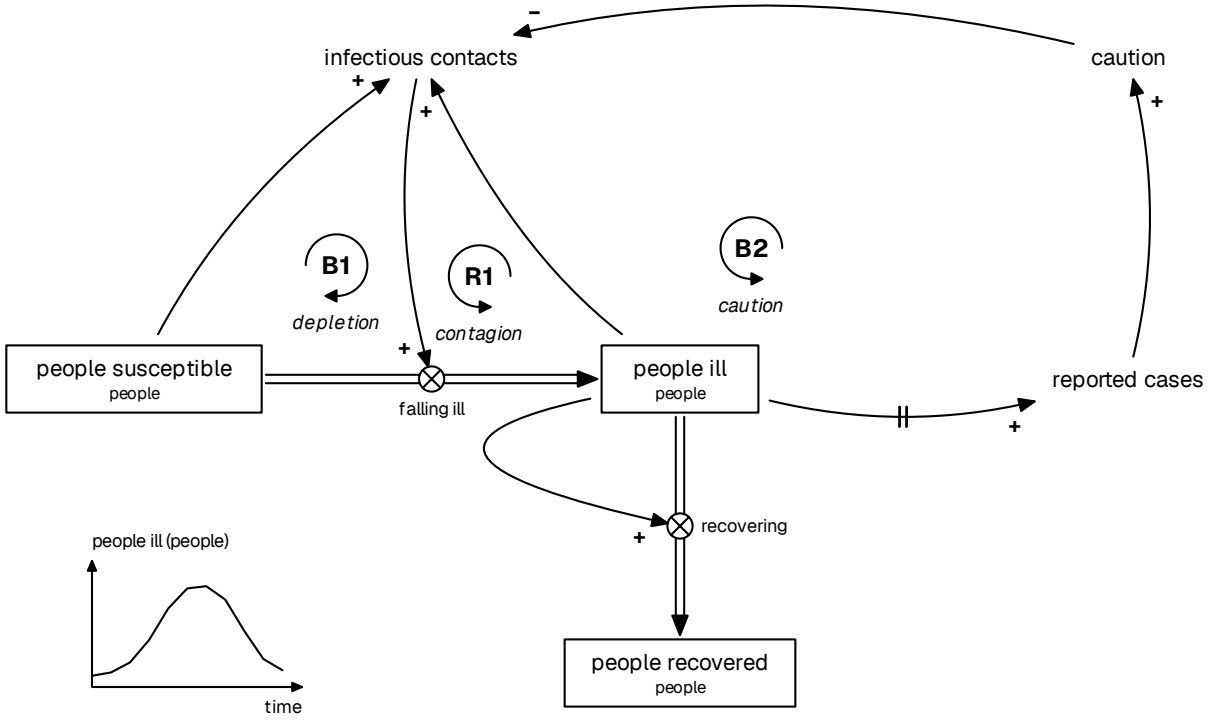
(chapter 4, The parity rule) counts the flow as one step: + from the flow into the stock it fills, – from the flow out of the stock it drains.

Infectious contacts are meetings between someone ill and someone susceptible, so they rise with both stocks. Three loops run through *falling ill*:

- **R1, contagion**: people ill → infectious contacts → falling ill, which fills people ill. No – step: reinforcing.
- **B1, depletion**: people susceptible → infectious contacts → falling ill, which drains people susceptible. One – step: balancing.
- **B2, caution**: people ill → reported cases → caution → infectious contacts (–) → falling ill, which fills people ill. One – step: balancing.

Falling ill counts + in R1 and – in B1, since it fills one stock and drains the other.

Loop dominance (chapter 5, Loop dominance) shifts as stocks fill and empty. Early in the season nearly everyone is susceptible, R1 dominates, and people ill grows exponentially. As people susceptible empties, each person ill meets fewer people who can catch flu; B1 dominates, falling ill drops below recovering, and people ill falls.



Conservation

Falling ill and *recovering* are transfers (chapter 6, Transfers), and the diagram has no cloud, so everyone who leaves one stock arrives in the next. The three stock equations,

```
change in people susceptible = – falling ill

change in people ill = falling ill – recovering

change in people recovered = recovering
```

add up to zero: the three stocks always total the region's million people.

Births, deaths and moves are left out. Drawn in, each would run from a source or to a sink, and people would cross the region's boundary (chapter 5, Boundaries) only along those flows. An external driver (chapter 5, External drivers) reaches a stock through a signal to an auxiliary or a valve, never to the stock: if school holidays cut contacts, *‹school holidays› → infectious contacts* is –.

Evidence coding (chapter 5, Evidence coding) marks signals only. A flow is never dashed: that people move from susceptible to ill isn't in question, only how fast, which the signals into its valve set.

Aging chains

An **aging chain** is a row of stocks joined by transfers, through which material passes in order: people susceptible, then ill, then recovered.

The time material spends in a stock is a delay. Someone who falls ill on a Monday is counted in people ill until about the next Monday, so a rise in falling ill shows in recovering about a week later, on average. *People ill → recovering* is +: with each person ill for about a week, about a seventh of those ill recover each day. *Recovering* carries no delay: the stock holds the week, and a delay on the flow would count it twice.

Material and signal delays

A delay in a stock & flow diagram, the two strokes of chapter 4's delays (chapter 4, Delays), sits on a flow or on a signal. A **material delay**, on a flow, holds material in transit, in neither stock: grain at sea between a port and a mill. A **signal delay**, on a signal, holds news: the people are already ill, and the reading of how many arrives late. *People ill → reported cases* carries a signal delay of a week.

Caution is set by reported cases, a reading of people ill a week old, so after people ill peaks, reported cases and caution go on rising for about a week, and caution is highest once *fewer* people are ill.

CHECK YOUR UNDERSTANDING

An office orders printer paper by the box. A box arrives five days after it is ordered, and the office manager counts the boxes in the cupboard only on Fridays, then orders from that count. Which of these is a signal delay?

a the five days between ordering a box and its arrival

b the days between a box leaving the cupboard and the Friday count

c the time a box spends in the cupboard before it is used

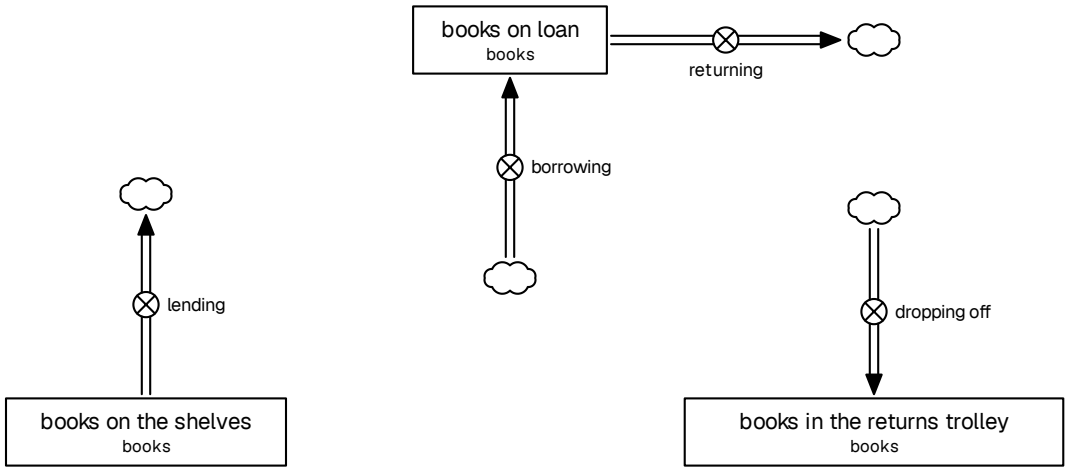
Feedback: Answers, chapter 7

Capacity limits

A stock's capacity is the most it can hold. As the stock nears it, the flow into it slows sharply: a nonlinear effect (chapter 5, Nonlinear effects) on a signal from the stock to its own inflow, its threshold an amount the stock holds. If the flu filled the region's hospital beds, *people in hospital → admissions* would be – and nonlinear: weak while beds are free, strong as the last ones fill.

The bad diagram

What's wrong with this diagram of a town library's books, lent from the shelves, returned to a trolley and reshelved?



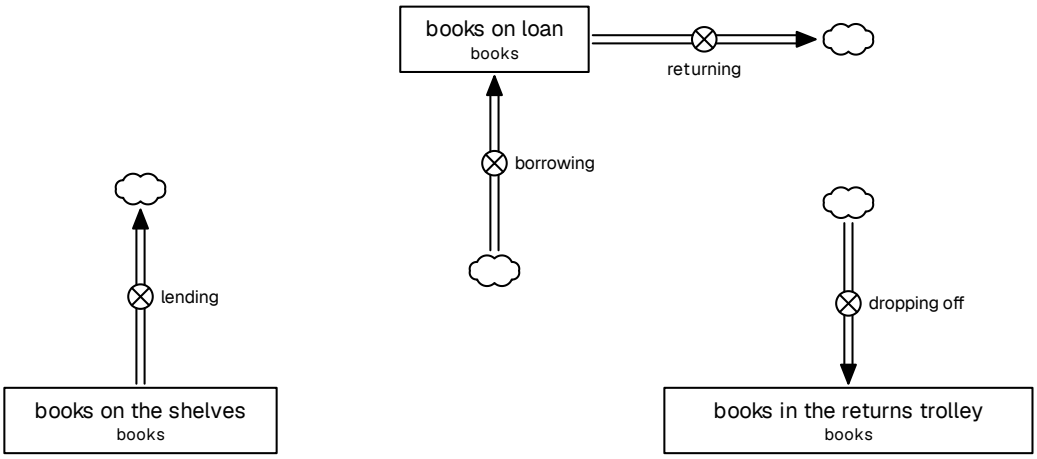
The books on the shelves, on loan and in the returns trolley are three stocks, but lending runs from the shelves to a cloud, borrowing from a cloud into the books on loan, returning to a cloud and dropping off from a cloud. Between each stage and the next the same books leave the model and come back into it, so the three stocks' total can rise or fall with no book bought or lost. The lab's check for at least three transfers reports:

> No transfers. Brief: at least 3. A transfer runs from one stock straight into another, with no cloud between them.

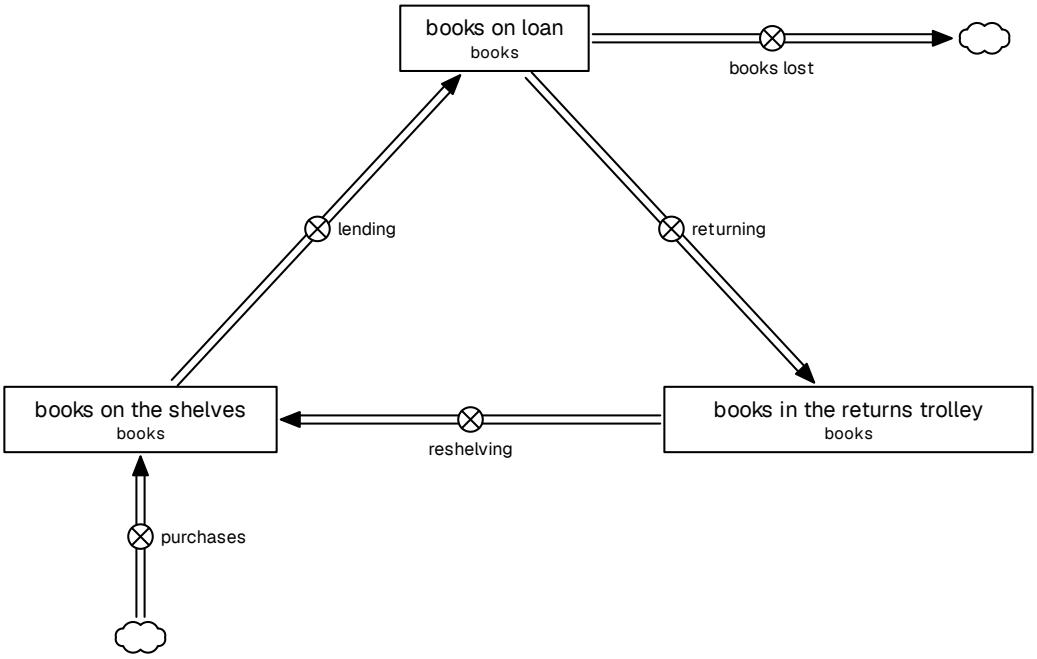
The corrected diagram

Corrected, lending, returning and reshelving are transfers around the three stocks; purchases arrive from a source and lost books leave to a sink, so each book is counted in one stock from the day it is bought until it is lost.

Bad diagram

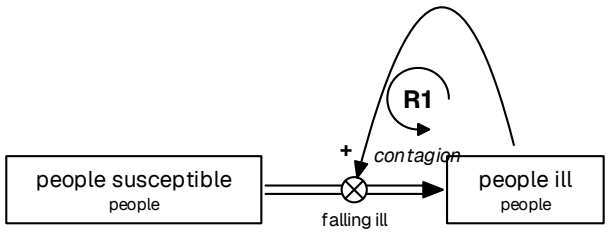
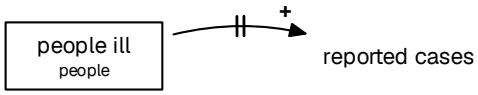
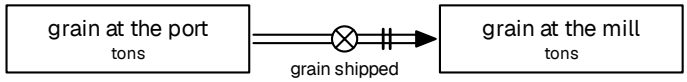
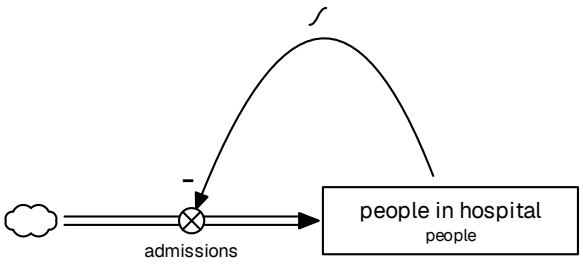


Corrected diagram

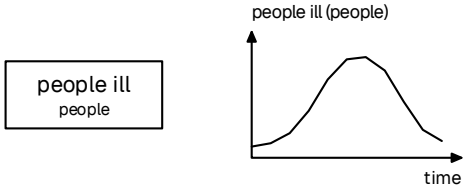


Labels unchanged. Flows: 3 added, 2 removed, lending now ends at books on loan instead of a cloud, returning now ends at books in the returns trolley instead of a cloud.

Notation moves

Notation move	When	What it shows	Example
Declare a loop through a flow	A signal from a stock reaches the valve of one of its own flows	Which loops change the stock, and through which flow	R1 *contagion*, through *falling ill*
			
Chain stocks with transfers	Material passes through stages in order	Where it waits, with none lost between stages	*people susceptible* → *people ill* → *people recovered*
			
Mark a signal delay	A reading arrives well after what it reads	News running behind a stock	*people ill* → *reported cases*
			
Mark a material delay	Material is in transit between stocks	Material in neither stock	grain shipped to a mill
			
Mark a nonlinear signal from a stock to its inflow	A stock nears the most it can hold	Where the capacity lies	*people in hospital* → *admissions*
			

Notation move	When	What it shows	Example
Graph a stock in a loop		The shape the shifts in dominance produce	*people ill*, overshoot and collapse



Common misreading

Reading a stock's graph as the shape of its inflow, the stock highest when the inflow is fastest, is the correlation heuristic (Cronin, Gonzalez and Sterman, 2009). Falling ill peaks first. At its peak more people still fall ill each day than recover, so people ill goes on rising; it peaks later, on the day falling ill has dropped to equal recovering.

Shown graphs of people entering and leaving a department store each minute, 96 percent of 173 graduate students in a business simulation course at MIT found the minute the most people entered, and 44 percent the minute the most people were *in* the store; 29 percent chose the minute of the largest net flow into the store.

The strongest objection

Without equations and simulation, a stock & flow diagram is a causal loop diagram with boxes: when loops trade dominance, and how far a stock overshoots, depend on numbers the diagram doesn't hold. Homer and Oliva (2001), answering Coyle (2000), argue that simulation lets a modeler draw behavioral inferences reliably "in a way that is rarely possible with maps alone".

A behavior-over-time graph drawn from the structure is a hypothesis until the model is simulated or the system measured: the graph of people ill shows an overshoot and collapse, not how high it peaks or in which week.

Units and conservation are checked on the drawing, before any number. The lab's checks catch a transfer between stocks in different units, books that vanish between the shelves and the loans, and a signal drawn into a stock; a causal loop diagram has no mark they could catch.

Check your understanding

CHECK YOUR UNDERSTANDING

Skiers join the queue for a chairlift at 10 a minute at 8:30, at 60 a minute at 9:30, and at 10 a minute again by 11:00. The lift carries 30 skiers a minute all morning. When is the queue longest?

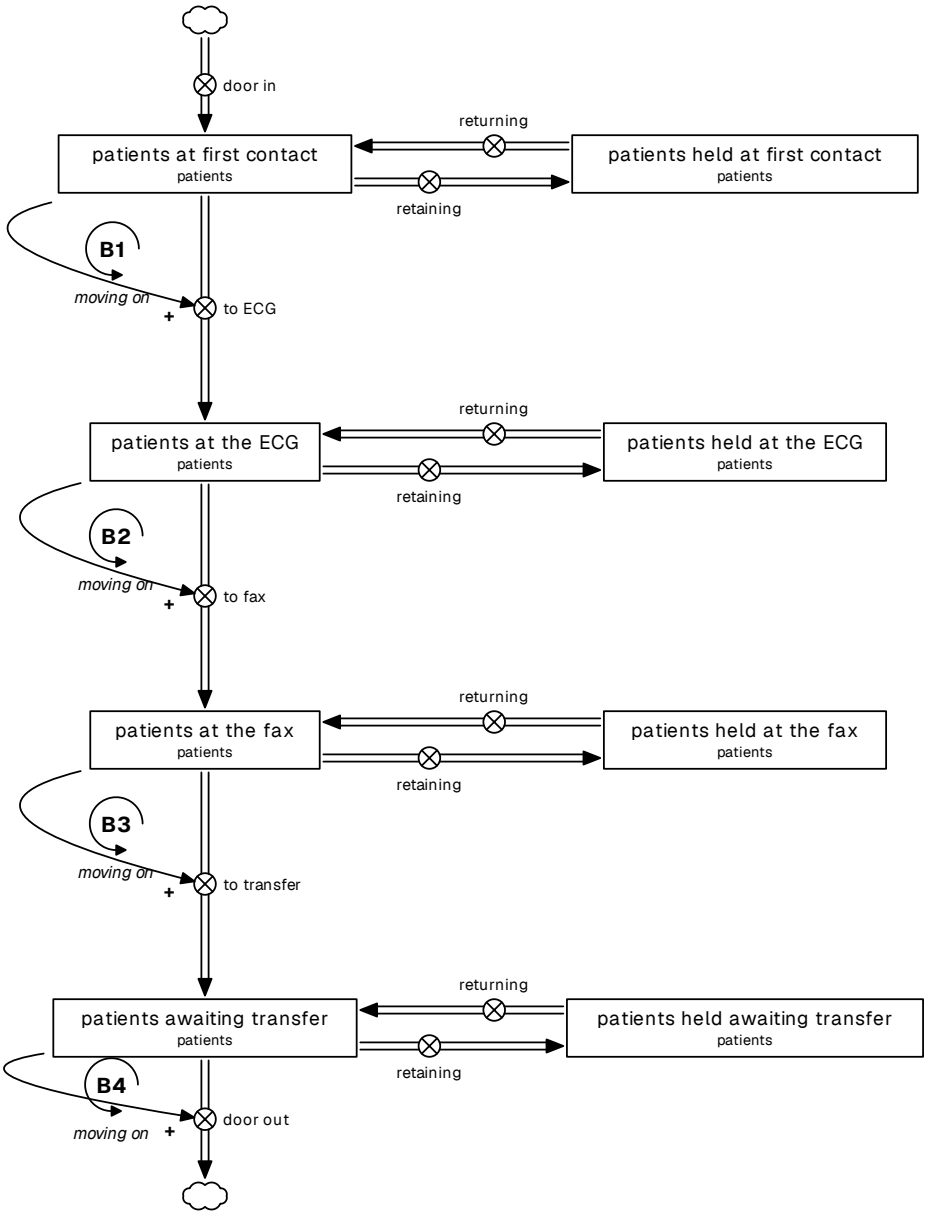
a at 9:30, when skiers join fastest

b after 9:30, when joining has fallen back to 30 a minute

c at 11:00, when joining is slowest

Feedback: Answers, chapter 7

Waits for heart attack care, redrawn



Redrawn from Luciano de Andrade, Catherine Lynch, Elias Carvalho, Clarissa Garcia Rodrigues, João Ricardo Nickenig Vissoci, Guttenberg Ferreira Passos, Ricardo Pietrobon, Oscar Kenji Nihei and Maria Dalva de Barros Carvalho, “System Dynamics Modeling in the Evaluation of Delays of Care in ST-Segment Elevation Myocardial Infarction Patients within a Tiered Health System”, PLOS ONE 9(7): e103577 (2014) doi.org/10.1371/journal.pone.0103577, Figure 4. CC BY 4.0 creativecommons.org/licenses/by/4.0/.

Its four stages, first medical contact (FMC), ECG and diagnosis (ECG), the ECG sent by fax to the PCI center, where the blocked artery is opened, and its reply (TXF), and the wait for transfer there (TWT), named for the patients at each; each Retained stock named for the patients held there, and its retain and back flows renamed retaining and returning; each output named for where its patients go, the last door out; its auxiliaries and their signals left out; its B1 to B4, each labeled inside a stage’s path of retaining and returning, which carries no signal, each drawn as the loop through the signal from its stage’s patients to their outflow, which it draws, and named moving on; the chain drawn downward.

QUESTION 1 OF 3

A patient reaches the first hospital at two o'clock and leaves for the PCI center at four. Where in the diagram are those two hours spent?

a In the flows, since a flow is the patient moving from one stage to the next.

b In the loops B1 to B4, since each loop keeps patients until they move on.

c In the stocks: at each stage in turn, and in a held stock wherever the patient is held.

QUESTION 2 OF 3

B2 runs from patients at the ECG to the valve of to fax, the flow that drains them. What does B2 do to patients at the ECG?

a The more patients at the ECG, the faster they leave for the fax, so a rise in that stock comes back against itself.

b It holds the patients' wait at the guidelines' optimal time, the value the authors compare each wait with.

c It makes patients at the ECG grow, since more of them send more on to the fax.

QUESTION 3 OF 3

At the fax stage, 76% of the patients the authors followed waited longer than the optimal time. Where does a patient's wait at that stage appear in the diagram?

a As a material delay on to transfer, for patients between the two stages.

b As the time a patient spends in patients at the fax and in patients held at the fax, with no delay drawn.

c As a signal delay on patients at the fax → to transfer, since the reply from the PCI center arrives late.

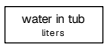
Feedback: Answers, chapter 7

Exercises

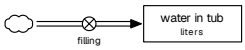
Passing the checks means meeting the brief, not being right.

SF 06 Players of an online game

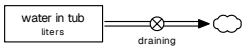
Your palette



stock

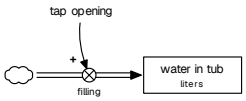


flow

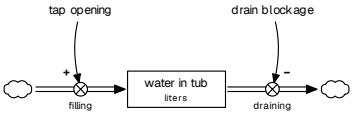


cloud

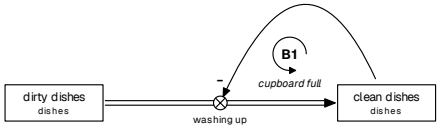
auxiliary



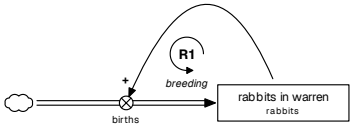
signal



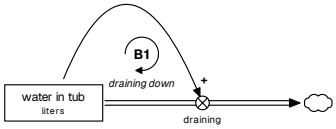
polarity



loop



reinforcing loop



balancing loop

SF 06 Players of an online game

Stocks embedded in feedback

Reasoning ●●●○○ 3 of 5 Polish ●●●●○ 4 of 5

Players around the world join an online puzzle game only by invitation: each day about one player in fifty invites a friend, who joins. Matches run on a fixed number of servers, so the more players there are, the longer each waits for a match, and the longer the wait, the more players quit each day. Count the stock in players, and time in days.

The brief

- [ ] Draw two flows: players joining, and players quitting.
- [ ] Declare one reinforcing loop.
- [ ] Declare one balancing loop.
- [ ] Run each loop through a flow, so that it passes through the stock.
- [ ] Each loop is named for what goes around it, such as word of mouth or queue frustration.

Your palette

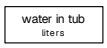
On the page before this sheet.

Draw here

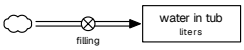
In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/accumulation/stocks-inside-feedback/#exercise-stock-and-flow-06

SF 07 Dogs at a rescue shelter

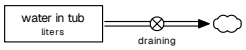
Your palette



stock

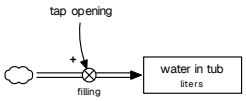


flow

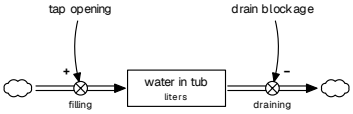


cloud

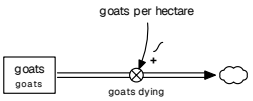
auxiliary



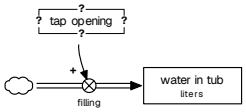
signal



polarity



nonlinear effect



leverage point

SF 07 Dogs at a rescue shelter

Capacity and nonlinear rates

Reasoning ●●●●○ 4 of 5 Polish ●●●●○ 4 of 5

A town's dog rescue shelter has 40 places. Owners and the council refer about eight dogs a week to its waiting list, and owners withdraw about one a week after finding a home elsewhere. Staff take dogs in from the list, but intake slows sharply as the places fill: about six dogs a week while 30 are in care, almost none at 38. Crowding lengthens stays: a dog waits about four weeks for adoption while the shelter is half full, seven while it is full. The manager proposes recruiting foster homes, each adding a place. Count both stocks in dogs, and time in weeks.

The brief

- [ ] Draw two stocks: dogs on the waiting list, and dogs in care.
- [ ] Join them with intake, a transfer.
- [ ] Mark the signal by which filling places slow intake as nonlinear.
- [ ] Mark what foster homes would add to as the one leverage point.
- [ ] The nonlinear signal reaches intake through occupancy.

Your palette

On the page before this sheet.

Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/accumulation/stocks-inside-feedback/#exercise-stock-and-flow-07

SF 08 Seedlings raised on a windowsill

Aging chain

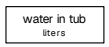
Reasoning ●●●●○ 4 of 5 Polish ●●●●○ 4 of 5

Amira raises tomatoes and peppers from seed on her kitchen windowsill. Each spring she sows about 60 seeds in trays; about one in five fails to sprout, and the rest come up within two weeks. Seedlings grow on the sill for about five weeks, and a few die of damping off. Before going into the garden, each seedling spends exactly ten days in a cold frame, hardening off, and cold nights kill a few there. The cold frame holds 24, so seedlings wait on the sill until it has room. Count every stage in seedlings, a seed counted from the day it is sown, and time in days.

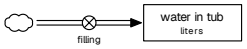
The brief

- [ ] Draw a stock for each stage: sown in trays, seedlings on the sill, in the cold frame, planted out.
- [ ] Chain the stages with transfers, so a seedling leaving one arrives in the next.
- [ ] Mark the ten days in the cold frame as a material delay.
- [ ] Add a behavior note.
- [ ] Where seedlings pile up, and why, is in the note.

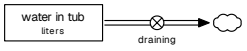
Your palette



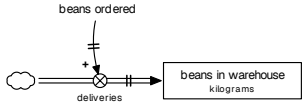
stock



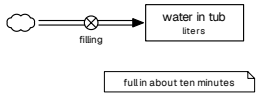
flow



cloud



delay



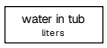
behavior note

Draw here

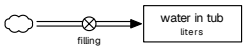
In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/accumulation/stocks-inside-feedback/#exercise-stock-and-flow-08

SF 09 A city's bike-share fleet

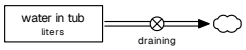
Your palette



stock

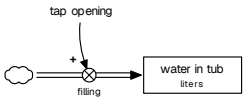


flow

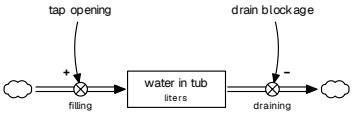


cloud

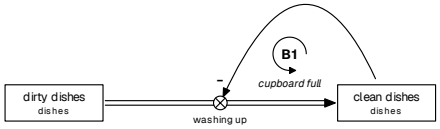
auxiliary



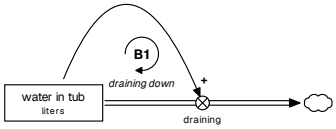
signal



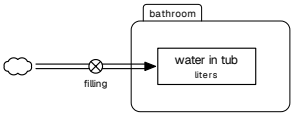
polarity



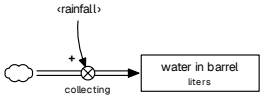
loop



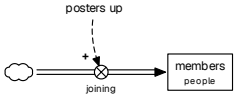
balancing loop



boundary



external driver



evidence coding

SF 09 A city's bike-share fleet

Multiple stocks, a boundary and evidence

Reasoning ●●●●● 5 of 5 Polish ●●●●● 5 of 5

A city's bike-share scheme has docks on a hilltop and by the river. Riders seldom pedal uphill, so rides between the two run downhill and bikes collect at the riverside docks; on rainy days about a third fewer bikes are ridden. Vans collect bikes from the riverside docks and bring them to the scheme's workshop, where mechanics check and repair them; the vans then deliver them to the hilltop docks. Bikes beyond repair are scrapped. Staff record rides, collections and deliveries each day. They believe the vans deliver more bikes the lower the hilltop docks run, but nobody has checked. Rain, and scrapped bikes once they leave, lie outside the scheme. Count every stock in bikes, and time in days.

The brief

- [ ] Draw a stock for each place bikes wait: the hilltop docks, the riverside docks, the workshop.
- [ ] Join the stocks with transfers, so no bike appears or vanishes between them.
- [ ] Declare a balancing loop through the vans' deliveries.
- [ ] Draw the scheme's boundary, with rain outside it as an external driver.
- [ ] Code the signal you judge less supported as a hypothesis.
- [ ] Rain's signal rests on ride counts and is solid; the vans' response, a belief, is the hypothesis, and the legend shows the coding.

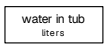
Your palette

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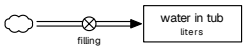
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SF 10 Teachers in a country's schools

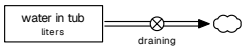
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stock

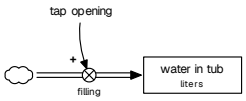


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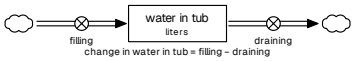


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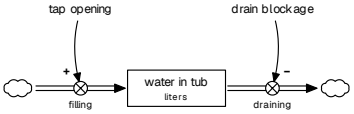
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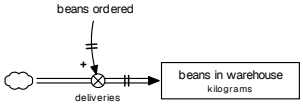
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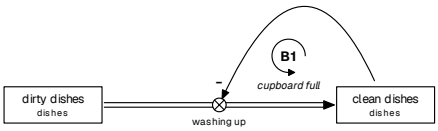
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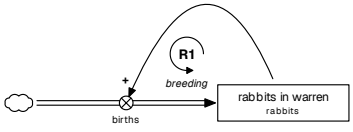
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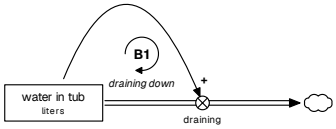
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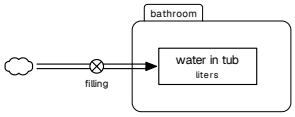
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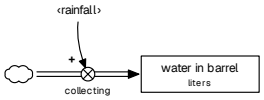
reinforcing loop



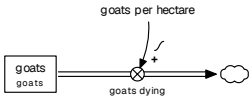
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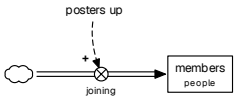
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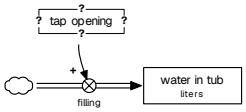
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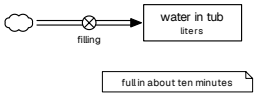
nonlinear effect



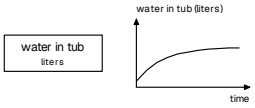
evidence coding



leverage point



behavior note



behavior-over-time graph

SF 10 Teachers in a country's schools

A complete model

Reasoning ●●●●● 5 of 5 Polish ●●●●● 5 of 5

Student teachers take a one-year course; about one in ten drops out. Newly qualified teachers count as experienced after three years, and about one in eight leaves each year before then; about one experienced teacher in fourteen leaves each year. Pupil numbers are rising, and the fewer experienced teachers there are, the heavier each one's workload. In exit surveys, teachers name workload as their main reason for leaving, and resignations rise a year or two after workload does. Head teachers believe that mentoring by experienced teachers keeps new teachers from leaving, but nobody has measured it. The education ministry proposes funding more training places; whether they would fill is untested. Pupil numbers lie outside the schools. Count every stage in teachers, student teachers included, and time in years.

The brief

- [ ] Draw a stock for each stage: student teachers, newly qualified teachers, experienced teachers.
- [ ] Join the stages with transfers.
- [ ] Declare two or more loops.
- [ ] Run every loop through a stock.
- [ ] Code each signal you judge less supported as a hypothesis.
- [ ] Mark what the ministry proposes to change as the one leverage point.
- [ ] Mark the year or two between heavier workload and more resignations as a signal delay.
- [ ] The leverage point's signal is a hypothesis, as mentoring's is; the legend shows the coding, and every other signal is solid.

Your palette

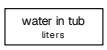
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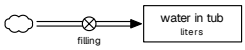
In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/accumulation/stocks-inside-feedback/#exercise-stock-and-flow-10

CS 07 Kelsham Primary School: four classes in a chain

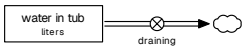
Your palette



stock

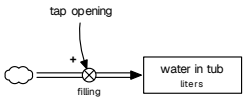


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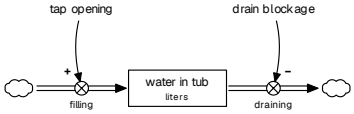


cloud

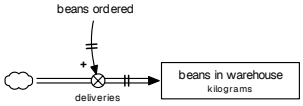
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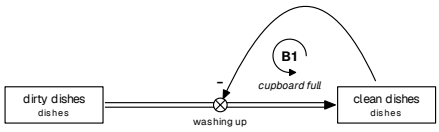
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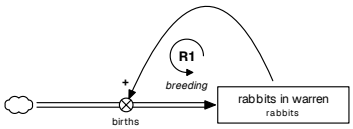
polarity



delay



loop



reinforcing loop

CS 07 Kelsham Primary School: four classes in a chain

A chain of stocks, and a loop through the flow that fills it

Reasoning ●●●●○ 4 of 5 Polish ●●●●○ 4 of 5

Since 2023 Kelsham Primary School has taught four classes: Reception, Years 1 and 2, Years 3 and 4, and Years 5 and 6. Children start in Reception each September; each September after that every pupil moves up a year, those finishing Reception, Year 2 and Year 4 into the next class, and Year 6 leaves for secondary school. Each October's count of every pupil sets the school's funding for the school year after it, at £4,800 a pupil. With less funding, Years 3 and 4 were taught as one class, and Priya Shah and other parents weigh mixed-age classes when they choose a school for a child about to start. Leave out pupils who move school during a school year. Count every class in pupils, and time in years.

The brief

- [ ] Draw a stock for each class: Reception, Years 1 and 2, Years 3 and 4, Years 5 and 6.
- [ ] Join the classes with transfers, as pupils move up each September.
- [ ] Close one reinforcing loop from the classes through the school's funding to the flow of children starting.
- [ ] Run the loop through a stock.
- [ ] Mark the school year between the October count and the funding it sets as a signal delay.
- [ ] The October count reads every class, not only Reception: the funding follows every pupil on roll.

Your palette

On the page before this sheet.

Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/accumulation/stocks-inside-feedback/#exercise-case-07

Sources

- Matthew A. Cronin, Cleotilde Gonzalez and John D. Sterman, “Why Don’t Well-Educated Adults Understand Accumulation? A Challenge to Researchers, Educators, and Citizens” doi.org/10.1016/j.obhdp.2008.03.003, *Organizational Behavior and Human Decision Processes* 108, no. 1 (2009), on the correlation heuristic and the department store task.
- John D. Sterman, *Business Dynamics: Systems Thinking and Modeling for a Complex World* (Irwin/McGraw-Hill, 2000), chapter 9, *S-Shaped Growth: Epidemics, Innovation Diffusion, and the Growth of New Products*, on epidemics; chapter 11, *Delays*, on delays in material and in information; and chapter 12, *Co-Flows and Aging Chains*.
- Jack B. Homer and Rogelio Oliva, “Maps and Models in System Dynamics: A Response to Coyle” doi.org/10.1002/sdr.224, *System Dynamics Review* 17, no. 4 (2001), on what simulation adds to maps.
- Geoff Coyle, “Qualitative and Quantitative Modelling in System Dynamics: Some Research Questions” doi.org/10.1002/1099-1727%28200023%2916:3%3C225::AID-SDR195%3E3.0.CO;2-D, *System Dynamics Review* 16, no. 3 (2000), the paper Homer and Oliva answer.

Sense, Compare, Correct

Feedback control diagrams

Part IV · Control · Chapter 8 of 12 · the first of two chapters on feedback control diagrams

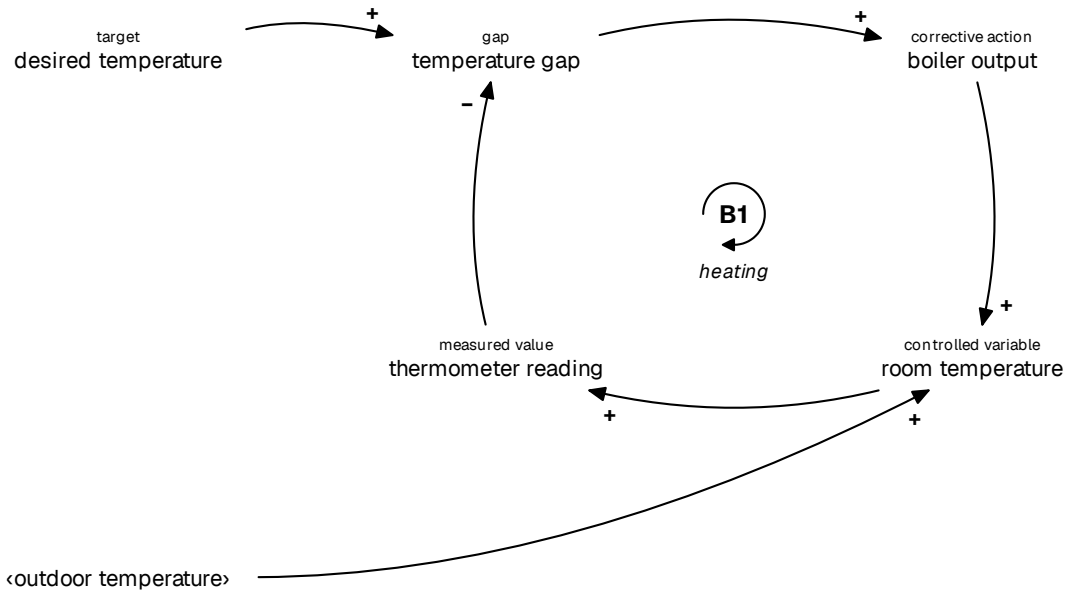
How does anything stay near a target? Its value is read, the reading is compared with the target, and the difference is corrected, in a loop. In a feedback control diagram, the part each variable plays in that loop is written above its name.

Signals you need this diagram

- Someone has chosen a value for a quantity to stay near: a temperature, a speed, a rate of inflation.
- The quantity and the reading of it can disagree, or the reading arrives late.
- A correction overshoots, or goes on after the quantity is back where it was wanted.
- Something outside keeps pushing the quantity away from that value.

A house kept warm on a winter evening

It is −2 °C outside, and someone sets the thermostat's dial to 20 °C. While the thermostat's thermometer reads less than 20 °C, the boiler runs and the room warms. At 20 °C the boiler stops, the room loses heat to the cold outside, the reading falls, and the boiler starts again.



What the notation expresses

A **feedback control diagram** is drawn as a causal loop diagram is, with the part each variable plays written in small type above its name, one part per variable. Its effects are **signals**: they carry readings and settings, not material.

Target and gap

The **target** is the value someone chooses for a quantity to stay near: *desired temperature*, 20 °C. No signal ends at a target, and a change of target is a new choice, not an effect.

The **gap** is chapter 4's gap (chapter 4, The gap): the difference between the target and the measured value. The target's and the measured value's signals into it carry opposite polarities: *desired temperature* → *temperature gap* is +, *thermometer reading* → *temperature gap* is –. Only the measured value's signal lies on the loop, so it is the one the parity rule (chapter 4, The parity rule) counts.

Measured value

The **measured value** is the controlled variable as it is read: *thermometer reading*, a variable of its own, with a signal from *room temperature*. The two come apart: a thermometer above a radiator reads the radiator's heat, not the room's.

CHECK YOUR UNDERSTANDING

A kitchen fridge's thermostat reads the air by the door. Each time the door opens, warm kitchen air reaches the thermostat first and the compressor starts, while the food at the back stays cold; by evening the milk on the back shelf has frozen. In a feedback control diagram of the fridge, which variable is the measured value?

a the temperature of the food on the back shelf

b the thermostat's reading of the air by the door

c the setting on the dial

Feedback: Answers, chapter 8

Corrective action

The **corrective action** is the variable changed to close the gap: *boiler output*, in kilowatts. The boiler is a thing; its output is a quantity, and only quantities are drawn. *Temperature gap* → *boiler output* is +: the wider the gap, the more heat the boiler puts out.

Controlled variable

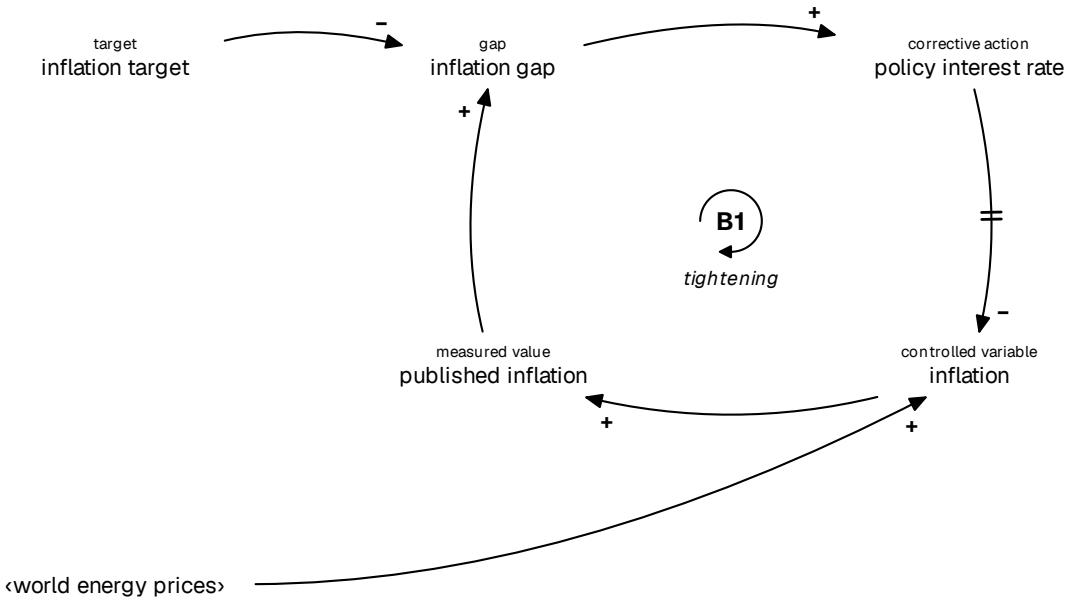
The **controlled variable** is the quantity the corrective action holds near the target: *room temperature*. The measured value reads it. The target and the measured value are counted in its units, degrees.

Control loops

A **control loop** is a declared balancing loop that runs from a gap through a corrective action, a controlled variable and a measured value, back to the gap: B1 *heating*, from *temperature gap* through *boiler output*, *room temperature* and *thermometer reading*.

A central bank steering inflation is drawn with the same six variables, roles and signals. The government sets the Bank of England a target of 2% inflation, and the Bank raises its policy interest rate, Bank Rate, to bring inflation

down.



Here the gap is inflation *above* the target, so the target's signal into it is – and published inflation's +; a higher rate lowers inflation, –. The loop holds one – signal, as the thermostat's does.

External drivers

In a feedback control diagram, an external driver (chapter 5, External drivers) acts on the controlled variable: *outdoor temperature → room temperature*, +. It may also act on the measured value, as noise, a draft across the thermometer, or on the corrective action, a path chapter 9 draws. It never acts on a gap or a target.

World energy prices act on inflation: the Bank of England names Russia's invasion of Ukraine, which cut the supply of gas and raised its price, among the causes of the rise in inflation. Like any external driver, they lie outside the boundary (chapter 5, Boundaries): nothing on the diagram changes them.

Delays in control

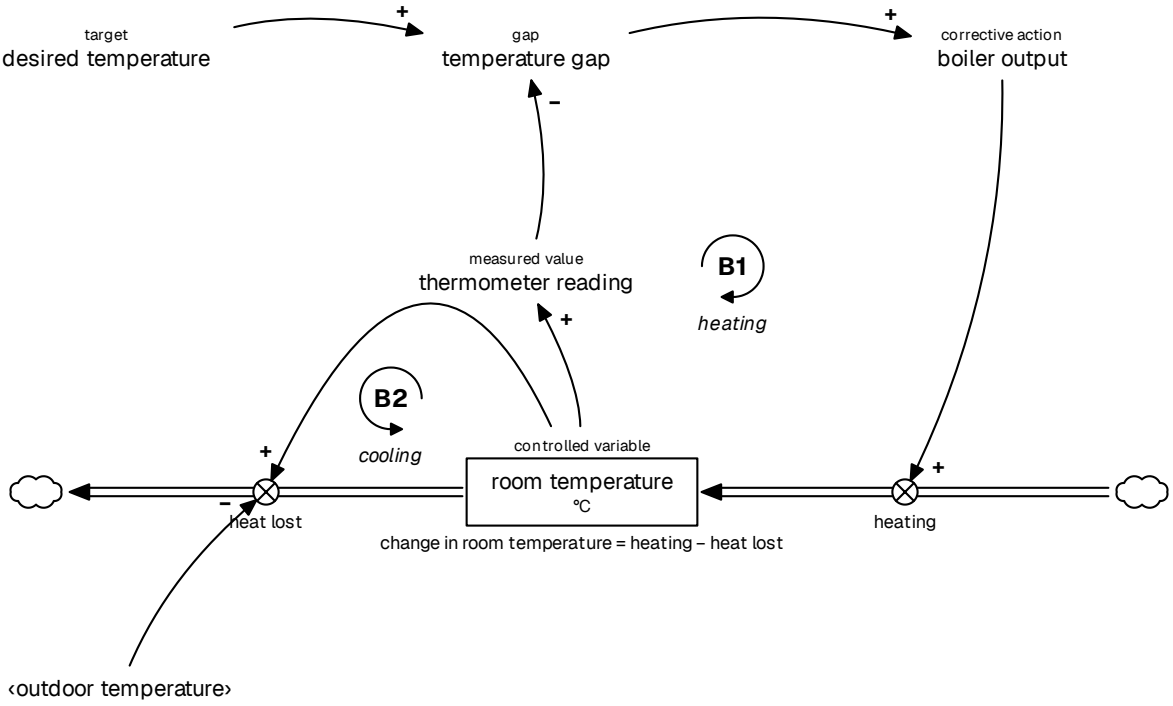
A delay (chapter 4, Delays) can sit on either half of a control loop. The **forward path** runs from the gap to the controlled variable; the **return path** runs from the controlled variable back to the gap, through the measured value.

A delay on the forward path is a correction arriving late. In estimates the Bank of England cites, the change in inflation after a change in interest rates peaks around one to two years later, so *policy interest rate → inflation* carries a delay. A delay on the return path is a reading arriving late: a thermometer read once an hour. Where the controlled variable is a stock, a delay on either path is a material or signal delay (chapter 7, Material and signal delays).

Control with accumulation

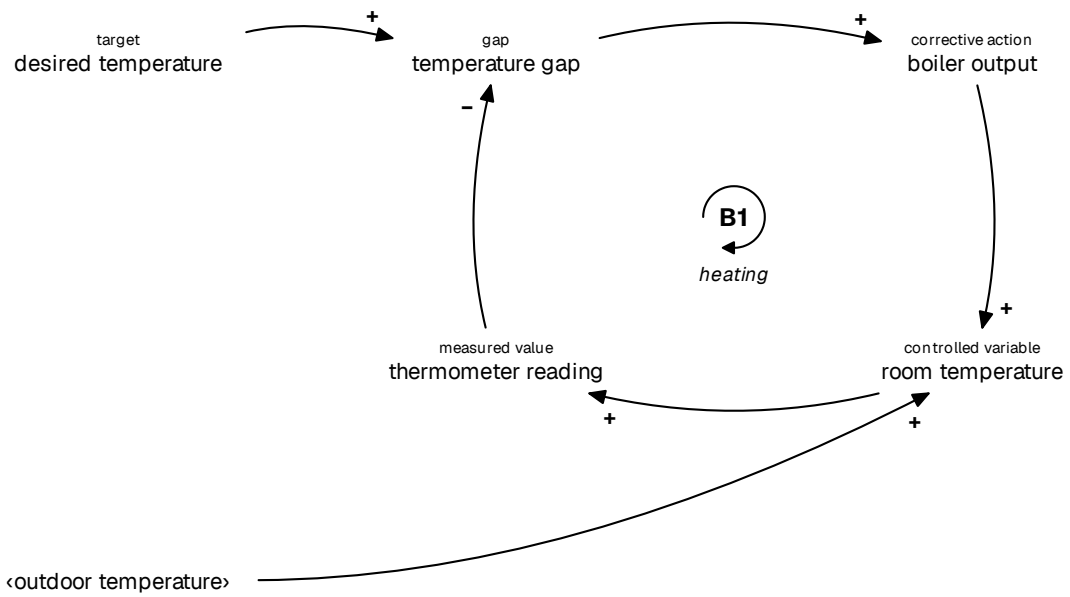
Where the controlled variable accumulates, it is drawn as a stock (chapter 6, Stocks), filled and drained by flows (chapter 6, Flows), and the corrective action and external drivers reach it by signals (chapter 6, Signals) to the flows'

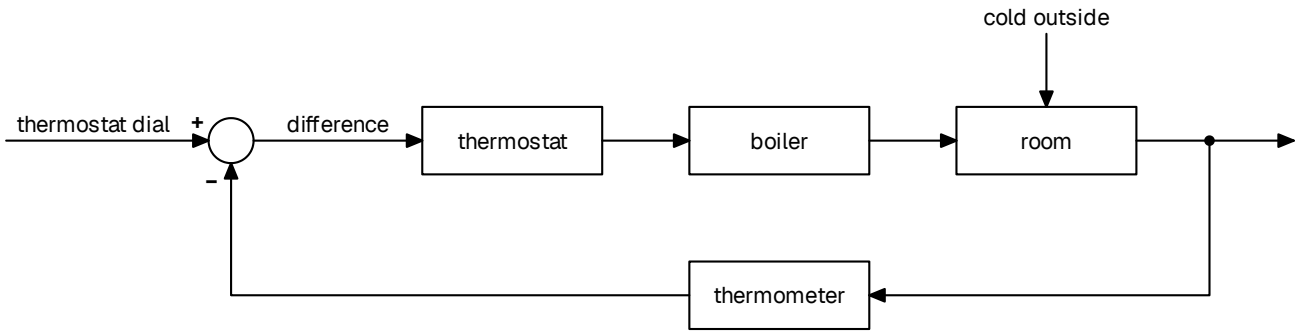
valves. Meadows draws the thermostat this way: the room's temperature as a stock, filled by heat from the furnace and drained by heat leaking outside.



Only the roles' words are added: *controlled variable* above the stock's box, *corrective action* above *boiler output*, whose signal reaches *heating*'s valve. B1 runs through *heating*, as chapter 7's loops through stocks (chapter 7, Loops through stocks) run through a flow. *Outdoor temperature* acts at *heat lost*'s valve, –: the colder outside, the faster heat leaks out. *Room temperature → heat lost* closes a second balancing loop, B2 *cooling*: the warmer the room, the faster it loses heat.

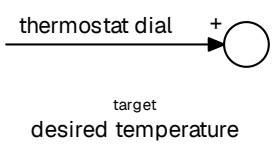
The engineering block diagram



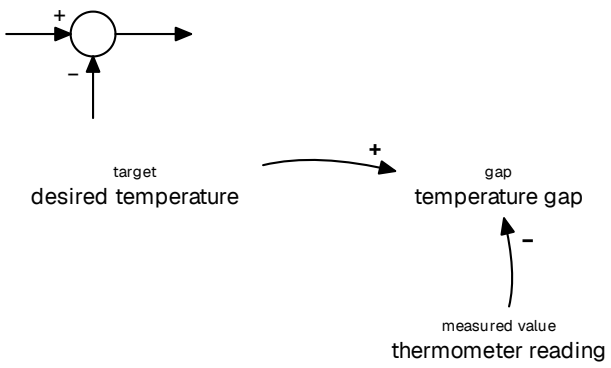


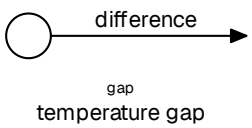
An engineer draws the same thermostat as a block diagram: a box for each part that acts, lines carrying signals between them, and a circle where two signals are subtracted.

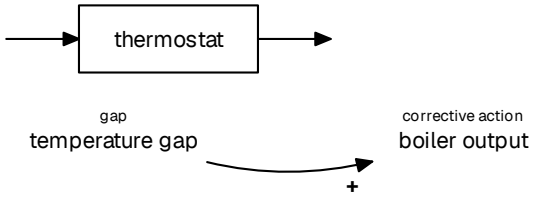
Engineering name	In the block diagram	In a feedback control diagram
setpoint	the line named *thermostat dial*, marked +	the target

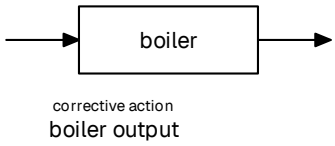


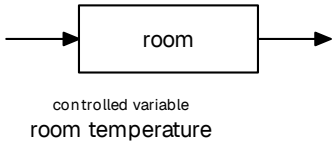
Engineering name	In the block diagram	In a feedback control diagram
comparator	the circle	the gap, which the target and the measured value both affect
error	the line named *difference*	the gap
controller	the *thermostat* box	the signal from the gap to the corrective action
actuator	the *boiler* box	the corrective action, *boiler output*
plant	the *room* box	the controlled variable, *room temperature*
sensor	the *thermometer* box	the measured value, *thermometer reading*

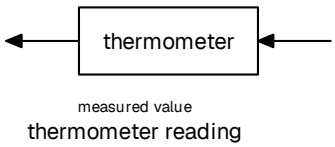




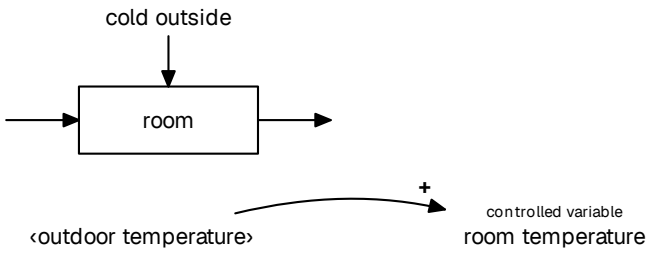








Engineering name	In the block diagram	In a feedback control diagram
disturbance	the line named *cold outside*	an external driver acting on the controlled variable



An engineer's box is a part that acts, such as the boiler; this book's box is a stock, and a part that acts appears only through the quantity it changes, such as *boiler output*.

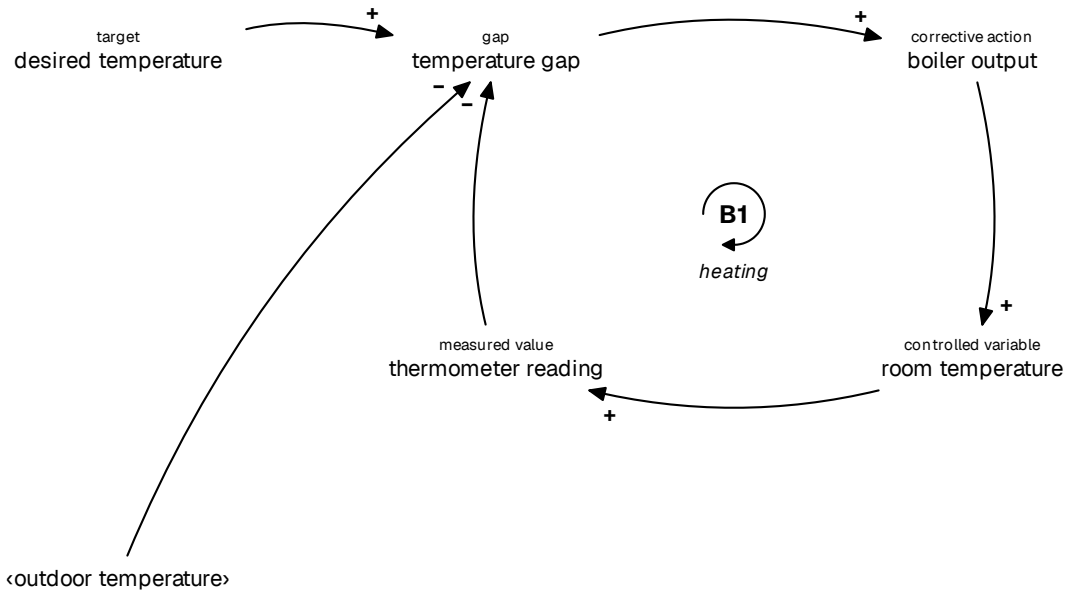
What stays informal

When no one chooses the value a quantity settles at, draw it as a causal loop diagram: a cup of tea cools toward the room's temperature through a balancing loop with no target, reading or corrective action. When the reading and the quantity read can't come apart, write a sentence: a toilet cistern's float rides on the water, so *the cistern fills until the float shuts the valve*.

How much the corrective action changes for each degree of gap, and how fast, are numbers the diagram doesn't hold: they go in a sentence or a table beside it.

The bad diagram

What's wrong with this diagram of the house kept warm on a winter evening?



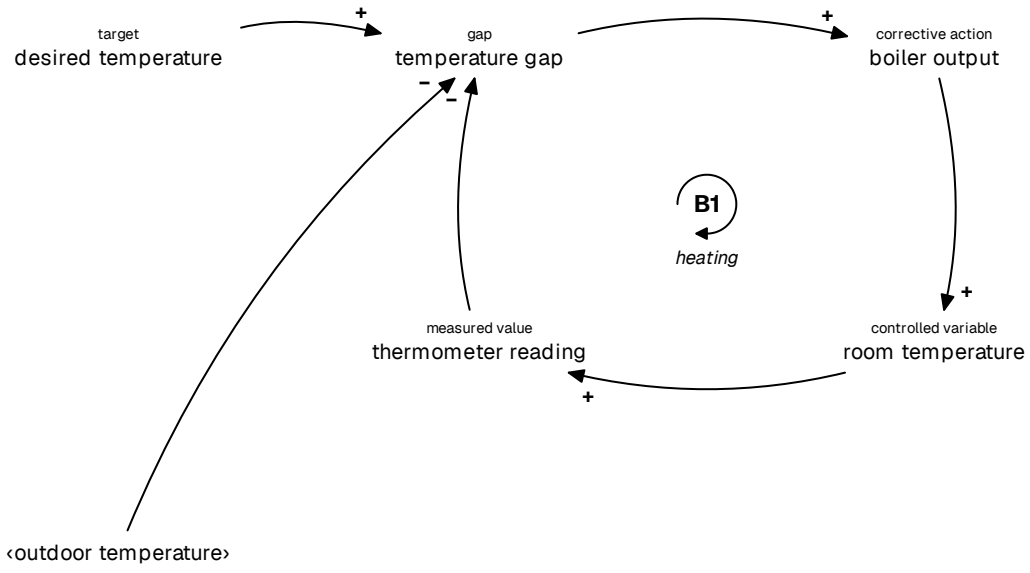
The cold outside changes the room's temperature, and the thermometer reads the room. Here the signal from *outdoor temperature* ends at the gap instead: the cold is drawn as if it changed the temperature someone wants, and the room's temperature as if only the boiler changed it. The lab's check reports:

> outdoor temperature → temperature gap ends at a gap. End it at the variable the external driver changes: an external driver acts on a controlled variable, a measured value or a corrective action, never on a gap or a target.

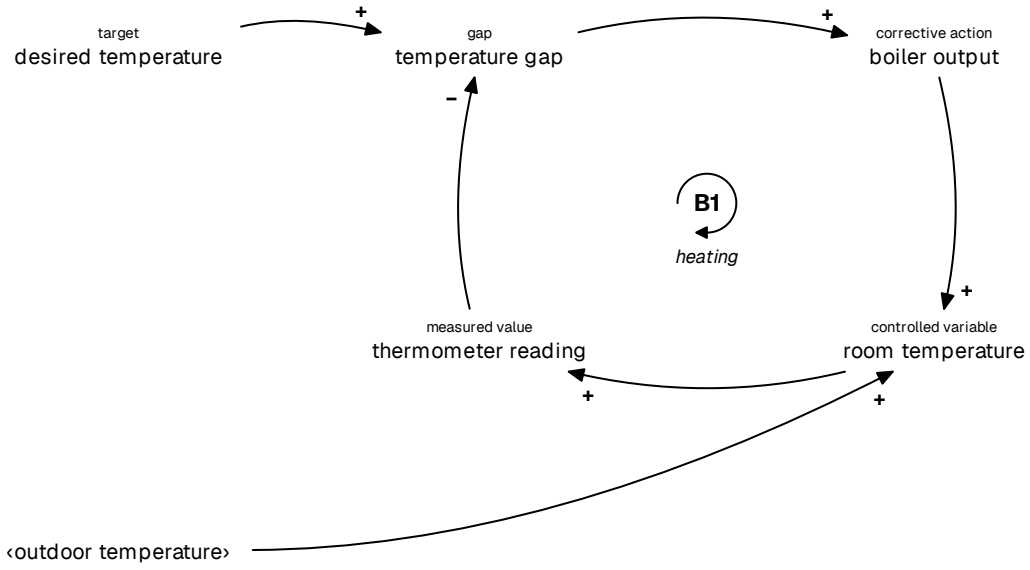
The corrected diagram

Corrected, the outdoor temperature's signal ends at *room temperature*, +, and only the target and the thermometer reading have signals into the gap.

Bad diagram

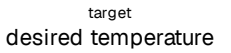
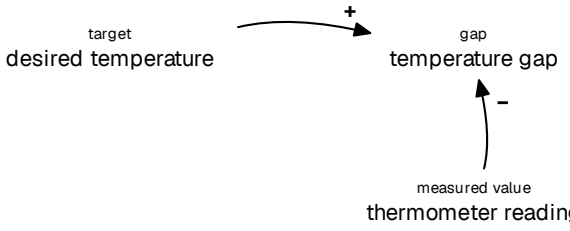
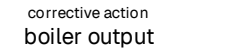
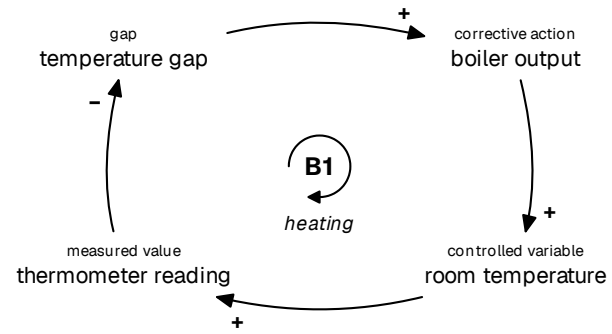


Corrected diagram

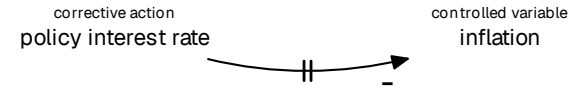


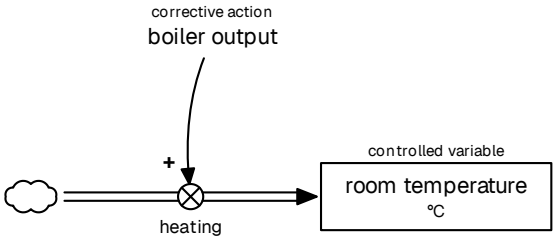
Labels unchanged. Signals: 1 added, 1 removed.

Notation moves

Notation move	When	What it shows	Example
Write *target* above a variable 	Someone chooses a value for a quantity to stay near	The chosen value, with no signal into it	*desired temperature*
Give the gap's two signals opposite polarities 		Which way the gap runs	*desired temperature* +, *thermometer reading* –
Draw the measured value apart from the controlled variable 		Where a reading can run late or mislead	*room temperature* → *thermometer reading*
Write *corrective action* above a quantity 		What is changed to close the gap	*boiler output*, not *boiler*
Declare the control loop 		The loop from gap to corrective action, controlled variable and measured value	B1 *heating*
End an external driver at the controlled variable 	Something outside pushes the quantity away from its target	Where the push enters	*outdoor temperature* → *room temperature*

Notation move	When	What it shows	Example
Mark a delay on the forward or return path	A correction or a reading arrives late	Which half of the loop runs late	*policy interest rate* → *inflation*
Draw the controlled variable as a stock	It accumulates	The flows the corrective action and external drivers reach	*room temperature*, filled by *heating*





Check your understanding

CHECK YOUR UNDERSTANDING

A hearing aid turns its volume down when the sound reaching its wearer's ear grows louder than the loudness an audiologist set, and up when it grows quieter. A bus passes in a noisy street. In a feedback control diagram of the hearing aid, which variable does the bus's noise act on?

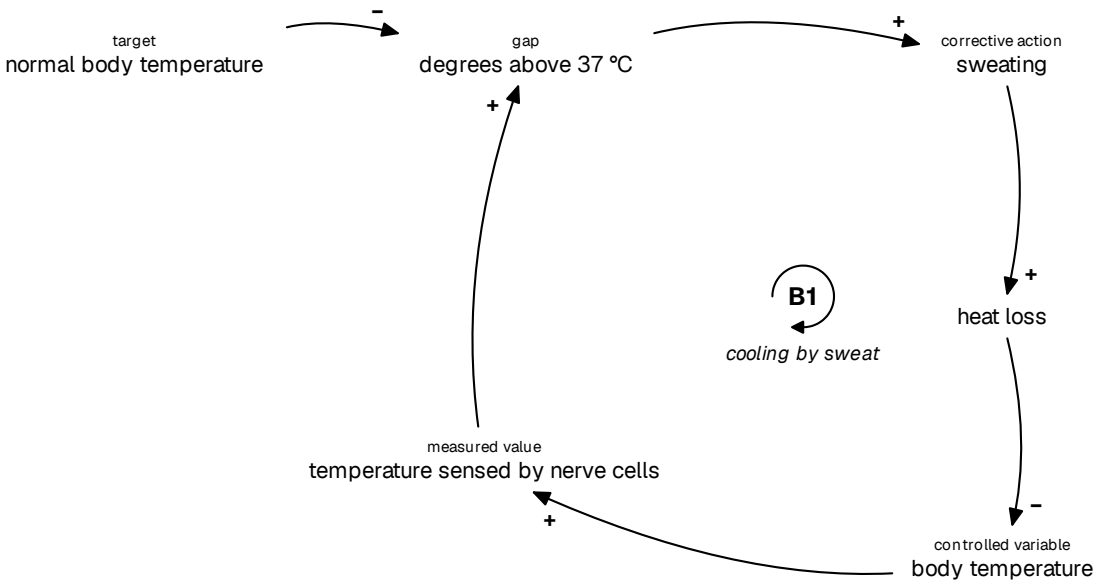
a the loudness at the wearer's ear

b the gap between the loudness set and the loudness read

c the hearing aid's volume

Feedback: Answers, chapter 8

Body temperature regulation, redrawn



Redrawn from OpenStax, Anatomy and Physiology 2e, section 1.6, “Homeostasis”, the copy on LibreTexts med.libretexts.org/Bookshelves/Anatomy_and_Physiology/Anatomy_and_Physiology_2e_(OpenStax)/01%3A_Levels_of_Organization/01%3A_An_Introduction_to_the_Human_Body/1.06%3A_Homeostasis, Figure 1.10, panel (b), Body temperature regulation. CC BY 4.0 creativecommons.org/licenses/by/4.0/.

Panel (b) alone, its five boxes drawn as variables with roles: body temperature exceeds 37 °C as body temperature, the controlled variable, and degrees above 37 °C, the gap; nerve cells in skin and brain as temperature sensed by nerve cells, the measured value; sweat glands throughout body as sweating, the corrective action; increased heat loss as heat loss; the temperature regulatory center in brain as the signal from the gap to sweating; normal body temperature, from its text, added as the target; polarities added and the loop named; its heavy red lines drawn as thin signals, and its colors left out.

QUESTION 1 OF 3

OpenStax names the temperature regulatory center in brain a control center, the part that compares a value with its normal range and activates the response; this book draws that work as the signal from the gap to the corrective action. Which part of the redrawing is it here?

a Temperature sensed by nerve cells, since the center receives the nerve cells’ reading.

b The signal from degrees above 37 °C to sweating, with its +.

c Normal body temperature, since the center holds the value of 37 °C.

QUESTION 2 OF 3

OpenStax names the nerve cells a sensor, which this book draws as a measured value, and the sweat glands an effector, a corrective action here. Why are those variables named temperature sensed by nerve cells and sweating, not nerve cells and sweat glands?

a Roles are written above the names, so naming the organs would repeat the roles.

b A variable is a quantity that can rise or fall: a reading and sweating can, while cells and glands are things.

c The body has too many nerve cells and sweat glands to count.

QUESTION 3 OF 3

Panel (b) begins with body temperature exceeding 37 °C and draws nothing that raises it. What would a hot day or a run add to the redrawing?

a A signal from the hot day to degrees above 37 °C, since heat widens the gap.

b A second target, since the body holds a higher temperature during a run.

c An external driver, its signal ending at body temperature.

Feedback: Answers, chapter 8

Exercises

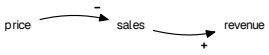
Passing the checks means meeting the brief, not being right.

FC 01 Fresh air in a choir's rehearsal room

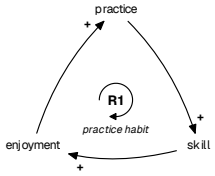
Your palette



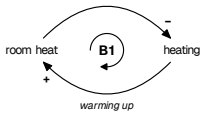
variable



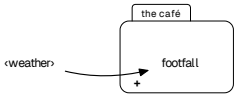
polarity



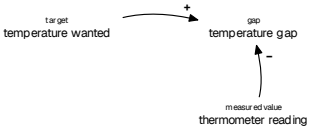
loop



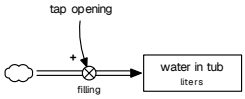
balancing loop



external driver



gap
a role, written above its variable's name



signal



target
a role, written above its variable's name



corrective action
a role, written above its variable's name



controlled variable
a role, written above its variable's name



measured value
a role, written above its variable's name

FC 01 Fresh air in a choir's rehearsal room

One balancing loop that holds a target

Reasoning ●○○○○ 1 of 5 Polish ●○○○○ 1 of 5

Forty singers rehearse for two hours in a room with its windows shut, and every breath adds carbon dioxide to the air. A meter on the wall shows the carbon dioxide in the air, in parts per million. The caretaker has set the ventilation fan to hold the air near 1,000 parts per million: the further the meter's reading rises above that, the faster the fan runs, and the faster it runs, the more carbon dioxide it carries out of the room.

The brief

- [ ] Draw one control loop of five variables, each with its part: the target, the gap, the fan's speed as the corrective action, the carbon dioxide in the air as the controlled variable, and the meter's reading as the measured value.
- [ ] Declare the control loop balancing.
- [ ] Draw the singers' breathing as an external driver acting on the carbon dioxide in the air.
- [ ] The fan's speed and the carbon dioxide in the air are two variables.

Your palette

On the page before this sheet.

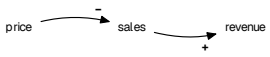
Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/control/sense-compare-correct/#exercise-feedback-control-01

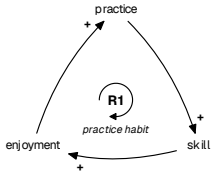
FC 02 Chlorine in a town's outdoor swimming pool

Your palette

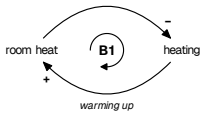
variable



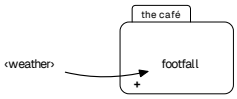
polarity



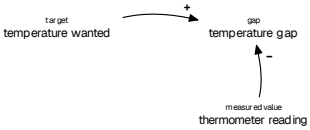
loop



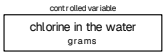
balancing loop



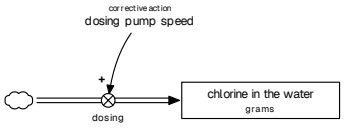
external driver



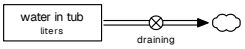
gap
a role, written above its variable's name



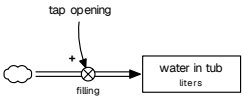
stock



flow



cloud



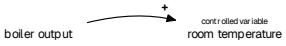
signal



target
a role, written above its variable's name



corrective action
a role, written above its variable's name



controlled variable
a role, written above its variable's name



measured value
a role, written above its variable's name

FC 02 Chlorine in a town's outdoor swimming pool

A target, a corrective action, and what uses it up

Reasoning ●○○○○ 1 of 5 Polish ●●○○○ 2 of 5

A town's outdoor swimming pool holds about 500 cubic meters of water, and the staff keep about 750 grams of chlorine in the water. A dosing pump adds chlorine from a tank: the faster it runs, the faster chlorine goes in. Sunshine and swimmers use chlorine up, faster on hot, crowded afternoons. Every two hours the staff test the water and set the pump's speed by how far the result falls short of 750 grams. Count the chlorine in grams, and time in hours.

The brief

- [ ] Draw the chlorine in the water as one stock, the controlled variable.
- [ ] Draw sunshine and swimmers as an external driver acting on the flow that uses chlorine up.
- [ ] Close one control loop through the flow that adds chlorine: the gap, the pump's speed, the chlorine in the water and the test result.
- [ ] The target and the test result name the same quantity, in grams.

Your palette

On the page before this sheet.

Draw here

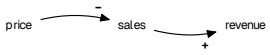
In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/control/sense-compare-correct/#exercise-feedback-control-02

FC 03 A kayaker crossing a river

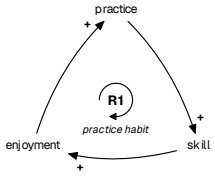
Your palette



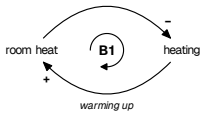
variable



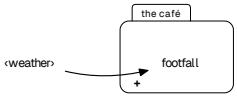
polarity



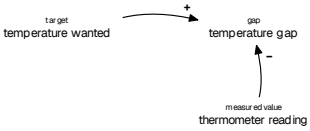
loop



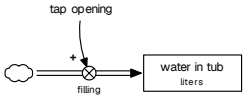
balancing loop



external driver



gap
a role, written above its variable's name



signal



target
a role, written above its variable's name



corrective action
a role, written above its variable's name



controlled variable
a role, written above its variable's name



measured value
a role, written above its variable's name

FC 03 A kayaker crossing a river

An external driver acting on the controlled variable

Reasoning ●●○○○ 2 of 5 Polish ●●○○○ 2 of 5

A kayaker is learning to cross a river. She aims the bow at a tree on the far bank, and the current pushes the bow downstream, away from the tree. She sees how far the bow has swung off the tree and takes extra strokes on the downstream side, which turn the bow back upstream, until it points at the tree again. Halfway across she picks a new tree.

Count a heading as an angle: the further upstream the bow points, the larger the angle.

The brief

- ☐ Draw the current's push as an external driver acting on the boat's heading.
- ☐ Close one control loop: the gap, her extra strokes, the boat's heading and the heading as she sees it.
- ☐ Draw one target: the heading to the tree she aims at.
- ☐ The new tree halfway across is her choice: no signal ends at the target.

Your palette

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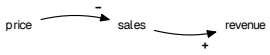
Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/control/sense-compare-correct/#exercise-feedback-control-03

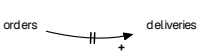
FC 04 A shower whose hot water arrives late

Your palette

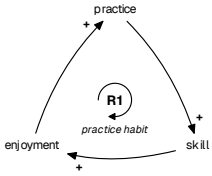
variable



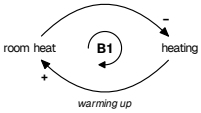
polarity



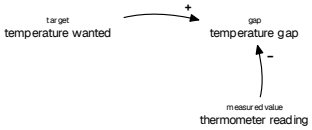
delay



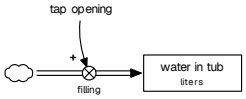
loop



balancing loop



gap
a role, written above its variable's name



signal



target
a role, written above its variable's name



corrective action
a role, written above its variable's name



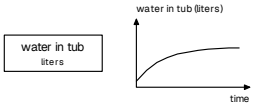
controlled variable
a role, written above its variable's name



measured value
a role, written above its variable's name



behavior note



behavior-over-time graph

FC 04 A shower whose hot water arrives late

A corrective action that arrives late

Reasoning ●●○○○ 2 of 5 Polish ●●●○○ 3 of 5

Sofia wants her morning shower at about 38 °C. After a turn of the tap, the water at the shower head changes about five seconds later, once the hot water reaches it. She feels the water, and while it feels too cold she keeps turning the tap toward hot. By the time the hot water arrives she has turned the tap too far, so the water runs too hot; she turns the tap back, and the water swings too hot and too cold before it settles near 38 °C.

The brief

- [ ] Mark the seconds between a turn of the tap and the water at the shower head as a delay on the forward path.
- [ ] Close one control loop: the gap, the tap, the water temperature at the head and how hot the water feels.
- [ ] Add a behavior-over-time graph of the water temperature at the head, overshooting and swinging, with a line at the temperature she wants.
- [ ] The delay sits between the tap and the water at the head, not between the water and her skin.

Your palette

On the page before this sheet.

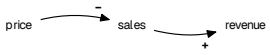
Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/control/sense-compare-correct/#exercise-feedback-control-04

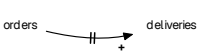
FC 05 Elephants in a national park

Your palette

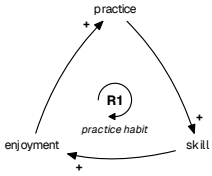
variable



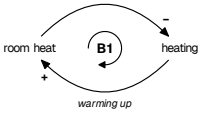
polarity



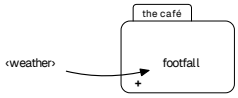
delay



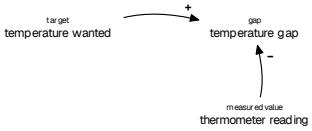
loop



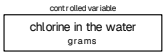
balancing loop



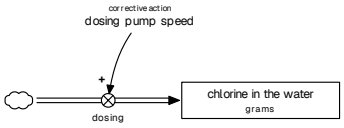
external driver



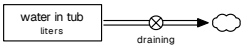
gap
a role, written above its variable's name



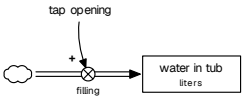
stock



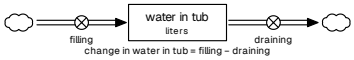
flow



cloud



signal



stock equation



target
a role, written above its variable's name



corrective action
a role, written above its variable's name



controlled variable
a role, written above its variable's name



measured value
a role, written above its variable's name

FC 05 Elephants in a national park

Control with accumulation

Reasoning ●●●○○ 3 of 5 Polish ●●●○○ 3 of 5

A national park's managers aim to hold its elephants near 2,000. In this park about 150 calves are born each year and about 60 elephants die, more in a year of drought. Every two years a survey plane counts the herd. From the latest count the managers approve moving elephants to other parks: the further the count is above 2,000, the more moves they approve. Moves approved this year happen the next year, when the elephants are caught and taken away by truck. Count the herd in elephants, and time in years.

The brief

- ☐ Draw the elephants in the park as one stock, the controlled variable, counted in elephants.
- ☐ Mark the year between moves approved and elephants moved as a delay on the forward path.
- ☐ Close one control loop through the flow of elephants moved: the gap, moves approved, the elephants in the park and the aerial count.
- ☐ Moves approved are a variable, and elephants moved the flow: the year lies between them.

Your palette

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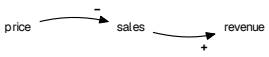
Draw here

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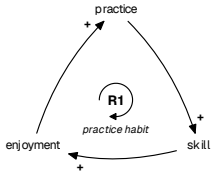
CS 08 Kelsham Primary School: the governors and the reserve

Your palette

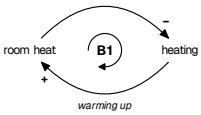
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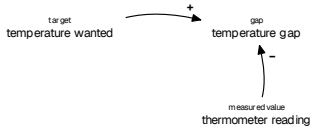
polarity



loop

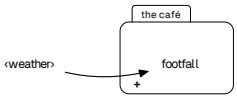


balancing loop

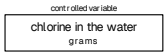


gap

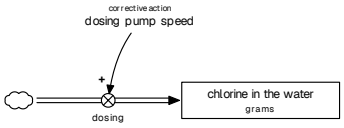
a role, written above its variable's name



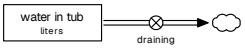
external driver



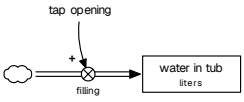
stock



flow



cloud



signal



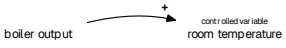
target

a role, written above its variable's name



corrective action

a role, written above its variable's name



controlled variable

a role, written above its variable's name



measured value

a role, written above its variable's name

CS 08 Kelsham Primary School: the governors and the reserve

A stock held to a target, with staff hours as the corrective action

Reasoning ●●●○○ 3 of 5 Polish ●●●○○ 3 of 5

Tom Hale and the governors hold the school's reserve to at least £60,000; in October 2026 it stood at £96,000. Funding arrives through the school year, £4,800 for each pupil at the October count before it and £140,000 whatever the school's size, and pay goes out, a teacher costing the school £52,000 a year. Each term the governors read the reserve in the budget report, and the further it reads below £60,000, the more staff hours they cut, a teaching assistant's before a teacher's. The governors set neither the funding for each pupil nor the pupils on roll. Count the reserve in pounds, and time in years.

The brief

- [ ] Draw the school's reserve as one stock, the controlled variable, counted in pounds.
- [ ] Close one control loop through the flow of spending: the gap, staff hours cut, the reserve and the reserve in the budget report.
- [ ] Draw funding for each pupil and the pupils on roll as external drivers acting on the flow of funding.
- [ ] The target and the reserve in the budget report are both counted in pounds, so the gap compares one quantity.

Your palette

On the page before this sheet.

Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/control/sense-compare-correct/#exercise-case-08

Sources

- Donella H. Meadows, *Thinking in Systems: A Primer* (Chelsea Green, 2008), chapter 2, *A Brief Visit to the Systems Zoo*, on the thermostat drawn as one stock, the room's temperature, with two competing balancing loops.
- Karl Johan Åström and Richard M. Murray, *Feedback Systems: An Introduction for Scientists and Engineers* fbswiki.org/wiki/index.php/Main_Page, second edition (Princeton University Press, 2021), chapter 1, on feedback, the parts of a feedback system and a thermostat's on-off rule, and chapter 3, on how engineers draw boxes and lines.
- Stephen Boyd, "Feedback Control Systems: Static Analysis" stanford.edu/~boyd/ee102/ctrl-static.pdf, lecture 12 of EE102 (Stanford University), on the names engineers give a feedback system's parts.
- James K. Roberge, *Operational Amplifiers: Theory and Practice* eng.libretexts.org/Bookshelves/Electrical_Engineering/Electronics/Operational_Amplifiers:_Theory_and_Practice_(Roberge)/02:_Properties_and_Modeling_of_Feedback_Systems/2.02:_SYMBOLOGY (MIT), section 2.2, the source of the engineering name for where the target and the measured value meet.
- Bank of England, *Monetary policy* www.bankofengland.co.uk/monetary-policy, on the 2% target the government sets.
- Bank of England, *What is happening with interest rates in the UK?* www.bankofengland.co.uk/explainers/current-interest-rate, on gas prices after Russia's invasion of Ukraine and the rate rises from the end of 2021.
- Bank of England, *Monetary Policy Report, August 2024* www.bankofengland.co.uk/-/media/boe/files/monetary-policy-report/2024/august/monetary-policy-report-august-2024.pdf, box C, on the impact of interest rates on inflation peaking at around one to two years.

Anticipation, Limits, and Nested Control

Feedback control diagrams

Part IV · Control · Chapter 9 of 12 · the second of two chapters on feedback control diagrams

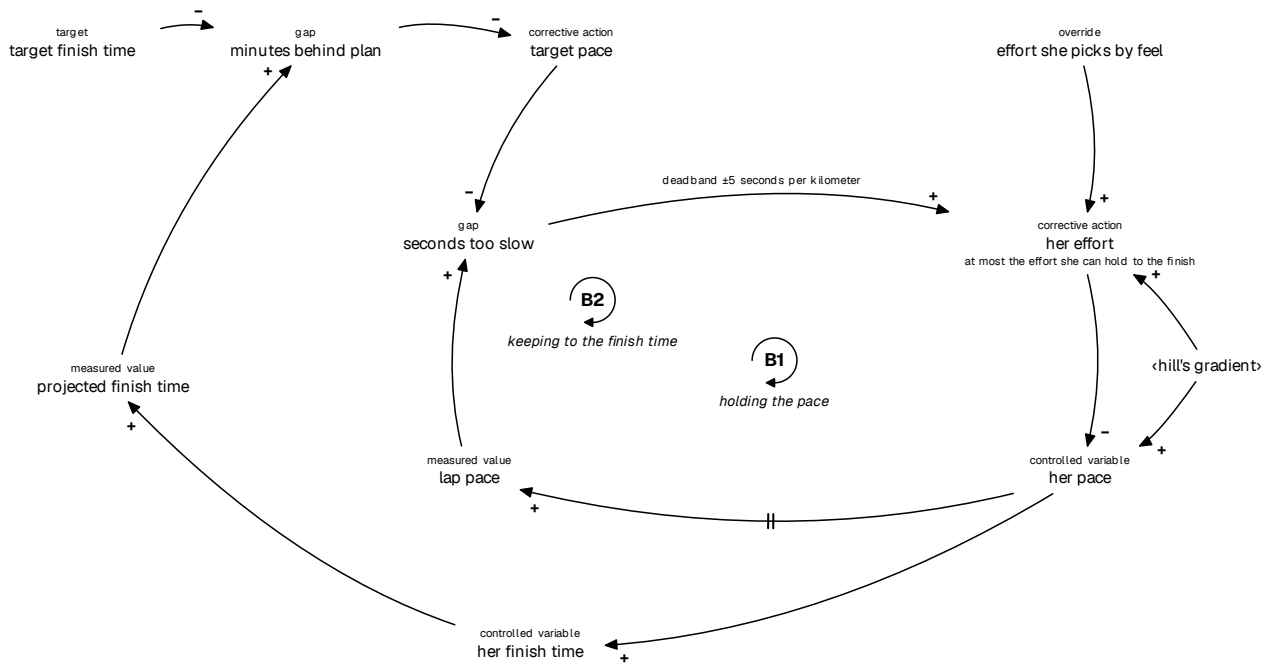
What happens when correction isn't enough? A correction can come too late, stop at a limit, follow noise in a reading, or be needed *before* any gap opens, and one loop's corrective action can be another's target. A feedback control diagram shows where each happens, and where a person takes over.

A marathon run to plan

A runner aims to finish a marathon, 42.2 kilometers, in 3 hours 30 minutes. Her watch projects her finish time from her pace so far. While the projection is later than 3:30 she sets herself a faster target pace, and while it is earlier, a slower one. Pace is minutes per kilometer, so the faster she runs, the lower it is.

At the end of each kilometer the watch shows her lap pace, her average over that kilometer. When it is more than 5 seconds slower than her target pace she runs harder; more than 5 seconds faster, she eases off. She runs no harder than the effort she can hold to the finish.

At 30 kilometers she sees a hill ahead and runs harder before she reaches it. If the day turns hot, she drops the plan and runs by feel.



Her two gaps (chapter 8, Target and gap) are *minutes behind plan*, the projected finish time less the target finish time, and *seconds too slow*, the lap pace less the target pace.

What the notation expresses

Feedforward

Feedforward is a path of signals from an external driver to a corrective action that passes through no gap. *Hill's gradient → her effort*, +, is one: she runs harder as the hill nears, before her pace slows and any gap opens. The gradient also acts on *her pace*, +, so if she misjudges the hill, she corrects the difference only once the lap pace reads it, up to a kilometer later. Feedforward has no mark of its own.

Sampling and filters

Sampling is how often the measured value updates, and a **filter** is how it is smoothed. Each is drawn as a delay on the return path (chapter 8, Delays in control), a signal delay (chapter 7, Material and signal delays). *Her pace → lap pace* carries one: the lap pace is sampled once a kilometer and averaged over it, so a water station or a corner barely moves it, and a slowdown shows up to a kilometer late.

Deadband

A **deadband** is a range of gaps within which the corrective action stays as it is. It is written beside the gap's signal to the corrective action: *deadband ±5 seconds per kilometer* on *seconds too slow → her effort*. She sets it wider than the few seconds by which her lap pace varies at an unchanged effort.

Saturation

Saturation is the most a corrective action can reach, however wide the gap. It is written beneath the corrective action's name as *at most* and its **limit**: *at most the effort she can hold to the finish*. At that limit a wider gap changes her effort no further: on a steep hill her pace slows, and the seconds lost are made up only after the top.

Saturation is not a nonlinear effect (chapter 5, Nonlinear effects). A nonlinear effect belongs to a signal: how strongly one variable changes another across its range. Saturation belongs to the corrective action: a bound on the variable itself, whichever signal reaches it, the gap's or the gradient's.

CHECK YOUR UNDERSTANDING

A basement floods, and someone sets a dehumidifier to bring its air down to 50% relative humidity. The dehumidifier runs flat out, removing at most 20 liters of water a day, and for a week the air stays far wetter than 50%. In a feedback control diagram of the basement, how is that limit drawn?

a as at most 20 liters a day, written beneath water removed, the corrective action

b as a nonlinear effect on the signal from water removed to the basement's humidity

c as a deadband on the signal from the humidity gap to water removed

Feedback: Answers, chapter 9

Competing targets

A **shared corrective action** is one corrective action on two or more control loops. If she also kept her heart rate below 165 beats a minute, *her effort* would be the corrective action of a heart-rate loop too. On the hill, as in coupled loops (chapter 4, Coupled loops), seconds too slow would raise her effort while beats too many lowered it, and no effort would close *both* gaps.

A **cross-effect** is a signal from a variable of one control loop to a variable of another, itself on no declared loop. A museum gallery with a temperature loop and a humidity loop has one: *heater output → gallery humidity*, –, since

warming air lowers its relative humidity, so each correction of the temperature opens a humidity gap.

Nested loops

A **nested loop** is a control loop whose target is another loop's corrective action. B2, *keeping to the finish time*, runs from *minutes behind plan* through *target pace* and on through B1's gap, effort and pace to *her finish time*. Nothing marks the nesting: *target pace* keeps its one role, corrective action, and its signal into *seconds too slow* makes it B1's target.

B1 closes a gap within a kilometer or two, and B2 moves the target pace over many: loop dominance (chapter 5, Loop dominance) here runs by timescale, B1 dominating her effort over a kilometer and B2 over the race.

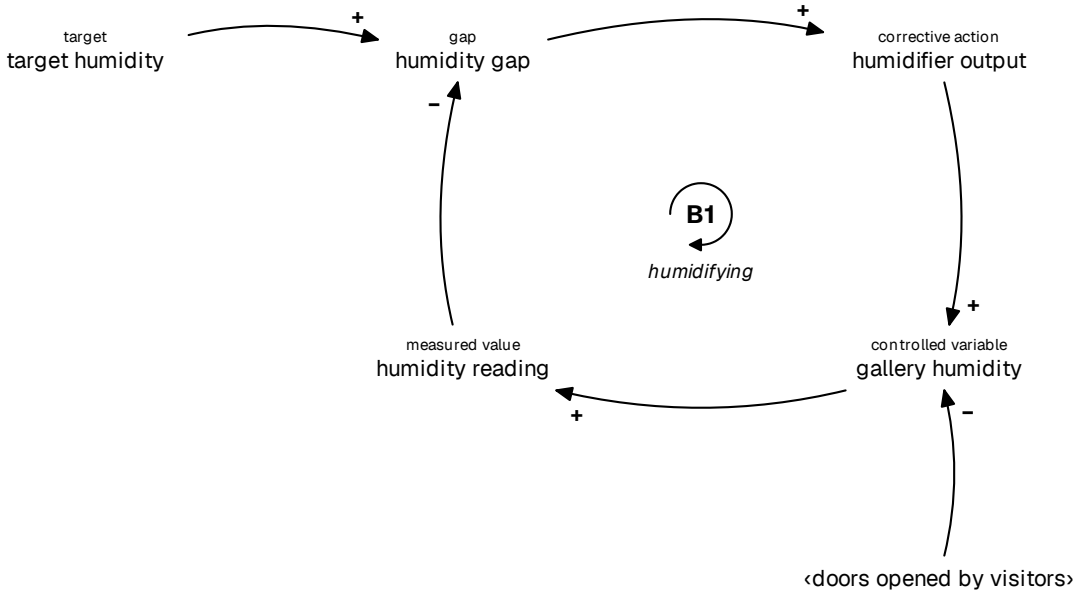
Override and false alarms

An **override** is a variable a person sets whose signal reaches a corrective action, replacing the loop's rule for a while; *override* is written above its name. *Effort she picks by feel → her effort*: when the day turns hot she drops the plan, and while she runs by feel neither gap changes her effort.

A false alarm is a gap opened by the reading alone. Among tall buildings the watch's satellite fix drifts, and the lap pace can read 20 seconds slow while her pace holds. By the loop's rule she would run harder; by override she holds her effort for that kilometer.

The bad diagram

What's wrong with this diagram of a museum gallery's humidity?



A museum keeps a gallery's paintings near 50% relative humidity, and a humidifier adds moisture when the air is drier than that. On a winter day each door a visitor opens lets in cold outdoor air, which, warmed, lowers the gallery's relative humidity for a minute. The reading, taken straight from the gallery's humidity, drops, and the

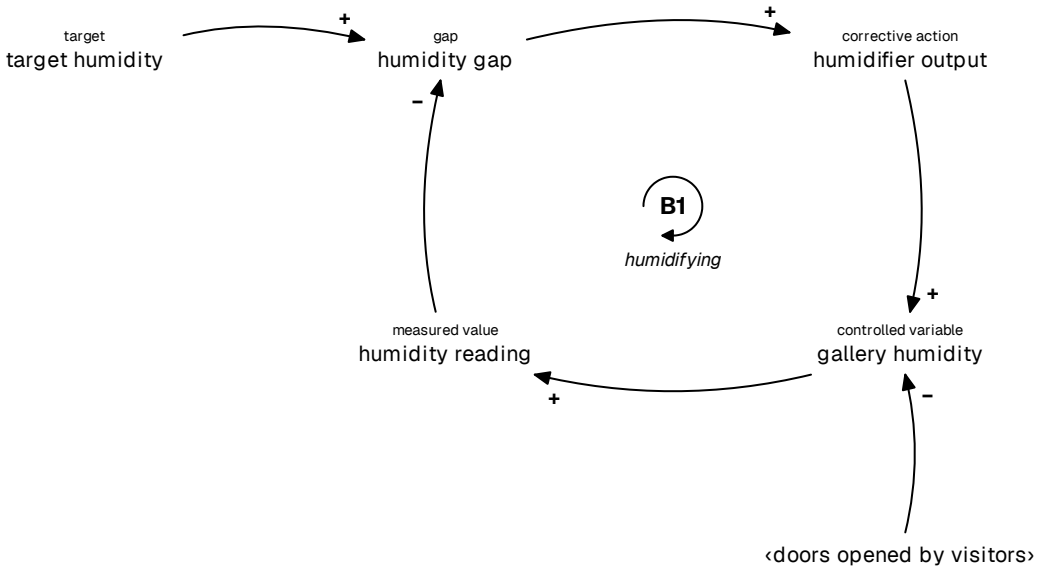
humidifier starts, then stops as the air recovers: every door opened changes its output. The lab's check for at least one deadband reports:

> 0 signals with a deadband. Brief: at least 1. A deadband is written on the signal from a gap to a corrective action.

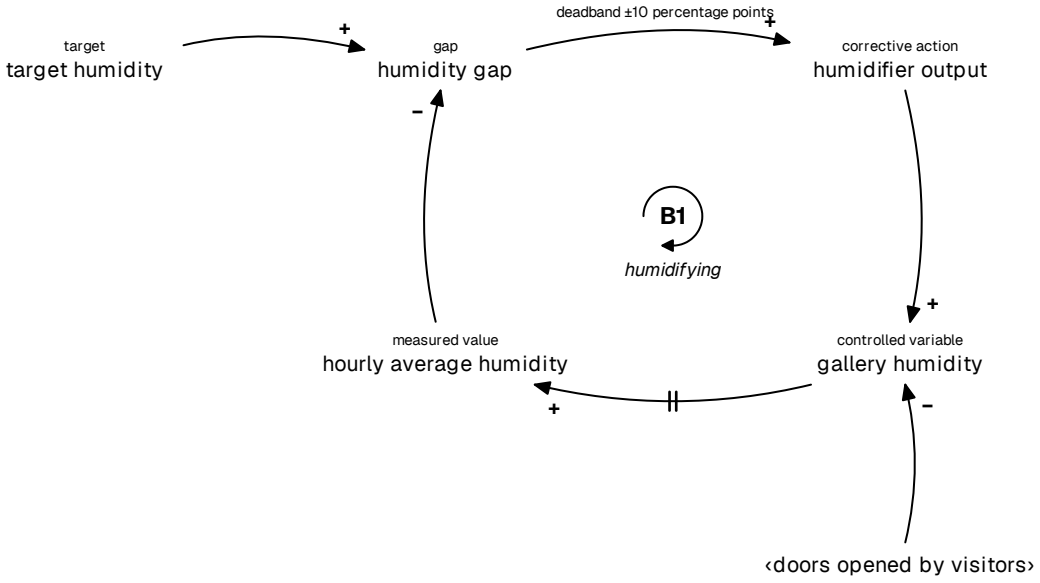
The corrected diagram

Corrected, the measured value is *hourly average humidity*, a filter drawn as a delay on the return path, and the gap's signal carries *deadband ±10 percentage points*: while the gap is less than 10 points either way, the humidifier output stays as it is. With the target at 50%, those gaps span the Bizot Green Protocol's range for paintings, 40–60% relative humidity.

Bad diagram



Corrected diagram

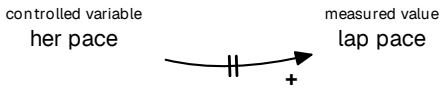


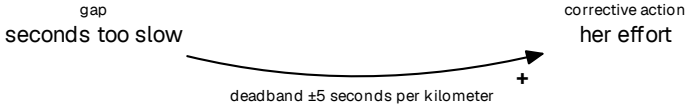
Changed: 1 label. Signals: 1 delay added, 1 deadband added.

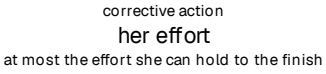
Notation moves

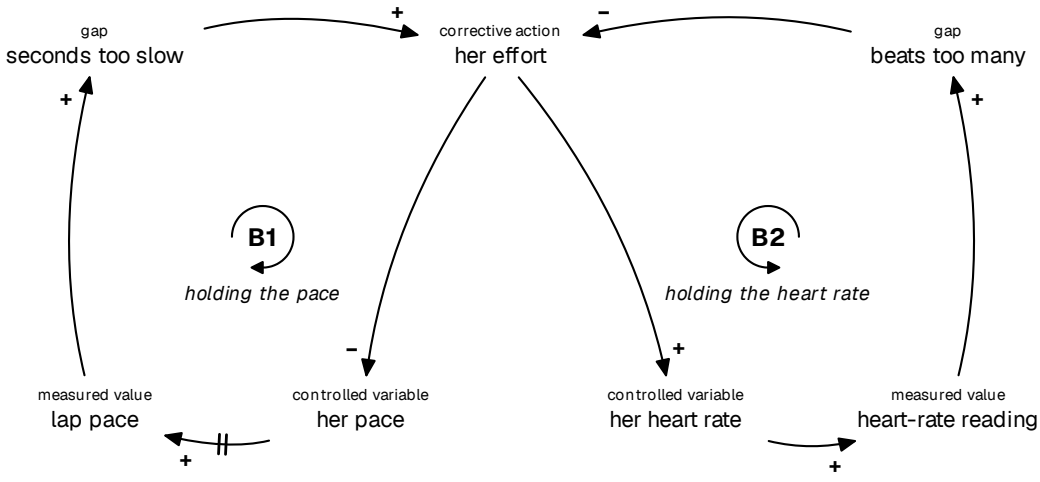
Notation move	When	What it shows	Example
Draw a signal from an external driver to a corrective action	The external driver is seen before it arrives	Feedforward: a correction before any gap opens	*hill's gradient → her effort*
Mark a delay on the return path	The reading is sampled or averaged	A reading arriving late	*her pace → lap pace*
Write *deadband* and its band beside the gap's signal	Small gaps go uncorrected	Which gaps no correction answers	*deadband ±5 seconds per kilometer*
Write *at most* and the limit beneath a corrective action	The corrective action has a most it can reach	Where a wider gap stops changing it	*at most the effort she can hold to the finish*
Give two control loops one corrective action	Two targets rest on one variable	A shared corrective action	*her effort*, on pace and heart-rate loops

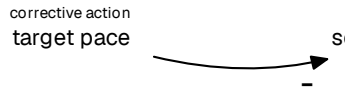
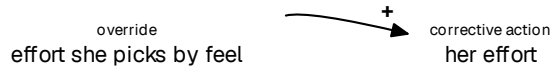










Notation move	When	What it shows	Example
End one loop's corrective action at another loop's gap	One loop moves another's target	A nested loop	*target pace → seconds too slow*
			
Write *override* above a variable a person sets	Someone can set the loop's rule aside	Where a person replaces the rule	*effort she picks by feel*
			

Common misreading

Read one way, correcting after every reading keeps a quantity closest to its target. In Deming's funnel experiment, marbles dropped through a funnel aimed at a mark land scattered around it. Moving the funnel after each drop, from where it stands, by the opposite of the last marble's miss doubles the variance of where the marbles land (Deming, 1986, as Pyzdek reproduces it). Each move answers a miss that came from chance, and adds a miss of its own.

Changing her effort after each kilometer to cancel the few seconds by which her last lap pace missed her target pace adds that change to the next lap's variation, and her pace scatters wider; inside the deadband of ±5 seconds per kilometer, her effort stays as it is.

The strongest objection

A diagram of roles holds no number for how hard a loop corrects: how much her effort changes for each second too slow. With the loop's delays, that number determines whether it settles or oscillates: raised far enough, it makes a loop oscillate, and the longer the delay, the more slowly a loop can be made to correct (Åström and Murray).

Tuning lies outside the diagram. Where the delay sits and where an external driver enters are *on* it, and they set what any tuning can do. However hard she corrects each second too slow, her effort changes for the hill only after the lap pace reads it; the feedforward path from *hill's gradient* changes it before. For a slow reading, the delay to shorten is on the return path: a lap pace averaged over 500 meters arrives sooner, and varies more from lap to lap.

Check your understanding

CHECK YOUR UNDERSTANDING

A smoke alarm hangs by a kitchen's toaster. When the smoke it reads passes its trigger it sounds, and someone opens the window and fans the smoke out. Toast browned too far sets it off with no fire, so the household presses its hush button, which silences it for ten minutes; then it reads the smoke again. In a feedback control diagram of the kitchen, what is the hush button pressed?

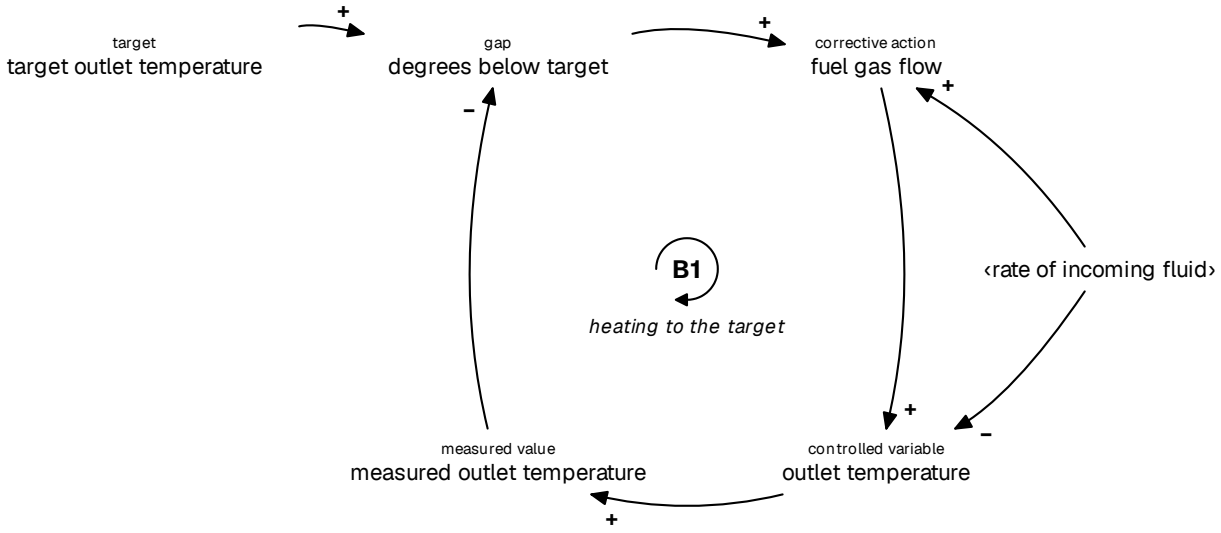
a an override, its signal ending at the alarm's sound

b a new target: a higher trigger for smoke

c an external driver acting on the smoke in the kitchen

Feedback: Answers, chapter 9

A furnace with feedforward, redrawn



Redrawn from Peter Woolf and others, Chemical Process Dynamics and Controls (University of Michigan), section 11.2, “Feed Forward Control”, on LibreTexts eng.libretexts.org/Bookshelves/Industrial_and_Systems_Engineering/Chemical_Process_Dynamics_and_Controls_(Woolf)/11%3A_Control_Architectures/11.02%3A_Feed_forward_control-_What_is_it_When_useful_When_not_Common_usage., the furnace drawn after “This system can also be represented by the following”. CC BY 3.0 creativecommons.org/licenses/by/3.0/.

Its boxes dropped and the lines between them drawn as variables with roles: its temperature setpoint as target outlet temperature, the target; its output as outlet temperature, the controlled variable; its output sensor’s reading as measured outlet temperature, the measured value; its input flow disturbance as rate of incoming fluid, the external driver; the gap, which it leaves inside its temperature controller, drawn as degrees below target, and that controller as the signal from the gap to fuel gas flow, the corrective action; its disturbance sensor and feed-forward controller as the signal from rate of incoming fluid to fuel gas flow; polarities added from its text, and the loop named.

QUESTION 1 OF 3

Which path in the redrawing is feedforward?

a Rate of incoming fluid → outlet temperature, −.

b Measured outlet temperature → degrees below target, −.

c Rate of incoming fluid → fuel gas flow, +.

QUESTION 2 OF 3

Fuel gas flow already rises with the rate of incoming fluid. What is left for B1 to correct?

a Whatever the feedforward rule gets wrong, and any change it doesn't read, such as in the furnace itself.

b Nothing while the rate of incoming fluid changes, since the feedforward has already made up for it.

c Only a change in the target outlet temperature.

QUESTION 3 OF 3

Heat from the burning fuel takes time to pass into the fluid and reach the outlet. Where would a delay be drawn?

a On measured outlet temperature → degrees below target, since the reading comes back late.

b On rate of incoming fluid → fuel gas flow, since feedforward arrives late.

c On fuel gas flow → outlet temperature, B1's forward path.

Feedback: Answers, chapter 9

Exercises

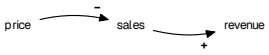
Passing the checks means meeting the brief, not being right.

FC 06 Entry gates at a concert as trains arrive

Your palette



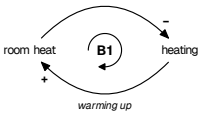
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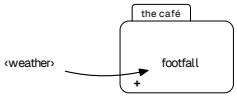
polarity



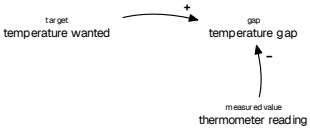
loop



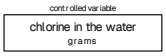
balancing loop



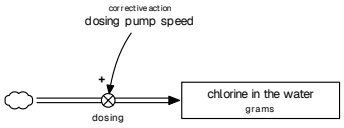
external driver



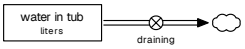
gap
a role, written above its variable's name



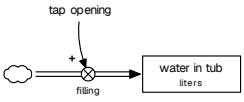
stock



flow



cloud



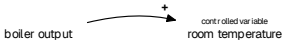
signal



target
a role, written above its variable's name



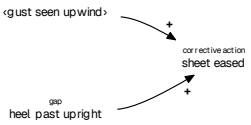
corrective action
a role, written above its variable's name



controlled variable
a role, written above its variable's name



measured value
a role, written above its variable's name



feedforward

FC 06 Entry gates at a concert as trains arrive

Feedforward, then correction

Reasoning ●●●○○ 3 of 5 Polish ●●●●○ 4 of 5

Fans reach a stadium concert by train and queue at the entry gates. The stewards aim for a wait of about ten minutes, which at the gates' pace is a queue of about 600 people. Every few minutes a steward counts the queue, and the further the count runs above 600, the more gates the stewards open. A full train brings about 1,000 fans to the gates within a few minutes of arriving. The station's arrivals board shows each train due, and when it shows a full train the stewards open more gates before its fans reach the queue. Count the queue in people, and time in minutes.

The brief

- [ ] Read the trains due on the arrivals board into gates open, by a path that passes no gap.
- [ ] Draw trains arriving as an external driver acting on the flow of people joining the queue.
- [ ] Close one control loop through the flow of people passing through the gates: the gap, gates open, the people queuing and the stewards' count.
- [ ] The feedforward path and the gap's signal both end at gates open.

Your palette

On the page before this sheet.

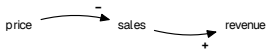
Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/control/anticipation-limits-and-nested-control/#exercise-feedback-control-06

FC 07 Tuning a guitar with a clip-on tuner

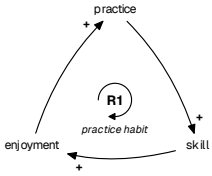
Your palette

variable

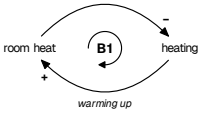


polarity

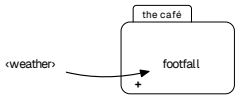
delay



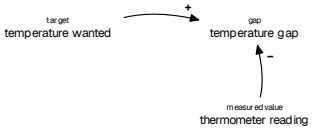
loop



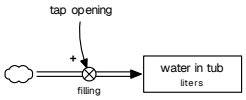
balancing loop



external driver



gap
a role, written above its variable's name



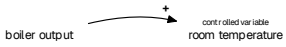
signal



target
a role, written above its variable's name



corrective action
a role, written above its variable's name



controlled variable
a role, written above its variable's name



measured value
a role, written above its variable's name



deadband

FC 07 Tuning a guitar with a clip-on tuner

A noisy reading, a wait, and a band left alone

Reasoning ●●●●○ 4 of 5 Polish ●●●●○ 4 of 5

Amara tunes her guitar's high E string to about 330 Hz with a clip-on tuner, which shows how many cents the string sits sharp or flat of E. Right after she plucks, the reading wobbles by several cents as the note rings and fades, so she waits about two seconds for it to settle before she reads it. When the settled reading is more than 3 cents flat she turns the peg to tighten the string, further the flatter it reads; when it is more than 3 cents sharp she turns the peg back; within 3 cents she leaves the peg alone. The strings are new, and as they stretch the string goes flat between tunings.

The brief

- [ ] Mark the wait while the tuner's reading settles as a delay on the return path.
- [ ] Write her 3 cents either way as a deadband on the signal from the gap to the peg.
- [ ] Draw the pluck's wobble as an external driver acting on the tuner's reading.
- [ ] Leaving the peg alone inside 3 cents is the deadband, not a second variable.

Your palette

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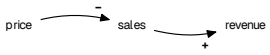
Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/control/anticipation-limits-and-nested-control/#exercise-feedback-control-07

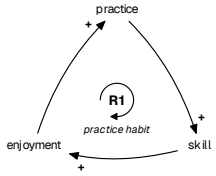
FC 08 A home reef aquarium

Your palette

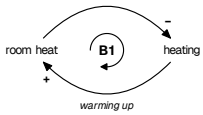
variable



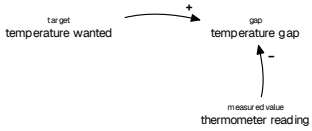
polarity



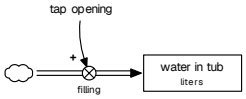
loop



balancing loop



gap
a role, written above its variable's name



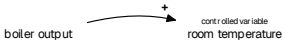
signal



target
a role, written above its variable's name



corrective action
a role, written above its variable's name



controlled variable
a role, written above its variable's name



measured value
a role, written above its variable's name



behavior note

FC 08 A home reef aquarium

Three targets, one shared corrective action

Reasoning ●●●●○ 4 of 5 Polish ●●●●○ 4 of 5

Keiko keeps a reef aquarium at home and holds three quantities near targets: the water at 25 °C, its salinity at 35 parts per thousand, and its alkalinity at 8 dKH. A thermometer in the tank reads the temperature, and the heater's output rises the cooler it reads. Once a week she reads the salinity with a refractometer and tests the alkalinity with a kit, then changes part of the water for new salt water mixed at 34 parts per thousand and 11 dKH: the higher the salinity reads, or the lower the alkalinity, the more water she changes that week. The new water comes from a bucket a few degrees cooler than the tank. The harder the heater runs, the faster the water evaporates, leaving its salt behind.

The brief

- [ ] Close three control loops, for temperature, salinity and alkalinity, each with its target, reading and gap.
- [ ] Make the water changed per week the corrective action of both the salinity loop and the alkalinity loop.
- [ ] Draw the heater's signal to salinity and the water changes' signal to the water temperature as cross-effects.
- [ ] A behavior note names the tradeoff between the loops.

Your palette

On the page before this sheet.

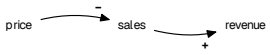
Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/control/anticipation-limits-and-nested-control/#exercise-feedback-control-08

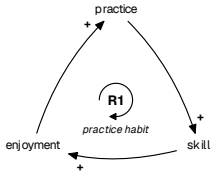
FC 09 A mail service's spam filter

Your palette

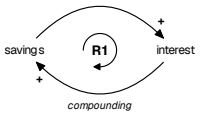
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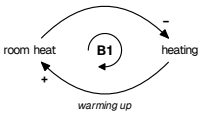
polarity



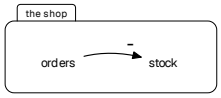
loop



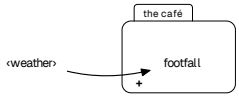
reinforcing loop



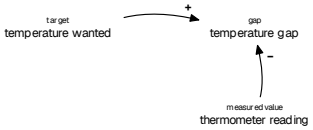
balancing loop



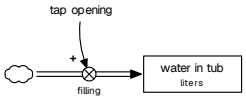
boundary



external driver



gap
a role, written above its variable's name



signal



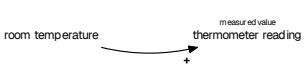
target
a role, written above its variable's name



corrective action
a role, written above its variable's name



controlled variable
a role, written above its variable's name



measured value
a role, written above its variable's name



override
a role, written above its variable's name



evidence coding

FC 09 A mail service's spam filter

Two loops on one corrective action, and a person's release

Reasoning ●●●●● 5 of 5 Polish ●●●●● 5 of 5

A mail service filters spam for hundreds of millions of users. It aims to let no more than 1 message in 1,000 reaching inboxes be spam, and to lose no more than 1 real message in 10,000 to spam folders. Users report the spam that gets through, and complain when real mail goes missing; the service's engineers read both each day and set how strict the filter is, stricter as reports rise and less strict as complaints rise. New spam campaigns start around the world every day, whatever the filter does. The engineers believe that each time the filter is made stricter, spammers change their tactics and get more spam through, but nobody has measured it. A user who finds a real message in the spam folder can mark it not spam, which releases it and makes the filter less strict for messages like it. Draw the model's boundary around spam filtering at the service, its users and the spammers' tactics.

The brief

- [ ] Draw a named boundary, with new spam campaigns worldwide outside it as an external driver.
- [ ] Close two control loops through filter strictness: one on spam reaching inboxes, read from users' reports, and one on real mail lost to spam folders, read from complaints.
- [ ] Declare the reinforcing loop through spammers' new tactics, inside the boundary.
- [ ] Draw users' releases of messages marked not spam as an override whose signal ends at filter strictness.
- [ ] The override is named as a quantity, mail released as not spam, which someone can count and read later.

Your palette

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Draw here

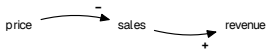
In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/control/anticipation-limits-and-nested-control/#exercise-feedback-control-09

FC 10 Cooling a data center through a heatwave

Your palette



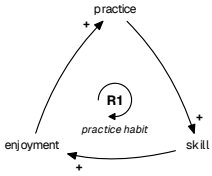
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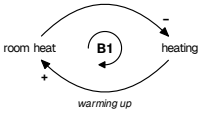
polarity



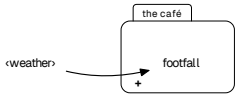
delay



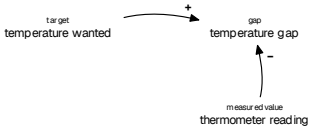
loop



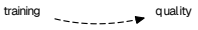
balancing loop



external driver



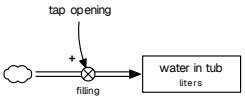
gap
a role, written above its variable's name



evidence coding



behavior note



signal



target
a role, written above its variable's name



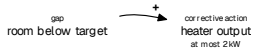
corrective action
a role, written above its variable's name



controlled variable
a role, written above its variable's name



measured value
a role, written above its variable's name



saturation



override
a role, written above its variable's name

FC 10 Cooling a data center through a heatwave

Nested loops, a limit, and a person taking over

Reasoning ●●●●● 5 of 5 Polish ●●●●● 5 of 5

A data center's cooling units blow cold air into its server rooms. A thermometer in that supply air reads its temperature every few seconds, and the units raise their cooling output the further it reads above the supply-air target. Engineers set that target: each hour they read the temperature at the servers' air inlets, which they hold near 27 °C, and lower the supply-air target the warmer the inlets read. The cooling output can rise no higher than the chillers' full output. In a heatwave the supply air warms, and once the chillers are at full output it keeps warming however low the target is set. The engineers can then set the cooling output themselves, in place of the units' rule, or shut down some servers, which they believe lowers the inlet temperature, though nobody knows by how much.

The brief

- [ ] Nest the fast loop on the supply air inside the slow loop on the server inlet temperature, whose corrective action is the supply-air target.
- [ ] Write the chillers' full output as the limit on cooling output.
- [ ] Draw the heatwave as an external driver acting on a controlled variable.
- [ ] Draw the engineers' own cooling setting as an override whose signal ends at cooling output.
- [ ] Code the signal for how much shutting down servers lowers the inlet temperature as a hypothesis.
- [ ] Recovery shows only in a later hourly inlet reading: the slow loop closes on that reading, not on the supply air.

Your palette

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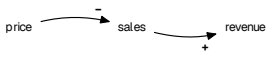
Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/control/anticipation-limits-and-nested-control/#exercise-feedback-control-10

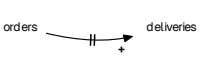
CS 09 Kelsham Primary School: a floor on staffing and the council's loop

Your palette

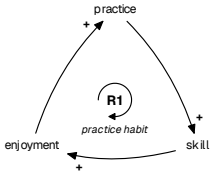
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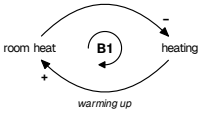
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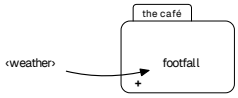
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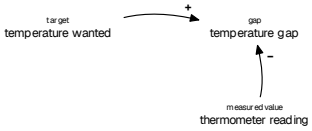
loop



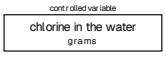
balancing loop



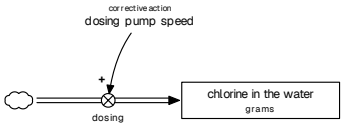
external driver



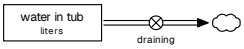
gap
a role, written above its variable's name



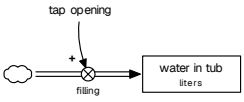
stock



flow



cloud



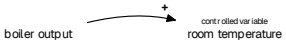
signal



target
a role, written above its variable's name



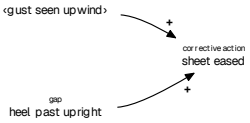
corrective action
a role, written above its variable's name



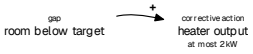
controlled variable
a role, written above its variable's name



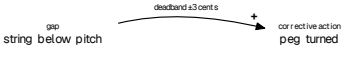
measured value
a role, written above its variable's name



feedforward



saturation



deadband

CS 09 Kelsham Primary School: a floor on staffing and the council's loop

Saturation, a deadband, feedforward and a nested loop

Reasoning ●●●●● 5 of 5 Polish ●●●●● 5 of 5

The governors can cut staff hours only as far as one teacher for each of the four classes. Within a school year the reserve rises and falls by up to £10,000 as funding arrives and pay goes out, so they change staff hours only when the budget report, read each term, differs from the reserve they must hold by more than £10,000. Around their loop runs the county council's: once a year David Brennan reads the school's spending for each pupil in its accounts, and the further it runs above the county's, the higher the reserve, from £60,000 up, that the council requires the governors to hold. He also forecasts the school's starters from the births in the villages four years ahead, and on a falling forecast the council raises the reserve it requires before the October count falls. The pupils on roll bring in funding and share the school's spending, and neither the governors nor the council sets them. Count the reserve in pounds, and time in years.

The brief

- [ ] Nest the governors' loop on the reserve inside the county council's loop on spending for each pupil, whose corrective action is the reserve the council requires.
- [ ] Write the hours above one teacher a class as the limit on staff hours cut.
- [ ] Write the £10,000 the reserve moves within a school year as a deadband on the gap's signal to staff hours cut.
- [ ] Read births in the villages into the reserve the council requires through David Brennan's forecast, by a path that passes no gap.
- [ ] Mark the budget report each term and the accounts each year as delays on the two return paths.
- [ ] Once staff hours cut reaches its limit, a higher reserve required changes nothing: both loops act through the same corrective action.

Your palette

On the page before this sheet.

Draw here

Sources

- Karl Johan Åström and Richard M. Murray, *Feedback Systems: An Introduction for Scientists and Engineers* fbswiki.org/wiki/index.php/Main_Page, second edition (Princeton University Press, 2021): chapter 1, on feedforward and nested loops; chapters 10 and 14, on how a delay limits a loop; chapter 11, on gain raised until a loop oscillates, and a throttle held at its limit on a steep hill.
- W. Edwards Deming, *Out of the Crisis* (MIT Center for Advanced Engineering Study, 1986), chapter 11, the funnel experiment, as reproduced by Yonatan Reshef, "The Funnel Experiment" sites.ualberta.ca/~yreshef/orga432/funnel.html (University of Alberta course notes), and by Thomas Pyzdek, *The Quality Engineering Handbook* qualityamerica.com/LSS-Knowledge-Center/statisticalprocesscontrol/tampering_effects_and_diagnosis.php, on the doubled variance.
- Bizot Group, *The Bizot Green Protocol* nationalmuseums.org.uk/media/uk_museum_cop/bizot_green_protocol_2023.pdf (refreshed September 2023), on 40–60% relative humidity for canvas paintings and other objects that absorb moisture.
- Helena Rodwell, "Can You Turn the Heating Up?" conservation.fitzmuseum.cam.ac.uk/?p=64 (The Fitzwilliam Museum), on warming lowering relative humidity.

Part V — Pattern and Judgment

Structures That Recur

System archetypes

Part V · Pattern and Judgment · Chapter 10 of 12 · the first of two chapters on system archetypes

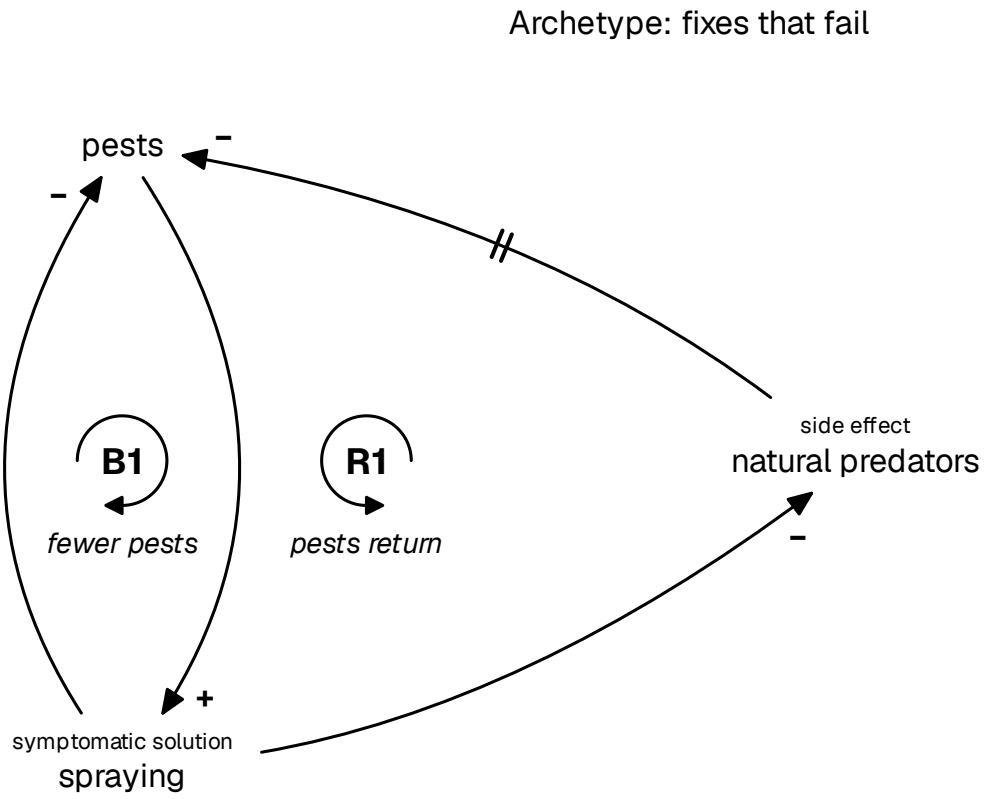
Which stories play out again and again? A few loop structures recur in situations that share nothing else: a fix that brings its problem back, growth that meets a limit, a shared resource used up. A system archetype is a causal loop diagram with the name of its structure written on it, and matching reads whether its loops have that structure.

Signals you need this diagram

- A fix worked at first, and the problem came back worse.
- Growth slowed while the effort behind it kept rising.
- A fast remedy goes on being used, and a slower one is never started.
- Of two people or groups drawing on one resource, the one ahead pulls further ahead.
- Several users of one shared resource each take more, and each gets less.
- A situation’s loops sound like a story from somewhere else.

Spraying a valley’s rice

Farmers in a river valley spray their rice when pests build up, and within days the pests fall. The spray also kills the spiders and parasitic wasps that prey on the pests. With fewer of them, the pests come back in greater numbers over the following seasons, and the farmers spray more often. In Asia’s rice fields, the International Rice Research Institute reports that early sprays kill the brown planthopper’s natural enemies and make its outbreaks ten times more likely.



B1, *fewer pests*, is the spray's relief; R1, *pests return*, runs through the predators it kills. The loops match the archetype written on the diagram, *fixes that fail*, with its delay.

What the notation expresses

A **system archetype** is drawn with a causal loop diagram's marks: variables, effects with their polarities, loops (chapter 4, Loops) and delays. It adds two kinds of words: a variable's role, in small type above its name, and a declared archetype, one line beginning *Archetype:*.

Archetypes

An **archetype** is a named loop structure that recurs across situations. Kim opens fixes that fail with a squeaky wheel: water stops the squeak, the wheel rusts, and it squeaks louder. The rice valley has the same loops. Each archetype is written as a **template**: its variables, its effects with their polarities, its loops with their kinds, and where a delay belongs.

A **declared archetype** is a line of words on the diagram, *Archetype: fixes that fail*: a hypothesis that the diagram's loops hold that archetype. A diagram may carry several.

Matching

A **match** is a place in a diagram where an archetype's loops sit: each of the template's variables stood in by a different variable of the diagram, each template effect drawn as one effect or a chain of up to four, and every loop

of the template of the same kind, by the parity rule (chapter 4, The parity rule). A chain holds variables the template leaves out: *pests → spraying* could run through *damaged leaves*.

Matching reads loops, their kinds and where delays (chapter 4, Delays) sit, never what a variable is: whether *natural predators* are spiders or rainfall, or whether spraying relieves anything. So a match is a hypothesis about structure, never a verdict on the situation. A **near miss** is an archetype's loops found with one of them of the other kind, or a match without a delay the archetype has.

In the lab, the matches are listed after every change, and each declared archetype is checked against them. Finding archetypes by algorithm has a precedent in simulation models (Schoenenberger, Schmid and Schwaninger, 2015).

Symptomatic and fundamental solutions

A **symptomatic solution** relieves a symptom quickly: *spraying*, with *symptomatic solution* written above its name. A **fundamental solution** acts on the cause, more slowly, and is written *fundamental solution*. The rice valley has none drawn. One drawn in reply to the pests, lowering them after a delay and weakened as the predators fall, would make it a shifting the burden.

Which remedy is which depends on who is asked: Kim writes that there may be no agreement on whether a remedy is symptomatic or fundamental. A role is written by whoever draws the diagram, and checked only for fitting a match: its variable must stand where the archetype puts that role.

CHECK YOUR UNDERSTANDING

Rain comes through a cracked roof tile into an attic. Whenever it rains, someone sets out pans and empties them, and the attic floor stays dry. Replacing the tile would take a roofer and a dry week, and the longer the pans keep the floor dry, the less anyone thinks of calling one. In a system archetype of the attic, which variable is the symptomatic solution?

a water on the attic floor

b pans emptied

c tiles replaced

d how used to the leak the household is

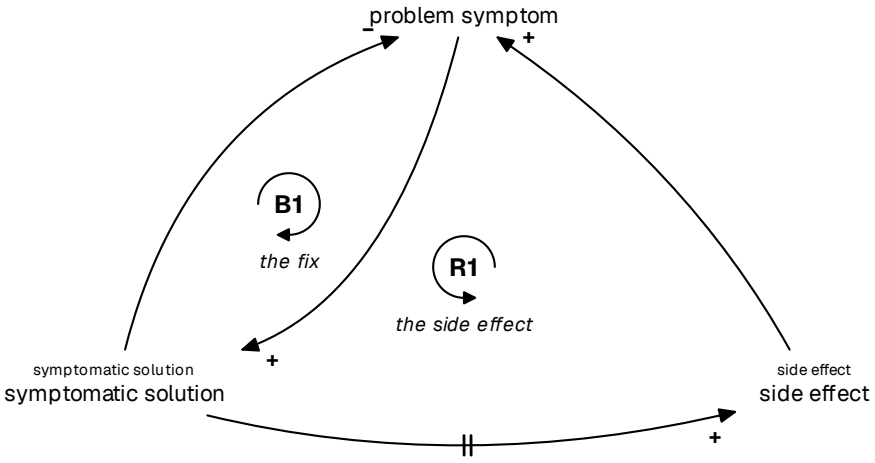
Feedback: Answers, chapter 10

Side effects

A **side effect** is a consequence of the symptomatic solution, usually delayed: *natural predators*, which spraying lowers, with *side effect* written above the name. In fixes that fail it worsens the problem symptom; in shifting the burden it weakens the fundamental solution. The role goes on the consequence, not on the symptom it brings back.

Fixes that fail

Archetype: fixes that fail

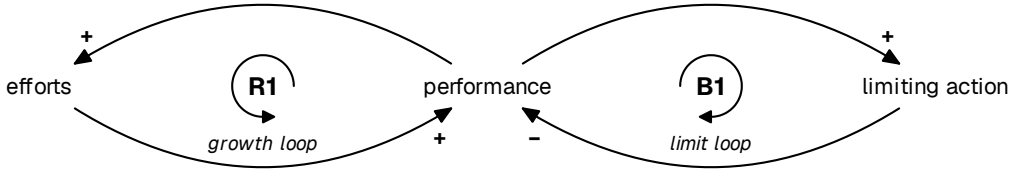


The fix loop (B1) relieves the problem symptom; the side effect's loop (R1) brings it back, after a delay on one of the effects through the side effect. Which of the two drives behavior when is loop dominance (chapter 5, Loop dominance): the fix first, the side effect after its delay.

The answers to chapter 4's CL 05 (chapter 4, CL 05), borrowing to get to the end of the month, and chapter 5's CL 07 (chapter 5, CL 07), antibiotics, match fixes that fail with its delay.

Limits to growth

Archetype: limits to growth



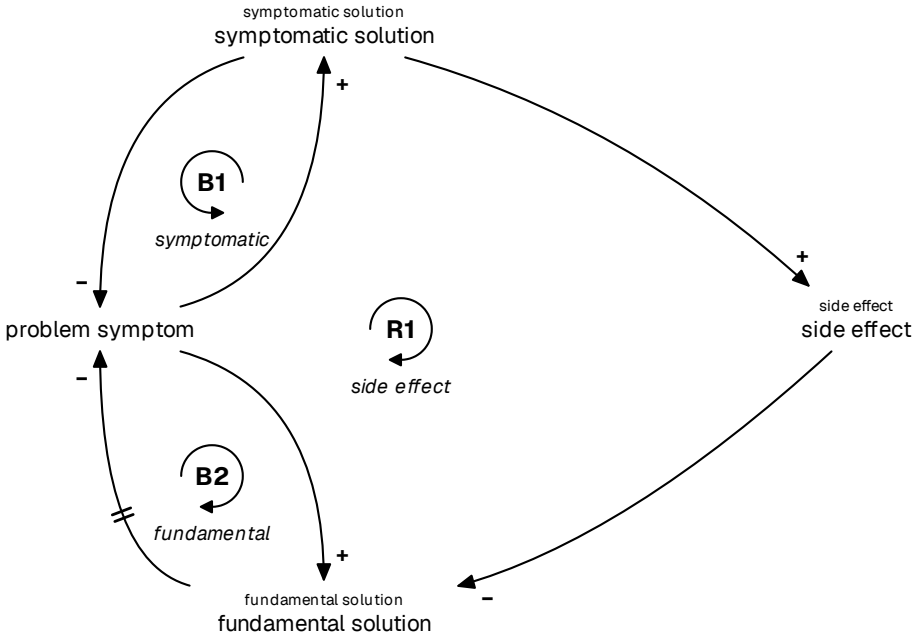
A reinforcing loop, the **growth loop**, and a balancing loop, the **limit loop**, share *performance*: efforts raise performance and performance spurs efforts, until the limiting action holds performance back. Kim calls limits to growth *limits to success*, and puts the leverage in removing what limits growth, not in pushing harder on the

growth loop: a leverage point (chapter 4, Leverage points) on the limiting action. What sets the limit, the **constraint**, acts from outside both loops, so the template leaves it out.

The answer to chapter 5's CL 09 (chapter 5, CL 09), an old town and its visitors, matches no limits to growth: its two loops share an effect, *holiday lets → visitors*, where limits to growth's share one *variable*.

Shifting the burden

Archetype: shifting the burden

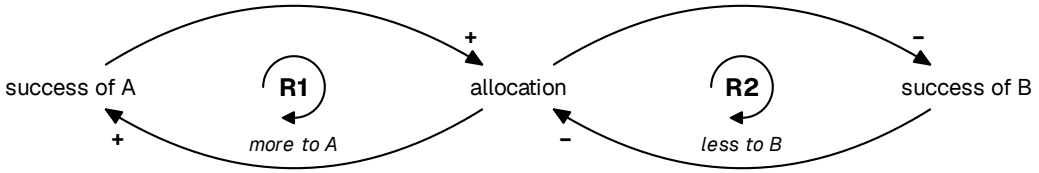


Two balancing loops relieve one problem symptom: the symptomatic solution's at once, the fundamental solution's after a delay. The symptomatic solution's side effect weakens the fundamental solution, closing a reinforcing loop through both. Its symptomatic loop and reinforcing loop together match fixes that fail, the side effect's way back to the problem symptom running through the fundamental solution. Where that way is a chain of four effects or fewer, as in the figure, every shifting the burden holds one.

The answer to chapter 5's CL 08 (chapter 5, CL 08), a parent who finishes the homework, matches shifting the burden with its delay.

Success to the successful

Archetype: success to the successful

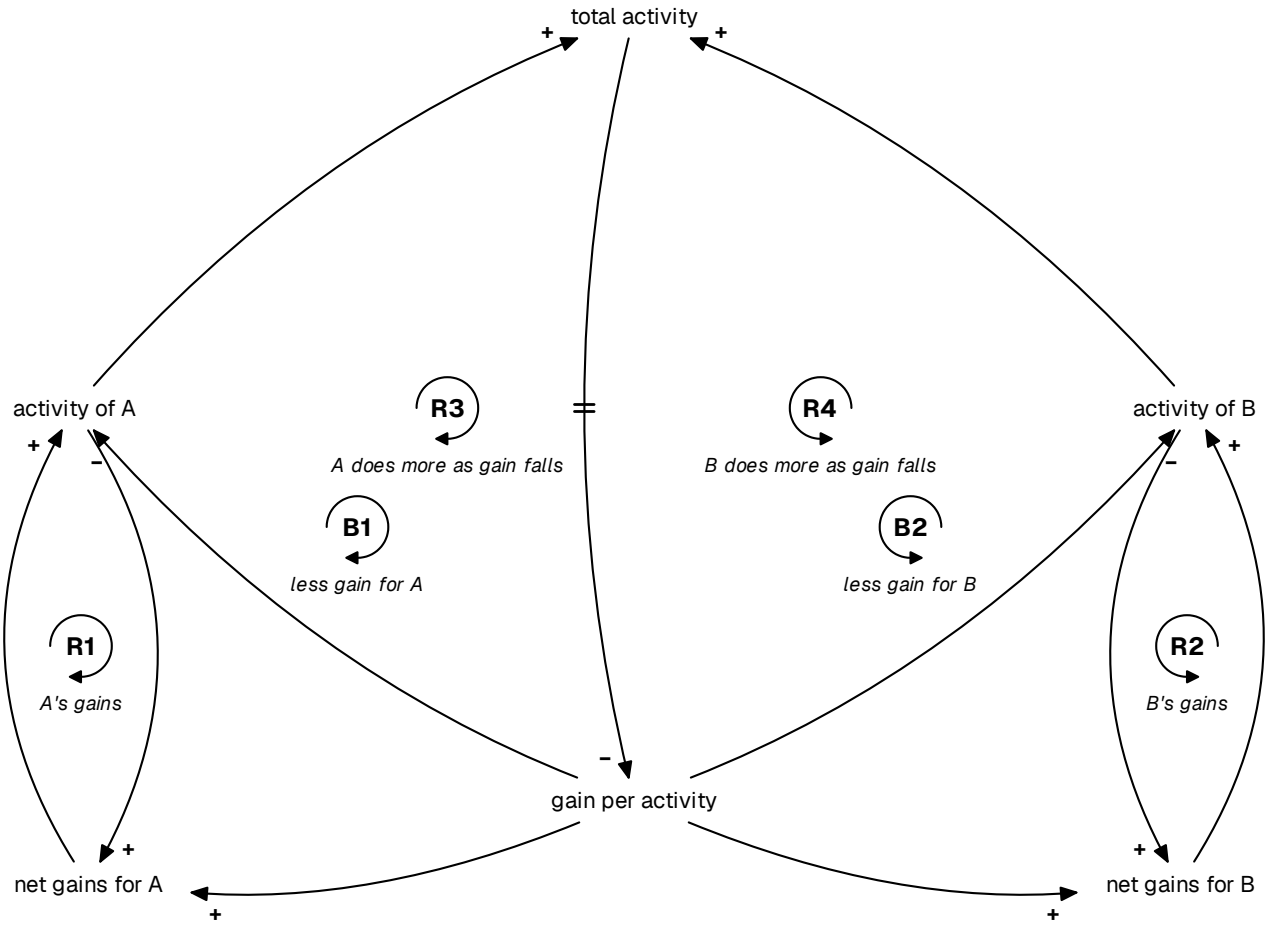


Two reinforcing loops share one allocation between A and B: success of A wins A a larger share, and a larger share to A is less to B, whose success falls and wins it less again. Which side ends ahead depends on where each started, as much as on what each could do with an equal share (Kim).

Any two reinforcing loops sharing one variable match it, whatever their polarities: *success of B* named as *failure of B* turns its two – into +.

Tragedy of the commons

Archetype: tragedy of the commons



Each user's activity raises their net gains, which raise their activity (R1, R2). All activity adds to total activity, which, after a delay, lowers the gain per activity of every user (B1, B2). A lower gain per activity raises each user's activity, closing two more reinforcing loops through total activity (R3, R4), which Kim draws and leaves unnamed. The resource limit sits outside the loops. Where the shared resource accumulates, as the fish on AR 05's fishing ground do, it is a stock (chapter 6, Stocks). Three users give three matches, one for each pair. Kim puts the remedy above the level of any one user.

A variable named as its opposite

In the rice valley, *natural predators* fall as spraying rises, and their fall raises the pests: two – effects where the template's side effect has two +. Named *predators lost*, the same variable would carry two +.

A variable named as its opposite changes the polarity of every effect into and out of it. A loop through it passes two of those, so the parity rule (chapter 4, The parity rule) gives it the same kind, and the match holds, with the variable reported as named as its opposite.

CHECK YOUR UNDERSTANDING

A gym fills up every January: each new member brings friends along, and the friends join. By February the crowded floor puts members off. Someone draws it with space on the gym floor where crowding would go: members → space on the gym floor –, space on the gym floor → members +, beside members → friends brought along → members, both +. Does it match limits to growth?

a Yes, with space on the gym floor named as its opposite

b No: the archetype has performance → limiting action +, and this effect is –

c No: with space where crowding would go, the loop through it is reinforcing

Feedback: Answers, chapter 10

What stays informal

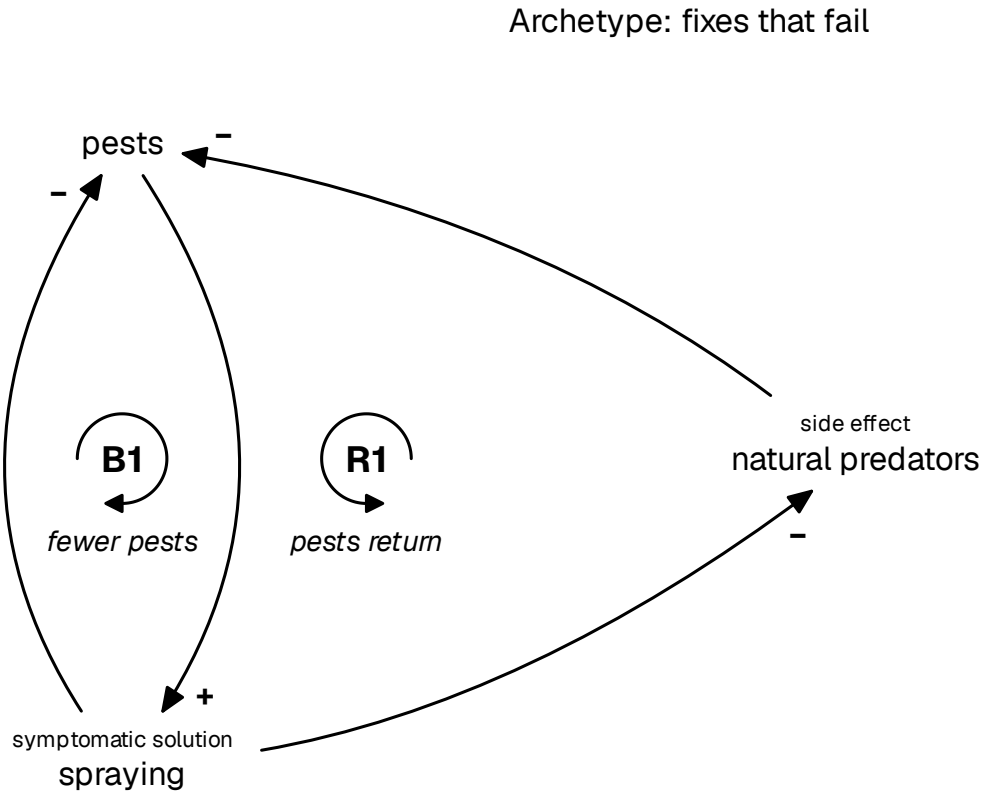
What a variable is: matching reads structure, so whether the valley's story is a fix that fails, whether these predators eat these pests, is a question for evidence about the valley.

Timing beyond where delays sit: a delay shows that a change arrives late, not whether a season or a decade late. That goes in a behavior note or a sentence.

Leverage beyond the leverage point's box: the box marks a hypothesis about where to act; why there, and how hard to push, go in prose beside the diagram.

The bad diagram

What's wrong with this diagram of the rice valley?



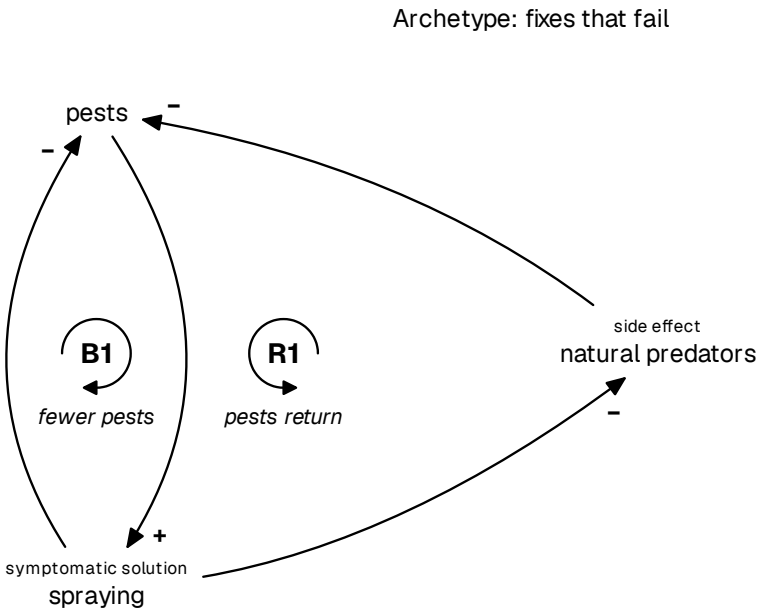
Its variables, polarities, loops and declaration are the corrected diagram's, and its loops match fixes that fail. But *natural predators → pests* carries no delay, as if the pests came back the *day* the spray killed their predators. The lab's check reports:

> Matches fixes that fail without its delay: the side effect comes late, and no effect on spraying → natural predators → pests has a delay. Brief: fixes that fail, with its delay.

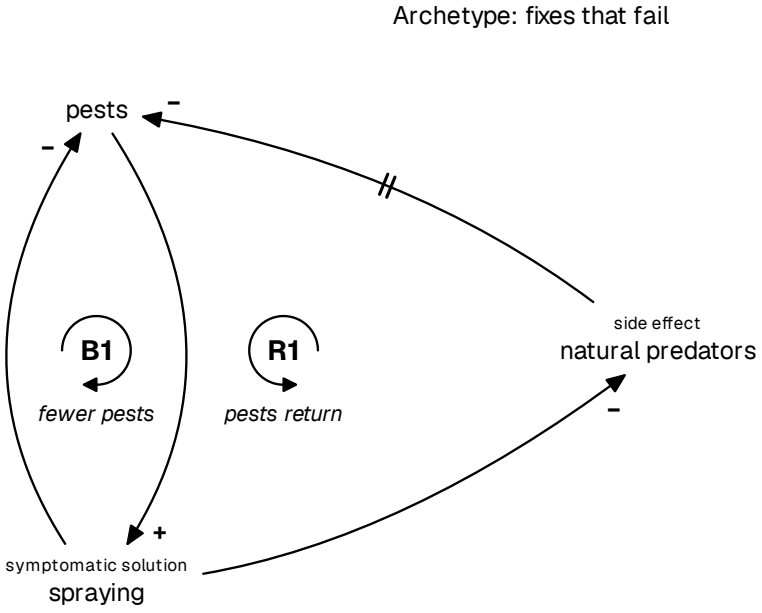
The corrected diagram

Corrected, *natural predators → pests* carries a delay: the pests come back over seasons, after weeks of relief.

Bad diagram



Corrected diagram

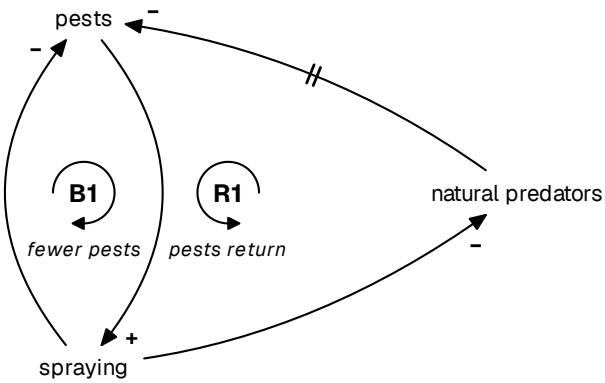


Labels unchanged. Effects: 1 delay added. Now matched with its delay: fixes that fail.

Notation moves

Notation move	When	What it shows	Example
Declare an archetype	The loops have a structure that recurs across situations	A hypothesis about the loops, checked against the matches	*Archetype: fixes that fail*
Write *symptomatic solution* above a variable	It relieves a symptom quickly	The fast remedy	*spraying*
Write *fundamental solution* above a variable	It acts on the cause, more slowly	The slow remedy the side effect weakens	*tiles replaced*, under a leaking roof
Write *side effect* above a variable	A consequence of the symptomatic solution comes back	Where the later loop leaves the fix	*natural predators*
Mark the archetype's delay		Which change comes late	*natural predators* → *pests*

Archetype: fixes that fail



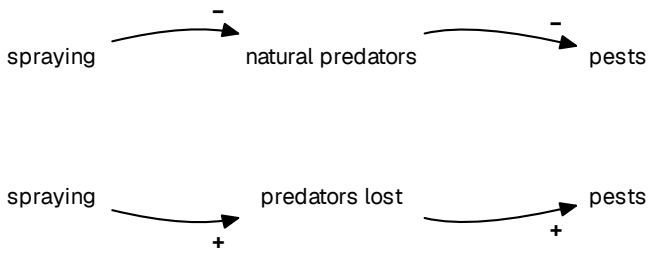
symptomatic solution
spraying

fundamental solution
tiles replaced

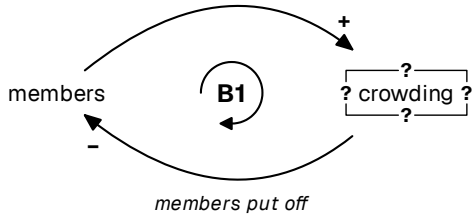
side effect
natural predators

side effect
natural predators
pests

Notation move	When	What it shows	Example
Name a variable as its opposite	Its name reads better the other way round	The same match	*natural predators* for *predators lost*



Propose a leverage point on the limiting action	Growth meets a limit	Where Kim puts the leverage	*crowding*, in a gym that fills every January



Check your understanding

CHECK YOUR UNDERSTANDING

Evening pick-up games on a park's basketball court: players bring friends, and the friends come back the next week. As the court fills, players wait longer between games, and some stop coming. A diagram of the court, with players, friends brought along and waiting time, matches limits to growth. What does the match show?

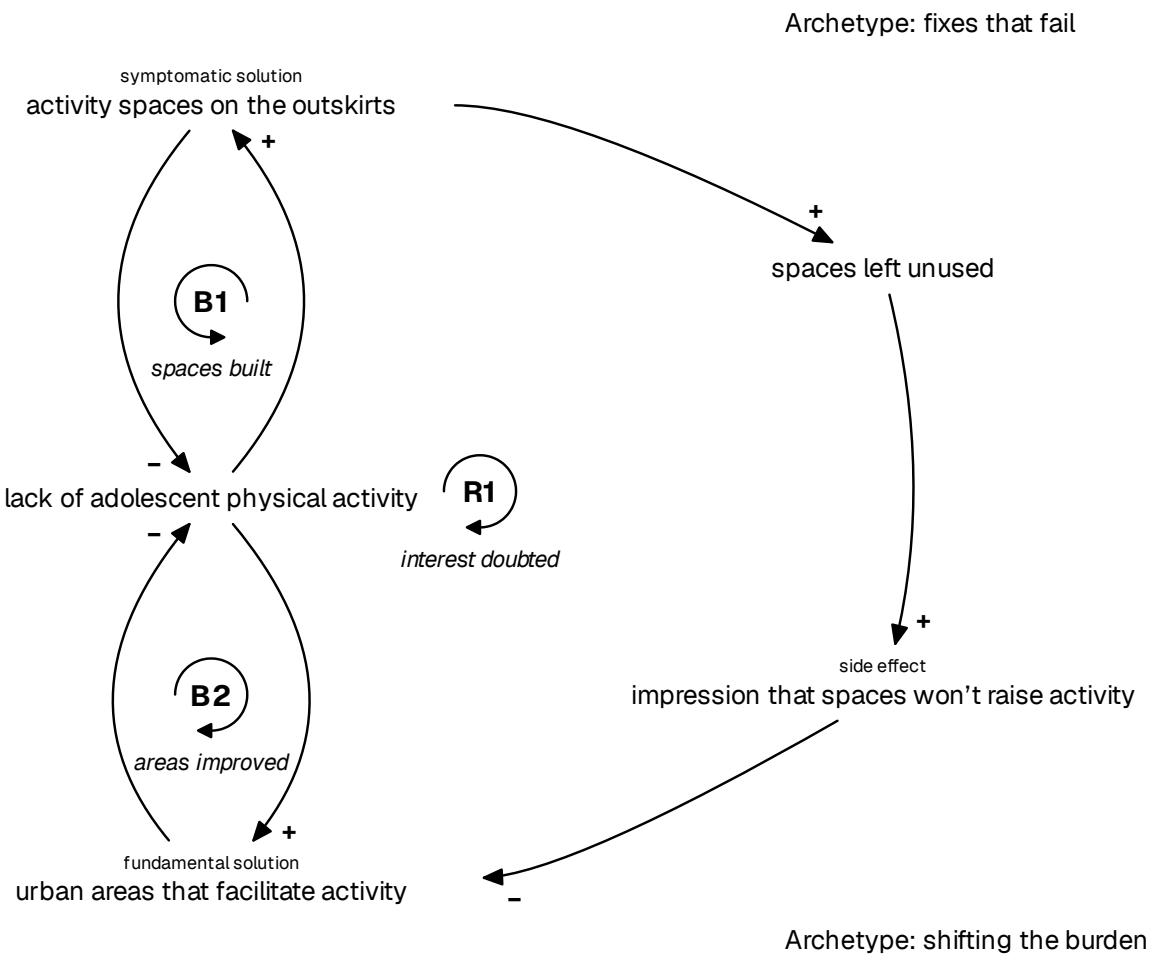
a That the diagram's loops have the structure of limits to growth

b That players stop coming because of the waiting

c That a second court is where to act

Feedback: Answers, chapter 10

Activity spaces on Amsterdam's outskirts, redrawn



Redrawn from Jillian O'Mara, Loes Crielaard, Luc Hagenaars, Karien Stronks and Wilma Waterlander, "Using systems archetypes to understand system behaviour and identify leverage points for change in local obesity prevention in The Netherlands", Health Promotion International 41(3), daag056 (2026) doi.org/10.1093/heapro/daag056, Table 1, LA2, its causal loop diagram. CC BY 4.0 creativecommons.org/licenses/by/4.0/.

Its prefixes Symptomatic solution, Fundamental solution and Side-effect written as roles above the names, and Problem symptom dropped; its dashed lines, its mark for an inverse effect, drawn solid with a –, since a dash here marks a hypothesis; its color left out; spaces aren't used renamed as an amount, spaces left unused, and the other four names shortened; each loop named; fixes that fail and shifting the burden, the two archetypes its authors name, declared.

QUESTION 1 OF 3

Its authors name two archetypes, and both are declared. Which loops hold fixes that fail?

a B1 and B2, the two balancing loops sharing the lack of adolescent physical activity.

b B1, spaces built, and R1, interest doubted.

c B2, areas improved, and R1, interest doubted.

QUESTION 2 OF 3

More impression that spaces won't raise activity: what does it change, and through which loop?

a More activity spaces on the outskirts, through its own effect on them.

b Nothing in the loops: a side effect sits outside them.

c Fewer urban areas that facilitate activity, so the lack of activity stays high: R1.

QUESTION 3 OF 3

The figure has no delay, as its authors drew none. On which effect does shifting the burden's delay belong?

a Urban areas that facilitate activity → lack of adolescent physical activity.

b Activity spaces on the outskirts → lack of adolescent physical activity.

c Spaces left unused → impression that spaces won't raise activity.

Feedback: Answers, chapter 10

Exercises

Passing the checks means meeting the brief, not being right.

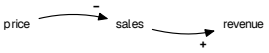
AR 01 Watering a lawn a little every evening

Your palette

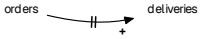
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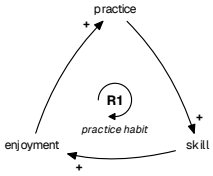
effect



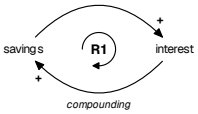
polarity



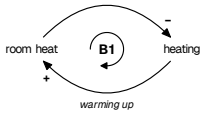
delay



loop



reinforcing loop



balancing loop



behavior note

Archetype: fixes that fail

archetype



symptomatic solution
a role, written above its variable's name



side effect
a role, written above its variable's name

AR 01 Watering a lawn a little every evening

A relief that brings the problem back

Reasoning ●○○○○ 1 of 5 Polish ●○○○○ 1 of 5

Every summer evening, Rosa waters her lawn for ten minutes wherever it has turned brown, and by morning the grass is green again: the browner the lawn, the more she waters. Ten minutes wets only the top few centimeters of soil, so over the following weeks the grass keeps its roots there, where the soil dries first: the more evening watering, the faster the grass dries in heat. The faster the grass dries, the browner the lawn in each hot spell.

The brief

- [ ] Draw the morning's relief as one balancing loop through the brown lawn and the evening watering.
- [ ] Draw the drying grass's return to the brown lawn as one reinforcing loop.
- [ ] Mark one delay: the weeks before the watering makes the grass dry faster.
- [ ] The two loops match fixes that fail, with its delay on the side effect's chain.
- [ ] Write the symptomatic solution above the evening watering.
- [ ] Write the side effect above how fast the grass dries.
- [ ] Add a behavior note.
- [ ] The note names the relief each morning and the browning that comes back faster.
- [ ] The brown lawn is drawn once, as the variable the watering relieves and the drying grass makes worse.

Your palette

On the page before this sheet.

Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/pattern-and-judgment/structures-that-recur/#exercise-system-archetype-01

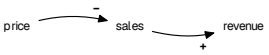
AR 02 Electric cars and public chargers

Your palette

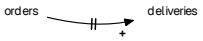
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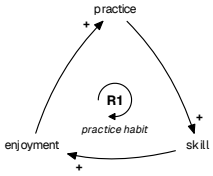
effect



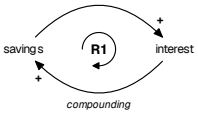
polarity



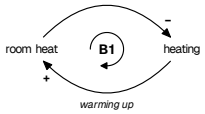
delay



loop



reinforcing loop



balancing loop

archetype

AR 02 Electric cars and public chargers

Growth held back by what it uses

Reasoning ●○○○○ 1 of 5 Polish ●●○○○ 2 of 5

In a country of five million people, electric cars are cheap to run, and their owners tell friends, family and colleagues so: the more electric cars on the road, the more owners' recommendations, and the more recommendations, the more electric cars people buy. Owners without a driveway charge at public chargers, so the more electric cars on the road, the longer the queues at public chargers, and the more public chargers, the shorter the queues. Word of hour-long waits takes months to reach people choosing their next car; then the longer the queues, the fewer electric cars join the road.

The brief

- [ ] Draw the recommendations as one reinforcing loop through the electric cars on the road.
- [ ] Draw the queues holding back new electric cars as one balancing loop.
- [ ] The two loops match limits to growth: a reinforcing loop and a balancing loop sharing one variable.
- [ ] Mark the months before word of the queues reaches buyers as a delay inside the balancing loop.
- [ ] The number of public chargers is the constraint: a variable outside both loops, with an effect into the balancing loop.

Your palette

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Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/pattern-and-judgment/structures-that-recur/#exercise-system-archetype-02

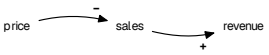
AR 03 A climbing club that hires guides for its trips

Your palette

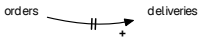
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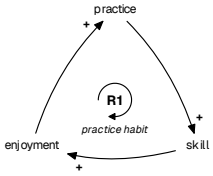
effect



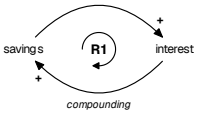
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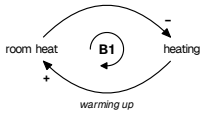
delay



loop

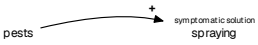


reinforcing loop



balancing loop

archetype



symptomatic solution
a role, written above its variable's name



fundamental solution
a role, written above its variable's name



side effect
a role, written above its variable's name

AR 03 A climbing club that hires guides for its trips

A quick relief that holds back a slower one

Reasoning ●●○○○ 2 of 5 Polish ●●○○○ 2 of 5

A climbing club of sixty members runs two trips a month, and each trip needs one qualified leader for every six climbers. When a trip is short of a leader, the club hires a mountain guide for the weekend and the trip goes ahead: the more trips short of a leader, the more hired guides, and the more hired guides, the fewer trips short of a leader. Members can qualify to lead trips themselves through courses and logged climbs that take a full season: the more trips short of a leader, the more members training to lead, and a season later, the more members training, the fewer trips short of a leader. Each guided trip shows the members that a guide will be hired: the more hired guides, the more the club relies on them, and the more it relies on them, the fewer members train to lead.

The brief

- [ ] Draw two balancing loops through the trips short of a leader: one through the hired guides, one through the members training to lead.
- [ ] Draw the reliance on hired guides closing one reinforcing loop.
- [ ] The loops match shifting the burden, with its delay on the training's loop.
- [ ] Write the symptomatic solution above the hired guides.
- [ ] Write the fundamental solution above the members training to lead.
- [ ] Write the side effect above the reliance on hired guides.
- [ ] The side effect is the reliance the hired guides build up, not a second shortage of leaders.

Your palette

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AR 04 Two parks and one maintenance budget

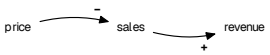
Your palette



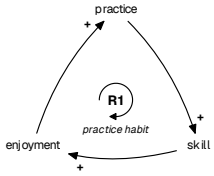
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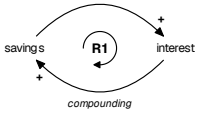
effect



polarity



loop



reinforcing loop



behavior note

archetype

AR 04 Two parks and one maintenance budget

A small lead that a split widens

Reasoning ●●○○○ 2 of 5 Polish ●●●○○ 3 of 5

A town of thirty thousand people has two parks, one by the river and one on the hill, and one maintenance budget for both. Each spring the council splits the budget by the two parks' visitor counts from the year before, and the larger a park's share, the better it is mowed, cleaned and repaired that year. The more visitors to the riverside park, the larger the share of the budget to the riverside park, and the larger that share, the more visitors to the riverside park. The more visitors to the hilltop park, the smaller the riverside park's share, and the larger the riverside park's share, the fewer visitors to the hilltop park. In the first year, the riverside park had a few hundred more visitors than the hilltop park.

The brief

- [ ] Draw the share of the budget to the riverside park as one variable, with two reinforcing loops through it: one through each park's visitors.
- [ ] The two loops match success to the successful: two reinforcing loops sharing one variable.
- [ ] Add a behavior note on the gap between the two parks' visitors.
- [ ] The two loops are drawn as mirror images, one on each side of the share.
- [ ] In the note: the first year's gap is small, and the split widens it every year after.

Your palette

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Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/pattern-and-judgment/structures-that-recur/#exercise-system-archetype-04

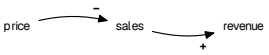
AR 05 Three countries' fleets on one fishing ground

Your palette

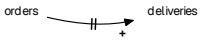
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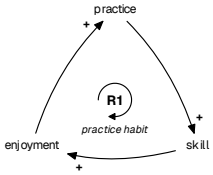
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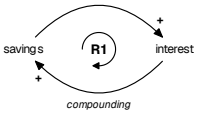
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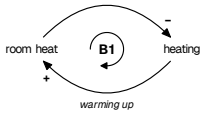
delay



loop



reinforcing loop



balancing loop

archetype

AR 05 Three countries' fleets on one fishing ground

Gains kept by each, losses shared by all

Reasoning ●●●○○ 3 of 5 Polish ●●●○○ 3 of 5

Three countries, called here the northern, western and eastern, send fishing fleets to one fishing ground in international waters. Each fleet's owners spend what they earn on more boats: the more northern boats, the more northern earnings, and the more northern earnings, the more northern boats, and the same holds for the western and eastern fleets. Every boat adds to the total catch, and the larger the total catch, the fewer fish are left to breed. The young fish that go unborn would have been caught years later, so only then does the catch per boat fall: the larger the total catch, the smaller the catch per boat, after a delay of years. The larger the catch per boat, the more each fleet earns; and the smaller the catch per boat, the more boats each fleet sends to make up its catch.

The brief

- [ ] Draw each fleet's boats and earnings as a reinforcing loop, and its boats, the total catch and the catch per boat as another: two for each of the three fleets.
- [ ] Draw each fleet's boats returning to its earnings through the total catch and the catch per boat as a balancing loop, one for each fleet.
- [ ] The loops match tragedy of the commons, with its delay on the total catch's effect on the catch per boat.
- [ ] The total catch is one variable, which all three fleets' boats add to, not one for each fleet.
- [ ] No effect crosses another where moving a variable would avoid it.

Your palette

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Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/pattern-and-judgment/structures-that-recur/#exercise-system-archetype-05

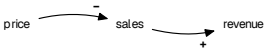
CS 10 Kelsham Primary School: merging classes to balance the budget

Your palette

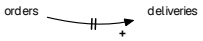
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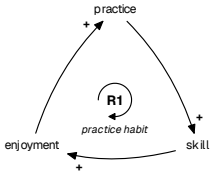
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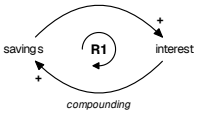
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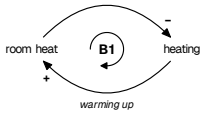
delay



loop



reinforcing loop



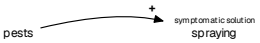
balancing loop



behavior note

Archetype: fixes that fail

archetype



symptomatic solution
a role, written above its variable's name



side effect
a role, written above its variable's name

CS 10 Kelsham Primary School: merging classes to balance the budget

A saving that brings the spending back

Reasoning ●●●○○ 3 of 5 Polish ●●●○○ 3 of 5

Kelsham Primary School is paid £4,800 for each pupil, set from the October count before each school year, so its funding falls a year after its roll does: the fewer pupils on roll, the less school funding, a year later, and the less school funding, the more spending above funding. When the school spends more than its funding, the governors merge classes. In 2023, with 108 pupils, they taught Years 3 and 4 as one class and paid four teachers instead of five, saving £52,000 a year at once: the more spending above funding, the more mixed-age classes, and the more mixed-age classes, the less spending above funding. Some parents, Priya Shah among them, would rather each year were taught as a class of its own, as at Brayford Primary School: the more mixed-age classes, the more parents choosing the town school, and the more parents choosing the town school, the fewer pupils on roll. In October 2026 the roll is 88, and Tom Hale, who chairs the governors, proposes teaching Reception with Years 1 and 2.

The brief

- [ ] Draw the saving as one balancing loop through spending above funding and mixed-age classes.
- [ ] Draw the families' leaving as one reinforcing loop back to spending above funding.
- [ ] Mark one delay: the October count, which sets the funding a year after pupils leave.
- [ ] The two loops match fixes that fail, with its delay on the side effect's chain.
- [ ] Write the symptomatic solution above its variable.
- [ ] Write the side effect above its variable.
- [ ] Declare the archetype the loops match, in one line.
- [ ] Add a behavior note.
- [ ] The note names the saving each merger brings at once and the spending that comes back as the roll falls.

Your palette

On the page before this sheet.

Draw here

Sources

- Daniel H. Kim, *Systems Archetypes I: Diagnosing Systemic Issues and Designing High-Leverage Interventions* thesystemsthinker.com/wp-content/uploads/2016/03/Systems-Archetypes-I-TRSA01_pk.pdf (Pegasus Communications, 1992, 2000): the archetypes used as templates, p. 2; Peter Senge's *The Fifth Discipline* (1990) as the source of the term, p. 3; fixes that fail and the squeaky wheel, pp. 16–17; Kim's name for limits to growth and where its leverage lies, pp. 20–21; shifting the burden, and disagreement over which remedy is symptomatic, pp. 22–23; success to the successful and its starting conditions, pp. 24–25; the tragedy of the commons and why its remedy lies above any one user, pp. 26–27.
- Lukas Schoenenberger, Alexander Schmid and Markus Schwaninger, "Towards the Algorithmic Detection of Archetypal Structures in System Dynamics" doi.org/10.1002/sdr.1526, *System Dynamics Review* 31, no. 1–2 (2015): 66–85, on algorithms that find archetypes in simulation models.
- International Rice Research Institute, "Letting Nature Manage Its Battles" ricetoday.irri.org/letting-nature-manage-its-battles/, *Rice Today* (6 October 2012), on early sprays that kill the brown planthopper's natural enemies and make its outbreaks ten times more likely.

Diagnosing Tangled Situations

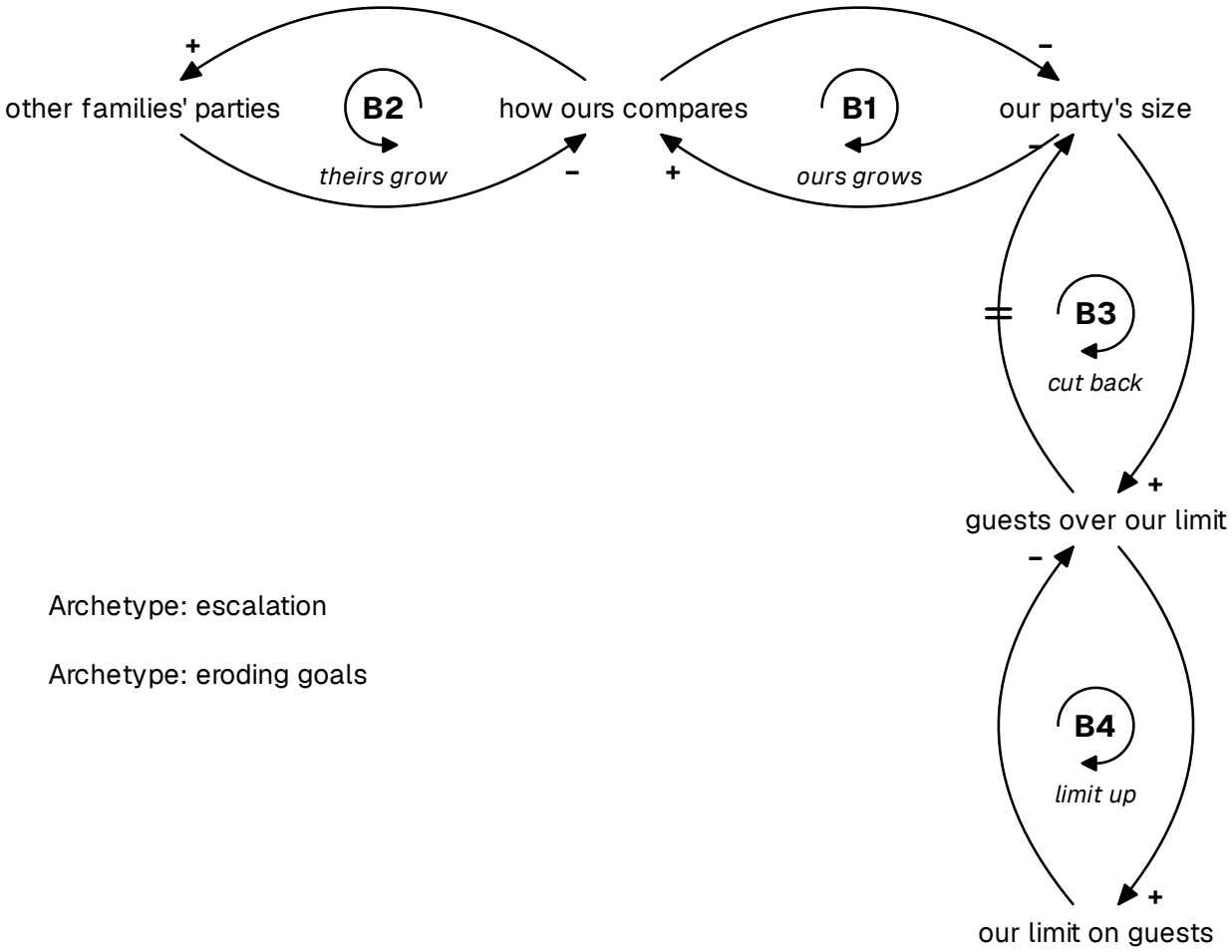
System archetypes

Part V · Pattern and Judgment · Chapter 11 of 12 · the second of two chapters on system archetypes

What if more than one story is true at once? Four more archetypes: two sides answering each other, growth short of capacity, a target that slips, partners who get in each other's way. One loop structure can be read as two of these stories, and one situation can hold two archetypes, coupled through the variables their loops share.

Birthday parties in one class

In one school class, each family holds a birthday party for its child and sets a limit on how many children it invites. Each family measures its party against the others': a party that looks small grows at the next birthday, and one that looks large makes the next family invite more. Guests over the limit are cut from the next party's list, a birthday later, or the family raises its limit toward the party it held.



Archetype: escalation

Archetype: eroding goals

B1 and B2 run through *how ours compares*, one family's party against the others': escalation. B3 and B4 run through *guests over our limit*, the party's size less the limit: eroding goals, with its delay on the cut. Both

archetypes are declared, and the loops match both.

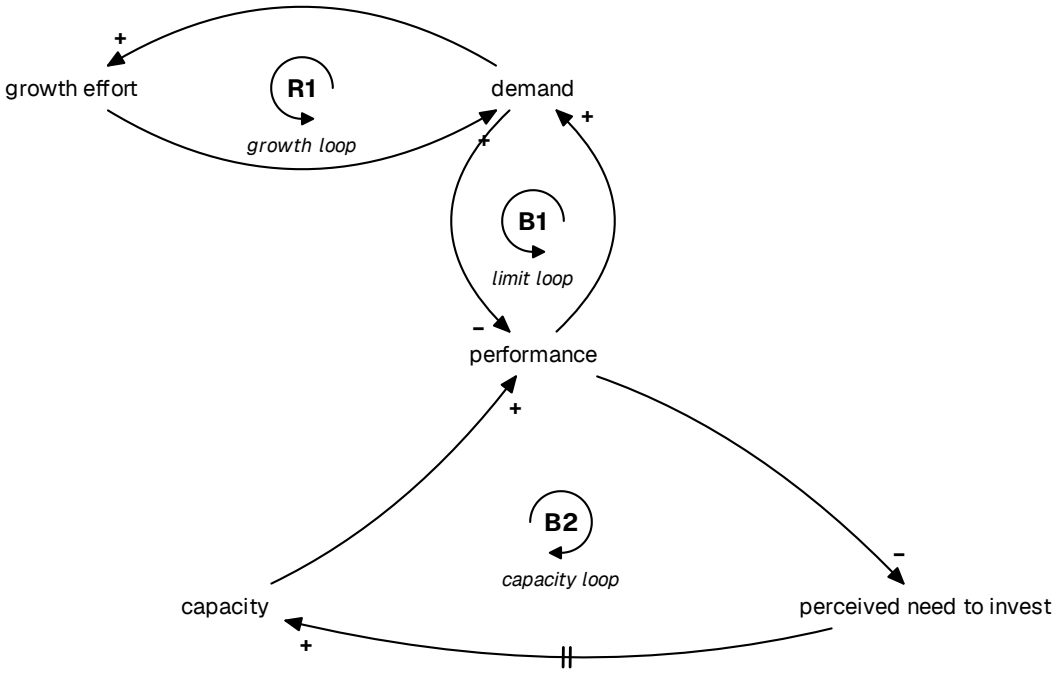
What the notation expresses

Escalation

Escalation is two sides acting on one comparison, *relative position*: A's activity raises it and B's lowers it. When it falls, A does more (B1); when it rises, B does (B2). Both loops are balancing, and together they trace a figure-8 that reinforces: each side's response is the other's reason to respond. The figure-8 passes *relative position* twice, so it is no loop of its own and carries no label. Kim notes that it takes two sides to escalate and one to stop, and asks whether the relative measure between them can change.

Growth and underinvestment

Archetype: growth and underinvestment



Growth and underinvestment is limits to growth (chapter 10, Limits to growth) with a third loop. Growth effort and demand raise each other (reinforcing loop R1, the growth loop) until demand lowers performance (balancing loop B1, the limit loop). Performance below the performance standard raises the perceived need to invest, which adds capacity after a delay and restores performance (B2, the capacity loop). Where the standard is lowered as performance falls, the need to invest falls too, and performance with it (Kim). Kim puts the leverage in judging capacity against demand before performance falls. The performance standard acts from outside the loops, so the template leaves it out.

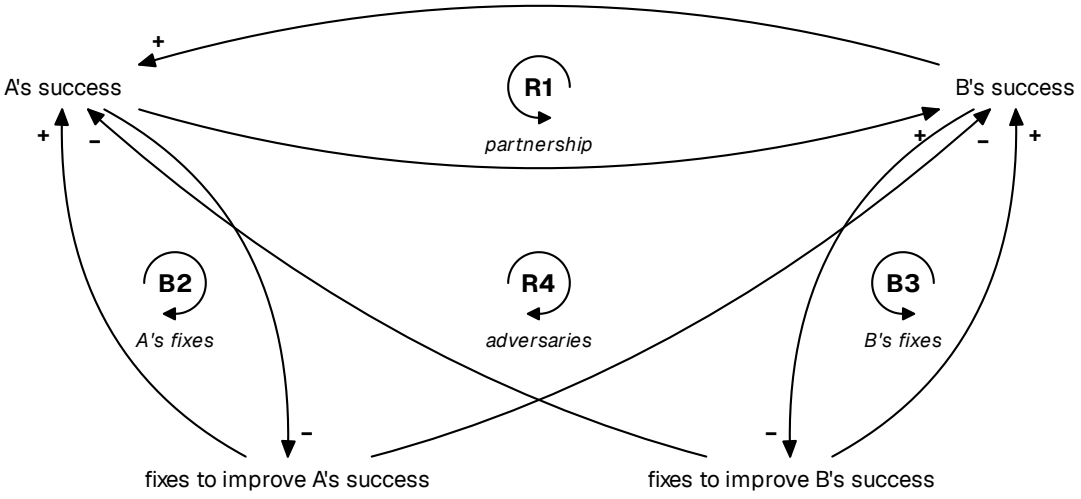
Eroding goals

In **eroding goals**, a gap between a target and actual performance closes two ways: corrective action raises actual performance, after a delay (B1), and pressure to lower the target brings the target down (B2). Kim calls eroding goals *drifting goals*. Lowering the target closes the gap at once and corrective action takes time, so B2 acts first: loop dominance (chapter 5, Loop dominance). Unlike chapter 8's target (chapter 8, Target and gap), here the target moves: the gap lowers it. Kim finds that targets set from outside the situation drift less.

In the parties, the gap is *guests over our limit*, the party's size less the limit: named as its opposite (chapter 10, A variable named as its opposite), so B3's and B4's effects carry the opposite polarities and both loops stay balancing.

Accidental adversaries

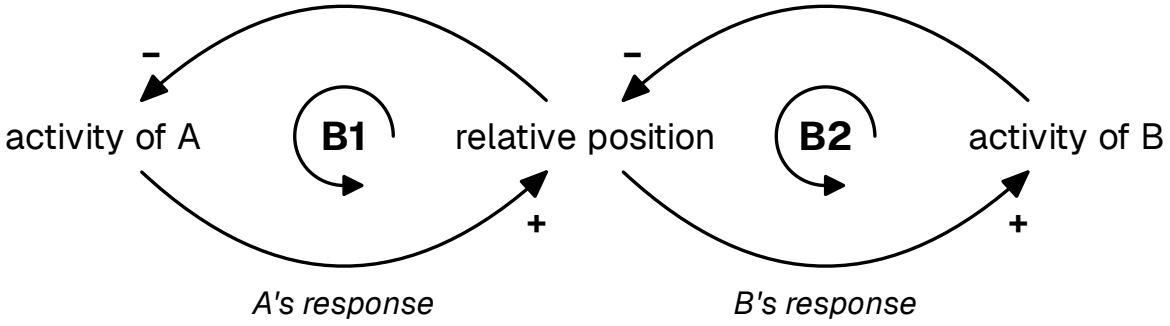
Archetype: accidental adversaries



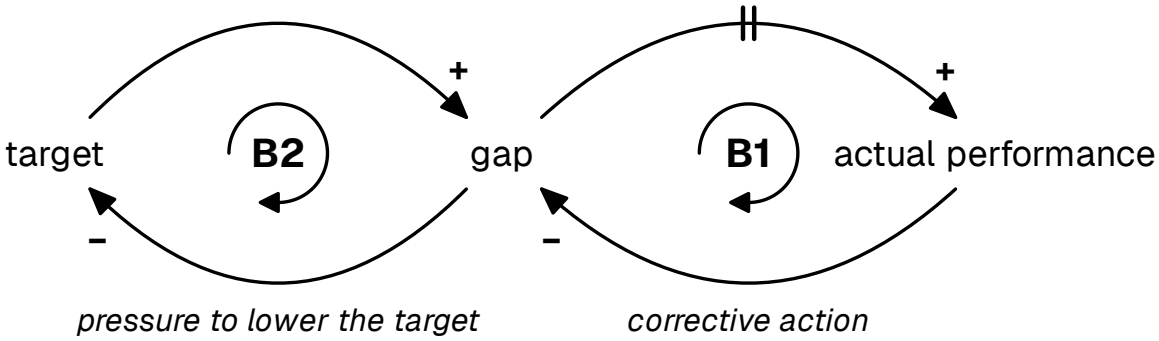
In **accidental adversaries**, two partners each raise the other's success (R1, partnership). When either is dissatisfied with its own results, it takes corrective measures alone (B2, B3) that, unseen, lower its partner's success; together the two sets of fixes close R4, the adversaries' loop. Kemeny's case, where the archetype was first recognized, is Procter & Gamble's price promotions and Walmart's stocking up on promoted goods; she puts the leverage in each partner understanding what the other needs. Each side's fixes, with the partner's success on the way back, also match fixes that fail (chapter 10, Fixes that fail), within accidental adversaries.

One structure, two stories

Archetype: escalation



Archetype: eroding goals



Escalation and eroding goals have one shape: two balancing loops sharing one variable. Matching (chapter 10, Matching) reads loops and their kinds, so every match of one is a match of the other, and the lab lists one with *Also reads as* the other. The stories differ in what the shared variable is: one side's position relative to another's, in escalation, or a gap between a target and actual performance, in eroding goals. Matching can't read that, so the loops alone don't settle which story holds; the declaration records the drawer's reading.

CHECK YOUR UNDERSTANDING

Two street musicians, Ines and Kofi, play on one corner, and each plays louder when the other drowns them out. A diagram shows Ines's volume → Ines against Kofi +, Ines against Kofi → Ines's volume –, Kofi's volume → Ines against Kofi –, and Ines against Kofi → Kofi's volume +. Its loops match escalation and eroding goals. Which story is it, and why?

a Escalation: the shared variable sets one musician's volume against the other's

b Eroding goals: Kofi's volume is the target Ines's volume closes on

c Either: the loops match both, so both declarations are equally right

Feedback: Answers, chapter 11

Coupled archetypes

Coupled archetypes are two matches sharing a variable: coupled loops (chapter 4, Coupled loops), read as archetypes, so a change in one archetype's loops changes the other's. In the parties, escalation (B1, B2) and eroding goals (B3, B4) share *our party's size*: a party grown to keep up opens a gap over the limit, and a party cut back to the limit looks small again. The lab reports them coupled through *our party's size* and *how ours compares*, pairing escalation with the eroding goals that B1 and B3, two balancing loops sharing *our party's size*, also match. An external driver (chapter 5, External drivers) acting on both archetypes' loops doesn't couple them: it stands in for no variable of any match.

Ranking leverage

Where several leverage points (chapter 4, Leverage points) are proposed, which to try first is a ranking, written beside the diagram, in words, each leverage point with its reason. No mark ranks: every leverage point is the same box. For the parties:

1. *how ours compares*: both escalation loops pass through it, and Kim asks of escalation whether the comparison between the sides can change. A class that agrees one number of guests for every party leaves nothing to compare.
2. *our limit on guests*: held where the family set it, B4 stops, and B3 cuts each party back to it, a birthday late.

A reason resting on a dashed effect, a hypothesis in evidence coding (chapter 5, Evidence coding), is a hypothesis too.

CHECK YOUR UNDERSTANDING

A pottery studio's evening classes fill by word of mouth, and its waiting list grows. A diagram of the studio shows two leverage points: the wheels in the studio, and the waiting list the owner treats as normal. Its author judges the waiting list the better place to act. How does the diagram show that?

a A ranking written beside it: the waiting list first, the wheels second, each with its reason

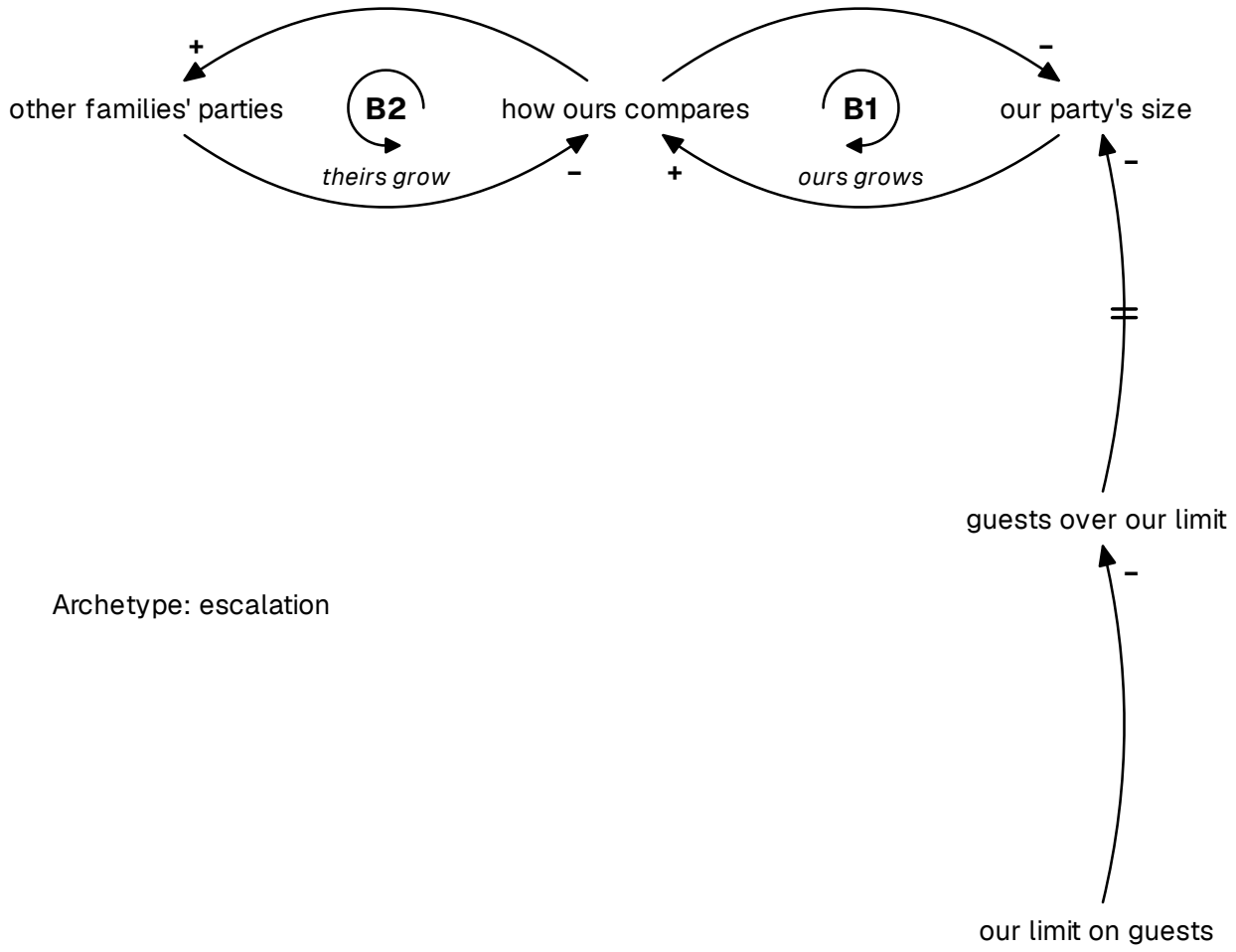
b A heavier box around the waiting list

c Only the waiting list boxed, the wheels left plain

Feedback: Answers, chapter 11

The bad diagram

What's wrong with this diagram of the birthday parties?



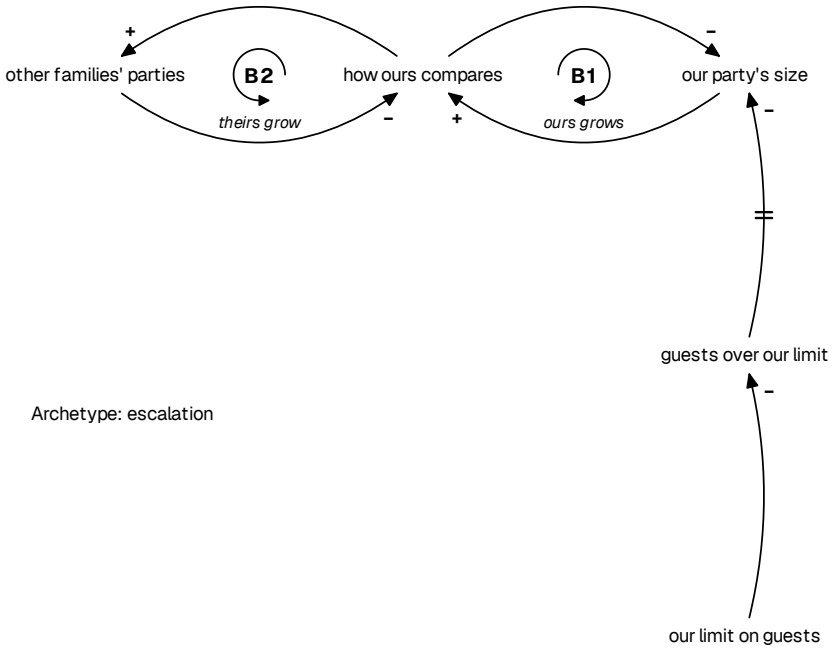
It shows the comparison alone, declared escalation. *Our limit on guests* and *guests over our limit* hold the party's size down but close no loop: the party's size never reaches *guests over our limit*, and the guests over it never move the limit. The lab's check for two coupled archetypes reports:

> 1 declared archetype. Brief: at least 2, coupled through a shared variable.

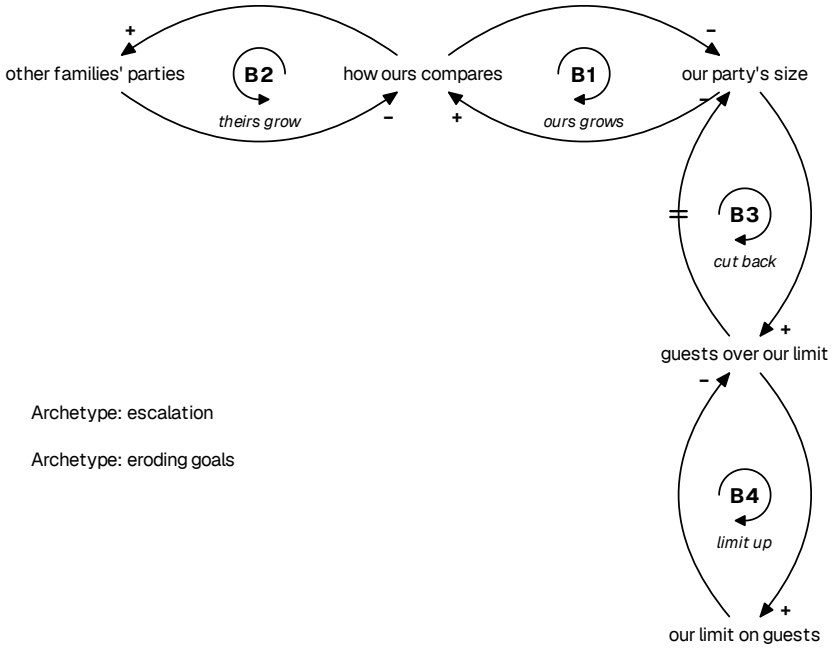
The corrected diagram

The party's size raises *guests over our limit*, closing B3, the cut, and the guests over the limit raise the limit, closing B4. Eroding goals is declared beside escalation.

Bad diagram



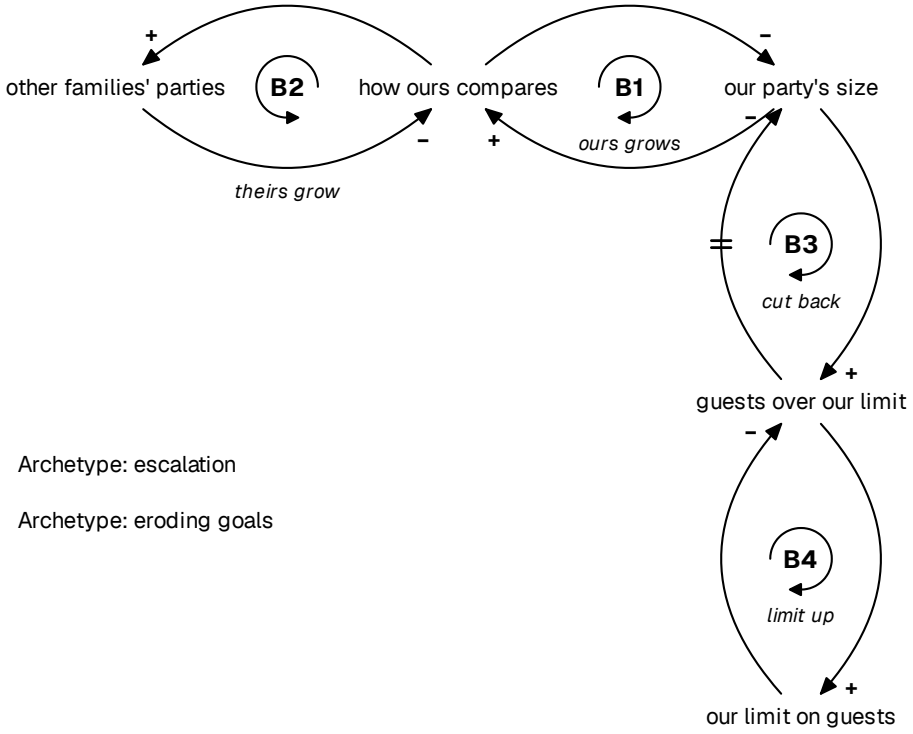
Corrected diagram



Labels unchanged. Declared archetypes: eroding goals added. Effects: 2 added. Loops: 2 added. Now matched with its delay: eroding goals.

Notation moves

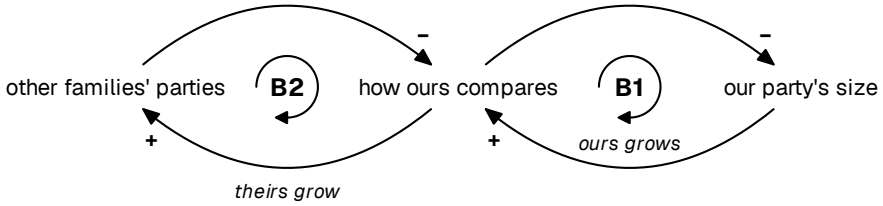
Notation move	When	What it shows	Example
Declare two archetypes on one diagram	Two stories run through one situation	Coupled archetypes, where their matches share a variable	*Archetype: escalation* and *Archetype: eroding goals*



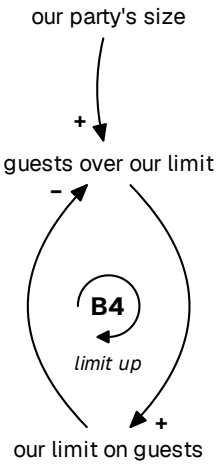
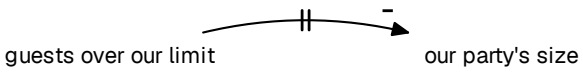
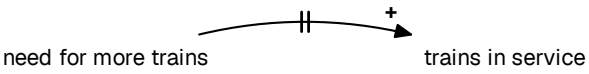
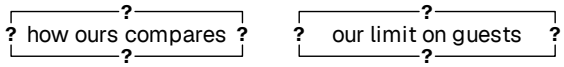
Archetype: escalation

Archetype: eroding goals

Declare escalation on two balancing loops sharing a variable	The shared variable compares two sides	The story the loops alone don't settle	*how ours compares*



Archetype: escalation

Notation move	When	What it shows	Example
Draw the gap as a variable between the target and actual performance 	The target moves with the gap	Eroding goals' second loop	*guests over our limit*
Mark the delay on corrective action's effect 	Correction arrives later than a lowered target	Which loop acts first	*guests over our limit* → *our party's size*
Mark the delay into capacity 	Capacity takes time to build	Capacity arriving late	*need for more trains* → *trains in service*, in AR 07
Propose several leverage points 	There is more than one place to act	Hypotheses about where to act, ranked in words beside the diagram	*how ours compares*, then *our limit on guests*

Common misreading

Read one way, a match is a diagnosis: the loops are there, so the situation is that archetype. In the parties, B1 and B2 also match eroding goals, *how ours compares* as the gap and either family's party as the target, and B3 and B4 also match escalation. The loops are the same either way; the stories differ in what the variables are. *How ours compares* sets one family's party against the others', so B1 and B2 are escalation; *guests over our limit* is a party's size less a number the family chose, so B3 and B4 are eroding goals.

The strongest objection

Archetypes fit any story told loosely enough, so naming one explains nothing. Lane (1998) divides generic structure in system dynamics into three kinds, of which the third, archetypes, involves “merely metaphorical thinking”.

The *names* are loose: escalation and eroding goals share one shape, and which one a drawing holds is the drawer’s reading, recorded in the declaration, not settled by the loops. The *structure* isn’t loose. A loop closes or doesn’t, its kind follows the parity rule (chapter 4, The parity rule), a delay sits on one effect and not another, and each is checked on the drawing and can be wrong: the bad diagram’s limit closes no loop, and the lab counts one declared archetype where two coupled ones were asked for.

Check your understanding

CHECK YOUR UNDERSTANDING

Sam and Jo share a flat and take turns cooking dinner for both, which leaves each of them free evenings. Short of time in the week, each starts cooking a week's lunches on Sunday afternoon. Sam's cooking takes the oven and every pan when Jo comes to cook, and Jo's leaves a sink of washing-up that Sam clears before starting. Which archetype's story is this?

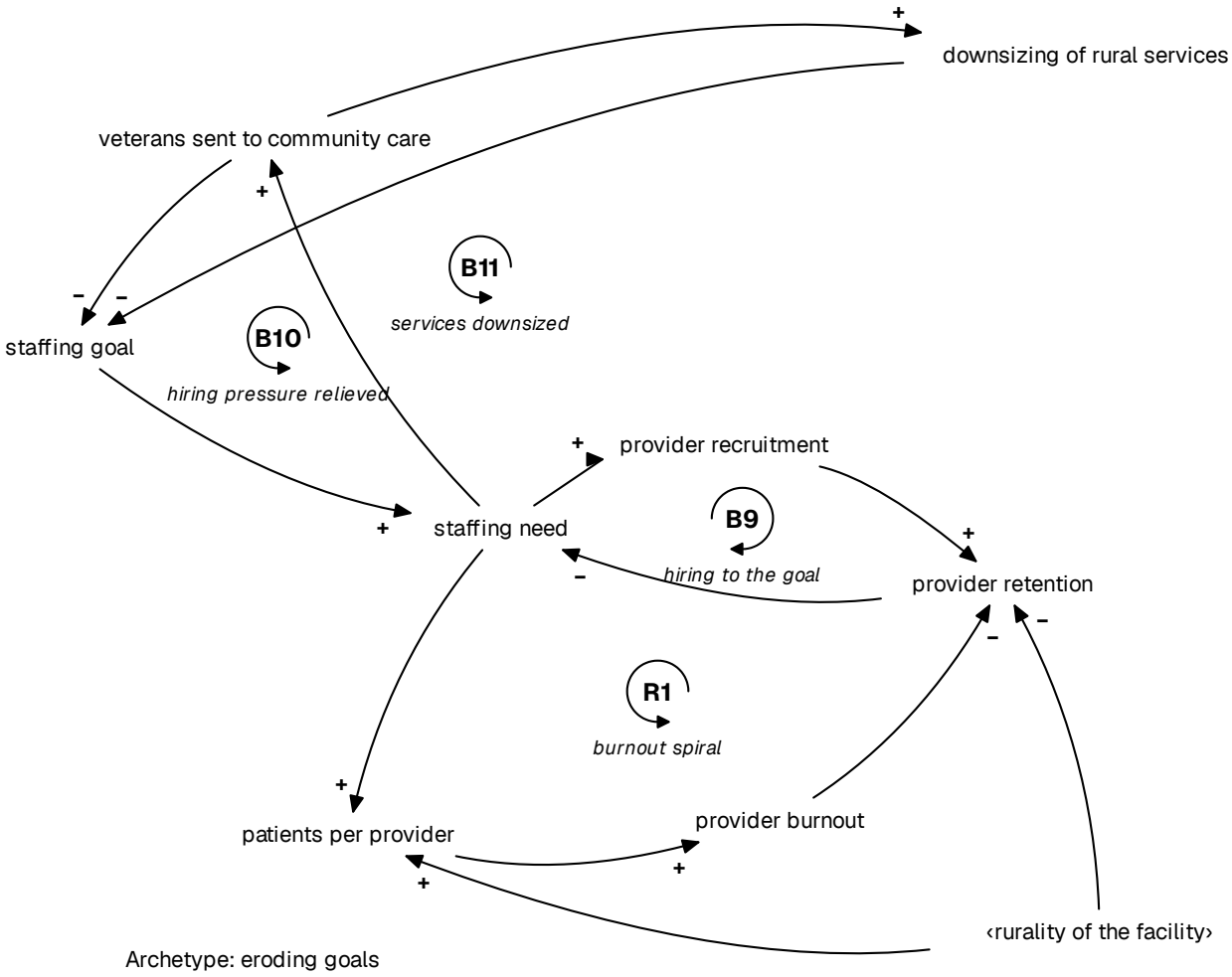
a Accidental adversaries

b Escalation

c Fixes that fail, once for each flatmate

Feedback: Answers, chapter 11

The VA's staffing goal, redrawn



Redrawn from Erin S. Kenzie, Mary Patzel, Erik Nelson, Travis Lovejoy, Sarah Ono and Melinda M. Davis, "Long drives and red tape: mapping rural veteran access to primary care using causal-loop diagramming", BMC Health Services Research 22, 1075 (2022) doi.org/10.1186/s12913-022-08318-2, Fig. 5. CC BY 4.0 creativecommons.org/licenses/by/4.0/.

Its blue lines marked + and red lines marked – drawn alike, each polarity kept; its faded variable, provider turnover, and its line left out; VA dropped from every name; sending veterans to community care renamed as an amount, veterans sent to community care, and three other names reworded; rurality of the facility marked as an external driver; its loops' labels kept, B9 to B11 numbered as in the authors' whole model, and their names reworded by what each loop does; eroding goals, which its authors name drifting goals, declared.

QUESTION 1 OF 3

Which variable is eroding goals' target, and what brings it down?

a Staffing need, lowered by community care.

b Staffing goal, lowered by veterans sent to community care (B10) and by the downsizing of rural services that follows (B11).

c Provider retention, lowered by provider burnout.

QUESTION 2 OF 3

Its authors count R1, the burnout spiral, in their drifting goals (eroding goals). With B9, R1 matches another archetype, coupled with eroding goals. Which?

a Shifting the burden, with community care as the symptomatic solution.

b Escalation, between provider recruitment and provider burnout.

c Fixes that fail: B9 brings retention back as the need rises, and R1 drives it down through patients per provider and burnout.

QUESTION 3 OF 3

Ranked by what Kim finds of eroding goals, which leverage point comes first?

a Provider recruitment, pushed harder.

b Veterans sent to community care, cut back.

c The staffing goal, set from outside the facilities and held there.

Feedback: Answers, chapter 11

Exercises

Passing the checks means meeting the brief, not being right.

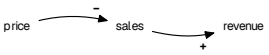
AR 06 An arms race between two neighboring countries

Your palette

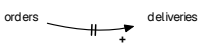
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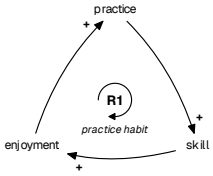
effect



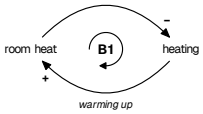
polarity



delay



loop



balancing loop

archetype

AR 06 An arms race between two neighboring countries

Each side's safety read against the other's

Reasoning ●●●○○ 3 of 5 Polish ●●●●○ 4 of 5

Two neighboring countries, called here North and South, each judge their safety by how their armed forces compare with the other's. North buys arms until its forces are well ahead of South's: the more arms North buys, the larger North's lead in forces, and the larger that lead, the fewer arms North buys. South buys arms while North is ahead: the more arms South buys, the smaller North's lead, and the larger North's lead, the more arms South buys. Each country pays for its arms from the budget that also pays for its schools and hospitals: the more arms either country buys, the less the two countries spend on schools and hospitals.

The brief

- [ ] Draw each country's arms purchases closing a balancing loop through one variable that compares the two countries' forces.
- [ ] The two loops match escalation.
- [ ] Draw the spending on schools and hospitals, reached from both countries' purchases.
- [ ] One variable compares the two countries' forces, and both loops pass through it.
- [ ] The spending on schools and hospitals returns to neither loop.
- [ ] The declared archetype is escalation, not eroding goals, though the same loops match both.

Your palette

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Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/pattern-and-judgment/diagnosing-tangled-situations/#exercise-system-archetype-06

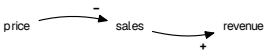
AR 07 A country's railways

Your palette

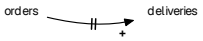
variable



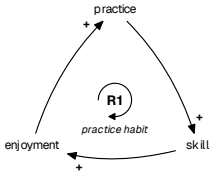
effect



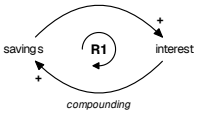
polarity



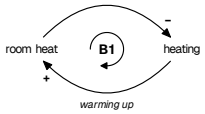
delay



loop



reinforcing loop



balancing loop



gap
drawn as an ordinary variable

archetype

AR 07 A country's railways

Growth held back by trains never ordered

Reasoning ●●●●○ 4 of 5 Polish ●●●●○ 4 of 5

A country's railway operator draws passengers with punctual trains and cheap fares: the more passengers, the more fare offers it can pay for, and the more fare offers, the more passengers. Crowded trains wait longer at every station: the more passengers, the lower the punctuality, and the higher the punctuality, the more passengers. The operator reads its need for more trains from how far punctuality falls short of its punctuality target, once a year's figures are in: the lower the punctuality, the greater the need for more trains, after a delay, and the higher the target, the greater the need. A new train takes four years to build: the greater the need, the more trains in service, after a delay, and the more trains in service, the higher the punctuality. When the need is large, the operator lowers its target rather than order trains: the greater the need for more trains, the lower the punctuality target.

The brief

- [ ] Draw the passengers and the fare offers closing a reinforcing loop.
- [ ] Draw a balancing loop through the passengers and the punctuality, and one through the need for more trains and the trains in service.
- [ ] The loops match growth and underinvestment, with its delay where new trains arrive.
- [ ] Draw a delay where the operator reads its need for more trains, and one where new trains arrive.
- [ ] The punctuality target acts on the need for more trains, and the greater the need, the lower the target.

Your palette

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Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/pattern-and-judgment/diagnosing-tangled-situations/#exercise-system-archetype-07

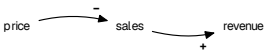
AR 08 Knee exercises after an operation

Your palette

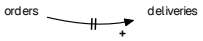
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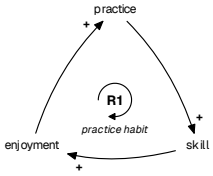
effect



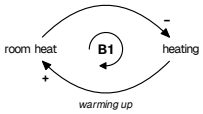
polarity



delay



loop



balancing loop



gap

drawn as an ordinary variable

archetype

AR 08 Knee exercises after an operation

A target that moves toward what was done

Reasoning ●●●●○ 4 of 5 Polish ●●●●○ 4 of 5

After an operation on her knee, Priya sets herself a weekly target of fifteen sessions of the exercises her physiotherapist gave her. Each Sunday she counts the sessions done that week, and the gap is the target minus the sessions done: the higher the target, the larger the gap, and the more sessions done, the smaller the gap. When the gap is large she fits extra sessions into the next week, so the gap raises the sessions done a week later: the larger the gap, the more sessions done, after a delay. On busy weeks at work she falls short, and each time she does, she sets next week's target closer to what she managed: the larger the gap, the lower the weekly target.

The brief

- [ ] Draw two balancing loops through the gap: one through the sessions done, one through the weekly target.
- [ ] The loops match eroding goals, with its delay on the extra sessions.
- [ ] The gap is a variable of its own: the weekly target minus the sessions done.
- [ ] The second loop is named for the lowered target, which closes the gap without a session more.

Your palette

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Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/pattern-and-judgment/diagnosing-tangled-situations/#exercise-system-archetype-08

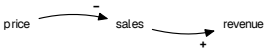
AR 09 Two parents sharing care after a separation

Your palette

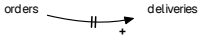
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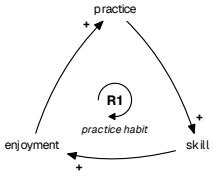
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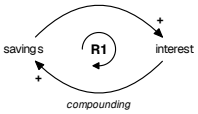
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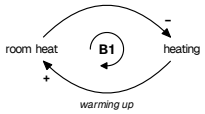
delay



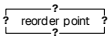
loop



reinforcing loop



balancing loop



leverage point

archetype

AR 09 Two parents sharing care after a separation

Partners whose own fixes hold each other back

Reasoning ●●●●● 5 of 5 Polish ●●●●● 5 of 5

Maya and Tom separated last year and share the care of their two children, a week each. Each helps the other's weeks go well, with lifts to football and the same homework rules in both homes: the better Maya's weeks go, the better Tom's go, and the better Tom's weeks go, the better Maya's go. When a week goes badly, each makes changes alone to ease their own weeks, such as a new bedtime or a swapped weekend: the worse Maya's weeks go, the more changes she makes alone, and the more changes she makes alone, the better her weeks go; the same holds for Tom. Each one's changes reach the other's home a week or two later, with the children: the more changes Maya makes alone, the worse Tom's weeks go, after a delay, and the more changes Tom makes alone, the worse Maya's weeks go, after a delay. Both parents see how settled the children are, which rises the better either parent's weeks go.

The brief

- [ ] The loops match accidental adversaries.
- [ ] Draw a delay on each parent's changes' effect on the other's weeks.
- [ ] Mark one leverage point.
- [ ] The two delays sit where each parent's changes reach the other's weeks, not on the help each gives the other.
- [ ] The leverage point is a measure both parents can see.

Your palette

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Draw here

AR 10 A coastal town and its sea walls

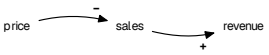
Your palette



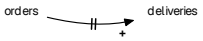
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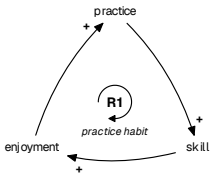
effect



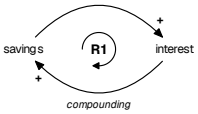
polarity



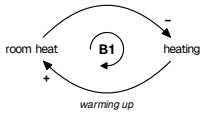
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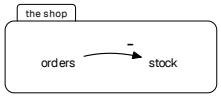
loop



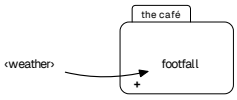
reinforcing loop



balancing loop



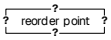
boundary



external driver



evidence coding



leverage point



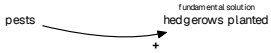
behavior note

Archetype: fixes that fail

archetype



symptomatic solution
a role, written above its variable's name



fundamental solution
a role, written above its variable's name



side effect
a role, written above its variable's name

AR 10 A coastal town and its sea walls

Two archetypes sharing one variable

Reasoning ●●●●● 5 of 5 Polish ●●●●● 5 of 5

A coastal town of eight thousand people floods when winter storms push the sea over its seafront: the more winter storms, the more flooding of the seafront. Each flood brings calls for sea walls, and a wall stops the sea at once: the more flooding of the seafront, the more sea walls built, and the more sea walls built, the less flooding. The walls stop the waves from carrying sand along the shore, so the beach in front of them thins, and years later the sea reaches the walls with more force: the more sea walls built, the more sand lost from the beach, and the more sand lost, the more flooding, after a delay. Restoring the dunes behind the beach would protect the coast for decades, though new dunes take years to grow: the more flooding, the more dune restoration, and the more dune restoration, the less flooding, after a delay. Behind each new wall, the town allows homes and shops: the more sea walls built, the more building behind the walls. The town's engineers think the new building makes dune restoration costlier, since the land behind the beach is no longer free, but they have no figures yet: the more building behind the walls, the less dune restoration.

The brief

- [ ] Declare each archetype the structure holds, at least two.
- [ ] The declared archetypes are coupled: their matches share a variable.
- [ ] Mark at least two leverage points.
- [ ] Code the effect you judge less supported as a hypothesis, declared in the legend.
- [ ] Draw at least three loops.
- [ ] Beside the diagram, rank the leverage points in a list, each with its reason.
- [ ] The winter storms sit outside a boundary named for the town's coast, and nothing inside acts on them.
- [ ] No variable is drawn twice: the sea walls built are one variable, in both archetypes.

Your palette

On the page before this sheet.

Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/pattern-and-judgment/diagnosing-tangled-situations/#exercise-system-archetype-10

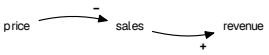
CS 11 Kelsham Primary School: the town school's pull and its rising class size

Your palette

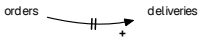
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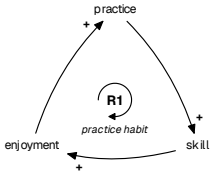
effect



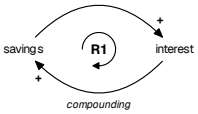
polarity



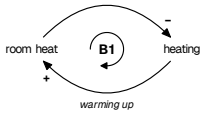
delay



loop



reinforcing loop



balancing loop



gap
drawn as an ordinary variable

archetype

CS 11 Kelsham Primary School: the town school's pull and its rising class size

Two archetypes coupled through one share

Reasoning ●●●●● 5 of 5 Polish ●●●●● 5 of 5

Brayford Primary School teaches each year in classes of its own, and Kelsham's families know it. The larger Brayford's share of the villages' starters, the more Kelsham children at Brayford, and the more Kelsham children at Brayford, the larger the share, as brothers, sisters and friends follow them there. The larger Brayford's share, the fewer pupils on roll at Kelsham; the fewer pupils on roll, the more mixed-age classes at Kelsham; and the more mixed-age classes, the larger Brayford's share. Helen Marsh, Brayford's head teacher, aimed for classes of 26. The more Kelsham children at Brayford, the larger its average class size, and the larger the average class size, the more pupils a class above Brayford's aim. Above its aim, Brayford offers fewer places to children from outside the town the next September: the more pupils a class above the aim, the smaller Brayford's share, a year later. Yet each year its classes run above the aim, Brayford's governors raise it, toward the most they allow, 30: the more pupils a class above the aim, the higher the class size Brayford aims for, and the higher the class size Brayford aims for, the fewer pupils a class above it.

The brief

- [ ] Draw Brayford's share of the villages' starters on two reinforcing loops that match success to the successful.
- [ ] Draw the gap between Brayford's class size and its aim on two balancing loops that match eroding goals, with its delay on the places held back.
- [ ] Declare both archetypes.
- [ ] The declared archetypes are coupled: their matches share a variable.
- [ ] Mark one delay: the September before places held back change the share.
- [ ] Brayford's share of the villages' starters is drawn once, on both archetypes' loops.
- [ ] Beside the diagram, one sentence says what each rise in Brayford's aim does to the pupils on roll at Kelsham.

Your palette

On the page before this sheet.

Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/pattern-and-judgment/diagnosing-tangled-situations/#exercise-case-11

Sources

- Daniel H. Kim, *Systems Archetypes I: Diagnosing Systemic Issues and Designing High-Leverage Interventions* thesystemsthinker.com/wp-content/uploads/2016/03/Systems-Archetypes-I-TRSA01_pk.pdf (Pegasus Communications, 1992, 2000): Kim's name for eroding goals, why lowering a target closes a gap sooner than corrective action, and targets set from outside, pp. 12–13; escalation, its figure-8, and the relative measure between the sides, pp. 14–15; growth and underinvestment, standards lowered as performance falls, and capacity judged against demand, pp. 6 and 18–19.
- Jennifer Kemeny, "'Accidental Adversaries': When Friends Become Foes" thesystemsthinker.com/wp-content/uploads/pdfs/050102p.pdf, *The Systems Thinker* 5, no. 1 (February 1994): 5–6, on partners whose corrective measures obstruct each other, Procter & Gamble and Walmart, and where the leverage lies.
- David C. Lane, "Can We Have Confidence in Generic Structures?" doi.org/10.1057/palgrave.jors.2600605, *Journal of the Operational Research Society* 49, no. 9 (1998): 936–947, on archetypes as metaphorical thinking (from its abstract).

Choosing the Diagram

All six diagram types Part V · Pattern and Judgment · Chapter 12 of 12 · the closing chapter

Which diagram, if any, answers your question? Each of the six diagram types answers its own kind of question, so you may draw several for one situation, and none for a question arithmetic answers.

Ana’s two hives

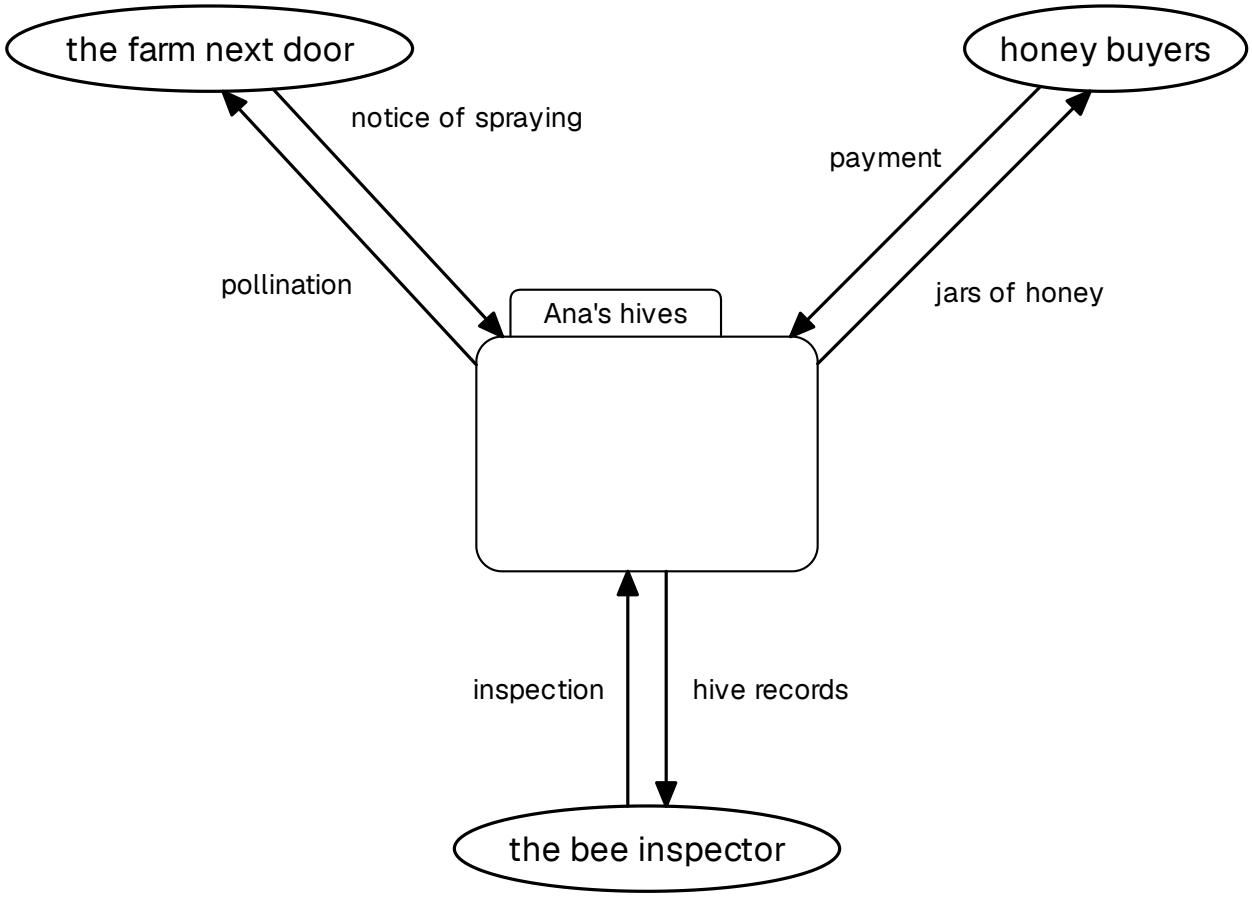
Ana keeps two colonies of honey bees in her garden. She sells honey, the farm next door sprays its crops, and a bee inspector calls. Her questions:

1. Whom do I deal with, and what passes each way?
2. What bears on the honey I harvest?
3. Why does a growing colony swarm?
4. How much honey can I take and still leave enough?
5. How do I keep each hive heavy enough for winter?
6. Have I seen this story before?

In Britain a colony needs 15 to 20 kg of stored honey to survive the winter. Beekeepers judge what a hive holds by hefting it, lifting one side a few inches, and feed a light one sugar syrup in autumn (Gill, 2021). A crowded colony swarms: half or more of its workers leave with the old queen, and the colony splits in two (Ellis, DeBerry and Crowley).

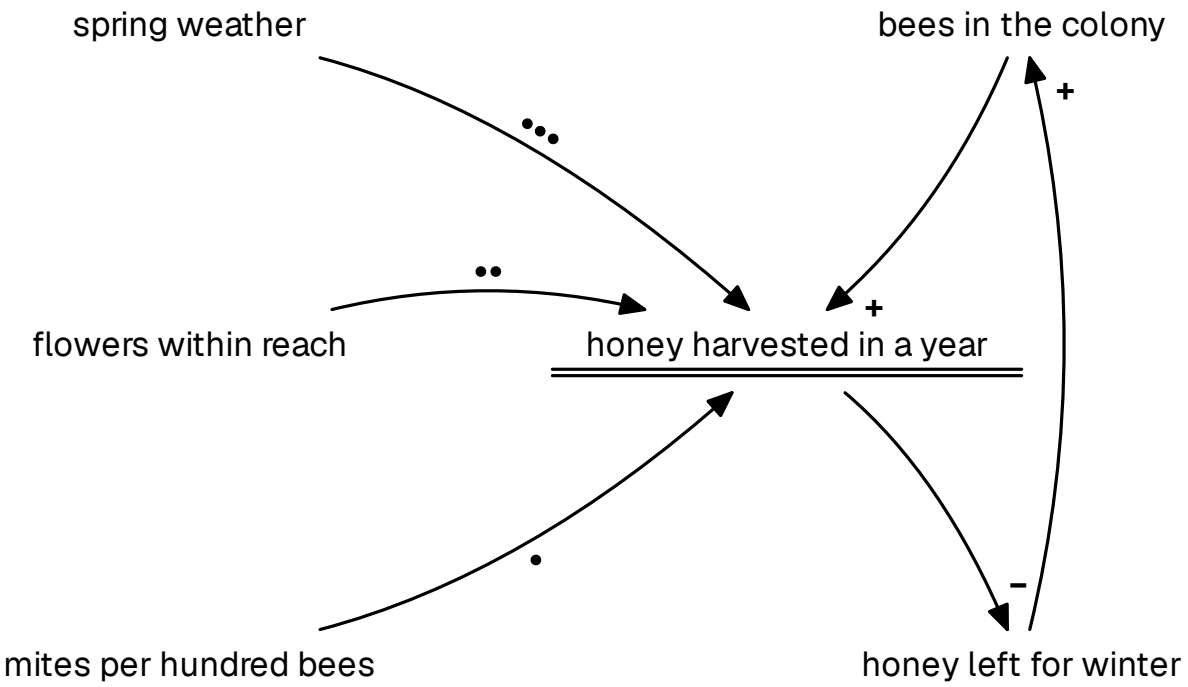
What each type answers

System context map



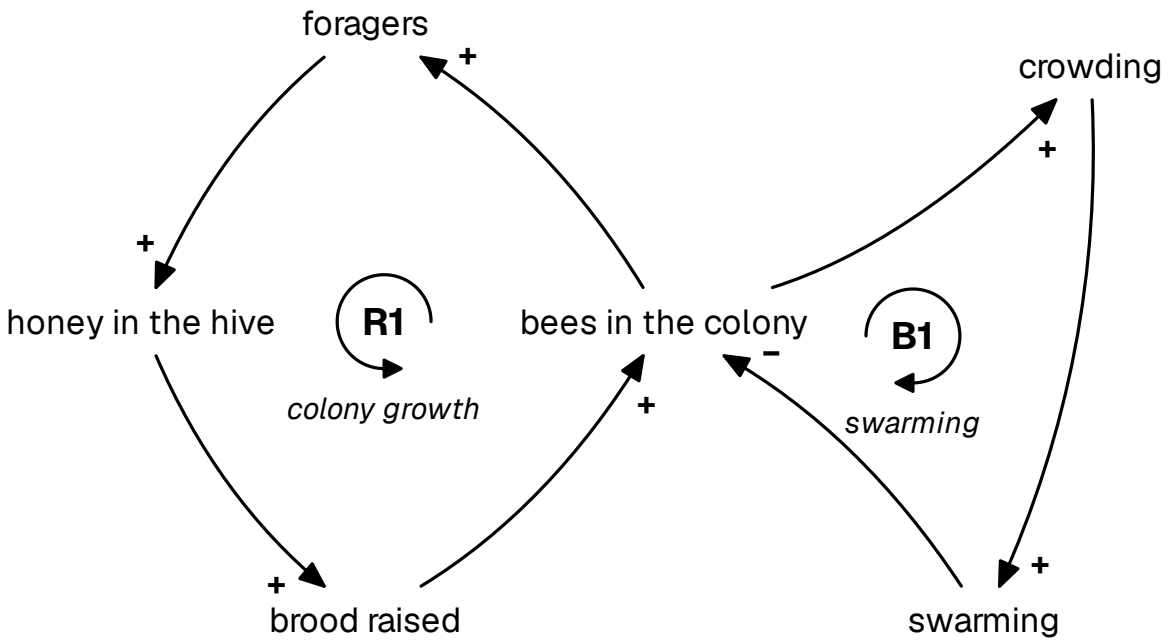
For question 1, the boundary is *Ana's hives*, with three parties outside it and one exchange each way with each. Nothing inside the hives is drawn, and no amount or date. The marks are chapter 2's (chapter 2, What the notation expresses).

Influence map



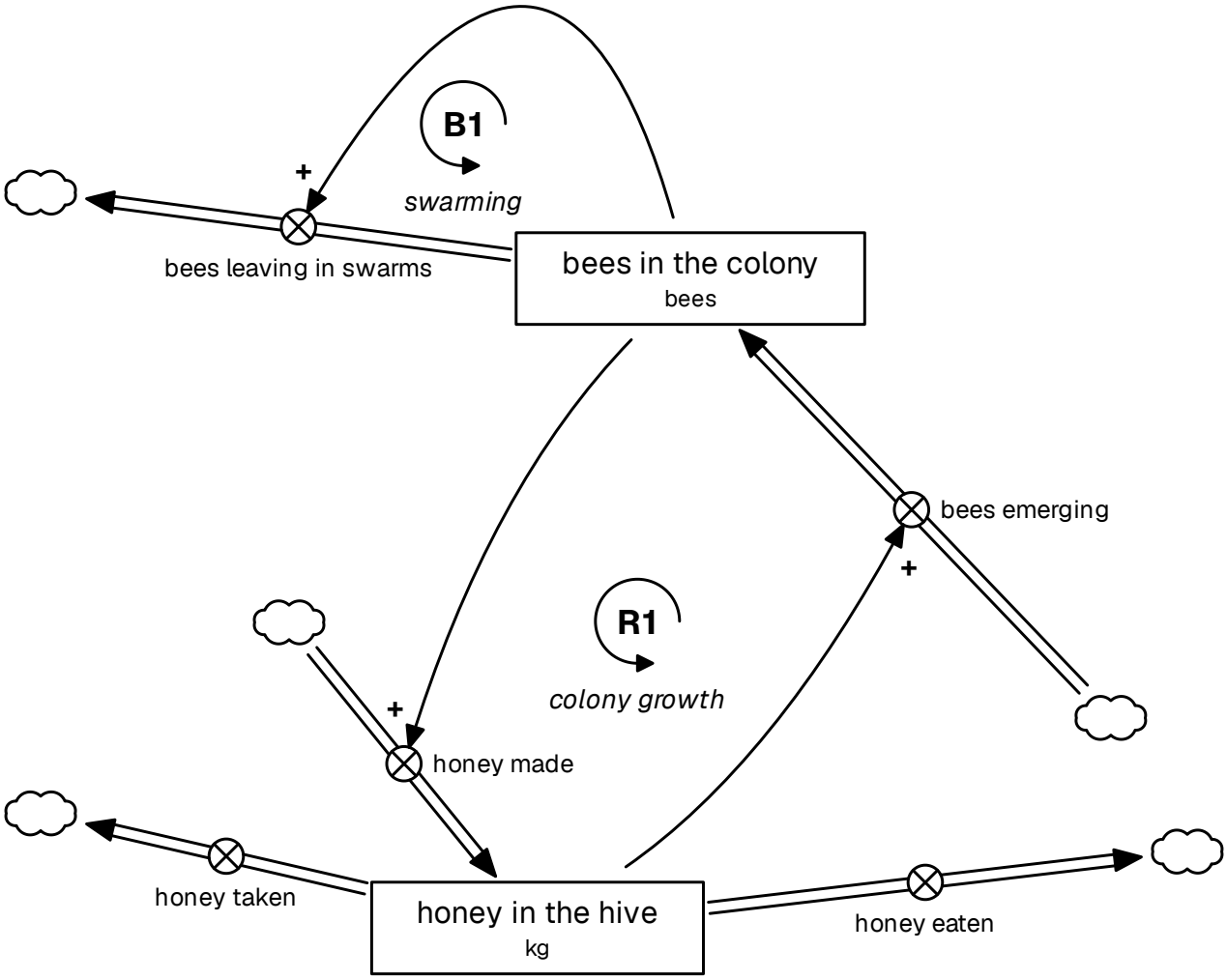
For question 2, spring weather, flowers within reach and mites per hundred bees bear on *honey harvested in a year*, weighted by Ana, with no direction: she has no record of which way each acts. Its causal claims are the three effects Ana measured from past years' records. No amount is drawn. The marks are chapter 3's (chapter 3, What the notation expresses).

Causal loop diagram



For question 3, R1, *colony growth*, runs through foragers, honey and brood, and B1, *swarming*, through crowding. The loops share only *bees in the colony*: the more bees, the more crowding, and a crowded colony swarms through B1. Nothing shows what accumulates, nor how many bees crowd a hive. The marks are chapter 4's (chapter 4, What the notation expresses), with chapter 5's.

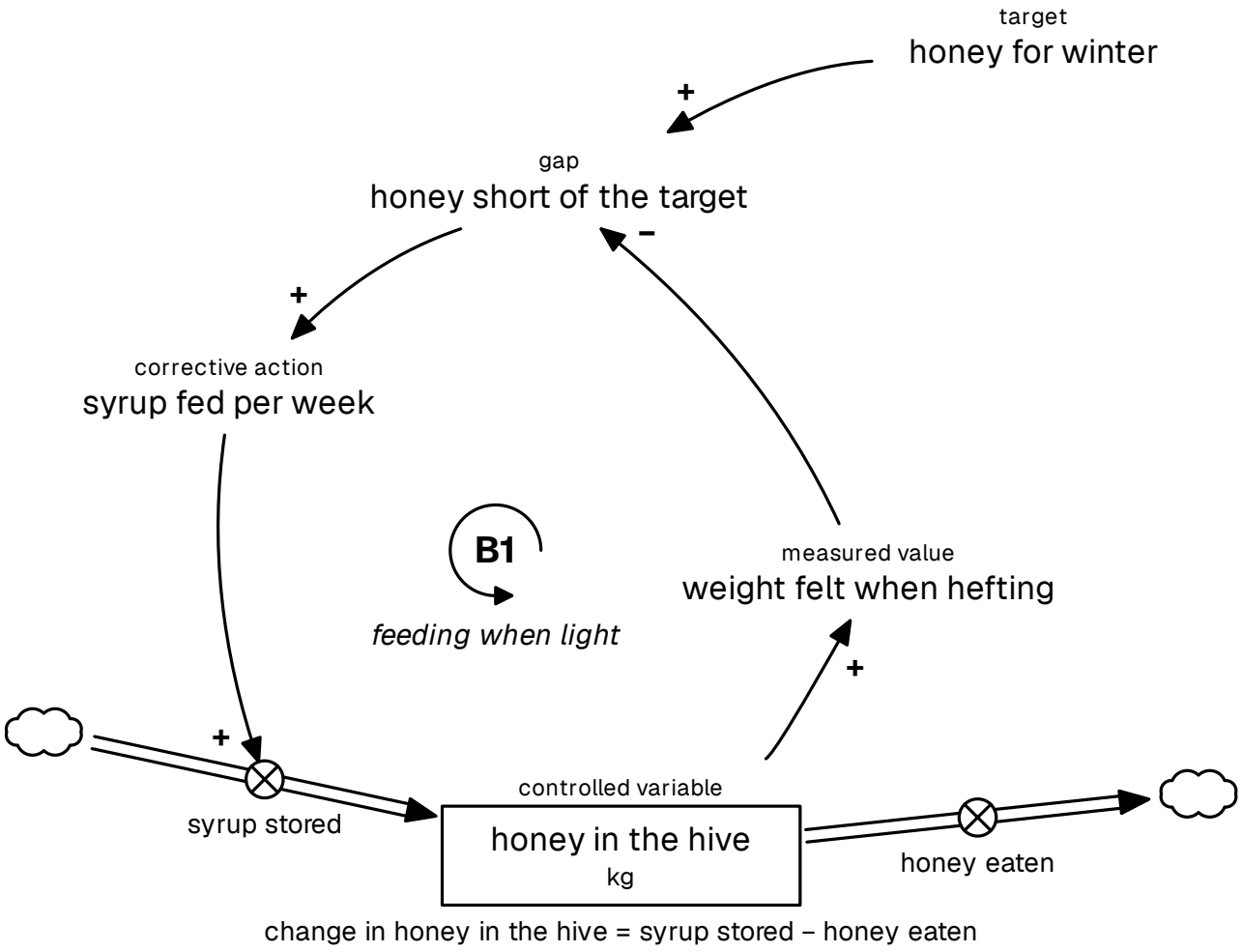
Stock & flow diagram



change in honey in the hive = honey made – honey eaten – honey taken

For question 4, *bees in the colony* and *honey in the hive* accumulate, in bees and kilograms, filled and drained by flows per week. Honey taken drains the stock that honey eaten drains all winter: the stock equation, *change in honey in the hive = honey made – honey eaten – honey taken*, shows that what Ana takes in late summer has to leave 15 to 20 kg behind. Why the flows change is drawn only as far as three signals. The marks are chapter 6's (chapter 6, What the notation expresses), with chapter 7's.

Feedback control diagram



For question 5, this is the stock & flow diagram's honey with four variables and an inflow, *syrup stored*, added, and roles written above names, as chapter 8's thermostat (chapter 8, Control with accumulation) is drawn over a stock: *honey for winter* is the target, *weight felt when hefting* the measured value, *honey short of the target* the gap, *syrup fed per week* the corrective action, and *honey in the hive* the controlled variable. B1, *feeding when light*, is its control loop. Honey made and honey taken, off the loop, are left out. The marks are chapter 8's (chapter 8, What the notation expresses), with chapter 9's.

CHECK YOUR UNDERSTANDING

A family of five fills its laundry basket in a day or two. Each evening one parent looks in, and runs a wash if the clothes are above a line marked inside the basket; the machine washes at most one basketful a day. The parents' question: does one look each evening keep the basket from overflowing? Which diagram answers it?

a A feedback control diagram

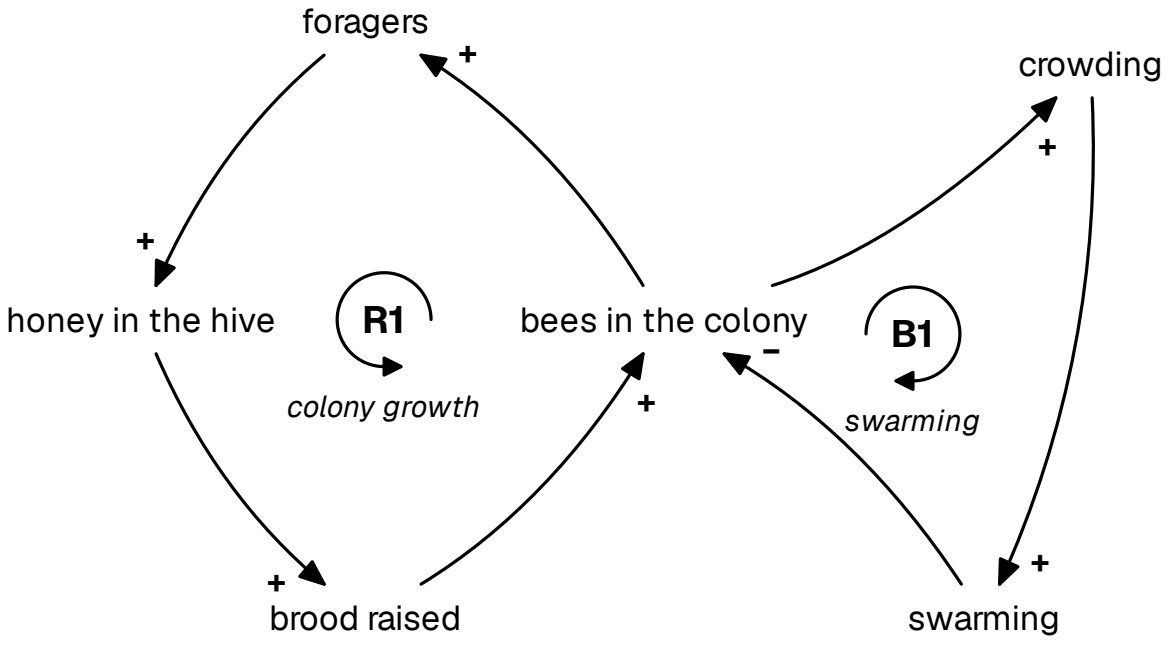
b A stock & flow diagram

c A causal loop diagram

d A system context map

Feedback: Answers, chapter 12

System archetype



Archetype: limits to growth

For question 6, this is the causal loop diagram with one line written on it: *Archetype: limits to growth*. A reinforcing loop and a balancing loop sharing one variable, *bees in the colony*, match limits to growth (chapter 10, Limits to growth): growth that meets a limit. No role is written, since limits to growth has none. The match is a hypothesis about the loops, not a verdict on the hives. The marks are chapter 10's (chapter 10, What the notation expresses), with chapter 11's.

Converting between types

An influence map into a causal loop diagram, in the lab: chapter 3's conversion (chapter 3, Conversion to a causal loop diagram) carries over the variables and causal claims only. From Ana's map, three causal claims carry over,

bees in the colony → honey harvested in a year → honey left for winter → bees in the colony, with one –: declared, their path is a balancing loop, *taking too much*. Ana decides which influence claim she upgrades next, and on what evidence.

A causal loop diagram into a system archetype, in the lab: a causal loop diagram's file opens in an archetype lab as its own, every variable, effect and loop carried over, with its matches (chapter 10, Matching) listed. Whoever draws it writes the roles and the declaration.

CHECK YOUR UNDERSTANDING

A causal loop diagram of a town's night buses shows R1, riders → fares collected → buses running → riders, all +, and B1, riders → standing passengers +, standing passengers → riders –. It is opened in an archetype lab and declared limits to growth. What changes in the drawing?

a One line is added: Archetype: limits to growth

b The variables are redrawn as stocks and flows

c Roles are written above riders, fares collected and standing passengers

d Nothing: the match is listed, so no declaration is written

Feedback: Answers, chapter 12

A causal loop diagram into a stock & flow diagram, by hand: Ana decides what accumulates. *Bees in the colony* and *honey in the hive* become stocks (chapter 6, Stocks); *brood raised* and *swarming* become the flows *bees emerging* and *bees leaving in swarms*; *foragers* and *crowding* fold into the signals (chapter 6, Signals) that set those flows. The lab has no such conversion: what accumulates is a judgment, and most causal loop diagrams have effects ending at variables that would become stocks, where a stock & flow diagram has no signal end.

A stock & flow diagram into a feedback control diagram, by hand: the stocks, flows, clouds and signals carry over, and Ana decides which variables are the target, the measured value, the gap, the corrective action and the controlled variable, adding those not yet drawn, as the thermostat is drawn over its stock in chapter 8 (chapter 8, Control with accumulation). Auxiliaries become plain variables. Here Ana keeps the honey and *honey eaten*, and adds the target, the hefted weight, the gap, the syrup fed and *syrup stored*.

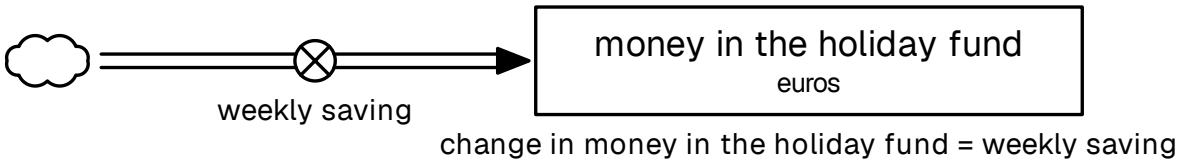
When not to draw

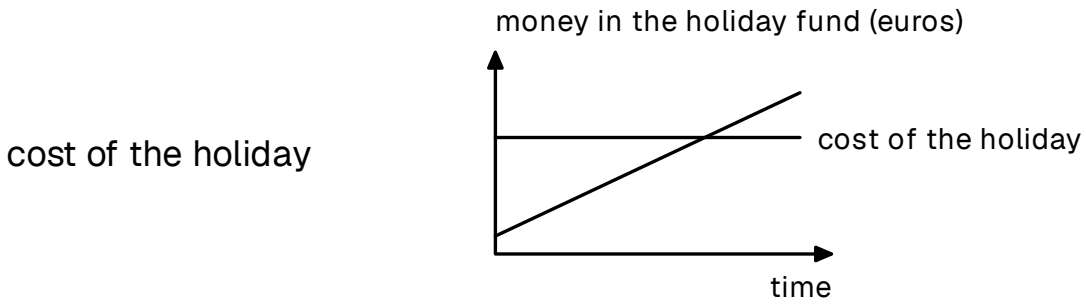
A sentence, a list or a table holds everything a diagram would when the answer is one quantity reached by arithmetic, when nothing comes back around, when no boundary is in dispute, or when the parties can be listed without what passes each way. Each type's own case is in its first chapter's *What stays informal*: chapter 2 (chapter 2, What stays informal), chapter 3 (chapter 3, What stays informal), chapter 4 (chapter 4, What stays informal), chapter 6 (chapter 6, What stays informal), chapter 8 (chapter 8, What stays informal) and chapter 10 (chapter 10, What stays informal).

A diagram shows in one place what is used together, so less has to be searched for; drawn without that grouping, a diagram takes as much searching as the words (Larkin and Simon, 1987).

The bad diagram

What's wrong with this diagram of a holiday fund?





Nothing in its marks: each of the lab's checks on a stock & flow diagram passes or is pending.

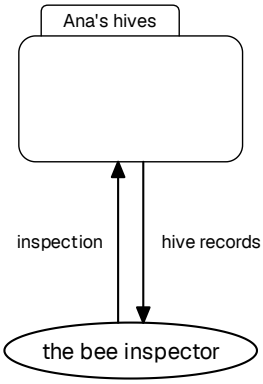
The sentence

> At €50 a week from the €400 already saved, the fund reaches the holiday's €1,200 in 16 weeks.

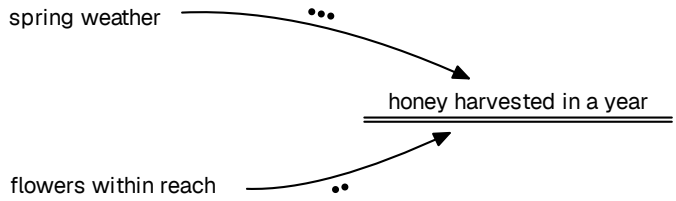
The diagram holds one stock, one steady inflow, no outflow and no loop, and the sentence holds all of it, with the numbers missing from the diagram.

Notation moves

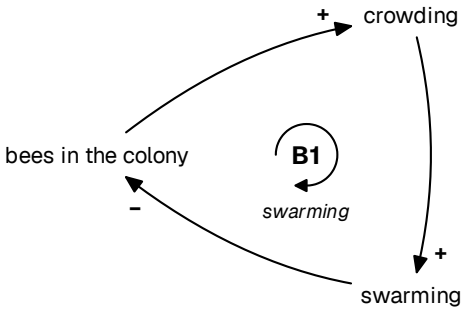
Notation move	When	What it shows	Example
Draw a system context map	The question is whom a system deals with	The boundary, the parties outside, what passes each way	*Ana's hives* and the bee inspector



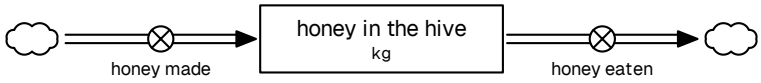
Notation move	When	What it shows	Example
Draw an influence map	Many things bear on one outcome, most in unmeasured directions	What bears on the outcome, ranked	*honey harvested in a year*



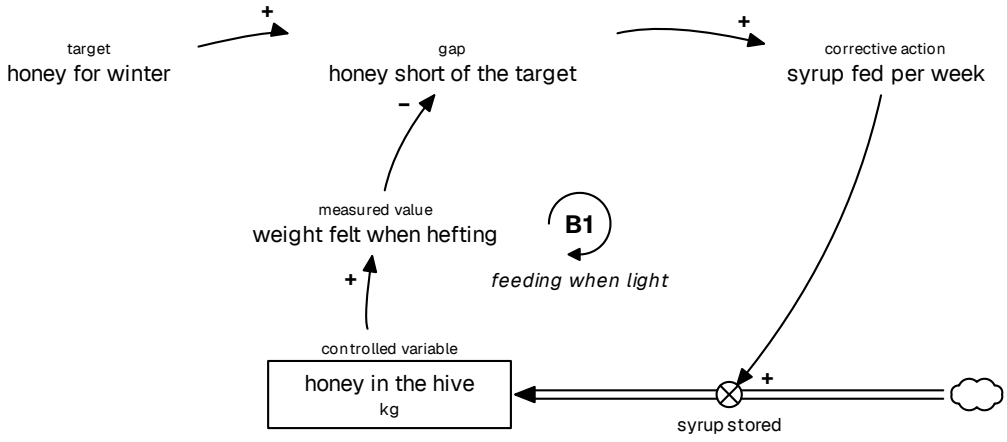
Draw a causal loop diagram	A change comes back around	Loops and their kinds	B1 *swarming*



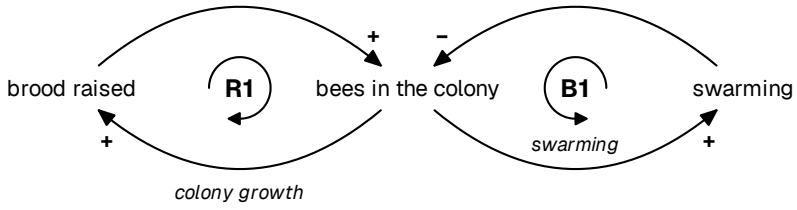
Draw a stock & flow diagram	Something accumulates	Stocks, the flows that fill and drain them, units	*honey in the hive*, in kg



Draw a feedback control diagram	Someone holds a quantity near a value they chose	The control loop, its roles written	*honey for winter*, the target

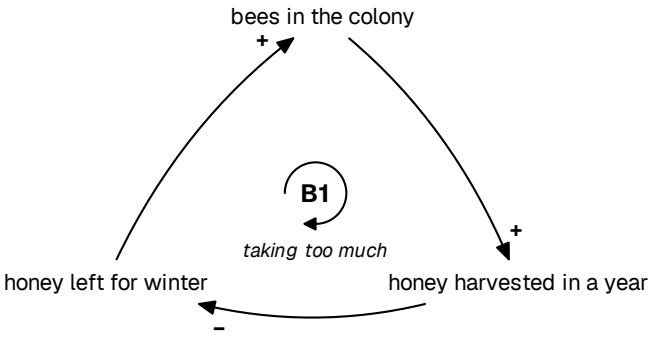


Notation move	When	What it shows	Example
Draw a system archetype	The loops have a structure that recurs across situations	A hypothesis about the loops	*Archetype: limits to growth*

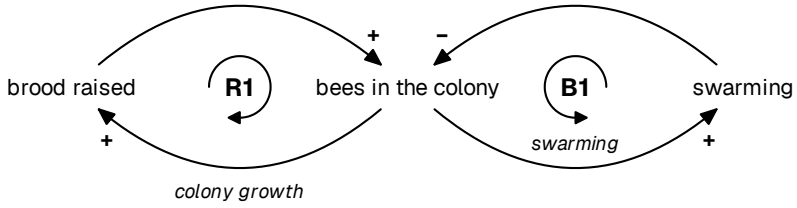


Archetype: limits to growth

Convert an influence map into a causal loop diagram	Causal claims close a path	The loop, to declare	B1 *taking too much*



Open a causal loop diagram in an archetype lab	The question turns to which archetype the loops match	The loops, their matches listed	the hives' R1 and B1



Write a sentence	The answer is one quantity reached by arithmetic	Everything the diagram would	the holiday fund

Common misreading

A type is read as a property of the situation: the hives as *a stock & flow situation*, the holiday fund as *a stock & flow problem*. The type belongs to the question. Ana's hives are drawn as all six types, one per question, and the holiday fund's one question as none.

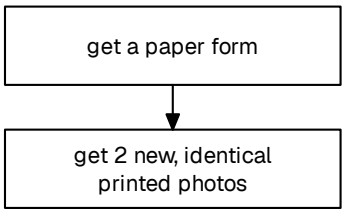
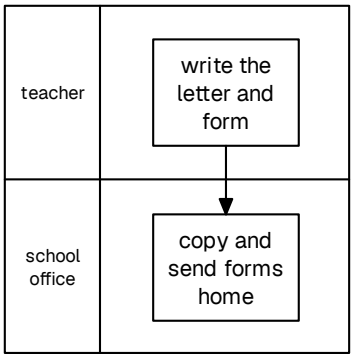
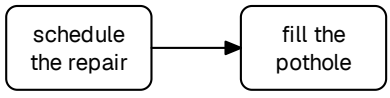
The strongest objection

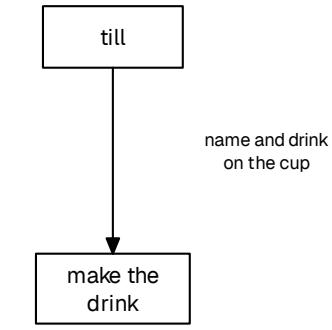
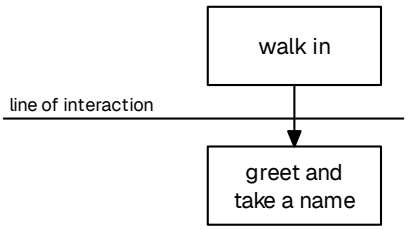
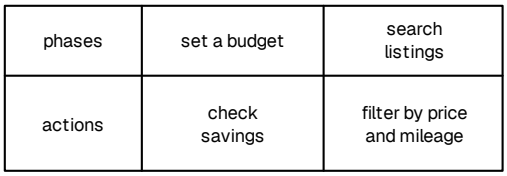
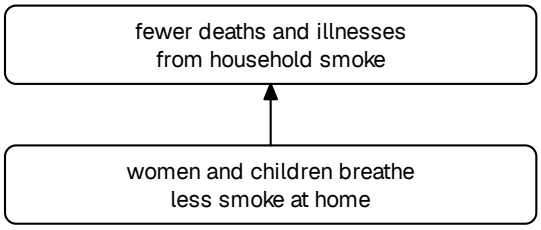
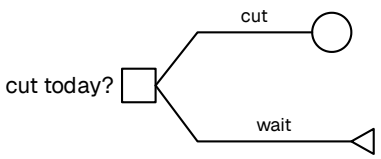
The question rarely comes first: people draw to find out what it is. In soft systems methodology the problem in many situations is "what is the problem?", and a rich picture of the situation is drawn before any problem is defined (Institute for Manufacturing).

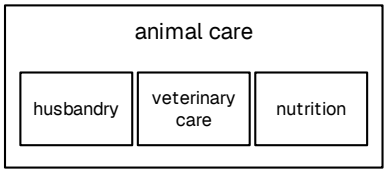
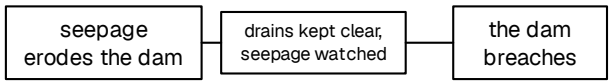
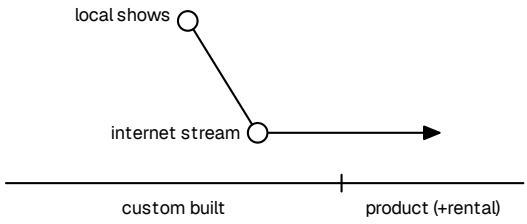
Two of the six types are drawn before the question is settled. A system context map holds only a boundary, the parties outside it and what passes each way, and an influence map only an outcome and what bears on it, no direction known. When the question changes, the drawing is converted, as Ana's influence map was into a causal loop diagram, or redrawn in the type of the new question.

Other families

A line with an arrowhead means *changes* in four of the six types, *passes* in a system context map and *bears on* in an influence map, but *then* in a process map, where a closed path is rework, not a loop, so a process map can't share their editor or checker.

Type	Family	Question it answers	A line with an arrowhead means
process map (field guide, Process map) 	processes & experience	What steps does the work go through, with its decisions, exceptions and rework?	*then*: the next step
swimlane diagram (field guide, Swimlane diagram) 	processes & experience	Who does each step, and where does work change hands?	*then*, across lanes at a change of hands
BPMN (field guide, BPMN) 	processes & experience	What happens, precisely enough that it could be run?	*then*; between participants, what is sent

Type	Family	Question it answers	A line with an arrowhead means
value stream map (field guide, Value stream map) 	processes & experience	Where does material wait from order to delivery, and what starts each step?	*then*; separate lines carry information
service blueprint (field guide, Service blueprint) 	processes & experience	How does what the customer sees connect to the work behind it?	*depends on*, across the rows; time is position
customer journey map (field guide, Customer journey map) 	processes & experience	How does the customer's experience change, stage by stage?	No arrowheads: stages are columns
theory of change (field guide, Theory of change) 	strategy & decisions	What must change, and in what order, to reach a long-term outcome?	*must come before*: a precondition
decision tree (field guide, Decision tree) 	strategy & decisions	Which choice, given the chances of what follows each?	No arrowheads: a branch per choice or outcome

Type	Family	Question it answers	A line with an arrowhead means
stakeholder map (field guide, Stakeholder map) 	strategy & decisions	Who can affect or is affected by a decision, with what power and interest?	Nothing: each party has a place on two axes
capability map (field guide, Capability map) 	strategy & decisions	What must an organization be able to do, whatever its structure?	Nothing: a box inside another is part of it
risk bow-tie (field guide, Risk bow-tie) 	strategy & decisions	What could release one hazard, what follows, and what barriers stand between?	No arrowheads: *can lead to*, threat to top event to consequence
Wardley map (field guide, Wardley map) 	strategy & decisions	What does someone need, what chain of components meets it, and how evolved is each?	*moves to*: expected evolution; plain lines, *needs*

Check your understanding

CHECK YOUR UNDERSTANDING

A chess club's treasurer is asked three things. Which one can the treasurer answer without a diagram?

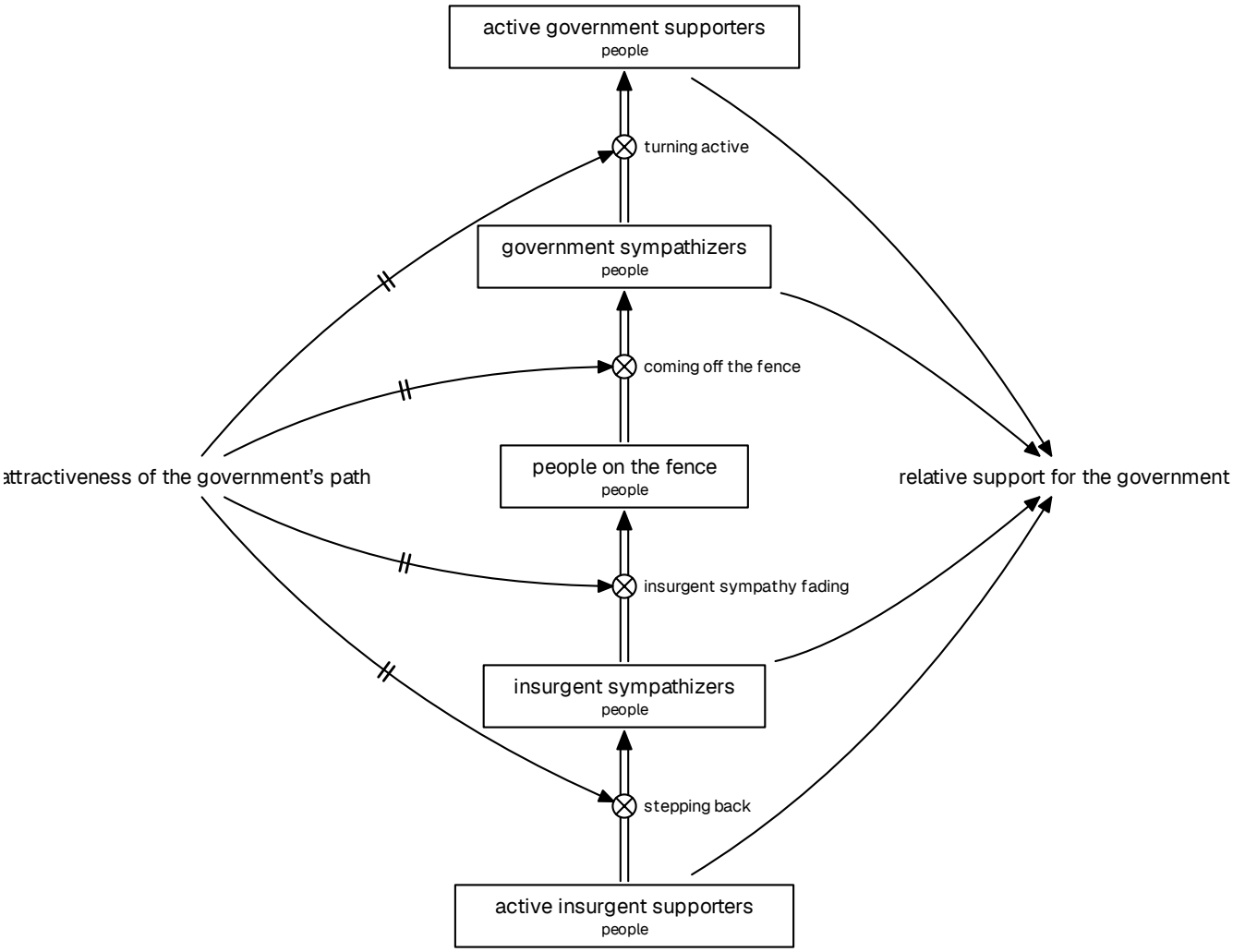
a How many weeks until the club's fund, €200 now and €40 added a week, reaches the €680 that new clocks cost

b Why more members bring more volunteers to teach beginners, and more teaching brings more members

c Whom the club deals with, from the hall it rents to the league it plays in, and what passes each way

Feedback: Answers, chapter 12

Popular support in Afghanistan, redrawn



Redrawn from PA Consulting Group, "Afghanistan Stability / COIN Dynamics", in Dynamic Planning for COIN in Afghanistan, working draft (2009), as published by NBC News

web.archive.org/web/20091228212221/http://msnbcmedia.msn.com:80/i/MSNBC/Components/Photo/_new/Afghanistan_Dynamic_Planning.pdf, page 22, its popular support cluster. © PA Knowledge Limited 2009; its structure and short labels only.

Seven of its 110 or so variables, its popular support cluster, with the lines into it from other clusters left out; its five stocks of people renamed shorter, the first losing & SF, and given units, people, and the month declared as the time unit the slide leaves out; each flow, drawn there running both ways, drawn one way, toward the government's side, as the net movement, and named; its other two names shortened; its lines left without + or –, as drawn; its double strokes for a significant delay drawn as delays; its color left out.

QUESTION 1 OF 3

Which question does this part of the slide, drawn as a stock & flow diagram, answer?

a Why people move toward the government or toward the insurgents.

b How many people hold each of five stances, and how fast they move between neighboring stances.

c Whether the coalition's actions shift popular support.

QUESTION 2 OF 3

The slide comes from a brief for planning a counterinsurgency: which actions shift popular support toward the government, and how fast. Which drawing would answer that?

a The whole slide, since every variable is on it.

b An influence map, with popular support as its central outcome.

c A stock & flow diagram of the five stocks with the few loops through their flows that the plan acts on.

QUESTION 3 OF 3

Would a sentence do in place of this part?

a No: five stocks are too many for a sentence.

b No: a sentence can't carry the delays.

c Yes: no loop closes in it, and one sentence holds what it shows.

Feedback: Answers, chapter 12

Exercises

Passing the checks means meeting the brief, not being right.

CD 01 A mountain rescue team

Ines is the new leader of a volunteer mountain rescue team in a valley of hill farms. The police take each emergency call from the hills and pass the team a callout, and after each rescue the team sends the police a rescue report. The team carries casualties down to the hospital in the valley town, and the hospital returns the team's stretchers. For a serious injury or a long carry, the team requests a helicopter from the helicopter service, which airlifts the casualty. Donors give the team money, and the team sends them a yearly account of what it spent. Walkers and farmers phone in reports of washed-out paths and fallen bridges, and the team posts route warnings at the valley's car parks. Ines's question: whom does the team deal with, and what passes each way?

WHICH DIAGRAM?

What does Ines draw, or write, to answer her question?

a A system context map

b No diagram: a list

c A causal loop diagram

d An influence map

e A stock & flow diagram

Feedback: Answers, chapter 12

CD 01 A mountain rescue team

The parties outside one boundary, and what passes each way

Reasoning ●●○○○ 2 of 5 Polish ●●○○○ 2 of 5

Ines is the new leader of a volunteer mountain rescue team in a valley of hill farms. The police take each emergency call from the hills and pass the team a callout, and after each rescue the team sends the police a rescue report. The team carries casualties down to the hospital in the valley town, and the hospital returns the team's stretchers. For a serious injury or a long carry, the team requests a helicopter from the helicopter service, which airlifts the casualty. Donors give the team money, and the team sends them a yearly account of what it spent. Walkers and farmers phone in reports of washed-out paths and fallen bridges, and the team posts route warnings at the valley's car parks. Ines's question: whom does the team deal with, and what passes each way?

The brief

- [ ] Draw one boundary around the team.
- [ ] Place at least four external entities outside it.
- [ ] Draw at least six exchanges, each naming one thing.
- [ ] Show at least three external entities that both give to the team and receive from it.
- [ ] The helicopter service is a party outside the team, not part of it.

Your palette



boundary external entity exchange

Draw here

CD 02 Moving to another city for a job

Mateus has been offered a job in a city four hours away by train, at a salary a third above what he earns now, leading a team of eight people; he has never led a team. His partner, Ilse, teaches piano to thirty pupils near their flat, and her chances of work in the city depend on its music schools, one of which is hiring. His parents live ten minutes away, and he spends about five hours a week helping them, how many depending on his father's health. Only the salary's pull is plain to him: the higher the salary on offer, the stronger his wish to move. Of the rest, he can't yet say which way each pushes: he would miss the Saturdays with his parents and would also have them to himself; leading eight people might draw him to the job or put him off it; and Ilse hasn't said whether starting again in the city would suit her. Mateus's question: what bears on his wish to move?

WHICH DIAGRAM?

What does Mateus draw, or write, to answer his question?

a A causal loop diagram

b No diagram: a list

c An influence map

d A system context map

e A stock & flow diagram

Feedback: Answers, chapter 12

CD 02 Moving to another city for a job

What bears on one outcome, most of it in no known direction

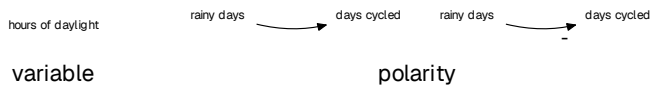
Reasoning ●●○○○ 2 of 5 Polish ●●●○○ 3 of 5

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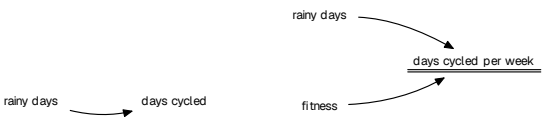
The brief

- [ ] Draw at least four direct influences on Mateus's wish to move.
- [ ] Draw at least one indirect influence.
- [ ] Leave at least three claims without a + or −.
- [ ] Upgrade exactly one claim: the one whose direction Mateus can say.
- [ ] Each variable is a quantity that could be more or less, such as hours a week helping his parents, not a topic such as family.

Your palette



variable polarity



influence claim central outcome

Draw here

CD 03 Carbon dioxide in the atmosphere

Halima reads that the world's yearly emissions of carbon dioxide may soon stop growing. Burning fossil fuels and clearing land put about 11 billion tonnes of carbon a year into the air, as carbon dioxide. The oceans absorb about 3 billion tonnes of it a year, and forests and other vegetation on land about 2; the rest stays in the air. Suppose emissions hold steady at 11 billion tonnes a year from now on, and the oceans and the vegetation go on absorbing about as much as now. Count the carbon dioxide by the carbon it holds, in billion tonnes, and time in years. Halima's question: if emissions stop growing and hold steady, does the carbon dioxide in the air stop rising?

WHICH DIAGRAM?

What does Halima draw, or write, to answer her question?

a A causal loop diagram

b A stock & flow diagram

c No diagram: a sentence

d An influence map

e A feedback control diagram

Feedback: Answers, chapter 12

CD 03 Carbon dioxide in the atmosphere

An amount filled faster than it drains

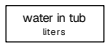
Reasoning ●●●○○ 3 of 5 Polish ●●●○○ 3 of 5

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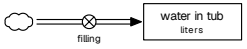
The brief

- [ ] Draw the carbon dioxide in the air as one stock, counted in billion tonnes of carbon.
- [ ] Draw the emissions as an inflow.
- [ ] Draw at least one outflow: what the oceans and vegetation on land absorb.
- [ ] Add a behavior-over-time graph of the stock while emissions hold steady: its direction is Halima's answer.
- [ ] Emissions held steady still exceed what the oceans and vegetation on land absorb.

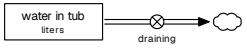
Your palette



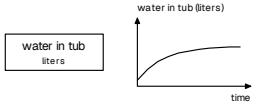
stock



flow



cloud



behavior-over-time graph

Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/pattern-and-judgment/choosing-the-diagram/#exercise-choosing-the-diagram-03

CD 04 Two siblings and one games console

Noor, eleven, and Felix, nine, share one games console. Each Sunday their father splits the coming week's turns on it between them by their best scores that week in the racing game they both play: the higher Noor's best score, the larger her share of the turns, and the higher Felix's, the smaller her share. The more turns a child gets, the more hours that child plays, and the more hours played, the higher that child's best score. In the first week, Noor scored a few points higher than Felix. Their father's question: is this a story others have seen, and how does it usually run?

WHICH DIAGRAM?

What does their father draw, or write, to answer his question?

a A causal loop diagram

b An influence map

c A system archetype

d A stock & flow diagram

e No diagram: a sentence

Feedback: Answers, chapter 12

CD 04 Two siblings and one games console

Two loops through one split, and the name of their story

Reasoning ●●●○○ 3 of 5 Polish ●●●○○ 3 of 5

Noor, eleven, and Felix, nine, share one games console. Each Sunday their father splits the coming week's turns on it between them by their best scores that week in the racing game they both play: the higher Noor's best score, the larger her share of the turns, and the higher Felix's, the smaller her share. The more turns a child gets, the more hours that child plays, and the more hours played, the higher that child's best score. In the first week, Noor scored a few points higher than Felix. Their father's question: is this a story others have seen, and how does it usually run?

The brief

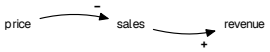
- [ ] Draw two reinforcing loops, one through each child's hours on the console.
- [ ] Match the two loops to one of chapter 10's archetypes.
- [ ] Declare that archetype in one line.
- [ ] Add a behavior note on how the split runs, week by week.
- [ ] The father's rule is one variable, Noor's share of the turns, on both loops.
- [ ] In the note: Noor's lead of a few points in the first week, and her share larger every week after.

Your palette

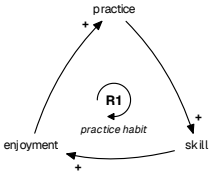
variable



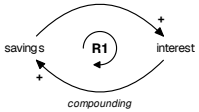
effect



polarity



loop



reinforcing loop



behavior note

archetype

Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/pattern-and-judgment/choosing-the-diagram/#exercise-choosing-the-diagram-04

CD 05 A canal through a dry summer

Through a dry summer, Ruth keeps the long top stretch of a canal deep enough for boats. Every boat through a lock at either end of the stretch draws thousands of litres of water out of it, and on a busy day dozens of boats pass. Water comes into the stretch from a lake dammed in the hills, along a feeder, and Ruth sets how much she lets in each day; the feeder carries only so much a day. She reads the depth on a gauge board once each morning, and the further it reads below the depth boats need, the more water she lets in that day. Count the water in the stretch as its depth, in centimetres, and time in days. Ruth's question: how do her morning reading and the water she lets in hold the stretch at the depth boats need, and where can that fall short?

WHICH DIAGRAM?

What does Ruth draw, or write, to answer her question?

a A stock & flow diagram

b A causal loop diagram

c A system context map

d A feedback control diagram

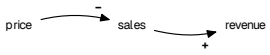
e No diagram: a sentence

Feedback: Answers, chapter 12

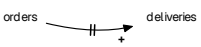
CD 05 A canal through a dry summer

Your palette

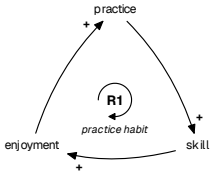
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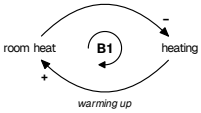
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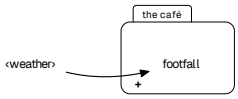
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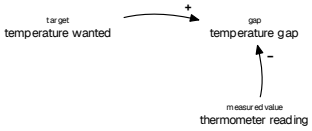
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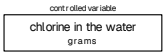
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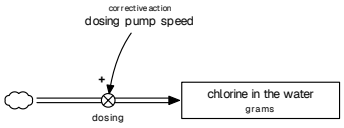
external driver



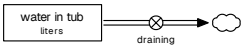
gap
a role, written above its variable's name



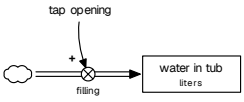
stock



flow



cloud



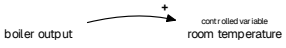
signal



target
a role, written above its variable's name



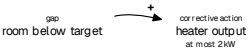
corrective action
a role, written above its variable's name



controlled variable
a role, written above its variable's name



measured value
a role, written above its variable's name



saturation

CD 05 A canal through a dry summer

A depth held by a reading once a day and an inflow with a limit

Reasoning ●●●●○ 4 of 5 Polish ●●●●○ 4 of 5

Through a dry summer, Ruth keeps the long top stretch of a canal deep enough for boats. Every boat through a lock at either end of the stretch draws thousands of litres of water out of it, and on a busy day dozens of boats pass. Water comes into the stretch from a lake dammed in the hills, along a feeder, and Ruth sets how much she lets in each day; the feeder carries only so much a day. She reads the depth on a gauge board once each morning, and the further it reads below the depth boats need, the more water she lets in that day. Count the water in the stretch as its depth, in centimetres, and time in days. Ruth's question: how do her morning reading and the water she lets in hold the stretch at the depth boats need, and where can that fall short?

The brief

- [ ] Draw the water in the stretch as one stock, counted in centimetres of depth.
- [ ] Close one control loop through the water from the hill lake.
- [ ] Write one target: the depth boats need.
- [ ] Draw the boats through the locks as an external driver acting on the water in the stretch.
- [ ] Mark the once-a-morning reading as a delay on the return path.
- [ ] Write what the feeder carries in a day as the limit on the water Ruth lets in.
- [ ] The target depth is Ruth's choice: no signal ends at it.

Your palette

On the page before this sheet.

Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/pattern-and-judgment/choosing-the-diagram/#exercise-choosing-the-diagram-05

CS 12 Kelsham Primary School: the council's question

In October 2026 Kelsham Primary School has 88 pupils, and the county council asks whether to close it. David Brennan, its officer for school places, has the births in the villages to 2025: 12 in 2023, 12 in 2024 and 11 in 2025. Each year's children start school in the September four years later, fewer of them at Kelsham than were born, since some families choose Brayford Primary School: in the year to October 2026, 9 children started and 16 pupils left. Larkfield Homes will finish the 60 homes at Mill Lane from 2027 to 2029, and the county council counts 0.25 children of primary school age for each new home: 15 children in all, joining as the homes are first lived in, and none once the last one is. Tom Hale tells the council the homes will turn the roll around. Count the pupils in pupils, and time in years. David Brennan's question: once the last Mill Lane home is lived in, does the roll go on falling?

WHICH DIAGRAM?

What does David Brennan draw, or write, to answer his question?

a A causal loop diagram

b A stock & flow diagram

c An influence map

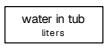
d A feedback control diagram

e No diagram: a sentence

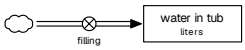
Feedback: Answers, chapter 12

CS 12 Kelsham Primary School: the council's question

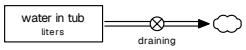
Your palette



stock

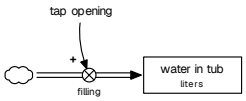


flow

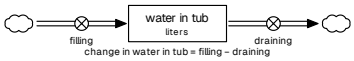


cloud

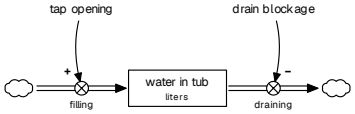
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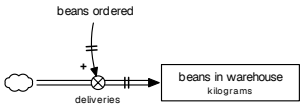
signal



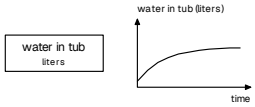
stock equation



polarity



delay



behavior-over-time graph

CS 12 Kelsham Primary School: the council's question

Choosing the drawing for whether the roll recovers

Reasoning ●●●●○ 4 of 5 Polish ●●●●○ 4 of 5

In October 2026 Kelsham Primary School has 88 pupils, and the county council asks whether to close it. David Brennan, its officer for school places, has the births in the villages to 2025: 12 in 2023, 12 in 2024 and 11 in 2025. Each year's children start school in the September four years later, fewer of them at Kelsham than were born, since some families choose Brayford Primary School: in the year to October 2026, 9 children started and 16 pupils left. Larkfield Homes will finish the 60 homes at Mill Lane from 2027 to 2029, and the county council counts 0.25 children of primary school age for each new home: 15 children in all, joining as the homes are first lived in, and none once the last one is. Tom Hale tells the council the homes will turn the roll around. Count the pupils in pupils, and time in years. David Brennan's question: once the last Mill Lane home is lived in, does the roll go on falling?

The brief

- [ ] Draw the pupils on roll as one stock, counted in pupils.
- [ ] Draw two inflows: the children starting each September, and the children moving into the Mill Lane homes.
- [ ] Draw the pupils leaving as one outflow.
- [ ] Show the stock equation.
- [ ] Draw the births in the villages with a signal to the children starting, delayed by the four years before a child starts.
- [ ] Add a behavior-over-time graph of the roll once the last Mill Lane home is lived in: its direction is David Brennan's answer.
- [ ] The inflow from Mill Lane ends with the last home lived in; the children starting go on each September.

Your palette

On the page before this sheet.

Draw here

Sources

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- James D. Ellis, Sara DeBerry and John Crowley, “Swarm Control for Managed Beehives” ask.ifas.ufl.edu/publication/IN970, UF/IFAS Extension, on crowding as a cause of swarming, and the workers who leave with the old queen.
- Jill H. Larkin and Herbert A. Simon, “Why a Diagram Is (Sometimes) Worth Ten Thousand Words” doi.org/10.1111/j.1551-6708.1987.tb00863.x, *Cognitive Science* 11, no. 1 (1987): 65–99, on diagrams that put together what is used together, pp. 98–99.
- Institute for Manufacturing, University of Cambridge, “Soft Systems Methodology” www.ifm.eng.cam.ac.uk/research/dstools/soft-systems-methodology/, summarizing Checkland and Scholes (1990).
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- John D. Sterman and Linda Booth Sweeney, “Understanding Public Complacency About Climate Change: Adults’ Mental Models of Climate Change Violate Conservation of Matter” www.mit.edu/~jsterman/Understanding_public.html, *Climatic Change* 80 (2007): 213–238, for CD 03.
- Canal & River Trust, *Water management FAQs* canalrivertrust.org.uk/about-us/water/water-management-faqs and *Day to day* canalrivertrust.org.uk/specialist-teams/managing-our-water/day-to-day, and the Macclesfield Canal Society, *Reservoirs & feeders* macclesfieldcanal.org.uk/reservoirs.htm, for CD 05.

A village primary school losing pupils

Kelsham Primary School, six miles from the market town of Brayford, had 126 pupils in October 2020 and 88 in October 2026. The last exercise of each chapter, CS 01 to CS 12, is one part of its story, drawn as that chapter's diagram type.

Kelsham, 2020 to 2026

Kelsham is a village of about 1,400 people, 25 minutes from Brayford by the school bus that Dale Coaches runs under contract to the county council. Kelsham Primary School teaches children from 4 to 11, Reception and Years 1 to 6, and has 140 places, 20 in each year. Ruth Okafor has been its head teacher since 2018 and teaches two days a week; Tom Hale, a farmer whose two children went to the school, chairs its governors. Brayford Primary School, the town's school, has 420 places, two classes of up to 30 in each year, and Helen Marsh is its head teacher.

Fewer children start each September. Births in the villages the school serves fell from 22 in 2016 to 11 in 2025, and a child starts in the September four years after the year of its birth, at Kelsham or at Brayford Primary School: fewer start at Kelsham than were born. Each October the school counts its roll, the last count plus the year's starters, less the pupils who left.

October	Pupils	Started	Left	Classes	Teachers
2020	126	19	20	5	5
2021	121	16	21	5	5
2022	114	15	22	5	5
2023	108	13	19	4	4
2024	101	12	19	4	4
2025	95	11	17	4	4
2026	88	9	16	4	4

The roll each October, with the children who started and the pupils who left in the year to it.

The school is paid £4,800 a year for each pupil, set from the October count before each school year, and £140,000 whatever its size; a teacher's pay and costs are £52,000 a year. In 2023, with 108 pupils, the governors paid four teachers instead of five, and since then Sam Lewis has taught Years 3 and 4 as one class. Some parents say mixed-age classes are why they chose Brayford, where each year has classes of its own; others stay for Kelsham's smaller classes. Priya Shah, with children in Year 1 and Year 4, is weighing the move. In October 2026 Ruth Okafor wrote to parents about the falling roll, with some counts and some beliefs.

The governors hold the school's reserve to a target of at least £60,000. It stood at £96,000 in October 2026, and within a school year it rises and falls by up to £10,000 as funding arrives and pay goes out, so the governors change staff hours only when the reserve differs from its target by more. They read it in a budget report each term and cut a teaching assistant's hours before a teacher's, but never below one teacher a class.

David Brennan, the county council's officer for school places, forecasts each school's starters from the births, and reads each school's spending for each pupil in its accounts once a year. Larkfield Homes will finish 60 homes at Mill Lane, a field beside the village, the first lived in from 2027 and the last by 2029; the council counts 0.25 children of primary school age for each new home, 15 children in all.

Brayford aimed for classes of 26 before Kelsham's children came in numbers, and its governors have raised the aim since, toward 30. In October 2026 the county council asks whether Kelsham Primary School should close.

What each type answers

- In chapter 1, a drawing of Ruth Okafor's letter, CS 01 (chapter 1, CS 01), shows the effects resting on counts as more supported and the parents' reasons as less supported.
- A system context map, CS 02 (chapter 2, CS 02), shows what passes each way between the school and each party it deals with.
- An influence map, CS 03 (chapter 3, CS 03), shows what bears on how many children start at Kelsham each September, and which of those effects anyone has counted.
- A causal loop diagram, CS 04 (chapter 4, CS 04), shows how a fall in the pupils on roll comes back to the roll through funding and classes, and where the school could act.
- A causal loop diagram with a boundary, CS 05 (chapter 5, CS 05), shows what acts on those loops from outside the school, and how late.
- A stock & flow diagram, CS 06 (chapter 6, CS 06), shows the roll as an amount that only the children starting and the pupils leaving change.
- A chain of stocks, CS 07 (chapter 7, CS 07), shows the pupils passing through the four classes, and how the October count reaches the children starting.
- A feedback control diagram, CS 08 (chapter 8, CS 08), shows how the governors hold the school's reserve to its target.
- A feedback control diagram with a nested loop, CS 09 (chapter 9, CS 09), shows what limits the governors' corrective action, and the county council's loop around theirs.
- A system archetype, CS 10 (chapter 10, CS 10), shows why merging classes to save money brings the spending back.
- Two coupled system archetypes, CS 11 (chapter 11, CS 11), show how Brayford's pull on the villages' starters and its rising class size work together on Kelsham's roll.
- In chapter 12, CS 12 (chapter 12, CS 12), choosing the type for the county council's question comes first, and the drawing chosen shows whether the roll goes on falling once the last Mill Lane home is lived in.

Your drawings

On paper, your drawings are on the sheets of CS 01 to CS 12, the last sheet of each chapter.

Field guide

The book's chapters teach the six diagram types of systems and feedback; the other twelve are described only here.

Systems & feedback

Type	Question it answers	A line with an arrowhead means
system context map (field guide, System context map)	What is inside the system you're responsible for?	*passes*: an exchange, one named thing from the party that gives to the party that receives
influence map (field guide, Influence map)	Which things affect an outcome, before you know how each changes it?	*bears on*: an influence claim, which way unsaid; *changes* once upgraded with a polarity
causal loop diagram (field guide, Causal loop diagram)	Why do some changes snowball while others settle?	*changes*: an effect, its polarity giving which way
stock & flow diagram (field guide, Stock & flow diagram)	What would still be there if everything stopped?	*moves*: a flow's double line, carrying material; *changes*: a signal, carrying a reading
feedback control diagram (field guide, Feedback control diagram)	How does anything stay near a target?	*changes*: a signal, carrying a reading or a setting; a flow's double line *moves* material
system archetype (field guide, System archetype)	Which stories play out again and again?	*changes*: an effect, as in a causal loop diagram

Processes & experience

Type	Question it answers	A line with an arrowhead means
process map (field guide, Process map)	What steps does the work go through, with its decisions, exceptions and rework?	*then*: the next step
swimlane diagram (field guide, Swimlane diagram)	Who does each step, and where does work change hands?	*then*, across lanes at a change of hands
BPMN (field guide, BPMN)	What happens, precisely enough that it could be run?	*then*; between participants, what is sent
value stream map (field guide, Value stream map)	Where does material wait from order to delivery, and what starts each step?	*then*; separate lines carry information
service blueprint (field guide, Service blueprint)	How does what the customer sees connect to the work behind it?	*depends on*, across the rows; time is position
customer journey map (field guide, Customer journey map)	How does the customer's experience change, stage by stage?	No arrowheads: stages are columns

Strategy & decisions

Type	Question it answers	A line with an arrowhead means
theory of change (field guide, Theory of change)	What must change, and in what order, to reach a long-term outcome?	*must come before*: a precondition
decision tree (field guide, Decision tree)	Which choice, given the chances of what follows each?	No arrowheads: a branch per choice or outcome
stakeholder map (field guide, Stakeholder map)	Who can affect or is affected by a decision, with what power and interest?	Nothing: each party has a place on two axes
capability map (field guide, Capability map)	What must an organization be able to do, whatever its structure?	Nothing: a box inside another is part of it
risk bow-tie (field guide, Risk bow-tie)	What could release one hazard, what follows, and what barriers stand between?	No arrowheads: *can lead to*, threat to top event to consequence
Wardley map (field guide, Wardley map)	What does someone need, what chain of components meets it, and how evolved is each?	*moves to*: expected evolution; plain lines, *needs*

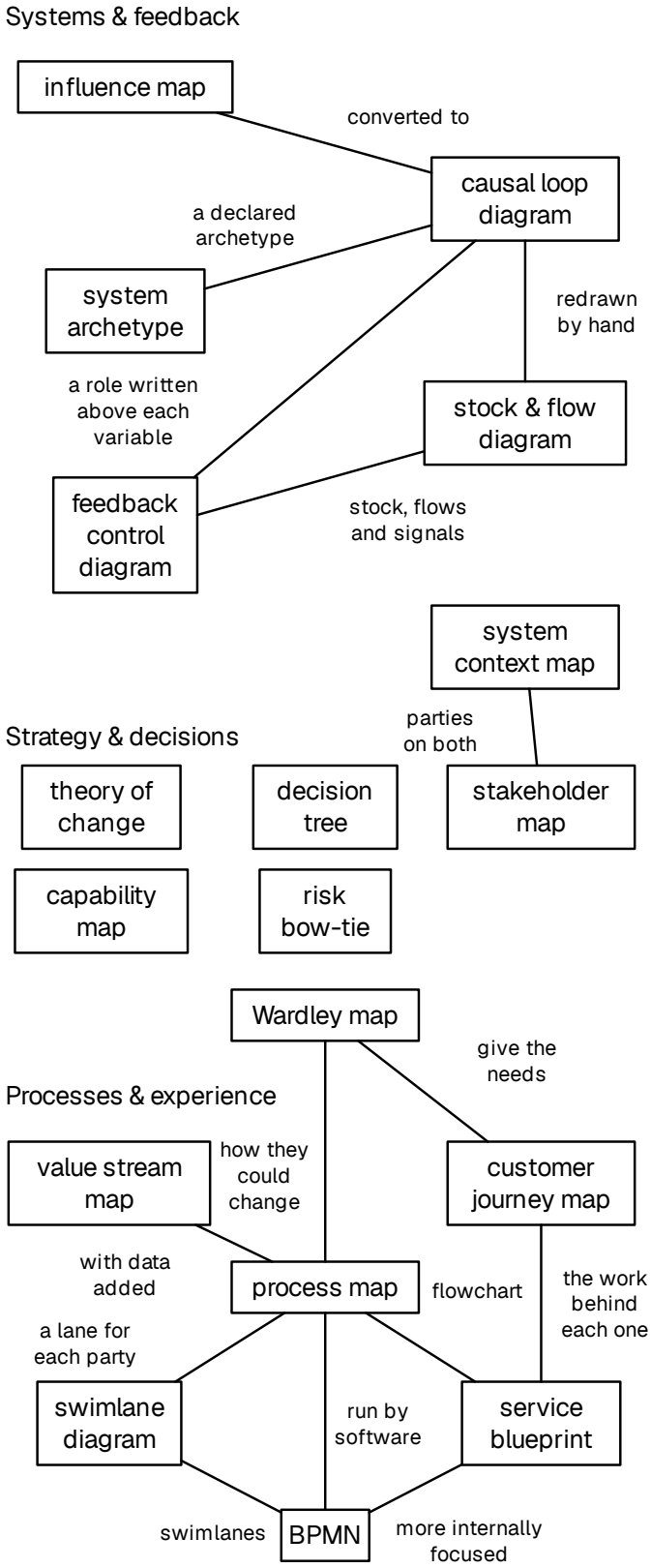
How the types relate

Types	How they relate	Support
influence map (field guide, Influence map) and causal loop diagram (field guide, Causal loop diagram)	An influence map is converted to a causal loop diagram: its variables and causal claims carry over, and its influence claims, weights and clusters are left behind.	chapter 3, Conversion to a causal loop diagram
causal loop diagram (field guide, Causal loop diagram) and stock & flow diagram (field guide, Stock & flow diagram)	A causal loop diagram is redrawn by hand as a stock & flow diagram, what accumulates becoming stocks, filled and drained by flows that signals set.	chapter 12, Converting between types
causal loop diagram (field guide, Causal loop diagram) and feedback control diagram (field guide, Feedback control diagram)	A feedback control diagram is drawn as a causal loop diagram is, with a role written above each variable that plays one, its effects called signals.	chapter 8, What the notation expresses
stock & flow diagram (field guide, Stock & flow diagram) and feedback control diagram (field guide, Feedback control diagram)	Where the controlled variable accumulates, it is drawn on a feedback control diagram with a stock & flow diagram's stock, flows and signals, the roles written above them.	chapter 8, Control with accumulation
causal loop diagram (field guide, Causal loop diagram) and system archetype (field guide, System archetype)	A system archetype is drawn with a causal loop diagram's marks, with roles and a declared archetype written on it.	chapter 10, What the notation expresses; chapter 12, Converting between types

Types	How they relate	Support
system context map (field guide, System context map) and stakeholder map (field guide, Stakeholder map)	There are parties on both: on a system context map, those outside a system's boundary, with what passes each way across it; on a stakeholder map, those inside an organization and outside it, placed by power and interest.	chapter 2, External entities; Eden and Ackermann 2021, §3 doi.org/10.1007/s10726-021-09745-y
process map (field guide, Process map) and swimlane diagram (field guide, Swimlane diagram)	A swimlane diagram is a process map with a lane for each party that does part of the work.	Improvement Cymru Academy, Swimlane Diagrams (2024) performanceandimprovement.nhs.wales/our-work/quality-safety-and-improvement/improvement/improvement-cymru-academy/resource-library/academy-toolkit-guides/swimlane-diagrams-toolkit-guide/
process map (field guide, Process map) and BPMN (field guide, BPMN)	In BPMN, steps, decisions and their order are drawn as on a process map, in a notation defined formally enough that some diagrams can be run by software.	BPMN 2.0.2, §7.1, p. 19, and §7.2.1, p. 21 www.omg.org/spec/BPMN/2.0.2/
swimlane diagram (field guide, Swimlane diagram) and BPMN (field guide, BPMN)	BPMN's swimlanes are of two kinds, a band for each participant and lanes within it, where a swimlane diagram has a lane for each party.	BPMN 2.0.2, Table 7.1, p. 27 www.omg.org/spec/BPMN/2.0.2/
process map (field guide, Process map) and value stream map (field guide, Value stream map)	A value stream map is a process map with data added: each step's time, the waiting between steps, and the information that tells each step what to make next.	Madsen and McManus 2012, slide 5 ocw.mit.edu/courses/16-660j-introduction-to-lean-six-sigma-methods-january-iap-2012/254d5fa6fe7849a112144f16282954de_MIT16_660JIAP12_1-6.pdf ; Rother and Shook 1999, p. 5 www.lean.org/wp-content/uploads/2021/01/Learning-to-See-part1.pdf
customer journey map (field guide, Customer journey map) and service blueprint (field guide, Service blueprint)	On a service blueprint, a customer journey map's steps run along the top, with the work behind each one drawn beneath.	Gibbons 2018 www.nngroup.com/articles/journey-mapping-101/; Gibbons 2017 www.nngroup.com/articles/service-blueprints-definition/
process map (field guide, Process map) and service blueprint (field guide, Service blueprint)	A service blueprint is a flowchart, as a process map is, with the customer's actions laid out first, along the top, and the work that supports them beneath.	Bitner, Ostrom and Morgan 2008, p. 72 cmr.berkeley.edu/2008/05/50-3-service-blueprinting-a-practical-technique-for-service-innovation/
service blueprint (field guide, Service blueprint) and BPMN (field guide, BPMN)	Diagrams of the work behind a service blueprint can be drawn in BPMN, a more internally focused notation, and referred to from the blueprint.	Bitner, Ostrom and Morgan 2008, p. 71 cmr.berkeley.edu/2008/05/50-3-service-blueprinting-a-practical-technique-for-service-innovation/
process map (field guide, Process map) and Wardley map (field guide, Wardley map)	A process map orders the steps of the work with no mark for how they could change; on a Wardley map each component is placed by how evolved it is, and its expected movement is drawn.	Wardley 2020, ch. 1, p. 27 learnwardleymapping.com/book/

Types	How they relate	Support
customer journey map (field guide, Customer journey map) and Wardley map (field guide, Wardley map)	A customer journey map can open a Wardley map: the journey's steps give the needs at the map's top, with the components that meet them beneath.	Wardley 2020, ch. 2, p. 50, and ch. 4, p. 108 learnwardleymapping.com/book/

Each line is a relationship from the table,
not an effect, and carries no arrowhead.



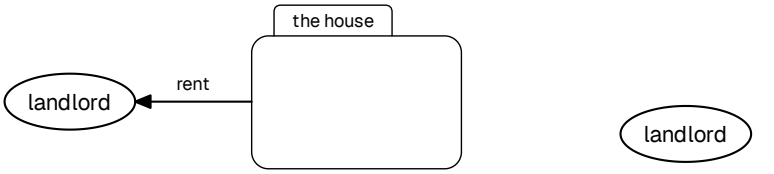
System context map

Systems & feedback Field guide · Systems & feedback · 1 of 6

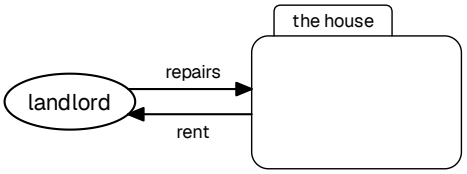
What is inside the system you're responsible for?

In place of variables and effects, a system context map shows a named boundary, the parties outside it in ovals, and named exchanges crossing it.

Marks



boundary external entity



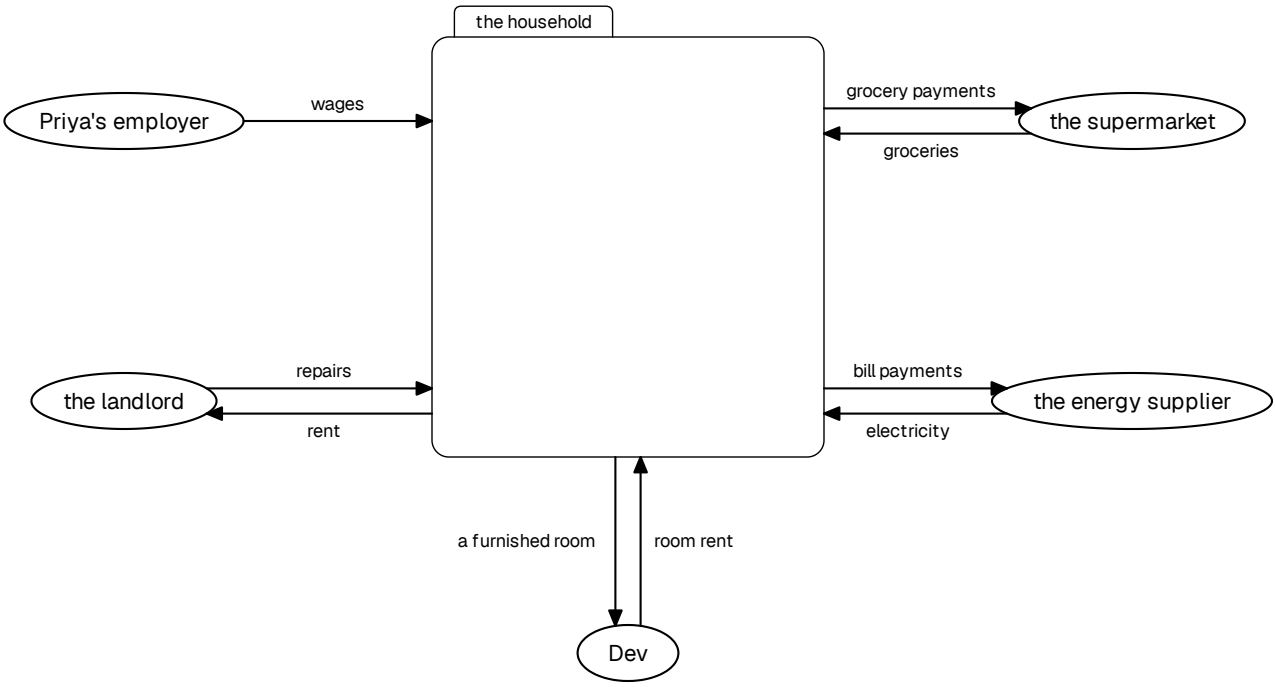
exchange

How each mark is drawn and read: chapter 2, What the notation expresses.

A line with an arrowhead

A line with an arrowhead is an **exchange**: one named thing passing between the boundary and an external entity, from the party that gives to the party that receives. It carries the thing, not a change: nothing on a system context map rises or falls.

A household with a lodger



Dev rents a room but runs his own meals, so he is an external entity beside the landlord, Priya's employer, the supermarket and the energy supplier; each exchanges one named thing each way with *the household*, except the employer, whose wages only arrive (chapter 2's household (chapter 2, A household with a lodger)).

When to draw one

Draw one when people disagree about whose job something is, when something arrives that nobody expected to deal with, or when a problem passes from one part to another, each saying it belongs elsewhere (chapter 2's signals (chapter 2, Signals you need this diagram)).

When not to draw one

With one or two parties, a sentence does, and when only who the system deals with is in question, a list of parties. Amounts, timing and causes aren't drawn: an influence map (chapter 3) or a causal loop diagram (chapter 4) shows causes (chapter 2, what stays informal (chapter 2, What stays informal)).

Reasoning and polish

Reasoning ●●●○○ 3 of 5 Polish ●●●●○ 4 of 5 *boundary sketch → architecture plate*

1. One boundary and the main external entities
2. Named exchanges, their direction, and the system's responsibilities
3. Nested boundaries, trust boundaries and owners

Related types

- There are parties on both: on a system context map, those outside a system's boundary, with what passes each way across it; on a stakeholder map (field guide, Stakeholder map), those inside an organization and outside it, placed by power and interest.

In this book

- Chapter 2, *Drawing the Boundary* (chapter 2): the boundary, external entities, exchanges, direction, nested boundaries and owners; exercises SC 01–05.

Sources

- Tom DeMarco, *Structured Analysis and System Specification* (Yourdon Press, 1978), on the diagram at the top of structured analysis's set: the whole system drawn as one shape among the parties outside it.
- Edward Yourdon, *Modern Structured Analysis* (Yourdon Press, 1989), on the environmental model, the part of structured analysis that draws a system's surroundings.
- Simon Brown, *The C4 model: System context diagram* c4model.com/diagrams/system-context, on the C4 model's zoomed-out view: a software system drawn as one box among the people and other systems it deals with.
- Donella H. Meadows, *Thinking in Systems: A Primer* (Chelsea Green, 2008), chapter 4, on boundaries as choices made afresh for each problem.
- John D. Sterman, *Business Dynamics: Systems Thinking and Modeling for a Complex World* (Irwin/McGraw-Hill, 2000), chapter 3, on the model boundary chart, which lists what a model treats as inside, as outside, and leaves out.

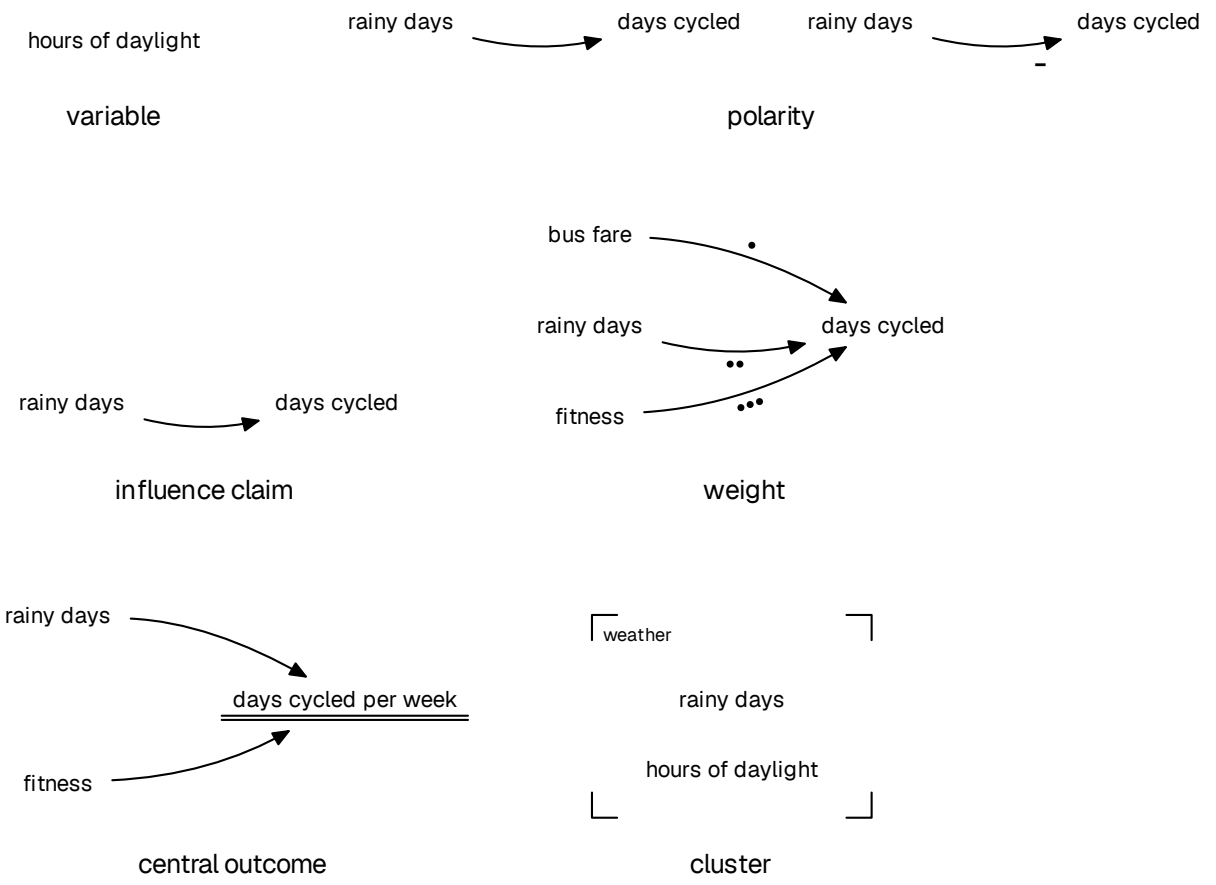
Influence map

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Which things affect an outcome, before you know how each changes it?

Over variables and effects, an influence map shows influence claims, effects with no polarity until their direction is measured; their weight in dots; one central outcome; and clusters.

Marks

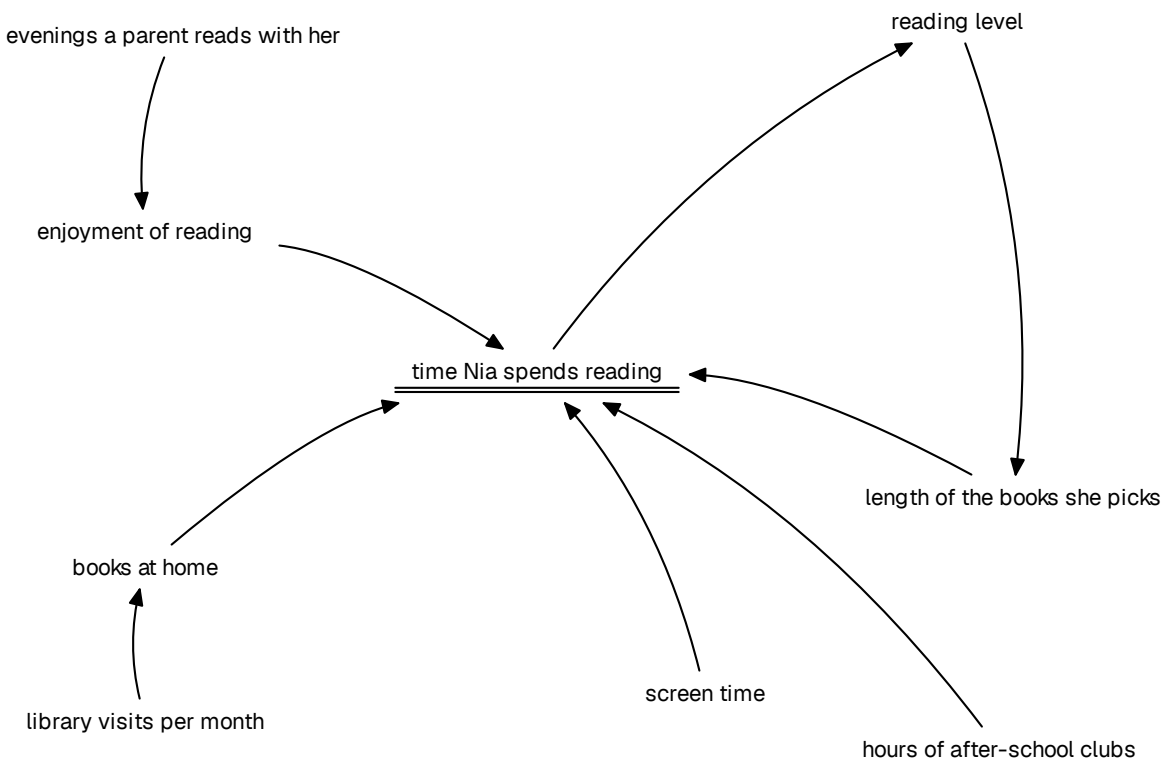


How each mark is drawn and read: chapter 3, What the notation expresses.

A line with an arrowhead

A line with an arrowhead with no + or – is an **influence claim**: the variable at its tail bears on the one at its head, which way unsaid. Upgraded with a polarity where its direction is measured, it becomes a causal claim and *changes*, as an effect in a causal loop diagram does.

Nia's reading for pleasure



Eight variables bear on *time Nia spends reading*, five directly and three through another; every claim is drawn without a polarity, the three effects her reading log and assessments measured included (chapter 3's Nia (chapter 3, Nia's reading for pleasure)).

When to draw one

Draw one when many things bear on one outcome and nobody knows which way most act, when a list of causes keeps growing with no order, or when some effects are measured and others only suspected (chapter 3's signals (chapter 3, Signals you need this diagram)).

When not to draw one

With a few influences, each acting on the outcome and none on another, a list of variables does what the map would; with one influence in question, a sentence does. Amounts and timing aren't drawn (chapter 3, what stays informal (chapter 3, What stays informal)).

Reasoning and polish

Reasoning ●●●●○ 4 of 5 Polish ●●●●● 5 of 5 *brain dump → weighted argument map*

1. Central outcome with direct influences
2. Clusters, upgrades, weight and uncertainty
3. Evidence, viewpoints, and conversion to a causal loop diagram

Related types

- An influence map is converted to a causal loop diagram (field guide, Causal loop diagram): its variables and causal claims carry over, and its influence claims, weights and clusters are left behind.

In this book

- Chapter 3, *Surfacing Influences* (chapter 3): the central outcome, influence claims, direct and indirect influences, clusters, weight, causal claims and conversion to a causal loop diagram; exercises IM 01–05.

Sources

- The Open University, *Diagramming for development 2: exploring interrelationships* www.open.edu/openlearn/digital-computing/diagramming-development-2-exploring-interrelationships/content-section-3.1 (OpenLearn), §3.1, *Influence diagram*, on influence diagrams: a snapshot of what can influence a situation, two influences that run both ways drawn as two lines, and stronger influences drawn thicker.
- Geoff Coyle, *Qualitative Modelling in System Dynamics, or What Are the Wise Limits of Quantification?* proceedings.systemdynamics.org/1999/PAPERS/KEYNOTE1.PDF, keynote to the System Dynamics Society's conference (Wellington, 1999), on influence diagrams drawn and studied without simulation, and what they are used for: a problem on one page, loops found in the diagram, and a basis for a quantified model.
- John D. Sterman, *Business Dynamics: Systems Thinking and Modeling for a Complex World* (Irwin/McGraw-Hill, 2000), chapter 5, on polarity in causal loop diagrams, with §5.2.1, *Causation versus Correlation*.
- George P. Richardson, "Problems with Causal-Loop Diagrams" doi.org/10.1002/sdr.4260020207, *System Dynamics Review* 2, no. 2 (1986), on what polarity does and doesn't mean.

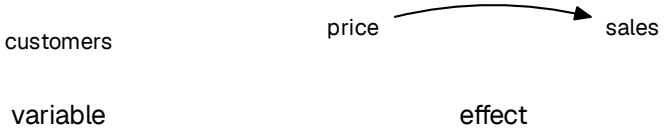
Causal loop diagram

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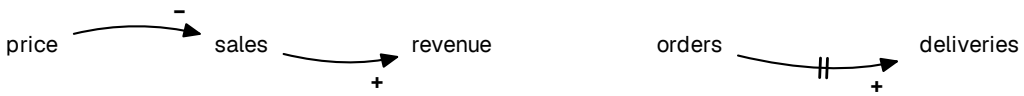
Why do some changes snowball while others settle?

Over variables and effects, a causal loop diagram shows each effect's polarity, the loops the effects close, delays, boundaries and external drivers.

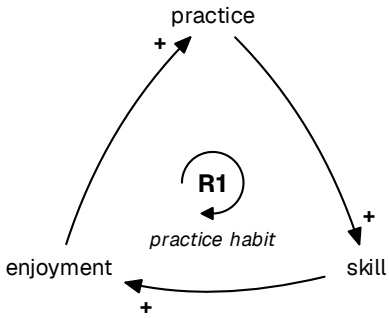
Marks



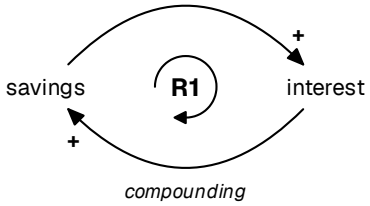
variable effect



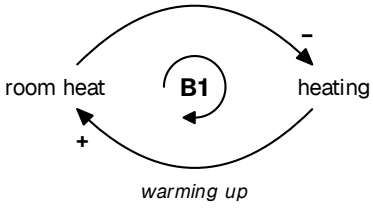
polarity delay



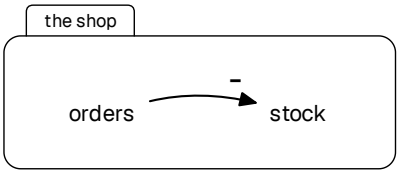
loop



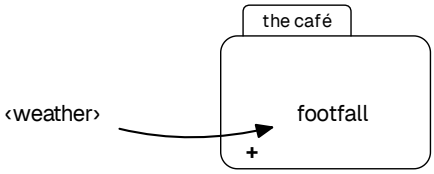
reinforcing loop



balancing loop



boundary



external driver

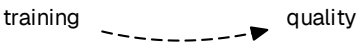


gap

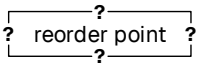
drawn as an ordinary variable



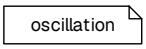
nonlinear effect



evidence coding



leverage point



behavior note



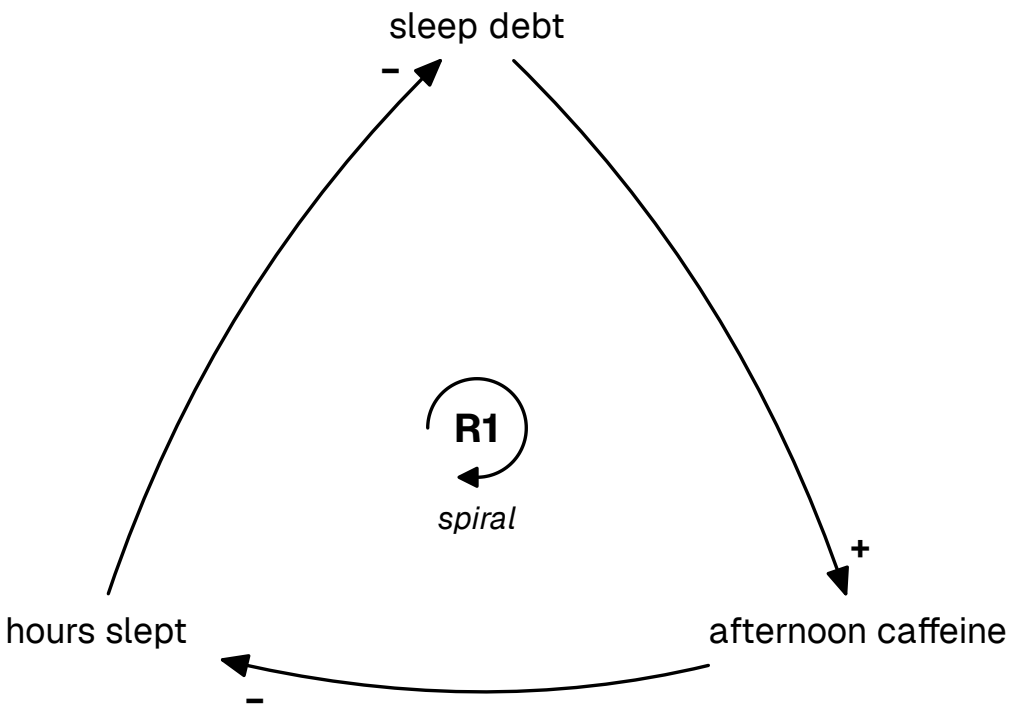
viewpoint tag

How each mark is drawn and read: chapter 4, What the notation expresses.

A line with an arrowhead

A line with an arrowhead is an **effect**: a change in the variable at its tail causes a change in the variable at its head. Its polarity gives which way, + for the same direction and – for the opposite.

A week of short nights



Sleep debt raises afternoon caffeine, caffeine cuts hours slept, and fewer hours slept raise sleep debt: two – effects make the loop reinforcing (chapter 4's week of short nights (chapter 4, A week of short nights)).

When to draw one

Draw one when a change seems to feed itself, when something drifts back however hard anyone pushes on it, or when a fix works for a while and then stops (chapter 4's signals (chapter 4, Signals you need this diagram)).

When not to draw one

When the answer turns on amounts, a stock & flow diagram (chapter 6) carries the numbers. An order of steps is a numbered list, and a change that feeds nothing back is a sentence (chapter 4, what stays informal (chapter 4, What stays informal)).

Reasoning and polish

Reasoning ●●●●● 5 of 5 Polish ●●●●○ 4 of 5 *rough loop → presentation model*

1. One loop, the polarity of each effect checked
2. Several interacting loops, delays, and loop names
3. Loop dominance, behavior notes and leverage points

Related types

- An influence map (field guide, Influence map) is converted to a causal loop diagram: its variables and causal claims carry over, and its influence claims, weights and clusters are left behind.
- A causal loop diagram is redrawn by hand as a stock & flow diagram (field guide, Stock & flow diagram), what accumulates becoming stocks, filled and drained by flows that signals set.
- A feedback control diagram (field guide, Feedback control diagram) is drawn as a causal loop diagram is, with a role written above each variable that plays one, its effects called signals.
- A system archetype (field guide, System archetype) is drawn with a causal loop diagram's marks, with roles and a declared archetype written on it.

In this book

- Chapter 4, *Loops That Amplify, Loops That Correct* (chapter 4): variables, polarity, loops, the parity rule, the gap, delays, behavior notes and leverage points; exercises CL 01–05.
- Chapter 5, *Delays, External Drivers, and Competing Loops* (chapter 5): boundaries, external drivers, nonlinear effects, evidence coding, viewpoint tags and loop dominance; exercises CL 06–10.

Sources

- Donella H. Meadows, *Thinking in Systems: A Primer* (Chelsea Green, 2008), chapter 1, on reinforcing and balancing loops, and chapter 2, on delays and shifting dominance.
- Donella H. Meadows, *Leverage Points: Places to Intervene in a System* donellameadows.org/archives/leverage-points-places-to-intervene-in-a-system/ (Sustainability Institute, 1999), on leverage points.
- John D. Sterman, *Business Dynamics: Systems Thinking and Modeling for a Complex World* (Irwin/McGraw-Hill, 2000), chapter 5, on causal loop diagrams: polarity, a loop's kind, delays, and naming variables as nouns rather than actions.
- John D. Sterman, "System Dynamics Modeling: Tools for Learning in a Complex World" doi.org/10.2307/41166098, *California Management Review* 43, no. 4 (2001), a short introduction to the same ideas.
- George P. Richardson, "Problems with Causal-Loop Diagrams" doi.org/10.1002/sdr.4260020207, *System Dynamics Review* 2, no. 2 (1986), on what polarity does and doesn't mean.

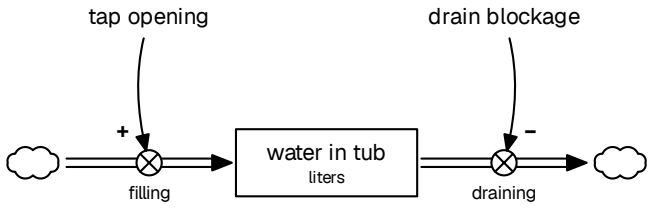
Stock & flow diagram

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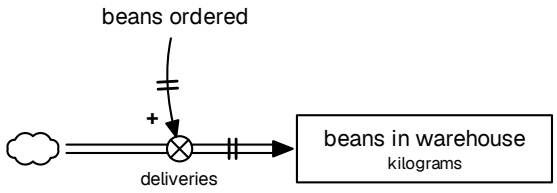
What would still be there if everything stopped?

Over variables and effects, a stock & flow diagram shows stocks, the flows that fill and drain them, clouds, and signals carrying readings to flows and to other variables.

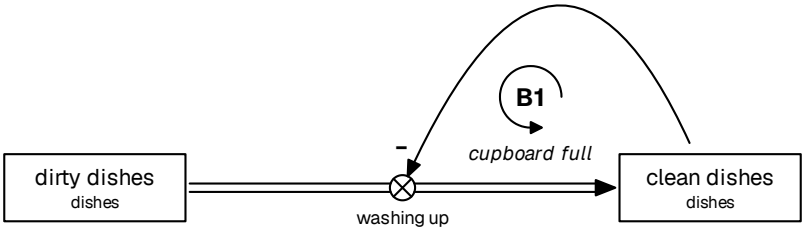
Marks



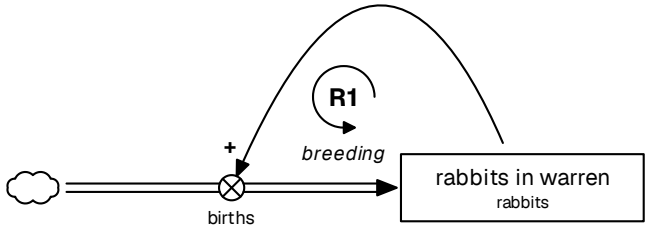
polarity



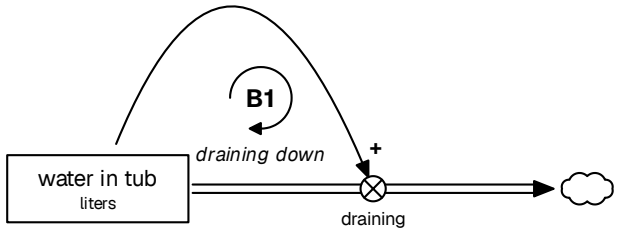
delay



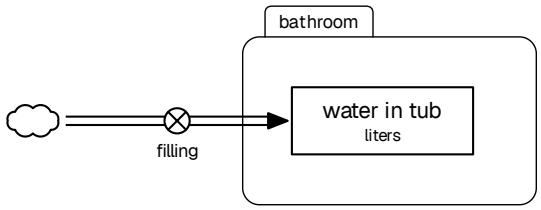
loop



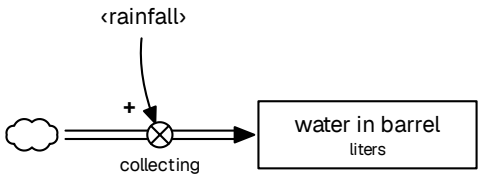
reinforcing loop



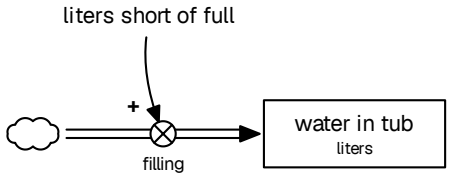
balancing loop



boundary

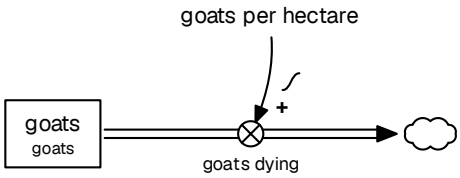


external driver

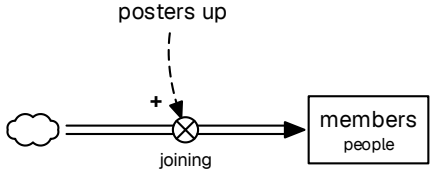


gap

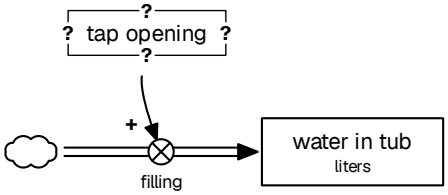
drawn as an ordinary variable



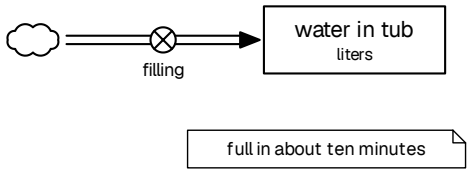
nonlinear effect



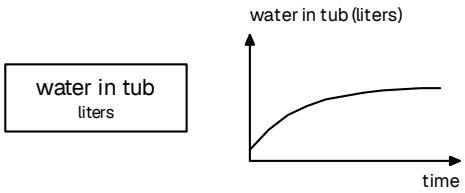
evidence coding



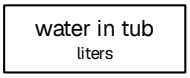
leverage point



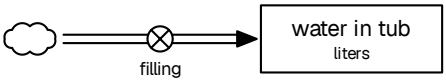
behavior note



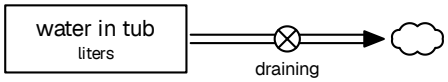
behavior-over-time graph



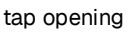
stock



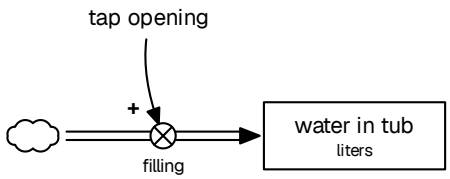
flow



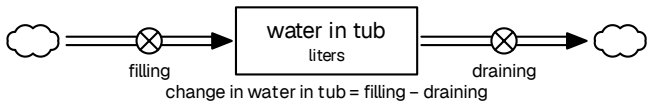
cloud



auxiliary



signal



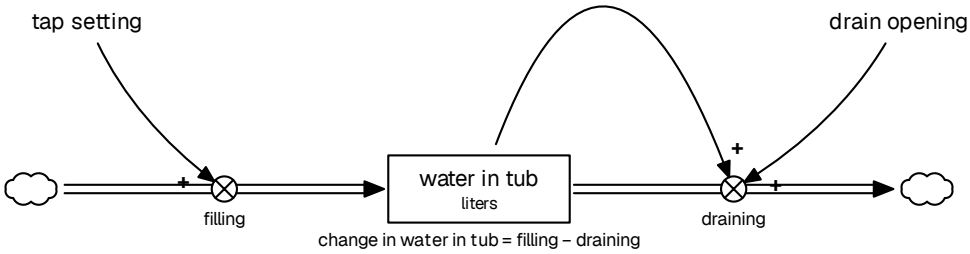
stock equation

How each mark is drawn and read: chapter 6, What the notation expresses.

A line with an arrowhead

A flow's double line moves material from one stock or cloud to another. A signal, a single thin line, is an effect carrying a reading to a flow's valve or an auxiliary, which it *changes*; no signal ends at a stock.

A bathtub filling and draining



Filling runs from a cloud into *water in tub* and *draining* out to another; signals from *tap setting* and *drain opening* set the flows, and the water's + signal to *draining* makes deeper water drain faster (chapter 6's bathtub (chapter 6, A bathtub filling and draining)).

When to draw one

Draw one when something builds up or runs down, when cutting what comes in hasn't stopped a total rising, or when something leaving one place has to turn up in another (chapter 6's signals (chapter 6, Signals you need this diagram)).

When not to draw one

When nothing accumulates, a sentence does, or a causal loop diagram (chapter 4) for effects running in a circle; how much there is now is a list of amounts. The diagram holds no numbers (chapter 6, what stays informal (chapter 6, What stays informal)).

Reasoning and polish

Reasoning ●●●●● 5 of 5 Polish ●●●●○ 4 of 5 *bathtub sketch → simulation model*

1. One stock with an inflow and outflow
2. Transfers between stocks, signals and delays
3. Units, nonlinear effects, constraints and behavior-over-time graphs

Related types

- A causal loop diagram (field guide, Causal loop diagram) is redrawn by hand as a stock & flow diagram, what accumulates becoming stocks, filled and drained by flows that signals set.
- Where the controlled variable accumulates, it is drawn on a feedback control diagram (field guide, Feedback control diagram) with a stock & flow diagram's stock, flows and signals, the roles written above them.

In this book

- Chapter 6, *What Accumulates* (chapter 6): stocks, flows, clouds, units, transfers, auxiliaries, signals, the stock equation, delays on flows and behavior-over-time graphs; exercises SF 01–05.
- Chapter 7, *Stocks Inside Feedback* (chapter 7): loops through stocks, conservation, aging chains, material and signal delays, and capacity limits; exercises SF 06–10.

Sources

- Donella H. Meadows, *Thinking in Systems: A Primer* (Chelsea Green, 2008), chapter 1, *The Basics*, on stocks, flows, clouds as sources and sinks, and the bathtub.
- John D. Sterman, *Business Dynamics: Systems Thinking and Modeling for a Complex World* (Irwin/McGraw-Hill, 2000), chapter 4, *Structure and Behavior of Dynamic Systems*, on the shapes behavior over time takes; chapter 6, *Stocks and Flows*, on the notation and on telling a stock from a flow by freezing a system in time; chapter 7, *Dynamics of Stocks and Flows*, on reading a stock's path from its net flow; chapter 11, *Delays*, on delays in material and in information; and chapter 12, *Co-Flows and Aging Chains*.
- Linda Booth Sweeney and John D. Sterman, "Bathtub Dynamics: Initial Results of a Systems Thinking Inventory" doi.org/10.1002/sdr.198, *System Dynamics Review* 16, no. 4 (2000), on how well students with no training in system dynamics read stocks and flows.
- isee systems, *Working with Building Blocks* iseesystems.com/resources/help/v3/Content/03-BuildingModels/Working_with_building_blocks.htm (Stella help), on the parts of a model in Stella, a modeling program.

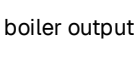
Feedback control diagram

Systems & feedback Field guide · Systems & feedback · 5 of 6

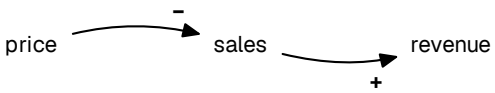
How does anything stay near a target?

Over the causal loop diagram's marks, a feedback control diagram shows each variable's role above its name, and a stock with its flows where the controlled variable accumulates.

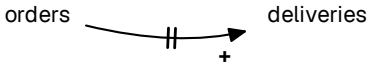
Marks



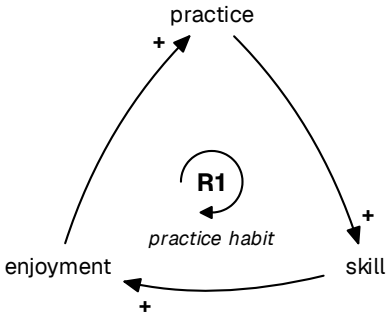
variable



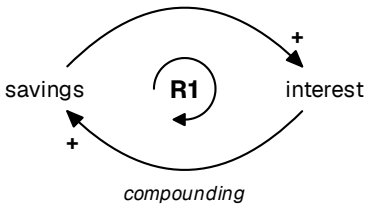
polarity



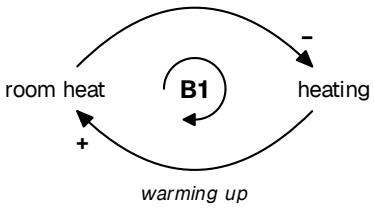
delay



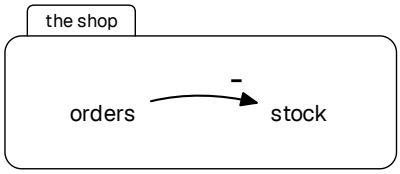
loop



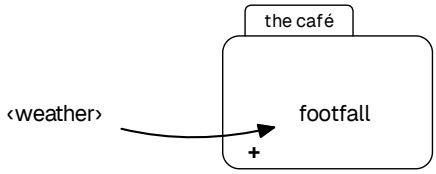
reinforcing loop



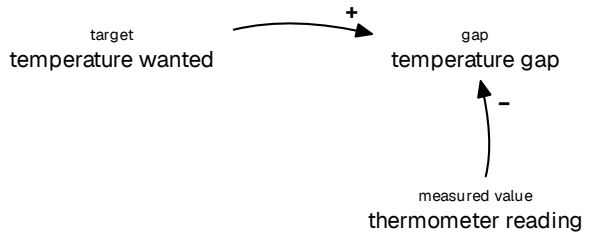
balancing loop



boundary



external driver

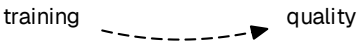


gap

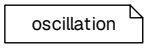
a role, written above its variable's name



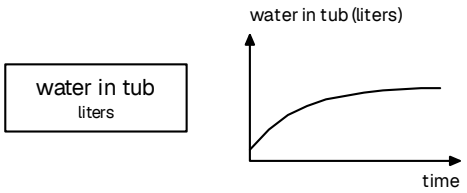
nonlinear effect



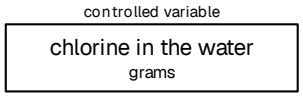
evidence coding



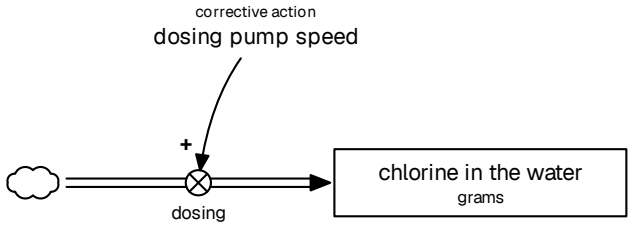
behavior note



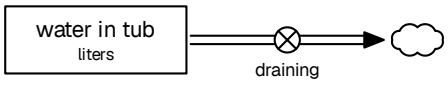
behavior-over-time graph



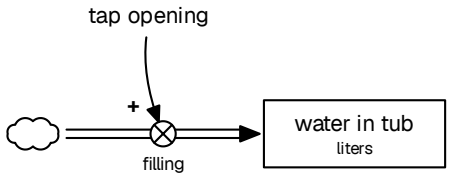
stock



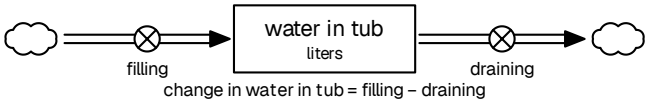
flow



cloud



signal



stock equation



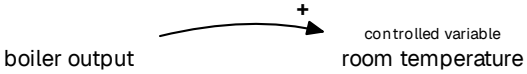
target

a role, written above its variable's name



corrective action

a role, written above its variable's name



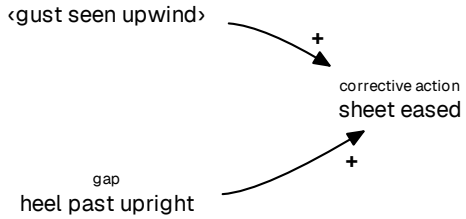
controlled variable

a role, written above its variable's name

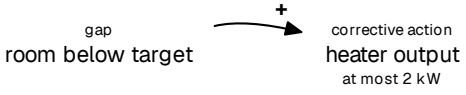


measured value

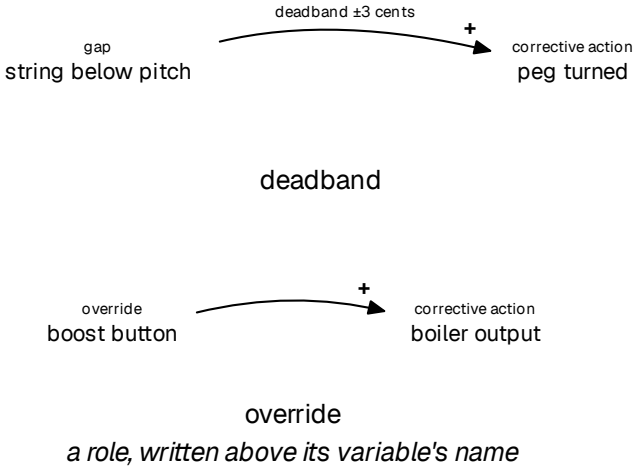
a role, written above its variable's name



feedforward



saturation

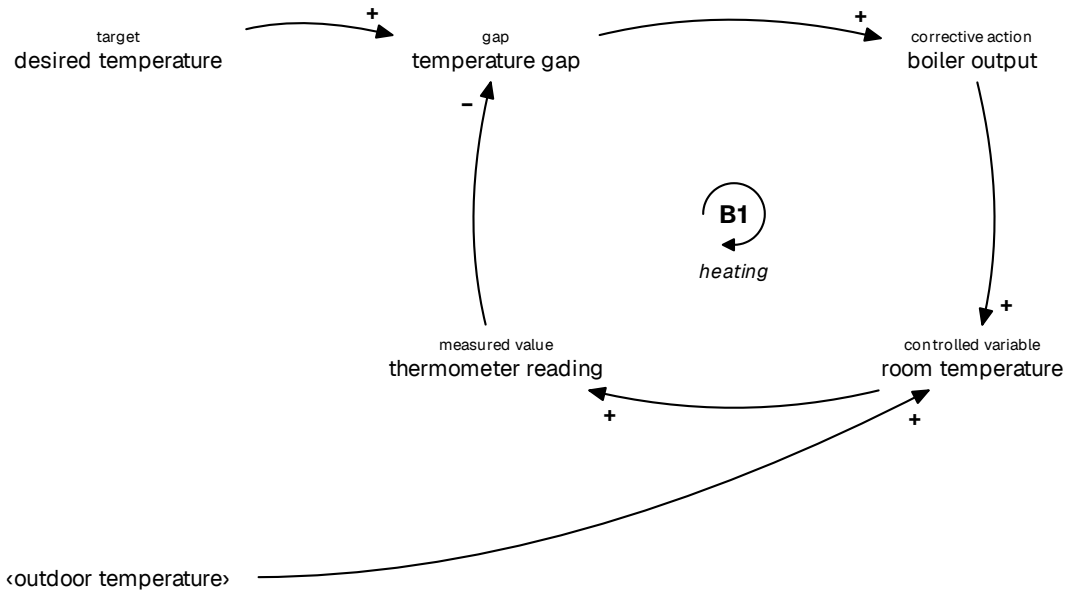


How each mark is drawn and read: chapter 8, What the notation expresses.

A line with an arrowhead

A thin line with an arrowhead is a **signal**: an effect carrying a reading or a setting, not material, that *changes* the variable at its head. Where the controlled variable is a stock, its flows' double lines move material.

A house kept warm on a winter evening



B1 *heating* runs from *temperature gap* through *boiler output*, *room temperature* and *thermometer reading*; *outdoor temperature*, an external driver, acts on *room temperature* from outside the loop (chapter 8's house (chapter 8, A house kept warm on a winter evening)).

When to draw one

Draw one when someone has chosen a value for a quantity to stay near, when the quantity and its reading can disagree, or when something outside keeps pushing it away (chapter 8's signals (chapter 8, Signals you need this diagram)).

When not to draw one

With no target, as when tea cools toward the room's temperature, a causal loop diagram (chapter 4) does; when the reading and the quantity can't come apart, as with a cistern's float, a sentence does (chapter 8, what stays informal (chapter 8, What stays informal)).

Reasoning and polish

Reasoning ●●●●○ 4 of 5 Polish ●●●●○ 4 of 5 *signal sketch → nested control loops*

1. Target, gap, corrective action, controlled variable and measured value
2. External drivers, delays, saturation and nested loops
3. Feedforward, adaptation, stability, and failure modes

Related types

- A feedback control diagram is drawn as a causal loop diagram (field guide, Causal loop diagram) is, with a role written above each variable that plays one, its effects called signals.
- Where the controlled variable accumulates, it is drawn on a feedback control diagram with a stock & flow diagram (field guide, Stock & flow diagram)'s stock, flows and signals, the roles written above them.

In this book

- Chapter 8, *Sense, Compare, Correct* (chapter 8): target and gap, measured value, corrective action, controlled variable, control loops, external drivers, delays, control with accumulation and the engineering names; exercises FC 01–05.
- Chapter 9, *Anticipation, Limits, and Nested Control* (chapter 9): feedforward, sampling and filters, deadband, saturation, competing targets, nested loops, override and false alarms; exercises FC 06–10.

Sources

- Donella H. Meadows, *Thinking in Systems: A Primer* (Chelsea Green, 2008), chapter 2, *A Brief Visit to the Systems Zoo*, on the thermostat drawn as one stock, the room's temperature, with two competing balancing loops.
- Karl Johan Åström and Richard M. Murray, *Feedback Systems: An Introduction for Scientists and Engineers* fbswiki.org/wiki/index.php/Main_Page, second edition (Princeton University Press, 2021), chapter 1, on feedback, the parts of a feedback system, a thermostat's on-off rule, feedforward and nested loops; chapter 3, on how engineers draw boxes and lines; and chapter 11, on a throttle held at its limit on a steep hill.
- Stephen Boyd, "Feedback Control Systems: Static Analysis" stanford.edu/~boyd/ee102/ctrl-static.pdf, lecture 12 of EE102 (Stanford University), on the names engineers give a feedback system's parts.
- James K. Roberge, *Operational Amplifiers: Theory and Practice* eng.libretexts.org/Bookshelves/Electrical_Engineering/Electronics/Operational_Amplifiers:_Theory_and_Practice_(Roberge)/02:_Properties_and_Modeling_of_Feedback_Systems/2.02:_SYMBOLOGY (MIT), section 2.2, the source of the engineering name for where the target and the measured value meet.

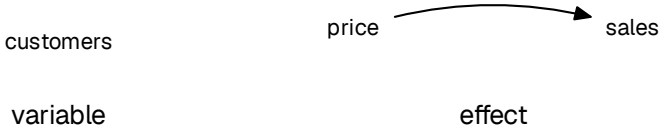
System archetype

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Which stories play out again and again?

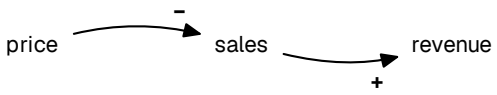
Over the causal loop diagram's marks, a system archetype shows a declared archetype, one line of words, and roles above variables' names.

Marks

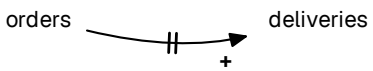


variable

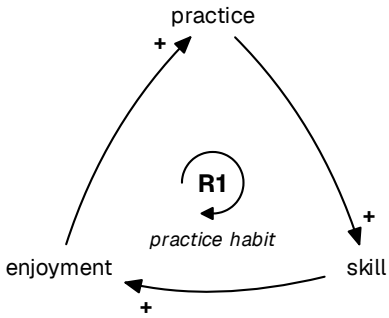
effect



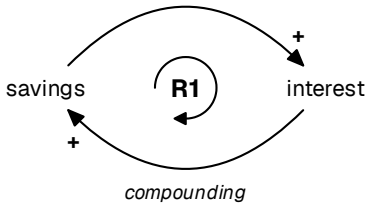
polarity



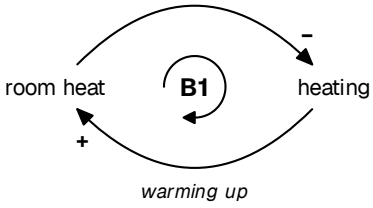
delay



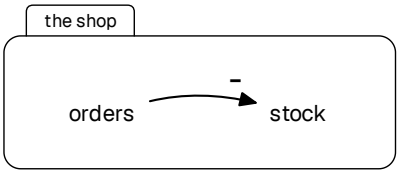
loop



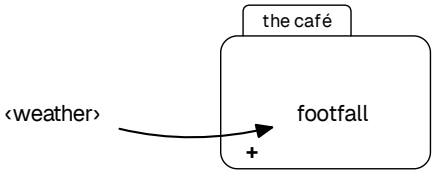
reinforcing loop



balancing loop



boundary



external driver

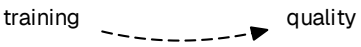


gap

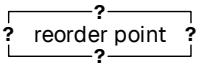
drawn as an ordinary variable



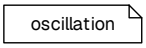
nonlinear effect



evidence coding



leverage point



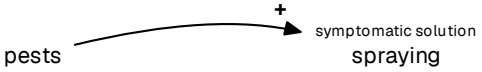
behavior note



viewpoint tag

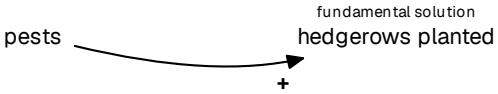
Archetype: fixes that fail

archetype



symptomatic solution

a role, written above its variable's name



fundamental solution

a role, written above its variable's name



side effect

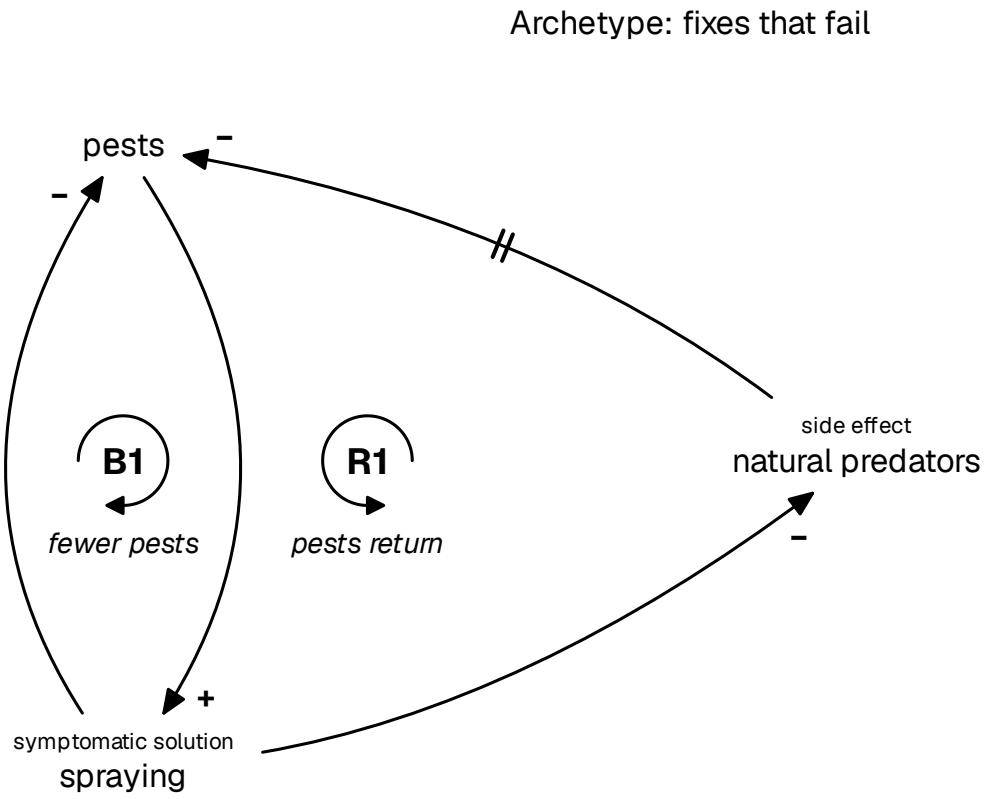
a role, written above its variable's name

How each mark is drawn and read: chapter 10, What the notation expresses.

A line with an arrowhead

A line with an arrowhead is an **effect**, as in a causal loop diagram: a change in the variable at its tail causes one in the variable at its head, its polarity giving which way.

Spraying a valley's rice



Spraying, the symptomatic solution, lowers pests in B1 *fewer pests*; through its side effect, *natural predators*, and a delay, R1 *pests return* brings them back: the loops of the declared archetype, *fixes that fail* (chapter 10's valley (chapter 10, Spraying a valley's rice)).

When to draw one

Draw one when a fix worked at first and the problem came back worse, when growth slowed while the effort behind it kept rising, or when a situation's loops sound like a story from somewhere else (chapter 10's signals (chapter 10, Signals you need this diagram)).

When not to draw one

Whether these predators eat these pests is a question for evidence, not for matching. How late a delayed change arrives, and why and how hard to act at a leverage point, go in a behavior note or prose beside the diagram (chapter 10, what stays informal (chapter 10, What stays informal)).

Reasoning and polish

Reasoning ●●●●● 5 of 5 Polish ●●●●○ 4 of 5 *archetype trace → leverage story*

1. Match a diagram's loops to one archetype
2. Adapt the structure and check every effect
3. Compare archetypes, side effects, delays and leverage points

Related types

- A system archetype is drawn with a causal loop diagram (field guide, Causal loop diagram)'s marks, with roles and a declared archetype written on it.

In this book

- Chapter 10, *Structures That Recur* (chapter 10): matching, symptomatic and fundamental solutions, side effects, five archetypes and a variable named as its opposite; exercises AR 01–05.
- Chapter 11, *Diagnosing Tangled Situations* (chapter 11): four more archetypes, one structure read as two stories, coupled archetypes and ranking leverage; exercises AR 06–10.

Sources

- Daniel H. Kim, *Systems Archetypes I: Diagnosing Systemic Issues and Designing High-Leverage Interventions* thesystemsthinker.com/wp-content/uploads/2016/03/Systems-Archetypes-I-TRSA01_pk.pdf (Pegasus Communications, 1992, 2000): the archetypes used as templates, p. 2; Peter Senge's *The Fifth Discipline* (1990) as the source of the term, p. 3; growth and underinvestment, pp. 6 and 18–19; eroding goals, pp. 12–13; escalation, pp. 14–15; fixes that fail, pp. 16–17; limits to growth, pp. 20–21; shifting the burden, pp. 22–23; success to the successful, pp. 24–25; the tragedy of the commons, pp. 26–27.
- Jennifer Kemeny, "'Accidental Adversaries': When Friends Become Foes" thesystemsthinker.com/wp-content/uploads/pdfs/050102p.pdf, *The Systems Thinker* 5, no. 1 (February 1994): 5–6, on partners whose corrective measures obstruct each other.
- Lukas Schoenenberger, Alexander Schmid and Markus Schwaninger, "Towards the Algorithmic Detection of Archetypal Structures in System Dynamics" doi.org/10.1002/sdr.1526, *System Dynamics Review* 31, no. 1–2 (2015): 66–85, on algorithms that find archetypes in simulation models.

Process map

Processes & experience Field guide · Processes & experience · 1 of 6

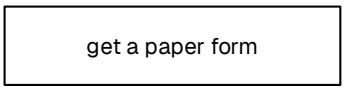
What steps does the work go through, with its decisions, exceptions and rework?

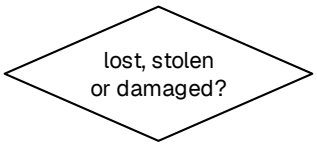
On a process map, each step of a piece of work is a box, each decision a diamond and the start and end ovals, joined in order by lines with arrowheads.

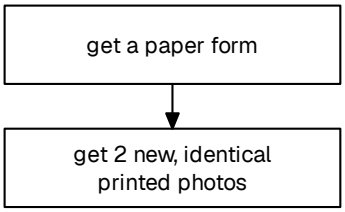
Marks

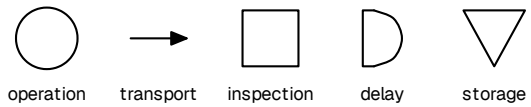
Mark	Drawn as	Stands for	Source
start or end	an oval with words	where the process starts, and each way it ends	NHS, p. 34; ANSI §3.4.2
step	a box with the step's name	a task done in the process	NHS, p. 34; ANSI §3.2.2
decision	a diamond with a question	a question with one path out for each answer	NHS, p. 34; ANSI §3.3.2.1
the next step	a line with an arrowhead	the order of the work	NHS, p. 34; ANSI §4.4
five kinds of step	a large circle, a short line with an arrowhead, a square, a D and a triangle	the ASME's operation, transport, inspection, delay (a wait, not an effect's delay) and storage, of 1947; not in the figure	Mackieh, p. 2; Barnes, ch. 5
work outside the department charted	a broken line	not in the figure, since a dash means hypothesis in this book	Gilbreth, Fig. 3
a remark on a step	words joined to it by a broken line	not in the figure, for the same reason	ANSI §3.2.4









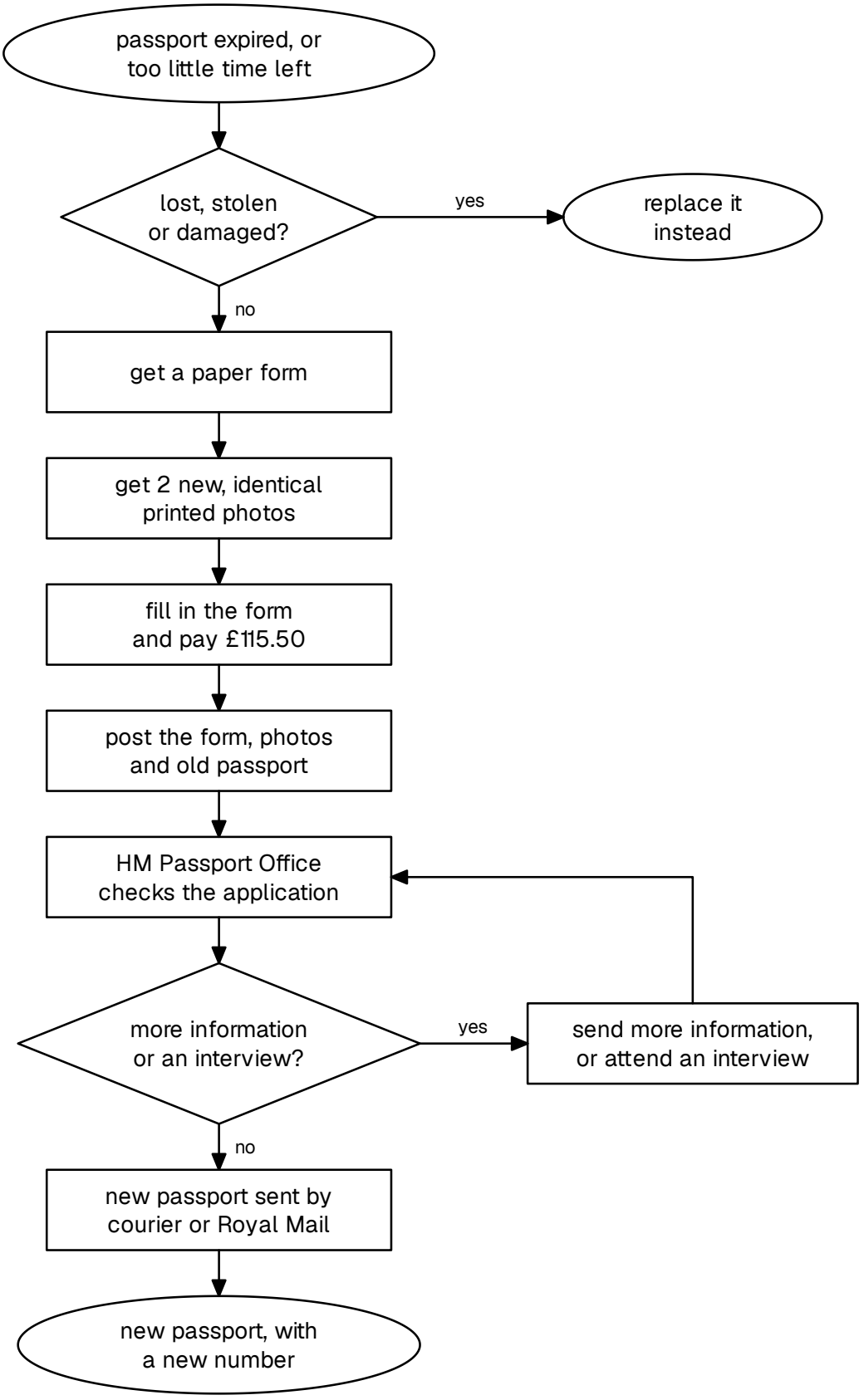


Mark	Drawn as	Stands for	Source
parallel processes; problems and ideas	a color of note or line for each	not in the figure, which is drawn in one color	NHS, pp. 17, 34

A line with an arrowhead

A line with an arrowhead means *then*: the step at its head comes next. Whereas an effect produces a change in the variable at its head, this line only orders two steps, so a path back to an earlier step is rework, the step done again, not a loop.

Renewing a passport by post



Someone renewing a UK passport by post first rules out a lost, stolen or damaged one, which is replaced instead, then fills in a paper form, pays £115.50 and posts the form with two photos and the old passport. The line back to the check is rework, which can take the application past the usual three weeks. The new passport, with a new number, comes by courier or Royal Mail.

When to draw one

Draw one before changing a piece of work, to see each step it goes through and each decision where it can go different ways. The Gilbreths charted the present method beside the proposed one in 1921, for production, selling, accounting and finance alike; NHS improvement teams map what happens to a patient 80% of the time, with each step's time and the wait between steps.

When not to draw one

Where the question is who does each step, the answer is a swimlane diagram (field guide, Swimlane diagram), with a lane for each party. Why a backlog keeps growing is a question of causes, not of order, and a causal loop diagram (field guide, Causal loop diagram) shows the loops that grow it. A short sequence one person does with no decision is a numbered list.

Reasoning and polish

Reasoning ●●●●○ 4 of 5 Polish ●●●●○ 4 of 5 *five-box flow → timed chart of the proposed method*

1. Start, tasks, one decision, and end
2. Waits, moves, checks, return paths, and the time of each step and each wait
3. Distances and times at every step, and the proposed method beside the present one

Related types

- A swimlane diagram (field guide, Swimlane diagram) is a process map with a lane for each party that does part of the work.
- In BPMN (field guide, BPMN), steps, decisions and their order are drawn as on a process map, in a notation defined formally enough that some diagrams can be run by software.
- A value stream map (field guide, Value stream map) is a process map with data added: each step's time, the waiting between steps, and the information that tells each step what to make next.
- A service blueprint (field guide, Service blueprint) is a flowchart, as a process map is, with the customer's actions laid out first, along the top, and the work that supports them beneath.
- A process map orders the steps of the work with no mark for how they could change; on a Wardley map (field guide, Wardley map) each component is placed by how evolved it is, and its expected movement is drawn.

Sources

- Frank B. Gilbreth and L. M. Gilbreth, "Process Charts: First Steps in Finding the One Best Way to Do Work" archive.org/details/processcharts00gilb, a paper to the American Society of Mechanical Engineers, New York, December 1921, on the process chart's purpose, the present and proposed methods, and the broken line for work outside the department charted.
- Ralph M. Barnes, *Motion and Time Study* archive.org/details/in.ernet.dli.2015.275373, 3rd ed. (Wiley, 1949), chapter 5, on process charts and the ASME's five symbols.
- Adham Mackieh, *Process Analysis* staff.emu.edu.tr/adhammackieh/Documents/courses/ieng301-mane301/Lecture-Notes/Lecture%20Notes-set-2.pdf,

lecture notes, Eastern Mediterranean University, pp. 1–4, on the ASME's five symbols as they differ from the Gilbreths', and the present and proposed methods charted side by side.

- American National Standards Institute, *Flowchart Symbols and Their Usage in Information Processing* nvlpubs.nist.gov/nistpubs/Legacy/FIPS/fipspub24.pdf, X3.5-1970, adopted as FIPS PUB 24 (National Bureau of Standards, 1973), on the terminal, process and decision symbols, the flowline and its direction, and the broken line of a remark.
- NHS Institute for Innovation and Improvement, *Improvement Leaders' Guide: Process Mapping, Analysis and Redesign* www.england.nhs.uk/improvement-hub/wp-content/uploads/sites/44/2017/11/ILG-1.2-Process-Mapping-Analysis-and-Redesign.pdf (2005), on the oval, box, diamond and lines with arrowheads, mapping what happens 80% of the time, and the time of each step and each wait.
- GOV.UK, *Renew or replace your adult passport* www.gov.uk/renew-adult-passport, and HM Passport Office, *About our services* www.gov.uk/government/organisations/hm-passport-office/about-our-services, for the figure's steps, its fee and its three weeks, as read on 10 October 2026.

Swimlane diagram

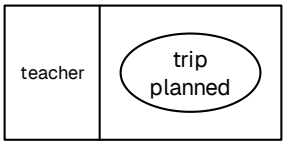
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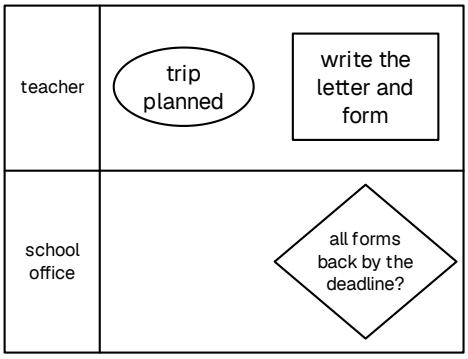
Who does each step, and where does work change hands?

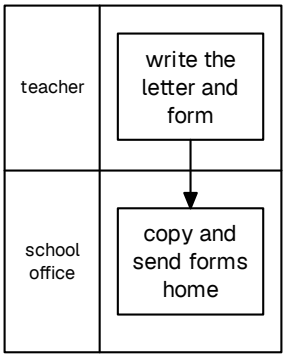
On a swimlane diagram, the steps of a piece of work run left to right through horizontal bands, one for each party, each step in the band of whoever does it, so a line with an arrowhead that crosses into another band is the work changing hands.

Marks

Mark	Drawn as	Stands for	Source
lane	a horizontal band between two ruled lines, its party's name at the left	one function, department or role	Rummler and Brache; Cymru
step, decision, start or end	a box, a diamond with a question, or an oval, inside the lane of whoever does it	a task; a question with one path out for each answer; where the process starts or ends	Cymru, step 3
the next step	a line with an arrowhead, crossing lanes where the work changes hands	the order of the work; across lanes, one party supplying its work to another	Rummler and Brache
a lane's color	each step colored by its lane	optional in the source; not in the figure, which is drawn in one color	Cymru



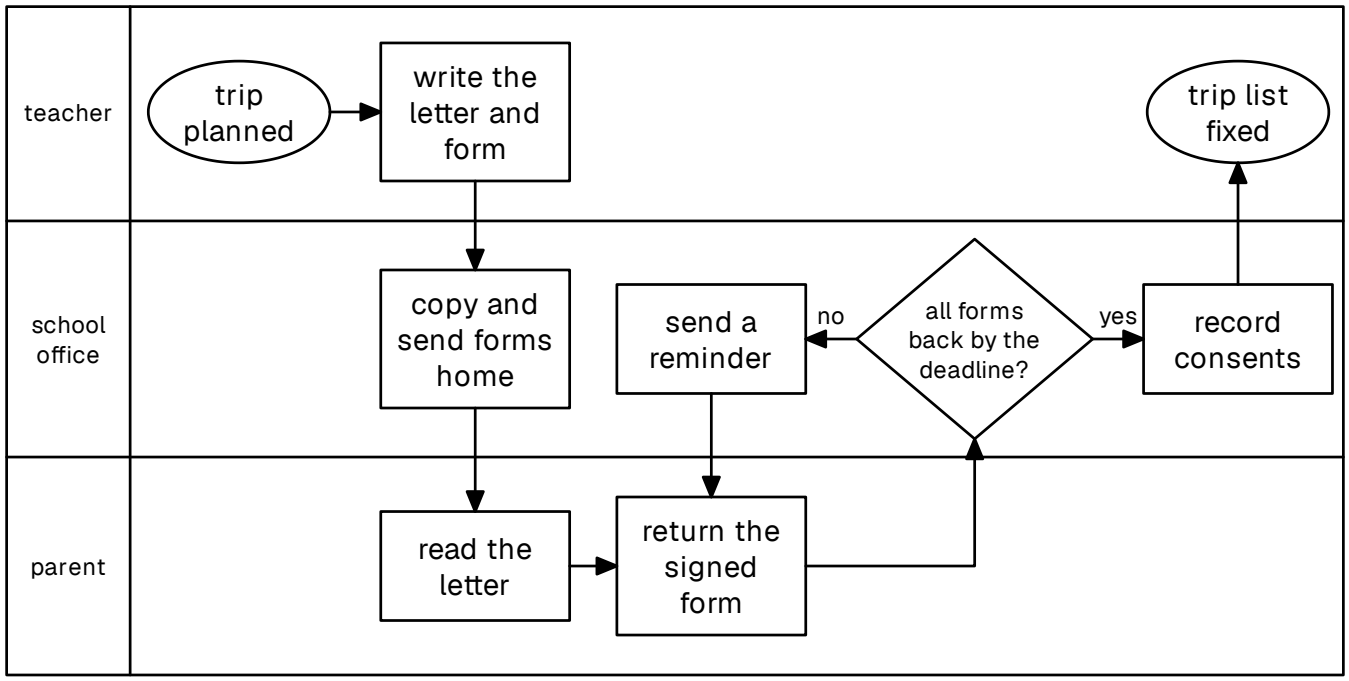




A line with an arrowhead

A line with an arrowhead means *then*: the step at its head comes next, and where it crosses from one lane to another, the work changes hands. Rummler and Brache treat each crossing as a point where one function supplies another, and read the whole map for disconnects: steps that are missing, illogical or extra. Whereas an effect produces a change in the variable at its head, this line only orders two steps, so a path back to an earlier step is rework, the step done again, not a loop.

Consent forms for a school trip



The teacher's letter and form go down to the school office to be copied and sent home, then to the parent to be read, signed and returned. Until every form is back by the deadline, the office sends reminders and the work goes round again. Five of the nine lines cross a lane, each a change of hands where a form can be lost or late.

When to draw one

Draw one where the work crosses departments or roles, as Rummler and Brache found most processes do, "spanning the 'white space' between the boxes on the organization chart". A team draws the process as it is done now, its "is" map, then as it should be done, and agrees the second.

When not to draw one

Work done wholly within one party, such as Rummler and Brache's example of programming, crosses no lanes, and a process map (field guide, Process map) orders its steps. Who answers for what, with no order of steps, is a table of roles against tasks, which Rummler and Brache call a role/responsibility matrix.

Reasoning and polish

Reasoning ●●●●○ 4 of 5 Polish ●●●●○ 4 of 5 *'is' map → agreed 'should' map*

1. One path across two or three lanes
2. Decisions, queues, systems, and return paths
3. Times at each change of lane, disconnects marked, and the 'should' map beside the 'is' map

Related types

- A swimlane diagram is a process map (field guide, Process map) with a lane for each party that does part of the work.
- BPMN (field guide, BPMN)'s swimlanes are of two kinds, a band for each participant and lanes within it, where a swimlane diagram has a lane for each party.

Sources

- Geary A. Rummler and Alan P. Brache, *The Process Level of Performance* www.rummlerbrache.com/process-level-performance (Rummler-Brache Group), on the horizontal band for each function, the points where one function supplies another, disconnects, the "is" and "should" maps, processes within one function or across several, and the role/responsibility matrix.
- Patricia A. Galagan, "Managing the White Space: The Work of Geary Rummler" assets.td.org/m/65dfbf9e88ad198a/original/MANAGING-THE-WHITE-SPACE-The-Work-of-GEARY-RUMMLER.pdf, *Training & Development*, August 1992, pp. 26–30, on Rummler's cross-functional process map.
- Improvement Cymru Academy, *Toolkit Guide: Swimlane Diagrams* performanceandimprovement.nhs.wales/our-work/quality-safety-and-improvement/improvement/improvement-cymru-academy/resource-library/academy-toolkit-guides/swimlane-diagrams-toolkit-guide/ (NHS Wales, 2024), on a lane for each role, steps drawn as a flowchart's shapes, and steps colored by lane or not.

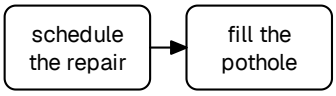
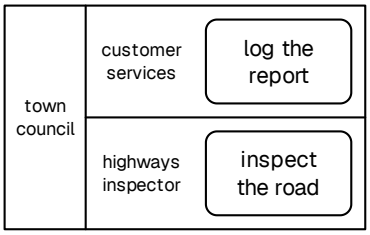
BPMN

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What happens, precisely enough that it could be run?

BPMN, Business Process Model and Notation, is the Object Management Group's standard for drawing a process as tasks, gateways and events in pools and lanes, each mark defined exactly enough that an engine can run an executable process drawn in it.

Marks

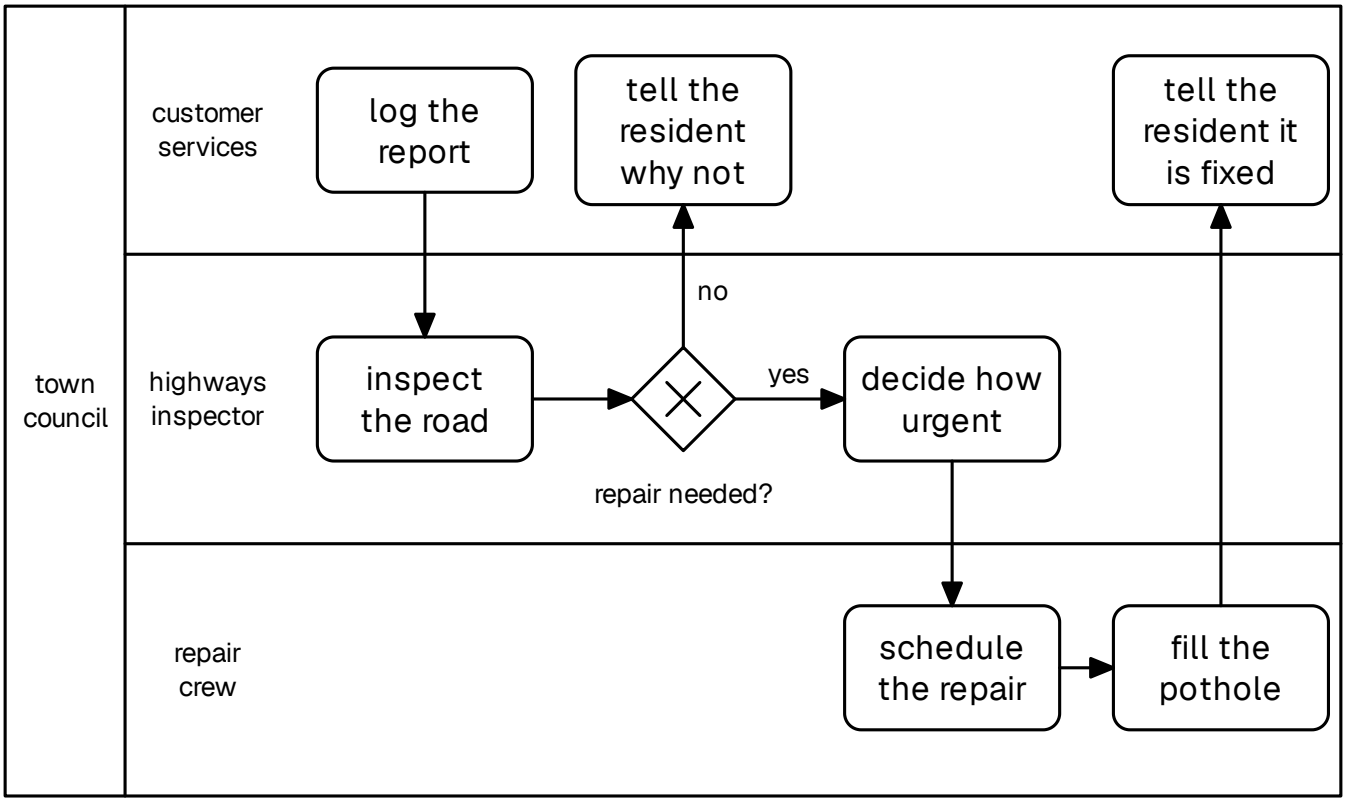
Mark	Drawn as	Stands for	Source
task 	a rounded box, thin-lined, its name inside	one unit of work	p. 154
gateway 	a diamond, an X inside an exclusive one	where paths split or join; at an exclusive one, one path is taken	pp. 286, 289
sequence flow 	a solid line with a solid arrowhead	the order of the work, within one pool	pp. 21, 95
pool 	a rectangle, named in a band at its side	one participant	p. 111
lane 	a band within a pool, named at its side	a role, system or department	pp. 304–305
start event; intermediate event 	a thin circle; a double thin circle	where the process starts; something happening during it	pp. 237, 249

Mark	Drawn as	Stands for	Source
end event	a thick circle	where a path ends; not in the figure, which is drawn at one width, so no start event either, which requires an end event	pp. 245–246
message flow	a dashed line from a small open circle to an open arrowhead	a message between two pools; not in the figure, since a dash means hypothesis in this book	p. 119
call activity	a thick-bordered rounded box	a reused process or task; not in the figure	p. 154
remark; marks of one kind	words in an open bracket, joined by a dotted line; a dashed rounded box around them	not in the figure	pp. 65–66, 69

A line with an arrowhead

A sequence flow means *then*: the task at its head is done next, within one pool. A message flow, between two pools, carries what one participant sends another. Whereas an effect produces a change in the variable at its head, a sequence flow only orders two tasks, and a message flow only moves a message.

A resident reporting a pothole



Customer services logs the report, and after the highways inspector's gateway it goes one of two ways: back to customer services to tell the resident why there will be no repair, or on to the repair crew. Each path ends at a task with no sequence flow out of it, valid where no events are drawn (p. 246).

When to draw one

Draw one where a process is to be run by an engine, or documented exactly, in as much detail as chosen, for others to build, check or take over: BPMN 2.0.2's executable and non-executable processes (p. 21).

When not to draw one

A process map (field guide, Process map) does for a process no one will run, build from or take over. Organizational models, functional breakdowns, data models, strategy and business rules are outside what BPMN covers, and it is not a data flow language (§7.2, p. 20).

Reasoning and polish

Reasoning ●●●●● 5 of 5 Polish ●●●●○ 4 of 5 *one-pool process → executable process*

1. Tasks, sequence flows and one exclusive gateway in one pool
2. Pools, messages, timers and subprocesses
3. Events attached to a task, transactions, choreography, and conformance

Related types

- In BPMN, steps, decisions and their order are drawn as on a process map (field guide, Process map), in a notation defined formally enough that some diagrams can be run by software.
- BPMN's swimlanes are of two kinds, a band for each participant and lanes within it, where a swimlane diagram (field guide, Swimlane diagram) has a lane for each party.
- Diagrams of the work behind a service blueprint (field guide, Service blueprint) can be drawn in BPMN, a more internally focused notation, and referred to from the blueprint.

Sources

- Object Management Group, *Business Process Model and Notation (BPMN)* www.omg.org/spec/BPMN/2.0.2/, version 2.0.2, formal/13-12-09 (January 2014), the source of every page number here, on every mark above and its drawing, executable and non-executable processes (§7.2.1), what a sequence flow and a message flow connect, optional start and end events (pp. 238, 246), and what BPMN leaves out (§7.2).

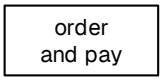
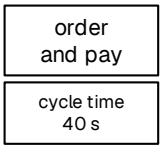
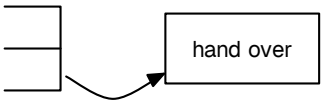
Value stream map

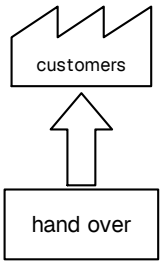
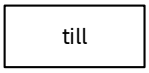
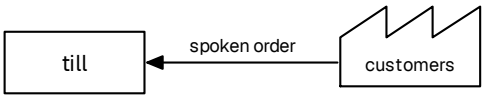
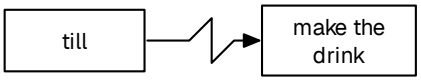
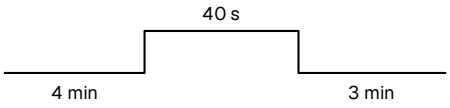
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Where does material wait from order to delivery, and what starts each step?

On a value stream map, one product family's path from order to delivery is drawn as process boxes, the inventory waiting between them, the information that starts each step, and a timeline beneath of work against waiting.

Marks

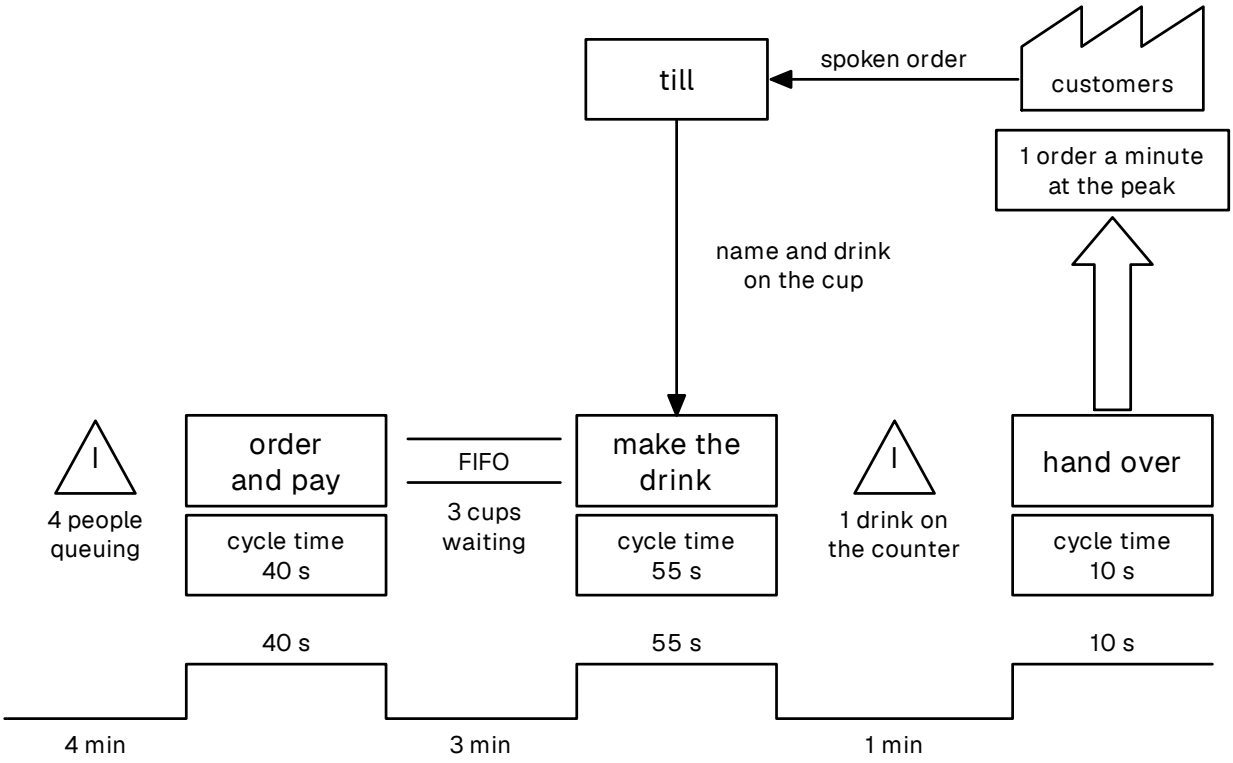
Mark	Drawn as	Stands for	Source
customer or supplier 	a factory outline with a saw-tooth roof	the supplier, top left; the customer, top right	UW
process box 	a box with the step's name	one area of material flow, ending wherever the flow stops	LEI Lexicon
data box 	a box of figures beneath a process box	its cycle time, changeover time, uptime and more	LEI Lexicon
inventory 	a triangle with an *I*, its count beneath	material waiting between steps	Roser; UW
FIFO lane 	two ruled lines around a square, a circle and a triangle, *MAX=XX* above; *FIFO* in the figure	material taken first in, first out, up to a limit	UW
supermarket; pull 	an E-shaped outline; a curved line with an arrowhead	a controlled store, and material taken from it	UW

Mark	Drawn as	Stands for	Source
shipment	a broad outlined arrow 	delivery	UW
push arrow	a broad striped arrow	material pushed to the next step; not in the figure, which has no fill	UW; Roser
production control	a box 	whoever schedules the work	UW
manual information	a thin straight line with an arrowhead 	information passed by memo, report or conversation	UW
electronic information	a zigzag line with an arrowhead 	information passed electronically	UW
shared process	a process box, its lower part hatched	a step shared with other value streams; not in the figure, which has no hatching	UW
timeline	a square wave beneath the boxes 	waits in its troughs, work on its peaks	UW; Roser

A line with an arrowhead

Between steps, material moves on *then*: pushed, along a push arrow; pulled from a supermarket; or passed first in, first out down a FIFO lane. A thin or zigzag line with an arrowhead carries the order or schedule that starts a step's work. Whereas an effect produces a change in the variable at its head, the lines between steps move material and the thin and zigzag lines carry orders.

A café's coffee order



about 10 min from queue to cup, under 2 min of it work

Of about ten minutes from joining the queue to taking the cup, under two are work; the timeline's troughs are the queue, the cups waiting in the FIFO lane and the drink on the counter. The order spoken at the till reaches the drink's maker written on the cup. Every time and count is illustrative.

When to draw one

Draw one before changing how a product reaches its customers, one product family at a time, the current state and then the future state, with material and information mapped together, in Rother and Shook's words, as "two sides of the same coin".

When not to draw one

The steps inside one area are a process map (field guide, Process map)'s. "Don't map your organization", Rother and Shook advise, but the flow of products through it. One total, such as order-to-delivery time, is a sentence.

Reasoning and polish

Reasoning ●●●●● 5 of 5 Polish ●●●●○ 4 of 5 *current-state walk → future-state design*

1. Process boxes from supplier to customer, inventory between them, the information that starts each step, and the timeline
2. Data boxes (cycle time, changeover, uptime, % complete and accurate), customer demand and takt time
3. The future-state map: pull, supermarkets, FIFO lanes, kaizen bursts, and the implementation plan

Related types

- A value stream map is a process map (field guide, Process map) with data added: each step's time, the waiting between steps, and the information that tells each step what to make next.

Sources

- Mike Rother and John Shook, *Learning to See*, Part I www.lean.org/wp-content/uploads/2021/01/Learning-to-See-part1.pdf (Lean Enterprise Institute, 1999), pp. 3–10, on material and information flow, the current-state and future-state maps, and one product family at a time.
- Lean Enterprise Institute, *Value Stream Mapping* www.lean.org/lexicon-terms/value-stream-mapping/ (Lean Lexicon), on process boxes and data boxes.
- Lean Enterprise Institute, "Understanding the Fundamentals of Value-Stream Mapping" www.lean.org/the-lean-post/articles/understanding-the-fundamentals-of-value-stream-mapping/, *The Lean Post*, 25 August 2022, on information flow.
- University of Washington, IE 337, *Value Stream Mapping* courses.washington.edu/ie337/Value_Stream_Mapping.pdf, slides 11–17, on each icon's shape and meaning: UW above.
- Christoph Roser, *Overview of Value Stream Mapping Symbols* www.allaboutlean.com/vsm-symbols/ (AllAboutLean.com, 2015), on the push arrow, the inventory triangle and the timeline.

Service blueprint

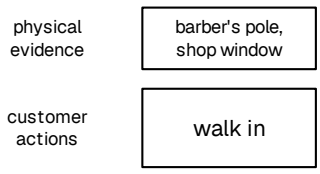
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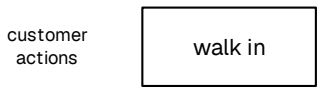
How does what the customer sees connect to the work behind it?

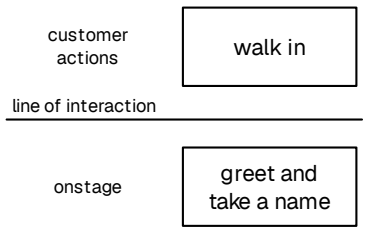
On a service blueprint, the customer's actions run left to right in time along the top, and the work behind each sits beneath it in rows divided by three ruled lines: where the customer meets staff, what the customer can see, and where staff meet the support processes.

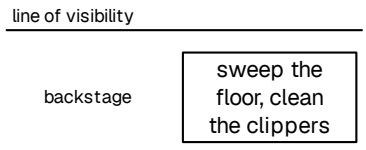
Marks

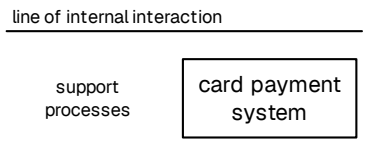
Mark	Drawn as	Stands for	Source
physical evidence	words in a box above each customer action	what the customer sees and handles at that step, the props of a service: Bitner, Ostrom and Morgan's term, not the evidence behind an effect	Bitner, pp. 72–73
customer action	a box in the top row	what the customer does	Bitner, p. 72
onstage action	a box below the line of interaction	what contact staff do in the customer's sight	Bitner, p. 72
backstage action	a box below the line of visibility	what contact staff do out of sight	Bitner, p. 72
support process	a box below the line of internal interaction	work by others that contact staff rely on	Bitner, p. 72



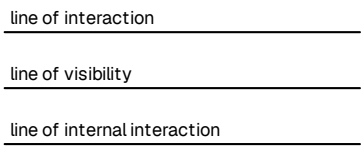


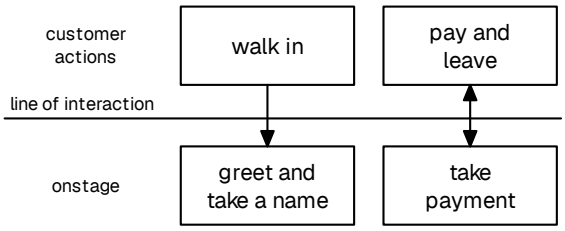


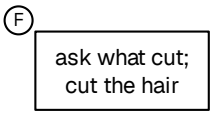




Mark	Drawn as	Stands for	Source
line of interaction, of visibility, of internal interaction	a ruled line across the rows; Gibbons dashes two, drawn solid here, as Bitner draws them	where the customer meets staff; above it, all the customer sees; where staff meet support	Bitner, pp. 72–73; Gibbons
dependency	a line with an arrowhead between rows, one-headed or two-headed	one action relying on another; two heads, agreement both ways	Bitner, pp. 72, 74; Gibbons
failure point	a symbol of the drawer's choosing	where the service can fail; not in the figure	Bitner, p. 80
grey; staff's emotions	row names and boxes filled grey; green and red faces	not in the figure, drawn in one color with no fill	Bitner, Fig. 2; Gibbons



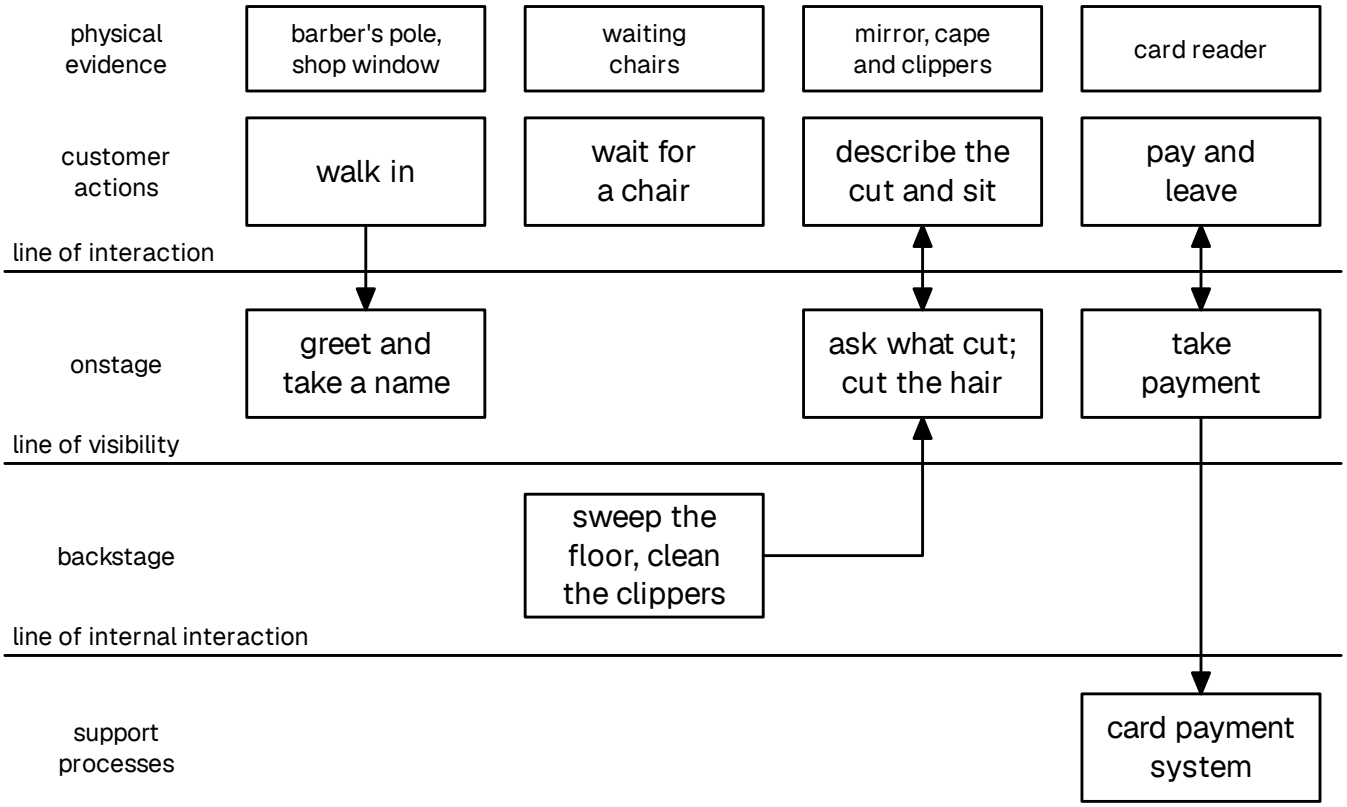




A line with an arrowhead

A line with an arrowhead means *depends on*: the action at one end relies on the one at the other, across the rows. Order in time is position, left to right, with no line from one customer action to the next. Whereas an effect produces a change in the variable at its head, this line shows only a dependence.

A haircut at a barber's



Above the line of visibility the customer sees the greeting, the cut and the payment; beneath it are the sweeping and cleaning the cut relies on, and the payment's card system. The two lines with an arrowhead at each end, at the cut and at paying, are dependencies both ways, each action relying on the other's agreement.

When to draw one

Draw one for a service the customer meets at several touchpoints, or whose delivery takes several departments' work (Gibbons), where a description in words risks "oversimplification and incompleteness" (Bitner, Ostrom and Morgan).

When not to draw one

The detail inside one support process is a process map (field guide, Process map)'s, or BPMN (field guide, BPMN)'s where it has to be exact enough to run. The customer's side alone, with what they think and feel at each stage, is a customer journey map (field guide, Customer journey map)'s.

Reasoning and polish

Reasoning ●●●●● 5 of 5 Polish ●●●●● 5 of 5 *concept blueprint → comprehensive blueprint*

1. Customer actions in time order, onstage actions, and the line of interaction
2. Backstage actions, support processes, the lines of visibility and internal interaction, and physical evidence
3. Failure points, time per step, staff emotions, measures, and the redesigned blueprint

Related types

- On a service blueprint, a customer journey map (field guide, Customer journey map)'s steps run along the top, with the work behind each one drawn beneath.
- A service blueprint is a flowchart, as a process map (field guide, Process map) is, with the customer's actions laid out first, along the top, and the work that supports them beneath.
- Diagrams of the work behind a service blueprint can be drawn in BPMN (field guide, BPMN), a more internally focused notation, and referred to from the blueprint.

Sources

- Mary Jo Bitner, Amy L. Ostrom and Felicia N. Morgan, "Service Blueprinting: A Practical Technique for Service Innovation" cmr.berkeley.edu/2008/05/50-3-service-blueprinting-a-practical-technique-for-service-innovation/ , *California Management Review* 50, no. 3 (2008): 66–94, on the five components, the three lines, the lines joining actions across rows, the concept and comprehensive blueprints, failure points, and services described in words; cited as Bitner.
- Sarah Gibbons, *Service Blueprints: Definition* www.nngroup.com/articles/service-blueprints-definition/ (Nielsen Norman Group, 27 August 2017), on lines with one and two arrowheads as dependencies, the lines between rows, staff's emotions, and when to draw one.

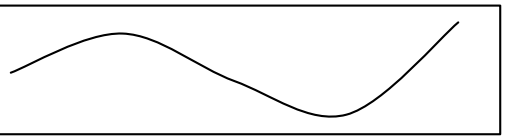
Customer journey map

Processes & experience Field guide · Processes & experience · 6 of 6

How does the customer's experience change, stage by stage?

On a customer journey map, one person, the actor, goes through the phases of a scenario, left to right in columns, with rows beneath for what they do and think, one line across the phases for how they feel, and the opportunities found along the way.

Marks

Mark	Drawn as	Stands for	Source
actor actor: a first-time buyer on a fixed budget	a persona's name, top left	the person who goes through the journey	Gibbons
scenario and expectations scenario: buying a secondhand car, expecting a fair price and no hidden faults	words in a box at the top	the situation, the actor's goal or need, and what they expect	Gibbons
phase phases | set a budget | search listings	a column's heading	a high-level stage of the journey	Gibbons
actions; mindsets phases | set a budget | search listings actions | check savings | filter by price and mileage mindsets | what can I afford? | is this mileage normal?	words in rows, one cell for each phase	what the actor does; what they think, ask and need	Gibbons
emotions delighted / emotions / frustrated 	one line across the phases, rising and falling	how the actor feels, from frustrated to delighted	Gibbons
opportunities opportunities | a history check before viewing | a price guide before haggling	words in the bottom row	what could be improved	Gibbons

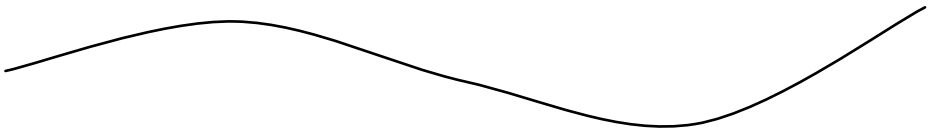
A line with an arrowhead

No line on a customer journey map has an arrowhead. The phases are columns, read left to right, as Lemon and Verhoef's experience runs from before a purchase, through it, to after it; the one line across them, the emotion line,

rises and falls with how the actor feels. That line is a plot of feeling, phase by phase, and no effect: nothing on it shows what changes what.

Buying a secondhand car

actor: a first-time buyer on a fixed budget
scenario: buying a secondhand car, expecting a fair price and no hidden faults

phases	set a budget	search listings	view and test-drive	negotiate and pay	register and drive away
actions	check savings	filter by price and mileage	inspect, drive, ask for the service history	haggle, pay	transfer the registration, insure
mindsets	what can I afford?	is this mileage normal?	has it been in a crash?	am I paying too much?	did I miss something?
delighted / emotions / frustrated					
opportunities			a history check before viewing	a price guide before haggling	

The buyer feels better while searching listings, worse at the viewing, worst when haggling and best driving away. The two opportunities sit where the line falls: a history check before the viewing, a price guide before haggling.

When to draw one

Draw one for a scenario that is a sequence of events, such as shopping or taking a trip, or one that crosses several channels, to find where the person is frustrated or delighted before changing anything; Gibbons separates journey maps, for discovery and understanding, from planning what to build.

When not to draw one

The organization's side, the work behind each step, is a service blueprint (field guide, Service blueprint)'s. Planning what to build is a list, and a situation with no sequence of events is a sentence.

Reasoning and polish

Reasoning ●●●●○ 4 of 5 Polish ●●●●● 5 of 5 *experience line → research-backed narrative*

1. Actor and scenario, phases, actions, an emotion line, and opportunities
2. Mindsets (thoughts, questions, needs), touchpoints and channels, pain points, and moments that matter
3. Research verbatims, segments, and opportunities with owners and metrics

Related types

- On a service blueprint (field guide, Service blueprint), a customer journey map's steps run along the top, with the work behind each one drawn beneath.

- A customer journey map can open a Wardley map (field guide, Wardley map): the journey's steps give the needs at the map's top, with the components that meet them beneath.

Sources

- Sarah Gibbons, *Journey Mapping 101* www.nngroup.com/articles/journey-mapping-101/ (Nielsen Norman Group, 9 December 2018), on the actor, scenario and expectations, phases, actions, mindsets, emotions and opportunities, and when to draw one.
- K. N. Lemon and P. C. Verhoef, "Understanding Customer Experience Throughout the Customer Journey" doi.org/10.1509/jm.15.0420, *Journal of Marketing* 80, no. 6 (2016): 69–96, on the experience's stages before, during and after a purchase (p. 76).

Theory of change

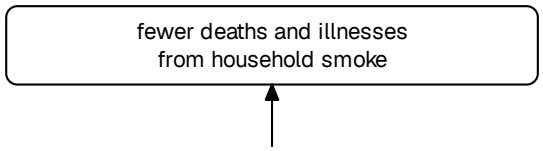
Strategy & decisions Field guide · Strategy & decisions · 1 of 6

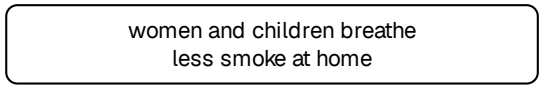
What must change, and in what order, to reach a long-term outcome?

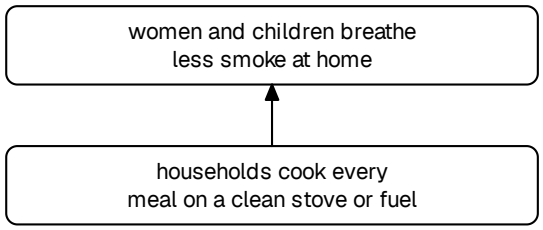
A theory of change is drawn backward from a long-term goal: beneath each outcome sit the outcomes that must come first, each joined to it by a line with an arrowhead, and a numbered intervention marks each place where someone must act.

Marks

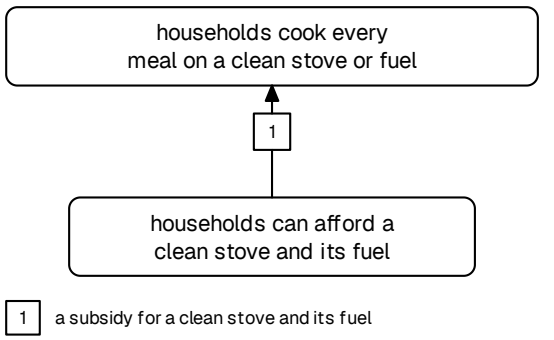
Mark	Drawn as	Stands for	Source
long-term outcome	the rounded box at the top	the goal the program is for	Glossary; Superwomen, stage 1
outcome	a rounded box with a written state	a needed condition, not yet in place	Glossary; Superwomen, stage 1
precondition	a solid line with an arrowhead, up to the outcome it is needed for	the outcome at its tail must come before the one at its head	Superwomen, stages 1–2

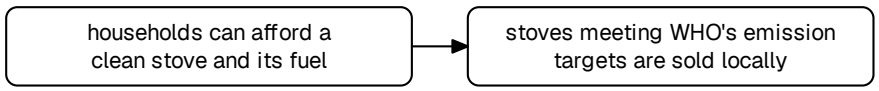


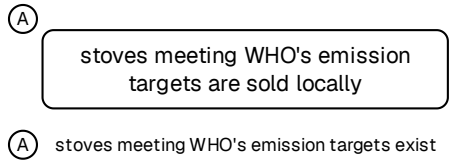




Mark	Drawn as	Stands for	Source
intervention	a dashed line with an arrowhead, carrying boxed numbers keyed to a list of activities; in the figure, solid, marked by its boxed number, since a dash means hypothesis in this book	an action the initiative takes to bring about an outcome that would not occur sufficiently without it	Superwomen, stage 4; Glossary
interaction	a sideways line with an arrowhead between two outcomes side by side	two outcomes that affect each other; not in the figure	Glossary
assumption	a capital letter in a small circle at an outcome's corner, keyed to a list	a condition already in place that the outcome relies on	Superwomen, stage 1; Glossary
accountability ceiling	a dotted line above the long-term outcome	what lies beyond the initiative's accountability; not in the figure, which has no broken line	Glossary; webinar



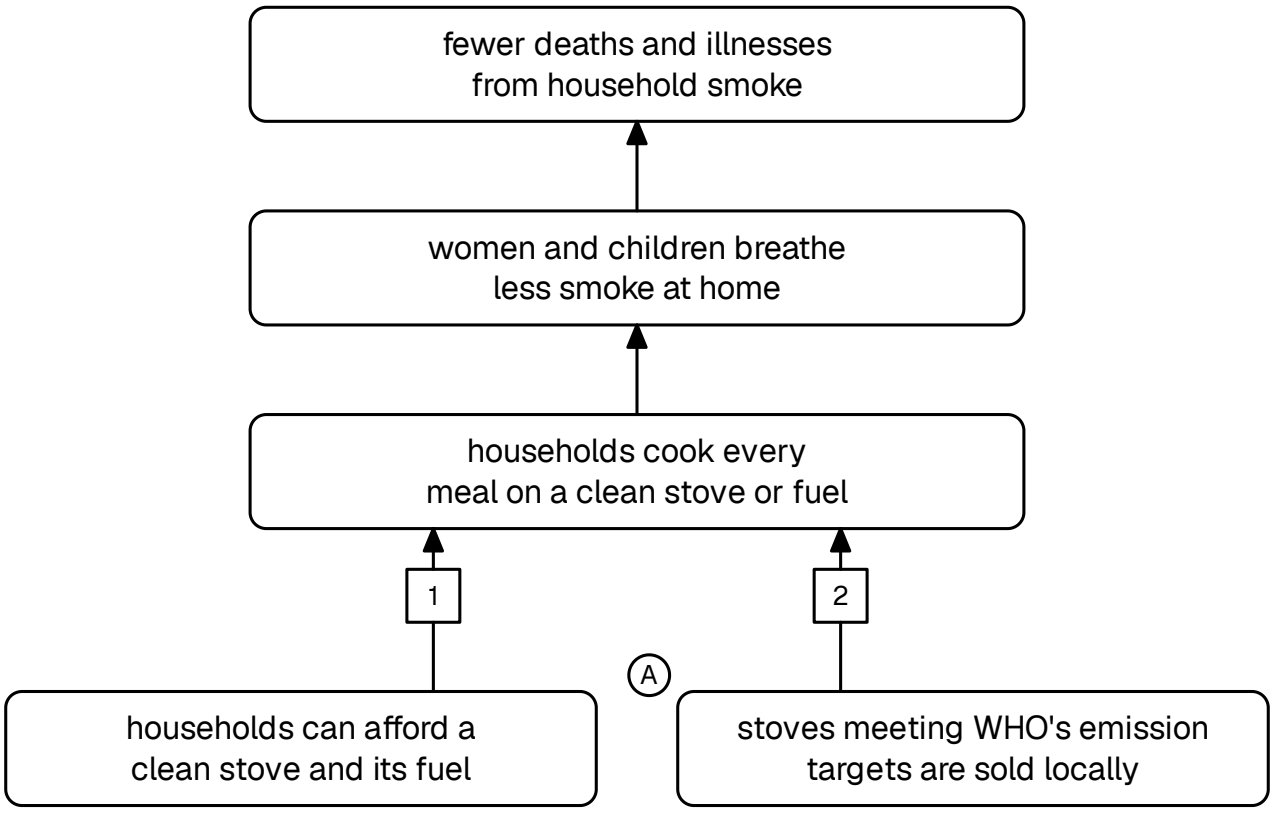




A line with an arrowhead

A line with an arrowhead means *must come before*: the outcome at its tail is a precondition of the one at its head, and the pathway is worked out downward from the long-term outcome. An effect produces a change in the variable at its head; this line orders two conditions, and why one should lead to the next is written beside the pathway, as a justification.

Clean cookstoves to cut illness from indoor smoke



1 a subsidy for a clean stove and its fuel

2 certifying stoves to WHO's emission targets

A stoves meeting WHO's emission targets exist

Household air pollution caused an estimated 2.9 million deaths a year in 2021, and about 2.1 billion people cook on open fires or inefficient stoves (World Health Organization). Fewer deaths depend on less smoke breathed at home, which depends on every meal cooked clean, which depends on stoves households can afford, through a subsidy (intervention 1), and stoves meeting WHO's emission targets on sale, through certification (intervention 2). Assumption A, that such stoves exist, already holds.

When to draw one

Draw one to design an initiative from the outcome it is for, to evaluate each outcome at the right time and in the right sequence, or to explain afterward why an initiative worked or didn't: Clark and Anderson's three uses.

When not to draw one

Where someone needs a program understood at a glance, Clark and Anderson point to a logic model, a list of the program's resources, activities, outputs and outcomes. A theory of change, they add, is a lot of work and takes time.

Reasoning and polish

Reasoning ●●●●○ 4 of 5 Polish ●●●●● 5 of 5 *outcome pathway → testable theory of change*

1. A long-term outcome and the preconditions beneath it
2. Assumptions, justifications and interventions on the pathway
3. Indicators, a narrative, and a check that the theory is plausible, doable and testable

Related types

No type is listed as related to this one.

Sources

- *What is Theory of Change?* www.theoryofchange.org/what-is-theory-of-change/ and *How does Theory of Change work?* www.theoryofchange.org/what-is-theory-of-change/how-does-theory-of-change-work/, Center for Theory of Change (theoryofchange.org), on working back from the long-term goal and the pathway of change.
- *Glossary* www.theoryofchange.org/what-is-theory-of-change/how-does-theory-of-change-work/glossary/, Center for Theory of Change (theoryofchange.org), on the outcome, the long-term and ultimate outcomes, the precondition, intervention, interaction, assumption and justification.
- ActKnowledge and the Aspen Institute Roundtable on Community Change, *Guided Example: Project Superwomen* www.theoryofchange.org/pdf/Superwomen_Example.pdf (2003, revised 2004), stages 1, 2 and 4, on how outcomes, preconditions, assumptions and interventions are drawn.
- ActKnowledge, *Theory of Change Fundamentals* www.theoryofchange.org/wp-content/uploads/toco_library/pdf/TheoryofChangeFundamentalsWebinarJune2013.pdf (webinar slides, June 2013), on the accountability ceiling and starting from the outcome.
- Hélène Clark and Andrea A. Anderson, *Theories of Change and Logic Models: Telling Them Apart* www.theoryofchange.org/wp-content/uploads/toco_library/pdf/TOCs_and_Logic_Models_forAEA.pdf (presentation to the American Evaluation Association, Atlanta, November 2004), on when to draw a theory of change and when a logic model.
- James P. Connell and Anne C. Kubisch, “Applying a Theory of Change Approach to the Evaluation of Comprehensive Community Initiatives” cnxus.org/wp-content/uploads/2022/04/08071320ApplyingTheoryofChangeApproach.pdf, in *New Approaches to Evaluating Community Initiatives*, vol. 2 (Aspen Institute, 1998), on a theory that is plausible, doable and testable.
- World Health Organization, *Household air pollution* www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health (fact sheet, 16 December 2025), for the figure’s outcomes, deaths and cooks, as read on 10 October 2026.

Decision tree

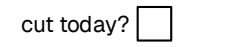
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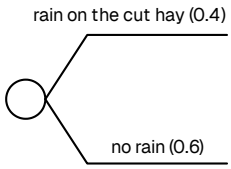
Which choice, given the chances of what follows each?

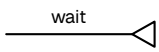
A decision tree branches left to right from a choice: a square where someone decides, a circle where something beyond their control turns out one way or another, and a branch for each choice or outcome, each path ending in the value of its result.

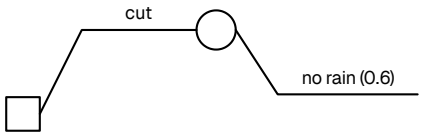
Marks

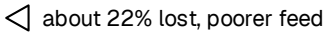
Mark	Drawn as	Stands for	Source
decision node	a small square	a point where the decision maker chooses one of several courses of action	Harvard, *Decision node*; Middleton §14.1
chance node	a small circle	a point where one of several events beyond the decision maker's control takes place, or becomes known	Harvard, *Chance node*; Middleton §14.1
end	a small triangle, or a branch's bare end when drawn by hand	the end of one path of decisions and events	Harvard, *Terminal node*; Middleton §14.1
branch	a line with its choice or event written on it, and a probability on each chance branch	one choice or one event; a node's branches exclude one another and cover every case	Middleton §14.1
payoff	a number or words at a path's end	the value of that path's result	Middleton §14.2









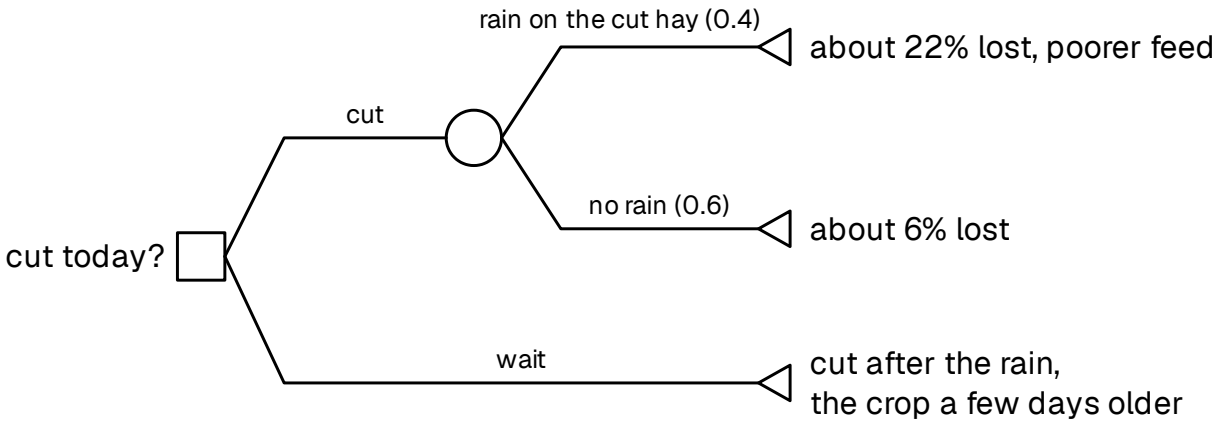


A line with an arrowhead

No line on a decision tree has an arrowhead: each branch is one choice or one outcome, read left to right in the order the decision maker learns of them, not necessarily the order in which events happen. An effect produces a change in the variable at its head; a branch leads to the next node and changes nothing, and the probabilities on a circle's branches add up to one. Howard and Matheson's influence diagram, from decision analysis, shows the

same decisions and chances as boxes and circles in one graph without loops; its lines into a chance node need not mean cause, and it is not the influence map (field guide, Influence map).

Cutting hay before forecast rain



The farmer's question is Rankin and Undersander's: the hay is ready to cut, but rain is forecast. In Collins's Wisconsin trial, alfalfa rained on after a day's curing lost 22% of its dry matter, against 6.3% for hay cured dry, and rained-on hay can lose 6 to 40% of its digestibility. The probabilities and the waiting branch's end are illustrative.

When to draw one

Draw one where a choice leads to uncertain events, or to further choices, and each path's result can be valued: ACCA teaches the tree for a series of business decisions, and Harvard's School of Public Health for clinical ones.

When not to draw one

Where the better choice is plain once the paths are written down, a sentence states it. Where no one can estimate the probabilities, which ACCA lists among the method's limits, a tree's expected values rest on guesses. Howard and Matheson found the tree's order rarely the order in which a decision maker's information is best assessed, and drew an influence diagram instead.

Reasoning and polish

Reasoning ●●●●● 5 of 5 Polish ●●●●○ 4 of 5 *choice sketch → quantified decision model*

1. One decision with distinct outcomes
2. Chance nodes, probabilities, costs and payoffs
3. Expected values, sensitivity, information value and staged options

Related types

No type is listed as related to this one.

Sources

- Harvard T.H. Chan School of Public Health, *Glossary* media.repository.chds.hsph.harvard.edu/static/filer_public/5c/a6/5ca61eed-1edf-4a6a-8616-948ca51dfdd8/2017_chds_builddec_trees_tp_gloss.pdf , teaching pack *Building Decision Trees*, on the decision tree and its decision, chance and terminal nodes.

- Mike Middleton, “Introduction to Decision Trees” cmps-people.ok.ubc.ca/bowenhui/iui/introduction-to-decision-trees.pdf, chapter 14 of his text on decision analysis with TreePlan (2007), §§14.1–14.2, on nodes and branches, their order, and terminal values.
- ACCA, “Decision trees” www.accaglobal.com/ie/en/student/exam-support-resources/fundamentals-exams-study-resources/f5/technical-articles/decision-trees.html , technical article, on drawing left to right, when to draw one, and estimating probabilities.
- Ronald A. Howard and James E. Matheson, “Influence Diagrams” doi.org/10.1287/deca.1050.0020, *Decision Analysis* 2, no. 3 (2005): 127–143, §§7 and 10, on the decision tree’s order and the influence diagram.
- Mike Rankin and Daniel Undersander, “Rain Damage to Forage During Hay and Silage Making” fyi.extension.wisc.edu/forage/files/2014/01/Raindam.pdf, *Focus on Forage* 2, no. 4 (University of Wisconsin, 2000), for the figure’s decision and losses, as read on 10 October 2026.

Stakeholder map

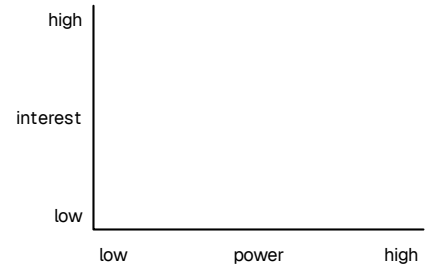
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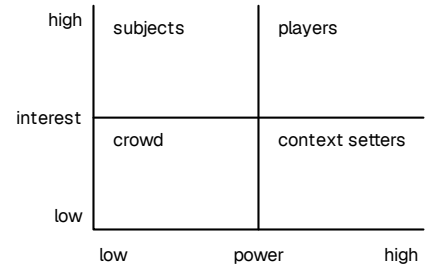
Who can affect or is affected by a decision, with what power and interest?

A stakeholder map places each party with a stake in an organization or a decision on a grid, by its power along the bottom and its interest up the side, in four quadrants named for the parties each holds.

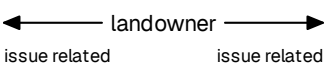
Marks

Mark	Drawn as	Stands for	Source
axes	two lines at a right angle, *interest* up and *power* across, each low to high	a party's interest in the organization or issue, and its power to affect its future	Bryson, pp. 30–31
quadrants	a line across the middle of each axis	*players* (interest and power), *subjects* (interest, little power), *context setters* (power, little interest) and *the crowd* (neither)	Bryson, p. 31
stakeholder	its name, written where it sits	a person, body or organization, inside the organization or outside it	Bryson, pp. 22, 31; Eden and Ackermann, §3
a place that varies	a line with an arrowhead at each end through a party's name, each end marked *issue related*	a party whose power and interest differ from one issue to another; not in the figure	Eden and Ackermann, Fig. 4





local planning authority

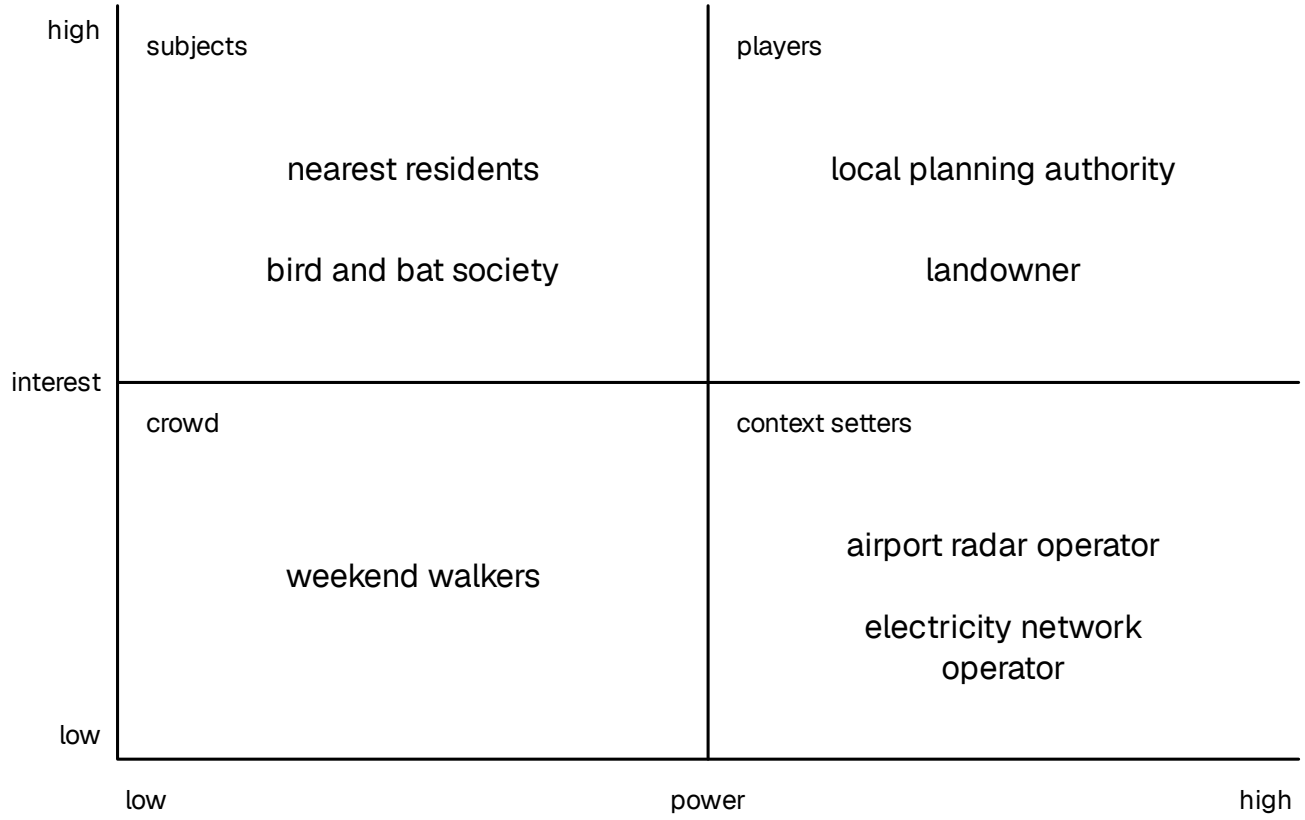


The Open University's grid swaps the axes and names the quadrants by how each party is handled: *manage closely*, *keep satisfied*, *keep informed* and *monitor*.

A line with an arrowhead

No line joins two parties: a party's place on the two axes is the whole of what the map shows about it. Eden and Ackermann draw one line with an arrowhead at each end through the media's name, each end marked *issue related*, since where the media sit depends on the issue; in Bryson's stakeholder influence diagram, drawn over the grid, lines of influence run from one party to another, each in its main direction. Neither is an effect: the first spans the places one party can take, and a line of influence joins two parties, not two quantities that rise and fall.

A wind turbine above a village



England's planning guidance on wind turbines covers noise, shadow flicker and the view for nearby residents, collision with the blades for birds and bats, and disruption to the radar that guides air traffic; local planning authorities decide schemes of 50 megawatts or less. The placings are judgements, made as in Bryson's method, where the planning team moves each name until everyone is satisfied with its place.

When to draw one

Draw one before a decision that others can help or stop: Bryson uses the grid to find whose interests and power must be taken into account, which coalitions to encourage or discourage, and whose buy-in to seek.

When not to draw one

What passes between a system and the parties outside it is a system context map (field guide, System context map)'s question. Who sways whom is Bryson's stakeholder influence diagram; who takes part in a decision, when and how, is his participation planning matrix, a table. Two or three parties are a list.

Reasoning and polish

Reasoning ●●●○○ 3 of 5 Polish ●●●●● 5 of 5 *power-interest grid → stakeholder influence diagram*

1. Parties placed by power and interest
2. Positions, lines of influence between parties, and intended moves in power or interest
3. Coalitions, conflicts, engagement strategy and change over time

Related types

- There are parties on both: on a system context map (field guide, System context map), those outside a system's boundary, with what passes each way across it; on a stakeholder map, those inside an organization and outside it, placed by power and interest.

Sources

- A. L. Mendelow, "Environmental Scanning: The Impact of the Stakeholder Concept" aisel.aisnet.org/icis1981/20, *ICIS 1981 Proceedings*, 20 (Second International Conference on Information Systems, 1981), the paper Ackermann, Eden and McKiernan name as the grid's origin.
- John M. Bryson, "What to Do When Stakeholders Matter: Stakeholder Identification and Analysis Techniques" doi.org/10.1080/14719030410001675722, *Public Management Review* 6, no. 1 (2004): 21–53, pp. 30–32, on the power versus interest grid after Eden and Ackermann (1998), its quadrants, how it is drawn and used, and the stakeholder influence diagram.
- Colin Eden and Fran Ackermann, "Modelling Stakeholder Dynamics for Supporting Group Decision and Negotiation: Theory to Practice" doi.org/10.1007/s10726-021-09745-y, *Group Decision and Negotiation* 30 (2021), §3 and Fig. 4, on internal and external stakeholders and a party whose place on the grid varies by issue.
- Fran Ackermann, Colin Eden and Peter McKiernan, "Stakeholders in Strategy Making" strathprints.strath.ac.uk/88429/1/Ackermann-etal-JSM-2024-Stakeholders-in-strategy-making.pdf, *Journal of Strategy and Management* 17, no. 2 (2024), on Mendelow's grid of 1981 and internal and external stakeholders.
- The Open University, *Successful IT systems* www.open.edu/openlearn/digital-computing/successful-it-systems/content-section-4.4, §4.4, *Power versus interest*, on the quadrants named by handling and interest that changes over time.
- GOV.UK, *Renewable and low carbon energy* www.gov.uk/guidance/renewable-and-low-carbon-energy (planning guidance, updated 14 August 2023), paras. 002, 007, 015, 016, 018, 020, 022 and 023, for the figure's parties, as read on 10 October 2026.

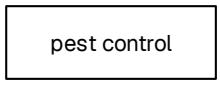
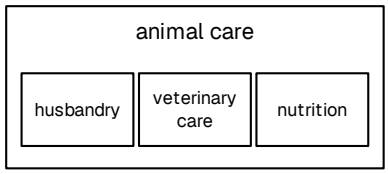
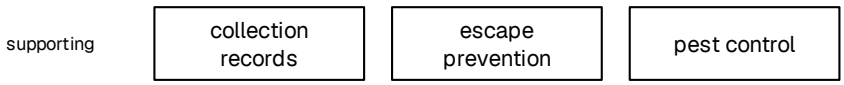
Capability map

Strategy & decisions Field guide · Strategy & decisions · 4 of 6

What must an organization be able to do, whatever its structure?

A capability map names what an organization does, each capability a box, the lower levels of a capability drawn as boxes inside it, and the first level sorted into tiers.

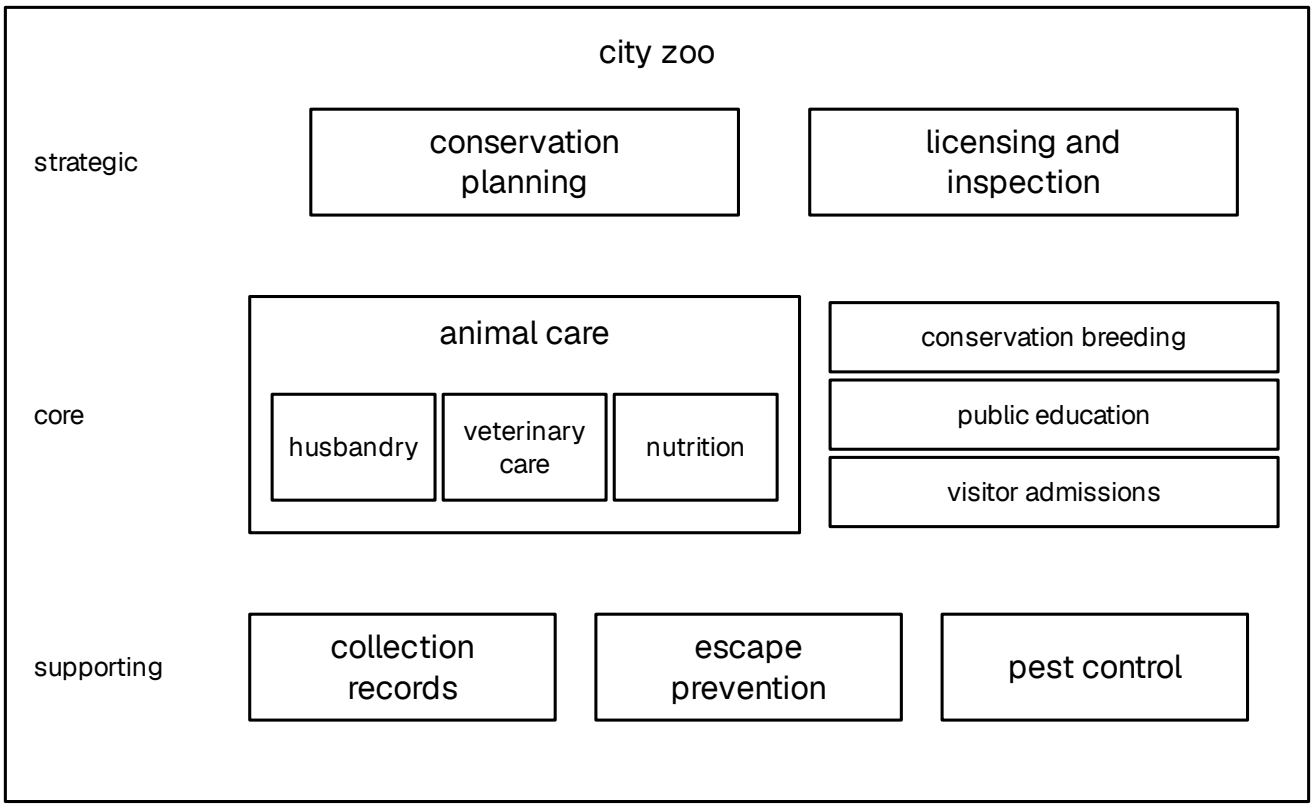
Marks

Mark	Drawn as	Stands for	Source
capability	a box with a noun phrase 	something the business does: “what we do”, not “how we do it”	G189 §2.1
lower level	boxes inside the box they divide 	the Level 2 or Level 3 capabilities that make up the one around them	G189 §3.2.2, Fig. 2
tier	a row of first-level boxes under its name 	strategic capabilities, core ones that face the customer, and supporting ones behind the scenes	G189 §3.2.1, Table 2
heat map	each box colored green, yellow, red or purple	at the maturity wanted, one level short, two or more short, or wanted and missing; not in the figure, which is drawn in one color	G189 §4.1

A line with an arrowhead

A capability map has no lines: a box inside another is part of it, a lower level of the capability around it, and a box’s tier is the row it sits in. Nesting shows neither order nor cause: an effect produces a change in the variable at its head, and a box inside another only belongs to it. G189’s authors build the map apart from the organization’s current structure, its ways of working and its IT systems.

A city zoo



Most of the capabilities are a licensed zoo's duties under the Zoo Licensing Act 1981, section 1A: conservation breeding or research, public education, animal care to a high standard of husbandry, veterinary care and nutrition, preventing escapes, keeping out pests and vermin, and up-to-date records of the collection. Conservation planning, licensing and inspection, and visitor admissions are added, and animal care is drawn to its second level. The tier each capability sits in is a judgement.

When to draw one

Draw one to set an organization's investments against what it does: G189's authors ask whether strategic investments are targeted appropriately, and where redundancy or duplication can be cut, which mapping capabilities to organizational units shows.

When not to draw one

The steps by which a capability's work gets done are a process map (field guide, Process map)'s: G189's authors name a capability with a noun, "what we do", not with a verb, "how we do it". Five or six capabilities with no lower levels are a list.

Reasoning and polish

Reasoning ●●●●○ 4 of 5 Polish ●●●●● 5 of 5 *capability inventory → investment heat map*

1. Stable level-one capabilities in strategic, core and supporting tiers
2. Lower levels, each capability described as the ability to do something
3. Heat maps of maturity, effectiveness and cost, and capabilities mapped to organizational units and value streams

Related types

No type is listed as related to this one.

Sources

- *TOGAF Series Guide: Business Capabilities* publications.opengroup.org/g189, The Open Group, G189 (June 2018), §§2.1, 3.2 and 4.1–4.2, Table 2 and Fig. 2, on what a capability is, its levels and tiers, heat maps and mapping to organizational units; read from a copy hosted by a third party. G189 is superseded by G211 publications.opengroup.org/g211 (April 2022), whose text is behind a login.
- Zoo Licensing Act 1981, section 1A www.legislation.gov.uk/ukpga/1981/37/section/1A, for the figure's capabilities, as read on 10 October 2026.

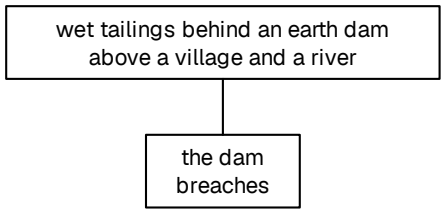
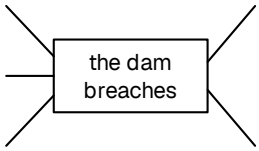
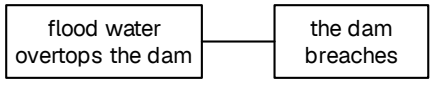
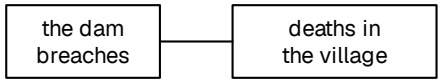
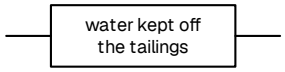
Risk bow-tie

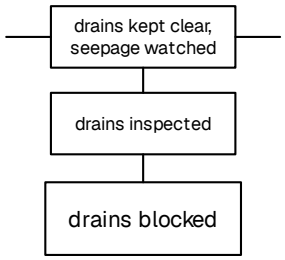
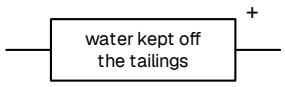
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What could release one hazard, what follows, and what barriers stand between?

A risk bow-tie is drawn around the moment control over one hazard is lost: the threats that could cause it on the left, the consequences that could follow on the right, and a barrier across each path between.

Marks

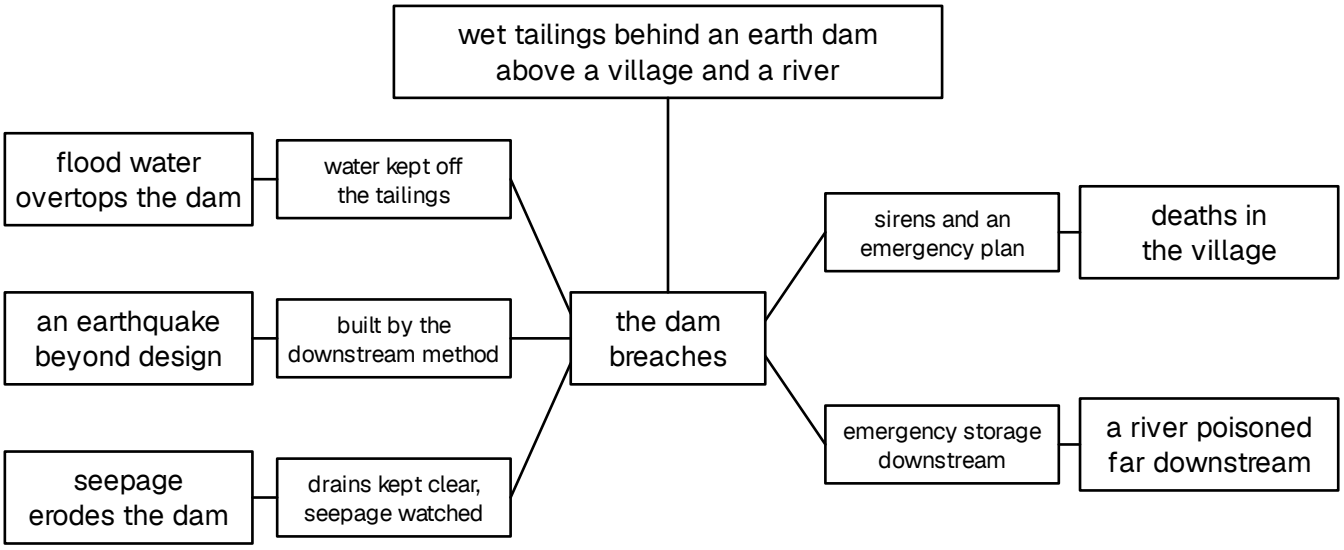
Mark	Drawn as	Stands for	Source
hazard	a box above the knot 	“any agent or operational situation that may cause harm”, with its scale and place	Manton et al.
top event	a box at the knot 	the moment control over the hazard is lost	Manton et al.
threat	a box at the left 	a cause enough by itself to bring about the top event	Manton et al.; Boult and McCulloch
consequence	a box at the right 	the worst credible result if no barrier holds	Manton et al.
barrier	a box across a path 	prevention on the left, mitigation on the right; each effective, independent and auditable	Manton et al.

Mark	Drawn as	Stands for	Source
degradation factor and control	a box on a side line into a barrier, its control across that line 	what can make a barrier fail, and what guards against it; not in the figure	Johnson et al., §2
barrier condition	a color on the barrier, or +, 0 or – beside it 	how well the barrier works; not in the figure, which is drawn in one color	Johnson et al., §5.1
lines of defense	thick lines	not in the figure, which is drawn at one width	MoD, §1.1.1

A line with an arrowhead

A risk bow-tie has no arrowheads: each line is a path that *can lead*, read left to right, from a threat to the top event and from it to a consequence. An effect relates two quantities, a change in one changing the other; a bow-tie's path joins events, and a barrier across it stops the path.

A mine's tailings dam failing



Of the tailings dam failures from 1915 to 2016 counted by the International Commission on Large Dams and by David Chambers, overtopping caused 44, earthquakes 27 and seepage 17. At Samarco in 2015 a breach killed nineteen people and the slurry traveled 650 km to the sea; the company had no emergency plan, warning lights

or sirens. After the Baia Mare spill of 2000, an international task force chaired by the European Commission insisted on emergency storage.

When to draw one

Draw one where the people who run a hazardous operation need to see, for one hazard, each threat, each consequence and the barriers on every path: the CCPS and Energy Institute committee wrote for operators, maintenance technicians and managers who want "short, clear, preferably visual, overviews". Outside oil and gas, where it began, the technique suits industries where quantifying the risk isn't warranted (MoD).

When not to draw one

Without fault tree or event tree analysis, a bow-tie is not quantified, and whether its barriers are enough is not evaluated (MoD). Johnson et al. warn against too many bow-ties drawn too soon.

Reasoning and polish

Reasoning ●●●●● 5 of 5 Polish ●●●●○ 4 of 5 *hazard sketch → safety case*

1. Hazard, top event, threats, consequences and barriers
2. Barrier owners and types, degradation factors and degradation controls
3. Barrier effectiveness and condition, independence, and review of degraded barriers

Related types

No type is listed as related to this one.

Sources

- Mark Manton and others, "Standardisation of Bow Tie Methodology and Terminology via a CCPS/EI Book" www.icheme.org/media/15543/poster-09.pdf, IChemE *Hazards 27*, Symposium Series 162 (2017), on each mark's meaning and the barrier rule.
- Martin Johnson, Mark Manton, Charles Cowley and Mark Scanlon, "Bow Ties in Risk Management: Using the New CCPS-EI Book to Avoid Pitfalls" www.icheme.org/media/16937/hazards-28-paper-31.pdf, IChemE *Hazards 28*, Symposium Series 163 (2018), §§2, 5.1 and 8.3, on the marks in order, degradation controls, barrier condition and too many bow-ties.
- Mark Boult and Paul McCulloch, *Introduction to the CCPS / Energy Institute Process Safety Book "Bow Ties in Risk Management"* assets.contenthub.wolterskluwer.com/api/public/content/8d4c7e05a991458eadd5a07c8d39dced (presentation, DNV GL and CGE, undated), on threats.
- UK Ministry of Defence, ASEMS, *Bow-Tie Diagram* www.asems.mod.uk/printpdf/content/bow-tie-diagram, §§1.1.1–1.1.3, on the two sides, lines of defence, safety cases, uses and limits.
- Charles Roche, Kristina Thygesen and Elaine Baker (eds), *Mine Tailings Storage: Safety Is No Accident* www.grida.no/publications/383 (UN Environment and GRID-Arendal, 2017), pp. 17, 29–30 and 44, for the figure's hazard, threats, barriers and consequences, with the International Commission on Large Dams' (2001) and Chambers's (2017) counts of failures by cause, reproduced on p. 30, as read on 10 October 2026.

Wardley map

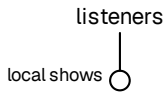
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What does someone need, what chain of components meets it, and how evolved is each?

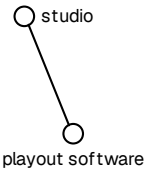
A Wardley map places the components that meet a user's need: up the map by how visible each is to the user, across it by how evolved, from genesis to commodity, each joined by a plain line to the components it needs.

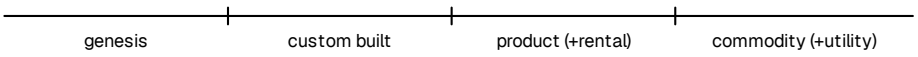
Marks

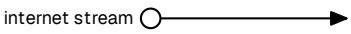
Mark	Drawn as	Stands for	Source
anchor	the user and their need, at the top	whom the map is for	ch. 2
component	a small circle with its name	a part of the value chain	ch. 2; WardleyMaps.com
need	a plain line from a component down to one it needs	"Each component needs the component below it"	ch. 2; WardleyMaps.com
evolution	an axis along the bottom in four stages: genesis, custom built, product (+rental), commodity (+utility)	how evolved each component is; all move left to right over time	ch. 2
movement	a dashed red line to an arrowhead	where a component is expected to evolve; drawn here solid, since a dash means hypothesis in this book	ch. 2, Fig. 12; WardleyMaps.com, *point of change*
inertia	a filled black rectangle across the movement	resistance to the change; not in the figure, which has no fills	WardleyMaps.com
constraint	a thick black line	a limit on a component; not in the figure, which is drawn at one width	WardleyMaps.com









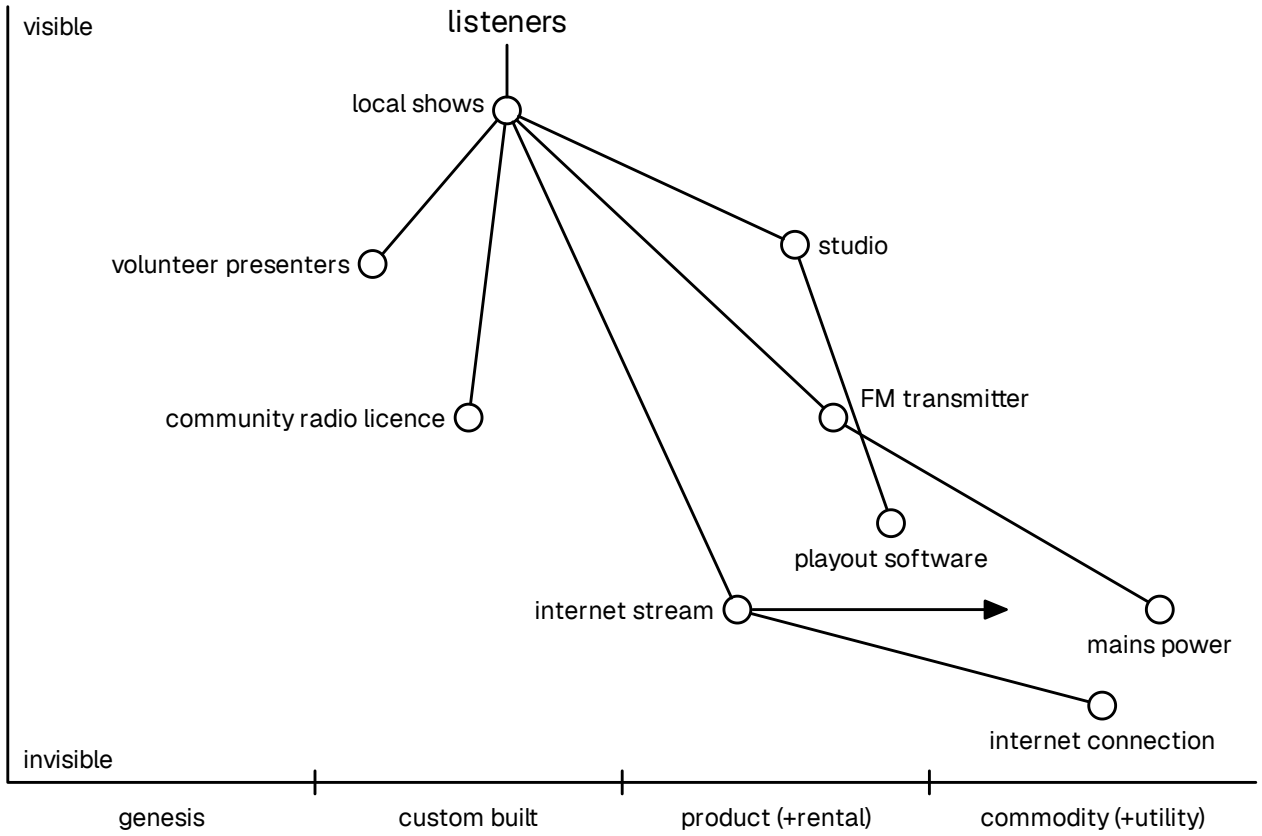


A line with an arrowhead

A plain line means *needs*: the component above it needs the one below, and the chain of needs runs down from the user. A line with an arrowhead is movement, a component's expected evolution toward commodity. Neither is an effect, a change in one quantity changing another: a need line joins two components, and movement shifts one

component along the evolution axis. Wardley also reads each line as a flow of capital between components, each component a store of capital, in his sense and not a stock & flow diagram's.

A community radio station



The station's listeners need local shows, which need volunteer presenters, a studio, a community radio licence, an FM transmitter and an internet stream. Under the Community Radio Order 2004 such a station is run to deliver social gain, its community given opportunities to take part in running it. The placings are judgements, and the stream's move toward a utility is the one movement drawn.

When to draw one

Draw one to see which parts of what an organization provides are commodities and which are still being worked out, and where each is moving: Wardley began mapping because a value chain alone shows no movement, and calls maps "a communication and learning tool".

When not to draw one

Wardley's own test: if a few hours' mapping teaches nothing new about a business, stop. The order of the work's steps is a process map (field guide, Process map)'s, which in Wardley's account has position but no movement. How users meet what is provided is a customer journey map (field guide, Customer journey map)'s, and Wardley calls a user journey "always a good start" toward finding their needs.

Reasoning and polish

Reasoning ●●●●● 5 of 5 Polish ●●●●● 5 of 5 *value-chain sketch → strategic movement map*

1. User need, value chain, each component's evolution and its movement
2. Climatic patterns, inertia, and flows of capital, risk and information
3. Doctrine, gameplay with accelerators, decelerators and constraints, and maps drawn wider or narrower

Related types

- A process map (field guide, Process map) orders the steps of the work with no mark for how they could change; on a Wardley map each component is placed by how evolved it is, and its expected movement is drawn.
- A customer journey map (field guide, Customer journey map) can open a Wardley map: the journey's steps give the needs at the map's top, with the components that meet them beneath.

Sources

- Simon Wardley, *Wardley Maps* learnwardleymapping.com/book/ (CC BY-SA 4.0; compiled for LearnWardleyMapping.com by Ben Mosior, December 2020), chapters 1, 2 and 4, on the map's basic marks, the anchor, needs, evolution, movement, capital flows, and when to stop.
- WardleyMaps.com, *Notation* www.wardleymaps.com/glossary/notation (adapted by Krzysztof Daniel from Wardley's material, CC BY-SA 4.0), on how the component, dependency, point of change, inertia and constraint are drawn.
- The Community Radio Order 2004, article 3 www.legislation.gov.uk/uksi/2004/1944/article/3, for the figure's licence, as read on 10 October 2026.

Glossary

Each term the book teaches, the chapter teaching it, and its names in other books.

archetype
A named loop structure that recurs across situations, such as fixes that fail, declared on a diagram as a hypothesis by one line of words: *Archetype: fixes that fail*.
Taught in chapter 10, Archetypes
Other names: pattern, motif

auxiliary
A variable in a stock & flow diagram that neither accumulates nor flows, such as a setting, a capacity or a ratio, drawn as its name alone.
Taught in chapter 6, Auxiliaries
Other names: converter, constant, parameter, aux

balancing loop
A loop that makes a change settle, moving a variable toward a target, with an odd number of – effects, labeled `B1`, `B2` and so on.
Taught in chapter 4, Loops
Other names: negative loop, goal-seeking loop, correcting loop, limit loop

behavior note
A few words on a diagram naming the behavior expected from its structure, such as *oscillation* or *overshoot*.
Taught in chapter 4, Behavior notes
Other names: annotation, caption, comment

behavior-over-time graph
A small graph of one quantity over time, drawn beside a diagram as two axes at a right angle, the quantity's name up the vertical and *time* along the horizontal, with one line of a named shape such as *exponential* or *overshoot and collapse*.
Taught in chapter 6, Behavior-over-time graphs
Other names: behavior sketch, behavior trace, behavior curve, goal line

boundary
A thin, solid, rounded outline drawn around a system, with a tab carrying the system's name, separating what the diagram accounts for from what sits outside it.
Taught in chapter 2, The boundary
Other names: system boundary, scope, frame, context

causal loop diagram
A diagram of variables joined by effects, each with its polarity, whose closed paths are declared as reinforcing or balancing loops.
Taught in chapter 4

central outcome

The one variable an influence map is drawn around, its name double-underlined.

Taught in chapter 3, The central outcome

Other names: center, root, goal

cloud

Where a flow's material comes from or goes to outside the model, drawn as a small scalloped outline with no name, at the end of exactly one flow.

Taught in chapter 6, Clouds

Other names: external pool

cluster

Two or more variables of an influence map that share something, drawn within four corner brackets, a label inside the top-left one naming what they share.

Taught in chapter 3, Clusters

Other names: group, theme, category

controlled variable

The quantity the corrective action holds near the target, such as *room temperature*, with *controlled variable* written in small type above its name, or above its stock's box where it accumulates.

Taught in chapter 8, Controlled variable

Other names: process, plant, process variable, controlled process

corrective action

The variable changed to close the gap, such as *boiler output*, with *corrective action* written in small type above its name.

Taught in chapter 8, Corrective action

Other names: actuator, control action, manipulated variable

deadband

A range of gaps within which the corrective action stays as it is, written beside the middle of the signal from the gap to the corrective action: *deadband ±3 cents*.

Taught in chapter 9, Deadband

Other names: tolerance, hysteresis

delay

Two short strokes across an effect or a flow, meaning that the change, or the material, arrives well after its cause.

Taught in chapter 4, Delays

Other names: lag, latency, delay mark

effect

A line with an arrowhead from one variable to another, meaning that a change in the first changes the second.

Taught in chapter 1, Effects

Other names: link, arrow, edge, connector, arc, relationship

evidence coding

Solid and dashed lines on effects, the author's judgment of how well supported each effect is as a causal mechanism: in a diagram with a dashed effect, a solid effect is more supported and a dashed one less supported, a hypothesis; where the author draws the line between them is a decision a reader can question.

Taught in chapter 1, Evidence coding

Other names: confidence, certainty, strength

exchange

One named thing crossing the boundary between the system and an external entity, drawn as a solid line with one arrowhead joining the entity's oval to the boundary, its name beside its middle.

Taught in chapter 2, Exchanges

Other names: flow, interface, channel, message

external driver

A variable outside every boundary that affects something inside and is not affected back, its name drawn in angle brackets: *‹regional population›*.

Taught in chapter 5, External drivers

Other names: exogenous variable, input, driver, disturbance, load, perturbation

external entity

A party outside the boundary that the system exchanges something with, such as a person or an organization, drawn as its name in an oval.

Taught in chapter 2, External entities

Other names: actor, stakeholder, user, external system

feedback control diagram

A diagram of corrective action holding a quantity near a target, drawn as a causal loop diagram is, with the part each variable plays in its control loop, such as *target* or *measured value*, written in small type above its name.

Taught in chapter 8

feedforward

A path of signals from an external driver to a corrective action that passes through no gap, so the correction starts before any gap opens, with no mark of its own.

Taught in chapter 9, Feedforward

Other names: anticipation, predictive action

flow

Material moving into or out of a stock, drawn as a double line with an arrowhead where the material goes and, at its middle, a valve with the flow's name beside it.

Taught in chapter 6, Flows

Other names: pipe, rate valve

fundamental solution

A variable standing for a remedy that acts on the cause, more slowly than a symptomatic solution, with *fundamental solution* written in small type above its name.

Taught in chapter 10, Symptomatic and fundamental solutions

Other names: root-cause fix, real solution

gap

The difference between the value someone wants and the value they have, drawn as a variable of its own, which a balancing loop closes.

Taught in chapter 4, The gap

Other names: error, discrepancy, deficit, shortfall, comparator

influence claim

An effect in an influence map with no + or −, drawn as a solid line with an arrowhead: one variable bears on another, in a direction not yet known.

Taught in chapter 3, Influence claims

Other names: soft link, association, correlation

influence map

A diagram of what bears on one central outcome, each influence claim with a weight where ranked and a polarity where its direction is measured, the variables gathered into clusters.

Taught in chapter 3

leverage point

A variable proposed as the place to intervene, drawn as a box with a question mark at the middle of each side: a hypothesis, not a proven fix.

Taught in chapter 4, Leverage points

Other names: intervention, lever, hatch, solution

loop

A closed path of effects, along which a variable ends up affecting itself.

Taught in chapter 4, Loops

Other names: cycle, circuit, feedback loop

material path

A flow's double line, two thin parallel lines along which material moves, and which never carries a reading.

Taught in chapter 6, Flows

Other names: physical flow, pipe, conveyor

measured value

The controlled variable as it is read, such as *thermometer reading*, drawn as a variable of its own because a reading can arrive late or stray, with *measured value* written in small type above its name.

Taught in chapter 8, Measured value

Other names: sensor, sensor reading, measurement, feedback signal

nonlinear effect

An effect that is weak over part of its range and sudden over another, or strong and then flat, drawn with a small S beside its middle.

Taught in chapter 5, Nonlinear effects

Other names: curve, threshold link, nonlinear curve, nonlinear link

override

A variable a person sets whose signal reaches a corrective action, replacing the loop's rule for a while, with *override* written in small type above its name.

Taught in chapter 9, Override and false alarms

Other names: manual mode, bypass

polarity

The + or – on an effect: + when the two variables move in the same direction, – when they move in opposite directions.

Taught in chapter 3, Causal claims

Other names: sign, valence, positive link, negative link, inhibition link

reinforcing loop

A loop that makes a change grow in whichever direction it starts, with an even number of – effects, labeled `R1`, `R2` and so on.

Taught in chapter 4, Loops

Other names: positive loop, virtuous cycle, vicious cycle, growth loop

saturation

The most a corrective action can reach, however wide the gap, written beneath its name as *at most* and the limit: *at most 2 kW*.

Taught in chapter 9, Saturation

Other names: ceiling, clipping

side effect

A consequence of a symptomatic solution, usually delayed, with *side effect* written in small type above its variable's name.

Taught in chapter 10, Side effects

Other names: unintended consequence, blowback

signal

An effect in a stock & flow or feedback control diagram, a single thin line with an arrowhead carrying a reading of a quantity rather than the quantity itself, and never ending at a stock.

Taught in chapter 6, Signals

Other names: information link, connector, feedback link, info arrow, signal arrow, controller

stock

A quantity that accumulates and changes only through its flows, drawn as a plain box around its name, its units beneath in smaller type.

Taught in chapter 6, Stocks

Other names: level, reservoir, accumulator, pool

stock & flow diagram

A diagram of what accumulates, drawn as stocks, and how it changes, drawn as flows, with auxiliaries and signals setting the flows' rates.

Taught in chapter 6

stock equation

The line beneath a stock's box adding its inflows and subtracting its outflows, as in *change in water in tub = filling – draining*, or *= 0* for a stock with no flows.

Taught in chapter 6, The stock equation

Other names: equation tag, balance equation

symptomatic solution

A variable standing for a remedy that relieves a symptom quickly, with *symptomatic solution* written in small type above its name.

Taught in chapter 10, Symptomatic and fundamental solutions

Other names: quick fix, band-aid

system archetype

A causal loop diagram carrying a line for each declared archetype and, above some variables' names, a role such as *symptomatic solution* or *side effect*.

Taught in chapter 10

system context map

A diagram of one system's boundary, the external entities outside it, and the exchanges crossing between them.

Taught in chapter 2

target

The value someone chooses for a quantity to stay near, such as *desired temperature*, with *target* written in small type above its name, and no signal ending at it.

Taught in chapter 8, Target and gap

Other names: setpoint, goal, reference, desired value

variable

A quantity that can rise or fall, named as a noun phrase such as *hours slept* and never as an action.

Taught in chapter 1, Variables

Other names: factor, element, node, item

viewpoint tag

A small labeled box beside an effect naming who stresses that effect, which marks emphasis and not a different structure.

Taught in chapter 5, Viewpoint tags

Other names: perspective, lens, color coding

weight

Where influences are ranked, an influence's relative importance, drawn as one, two or three dots beside the middle of its line.

Taught in chapter 3, Weight

Other names: strength, thickness, priority

Answers

Chapter 1 · What Is a Diagram For?

A neighbour is sure the new streetlights on her road have cut burglaries there, and draws streetlights on the road → burglaries on the road as a solid effect. Which of these would give her the strongest grounds for drawing it solid?

a Burglaries on her road counted for a year before the lights went in and a year after
Yes. That counts the change in burglaries alongside the change in the lights, the strongest support of the three. Whether the lights cut burglaries, or only came before a fall on every road, is still to be asked of it; a count on roads without new lights would answer it.

b The police count showing twelve burglaries on her road this year
Not quite. That counts a variable, burglaries on her road, once: no change in it is counted alongside the lights going in. A variable counted alone supports no effect.

c Her twenty years on the road, and how sure she is
Not quite. Knowing the road makes her testimony informed, and testimony is weaker support than a count. She may still draw the effect solid; a reader who knows that is all she has can question where she drew the line.

A florist draws roadworks on her street → customers a day as a solid effect: her till shows customers fell by a third the week the roadworks began. Which question about that effect has her till left open?

a Whether the roadworks changed her customers, or only came before the fall
Yes. The till counted the fall alongside the roadworks, and on that count she draws the effect solid. The same week might have brought rain, a school holiday or a new florist two streets away, and the count would be the same.

b What changes
Not quite. Customers a day, the variable the effect ends at, is what changes, and the till counts it.

c Whether customers fell
Not quite. The till counted the fall, in the week the roadworks began; that count is her grounds for drawing the effect solid.

A theatre company's report to its funders has a diagram of nine variables and twelve effects, every effect solid, and no legend. What can a reader tell from it about the evidence for each effect?

a Every effect is well supported
Not quite. A diagram with no dashed effect carries no coding, so its solid lines don't show where the company drew a line between more and less supported, or whether it drew one. All twelve effects may rest on counts, or none.

b Every effect is a hypothesis
Not quite. A hypothesis is drawn dashed, and nothing here is. With no coding, an effect resting on a count and one resting on a belief are drawn alike.

c Nothing: each effect's evidence has to be asked about
Yes. With no dashed effect there is no coding and no evidence entry in a legend. Each line is the company's claim, and how anyone knows is a question for each of the twelve.

QUESTION 1 OF 3

Which of these effects could a study support by counting the change in the second variable alongside a change in the first?

a Psychological ambivalence → conscious control of accumulation.
Not quite. Neither quantity has an agreed count, so nobody can count a change in one alongside a change in the other without first defining both.

b Physical activity → available energy.
Yes. Both can be counted: minutes of activity, and energy used against energy eaten. A study counting one alongside the other would support this effect.

c Every effect, since each is drawn with an arrowhead.
Not quite. An arrowhead shows which way an effect runs, not whether anyone could count it. Lock-in to accumulate energy, for one, has no count to take.

QUESTION 2 OF 3

In the source, twelve of these effects are dotted lines ending in a square. What did that line mean there, and why are those effects drawn solid here?

a That the effect was less supported, as a dash means here.
Not quite. The source's legend reads Negative Influence for that line: the second variable moves opposite to the first. Drawn dashed, the twelve would read as less supported, which the source never says.

b A weaker effect than a solid line.
Not quite. No line in the source's legend marks how strong an effect is. That line is a negative influence: the second variable moves opposite to the first.

c A negative influence, the second variable moving opposite to the first; here a dash means less supported, a hypothesis, so they are drawn solid, with no polarity.
Yes. In a causal loop diagram that direction is a – polarity; here no effect carries one. A dash means only that its author judges an effect less supported.

QUESTION 3 OF 3

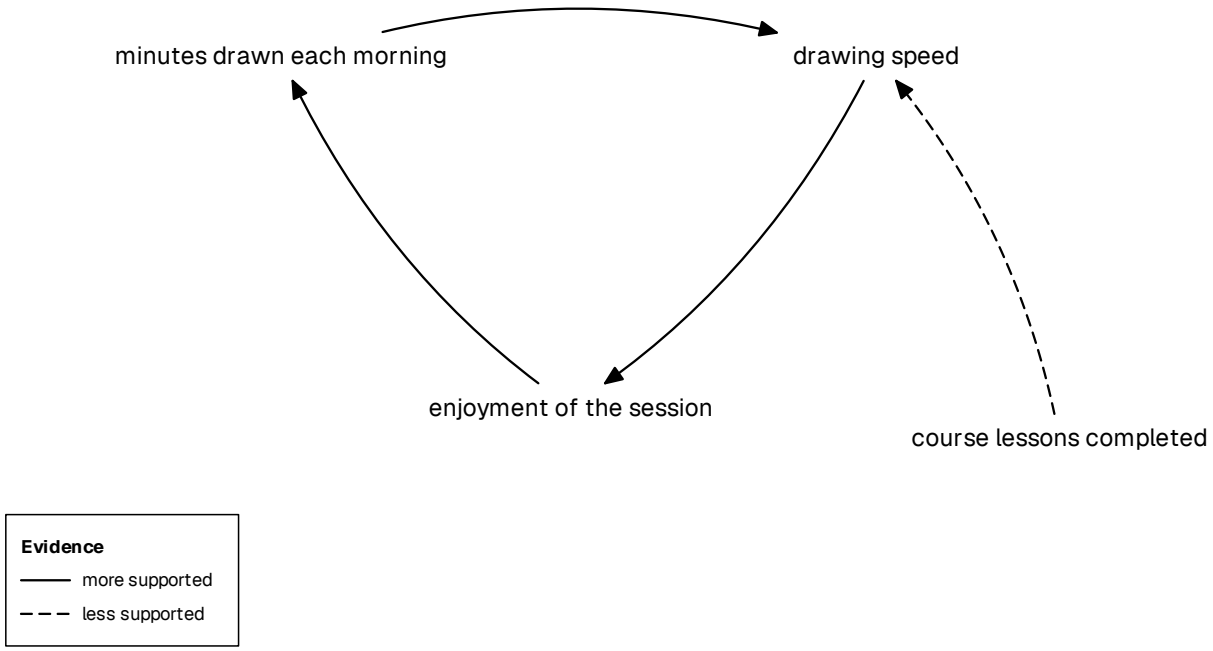
No effect here is dashed. Which of the solid effects did the atlas's authors judge more supported?

a Nobody can tell from the lines: a diagram with no dashed effect carries no coding.
Yes. Its solid effects are its authors' claims, their evidence unrecorded. Which rest on counts is a question for the atlas's text and its sources, not for the drawing.

b All of them: a solid effect is more supported.
Not quite. A solid line reads as more supported only beside a dashed one. With none dashed, the diagram carries no coding.

c None of them: with no legend, a solid effect is a hypothesis.
Not quite. A hypothesis is drawn dashed. With no dashed effect, the lines say nothing either way.

DF 01 Greta's morning drawing



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The minutes Greta draws each morning change her drawing speed, her speed changes her enjoyment of the session, and her enjoyment changes the minutes she draws: three effects whose changes she timed, marked or logged side by side, closing a circle, and she draws each solid. The lessons of the online course change her speed too, an effect she believes and hasn't counted alongside her times, so she dashes it, and the legend lists the dashed line as less supported.

Why it works

- Four quantities, each able to rise or fall
- Three effects Greta draws solid close a circle, each a change she logged alongside another
- Greta's one belief, course lessons completed → drawing speed, dashed
- Legend on, listing the dashed line as less supported

Step by step

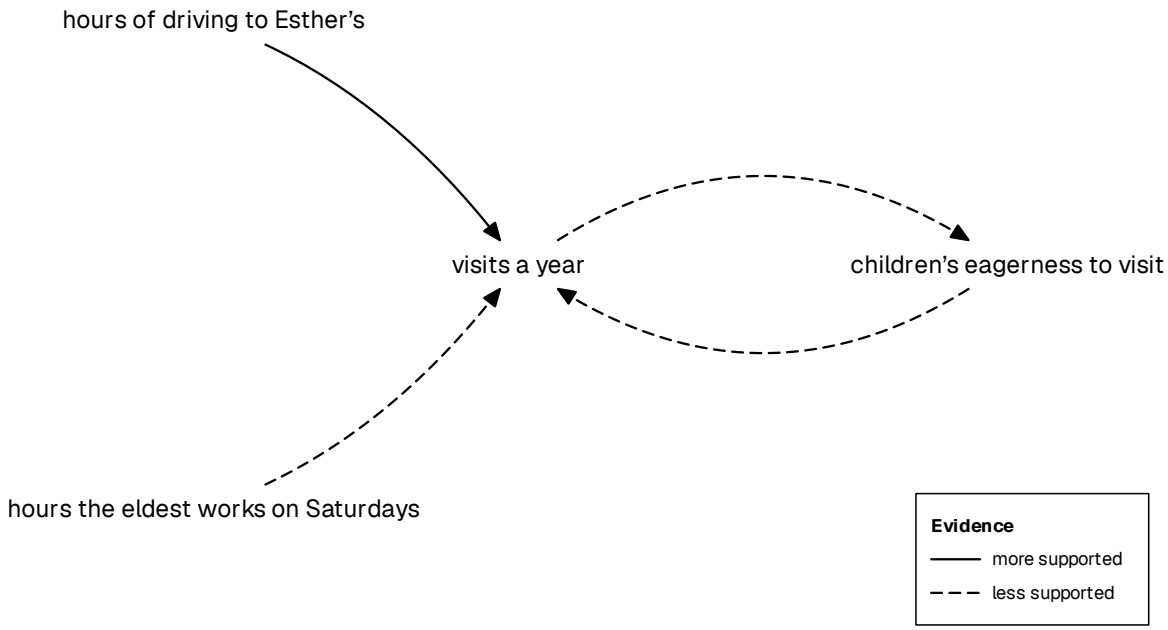
1. Minutes drawn each morning and drawing speed, with an effect between them that Greta draws solid: her log opens with her times beside the weeks she drew longest and the fortnight she barely drew.
2. Enjoyment of the session, with a solid effect into it from drawing speed and another from it to minutes drawn each morning, which closes the circle before anything is dashed: her one-to-five marks and her longer mornings are in the log too, so she draws both solid.
3. Course lessons completed, with a dashed effect on drawing speed, and the legend with it, since this is the one dashed line: Greta has no count of lessons beside her times, so she dashes it.

What another defensible answer might vary

Another answer might close the circle from drawing speed straight back to minutes drawn each morning, since Greta's faster mornings are also her longer ones, and leave enjoyment of the session an effect of speed alone. With a fifth variable, beyond this brief's four, another might add sleep the night before as a second dashed effect

on drawing speed. What stays is a circle of solid effects through the minutes she draws, and the course's effect on her speed dashed, with the legend on.

DF 02 Esther's grandchildren's visits



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The hours of driving to Esther's changed the visits a year, from twelve to four, from the first month after the move: her calendar counts the change in the visits alongside the move, so she draws the effect solid, and her son agrees with it. She dashes her three beliefs, which no count supports and her son rejects: the hours the eldest works on Saturdays changing the visits, and a circle in which fewer visits lower the children's eagerness to visit and lower eagerness means fewer visits. The legend lists the dashed line as less supported.

Why it works

- Four quantities, each able to rise or fall
- The one effect Esther draws solid, on the calendar's count of the visits alongside the move: hours of driving to Esther's → visits a year
- Esther's three beliefs dashed, the two that close a circle among them
- The solid effect is the one Esther and her son agree on; every dashed one is hers alone
- Legend on, listing the dashed line as less supported

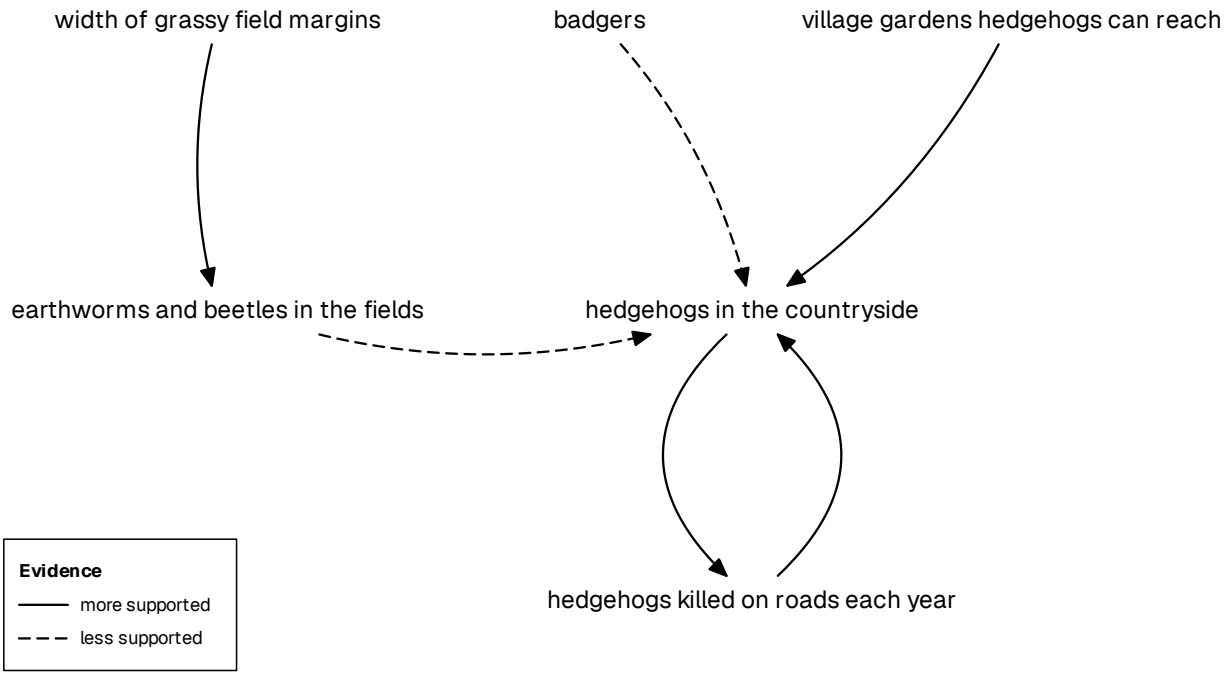
Step by step

1. Hours of driving to Esther's and visits a year, with a solid effect between them, before anything dashed: the calendar is the one count in the paragraph, and Esther draws the effect solid on it.
2. Hours the eldest works on Saturdays, with a dashed effect on visits a year, and the legend with this, the one dashed line so far: Esther hasn't set the calendar beside the bakery shifts, so she dashes it.
3. Children's eagerness to visit, with a dashed effect into it from visits a year and another from it back to them, the circle drawn whole in one step because Esther believes it both ways at once; she hasn't asked the children, so she dashes both.

What another defensible answer might vary

Another answer might draw the Saturday job's effect on the children's eagerness to visit instead of on the visits, still dashed, since Esther hasn't asked the eldest either. What stays is one solid effect from the drive to the visits, every one of Esther's beliefs dashed, and the legend on.

DF 03 Hedgehogs in Britain's countryside



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

This answer draws its line at a count. Four effects have a change counted alongside another and are drawn solid: wide, grassy field margins hold more earthworms and beetles; the more village gardens hedgehogs can reach, the more hedgehogs, since they are densest there; and hedgehogs and the hedgehogs killed on roads, counted falling together since 1990, change each other. Whether road deaths are behind the hedgehogs' fall, which the authors call unclear, is a question for reading that solid effect. The badgers' effect on the hedgehogs rests on the authors' word that it is likely, weaker support than a count, and the prey's on a question they are still studying, so both fall below the line and are dashed. The legend lists the dashed line as less supported.

Why it works

- Six quantities, each able to rise or fall
- Solid effects where a change was counted alongside another, the line drawn at a count: field margins on prey, gardens on hedgehogs, and hedgehogs and road deaths each on the other
- Dashed effects where the newsletter reports no count: badgers and prey, each on the hedgehogs
- Road deaths drawn both ways, both solid on the one count: which changes which is the question the authors leave unclear
- Legend on, listing the dashed line as less supported

Step by step

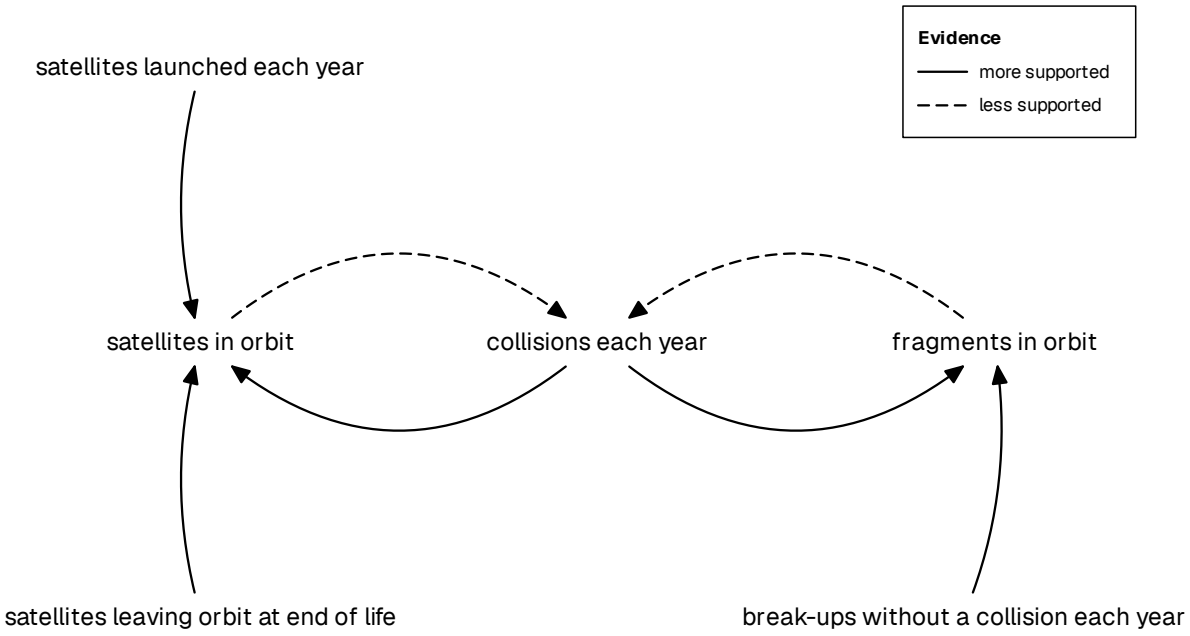
1. Hedgehogs in the countryside and hedgehogs killed on roads each year, with a solid effect each way, the line drawn at a count: the newsletter opens with these two counts, both falling.
2. Width of grassy field margins and earthworms and beetles in the fields, with a solid effect between them from the studies of margins; nothing counted joins the prey to the hedgehogs, so no solid effect does.

3. Village gardens hedgehogs can reach, with a solid effect on the hedgehogs, from the researchers' count of hedgehogs densest in village gardens on arable land.
4. Badgers, with a dashed effect on the hedgehogs, and the legend with this, the one dashed line so far: the authors call the effect likely, testimony weaker than a count, so it falls below the line.
5. A dashed effect from earthworms and beetles to the hedgehogs joins the field margins to the rest of the drawing, on a question the authors list as still being studied.

What another defensible answer might vary

Another answer might dash the gardens' effect, since the studies found where hedgehogs feed and are densest, not how many more a hole in a fence adds. Another might add badgers → earthworms and beetles in the fields, dashed, for the food the two compete for, which the newsletter doesn't count. What stays is the badgers' and the prey's effects dashed, and the legend on.

DF 04 Objects in orbit



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Five effects rest on counts and are drawn solid: satellites launched each year add to the satellites in orbit, and satellites leaving at the end of their life take from them; collisions each year take satellites out and add fragments, as Iridium 33 and Cosmos 2251 did; and break-ups without a collision each year add more fragments. Two effects come from models, Kessler and Cour-Palais's in 1978 and ESA's now: more satellites and more fragments in orbit bring more collisions. Those two dashed effects close both circles through collisions, so the cascade in the models runs on two less supported effects. The legend lists the dashed line as less supported.

Why it works

- Six quantities, satellites in orbit and fragments in orbit apart
- Five effects the counts support, solid: launches, departures at end of life, the collision's two, and break-ups
- The two modelled effects, satellites in orbit → collisions each year and fragments in orbit → collisions each year, dashed
- Each circle closes through a dashed effect
- Legend on, listing the dashed line as less supported

Step by step

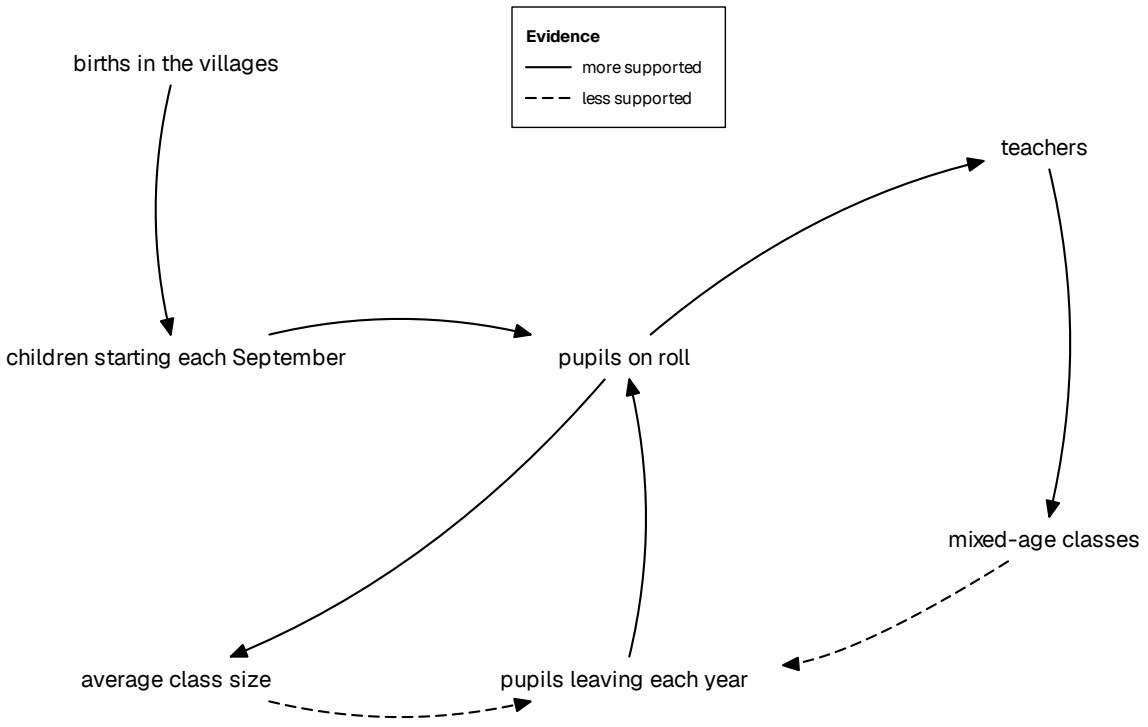
1. Satellites in orbit, with solid effects from satellites launched each year and satellites leaving orbit at end of life, the two counts the notes open with.
2. Collisions each year and fragments in orbit, with solid effects from collisions to satellites in orbit and to fragments in orbit: Iridium 33 and Cosmos 2251 broke apart into 823 catalogued fragments.
3. Break-ups without a collision each year, with a solid effect on fragments in orbit: ESA counts them as the largest source of fragments today.

4. Dashed effects from satellites in orbit and from fragments in orbit to collisions each year, with the legend, after every solid effect: these two alone turn the chain of counts into two circles.

What another defensible answer might vary

Another answer might draw one variable, objects in orbit, for satellites and fragments together, with one dashed effect on collisions; this brief keeps the two apart, since launches and departures change the satellites and break-ups the fragments. Another might leave out collisions each year → satellites in orbit, since one collision took out two satellites. What stays is the effects on collisions dashed, the rest solid, and the legend on.

CS 01 Kelsham Primary School: the head teacher's letter



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Six effects rest on counts and are drawn solid: the births in the villages changed the children starting each September four years later; the starters and the pupils leaving each year changed the pupils on roll; the roll, through the funding each October's count sets, changed the teachers, and fewer teachers made Years 3 and 4 one mixed-age class; and the roll in four classes set the average class size. The parents' two reasons, mixed-age classes and average class size each changing the pupils leaving each year, rest on their word and are dashed, and each closes a circle back through the pupils on roll. The legend lists the dashed line as less supported.

Why it works

- Seven quantities, the starters and the pupils leaving each year apart
- Six effects the counts support, solid: births on the starters, the starters and the leavers on the roll, the roll on teachers and on average class size, and teachers on mixed-age classes
- The parents' two reasons dashed: mixed-age classes → pupils leaving each year, and average class size → pupils leaving each year
- Each circle through the pupils on roll closes through a dashed effect
- Legend on, listing the dashed line as less supported

Step by step

1. Births in the villages, children starting each September and pupils on roll, with a solid effect from each to the next, the first counts in the letter: the county council's records and the roll.
2. Pupils leaving each year, with a solid effect on pupils on roll: each October's roll is the last one's plus the starters, less those who left.

3. Teachers and mixed-age classes, with solid effects from the roll to teachers and from teachers to mixed-age classes: in 2023 the roll paid for four teachers, and Years 3 and 4 became one class.
4. Average class size, with a solid effect from the roll: 88 pupils in four classes, counted this October.
5. Dashed effects from mixed-age classes and from average class size to pupils leaving each year, with the legend, after every solid effect: the parents' two reasons, resting on their word, close both circles.

What another defensible answer might vary

Another answer might draw school funding between the pupils on roll and the teachers, since the count sets the funding and the funding pays the teachers, or draw the parents' reasons on the children starting each September as well, still dashed. What stays is the counts' effects solid, the parents' reasons dashed, and the legend on.

Chapter 2 · Drawing the Boundary

Dev stops paying rent. Sam's sister asks the household to take him in as one of the family, and from then on he eats its meals and shares its money and chores. Is Dev still an external entity?

a Yes: he's a nephew, not one of Priya and Sam's children
Not quite. Family ties don't place a party. What places Dev is whether the household runs his meals and money or only exchanges with him.

b No: the household now runs his meals and money, so he's inside the boundary, with no oval
Yes. An external entity is a party the system exchanges with and doesn't run. Nothing crosses between Dev and the household any more: his meals and money are the household's, so he's part of it.

c Yes: he still sleeps in the spare room
Not quite. The room was an exchange while Dev paid rent for it. Now no rent crosses, and the room is part of how the household houses its own members.

d Yes, drawn as an oval inside the boundary
Not quite. An oval inside a boundary is a mistake the lab names: an external entity sits outside. A member of the system is inside it and has no oval.

Ana, who lives down the street, starts minding the daughter after school, and the household pays her each week. On the map with the parts meals, earnings and housing, how are these drawn?

a One exchange, childminding, between Ana and the household
Not quite. One exchange carries one thing one way. Care comes in and fees go out: two exchanges. With parts drawn, each also reaches the part that handles it.

b A new nested boundary, childcare, with childminding running into it from Ana and fees running out to her
Yes. No part on the map handles care, so a new part, named for what it does, owns both exchanges. Two things cross, one each way, so there are two exchanges.

c Fees out of earnings, since earnings receives the wages
Not quite. An owner is the part that handles an exchange, not the part that receives the money: in this household meals pays the supermarket and housing pays the landlord.

d A nested boundary named Ana, inside the household
Not quite. The household exchanges with Ana and doesn't run her, so she's an external entity, an oval outside. A part is named for what it does, not for who does it.

QUESTION 1 OF 3

Which parties sit outside the boundary?

a None: the source's figure has every party in a box, as it has the system.
Not quite. Here the system's box became the boundary, and each other box a party in an oval, outside it.

b Only the personal banking customer: the other two are software, as the system is.
Not quite. What kind of thing a party is doesn't place it. Amazon's e-mail service and the core banking system each exchange something with the Internet Banking System, and neither is run by it.

c All three: the customer, Amazon's e-mail service and the core banking system.
Yes. Each gives the system something or receives something from it, and the system runs none of them: it hands e-mails to Amazon's service and gets account information from the core banking system.

QUESTION 2 OF 3

The source's figure has four lines. Which one is no exchange on this map, and so is left out?

a The customer → the system, since the customer also receives from the system.
Not quite. That line carries two things, so it became two exchanges: payment instructions from the customer, account balances to the customer, each pointing from the party that gives.

b Amazon's e-mail service → the customer, labeled Sends e-mails to.
Yes. An exchange crosses the boundary between the system and a party outside. This line runs between two parties outside, so it crosses no boundary drawn here.

c The system → Amazon's e-mail service, since an e-mail is information, not a thing given.
Not quite. Information crosses as goods do: the system hands Amazon's service the e-mails to send, drawn as that exchange.

QUESTION 3 OF 3

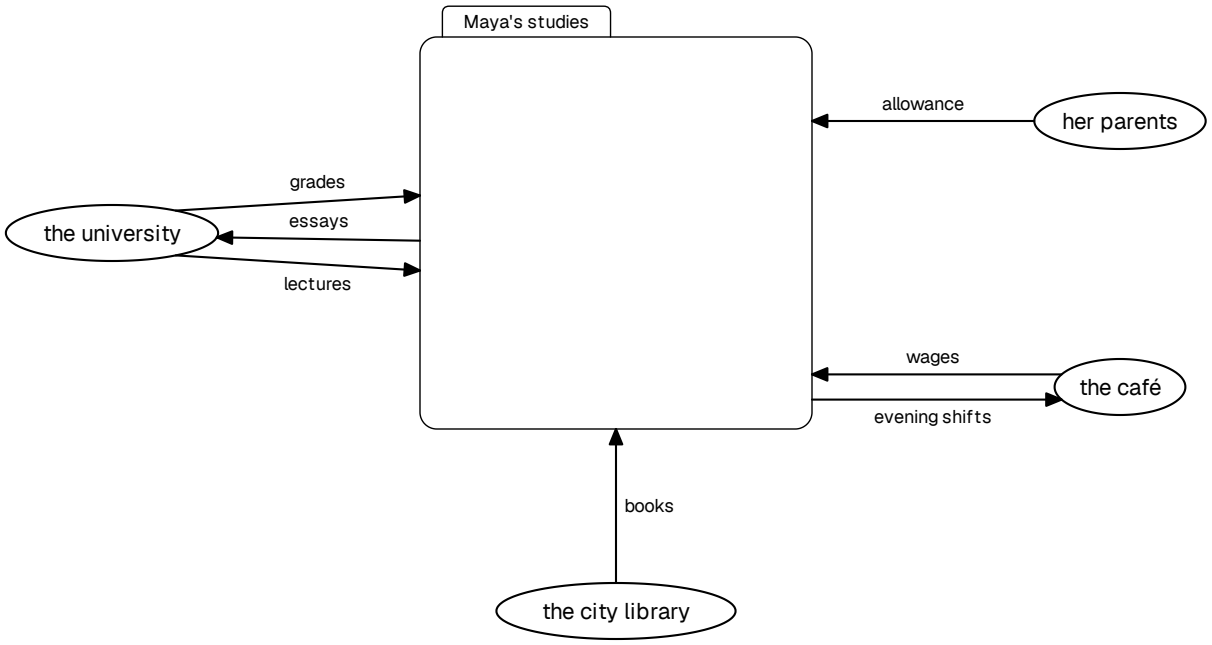
The core banking system belongs to the same bank as the Internet Banking System. With the boundary drawn around the bank instead, what changes?

a Nothing: the core banking system is a separate piece of software either way.
Not quite. A party's place comes from the boundary's name, not from what it is. Inside a boundary named the bank, the core banking system is a part of the system.

b The customer moves inside too, as a customer of the bank.
Not quite. The bank doesn't run its customers: the customer still gives payment instructions and receives balances from outside.

c The core banking system moves inside, and account information and payments to make no longer cross the boundary.
Yes. The boundary's name says what the map explains. Around the bank, the core banking system is a part, and what passes between it and internet banking stays inside, as what passes between parts does.

SC 01 A first term away from home



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One boundary, Maya's studies, with four parties outside it: the university, her parents, the café and the city library. Seven named exchanges cross the boundary. Lectures and grades come in from the university and essays go out to it; the café takes her evening shifts and pays wages.

Why it works

- One boundary, named for the system
- Four parties, each outside the boundary
- Every party gives or receives at least one thing
- Each exchange named for the one thing it carries
- Housemates and friends left out

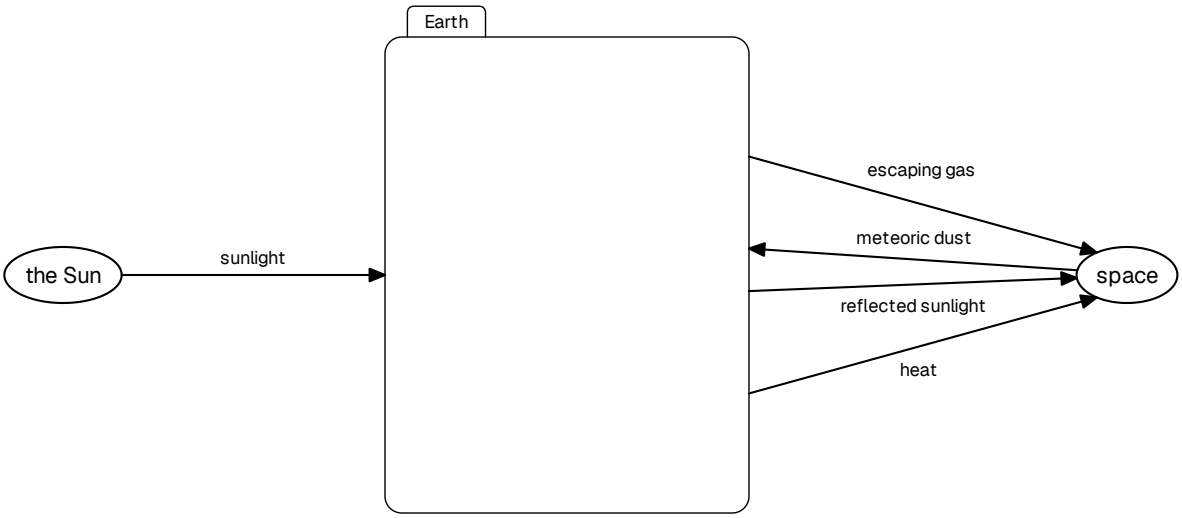
Step by step

1. The boundary, Maya's studies, before any party, since every party goes outside it.
2. The university, the party the paragraph opens with, with lectures and grades crossing in and essays crossing out.
3. Her parents, with the allowance crossing in, and the café, with evening shifts out and wages back: the two parties that pay her, in the paragraph's order.
4. The city library, with books crossing in, the last party the paragraph names.

What another defensible answer might vary

Another defensible answer might draw her whole first term as the system, with a landlord as a fifth party, or name the café's exchanges as time and money. What stays the same is one named boundary, parties outside it, and a name on every exchange.

SC 02 Earth



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Earth is the boundary, with the Sun and space outside it. Energy crosses as sunlight in from the Sun, and as heat and reflected sunlight out to space. Matter crosses as meteoric dust in from space and escaping gas out to it.

Why it works

- One boundary around the planet, named Earth
- The Sun only gives; space both gives and receives
- Reflected sunlight and heat drawn as two exchanges, since they are two things
- Sunlight, heat and reflected sunlight are energy; meteoric dust and escaping gas are matter

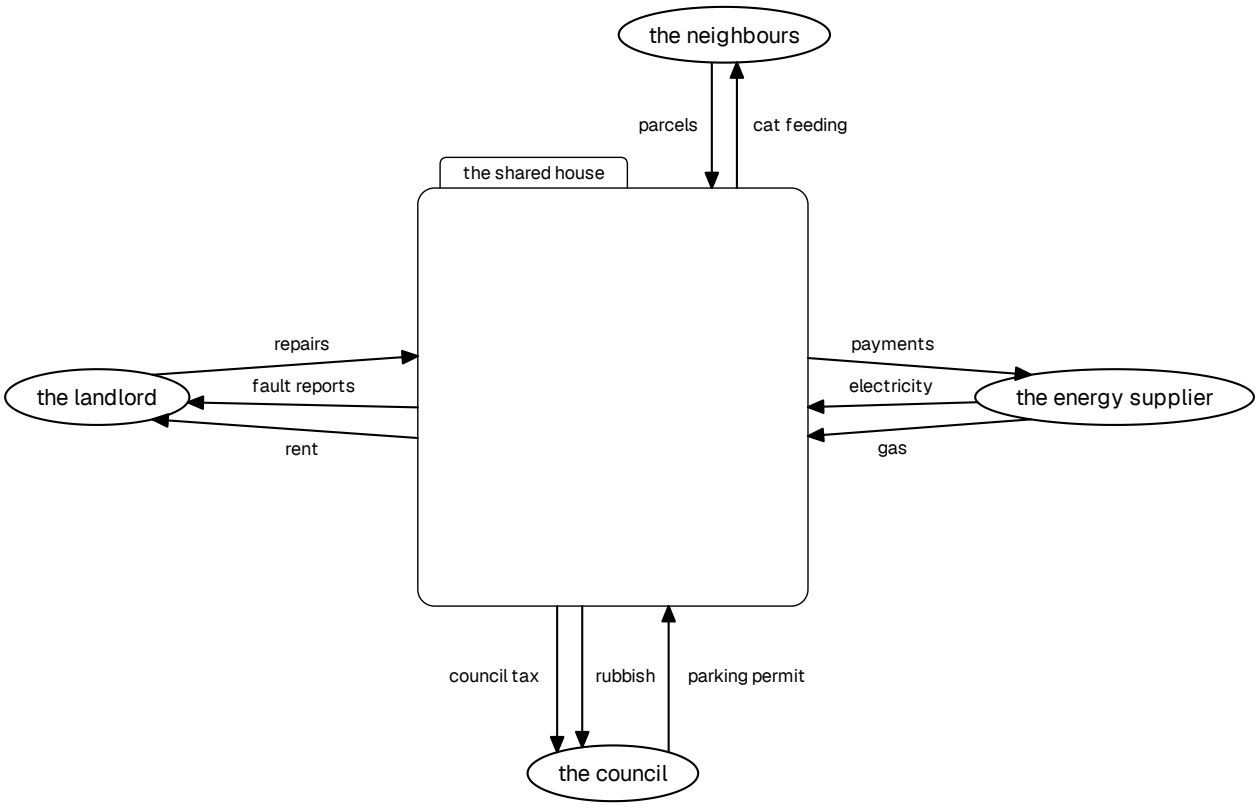
Step by step

1. The boundary, Earth, before the Sun and space, since every crossing after it goes in or out across this line.
2. The Sun, with sunlight crossing in: the energy that the heat and reflected sunlight going out both start from.
3. Space, with heat and reflected sunlight crossing out to it as two exchanges, the energy leaving after the energy arriving.
4. Meteoric dust in from space and escaping gas out to it, the matter crossings, after the energy ones, as the paragraph lists them.

What another defensible answer might vary

Another defensible answer might name the heat as infrared radiation, or draw the escaping gas as two exchanges, hydrogen and helium. What stays the same is two parties, five things crossing, and each exchange carrying one thing one way.

SC 03 A shared house



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One boundary, the shared house, with four parties outside it: the landlord, the energy supplier, the council and the neighbours. Eleven named exchanges cross it, and every party both gives and receives. Rent and fault reports go to the landlord and repairs come back; gas and electricity come in from the supplier and payments go out; council tax and rubbish go to the council and a parking permit comes back; parcels come in from the neighbours and cat feeding goes out.

Why it works

- One boundary, named for the household
- The five students are the system, so none of them is drawn as a party
- Rent and repairs drawn as two exchanges, one each way
- Gas and electricity drawn as two exchanges, since they are two things
- Every party gives and receives at least one thing

Step by step

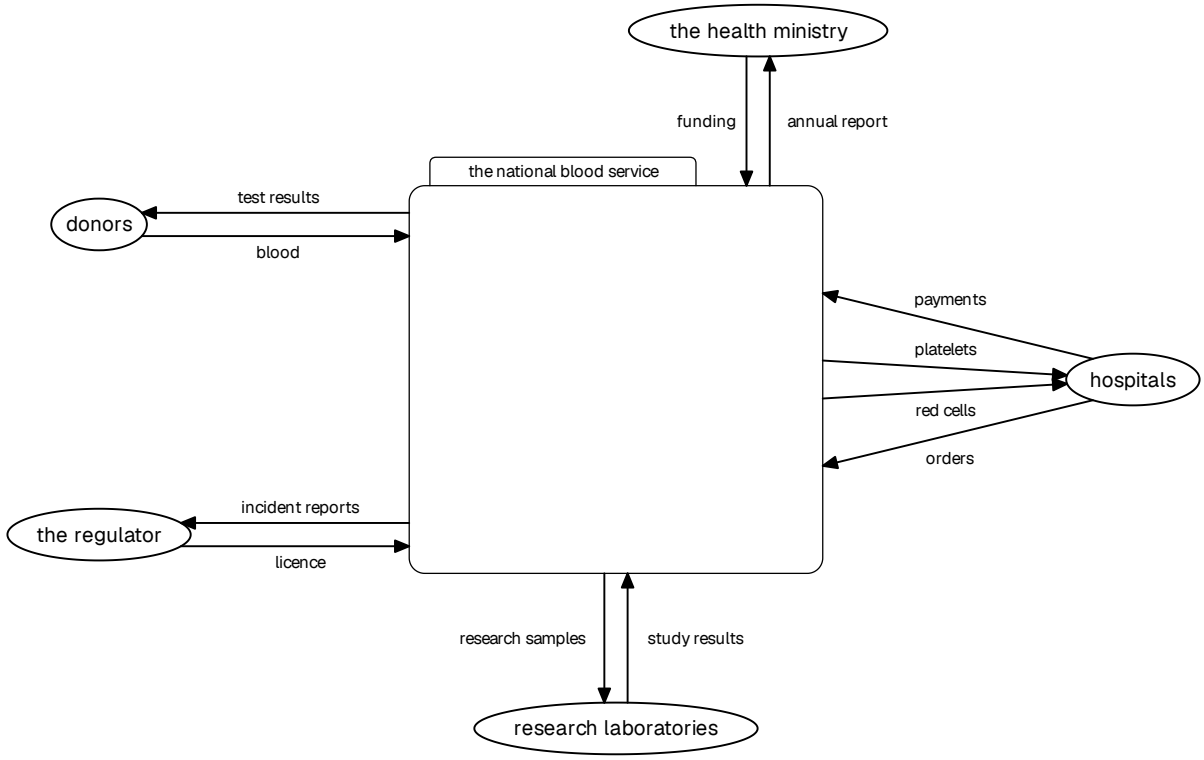
1. The boundary, the shared house, with the five students inside it, before any of the parties they deal with.
2. The landlord, with rent and fault reports going out and repairs coming back, as the paragraph's second sentence lists them.
3. The energy supplier, with gas and electricity coming in as two exchanges and payments going out by direct debit.
4. The council, with council tax and rubbish going out and a parking permit coming back, one exchange for each thing it collects, empties or issues.

5. The neighbours, with parcels coming in and cat feeding going out, the last party and the only one paid in favours.

What another defensible answer might vary

Another defensible answer might leave out the parking permit, or add the supplier's quarterly bills as a further exchange. What stays the same is one named boundary, the four parties outside it, and one thing per exchange.

SC 04 A national blood service



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One boundary, the national blood service, with five parties outside it: donors, hospitals, the health ministry, the regulator and research laboratories. Twelve named exchanges cross it, and every party both gives and receives. Blood comes in from donors and test results go back; orders and payments come in from hospitals, and red cells and platelets go out to them; funding and a licence come in, and an annual report and incident reports go out; research samples go to the laboratories and study results come back.

Why it works

- One boundary around the service, named for it
- Donors outside the boundary, since the service doesn't run them
- Red cells and platelets drawn as two exchanges, since they are two things
- Every party gives and receives, each direction its own exchange

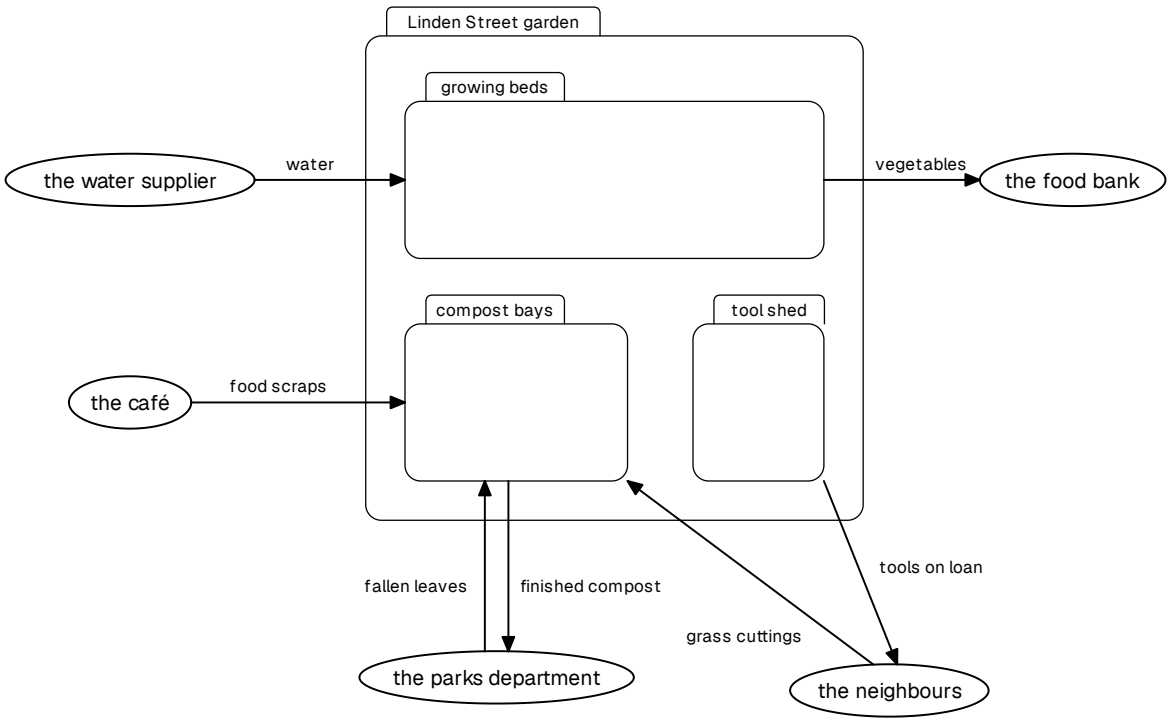
Step by step

1. The boundary, the national blood service, before any party, so that every party, donors included, goes outside it.
2. Donors, with blood coming in and test results going back, where the blood's path starts.
3. Hospitals, where the blood's path ends, with orders and payments coming in and red cells and platelets going out as two exchanges.
4. The health ministry and the regulator, the two parties that oversee the service, with funding and a licence coming in and an annual report and incident reports going out.
5. Research laboratories, with research samples going out and study results coming back: the donations unfit for transfusion, which leave the blood's path.

What another defensible answer might vary

Another defensible answer might add plasma as a third product, sent to a maker of medicines as a sixth party, or draw the regulator's inspections as an exchange beside the licence. What stays the same is one named boundary, donors and hospitals outside it, and one thing per exchange.

SC 05 A community garden



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One outer boundary, Linden Street garden, holds three parts: growing beds, compost bays and the tool shed. Five parties sit outside it. Each of the seven exchanges reaches the part that handles it: water and vegetables reach the growing beds; food scraps, fallen leaves, grass cuttings and finished compost reach the compost bays; tools on loan leave from the tool shed.

Why it works

- One outer boundary, named for the garden
- Three parts, each named for what it does
- Every exchange reaches one part, none the garden as a whole
- The neighbours exchange with two parts: grass cuttings go to the compost bays and tools come from the tool shed
- The parks department both gives and receives through the compost bays

Step by step

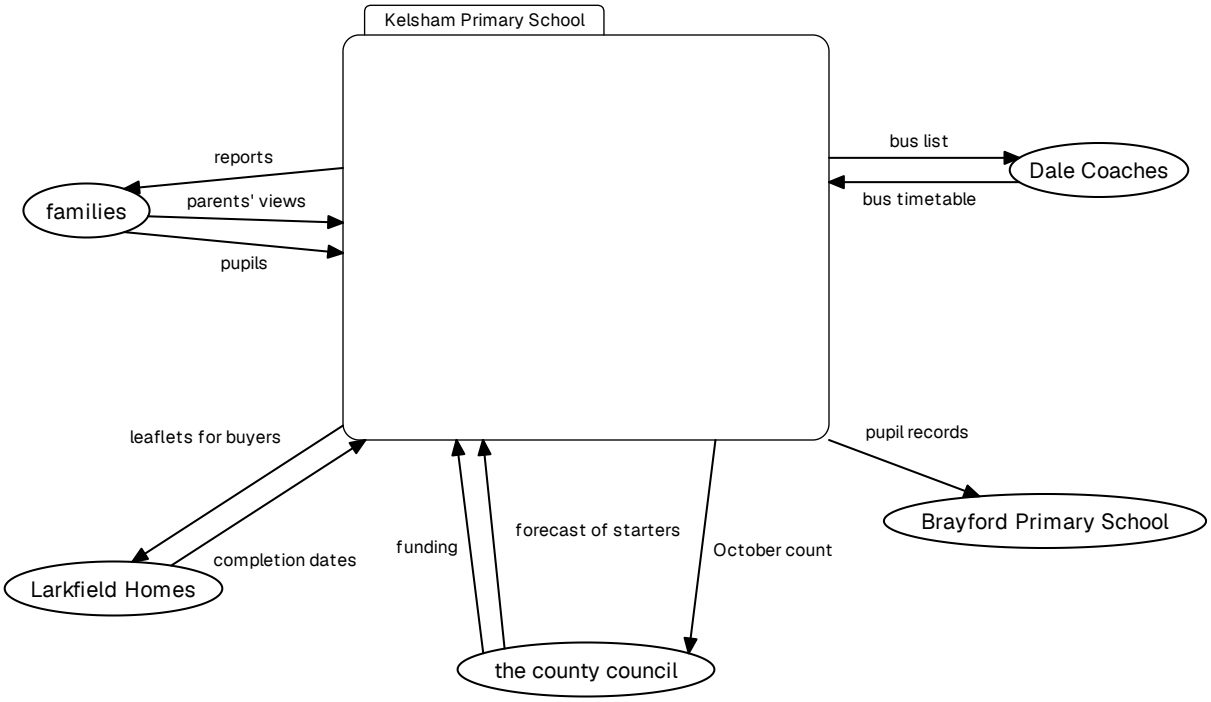
1. The outer boundary, Linden Street garden, before its parts, which sit inside it.
2. Its three parts, growing beds, compost bays and the tool shed, each a boundary inside it, before any party, since each exchange ends at a part.
3. The water supplier and the food bank, with water in to the growing beds and vegetables out from them, as the paragraph opens.
4. The café and the parks department, at the compost bays: food scraps and fallen leaves in, and finished compost back out to the parks department.

5. The neighbours last, since they reach two parts, with grass cuttings in to the compost bays and tools on loan out from the tool shed.

What another defensible answer might vary

Another defensible answer might draw the tools' return as a second exchange with the tool shed, or add a seed store as a fourth part. What stays the same is one outer boundary named for the garden, parts named for what they do, and every exchange reaching one part.

CS 02 Kelsham Primary School and the parties it deals with



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One boundary, Kelsham Primary School, with five parties outside it: families, the county council, Dale Coaches, Brayford Primary School and Larkfield Homes. Eleven named exchanges cross it. Pupils and parents' views come in from families and reports go out; funding and a forecast of starters come in from the county council and the October count goes out; the bus timetable comes in from Dale Coaches and the bus list goes out; pupil records go out to Brayford Primary School; completion dates come in from Larkfield Homes and leaflets for buyers go out.

Why it works

- One boundary, named for the school
- Funding, the forecast and the October count drawn as three exchanges with the county council, one thing each
- Four parties both give and receive; Brayford Primary School only receives, since nothing in the paragraph comes back from it
- The county council's contract with Dale Coaches left off: it crosses no part of the school's boundary

Step by step

1. The boundary, Kelsham Primary School, alone: every exchange in the paragraph crosses it.
2. Families, with pupils and parents' views coming in and reports going out, the party the paragraph names first.
3. The county council, with funding and a forecast of starters coming in and the October count going out: three exchanges, since each carries one thing.
4. Dale Coaches, with the bus timetable coming in and the bus list going out.
5. Brayford Primary School, with pupil records going out, the one party that sends the school nothing.

6. Larkfield Homes, with completion dates coming in and leaflets for buyers going out, the party whose 60 homes are not yet lived in.

What another defensible answer might vary

Another defensible answer might draw David Brennan as a party of his own beside the county council, or add pupils going out to Brayford Primary School beside their records. What stays the same is one boundary named for the school, the five parties outside it, and one thing per exchange.

Chapter 3 · Surfacing Influences

A bakery's till records show that it sells more loaves on market days, and fewer in the weeks after each rise in the price of a loaf. The owner believes her new window display brings in customers, but nobody has counted them. On a map around loaves sold per day, which influence claims can be upgraded?

a Market days per week, with a +, and the price of a loaf, with a –; the window display stays an influence claim
Yes. The till records measured those two effects and which way each runs: more market days, more loaves; a higher price, fewer. Nothing has measured the display's, so its claim says only that it bears on sales.

b All three: the owner knows her shop
Not quite. Knowing the shop is grounds for drawing an influence claim from the display. A polarity says which way the change runs, and only a record or a count shows that.

c Only the window display, with a +: the owner put it there to bring customers in
Not quite. Why the owner put the display there says what she expects, not what happened. The display's claim is the one left unmeasured; the other two have the till records behind them.

d None: an influence map holds no causal claims
Not quite. An influence map holds both kinds. Upgrading a claim gives it a polarity and makes it a causal claim; the map stays an influence map.

An influence map of an allotment has the central outcome crop yield. Water per week → crop yield and crop yield → seed saved are causal claims, each +. Seed saved → crop yield and compost spread → crop yield are influence claims. Converted to a causal loop diagram, what loop can be declared there?

a None
Yes. Only the causal claims carry over. Seed saved → crop yield is an influence claim, so it is left behind, and the path from crop yield to seed saved doesn't return. Upgrading that claim, if a record shows which way it runs, would close the path.

b One reinforcing loop: crop yield → seed saved → crop yield
Not quite. That path closes only through an influence claim. The conversion leaves influence claims behind rather than carrying them without a polarity, so in the causal loop diagram the path is open.

c Two: one through seed saved and one through compost spread
Not quite. Nothing runs from crop yield back to compost spread, so no path closes there. The path through seed saved closes only by an influence claim, which the conversion leaves behind.

QUESTION 1 OF 3

The source's figure has no box for deforestation. Why does the redrawing add tropical deforestation, double-underlined?

a It is the quantity in question, named in the figure's title, and every path of claims ends there.
Yes. The figure's title reads Causative pattern of tropical deforestation. Drawn, it is the one variable the map is drawn around, reached from every underlying driving force through the four proximate causes.

b It marks the result of agricultural expansion, the cause found most often.
Not quite. Agricultural expansion was found in 96% of the cases, and it is one of four claims ending at deforestation. The central outcome is what the map is drawn around, not the cause found most often.

c Every influence map has a variable that no claim leaves.
Not quite. A central outcome is chosen as the quantity in question, not for having no claim leave it.

QUESTION 2 OF 3

Which variables share a cluster with wood extraction?

a Economic forces and political and institutional forces, which bear on it in the most cases.
Not quite. Those two bear on wood extraction from the other cluster, underlying driving forces. A cluster holds variables that share something, not variables joined by claims.

b Tropical deforestation, which it bears on directly.
Not quite. The central outcome sits in no cluster.

c Infrastructure extension, agricultural expansion and other causes.
Yes. The four are the source's proximate causes, which clear the forest directly; its five underlying driving forces reach deforestation only through them.

QUESTION 3 OF 3

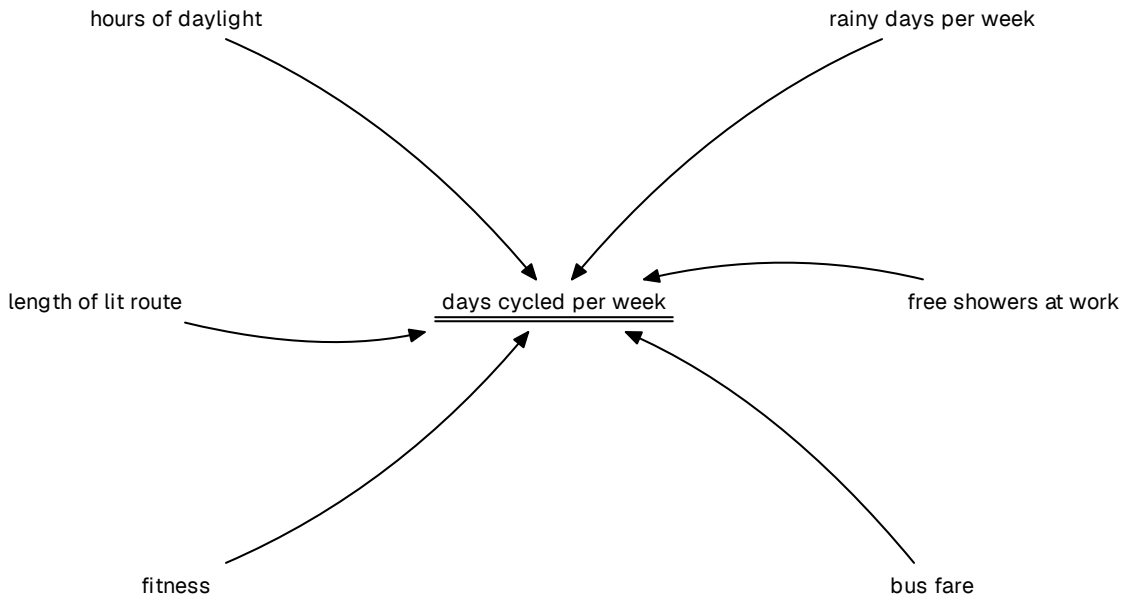
Which claim could be upgraded with a polarity, from what the source's authors report?

a Agricultural expansion → tropical deforestation, whose three dots mark it found in 96% of the cases.
Not quite. The dots here count the cases in which the two were found together, not which way a change runs, nor how strongly. An upgrade takes a direction someone can say how they know.

b None: an influence map's claims carry no polarity.
Not quite. A claim is upgraded where someone can say how they know its direction, as the reading log let Nia's parents say for three of theirs.

c Infrastructure extension → economic forces, +, one of the source's two dashed lines labeled Feedback.
Yes. The authors report that new roads and settlements feed the growth of wood and food markets, which amplify deforestation: more infrastructure extension, more economic forces at work. Its dashes mark feedback in the source; no line in an influence map is dashed, so it is solid here.

IM 01 Cycling to work through the winter



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Days cycled per week, double-underlined as the central outcome, with six variables acting on it straight: hours of daylight, rainy days per week, length of lit route, free showers at work, fitness and bus fare. Every influence is an influence claim with no + or −.

Why it works

- One central outcome, the number Tomás counts
- Six direct influences and no indirect ones
- No polarity: nothing in the situation was measured
- Each variable a quantity: free showers at work, not the showers

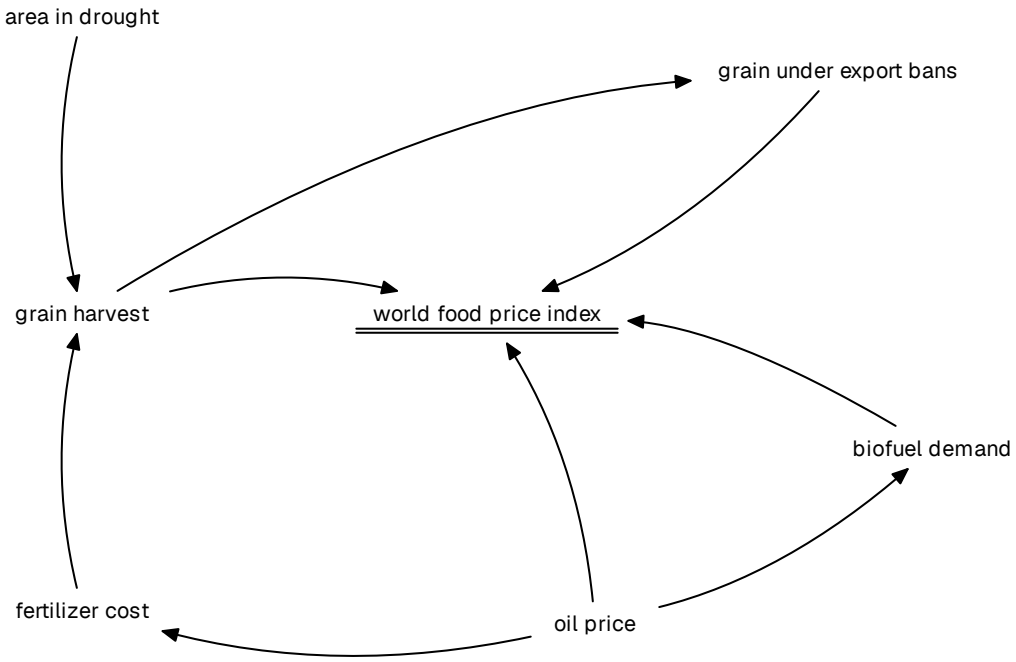
Step by step

1. Days cycled per week, double-underlined as the central outcome, alone before any influence claim, since every claim in the brief ends at it.
2. Hours of daylight and rainy days per week, each with an influence claim on days cycled per week: the two the autumn moves, one falling and one rising.
3. Length of lit route and free showers at work, each with an influence claim: the route and the office, which change with the council's work and the morning's rush.
4. Fitness and bus fare, each with an influence claim: what Tomás brings to the ride and what the other way to work costs.

What another defensible answer might vary

Another defensible answer might leave out the bus fare, draw morning temperature as a seventh variable, or name rainy days per week as hours of rain. What stays the same is one central outcome, each variable a quantity, and every influence claim drawn straight to it with no + or −.

IM 02 World food prices



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The world food price index as the central outcome, with four direct influences: grain harvest, oil price, biofuel demand and grain under export bans. Area in drought and fertilizer cost reach the index through the grain harvest, the oil price also acts on fertilizer cost and biofuel demand, and the grain harvest acts on grain under export bans. Every influence is an influence claim with no + or −.

Why it works

- One central outcome: the world food price index
- Four direct influences, each ending at the index
- Five indirect influences, each drawn to the variable it acts on
- The oil price on three paths: straight, through fertilizer cost and through biofuel demand
- Every variable has a path to the index

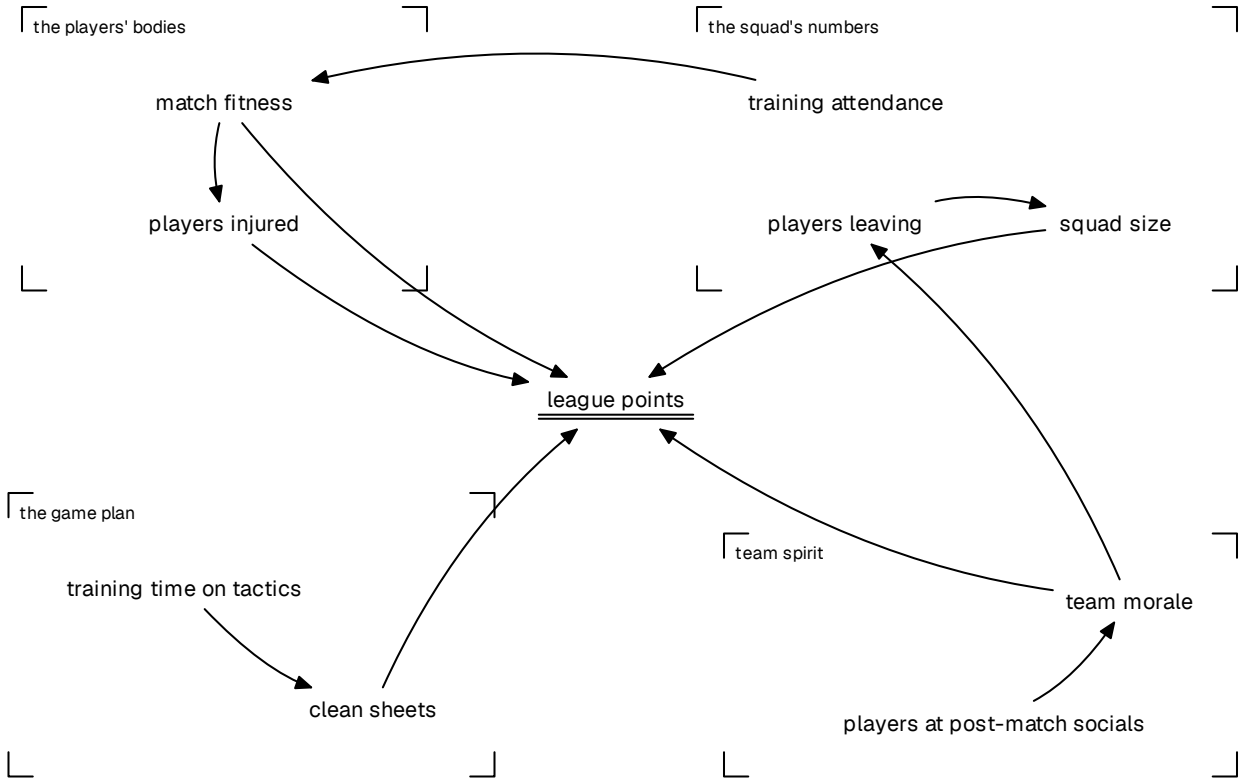
Step by step

1. The world food price index, double-underlined as the central outcome, alone before any influence claim, since every path in the drawing ends at it.
2. Grain harvest, oil price, biofuel demand and grain under export bans, each with an influence claim on the index, before anything indirect: a variable acting through another comes after it.
3. Area in drought and fertilizer cost, each with an influence claim on the grain harvest, the variable both act through.
4. Three influence claims among variables already drawn: the oil price on fertilizer cost and on biofuel demand, and the grain harvest on grain under export bans.

What another defensible answer might vary

Another defensible answer might draw fertilizer cost straight to the index as a cost of farming, add grain stocks between the harvest and the index, or leave out the influence claim from the grain harvest to grain under export bans. What stays the same is one central outcome, and the area in drought reaching it only through the grain harvest.

IM 03 An amateur football team's season



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

League points as the central outcome, in no cluster, with four clusters around it: the players' bodies (match fitness, players injured), the squad's numbers (training attendance, players leaving, squad size), the game plan (training time on tactics, clean sheets) and team spirit (team morale, players at post-match socials). Match fitness, players injured, squad size, clean sheets and team morale act on league points straight; the other four reach it through one of them. Every influence is an influence claim with no + or –.

Why it works

- One central outcome, league points, outside every cluster
- Four clusters, each labeled for what its variables share
- Every other variable in one cluster, and two or more in each
- Five direct influences and six indirect ones
- No polarity: nobody at the club measured any of them

Step by step

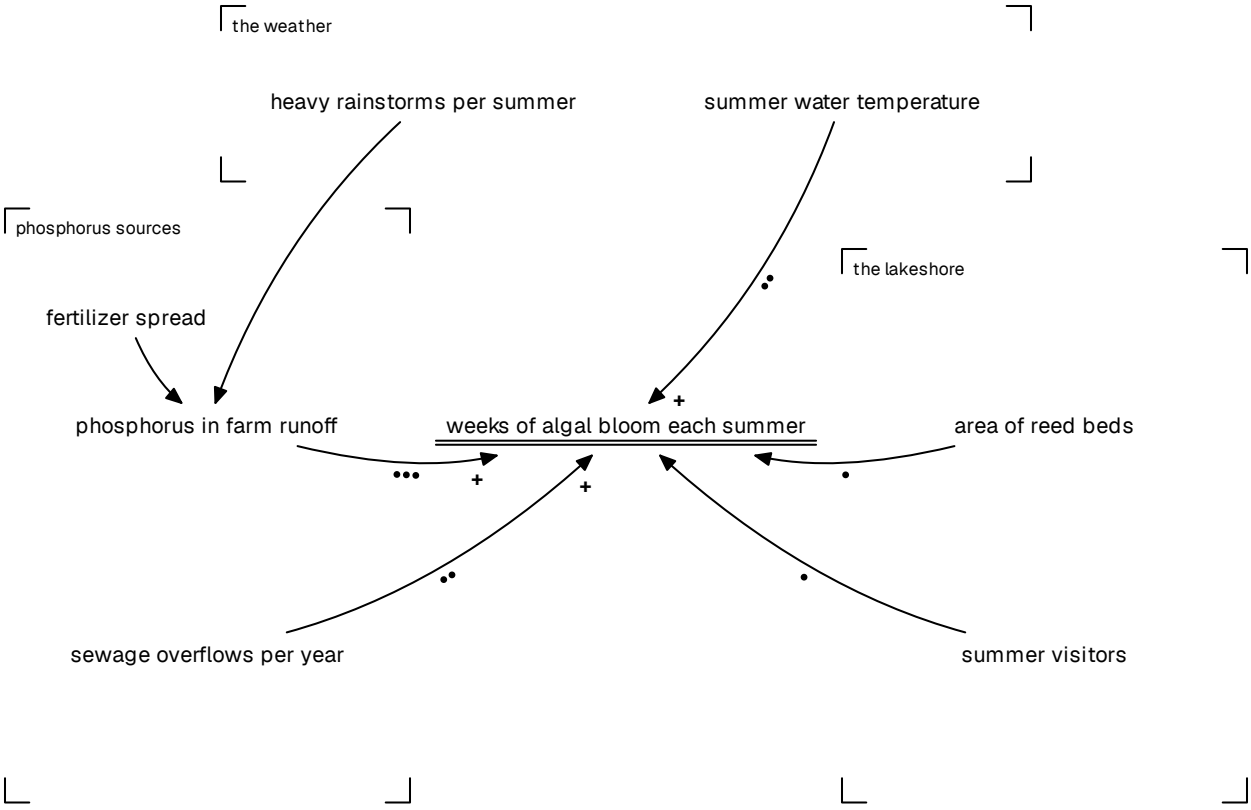
1. League points, double-underlined as the central outcome, alone before any influence claim, as the score every other variable reaches.
2. Match fitness, players injured, squad size, clean sheets and team morale, each with an influence claim on league points: the five that act on it straight.
3. Training attendance, training time on tactics and players at post-match socials, each with an influence claim on the direct influence it acts through: match fitness, clean sheets and team morale.

4. Players leaving, with an influence claim into it from team morale and one from it to squad size, and the claim from match fitness to players injured: the last claims, each between variables drawn.
5. The four clusters, the players' bodies, the squad's numbers, the game plan and team spirit, drawn last because each goes round variables already in place.

What another defensible answer might vary

Another defensible answer might put training attendance with the players' bodies, label the squad's numbers as who is available, or label the game plan as defending. What stays the same is league points outside every cluster, and each cluster holding two or more variables that share what its label names.

IM 04 Algal blooms in a lake



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Weeks of algal bloom each summer as the central outcome, with five direct influences, each weighted. Each of the three the authority measured is a causal claim with a +: phosphorus in farm runoff (weight 3), sewage overflows per year (weight 2) and summer water temperature (weight 2). The area of reed beds and summer visitors, blamed but not measured, each stays an influence claim of weight 1. Fertilizer spread and heavy rainstorms reach the blooms through farm runoff. Three clusters hold every variable but the central outcome: phosphorus sources, the weather and the lakeshore.

Why it works

- A causal claim with a + for each of the three the authority measured, and for nothing else
- The reed beds and the visitors each kept as an influence claim: blamed, not measured
- A weight on every direct influence, the most on farm runoff, which carries two-thirds of the phosphorus
- Three clusters, the central outcome in none

Step by step

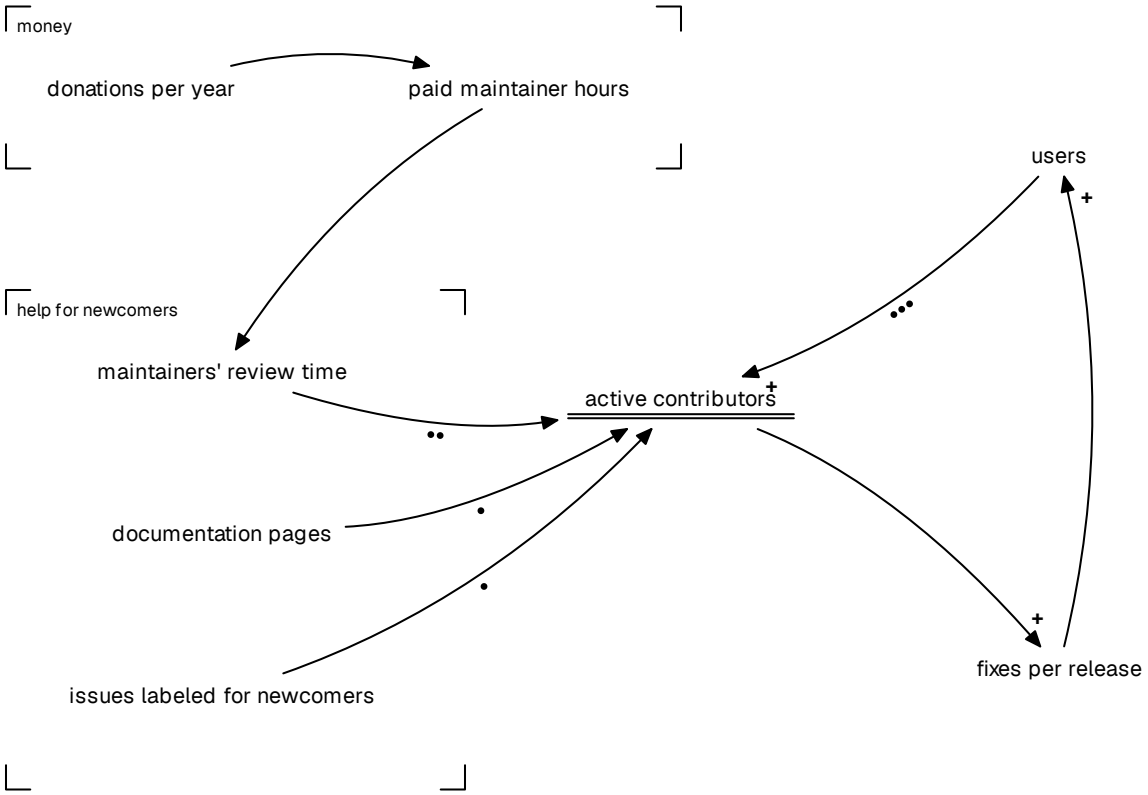
1. Weeks of algal bloom each summer, double-underlined as the central outcome, alone before any claim.
2. Area of reed beds and summer visitors, each an influence claim of weight 1 on the blooms: the anglers' and the boat operators' blame.
3. Phosphorus in farm runoff, sewage overflows per year and summer water temperature, each drawn upgraded, a causal claim with a +, weighted 3, 2 and 2: ten years of the authority's counts rise and fall with the blooms.
4. Fertilizer spread and heavy rainstorms per summer, each with an influence claim on phosphorus in farm runoff, after it, since they reach the blooms only through the runoff.

5. The three clusters, phosphorus sources, the weather and the lakeshore, drawn last around variables already in place.

What another defensible answer might vary

Another defensible answer might give summer water temperature a weight of 3 or sewage overflows a weight of 1, draw heavy rainstorms to sewage overflows as well, or name phosphorus sources as what reaches the water. What stays the same is a causal claim for each of the three the authority measured, and every other claim an influence claim.

IM 05 An open-source project's contributors



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Active contributors as the central outcome. The three claims the records show are causal claims, each with a +, and they close a path: active contributors → fixes per release → users → active contributors. Maintainers' review time, documentation pages and issues labeled for newcomers each act on active contributors as an influence claim, in a cluster, help for newcomers; donations per year reach review time through paid maintainer hours, the two in a cluster, money. Every direct influence has a weight, 3 on users. The conversion to a causal loop diagram carries the eight variables and the three causal claims, and leaves behind five influence claims, two clusters, four weights and the central outcome's mark.

Why it works

- A causal claim with a + for each of the three the records show, and for nothing else
- One closed path of causal claims, active contributors → fixes per release → users → active contributors, with no – claims: reinforcing by the parity rule
- Review time, documentation, newcomer issues and donations each kept as an influence claim: believed, not measured
- Two clusters, the central outcome in neither, and a weight on every direct influence

Step by step

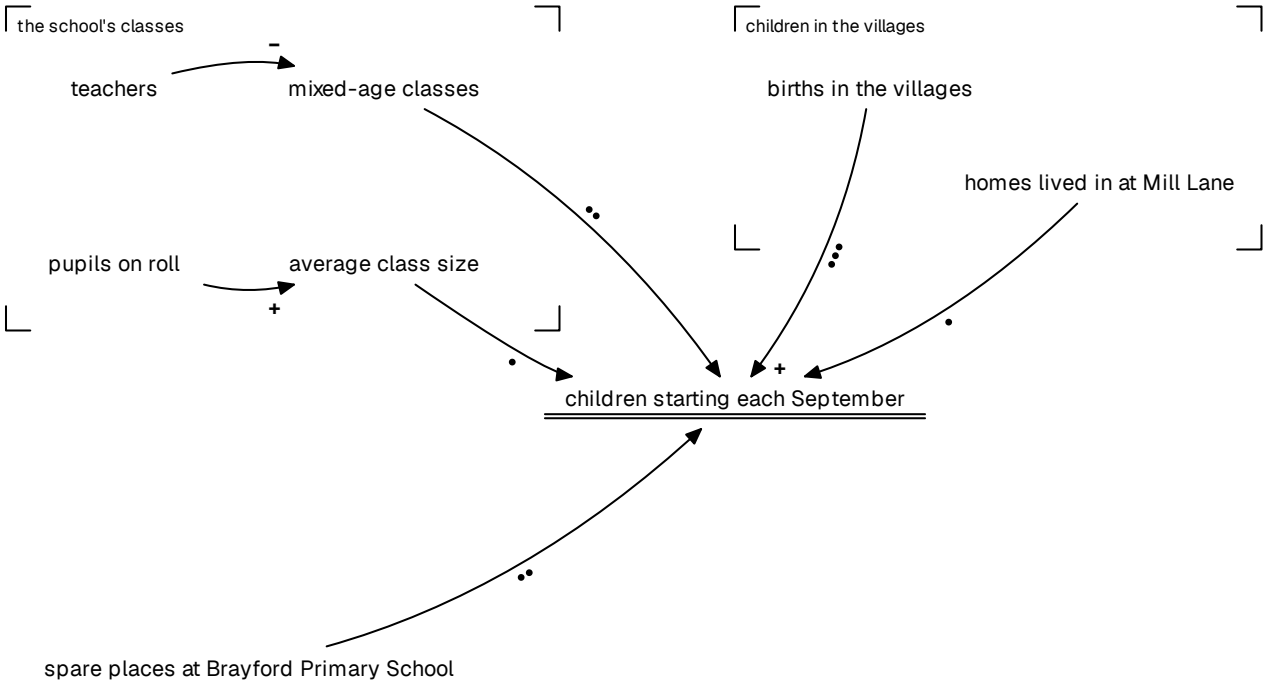
1. Active contributors, double-underlined as the central outcome, the number the maintainers count each month, alone before any claim.
2. Maintainers' review time, documentation pages and issues labeled for newcomers, each an influence claim on active contributors, weighted 2, 1 and 1: what the maintainers believe keeps newcomers.

3. Donations per year and paid maintainer hours, with influence claims from donations to the hours and from the hours to review time, the review the money pays for.
4. Fixes per release and users, with three causal claims, each a +, running from active contributors through fixes and users and back, weight 3 on the last: the upgrades, drawn once every influence claim is in place.
5. The two clusters, money and help for newcomers, drawn last around variables already in place.

What another defensible answer might vary

Another defensible answer might make users the central outcome, draw paid maintainer hours to fixes per release as well, or put fixes per release and users in a third cluster. What stays the same is a causal claim with a + for each of the three the records show, closing one path, and every other claim an influence claim.

CS 03 Kelsham Primary School: what decides where a child starts



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Children starting each September as the central outcome, with five direct influences, each weighted. Births in the villages, counted against the starters four years later, is a causal claim with a +, weight 3. Mixed-age classes and average class size, the parents' reasons, spare places at Brayford Primary School and homes lived in at Mill Lane each stay an influence claim: told, said or forecast, never counted against the starters. Teachers reach the starters through mixed-age classes, with a –, and pupils on roll through average class size, with a +: two causal claims the school has counted. A count of each September's starters beside the mixed-age classes, the class sizes or Brayford's spare places would upgrade that claim. Two clusters: the school's classes and children in the villages.

Why it works

- A causal claim for each of the three changes someone counted, and for nothing else
- Births weighted 3: every September's starters have followed them
- The parents' two reasons, Brayford's places and the new homes each kept as an influence claim
- Teachers and pupils on roll reach the starters only through the parents' reasons, so the outcome still rests on influence claims
- Two clusters, the central outcome and spare places at Brayford Primary School in neither

Step by step

1. Children starting each September, double-underlined as the central outcome, alone before any claim: the number Tom Hale asks about.

2. Mixed-age classes, average class size, spare places at Brayford Primary School and homes lived in at Mill Lane, each an influence claim on the starters, weighted 2, 1, 2 and 1: what parents tell, what Helen Marsh says and what David Brennan forecasts.
3. Births in the villages, with a causal claim with a + on the starters, weight 3, drawn after the influence claims as the one upgrade among the direct influences: the county council counts both.
4. Teachers and pupils on roll, with a causal claim with a – on mixed-age classes and one with a + on average class size, each reaching the starters through a parent's reason: the school counts both.
5. The two clusters, the school's classes and children in the villages, drawn last around variables already in place.

What another defensible answer might vary

Another defensible answer might weight the parents' reasons 3 and the births 2, draw pupils on roll as a variable the starters change, or put spare places at Brayford Primary School in a third cluster with a variable such as the bus journey's minutes. What stays the same is a causal claim for each of the three counted changes, and every other claim an influence claim.

Chapter 4 · Loops That Amplify, Loops That Correct

Which of these names could be a variable on a causal loop diagram?

a go to bed early
Not quite. That's an action: something you do, not something there can be more or less of. The quantity inside it is early nights, a count that rises and falls from week to week.

b hours slept
Yes. It's a quantity that can rise or fall, and “more hours slept” makes sense. Every effect into or out of it can show which way it moves.

c the deadline
Not quite. That's an event: it happens once, on a date. What rises and falls around it is something like work still to do, and that would be the variable.

d tiredness increases
Not quite. The increase doesn't belong in the name: which way tiredness moves is what the effects' polarity shows. The variable is tiredness.

A loop has four effects. Three are + and one is –. What kind of loop is it?

a Reinforcing, because most of its effects are +
Not quite. A + effect passes a change on unchanged, so only the – effects count, and one is an odd number.

b Balancing
Yes. One – effect is an odd number. A change that goes around the loop comes back reversed, so the loop opposes it.

c It depends on which effect carries the –
Not quite. Each – effect reverses a change wherever it sits, so only the number of reversals counts.

d You can't tell without knowing what the variables are
Not quite. You need the variables to judge whether the diagram is true. You don't need them to know its kind: the parity rule works from the polarities alone.

You're warming a pan of soup on an electric stove that takes several minutes to respond. Whenever the soup seems too cool you turn the heat up, and whenever it seems too hot you turn it down. What does the structure predict?

a A smooth rise to the temperature you want
Not quite. That's what a balancing loop does when nothing in it is delayed. Here the stove goes on heating for minutes after you turn it down, so the soup can't stop where you meant it to.

b Swings between too hot and too cool before it settles
Yes. It's a balancing loop with a delay on the effect from the heat setting to the soup's warmth. Each correction goes on acting after the gap has closed, so the soup overshoots, and the next correction overshoots the other way. A behavior note would read oscillation.

c The soup getting hotter and hotter
Not quite. That would take a reinforcing loop. Turning the heat down when the soup is too hot puts one – effect in the loop, an odd number, so the loop is balancing.

d Nothing: without numbers the diagram can't predict anything
Not quite. Without numbers you can't say how large the swings are or how long they last. The structure alone still predicts that they'll happen.

QUESTION 1 OF 3

R1 runs from people with opioid use disorder through overdoses, calls to 911, lives saved and overdose deaths, and back. By the parity rule, what kind of loop is it?

a Reinforcing: it has two – effects, an even number.
Yes. Lives saved → overdose deaths and overdose deaths → people with opioid use disorder are the two, and their reversals cancel. More calls to 911 save more lives, so fewer people die and more remain at risk of another overdose: the change comes back the way it set out.

b Balancing: any loop with a – effect in it is balancing.
Not quite. Only an odd number of – effects makes a loop balancing. Each – effect reverses a change, and two reversals cancel.

c Balancing: a call to 911 is made to bring overdose deaths down.
Not quite. A loop's kind comes from its effects' polarities, not from anyone's purpose. R1 has two – effects, so it is reinforcing, whatever each caller intends.

QUESTION 2 OF 3

B1 leaves overdoses through trauma and burnout of first responders, then mistreatment of patients, joins R1 at calls to 911 and follows it back. What kind of loop is it?

a Reinforcing: it shares four effects with R1, which is reinforcing.
Not quite. Loops that share effects are coupled, but each has its own kind. B1's own path adds a – effect, mistreatment → calls to 911, which makes three.

b Balancing: it has three – effects, an odd number.
Yes. Mistreatment → calls to 911 is the third, beside R1's two. More overdoses bring more burnout, more mistreatment and fewer calls, so fewer lives are saved, more people die, and fewer remain to overdose: the change comes back against itself.

c Reinforcing: burnout and mistreatment both rise as overdoses rise.
Not quite. Those two effects are +, and a + effect changes no loop's kind. Its kind comes from the – effects counted around the whole loop: three, so balancing.

QUESTION 3 OF 3

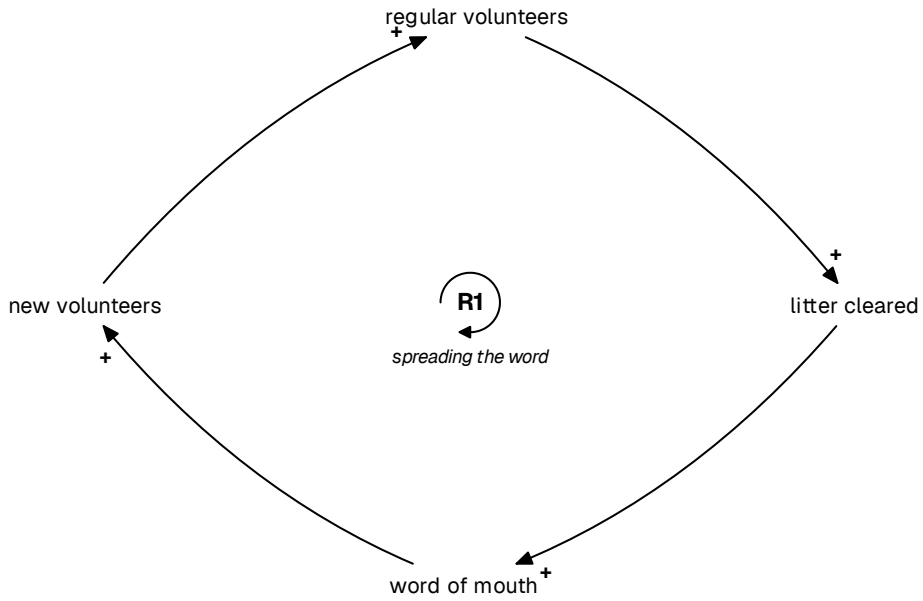
Burnout among first responders keeps growing, so mistreatment keeps more people from calling 911. Which loop comes to dominate, and what happens to overdose deaths?

a B1, and overdose deaths fall, since a balancing loop corrects the problem.
Not quite. B1 does come to dominate, but it runs through lives saved → overdose deaths, a – effect: fewer lives saved, more deaths. Balancing names what the loop does to a change, not whether the result is good.

b R1, since overdoses keep rising and R1 runs through them.
Not quite. Both loops run through overdoses. Growing burnout strengthens only the path through mistreatment, which B1 alone runs through, so B1 gains on R1.

c B1, and overdose deaths rise.
Yes. B1 strengthens through its own path, so it brings overdoses down, but by fewer calls, fewer lives saved and more deaths. A balancing loop makes a change settle; nothing in its kind makes the outcome welcome.

CL 01 A riverbank cleanup that grows by word of mouth



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Four variables close one chain of + effects. More regular volunteers clear more litter, the cleared riverbank gets talked about, and the talk brings new volunteers, so a change compounds in the direction it starts.

Why it works

- Four quantities that can rise or fall
- Closed chain
- All effects +
- Loop named by its behavior

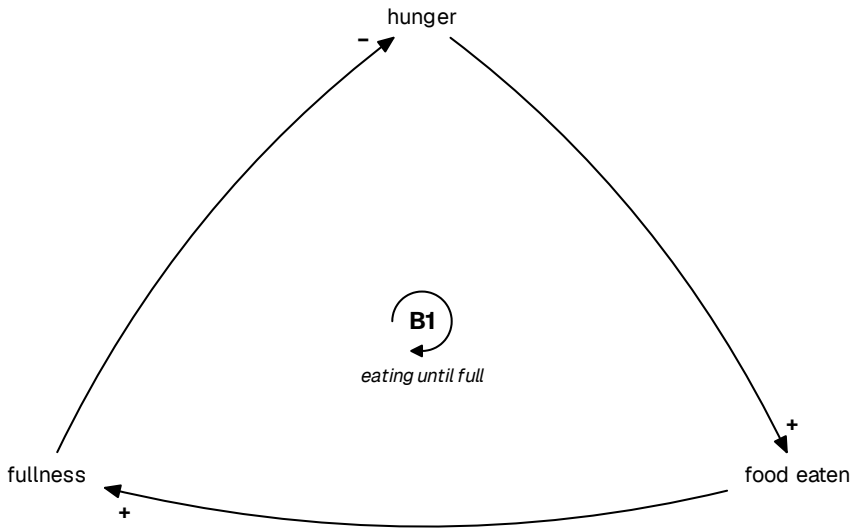
Step by step

1. Regular volunteers and litter cleared, the two quantities the paragraph opens with, and the + effect between them: more volunteers clear more litter.
2. Word of mouth, with a + effect into it from litter cleared: each cleared stretch shows from the footpath, and people who walk there talk about it.
3. New volunteers, with a + effect into them from word of mouth: some of the people who hear about the cleanup come to the next one.
4. The loop closes with a + effect from new volunteers back to regular volunteers, since some newcomers keep coming; with no – effect it is reinforcing, R1, named spreading the word.

What another defensible answer might vary

Another defensible answer might take a different step between the regular volunteers and the newcomers, such as invitations to friends in place of litter cleared, or start the chain at a different variable. What stays the same is four quantities that can rise or fall, closed into one loop of + effects.

CL 02 Hunger and eating



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Hunger raises the food eaten; food eaten raises fullness; fullness lowers hunger. One – effect makes the loop balancing: after each meal it brings hunger back down.

Why it works

- Hunger is a quantity
- One opposite-direction effect
- Closed correction loop
- No meal-by-meal steps

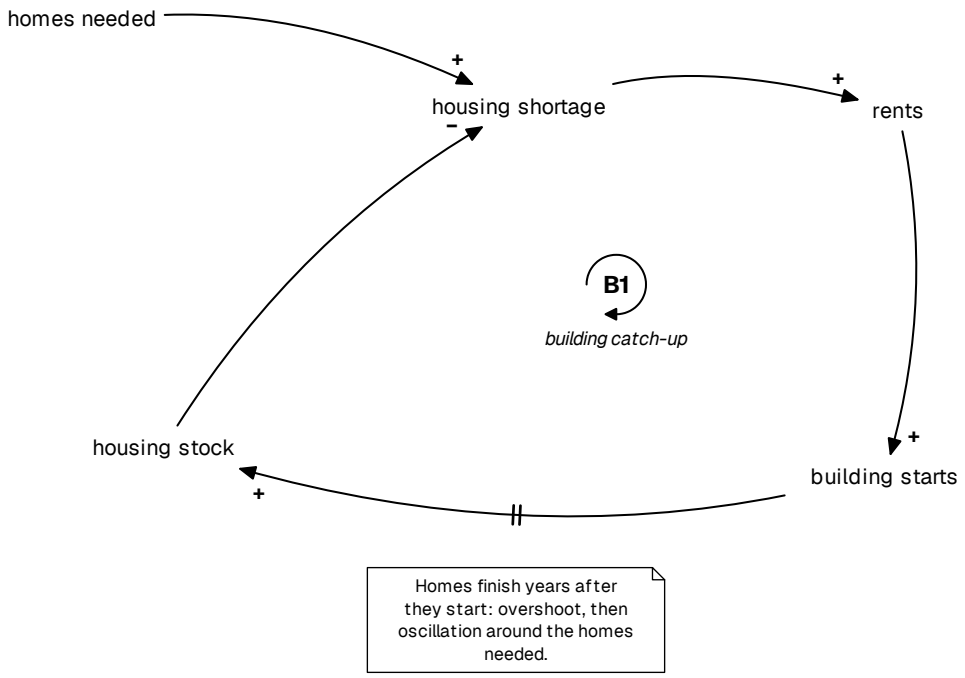
Step by step

1. Hunger and food eaten, with a + effect between them: when hunger rises, a person eats.
2. Fullness, with a + effect into it from food eaten, since food fills the stomach.
3. The loop closes with a – effect from fullness back to hunger, and its label goes on with it: balancing, B1, eating until full.

What another defensible answer might vary

Another defensible answer might add a fourth variable, as the brief allows, such as stomach stretch between food eaten and fullness, or start the chain at a different variable. What stays the same is a single – effect closing one balancing loop around hunger.

CL 03 A housing shortage and the building boom that overshoots it



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Rising rents draw new building that closes the shortage, but homes finish years after they start. Starts made during the delay overshoot the need, and building then falls off: oscillation.

Why it works

- Target and gap are separate
- Delay sits on building starts → housing stock
- Housing stock is a quantity, not an action
- Behavior note names oscillation

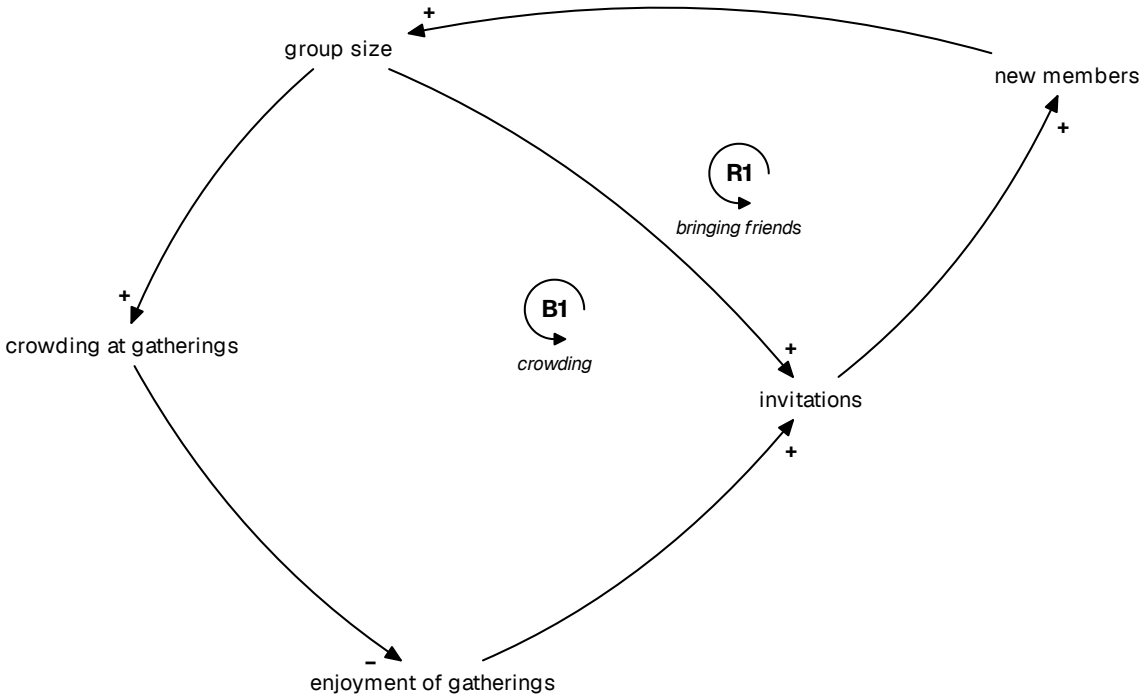
Step by step

1. Homes needed and the housing shortage, with a + effect between them: the need the city's households set, and how far the homes fall short of it.
2. Rents and building starts, with + effects from the shortage to rents and from rents to starts, the developers' answer to high rents.
3. Housing stock, with a + effect from building starts delayed by the two to three years a building takes, and a – effect back to the shortage that closes the loop: balancing, B1, building catch-up.
4. The behavior note, beside the loop once the loop and its delay are both drawn, since the overshoot it names comes from the two together.

What another defensible answer might vary

Another defensible answer might drop rents and let the shortage raise building starts directly, or split the housing stock into homes under construction and homes finished. What stays the same is the homes needed feeding the shortage from outside the loop, one balancing loop through the shortage, the delay on the effect that carries starts into the stock, and a note naming oscillation.

CL 04 A friendship group that grows until gatherings feel crowded



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Group size sits on two loops: invitations bring in new members and grow the group, while crowding lowers enjoyment of gatherings and, with it, the invitations.

Why it works

- Group size is shared
- R and B loops touch
- Crowding path is readable
- Crossings avoided

Step by step

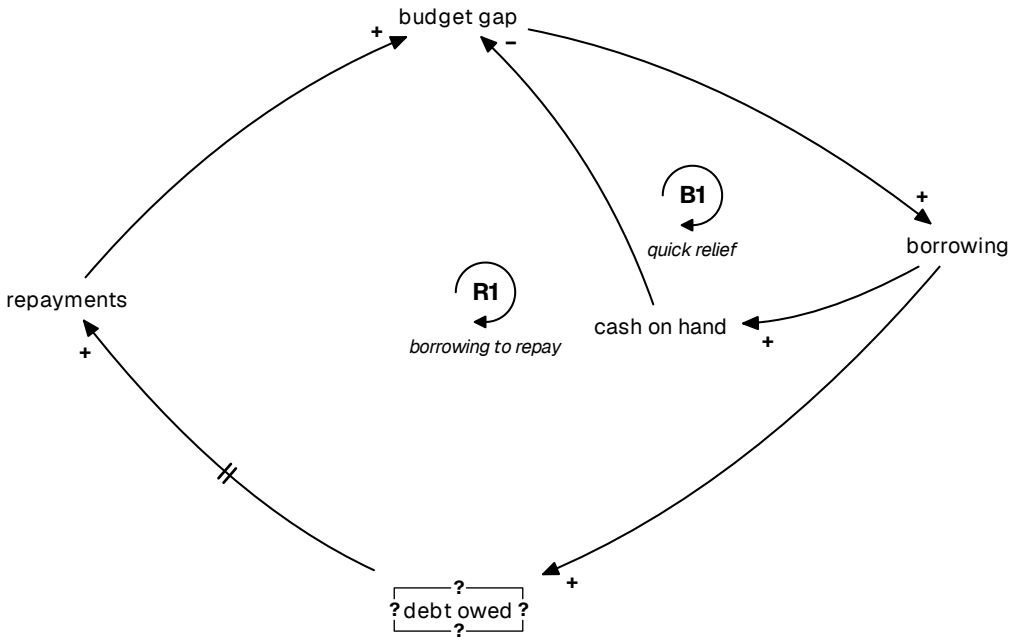
1. Group size and invitations, with a + effect between them: members invite friends of their own.
2. New members, with + effects from invitations and on into group size, closing a loop with no – effect: reinforcing, R1, bringing friends.
3. Crowding at gatherings, with a + effect from group size, which both loops pass through.
4. Enjoyment of gatherings, with a – effect from crowding and a + effect into invitations, which closes a second loop through R1's invitations and new members: one – effect, so balancing, B1, crowding.

What another defensible answer might vary

Another defensible answer might carry the limit through a different quantity, such as time with each friend in place of enjoyment, or let crowding lower how many new members stay rather than the invitations. What stays

the same is one reinforcing and one balancing loop passing through group size, with the single – effect on the crowding path.

CL 05 Borrowing to get to the end of the month



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Borrowing closes this month's gap at once, while the debt it adds comes back as repayments in later months and widens the gap again.

Why it works

- Fast and slow paths separated
- Effect on repayments delayed
- Trap closes as a reinforcing loop
- Debt owed rises before repayments do: the leverage point

Step by step

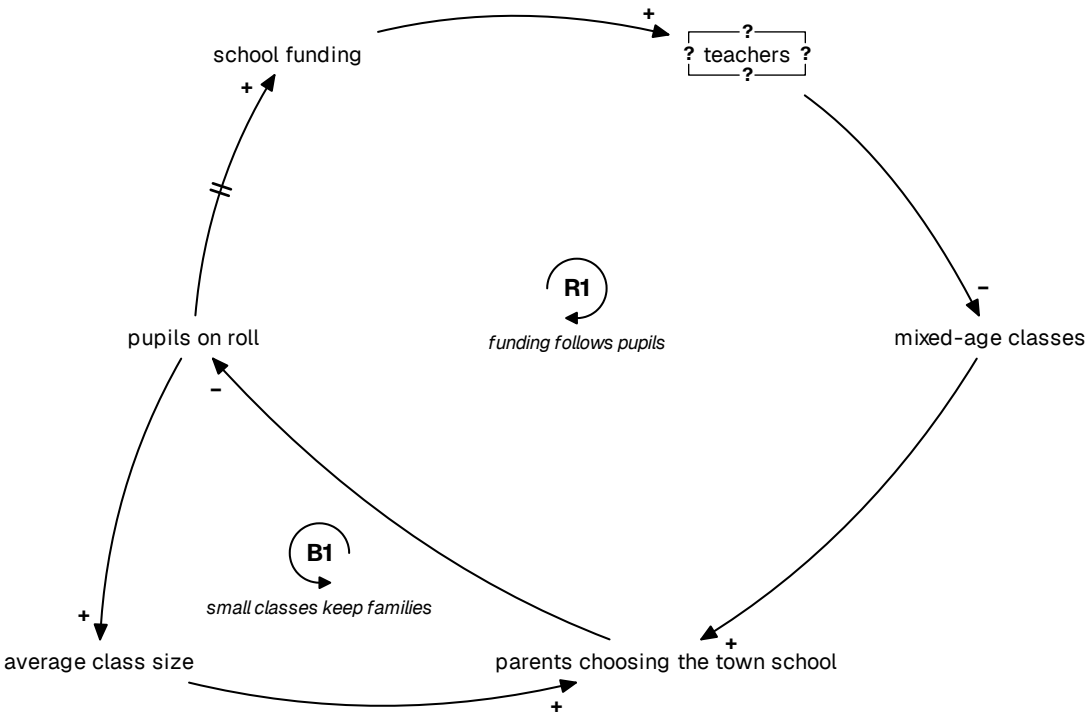
1. Budget gap and borrowing, with a + effect between them: the household covers the month's gap with a credit card.
2. Cash on hand, with a + effect from borrowing and a – effect back to the budget gap, closing the fast loop: balancing, B1, quick relief.
3. Debt owed, with a + effect from borrowing, marked as the leverage point, the variable to monitor first.
4. Repayments, with a + effect from debt owed delayed by the weeks before they start, and a + effect back to the budget gap, closing the slow loop: reinforcing, R1, borrowing to repay.

What another defensible answer might vary

Another defensible answer might put the delay on borrowing → debt owed, as interest builds, or make repayments the leverage point, since they show in the budget each month. What stays the same is a fast

balancing loop of relief and a slower reinforcing loop, through the debt, that reopens the gap.

CS 04 Kelsham Primary School: funding that follows its pupils



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The pupils on roll sit on two coupled loops. Through funding, teachers and mixed-age classes, fewer pupils bring fewer pupils still, a year behind each count; through average class size, fewer pupils make smaller classes, which keep some families from the town school and slow the fall.

Why it works

- Every name passes the more test: more pupils on roll, more mixed-age classes
- R1 has two – effects and B1 one, as the parity rule gives
- The delay on pupils on roll → school funding: the October count
- Both loops share pupils on roll, parents choosing the town school and the effect between them
- Teachers, the leverage point, sit on R1 only: holding their number up weakens R1 and leaves B1

Step by step

1. Pupils on roll, which both loops pass through, and school funding, joined by a + effect with a delay: each October's count sets the funding for the school year after it.
2. Teachers, with a + effect from the funding that pays them, marked as the leverage point: holding their number up cuts the path from the count to the classes.
3. Mixed-age classes, more of them as teachers fall (–), and parents choosing the town school, more of them as classes are mixed (+).
4. A – effect from parents choosing the town school back to pupils on roll closes R1: two – effects, an even number, so it is reinforcing, and a fall in pupils brings a further fall.

5. Average class size, rising with pupils on roll (+) and sending parents to the town school (+), closes B1 through the same – effect: one – effect, so it is balancing, and it slows the fall.

What another defensible answer might vary

Another defensible answer might propose mixed-age classes as the leverage point, keeping Years 3 and 4 apart with a teacher paid from the reserve, or parents choosing the town school, through what families hear about Kelsham. It might also draw a + effect from mixed-age classes to average class size, closing a second reinforcing loop. What stays the same is a reinforcing loop through funding and a balancing loop through class size, coupled at the pupils on roll, with the delay on the funding.

Chapter 5 · Delays, External Drivers, and Competing Loops

In the road diagram, shorter travel times bring more homes on the outskirts, and more homes bring more car trips. Should homes on the outskirts be drawn as an external driver?

a Yes: the homes are on the outskirts, outside the town
Not quite. Where a thing sits on a map doesn't decide it. The boundary marks what the model explains, and the model explains these homes: travel time changes them.

b No: travel time affects them, so they belong inside the boundary
Yes. An external driver affects the inside and isn't affected back. An effect runs from travel time into homes on the outskirts, so they're part of what the model explains, and of loop B3.

c Yes: developers decide what gets built, not the council
Not quite. Who decides doesn't settle it. What settles it is whether anything inside the boundary changes the variable, and travel time does.

d Only once the homes outnumber the town's own
Not quite. Size doesn't make a variable external. One homeowner or ten thousand, an effect into it from inside the boundary keeps it inside.

Five years after the widening, travel time is back where it was. Suppose the regional population hadn't grown at all. Which reading of the road diagram fits?

a B1 never moved travel time: widening did nothing
Not quite. Travel time fell in the first year, so B1 led then; other loops took over later.

b B1 led at first; B2 and B3 led once trips and homes had grown
Yes. That's the shift in loop dominance the behavior note names. B2 changes travel time within months and B3, through its delay, over years; both pull travel time back toward the level motorists will put up with.

c A reinforcing loop formed somewhere in the town
Not quite. Every loop in the diagram is balancing: each has one – effect. Travel time returning to a level, rather than growing without end, is what balancing loops produce.

d Travel time came back through the external driver
Not quite. With the regional population flat, nothing outside the boundary changed: the town's own loops brought travel time back.

QUESTION 1 OF 3

Which variable is drawn as an external driver, in angle brackets, and why?

a Variety of children’s circumstances: it changes the quality of help, and nothing drawn changes it.
Yes. Children’s circumstances vary for reasons no rule or target reaches, so no effect runs into it. Its one effect leaves it: the wider the variety, the less help a fixed procedure gives.

b Target level of prescription: government sets it, from outside the profession.
Not quite. Perceived effectiveness of prescription changes the target through a + effect, so the target sits inside B2 and R1. An external driver has no effect running into it.

c Mistakes: they arise in children’s lives, outside any office.
Not quite. Quality of help changes mistakes through a – effect, and mistakes change reflection on the prescriptive approach: mistakes sit inside B2.

QUESTION 2 OF 3

In the review's account, R1, we followed procedures, keeps B2, but it's going wrong, from bringing the target level of prescription down. Where do the two loops compete?

a At compliance enforcement, where B1, comply, joins them.
Not quite. B2 and R1 both reach enforcement the same way, from the target. They pull apart earlier, at perceived effectiveness of prescription, which each changes through its own – effect.

b At mistakes, which R1 brings down.
Not quite. R1 doesn't run through mistakes. It changes whether mistakes are acknowledged, and so meets B2 at perceived effectiveness of prescription.

c At perceived effectiveness of prescription: mistakes bring it down through reflection, while the rules defense holds it up.
Yes. Two – effects end there. Through B2, more mistakes bring more reflection and lower it; through R1, more compliance makes the rules defense more available, mistakes harder to acknowledge, and raises it. While R1 dominates, the target stays high whatever the mistakes.

QUESTION 3 OF 3

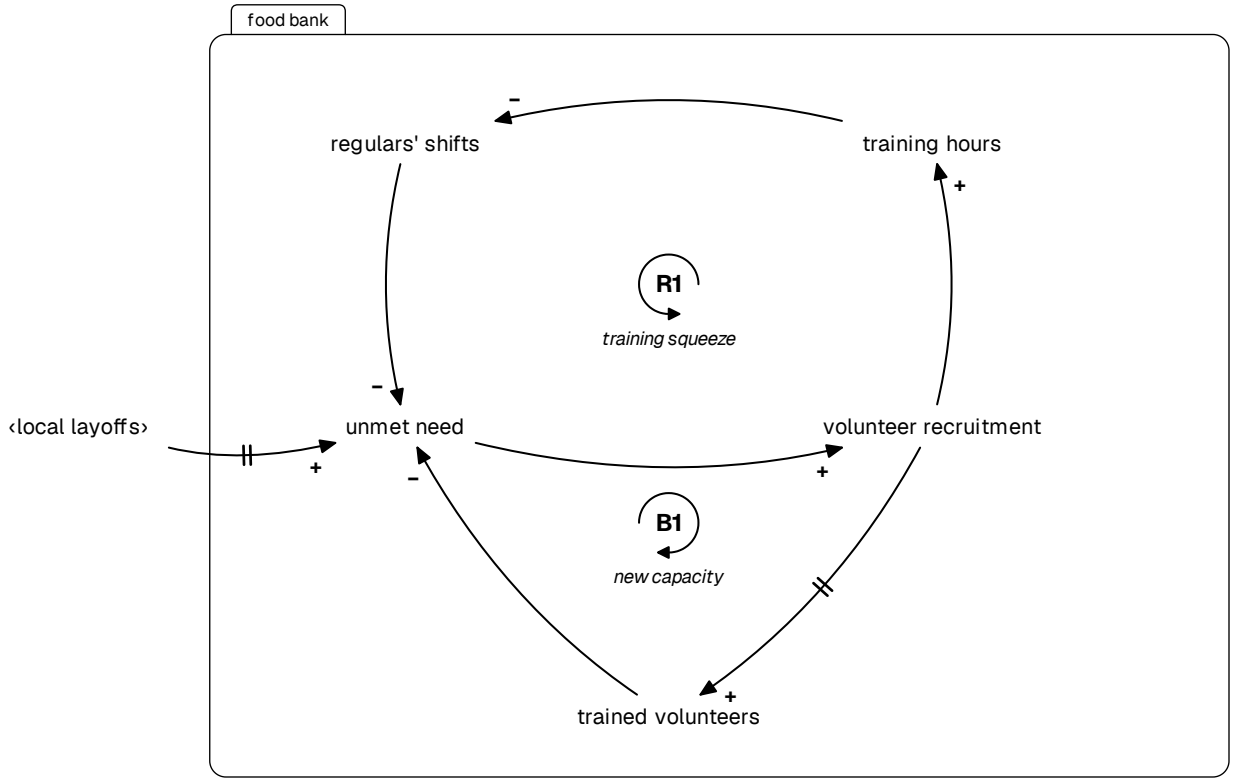
No effect in the figure carries a delay. On which effect would a delay belong?

a Compliance enforcement → room for professional judgment.
Not quite. An enforced rule narrows what a social worker may do from the day it applies: the change in room follows the change in enforcement with no delay to mark.

b Quality of help to children → mistakes.
Yes. A mistake in the help given is found when harm to a child comes to light, often months or years later: the change in mistakes comes long after the change in quality of help. With that delay, B2 corrects slowly, and R1 has time to dominate.

c Room for professional judgment → compliance with prescriptions.
Not quite. Compliance is, in the review's words, "the proximal effect" of a cut in that room: the change in compliance follows the change in room with no delay to mark.

CL 06 A food bank in a downturn



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Layoffs raise unmet need months later. Recruiting answers it, but training takes the regulars off their shifts before trained volunteers arrive, so unmet need grows before it falls.

Why it works

- Layoffs outside the boundary, with no effect into them
- Two delays: savings running out, and training
- Training squeeze reinforcing, new capacity balancing
- The squeeze has no delay, so it leads

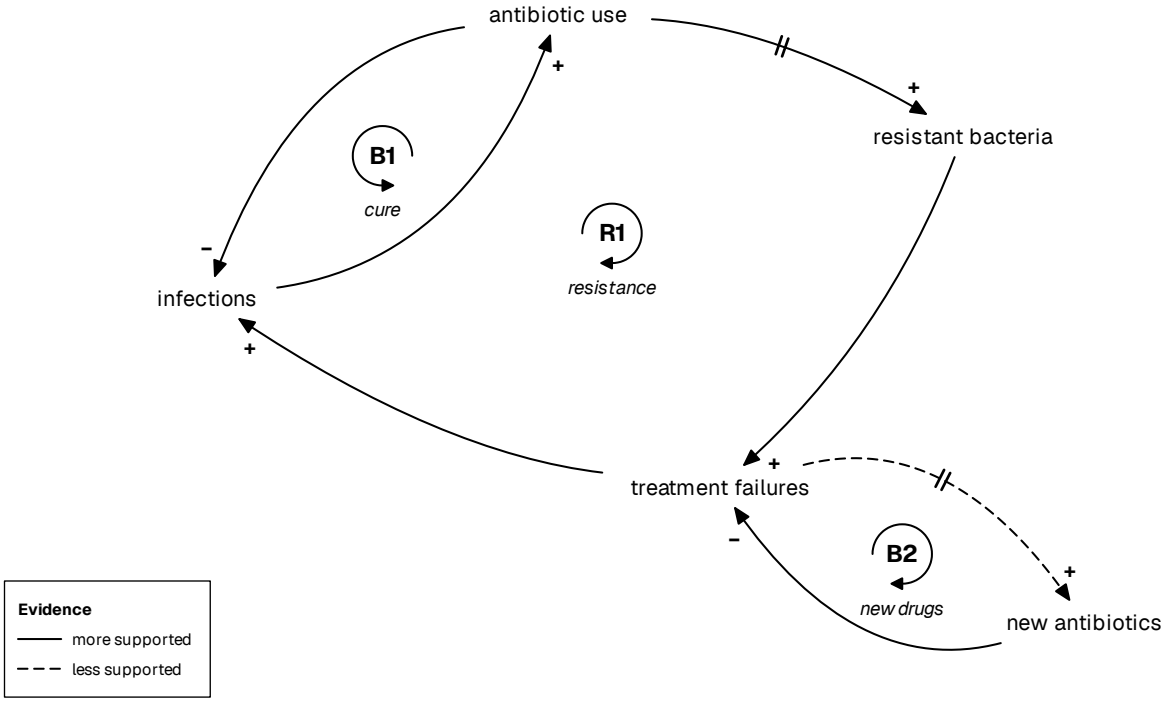
Step by step

1. The boundary, food bank, with local layoffs outside it and unmet need inside, joined by a + effect delayed by the months families' savings last.
2. Volunteer recruitment, with a + effect from unmet need: the food bank's response, which both loops pass through.
3. Training hours and regulars' shifts, with a + effect from recruitment to training hours, a – effect on to the regulars' shifts and a – effect back to unmet need: two – effects, so reinforcing, R1, training squeeze.
4. Trained volunteers, with a + effect from recruitment delayed by the weeks of training, and a – effect on unmet need: one – effect, so balancing, B1, new capacity, drawn after the squeeze it follows in time.

What another defensible answer might vary

Another answer might put the first delay on unmet need → volunteer recruitment instead, add a variable such as shifts covered between trained volunteers and unmet need, or name the boundary differently. What stays is training hours arriving before trained volunteers, so unmet need grows first: a reinforcing loop through the regulars' shifts, a balancing loop through trained volunteers, and layoffs outside the boundary with no effect running into them.

CL 07 Antibiotics and the resistance they breed



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Prescribing cures infections, and over years breeds the resistant bacteria that make them harder to cure. New antibiotics would balance the failures a decade later, if drug makers develop them.

Why it works

- Three loops share infections, antibiotic use and treatment failures
- The uncertain effect, treatment failures → new antibiotics, dashed
- Legend lists the dashed line as less supported
- Resistance and new antibiotics both arrive after a delay

Step by step

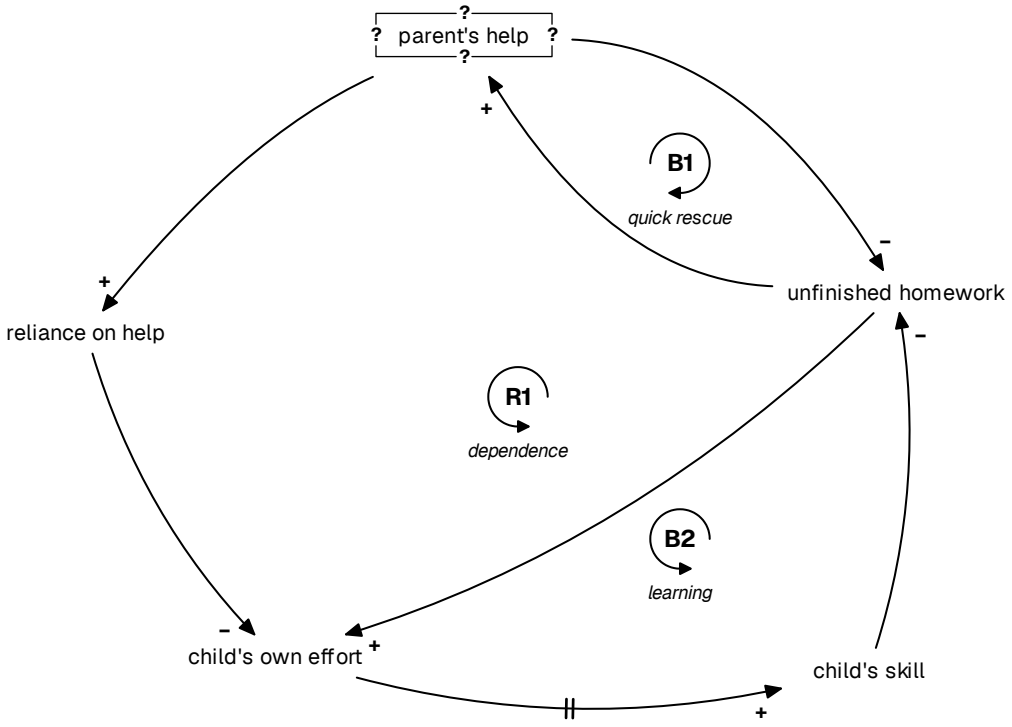
1. Infections and antibiotic use, with a + effect from infections to use and a – effect back as cures bring infections down: balancing, B1, cure.
2. Resistant bacteria and treatment failures, with a + effect from antibiotic use delayed by years of heavy use, and + effects on to treatment failures and back to infections: no – effect, so reinforcing, R1, resistance.
3. New antibiotics, with a + effect from treatment failures delayed by a decade and dashed as a hypothesis, and a – effect back on failures: balancing, B2, new drugs, with the legend for the one dashed line.

What another defensible answer might vary

Another answer might add a stewardship loop in which treatment failures cut antibiotic use, route resistance through broader prescribing rather than through spreading infections, or code a different effect as the hypothesis.

What stays is a balancing cure loop undone by a reinforcing resistance loop, a slower balancing loop through new antibiotics, and the hypothesis dashed and declared in the legend.

CL 08 A parent who finishes the homework



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The parent's help clears tonight's homework at once. It also builds the child's reliance on help, which cuts the child's own effort, so skill builds slower and the next assignment gets help too.

Why it works

- Quick rescue at the top, read first
- Skill arrives after a delay
- Reliance on help cuts the child's own effort: a – effect
- Dependence is the reinforcing loop the rescue feeds

Step by step

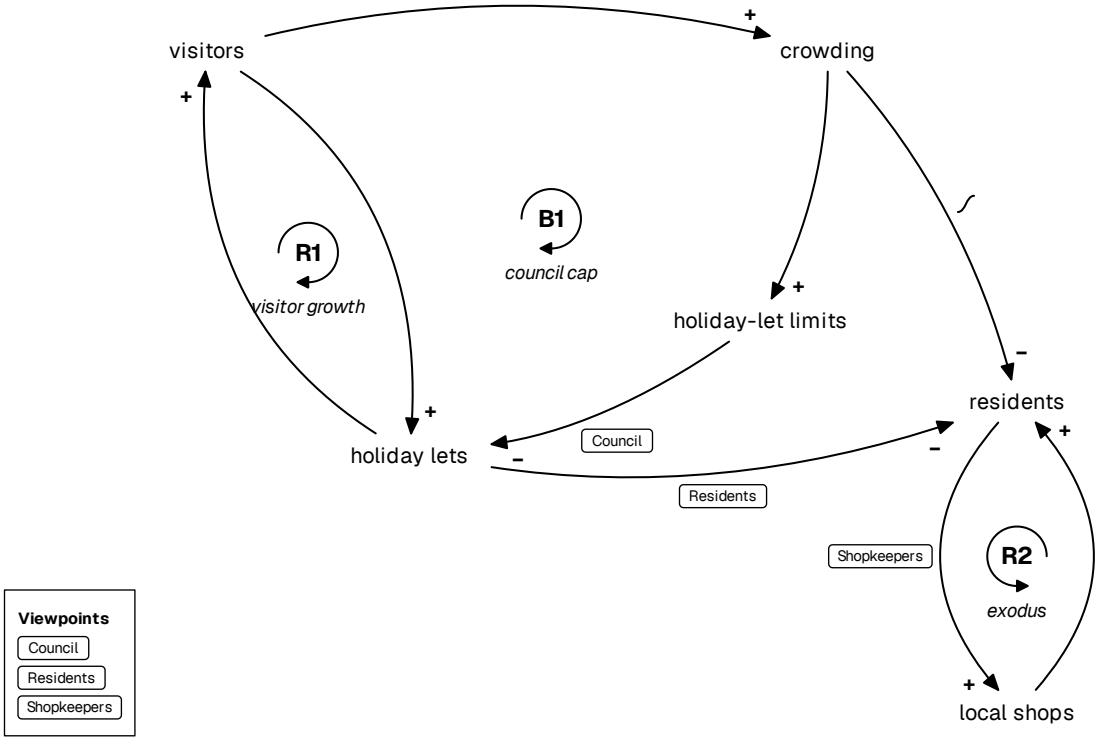
1. Unfinished homework and parent's help, marked as the leverage point, with a + effect to the help and a – effect back: balancing, B1, quick rescue, the part of the story each rushed evening starts with.
2. Child's own effort and child's skill, with a + effect from unfinished homework to effort, a + effect from effort to skill delayed by weeks, and a – effect from skill back to unfinished homework: balancing, B2, learning.
3. Reliance on help, with a + effect from parent's help and a – effect on the child's own effort, closing a loop through the rescue and the learning: two – effects, so reinforcing, R1, dependence.

What another defensible answer might vary

Another answer might run the – effect straight from parent's help to the child's own effort and leave reliance out, or make the child's own effort the leverage point instead of the parent's help. What stays is the shifting-the-

burden shape: a fast balancing rescue, a slower balancing loop through the child's skill, and a reinforcing dependence that the help feeds by crowding out the child's effort.

CL 09 An old town and its visitors



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Visitors and holiday lets feed each other, and the council's limits balance them through crowding. Past the threshold, residents leave fast, and the local shops they keep open close, so more leave.

Why it works

- Visitor growth, council cap and exodus
- Threshold marked on crowding → residents
- Council, residents and shopkeepers tagged
- Legend lists the three viewpoints

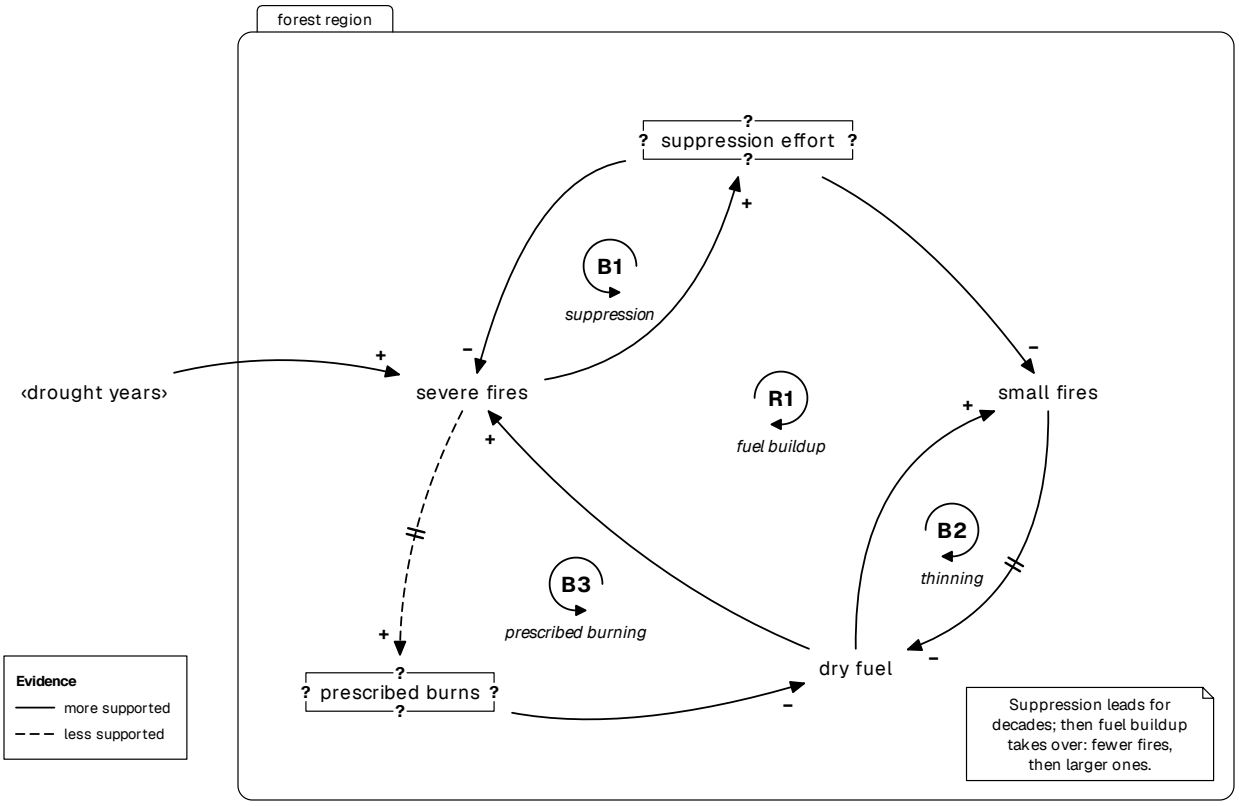
Step by step

1. Visitors and holiday lets, with a + effect each way, since visitors fill lets and lets draw visitors: reinforcing, R1, visitor growth.
2. Crowding and holiday-let limits, with + effects from visitors to crowding and on to the limits, and a – effect from the limits on holiday lets, tagged Council: one – effect, so balancing, B1, council cap, with the legend, since the Council tag is the one viewpoint drawn so far.
3. Residents, with a – effect from holiday lets, tagged Residents, and a – effect from crowding, marked nonlinear for the point where summer visitors outnumber them.
4. Local shops, with a + effect from residents, tagged Shopkeepers, and a + effect back to residents: reinforcing, R2, exodus, drawn last as the situation's third sentence has it.

What another defensible answer might vary

Another answer might put the threshold on holiday lets → residents instead, tag different effects with the three viewpoints, or add visitor spending, which keeps shops for visitors open while local shops close. What stays is two reinforcing loops, visitor growth and the exodus, a balancing loop through the council's limits, one nonlinear effect, and three viewpoints that differ in emphasis, not structure.

CL 10 A forest region and its fires



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Suppression puts out severe fires quickly, and the small fires that thin the fuel too, so fuel builds and severe fires return larger. Prescribed burns would balance the buildup after a delay, if severe fires lead to their funding.

Why it works

- Four named loops share severe fires and dry fuel
- Drought years outside the boundary, with no effect into them
- The funding effect dashed and declared in the legend
- Leverage points on suppression effort and prescribed burns
- Behavior note: suppression leads first, fuel buildup later

Step by step

1. The boundary, forest region, with dry fuel and small fires inside it, a + effect from fuel to small fires and a – effect back, delayed as the fires thin the undergrowth: balancing, B2, thinning, the forest before suppression.
2. Severe fires, with a + effect from dry fuel, and suppression effort, marked as a leverage point, with a + effect from severe fires and a – effect back on them: balancing, B1, suppression.
3. A – effect from suppression effort on small fires closes a loop back through dry fuel to severe fires: two – effects, so reinforcing, R1, fuel buildup.
4. Drought years, the external driver, outside the boundary, with a + effect on severe fires, drawn once the fires it acts on are in place.
5. Prescribed burns, marked as a leverage point, with a + effect from severe fires, delayed and dashed as a hypothesis, and a – effect on dry fuel: balancing, B3, prescribed burning, with the legend for the one dashed

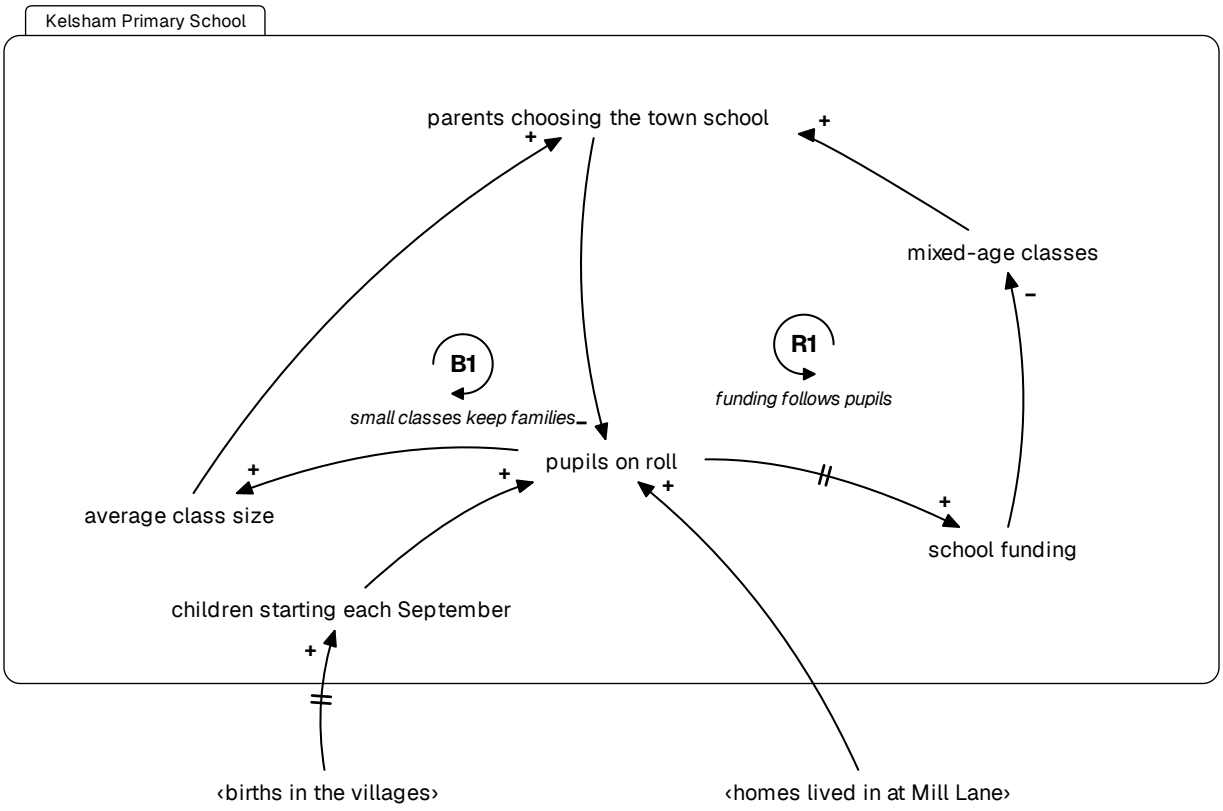
line.

6. The behavior note, once all four loops are drawn, since it is about two of them: B1 leading, R1 taking over.

What another defensible answer might vary

Another answer might add homes built in the forest, which raise suppression effort, mark dry fuel → severe fires as nonlinear past a fuel threshold, or code a different effect as the hypothesis. What stays is four named loops sharing severe fires and dry fuel, drought years outside a named boundary with no effect running into them, and the evidence coding declared in the legend.

CS 05 Kelsham Primary School: births, new homes and two loops



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Births in the villages and homes lived in at Mill Lane sit outside the boundary as external drivers: nothing the school does changes either. Births reach the starters four years later, so the fall from 22 births to 11 reaches the starters until 2029. Inside, two loops compete through the roll: R1, funding follows pupils, carries a fall in the roll further, a school year behind each October count, and B1, small classes keep families, slows it. The new homes raise the roll from 2027, and R1 then carries the rise further while B1 resists it as classes fill.

Why it works

- Births and the new homes outside the boundary, with no effect into either
- Two delays: the four years from births to starters, and the October count on the funding
- R1 has two – effects and B1 one, as the parity rule gives
- The loops share the roll, parents choosing the town school and the – effect between them, so a change in the roll runs through both
- The new homes act on the roll, not the starters: their children join every year group

Step by step

1. The boundary, Kelsham Primary School, with births in the villages outside it and children starting each September inside, joined by a + effect with a delay: a child born in the villages starts four Septembers later.
2. Pupils on roll, with + effects from the starters and from homes lived in at Mill Lane, the second external driver, whose children join every year group.
3. School funding, with a + effect from the roll and a delay: each October count sets the funding for the school year after it.

4. Mixed-age classes and parents choosing the town school, with a – effect from the funding, a + effect between them and a – effect back to the roll: two – effects, so reinforcing, R1, funding follows pupils.
5. Average class size, with + effects from the roll and on parents choosing the town school: one – effect on the way back, so balancing, B1, small classes keep families, competing with R1 for the roll.

What another defensible answer might vary

Another defensible answer might keep teachers between school funding and mixed-age classes, as CS 04 draws them, or draw parents choosing the town school on the children starting each September as well, since most families choose a school when a child starts. What stays the same is two external drivers outside a named boundary, the delay from births to starters, and a reinforcing loop through funding competing with a balancing loop through class size.

Chapter 6 · What Accumulates

A phone charges overnight and runs down through the day. Which of these is a stock?

a the charge in its battery
Yes. Unplug the phone and switch it off, and the charge is still there to be measured, as a percentage of a full battery. Charging fills it and use drains it.

b charging
Not quite. Charging is a flow: it fills the battery, counted in percent per hour, and it stops when the phone is unplugged. What it leaves behind, the charge, is the stock.

c the screen's brightness
Not quite. Brightness is an auxiliary: a setting that changes how fast use drains the battery. Nothing builds up in it, so it is drawn as a name with a signal to the valve of the battery's outflow.

Emails reach Dana's inbox at 60 a day, and she answers or archives 50 a day. This week, arrivals fall to 55 a day while she still clears 50. What do the emails in her inbox do this week?

a They keep rising, by 5 a day instead of 10
Yes. change in emails in inbox = emails arriving − emails cleared: 55 − 50, so the net flow is 5 a day. The inflow fell but still exceeds the outflow, so the stock rises, more slowly.

b They fall, because fewer emails arrive
Not quite. Fewer arrive than last week, but more still arrive than leave. The inbox falls only once arrivals drop below the 50 a day she clears.

c They hold steady
Not quite. The inbox holds steady only while arrivals equal clearing, 50 a day each. At 55 in and 50 out, it holds 5 more emails each evening than the evening before.

QUESTION 1 OF 3

USGS calls each place water is stored a pool, drawn here as a stock, and each way water moves between pools a flux, drawn as a flow. Which flow is not a transfer?

a Evapotranspiration, since liquid water leaves the soil as vapor.
Not quite. The water changes state on the way, but it leaves soil moisture and arrives in atmospheric moisture over land, both stocks counted in cubic kilometers: a transfer.

b Agricultural water use, which ends at a cloud.
Yes. A transfer runs from one stock straight into another. Agricultural water use leaves groundwater for a cloud: the irrigated fields, and wherever their water goes next, lie outside the model.

c Transport of moisture from ocean to land, since it carries water sideways through the air rather than into or out of the ground or the sea.
Not quite. It drains atmospheric moisture over ocean and fills atmospheric moisture over land. Air holds stocks as the sea does, so a flow between two of them is a transfer.

QUESTION 2 OF 3

USGS gives no amounts. The redrawing counts every stock in cubic kilometers and declares the year as its time unit. In what units does ocean evaporation run?

a Cubic kilometers.
Not quite. Those are the units of the two stocks it joins, the ocean's mixed zone and atmospheric moisture over ocean. A flow is counted per time unit.

b Millimeters a year, the depth of water lost from the sea's surface.
Not quite. A depth a year is one way to report evaporation, but a flow moves material between stocks, so it runs in their units per time unit, not in units of its own.

c Cubic kilometers a year.
Yes. A flow's units are its stock's units per time unit. Ocean evaporation is a transfer, so the stock it drains and the stock it fills both count what it moves in cubic kilometers.

QUESTION 3 OF 3

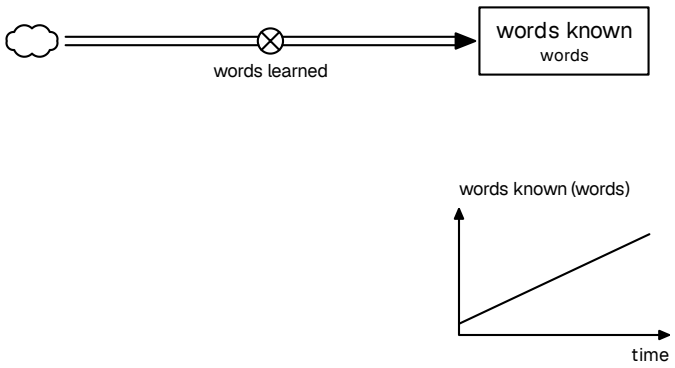
Which is the stock equation of groundwater?

a change in groundwater = groundwater recharge – groundwater discharge to ocean – agricultural water use
Yes. Groundwater recharge is its one inflow; groundwater discharge to ocean and agricultural water use are its two outflows. Every flow into or out of the stock appears, the one to a cloud as much as the transfers.

b change in groundwater = groundwater recharge – groundwater discharge to ocean
Not quite. That leaves out agricultural water use, which drains groundwater too. A flow ending at a cloud still changes the stock it leaves.

c change in groundwater = groundwater recharge + runoff – groundwater discharge to ocean
Not quite. Runoff leaves soil moisture for the water in rivers and never reaches groundwater, so it belongs in those two stocks' equations, not this one.

SF 01 Words a language learner knows



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One stock, words known, counted in words, filled from a cloud by one flow, words learned. The time unit is a week, so words learned is counted in words per week. Nothing drains the stock and about forty words arrive each week, so the graph of words known rises steadily.

Why it works

- Words known is the stock: it could be counted on any day, and would still be there if Lena stopped studying
- Words learned is the flow that fills it, counted in words per week
- The cloud is where new words come from, outside what the model holds
- Forgetting is left out, so the graph rises in a straight line

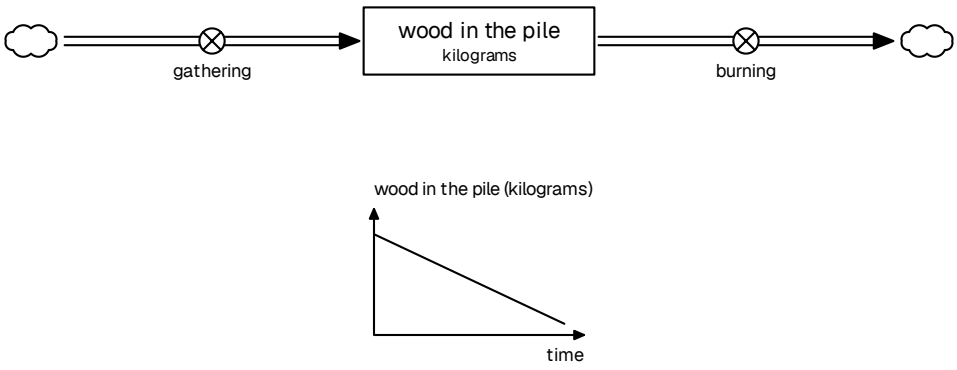
Step by step

1. Words known, the stock, counted in words, with the time unit a week: about 300 words today, the count that the flow fills and the graph follows.
2. Words learned, the flow that fills the stock, drawn with its cloud, since a flow has an end on each side: the words Lena has yet to meet lie outside what the model counts.
3. A behavior-over-time graph of words known, rising in a straight line: forty words a week arrive, and with forgetting left out, none leave.

What another defensible answer might vary

Another defensible answer might name the stock Portuguese words known, or the flow new words learned. What stays the same is one stock with its units, one inflow from one cloud, the time unit a week, and a graph that rises steadily.

SF 02 Firewood at a scout camp



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One stock, wood in the pile, counted in kilograms, filled from a cloud by gathering and drained to another by burning. The time unit is an hour, so both flows are counted in kilograms per hour. After dark the fire burns about twelve kilograms an hour and the scouts gather about five, so the pile falls by about seven kilograms an hour: a straight line down.

Why it works

- The pile is the stock: it could be weighed at any moment
- The pile changes only through gathering and burning
- One cloud for the branches still lying in the field, one for the smoke and ash: both outside what the model holds
- The graph covers the evening, when burning outpaces gathering by a steady seven kilograms an hour

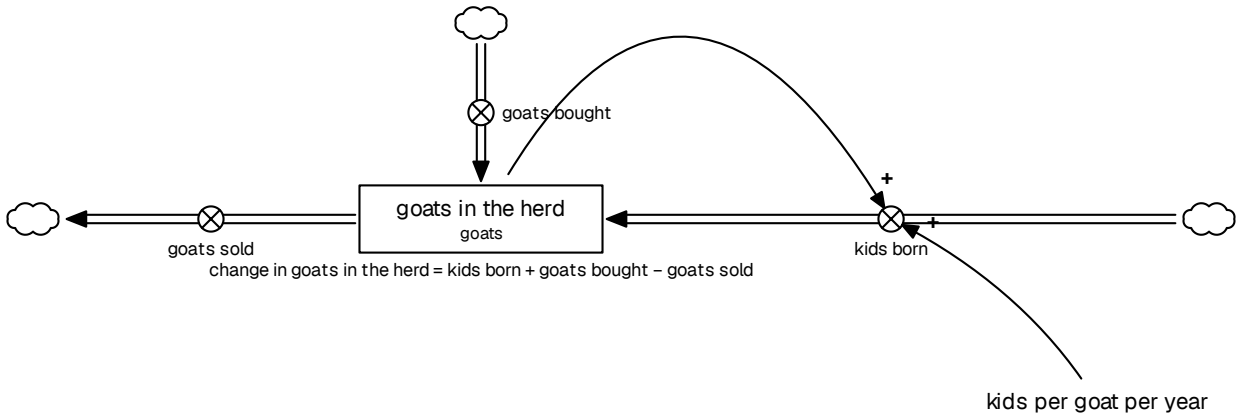
Step by step

1. Wood in the pile, the stock, counted in kilograms, with the time unit an hour: the branches the scouts gather wait here until the fire burns them.
2. Gathering, the inflow, with a cloud at its start, since a fallen branch counts only once it reaches the pile: about thirty kilograms an hour in the afternoon, five after dark.
3. Burning, the outflow, with a cloud at its end for what leaves the fire: about twelve kilograms an hour.
4. A behavior-over-time graph of the pile through the evening, falling in a straight line: twelve kilograms burned against five gathered leaves the pile seven kilograms lighter each hour.

What another defensible answer might vary

Another defensible answer might count the wood in logs, or name the flows wood gathered and wood burned. What stays the same is one stock, one inflow and one outflow, a cloud at each end, the time unit an hour, and a graph that falls steadily.

SF 03 Goats on a family smallholding



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One stock, goats in the herd, counted in goats, filled by kids born and goats bought and drained by goats sold, each flow with a cloud at its other end. The time unit is a year. Signals from the herd and from kids per goat per year, an auxiliary, end at the valve of kids born, both +: a bigger herd has more kids. The stock equation reads change in goats in the herd = kids born + goats bought – goats sold.

Why it works

- Goats in the herd is the one stock: it could be counted on any day
- Kids born, goats bought and goats sold are its flows, each counted in goats per year
- Kids per goat per year is an auxiliary: it holds nothing and moves nothing
- The signal from the herd ends at the valve of kids born, not at the stock: the herd changes only through its flows
- The stock equation is written out from the three flows

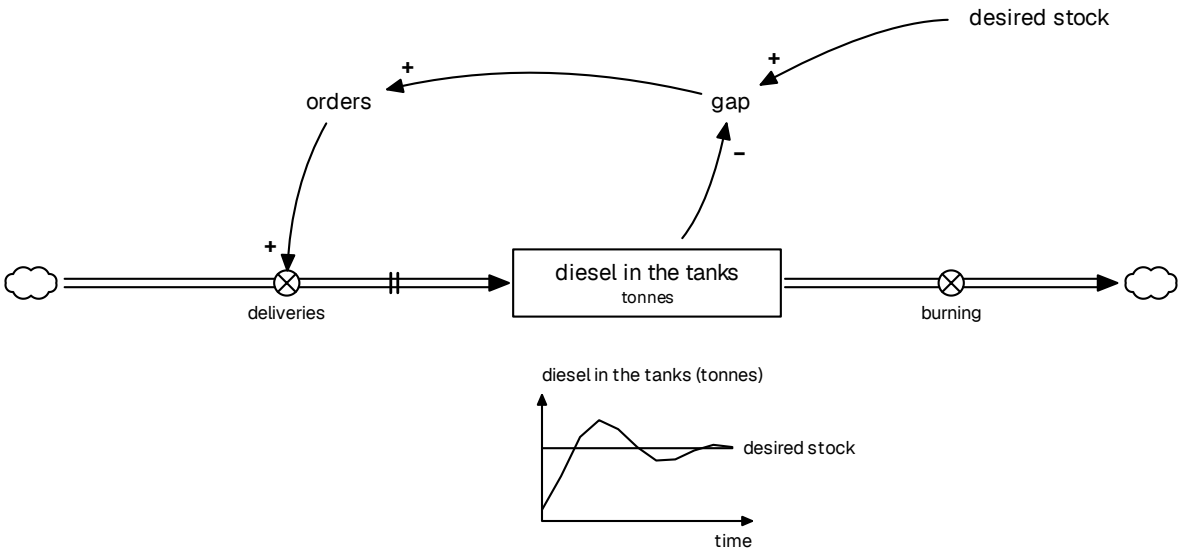
Step by step

1. Goats in the herd, the stock, counted in goats, with the time unit a year and its stock equation beneath it, which gains a term with each flow drawn: twenty goats at the start of the year.
2. Kids born, an inflow from a cloud, since a kid enters the count only when it is born.
3. Goats bought and goats sold, an inflow from a cloud for the market and an outflow to a cloud for the buyers: about two in and fifteen out each year, the last terms of the stock equation.
4. Kids per goat per year, an auxiliary, and + signals from it and from the herd to the valve of kids born: twenty goats with about one kid each bring about twenty kids a spring, and forty bring forty.

What another defensible answer might vary

Another defensible answer might put a second auxiliary, does in the herd, between the herd and kids born, or name the flows births, purchases and sales. What stays the same is one stock with two inflows and one outflow, a path of signals from the herd to kids born, and the stock equation shown.

SF 04 Diesel for an island's power station



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One stock, diesel in the tanks, counted in tonnes, filled from a cloud by deliveries and drained to another by burning; the time unit is a week. Signals run from the stock (–) and from desired stock (+) to the gap, from the gap to orders (+), and from orders to the valve of deliveries (+). Deliveries carry a material delay: each order arrives four weeks after it is placed. Orders keep rising while the ordered diesel is still at sea, so the tanks rise past 250 tonnes to about 340, fall back to about 190, and swing closer each time: the graph oscillates around the line at desired stock.

Why it works

- Orders are an auxiliary: an order placed moves no diesel until its tanker arrives
- Deliveries are the flow, and the four weeks are a material delay on it
- The gap reads the stock and desired stock, and sets orders
- The path from the stock to deliveries ends at the flow's valve: the tanks change only through their flows
- The graph's line is drawn at the desired stock auxiliary, solid

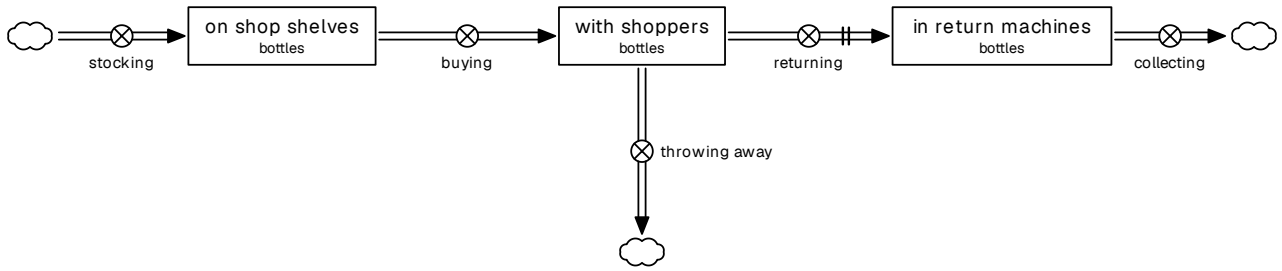
Step by step

1. Diesel in the tanks, the stock, counted in tonnes, with the time unit a week: 100 tonnes after the storms, against the 250 the manager aims to keep.
2. Burning, the outflow to a cloud: the power station burns about 40 tonnes a week, whatever the tanks hold.
3. Deliveries, the inflow from a cloud, with a material delay, since a tanker brings each order four weeks after the manager places it.
4. Desired stock and the gap, two auxiliaries, with a + signal from desired stock and a – signal from the tanks into the gap: the lower the tanks run below 250 tonnes, the larger the gap.
5. Orders, an auxiliary, with a + signal from the gap and a + signal to the valve of deliveries: each week's order is 40 tonnes plus a quarter of the gap, and its diesel reaches the tanks only through deliveries.
6. A behavior-over-time graph of the tanks, with a solid line at desired stock: with four weeks of orders still at sea when the tanks reach 250 tonnes, they rise on to about 340, fall to about 190, and swing closer each time.

What another defensible answer might vary

Another defensible answer might add a signal from burning to orders, for the 40 tonnes ordered each week, or name the stock fuel stock. What stays the same is orders as an auxiliary, deliveries as the flow with one material delay, a path of signals from the stock through the gap to deliveries, and an oscillating graph with its line at the desired stock.

SF 05 Bottles in a deposit-return scheme



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Three stocks in a row, each counted in bottles: on shop shelves, with shoppers, in return machines. Stocking fills the shelves from a cloud; buying and returning are transfers, so a bottle leaving one stock arrives in the next; throwing away drains the shoppers' stock to a cloud, and collecting drains the machines to another. The time unit is a week. Bottles wait longest with shoppers, about five weeks, so the material delay is on returning.

Why it works

- Each stock is a place where bottles could be counted at an instant
- Buying and returning run from stock to stock, so no bottle appears or vanishes between stages
- Every stock is counted in bottles, so both transfers keep their units
- Throwing away and collecting end at clouds: where a bottle goes after the bin or the recycling lorry lies outside the model
- One delay, on returning: about five weeks with shoppers, against two on a shelf and half a week in a machine

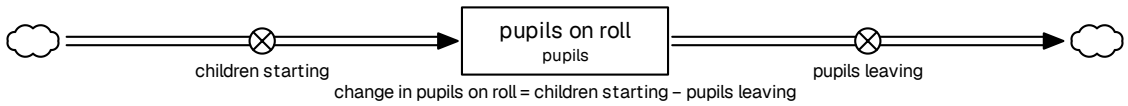
Step by step

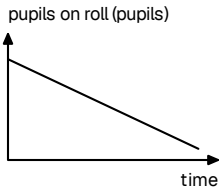
1. Three stocks in a row, each counted in bottles, with the time unit a week, in the order a bottle passes through them: on shop shelves, with shoppers, in return machines.
2. Stocking, the inflow to the shelves, from a cloud: a bottle enters the count when the bottlers deliver it to a shop.
3. Buying and returning, two transfers, each from one stock into the next, returning with the material delay: a shopper keeps a bottle about five weeks, longer than it waits anywhere else.
4. Throwing away, out of the shoppers' stock, and collecting, out of the machines, each to a cloud: about one bottle in ten goes in a bin, and the machines are emptied twice a week.

What another defensible answer might vary

Another defensible answer might add a flow from the shelves to a cloud for bottles broken in shops, or name the stocks bottles on sale, bottles at home and bottles awaiting collection. What stays the same is three stocks in bottles in a row, transfers between them, bottles thrown away to a cloud, and one material delay, on returning.

CS 06 Kelsham Primary School: the roll, filled and drained





This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One stock, pupils on roll, counted in pupils, filled from a cloud by children starting and drained to a cloud by pupils leaving, both in pupils per year. The time unit is a year, and the stock equation reads change in pupils on roll = children starting – pupils leaving: in the year to October 2026, 9 – 16, taking the roll from 95 to 88. Every year from 2020 more pupils left than started, so the graph of the roll falls, from 126 to 88.

Why it works

- Pupils on roll is the stock: it could be counted on any day, and the October count is one such count
- Children starting and pupils leaving are its flows, each counted in pupils per year
- The two clouds are the villages' children not yet at school and the schools pupils leave for, outside what the model counts
- Each October's roll is the last one's plus its starters less its leavers, so the stock equation balances in every year the counts give
- The graph falls because leaving runs above starting every year, though both flows fall

Step by step

1. Pupils on roll, the stock, counted in pupils, with the time unit a year and its stock equation beneath it, which gains a term with each flow drawn: 126 pupils in October 2020.
2. Children starting, an inflow from a cloud, since a child enters the count only in the September they start in Reception: 9 in the year to October 2026.
3. Pupils leaving, an outflow to a cloud for secondary schools and other schools: 16 in the year to October 2026, so the equation takes 95 pupils to 88.
4. A behavior-over-time graph of pupils on roll, falling close to a straight line from 126 to 88: in every year more pupils left than started.

What another defensible answer might vary

Another defensible answer might draw two outflows, Year 6 leaving for secondary school and pupils moving to other schools, or name the inflow starters. What stays the same is one stock in pupils filled by the children starting and drained by those leaving, the time unit a year, the stock equation shown, and a graph of the roll falling.

Chapter 7 · Stocks Inside Feedback

An office orders printer paper by the box. A box arrives five days after it is ordered, and the office manager counts the boxes in the cupboard only on Fridays, then orders from that count. Which of these is a signal delay?

a the five days between ordering a box and its arrival
Not quite. That is a material delay: for those five days the box is in transit, in neither the supplier's stock nor the cupboard. It is marked on the flow of deliveries.

b the days between a box leaving the cupboard and the Friday count
Yes. The box has already left the cupboard; only the count of it is late. The delay is marked on the signal from the boxes in the cupboard to orders.

c the time a box spends in the cupboard before it is used
Not quite. That is the time spent in a stock. The cupboard holds the box for that time, so no delay is drawn for it.

Skiers join the queue for a chairlift at 10 a minute at 8:30, at 60 a minute at 9:30, and at 10 a minute again by 11:00. The lift carries 30 skiers a minute all morning. When is the queue longest?

a at 9:30, when skiers join fastest
Not quite. That reads the queue's graph as the shape of its inflow. At 9:30, 60 skiers join a minute and 30 leave, so the queue is still growing by 30 a minute.

b after 9:30, when joining has fallen back to 30 a minute
Yes. The queue grows while more skiers join than the lift carries, and shrinks once fewer do, so it is longest when joining equals the lift's 30 a minute.

c at 11:00, when joining is slowest
Not quite. By 11:00, 10 skiers join a minute and 30 leave, so the queue has been shrinking since joining fell below 30 a minute.

QUESTION 1 OF 3

A patient reaches the first hospital at two o’clock and leaves for the PCI center at four. Where in the diagram are those two hours spent?

a In the flows, since a flow is the patient moving from one stage to the next.
Not quite. A flow is a rate, patients a minute, and holds no one at an instant. Every patient counted at an instant is in one of the eight stocks.

b In the loops B1 to B4, since each loop keeps patients until they move on.
Not quite. A loop is a closed path, here a signal and a flow: it sets how fast patients leave a stage, and holds no one. Patients wait only in stocks.

c In the stocks: at each stage in turn, and in a held stock wherever the patient is held.
Yes. A stock is where material waits between the flows that fill and drain it. The four stages are an aging chain, passed through in order, and a stay in a held stock adds to the time at its stage until returning brings the patient back.

QUESTION 2 OF 3

B2 runs from patients at the ECG to the valve of to fax, the flow that drains them. What does B2 do to patients at the ECG?

a The more patients at the ECG, the faster they leave for the fax, so a rise in that stock comes back against itself.
Yes. The signal is +, and to fax counts – from the flow into the stock it drains: one – step, so B2 is balancing. The stock settles where its outflows run as fast as its inflows.

b It holds the patients' wait at the guidelines' optimal time, the value the authors compare each wait with.
Not quite. No target is drawn: no variable holds a chosen time, and nothing compares one with the wait. B2 drains the stock faster the fuller it is, and no more.

c It makes patients at the ECG grow, since more of them send more on to the fax.
Not quite. More patients sent on is a faster outflow from patients at the ECG, which lowers it. The rise is in patients at the fax, the next stock along.

QUESTION 3 OF 3

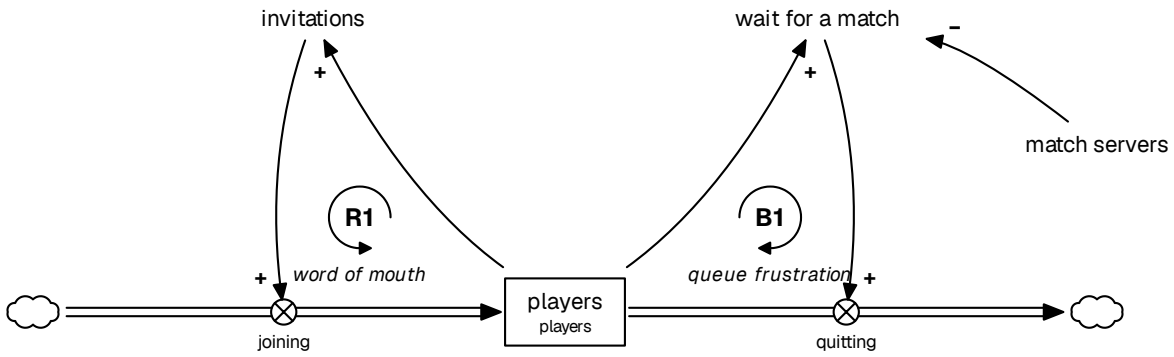
At the fax stage, 76% of the patients the authors followed waited longer than the optimal time. Where does a patient's wait at that stage appear in the diagram?

a As a material delay on to transfer, for patients between the two stages.
Not quite. A material delay holds material in neither stock, as grain at sea is. These patients wait at the fax stage, counted in its stocks; moving on to transfer takes no time of its own.

b As the time a patient spends in patients at the fax and in patients held at the fax, with no delay drawn.
Yes. The time material spends in a stock is a delay already, so a delay drawn on to transfer would count the wait twice. A patient held adds the time in the held stock.

c As a signal delay on patients at the fax → to transfer, since the reply from the PCI center arrives late.
Not quite. A signal delay holds news of a quantity. The reply is what the patients wait for, and the patients themselves sit in the stock, counted there until they move on.

SF 06 Players of an online game



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One stock, players, filled from a cloud by joining and drained to another by quitting; the time unit is a day. R1, word of mouth, runs from players to invitations (+), to the valve of joining (+), and along joining, which fills players: no – step, so reinforcing. B1, queue frustration, runs from players to the wait for a match (+), to the valve of quitting (+), and along quitting, which drains players: one – step, so balancing. Match servers shorten the wait (–) and sit on no loop.

Why it works

- Each loop closes through a flow and the stock it fills or drains, never through a signal into the stock
- Joining fills players, counted +; quitting drains them, counted –
- B1 has one – step, the drained stock, so it is balancing; R1 has none, so it is reinforcing
- Invitations and the wait for a match are auxiliaries: they hold no players
- Each loop's name says what goes around it

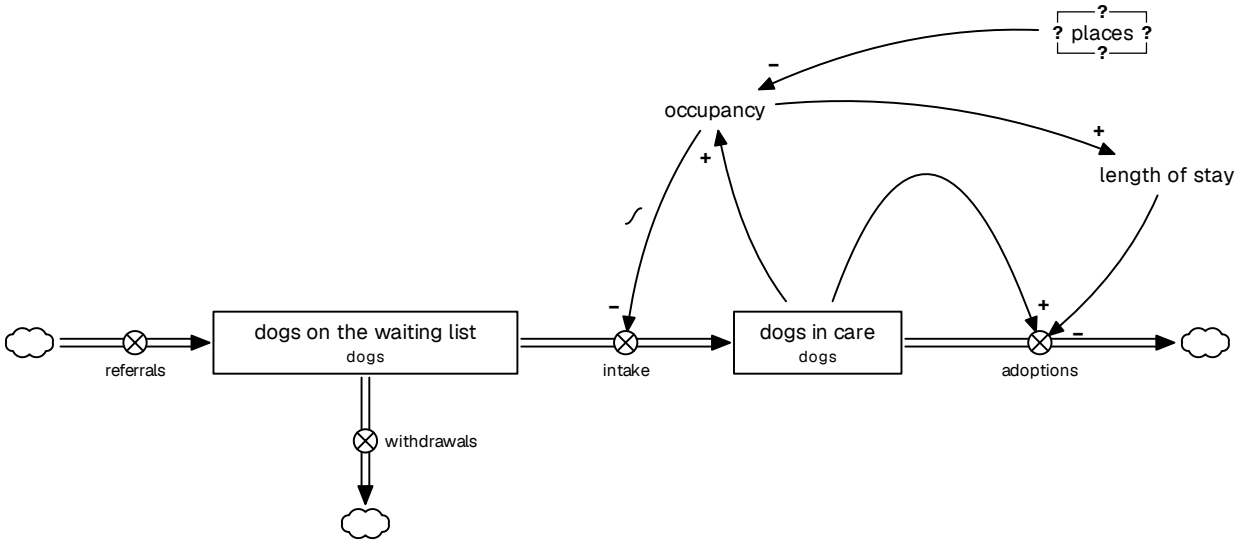
Step by step

1. Players, the stock, counted in players, with the time unit a day: players join only by invitation and quit when matches are slow to start, so both loops run through this count.
2. Joining and quitting, an inflow and an outflow, each with a cloud: invited friends enter the count when they join, and players who quit leave it.
3. Invitations, an auxiliary, with + signals from players to it and from it to the valve of joining, which close R1, word of mouth, through joining: about one player in fifty invites a friend each day, so more players bring in more.
4. The wait for a match, an auxiliary, with + signals from players to it and from it to the valve of quitting, which close B1, queue frustration, through quitting: the more players, the longer each waits, and the more quit each day.
5. Match servers, an auxiliary on neither loop, with a – signal to the wait for a match: their number is fixed, and it sets how long a given number of players waits.

What another defensible answer might vary

Another defensible answer might draw the signal from players straight to the valve of joining, with no invitations auxiliary, or leave match servers out. What stays the same is one stock with an inflow and an outflow, a reinforcing loop through joining, and a balancing loop through quitting.

SF 07 Dogs at a rescue shelter



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Two stocks, counted in dogs: dogs on the waiting list, filled by referrals from a cloud and drained by withdrawals to another, and dogs in care, drained by adoptions to a third. Intake is a transfer from the list into care. The time unit is a week. Occupancy reads dogs in care (+) and places (–); its signal to the valve of intake is – and nonlinear, weak while places are free and sudden as they run out. Occupancy also lengthens stays (+), and a longer stay means fewer adoptions a week (–), while more dogs in care means more (+). Places, which foster homes would add to, is the leverage point.

Why it works

- Intake runs from the waiting list straight into care, so no dog appears or vanishes between them
- The capacity effect is a signal, from occupancy to the valve of intake, marked nonlinear: weak, then sudden
- Crowding reaches adoptions through length of stay, and no signal ends at a stock
- Places is an auxiliary: foster homes would raise it, so it is the leverage point, a box with question marks
- Every flow and both stocks are in dogs, so intake keeps its units

Step by step

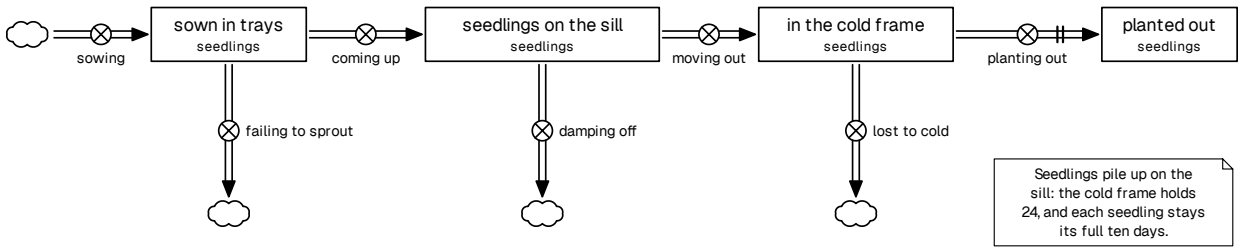
1. Two stocks, each counted in dogs, with the time unit a week: dogs on the waiting list and dogs in care, the two places a referred dog waits.
2. Intake, a transfer from the waiting list into care, with no cloud: staff take each dog in from the list.
3. Referrals and withdrawals on the waiting list, and adoptions out of care, each with a cloud at its open end: about eight dogs a week are referred, and about one a week is withdrawn when its owner finds a home elsewhere.
4. Places and occupancy, two auxiliaries, occupancy rising with dogs in care (+) and falling with places (–), and places marked as the leverage point, since each foster home the manager proposes would add one.
5. A – signal from occupancy to the valve of intake, marked nonlinear: about six dogs a week come in while 30 are in care, and almost none at 38.
6. Length of stay, an auxiliary, with a + signal from occupancy and a – signal to the valve of adoptions, beside a + signal from dogs in care to the same valve: a dog waits about four weeks for adoption while the shelter is half

full, and seven while it is full.

What another defensible answer might vary

Another defensible answer might add a signal from the waiting list to intake, since no dog can be taken in from an empty list, or draw dogs in foster homes as a third stock fed from care. What stays the same is two stocks joined by intake, one nonlinear signal from occupancy to intake, and one leverage point on places.

SF 08 Seedlings raised on a windowsill



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Four stocks in a chain, each counted in seedlings: sown in trays, seedlings on the sill, in the cold frame, planted out. Sowing fills the trays from a cloud; coming up, moving out and planting out are transfers down the chain; failing to sprout, damping off and lost to cold drain the first three stages to clouds. The time unit is a day. Planting out carries the material delay: a seedling leaves the cold frame exactly ten days after it arrives. In the note: seedlings pile up on the sill, since the cold frame holds 24 and empties only as seedlings finish their ten days.

Why it works

- Each stage is a stock, where seedlings could be counted on any day
- Three transfers chain the four stocks, so no seedling appears or vanishes between stages
- Losses leave each of the first three stages by a flow of their own, to a cloud
- The ten days are a material delay on planting out, the flow out of the cold frame, not a separate shape
- The behavior note names where seedlings pile up and why

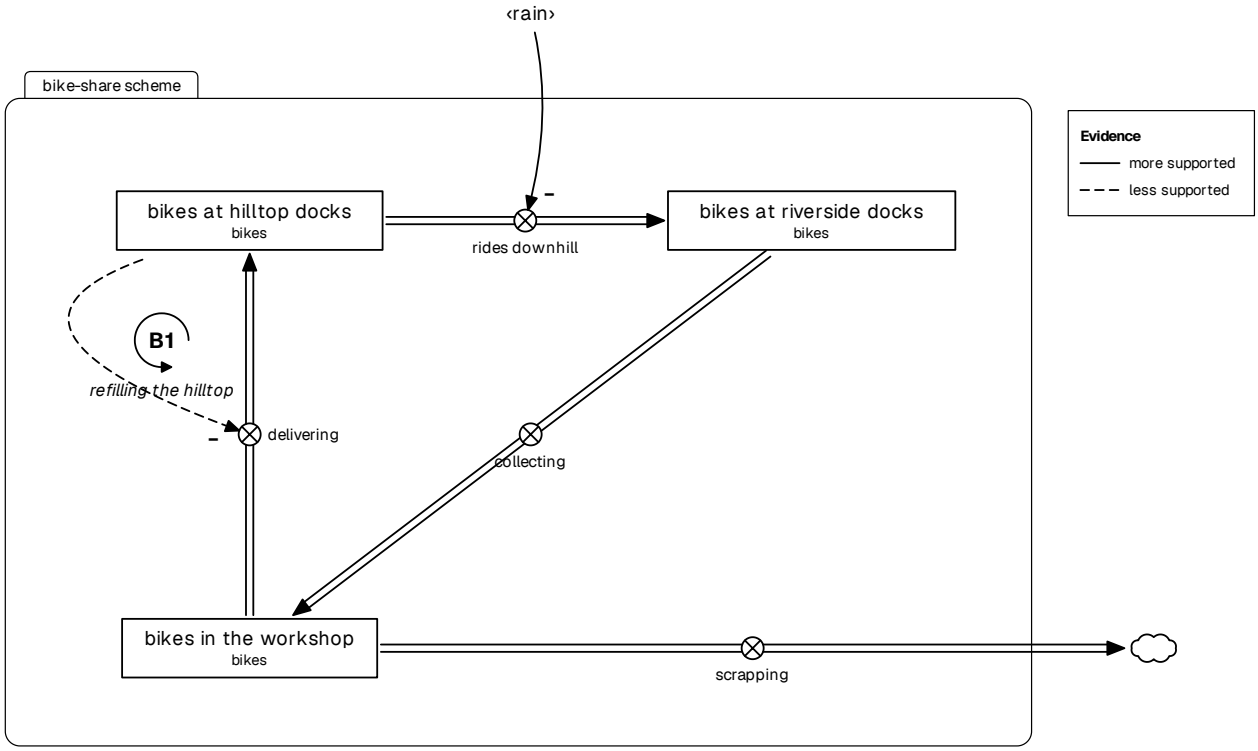
Step by step

1. Four stocks in a chain, each counted in seedlings, with the time unit a day, in the order a seedling passes through them: sown in trays, seedlings on the sill, in the cold frame, planted out.
2. Sowing, the inflow to the trays, from a cloud: about 60 seeds each spring, each counted from the day it is sown.
3. Coming up, moving out and planting out, three transfers down the chain, planting out with the material delay: a seedling leaves the cold frame exactly ten days after it arrives.
4. Failing to sprout, damping off and lost to cold, an outflow from each of the first three stages, each to a cloud: about one seed in five never comes up, and a few seedlings die on the sill and in the cold frame.
5. A behavior note on where seedlings pile up: moving out can run no faster than planting out frees places in the cold frame, 24 at most, so seedlings wait on the sill.

What another defensible answer might vary

Another defensible answer might add losses after planting out, to slugs, or split the sill's stock into tomatoes and peppers. What stays the same is four stocks in seedlings chained by transfers, a loss flow from each stage before planting out, one material delay on planting out, and a note on where seedlings pile up.

SF 09 A city's bike-share fleet



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Three stocks, each counted in bikes: at hilltop docks, at riverside docks, in the workshop. Rides downhill, collecting and delivering are transfers around them, so every bike that leaves one stock arrives in another; scrapping drains the workshop to a cloud. The time unit is a day. Rain, an external driver outside the bike-share scheme's boundary, cuts rides downhill (–), a solid signal resting on the ride counts. B1, refilling the hilltop, runs from the hilltop docks to the valve of delivering (–) and along delivering, which fills them (+): one – step, so balancing. That signal, the vans' response, is coded as the hypothesis and drawn dashed, and the legend shows the coding.

Why it works

- Each place a bike waits is a stock, and every flow between two of them is a transfer, so the count of bikes is kept
- No signal ends at a stock: rain and the hilltop docks reach the valves of rides downhill and delivering
- The balancing loop closes through delivering, which fills the hilltop docks
- Rain sits outside the boundary with no signal into it, and the one cloud, where scrapped bikes go, sits outside too
- The legend shows the coding: rain's signal solid, the vans' response dashed

Step by step

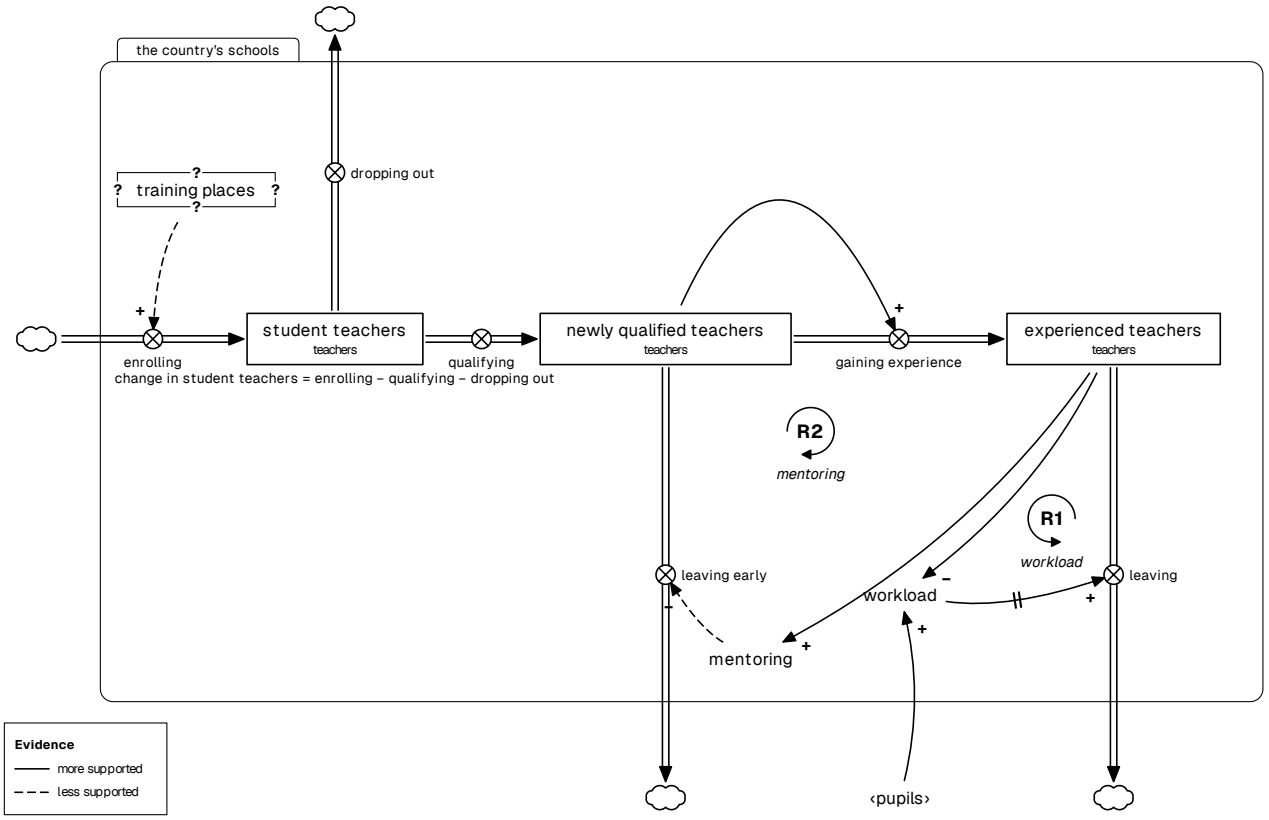
1. Three stocks, each counted in bikes, with the time unit a day: bikes at hilltop docks, at riverside docks and in the workshop, each a count staff could take on any day.
2. Rides downhill, collecting and delivering, three transfers around the stocks: a bike rides from the hilltop to the river, goes by van to the workshop, and returns by van to the hilltop.

3. Scrapping, an outflow from the workshop to a cloud, for the bikes beyond repair that leave the scheme.
4. A – signal from the hilltop docks to the valve of delivering, the staff's belief, coded as a hypothesis and dashed, which closes B1, refilling the hilltop, through delivering: the emptier the hilltop docks, the more bikes the vans bring back to them.
5. The boundary, bike-share scheme, with rain outside it as an external driver, its – signal to the valve of rides downhill solid, since staff count rides every day and about a third fewer bikes are ridden in rain, and the legend for the coding.

What another defensible answer might vary

Another defensible answer might add a signal from the riverside docks to collecting, a few rides uphill as a flow of their own drawn apart from rides downhill, or a stock of bikes on the vans between collecting and delivering. What stays the same is three stocks in bikes joined by transfers, a balancing loop through delivering coded as the hypothesis, rain outside a named boundary, and the legend on.

SF 10 Teachers in a country's schools



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Three stocks in a chain, each counted in teachers: student teachers, newly qualified teachers, experienced teachers, joined by qualifying and gaining experience, two transfers. Enrolling fills the first stock from a cloud; dropping out, leaving early and leaving drain each stage to a cloud. The time unit is a year, and the student teachers' stock equation is shown. R1, workload, runs from experienced teachers to workload (–), to the valve of leaving (+, with a delay), and along leaving, which drains them: two – steps, so reinforcing. R2, mentoring, runs from experienced teachers to mentoring (+), to the valve of leaving early (–), along leaving early, which drains newly qualified teachers, then to the valve of gaining experience (+) and along it, which fills experienced teachers: two – steps, so reinforcing. Pupils, an external driver outside the schools' boundary, raise workload (+). Training places, the leverage point, and mentoring's signal are coded as hypotheses, and the legend shows the coding.

Why it works

- Each stage is a stock in teachers, and the two transfers keep every teacher counted between stages
- Both loops run through flows, so the parity rule counts each drained stock as a – step
- Workload and mentoring reach the valves of leaving and leaving early: no signal ends at a stock
- The delay is on the signal from workload to leaving: resignations rise a year or two after workload does
- Pupils sit outside the boundary with no signal into them, and every cloud sits outside it too
- Mentoring's and the training places' signals are dashed, and the legend shows the coding

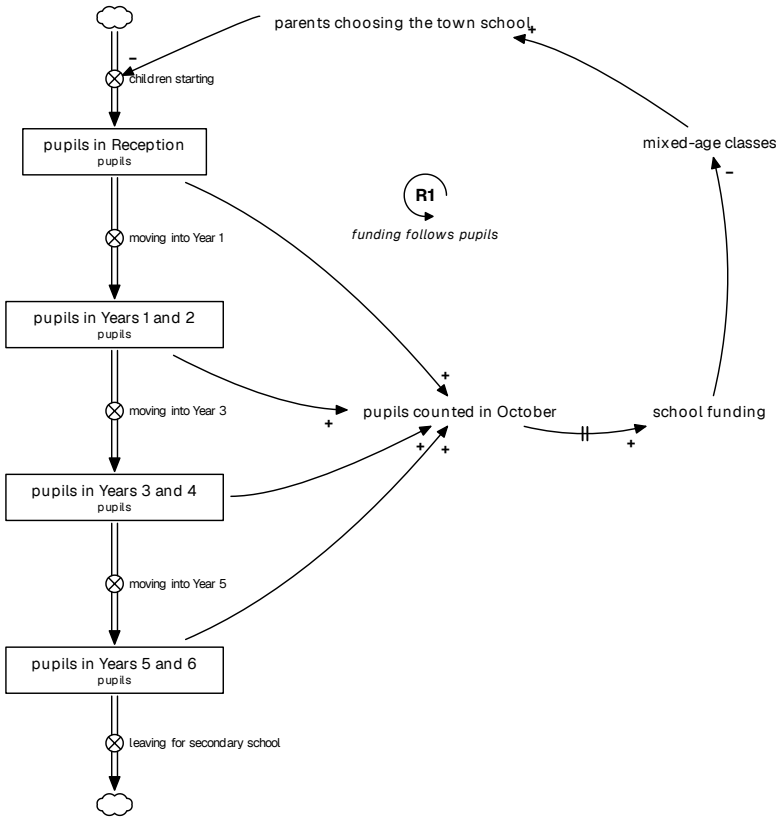
Step by step

1. Three stocks in a chain, each counted in teachers, with the time unit a year: student teachers, whose stock equation is shown, newly qualified teachers and experienced teachers.
2. Qualifying and gaining experience, two transfers down the chain: a student teacher qualifies after the one-year course, and a newly qualified teacher counts as experienced after three years.
3. Enrolling from a cloud, and dropping out, leaving early and leaving, one out of each stage to a cloud: about one student teacher in ten drops out, one newly qualified teacher in eight leaves each year, and one experienced teacher in fourteen.
4. Workload, an auxiliary, with a – signal from experienced teachers and a + signal to the valve of leaving, delayed a year or two, which close R1, workload, through leaving: fewer experienced teachers each carry more work, more of them resign, and fewer still remain.
5. Mentoring, an auxiliary, with a + signal from experienced teachers, a – signal to the valve of leaving early, dashed as a hypothesis, the head teachers' belief, and a + signal from newly qualified teachers to the valve of gaining experience, which close R2, mentoring: new teachers kept by mentoring become experienced teachers who mentor.
6. The boundary, the country's schools, with pupils outside it as an external driver, its + signal to workload: pupil numbers are rising, and nothing in the schools sets them.
7. Training places, an auxiliary and the leverage point the ministry proposes to fund, with a + signal to the valve of enrolling, dashed as a hypothesis, the ministry's expectation that the places would fill, and the legend for the coding.

What another defensible answer might vary

Another defensible answer might add a signal from workload to leaving early, a signal from newly qualified teachers to workload, a behavior note or a graph of experienced teachers falling, or a material delay on qualifying for the one-year course. What stays the same is three stocks in teachers joined by transfers, two loops through stocks, mentoring's and the training places' signals coded as hypotheses, training places as the leverage point, and a delay on the signal from workload to leaving.

CS 07 Kelsham Primary School: four classes in a chain



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Four stocks in a chain, each counted in pupils: pupils in Reception, in Years 1 and 2, in Years 3 and 4 and in Years 5 and 6, joined by moving into Year 1, Year 3 and Year 5, three transfers each September. Children starting fills Reception from a cloud, and leaving for secondary school drains Years 5 and 6 to a cloud. The time unit is a year. Pupils counted in October, an auxiliary, reads all four stocks (+) and sets school funding (+) a school year later; less funding brings more mixed-age classes (–), more parents choosing the town school (+), and fewer children starting (–). R1, funding follows pupils, runs from Reception through the count, the funding and the parents' choice to the valve of children starting, which fills Reception: two – steps, so reinforcing.

Why it works

- Each class is a stock in pupils, and the transfers keep every pupil counted as they move up
- Only Reception fills from a cloud and only Years 5 and 6 drain to one: with moves during a school year left out, the chain has no other ends
- The October count reads every stock, since the funding follows every pupil, not only the youngest
- The delay sits on the signal from the count to the funding: each count sets the school year after it
- R1 reaches the chain at the valve of children starting, never at a stock, and its two – steps make it reinforcing

Step by step

1. Four stocks in a chain, each counted in pupils, with the time unit a year: pupils in Reception, in Years 1 and 2, in Years 3 and 4 and in Years 5 and 6, the four classes since 2023.
2. Moving into Year 1, Year 3 and Year 5, three transfers down the chain: each September the pupils finishing Reception, Year 2 and Year 4 move into the next class.

3. Children starting, into Reception from a cloud, and leaving for secondary school, out of Years 5 and 6 to a cloud: with moves during a school year left out, these are the chain's two ends.
4. Pupils counted in October, an auxiliary with a + signal from each class, and school funding, with a + signal from the count delayed a school year: each October's count sets the funding for the year after it, at £4,800 a pupil.
5. Mixed-age classes, with a – signal from the funding, and parents choosing the town school, with a + signal from them and a – signal to the valve of children starting, which close R1, funding follows pupils: fewer children start, the count falls, and the funding with it.

What another defensible answer might vary

Another defensible answer might draw seven stocks, one for each year group, or five, one for each class before 2023, with Years 3 and 4 apart; or let parents choosing the town school drain each class through a flow to a cloud as well. What stays the same is a chain of stocks in pupils joined by transfers, one inflow into Reception, a reinforcing loop from the count through the funding to the flow of children starting, and the delay between the count and the funding.

Chapter 8 · Sense, Compare, Correct

A kitchen fridge's thermostat reads the air by the door. Each time the door opens, warm kitchen air reaches the thermostat first and the compressor starts, while the food at the back stays cold; by evening the milk on the back shelf has frozen. In a feedback control diagram of the fridge, which variable is the measured value?

a the temperature of the food on the back shelf
Not quite. That is the controlled variable: the temperature someone wants held near the dial's setting. Nothing in the fridge reads it.

b the thermostat's reading of the air by the door
Yes. The thermostat reads the air by the door, a variable of its own, with a signal from the food's temperature. The open door changes the reading far more than the food, so the gap opens while the food is already cold, and the compressor runs on.

c the setting on the dial
Not quite. The dial's setting is the target: a value someone chose, with a signal into the gap and none into it.

A hearing aid turns its volume down when the sound reaching its wearer's ear grows louder than the loudness an audiologist set, and up when it grows quieter. A bus passes in a noisy street. In a feedback control diagram of the hearing aid, which variable does the bus's noise act on?

a the loudness at the wearer's ear
Yes. The noise makes the sound at the ear louder: an external driver acting on the controlled variable. The reading follows it, the gap opens, and the hearing aid turns its volume down.

b the gap between the loudness set and the loudness read
Not quite. A signal from the noise into the gap would draw the bus changing the loudness the audiologist set. The gap changes only because the reading of the ear's loudness does.

c the hearing aid's volume
Not quite. The volume is the corrective action. The noise changes it only through the loudness at the ear, the reading and the gap.

QUESTION 1 OF 3

OpenStax names the temperature regulatory center in brain a control center, the part that compares a value with its normal range and activates the response; this book draws that work as the signal from the gap to the corrective action. Which part of the redrawing is it here?

a Temperature sensed by nerve cells, since the center receives the nerve cells' reading.
Not quite. That variable is the reading itself, the measured value. The center acts once the reading is compared with the target: from the gap on.

b The signal from degrees above 37 °C to sweating, with its +.
Yes. The comparison is the gap itself, read from the target and the measured value; what the center then does, more sweating for each degree above 37 °C, is the signal from the gap to sweating and its polarity. The center is an organ, and only quantities are drawn.

c Normal body temperature, since the center holds the value of 37 °C.
Not quite. Normal body temperature is the target, the value chosen to stay near, with no signal into it. Comparing readings with it and driving the sweating is the signal from the gap to sweating.

QUESTION 2 OF 3

OpenStax names the nerve cells a sensor, which this book draws as a measured value, and the sweat glands an effector, a corrective action here. Why are those variables named temperature sensed by nerve cells and sweating, not nerve cells and sweat glands?

a Roles are written above the names, so naming the organs would repeat the roles.
Not quite. A role names the part a variable plays; the name says which quantity plays it. Nerve cells and sweat glands are things, so they appear only through quantities they produce.

b A variable is a quantity that can rise or fall: a reading and sweating can, while cells and glands are things.
Yes. More temperature sensed and more sweating pass the more test. More nerve cells names a different quantity, how many there are, which the loop never changes. A part that acts appears through the quantity it changes, as boiler output stands for the boiler.

c The body has too many nerve cells and sweat glands to count.
Not quite. They could be counted, but their number is not what rises and falls as the body heats and cools: the reading and the sweating are.

QUESTION 3 OF 3

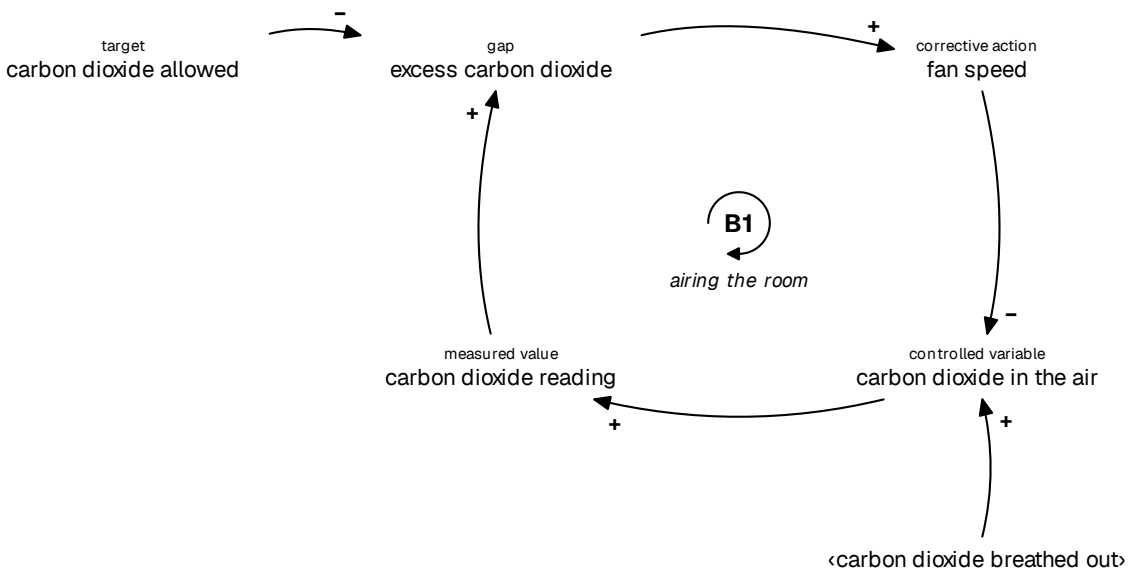
Panel (b) begins with body temperature exceeding 37 °C and draws nothing that raises it. What would a hot day or a run add to the redrawing?

a A signal from the hot day to degrees above 37 °C, since heat widens the gap.
Not quite. An external driver never acts on a gap. Heat raises body temperature, and the gap widens as the nerve cells read the rise.

b A second target, since the body holds a higher temperature during a run.
Not quite. The target stays at 37 °C; what changes is the push away from it. Nothing in the figure or its text moves the target.

c An external driver, its signal ending at body temperature.
Yes. Heat from the air or from working muscles pushes body temperature away from 37 °C and isn't pushed back by it: an external driver acting on the controlled variable, as outdoor temperature acts on room temperature in a house.

FC 01 Fresh air in a choir's rehearsal room



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Five variables, each with its part: carbon dioxide allowed is the target, excess carbon dioxide the gap, fan speed the corrective action, carbon dioxide in the air the controlled variable, and carbon dioxide reading the measured value. The gap rises with the reading (+) and falls as the target rises (–). A larger gap speeds the fan (+), a faster fan lowers the carbon dioxide in the air (–), and the reading follows the air (+): one – signal on the loop, so B1 is balancing. Carbon dioxide breathed out is an external driver acting on the air, off the loop.

Why it works

- The gap is the difference between the reading and the target, so the two signals into it have opposite polarities
- The reading is a variable apart from the air: the fan answers the meter, and the singers breathe into the air
- Fan speed is the corrective action; the carbon dioxide in the air is the controlled variable it changes
- The singers' breath acts on the air, never on the gap or the target: the caretaker sets the target
- One – signal on the loop makes it balancing, as declared

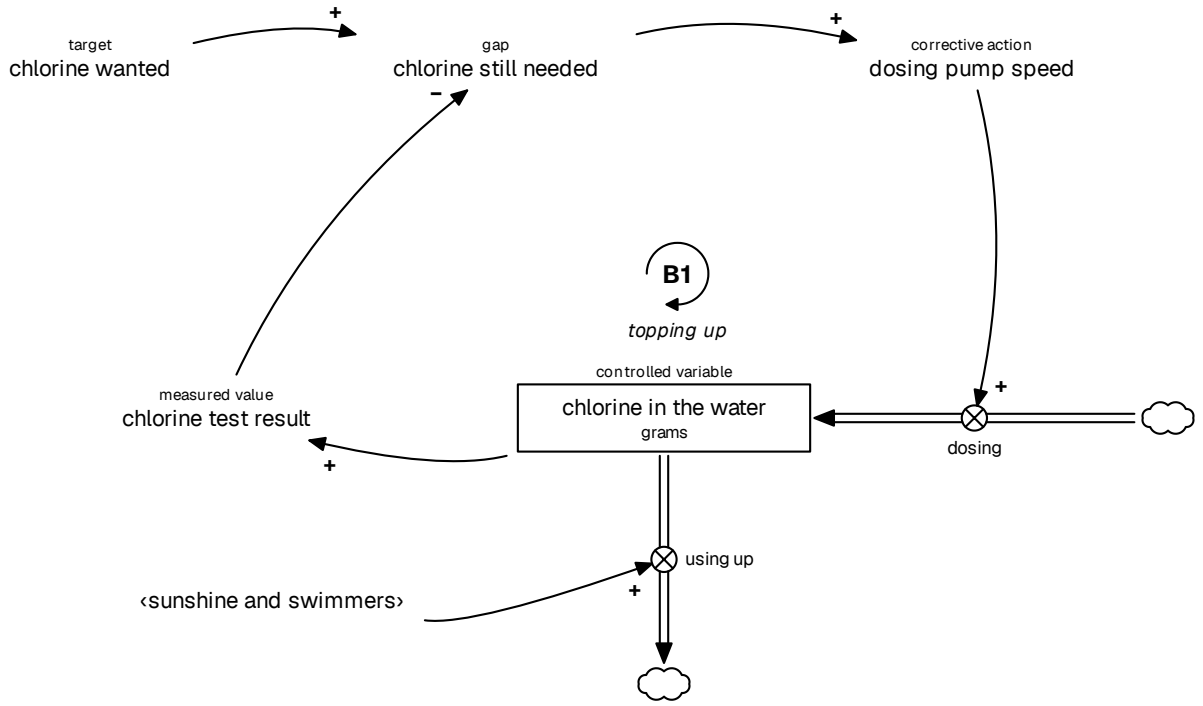
Step by step

1. Carbon dioxide in the air, the controlled variable: the quantity the caretaker set the fan to hold near 1,000 parts per million.
2. Carbon dioxide reading, the measured value, with a + signal from the air: the fan runs on what the meter on the wall shows.
3. Carbon dioxide allowed, the target, and excess carbon dioxide, the gap, read from the reading (+) and the target (–): how far the meter shows above 1,000 parts per million.
4. Fan speed, the corrective action, with a + signal from the gap and a – signal to the air, which close B1, airing the room: the larger the gap, the faster the fan runs, and the more carbon dioxide it carries out.
5. Carbon dioxide breathed out, an external driver, with a + signal to the air, off the loop: forty singers breathe into the room whatever the fan does.

What another defensible answer might vary

Another defensible answer might name the gap carbon dioxide above the target, or the external driver the singers' breath. What stays the same is five variables with their parts on one balancing loop through the gap, opposite polarities into the gap, and the breath acting on the carbon dioxide in the air.

FC 02 Chlorine in a town's outdoor swimming pool



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One stock, chlorine in the water, counted in grams: the controlled variable. Dosing fills it from a cloud and using up drains it to another, both in grams per hour. Chlorine still needed is the gap, read from chlorine wanted (+) and the chlorine test result (–); the gap sets the dosing pump's speed, whose signal ends at the dosing valve. B1 runs through the dosing flow, counted + into the stock, and has one – step, so it is balancing. Sunshine and swimmers act at the valve of using up, off the loop.

Why it works

- Chlorine moves only along the two flows; every other line is a signal
- The pump's speed is the corrective action, and its signal ends at the dosing valve, never at the stock
- The test result is a variable apart from the chlorine in the water, read from it
- Sunshine and swimmers act on the controlled variable through the flow they drain it by, never on the gap
- The one – step, from the test result to the gap, makes the loop balancing

Step by step

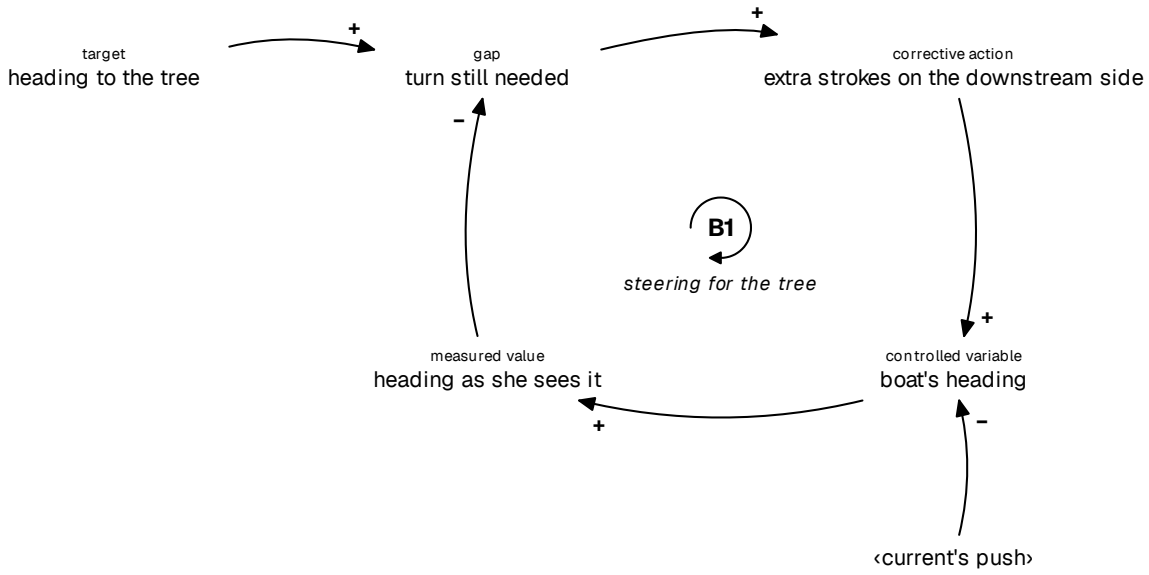
1. Chlorine in the water, the controlled variable, a stock counted in grams, with the time unit an hour: the staff keep about 750 grams in about 500 cubic meters of water.
2. Dosing, an inflow from a cloud for the tank, and using up, an outflow to a cloud: chlorine counts from when the pump adds it until sunshine and swimmers use it up.
3. Chlorine test result, the measured value, with a + signal from the stock: the staff set the pump by a test taken every two hours.
4. Chlorine wanted, the target, and chlorine still needed, the gap, read from the target (+) and the test result (–): how far the result falls short of 750 grams.

5. Dosing pump speed, the corrective action, with a + signal from the gap and a + signal to the valve of dosing, which close B1, topping up, through the stock: the further the result falls short, the faster the pump adds chlorine.
6. Sunshine and swimmers, an external driver, with a + signal to the valve of using up, off the loop: hot, crowded afternoons use chlorine up faster.

What another defensible answer might vary

Another defensible answer might name the gap chlorine short, or draw the staff's test as the measured value. What stays the same is one stock in grams with one inflow and one outflow, the time unit an hour, a balancing loop through the dosing flow, and the external driver at the valve of the flow that uses chlorine up.

FC 03 A kayaker crossing a river



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The boat's heading is the controlled variable, and the heading to the tree the target. Turn still needed is the gap, read from the target (+) and the heading as she sees it (–). The gap sets her extra strokes on the downstream side (+), the strokes turn the boat's heading upstream (+), and she sees the heading against the tree (+). B1 has one – step, so it is balancing. The current's push acts on the boat's heading (–), off the loop. When she picks a new tree, the target changes by her choice, and no signal reaches it.

Why it works

- The gap reads the target + and the heading as she sees it –: their difference is which way, and how far, she still has to turn
- The current's push acts on the boat's heading, never on the gap: a push from outside, not a change of target
- The heading as she sees it is a variable apart from the boat's heading, read from it against the tree
- No signal reaches the target: picking a new tree is her choice
- The one – step, from the heading as she sees it to the gap, makes the loop balancing

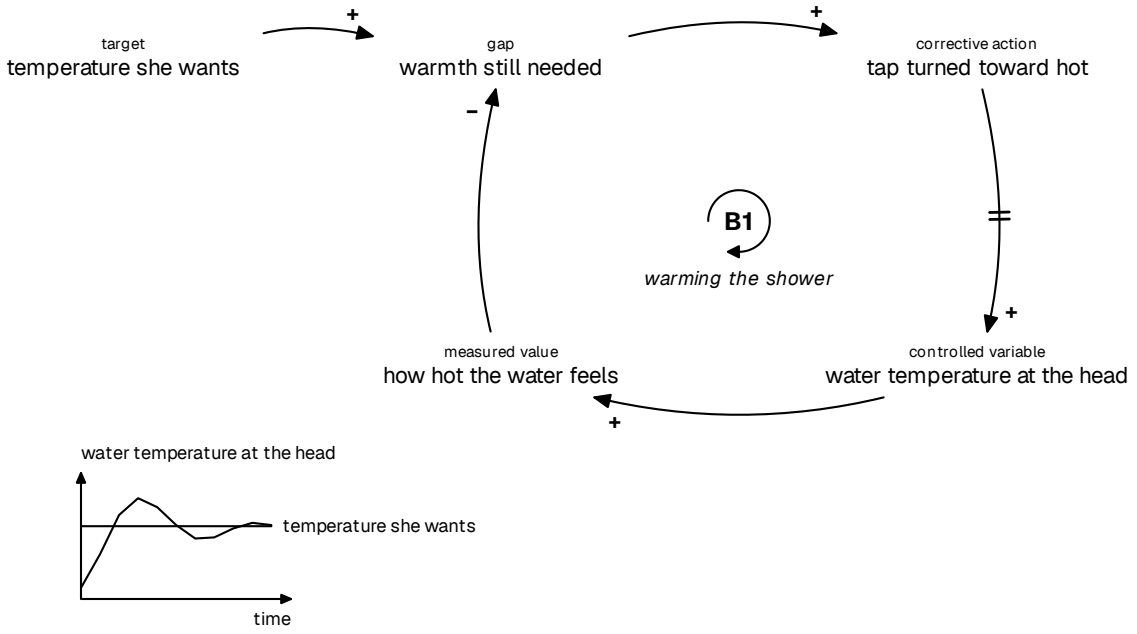
Step by step

1. The boat's heading, the controlled variable, counted as an angle that grows the further upstream the bow points.
2. Heading as she sees it, the measured value, with a + signal from the boat's heading: she judges the heading by where the bow points against the tree.
3. Heading to the tree, the target, and turn still needed, the gap, read from the target (+) and the heading as she sees it (–): the angle between where she aims and where she sees the bow pointing.
4. Extra strokes on the downstream side, the corrective action, with a + signal from the gap and a + signal to the boat's heading, which close B1, steering for the tree: she keeps stroking until the bow points at the tree again.
5. The current's push, an external driver, with a – signal to the boat's heading, off the loop: it swings the bow downstream whatever tree she aims at.

What another defensible answer might vary

Another defensible answer might count headings the other way, as how far the bow points downstream of the tree, with the gap reading the target – and the heading as she sees it +, and the current's push +. What stays the same is one target with no signal into it, a gap read with opposite polarities, one balancing control loop, and the current's push acting on the boat's heading.

FC 04 A shower whose hot water arrives late



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The water temperature at the head is the controlled variable, and the temperature she wants the target. Warmth still needed is the gap, read from the target (+) and how hot the water feels (–); it sets how far the tap is turned toward hot (+), and the tap changes the water at the head (+) five seconds later: a delay on the forward path. B1 has one – step, so it is balancing. While the hot water is on its way she keeps turning, so the water arrives too hot; she turns back, and it arrives too cold. The graph overshoots the line at the temperature she wants and swings around it, closer each time.

Why it works

- The delay is on the signal from the tap to the water at the head: the forward path, where the correction arrives late
- How hot the water feels is read from the water at the head with no delay: she feels the water as soon as it arrives
- She keeps turning the tap while the hot water is on its way, so the water overshoots, and the graph oscillates around the target
- The graph's line is drawn at the temperature she wants, solid: a dashed line marks a hypothesis
- The one – step, from how hot the water feels to the gap, makes the loop balancing

Step by step

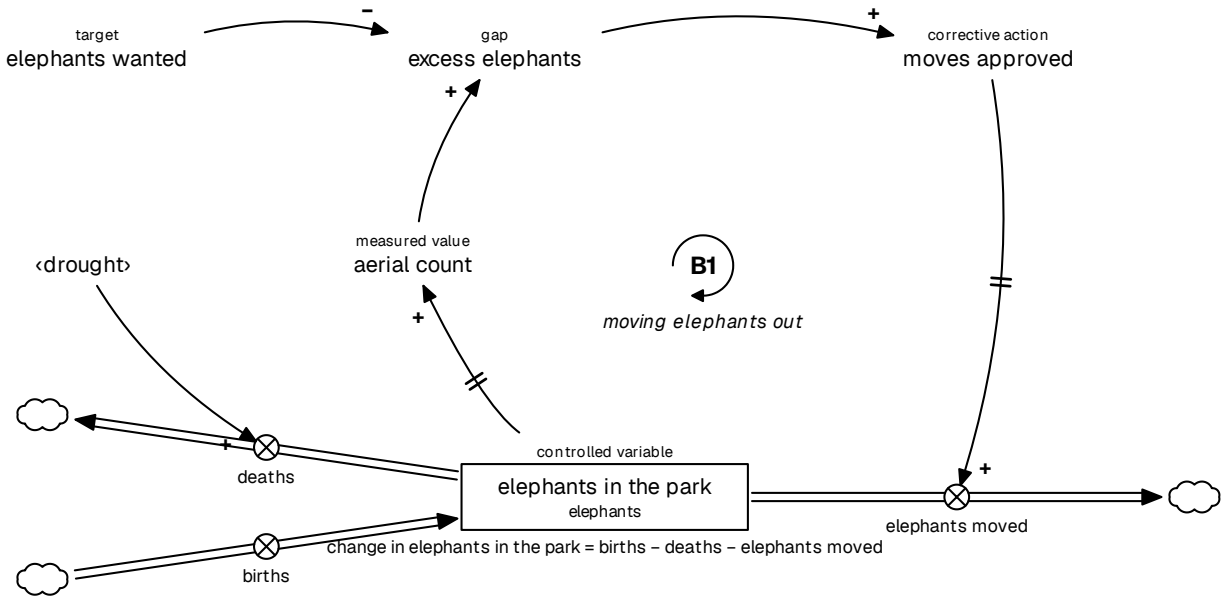
1. Water temperature at the head, the controlled variable: the water she showers in, which she wants at about 38 °C.
2. How hot the water feels, the measured value, with a + signal from the water at the head and no delay, since she stands in the water as it leaves the head.

3. Temperature she wants, the target, and warmth still needed, the gap, read from the target (+) and how hot the water feels (–): above zero while the water feels too cold, below zero once it feels too hot.
4. Tap turned toward hot, the corrective action, with a + signal from the gap and a + signal to the water at the head, delayed about five seconds while the hot water travels to the head, which close B1, warming the shower.
5. A behavior-over-time graph of the water at the head, with a solid line at the temperature she wants: each turn of the tap shows at the head only five seconds later, so the water swings too hot and too cold around the line before it settles near 38 °C.

What another defensible answer might vary

Another defensible answer might add a behavior note on the water swinging past 38 °C each way before it settles, or name the gap too cold by. What stays the same is one balancing control loop, one delay on the signal from the tap to the water at the head, and an oscillating graph of that water's temperature with a solid line at the temperature she wants.

FC 05 Elephants in a national park



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One stock, elephants in the park, counted in elephants: the controlled variable. Births fill it from a cloud; deaths and elephants moved drain it to clouds, each in elephants per year, and its stock equation is written beneath it. Excess elephants is the gap, read from elephants wanted (–) and the aerial count (+); it sets moves approved (+), whose signal reaches the valve of elephants moved a year later (+): a delay on the forward path. The aerial count reads the stock every two years: a delay on the return path. B1 runs through elephants moved, counted – out of the stock, and has one – step, so it is balancing. Drought acts at the valve of deaths, off the loop.

Why it works

- Moves approved are a variable and elephants moved the flow; the year between them is a delay on the forward path
- The aerial count is a variable apart from the elephants in the park, and the two years between counts are a delay on the return path
- Elephants enter and leave the park only along the three flows; every other line is a signal
- Drought acts on the controlled variable through the flow of deaths, never on the gap
- The one – step, elephants moved draining the stock, makes the loop balancing

Step by step

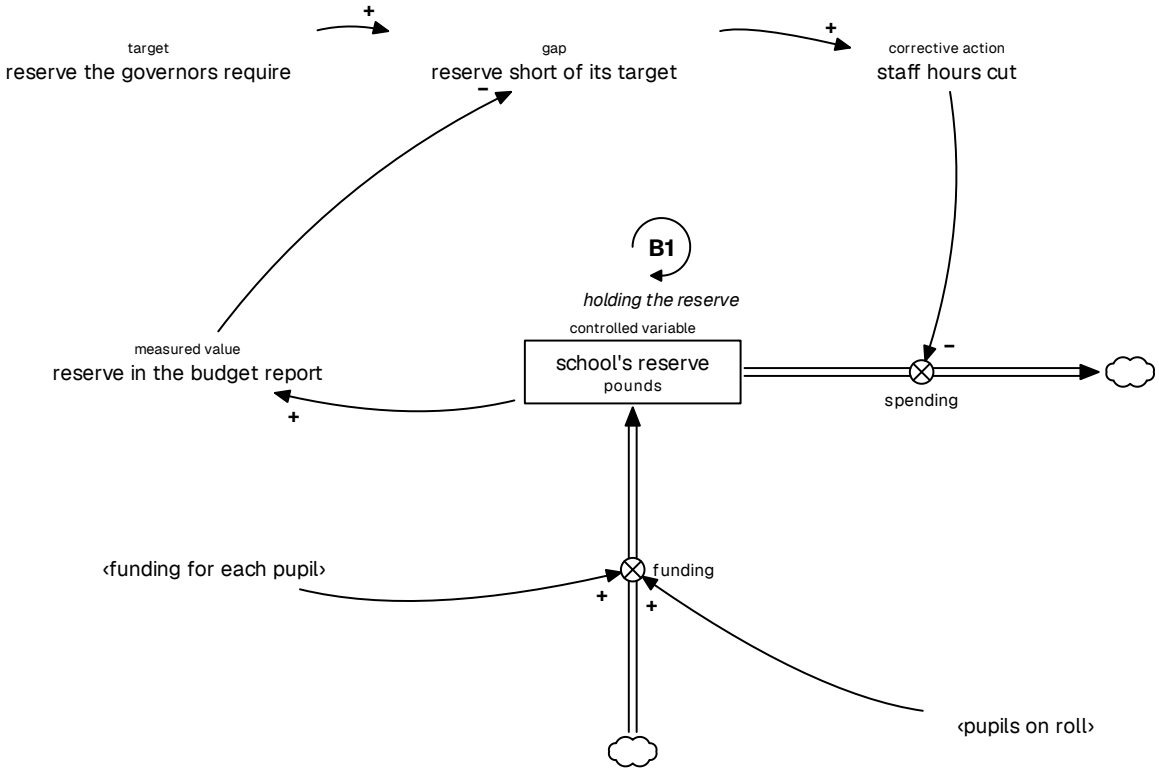
1. Elephants in the park, the controlled variable, a stock counted in elephants, with the time unit a year and its stock equation beneath it: the managers aim to hold it near 2,000.
2. Births, from a cloud, and deaths and elephants moved, each to a cloud: about 150 calves a year against about 60 deaths, so with no elephants moved the herd grows by about 90 a year.
3. Aerial count, the measured value, with a + signal from the stock, delayed since the survey plane counts the herd only every two years.

4. Elephants wanted, the target, and excess elephants, the gap, read from the aerial count (+) and the target (–): how far the latest count sits above 2,000.
5. Moves approved, the corrective action, with a + signal from the gap and a + signal to the valve of elephants moved, delayed a year while the elephants are caught and taken away by truck, which close B1, moving elephants out, through the stock.
6. Drought, an external driver, with a + signal to the valve of deaths, off the loop: more elephants die in a dry year, whatever the managers approve.

What another defensible answer might vary

Another defensible answer might add a signal from the stock to the valve of births, with a reinforcing loop of its own, or name the gap elephants over the number. What stays the same is one stock in elephants with births in and two flows out, the time unit a year, one balancing control loop through elephants moved, one delay between moves approved and elephants moved, and drought at the valve of deaths.

CS 08 Kelsham Primary School: the governors and the reserve



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One stock, the school's reserve, counted in pounds: the controlled variable. Funding fills it from a cloud and spending drains it to another, both in pounds per year. Reserve short of its target is the gap, read from reserve the governors require (+) and the reserve in the budget report (–); the gap raises staff hours cut (+), whose signal lowers the valve of spending (–). B1, holding the reserve, runs through spending, counted – out of the stock, and has three – steps, so it is balancing. Funding for each pupil and the pupils on roll act at the valve of funding, off the loop: £4,800 for each of 88 pupils and £140,000 come to £562,400 a year.

Why it works

- Money moves only along funding and spending; every other line is a signal
- Staff hours cut is the corrective action, and its signal ends at the valve of spending, never at the stock
- The reserve in the budget report is a variable apart from the reserve, read from it each term
- The two external drivers act on the reserve at the valve of funding, never on the gap
- Three – steps, from the report to the gap, from the cut to spending and along spending, make the loop balancing

Step by step

1. The school's reserve, the controlled variable, a stock counted in pounds, with the time unit a year: £96,000 in October 2026.
2. Funding, an inflow from a cloud for the county council, and spending, an outflow to a cloud for pay and bills: money counts in the reserve from when it arrives until it is spent.

3. Reserve in the budget report, the measured value, with a + signal from the stock: the governors read it each term.
4. Reserve the governors require, the target, and reserve short of its target, the gap, read from the target (+) and the report (–): how far the report reads below £60,000.
5. Staff hours cut, the corrective action, with a + signal from the gap and a – signal to the valve of spending, which close B1, holding the reserve, through the stock: the further the report reads below £60,000, the more hours the governors cut and the less the school spends.
6. Funding for each pupil and pupils on roll, two external drivers, with + signals to the valve of funding, off the loop: the county council sets the £4,800, and parents and births set the roll.

What another defensible answer might vary

Another defensible answer might draw one external driver, funding for the school year, with the rate for each pupil and the roll folded into it, or name the corrective action staff hours paid for, with a + signal to the valve of spending and the gap read the other way round. What stays the same is one stock in pounds with funding in and spending out, the time unit a year, one balancing control loop through spending, and the external drivers acting at the valve of funding.

Chapter 9 · Anticipation, Limits, and Nested Control

A basement floods, and someone sets a dehumidifier to bring its air down to 50% relative humidity. The dehumidifier runs flat out, removing at most 20 liters of water a day, and for a week the air stays far wetter than 50%. In a feedback control diagram of the basement, how is that limit drawn?

a as at most 20 liters a day, written beneath water removed, the corrective action
Yes. Saturation belongs to the corrective action. Past 20 liters a day a wider gap changes the water removed no further, so the air dries only as fast as 20 liters a day allows.

b as a nonlinear effect on the signal from water removed to the basement's humidity
Not quite. Each liter removed dries the air as much at full output as at half, so that signal is unchanged. The limit is on the water removed itself, whichever signal reaches it.

c as a deadband on the signal from the humidity gap to water removed
Not quite. A deadband is a range of gaps small enough that the corrective action stays as it is. Here the gap is wide and the water removed is as large as it can be.

A smoke alarm hangs by a kitchen's toaster. When the smoke it reads passes its trigger it sounds, and someone opens the window and fans the smoke out. Toast browned too far sets it off with no fire, so the household presses its hush button, which silences it for ten minutes; then it reads the smoke again. In a feedback control diagram of the kitchen, what is the hush button pressed?

a an override, its signal ending at the alarm's sound
Yes. Someone sets it, and for ten minutes it replaces the rule from the gap to the alarm's sound. The burnt toast is a false alarm: the reading passes the trigger with no fire.

b a new target: a higher trigger for smoke
Not quite. The trigger is unchanged: ten minutes later the same smoke sets the alarm off again. A new target would last until someone changed it back.

c an external driver acting on the smoke in the kitchen
Not quite. The burnt toast is that: it adds smoke from outside the loop. The hush button changes no smoke; it silences the alarm.

QUESTION 1 OF 3

Which path in the redrawing is feedforward?

a Rate of incoming fluid → outlet temperature, −.
Not quite. That is the external driver acting on the controlled variable: more cold fluid to heat lowers the outlet temperature. A feedforward path ends at a corrective action.

b Measured outlet temperature → degrees below target, −.
Not quite. That signal carries the reading back to the gap, on B1's return path: feedback. A feedforward path passes through no gap.

c Rate of incoming fluid → fuel gas flow, +.
Yes. It runs from an external driver to the corrective action through no gap. Woolf and others give the rule: 10% more fluid coming in takes about 10% more heat, and the fuel gas flow is raised at once, before the outlet cools.

QUESTION 2 OF 3

Fuel gas flow already rises with the rate of incoming fluid. What is left for B1 to correct?

a Whatever the feedforward rule gets wrong, and any change it doesn't read, such as in the furnace itself.
Yes. The rule sets the fuel from the rate of incoming fluid alone, about 10% for 10%. Any gap that opens at the outlet, from the rule's misjudgment or from anything else that moves the outlet temperature, is read only through B1, which Woolf and others combine with the feedforward for that reason.

b Nothing while the rate of incoming fluid changes, since the feedforward has already made up for it.
Not quite. The feedforward acts on a forecast of the fuel needed, not on the outlet temperature. If the forecast is off, a gap opens, and only B1 reads it.

c Only a change in the target outlet temperature.
Not quite. A new target opens a gap that B1 closes, but so does anything that moves the outlet temperature away from it, the feedforward's misjudgments included.

QUESTION 3 OF 3

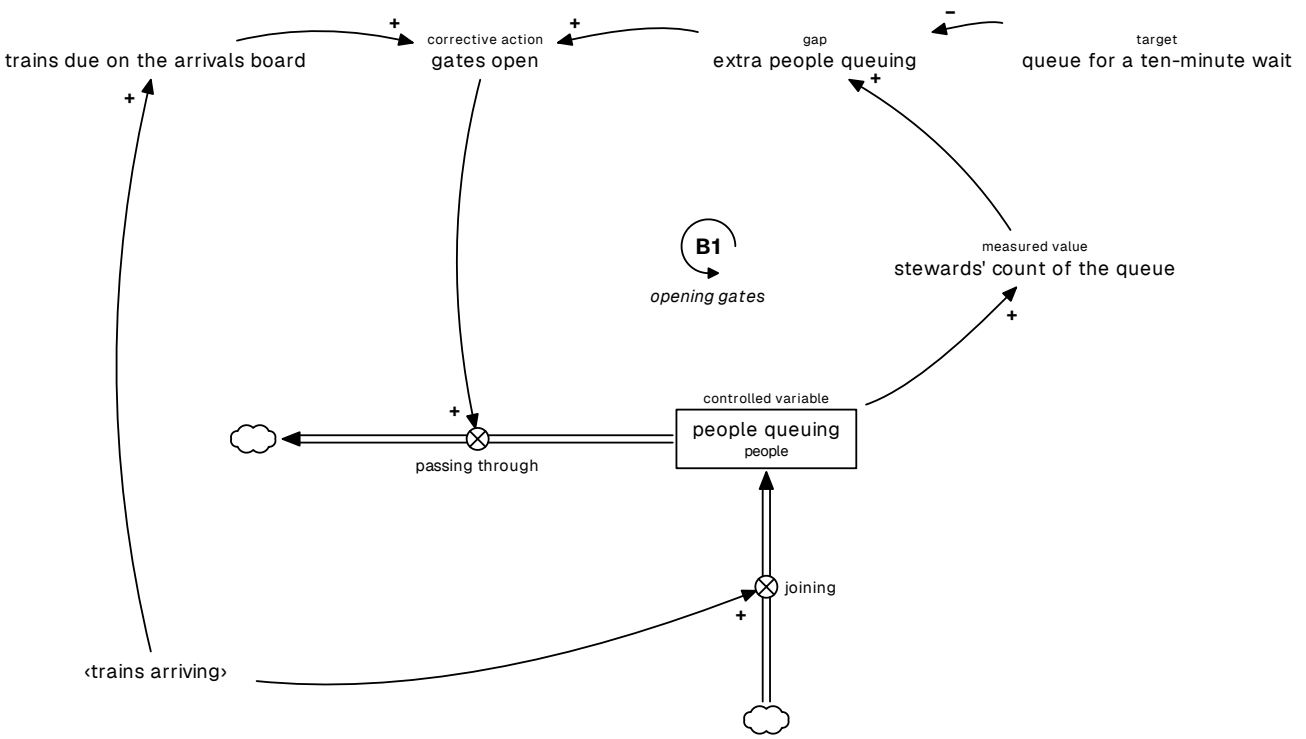
Heat from the burning fuel takes time to pass into the fluid and reach the outlet. Where would a delay be drawn?

a On measured outlet temperature → degrees below target, since the reading comes back late.
Not quite. That would be a reading arriving late, on the return path. Here the reading is prompt; the heat is slow, between the fuel and the outlet.

b On rate of incoming fluid → fuel gas flow, since feedforward arrives late.
Not quite. Woolf and others describe the feedforward change in fuel as immediate. Its slowness comes after, as for every change in fuel, on fuel gas flow → outlet temperature.

c On fuel gas flow → outlet temperature, B1's forward path.
Yes. A change in fuel reaches the outlet late, and so does every correction B1 makes. The feedforward path starts that change as soon as more fluid comes in, instead of waiting for the outlet to cool and a gap to open.

FC 06 Entry gates at a concert as trains arrive



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One stock, people queuing, counted in people: the controlled variable. Joining fills it from a cloud and passing through drains it to a cloud, both in people per minute. Extra people queuing is the gap, read from the queue for a ten-minute wait (–) and the stewards' count of the queue (+); it sets gates open (+), whose signal reaches the valve of passing through (+). B1 runs through passing through, counted – out of the stock, and has one – step, so it is balancing. Trains arriving act at the valve of joining, and reach gates open through the trains due on the arrivals board: a feedforward path, passing no gap, so the gates open before a train's fans join the queue.

Why it works

- The arrivals board's signal ends at gates open, not at the gap, so it changes the gates before the queue grows
- Gates open has two signals in, from the gap and from the arrivals board, and one out, to the valve of passing through
- The stewards' count is a variable apart from the people queuing, and the target is a queue in people, so the gap compares one quantity
- Trains arriving act on the controlled variable at the valve of joining, never on the gap
- The one – step, passing through draining the stock, makes the loop balancing

Step by step

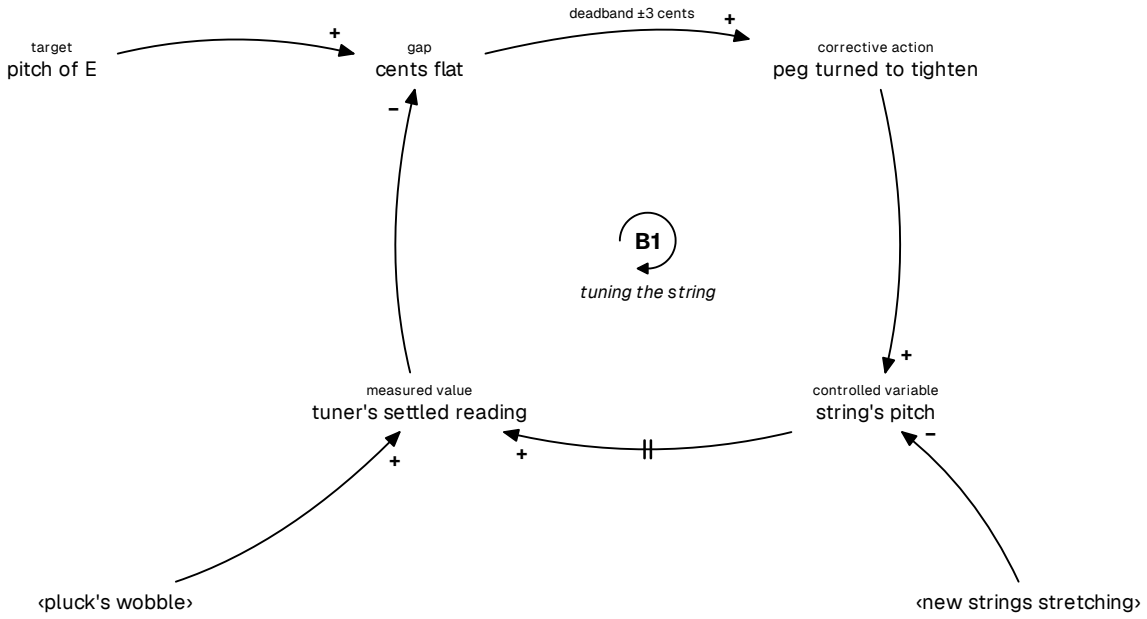
1. People queuing, the controlled variable, a stock counted in people, with the time unit a minute: the stewards aim for about 600, a ten-minute wait at the gates' pace.
2. Joining, from a cloud for the station, and passing through, to a cloud for the stadium: fans count from when they join the queue until they pass a gate.

3. Stewards' count of the queue, the measured value, with a + signal from the stock: a steward counts the queue every few minutes.
4. Queue for a ten-minute wait, the target, and extra people queuing, the gap, read from the count (+) and the target (–): how far the count runs above 600.
5. Gates open, the corrective action, with a + signal from the gap and a + signal to the valve of passing through, which close B1, opening gates, through the stock: the longer the queue, the more gates the stewards open, and the faster fans pass through.
6. Trains arriving, an external driver, with a + signal to the valve of joining, off the loop: a full train brings about 1,000 fans to the queue within a few minutes.
7. Trains due on the arrivals board, with + signals from trains arriving and to gates open, a feedforward path: the stewards open gates on the board's news of a full train, before its fans add to the count.

What another defensible answer might vary

Another defensible answer might count the target and the stewards' estimate in minutes of waiting rather than people, or draw the fans walking from the platform as a stock of their own between the station and the queue. What stays the same is one stock in people with joining in and passing through out, the time unit a minute, one balancing control loop through passing through, trains arriving at the valve of joining, and one path from trains arriving to gates open that passes no gap.

FC 07 Tuning a guitar with a clip-on tuner



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The string's pitch is the controlled variable, and the pitch of E the target. Cents flat is the gap, read from the pitch of E (+) and the tuner's settled reading (–); it sets how far she turns the peg to tighten (+), and the peg raises the string's pitch (+). The signal from the gap to the peg carries deadband ±3 cents: inside it the peg stays put. The settled reading follows the string's pitch two seconds late: a delay on the return path. B1 has one – step, so it is balancing. New strings stretching lower the string's pitch (–); the pluck's wobble, counted in the cents it adds to the reading, sharp or flat, acts on the reading (+).

Why it works

- The deadband is written on the signal from the gap to the peg: within 3 cents either way, a change in the gap changes nothing at the peg
- The two-second wait for the reading to settle is a delay between the string's pitch and the reading: the return path
- The pluck's wobble acts on the tuner's reading, not on the string: it is noise in what she reads
- New strings stretching act on the string's pitch, the controlled variable, never on the gap
- The one – step, from the settled reading to the gap, makes the loop balancing

Step by step

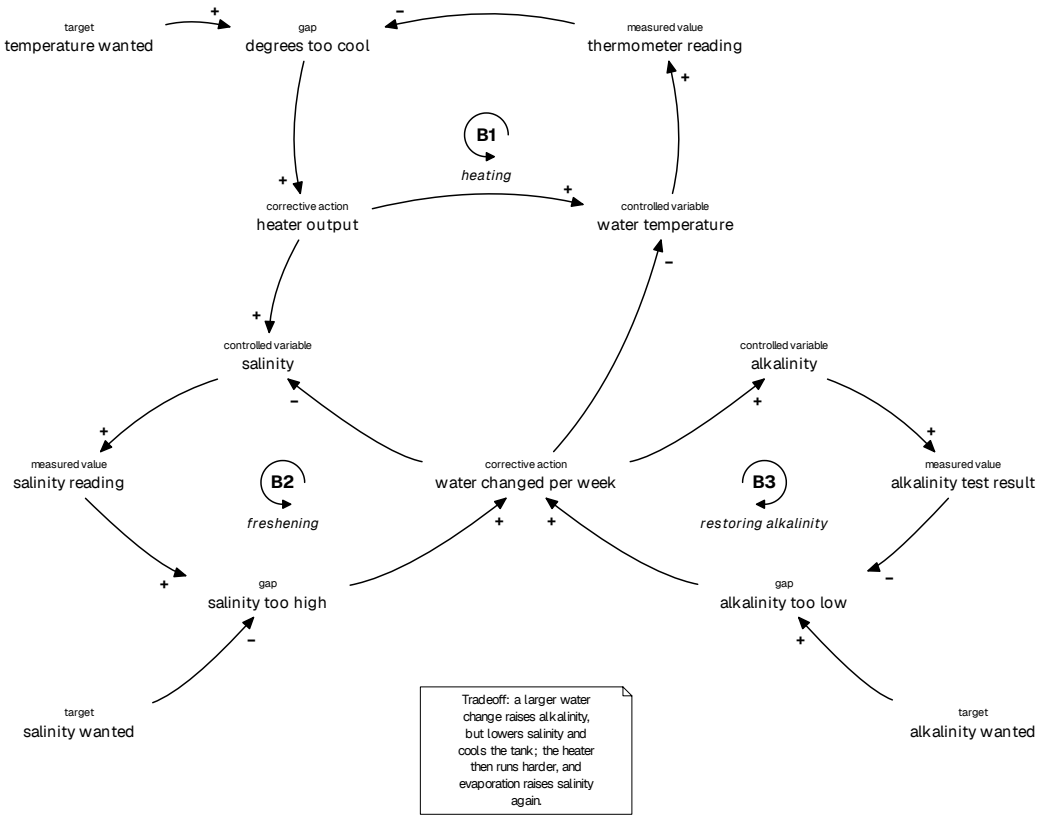
1. The string's pitch, the controlled variable: the high E string, tuned to about 330 Hz.
2. Tuner's settled reading, the measured value, with a + signal from the string's pitch, delayed about two seconds while the note rings and the reading settles: a delay on the return path.
3. Pitch of E, the target, and cents flat, the gap, read from the target (+) and the settled reading (–): a reading sharp of E puts the gap below zero.

4. Peg turned to tighten, the corrective action, with a + signal from the gap carrying deadband ±3 cents and a + signal to the string's pitch, which close B1, tuning the string: a reading 2 cents flat leaves the peg where it is, and one 5 cents flat turns it.
5. Two external drivers, off the loop: new strings stretching, with a – signal to the string's pitch, which goes flat between tunings, and the pluck's wobble, with a + signal to the reading, which shifts what she reads but not the string.

What another defensible answer might vary

Another defensible answer might name the gap cents off E and the corrective action peg turned, a turn back counted below zero. What stays the same is one balancing control loop, one delay between the string's pitch and the reading, deadband ±3 cents on the signal from the gap to the peg, the wobble acting on the reading, and stretching acting on the string's pitch.

FC 08 A home reef aquarium



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Three control loops, each with its target, gap, corrective action, controlled variable and measured value. B1: degrees too cool, read from temperature wanted (+) and the thermometer reading (–), sets the heater output (+), which warms the water (+). B2: salinity too high, read from salinity wanted (–) and the salinity reading (+), sets the water changed per week (+), and new water mixed at 34 parts per thousand lowers the salinity (–). B3: alkalinity too low, read from alkalinity wanted (+) and the alkalinity test result (–), sets the same water changed per week (+), which raises the alkalinity (+). Each loop has one – step, so each is balancing. Two cross-effects join the loops: heater output raises salinity through evaporation (+), and water changed cools the water (–). The behavior note names the tradeoff.

Why it works

- Water changed per week is one variable, the corrective action of B2 and of B3, drawn once with a signal in from each gap
- Each of the three loops has its own target and its own reading, so each gap compares one quantity
- The cross-effects are signals between loops that lie on no declared loop: heater output to salinity, water changed to water temperature
- The two cross-effects close a longer loop, left undeclared, through the temperature and salinity gaps: the tradeoff the behavior note names
- Each loop has one – step, so each is balancing

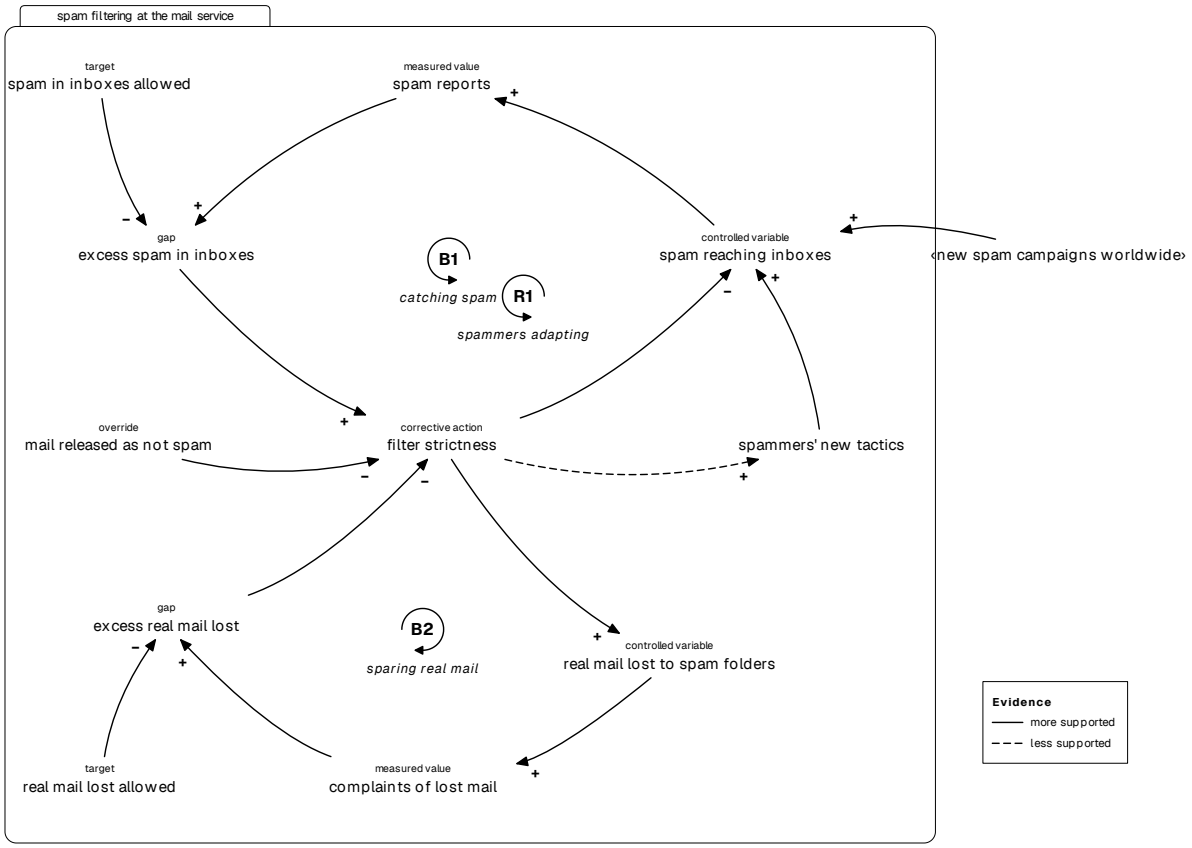
Step by step

1. Water temperature, a controlled variable, and the thermometer reading, its measured value, with a + signal from one to the other: the heater answers a thermometer in the tank, the one reading taken without her.
2. Temperature wanted, the target, degrees too cool, the gap, and heater output, the corrective action, with the signals that close B1, heating: the cooler the thermometer reads below 25 °C, the harder the heater runs.
3. Salinity and alkalinity, two more controlled variables, each with a + signal to its measured value: the refractometer's salinity reading and the kit's alkalinity test result, both taken once a week.
4. Salinity wanted with salinity too high, and alkalinity wanted with alkalinity too low, two targets and two gaps: the salinity gap grows as the reading rises above 35 parts per thousand, the alkalinity gap as the test falls below 8 dKH.
5. Water changed per week, one corrective action for both, with + signals from each gap, a − signal to salinity and a + signal to alkalinity, which close B2, freshening, and B3, restoring alkalinity: new water mixed at 34 parts per thousand and 11 dKH dilutes the salt and adds alkalinity.
6. Two cross-effects, on no declared loop: heater output raises salinity (+), since warmer water evaporates faster and leaves its salt, and water changed lowers the water temperature (−), since the new water comes from a bucket a few degrees cooler.
7. A behavior note on the tradeoff the two cross-effects make between the loops: no water change raises alkalinity without cooling the tank and, through the heater, raising its salinity.

What another defensible answer might vary

Another defensible answer might name the gaps salinity over target and alkalinity under target, or add a signal from the water temperature to salinity, a third cross-effect for evaporation. What stays the same is three targets, three readings and three gaps; one variable for the water changes, the corrective action of both the salinity loop and the alkalinity loop; and the two cross-effects, heater output to salinity and water changed to water temperature.

FC 09 A mail service's spam filter



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Filter strictness is the corrective action of two control loops. B1: excess spam in inboxes, read from spam in inboxes allowed (–) and spam reports (+), raises filter strictness (+), which lowers spam reaching inboxes (–). B2: excess real mail lost, read from real mail lost allowed (–) and complaints of lost mail (+), lowers filter strictness (–), which raises real mail lost to spam folders (+). Each has one – step, so each is balancing. R1 runs from filter strictness through spammers' new tactics to spam reaching inboxes and back through B1's gap, with no – step, so it is reinforcing; its first signal, from strictness to tactics, is coded as a hypothesis and drawn dashed, and the legend shows the coding. New spam campaigns worldwide sit outside the boundary, spam filtering at the mail service, acting on spam reaching inboxes. Messages released as not spam, the override, lower filter strictness (–).

Why it works

- Spammers' new tactics change with filter strictness, so they sit inside the boundary, on a loop, not outside it as an external driver
- New spam campaigns start whatever the filter does, so they are an external driver outside the boundary, with no signal into them
- One variable, filter strictness, is the corrective action of both balancing loops, and their gaps reach it with opposite polarities
- The override's signal ends at filter strictness, the corrective action, and is a step of no declared loop
- Only the engineers' belief, that stricter filtering brings new tactics, is dashed

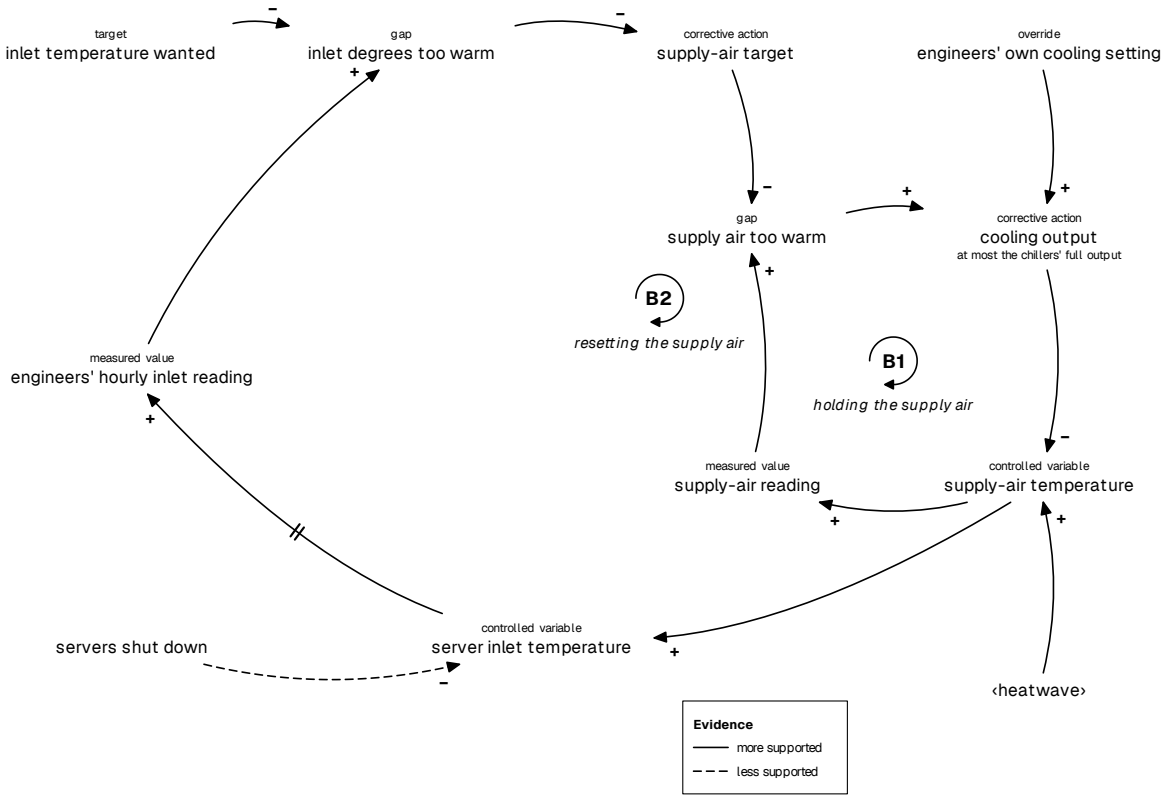
Step by step

1. Spam reaching inboxes and real mail lost to spam folders, two controlled variables, each with a + signal to its measured value: spam reports, from users who see the spam that gets through, and complaints of lost mail.
2. Two targets and two gaps, each gap read from its target (–) and its measured value (+): excess spam in inboxes, against 1 message in 1,000, and excess real mail lost, against 1 in 10,000.
3. Filter strictness, the corrective action of both, raised by excess spam (+) and lowered by excess real mail lost (–), with a – signal to spam reaching inboxes and a + signal to real mail lost, which close B1, catching spam, and B2, sparing real mail: the engineers set one filter from reports and complaints each day.
4. The boundary, spam filtering at the mail service, with new spam campaigns worldwide outside it as an external driver, its + signal to spam reaching inboxes: campaigns start every day, and nothing at the service changes how many.
5. Spammers' new tactics, with a + signal from filter strictness, the engineers' belief, coded as a hypothesis and dashed, and a + signal to spam reaching inboxes, which close R1, spammers adapting, through B1's measured value and gap, with the legend for the coding.
6. Mail released as not spam, the override, with a – signal to filter strictness: each message a user marks not spam leaves the spam folder and loosens the filter for messages like it.

What another defensible answer might vary

Another defensible answer might count both targets in messages per day, or code the signal from spammers' new tactics to spam reaching inboxes as a hypothesis too, since the same belief runs through it. What stays the same is two balancing control loops sharing filter strictness, one reinforcing loop through spammers' new tactics inside a named boundary, new spam campaigns outside it, one override ending at filter strictness, and one signal coded as a hypothesis with the legend on.

FC 10 Cooling a data center through a heatwave



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Two control loops, one inside the other. B1, the fast loop: supply air too warm, read from the supply-air target (–) and the supply-air reading (+), raises cooling output (+), which cools the supply air (–); one – step, so balancing. B2, the slow loop: inlet degrees too warm, read from inlet temperature wanted (–) and the engineers' hourly inlet reading (+), lowers the supply-air target (–), whose signal reaches B1's gap (–), and B2 runs on through cooling output and the supply air to the server inlet temperature (+), read an hour late: three – steps, so balancing. The supply-air target is B2's corrective action and B1's target, so B1 is nested inside B2. Cooling output is at most the chillers' full output. The heatwave warms the supply air (+); the engineers' own cooling setting, the override, ends at cooling output (+); servers shut down lower the inlet temperature (–), a signal coded as a hypothesis, drawn dashed, with the legend.

Why it works

- The supply-air target keeps one role, B2's corrective action, and its signal into B1's gap is B1's target: no second role is drawn
- The hour between the inlet temperature and the engineers' reading is a delay on B2's return path, so B2 is slow and B1 fast
- The saturation sits beneath cooling output, the corrective action whose limit the heatwave reaches
- The heatwave acts on the supply-air temperature, a controlled variable, never on a gap or a target
- Only the less supported signal, from servers shut down to the inlet temperature, is dashed, and the legend shows the coding

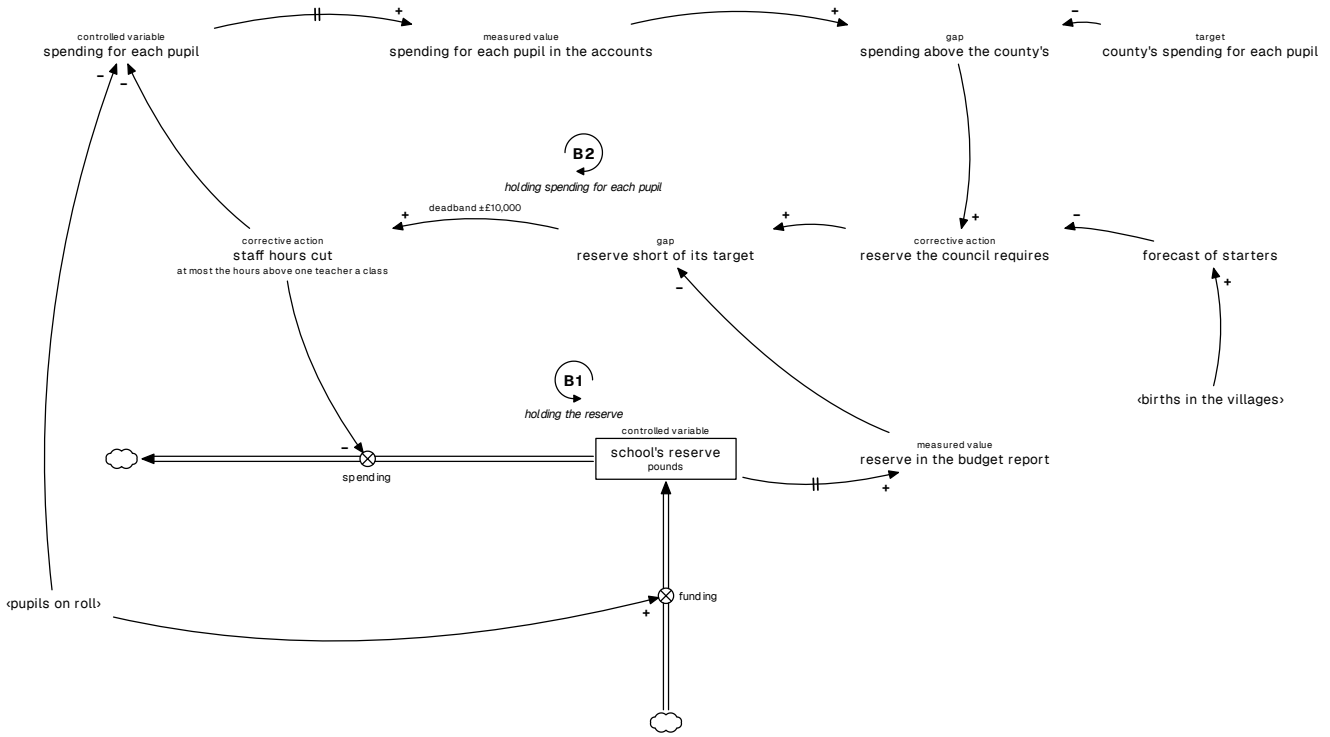
Step by step

1. Supply-air temperature, the fast loop's controlled variable, and the supply-air reading, its measured value, with a + signal from one to the other: the thermometer in the supply air reads it every few seconds.
2. Supply air too warm, the gap, read from the supply-air reading (+) and the supply-air target (–), the target drawn with its role in the slower loop, corrective action, since the engineers reset it each hour from the inlet reading.
3. Cooling output, the corrective action, with saturation at the chillers' full output, a + signal from the gap and a – signal to the supply air, which close B1, holding the supply air: the units cool harder the warmer the supply air reads, up to that limit.
4. Server inlet temperature, the slow loop's controlled variable, with a + signal from the supply air, and the engineers' hourly inlet reading, its measured value, with a + signal from the inlets delayed an hour: a delay on the return path.
5. Inlet temperature wanted, the target, and inlet degrees too warm, the gap, with a – signal from the gap to the supply-air target, which close B2, resetting the supply air, around B1: the warmer the inlets read each hour, the lower the engineers set the supply-air target.
6. The heatwave, an external driver, with a + signal to the supply-air temperature: once the chillers run at full output, the supply air warms however low the target is set.
7. The engineers' own cooling setting, the override, with a + signal to cooling output, and servers shut down, with a – signal to the inlet temperature, dashed as a hypothesis since nobody knows by how much, and the legend for the coding.

What another defensible answer might vary

Another defensible answer might draw the heatwave acting on the server inlet temperature instead, or add a behavior note on the inlet temperature climbing while cooling output sits at its limit. What stays the same is two balancing control loops, the fast one on the supply air nested inside the slow one on the inlet temperature, the supply-air target as the slow loop's corrective action, cooling output at most the chillers' full output, an override ending at cooling output, and one signal coded as a hypothesis with the legend on.

CS 09 Kelsham Primary School: a floor on staffing and the council's loop



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Two control loops, one inside the other. B1, holding the reserve: reserve short of its target, read from the reserve the council requires (+) and the reserve in the budget report (–), raises staff hours cut (+), which lowers the valve of spending (–), and spending drains the school's reserve (–), read by the report a term late: three – steps, so balancing. B2, holding spending for each pupil: spending above the county's, read from spending for each pupil in the accounts (+), a year late, and the county's spending for each pupil (–), raises the reserve the council requires (+), whose signal is B1's target, and runs on through B1's gap and staff hours cut to spending for each pupil (–): one – step, so balancing, with B1 nested inside it. Staff hours cut is at most the hours above one teacher a class, and the governors leave it as it is while the gap stays within ±£10,000. Births in the villages reach the reserve the council requires through the forecast of starters (+, then –), a feedforward path that passes no gap. The pupils on roll, an external driver, raise funding (+) and lower spending for each pupil (–).

Why it works

- The reserve the council requires keeps one role, B2's corrective action, and its signal into reserve short of its target makes it B1's target
- The saturation sits beneath staff hours cut: once the hours above one teacher a class are gone, a wider gap cuts no further, and neither loop can lower spending again
- The deadband sits on the signal from the gap to staff hours cut, as wide as the reserve's swing within a school year, so a term's swing changes no hours
- The forecast's path ends at a corrective action and passes no gap, so the council acts on births before the October count falls
- The two readings, each term and each year, are delays on the return paths: B1 corrects within a year, B2 over several

Step by step

1. The school's reserve, B1's controlled variable, a stock counted in pounds, with the time unit a year, filled by funding from a cloud and drained by spending to another.
2. Reserve in the budget report, the measured value, with a + signal from the stock delayed a term: the governors read the report each term, a delay on the return path.
3. Reserve short of its target, the gap, read from the report (–) and the reserve the council requires (+), the target drawn with its role in the council's loop, corrective action, since the council sets it from £60,000 up.
4. Staff hours cut, the corrective action, with saturation at the hours above one teacher a class, a + signal from the gap with a deadband of ±£10,000 and a – signal to the valve of spending, which close B1, holding the reserve: a term's swing changes no hours, and no gap cuts below one teacher a class.
5. Spending for each pupil, B2's controlled variable, with a – signal from staff hours cut, and spending for each pupil in the accounts, its measured value, with a + signal from it delayed a year: David Brennan reads the accounts once a year.
6. County's spending for each pupil, the target, and spending above the county's, the gap, read from the accounts (+) and the target (–), with a + signal to the reserve the council requires, which close B2, holding spending for each pupil, around B1.
7. Pupils on roll, an external driver, with a + signal to the valve of funding and a – signal to spending for each pupil, and births in the villages, a second, read through the forecast of starters into the reserve the council requires: a feedforward path that passes no gap.

What another defensible answer might vary

Another defensible answer might draw births in the villages → pupils on roll, delayed four years, so that the roll is no longer an external driver; send the forecast to staff hours cut, the governors acting on it; or read spending for each pupil from the flow of spending. What stays the same is two balancing control loops, the governors' nested inside the council's through the reserve the council requires, staff hours cut with its limit, a deadband on the signal from the reserve's gap, one feedforward path from births, and a delay on each return path.

Chapter 10 · Structures That Recur

Rain comes through a cracked roof tile into an attic. Whenever it rains, someone sets out pans and empties them, and the attic floor stays dry. Replacing the tile would take a roofer and a dry week, and the longer the pans keep the floor dry, the less anyone thinks of calling one. In a system archetype of the attic, which variable is the symptomatic solution?

a water on the attic floor
Not quite. That is the problem symptom: the quantity the pans and the new tile both lower.

b pans emptied
Yes. The pans lower the water on the floor within the hour and leave the crack as it was, so they relieve the symptom quickly: the symptomatic solution.

c tiles replaced
Not quite. Replacing the tile acts on the cause, more slowly, after a roofer and a dry week: the fundamental solution, with the delay on its effect.

d how used to the leak the household is
Not quite. That is the side effect: the pans raise it, and it lowers the tiles replaced, closing a reinforcing loop through both remedies, as shifting the burden has it.

A gym fills up every January: each new member brings friends along, and the friends join. By February the crowded floor puts members off. Someone draws it with space on the gym floor where crowding would go: members → space on the gym floor –, space on the gym floor → members +, beside members → friends brought along → members, both +. Does it match limits to growth?

a Yes, with space on the gym floor named as its opposite
Yes. Members and friends brought along close a reinforcing loop. Members and space on the gym floor close a loop with one –, so it is balancing. The limiting action rises with performance; space falls as members rise, so it stands as the limiting action named as its opposite.

b No: the archetype has performance → limiting action +, and this effect is –
Not quite. Matching reads loop kinds, not each effect's polarity. Naming crowding as space on the gym floor changes the polarity of both effects on the loop through it, so the loop keeps one – and stays balancing.

c No: with space where crowding would go, the loop through it is reinforcing
Not quite. Count the – effects: members → space on the gym floor is the only one. One is odd, so the loop is balancing, as limits to growth has it.

Evening pick-up games on a park's basketball court: players bring friends, and the friends come back the next week. As the court fills, players wait longer between games, and some stop coming. A diagram of the court, with players, friends brought along and waiting time, matches limits to growth. What does the match show?

a That the diagram's loops have the structure of limits to growth
Yes. Matching reads loops, their kinds and where delays sit: here a reinforcing loop and a balancing loop sharing players. Whether waiting time is what keeps players away is a question about the court, not about the drawing.

b That players stop coming because of the waiting
Not quite. That is the story the diagram was drawn from. If players stop coming because the evenings grow dark, the same loops are in the diagram, and they still match; the story is what would be wrong.

c That a second court is where to act
Not quite. Kim puts the leverage in limits to growth at the limit, and a second court acts there. But that is a leverage point, a hypothesis drawn in its own box; a match places no leverage point.

QUESTION 1 OF 3

Its authors name two archetypes, and both are declared. Which loops hold fixes that fail?

a B1 and B2, the two balancing loops sharing the lack of adolescent physical activity.
Not quite. Two balancing loops sharing one variable have the shape of escalation and eroding goals, and both match here, within shifting the burden. Fixes that fail has a reinforcing loop, and R1 is the only one.

b B1, spaces built, and R1, interest doubted.
Yes. B1 is the fix, through activity spaces on the outskirts; R1 leaves the same spaces through the side effect and comes back to the problem symptom through urban areas that facilitate activity. That way back is a chain of two effects, so fixes that fail sits within shifting the burden, as it does wherever the way back is four effects or fewer.

c B2, areas improved, and R1, interest doubted.
Not quite. Fixes that fail's balancing loop runs through the variable its side effect leaves from, the symptomatic solution. B2 runs through urban areas that facilitate activity, the fundamental solution, and the side effect leaves from the spaces on the outskirts.

QUESTION 2 OF 3

More impression that spaces won't raise activity: what does it change, and through which loop?

a More activity spaces on the outskirts, through its own effect on them.
Not quite. No effect runs from the impression to the spaces. Its one effect, a –, ends at urban areas that facilitate activity; the spaces rise only as the lack of activity does, around R1.

b Nothing in the loops: a side effect sits outside them.
Not quite. R1 runs through it, from spaces left unused to urban areas that facilitate activity: the side effect is the reinforcing loop's middle, and without it R1 doesn't close.

c Fewer urban areas that facilitate activity, so the lack of activity stays high: R1.
Yes. Its – effect lowers the fundamental solution: spaces left unused read as no interest, and less goes into areas close to home. B2 weakens, the lack of activity stays high, and more spaces go on the outskirts, closing R1.

The figure has no delay, as its authors drew none. On which effect does shifting the burden's delay belong?

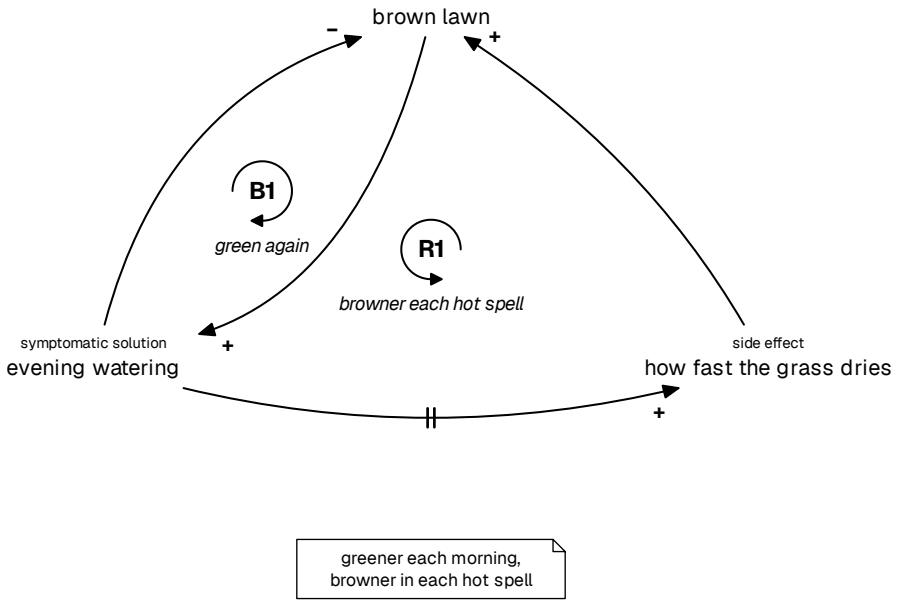
a Urban areas that facilitate activity → lack of adolescent physical activity.
Yes. Streets, squares and routes to school take years to rebuild, and habits of walking and playing outside follow later: the change in activity comes long after the change in the areas. With that delay, B2 relieves the problem symptom slowly while B1 seems to relieve it at once, and the spaces on the outskirts are built first.

b Activity spaces on the outskirts → lack of adolescent physical activity.
Not quite. That is the symptomatic solution's effect. Shifting the burden's symptomatic solution relieves at once; a delay there would take away the reason it is reached for first.

c Spaces left unused → impression that spaces won't raise activity.
Not quite. An impression may form over months, and a delay there would be a defensible addition. The archetype's own delay is the fundamental solution's, on B2, and the match lacks it.

AR 01 Watering a lawn a little every evening

Archetype: fixes that fail



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The browner the lawn, the more Rosa waters (+), and the more she waters, the less brown the lawn by morning (–): one – effect, so B1 is balancing. Over weeks the watering keeps the roots shallow, so the grass dries faster (+, with a delay), and the faster it dries, the browner the lawn (+): R1 has no – effect, so it is reinforcing. Evening watering is the symptomatic solution and how fast the grass dries the side effect; the declared archetype is fixes that fail, which the structure matches with its delay.

Why it works

- Both loops pass through the brown lawn, the change Rosa waters to undo
- One – effect makes the morning's relief balancing
- No – effect makes the return through the drying grass reinforcing
- The delay sits on evening watering → how fast the grass dries, where weeks pass
- Each role is written above its variable: the watering's and the drying grass's

Step by step

1. Brown lawn, drawn first: it is what Rosa sees each evening, before she waters.
2. Evening watering, the symptomatic solution, with a + effect from the brown lawn and a – effect back, closing B1, green again: the relief Rosa sees by the next morning.
3. How fast the grass dries, the side effect, with a + effect from the watering, delayed over the weeks the grass keeps its roots in the top few centimeters, and a + effect to the brown lawn, closing R1, browner each hot spell: drawn after B1, as it shows only after weeks of relief.

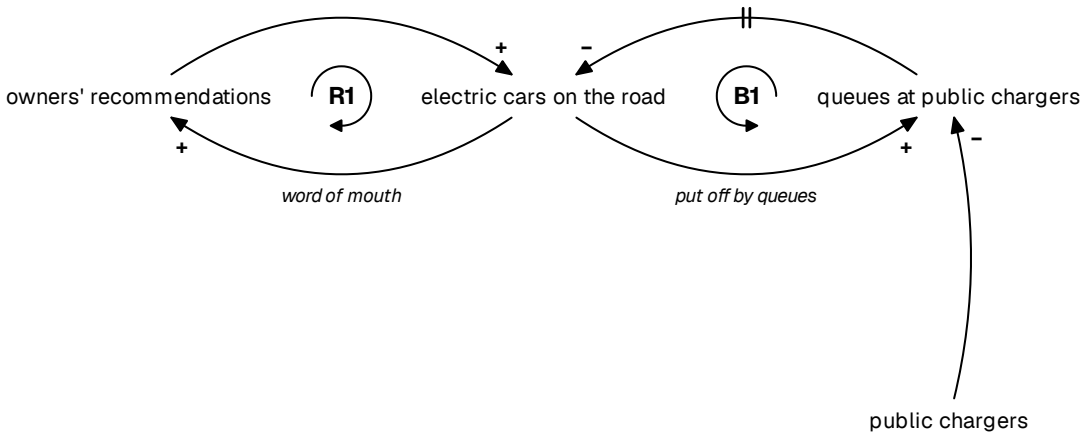
4. The behavior note, written once both loops are drawn, since each half of it comes from one: greener each morning from B1, browner in each hot spell from R1.
5. Fixes that fail, declared last: until R1 is drawn, the watering only fixes, and nothing fails.

What another defensible answer might vary

Another defensible answer might put the delay on how fast the grass dries → brown lawn, waiting for the next hot spell, or name the side effect how deep the grass grows, with – effects into and out of it: a variable named as its opposite, which keeps R1 reinforcing and still matches fixes that fail. What stays the same is a balancing loop of relief and a reinforcing loop, through the side effect and a delay, that returns to the brown lawn.

AR 02 Electric cars and public chargers

Archetype: limits to growth



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The more electric cars on the road, the more owners' recommendations (+), and the more recommendations, the more electric cars on the road (+): no – effect, so R1 is reinforcing. The more electric cars, the longer the queues at public chargers (+), and the longer the queues, the fewer electric cars join the road (–, with a delay): one – effect, so B1 is balancing. The two loops share only the electric cars on the road, so they match limits to growth: R1 grows the number of cars, and B1 holds it back. The public chargers shorten the queues (–) from outside both loops: the constraint.

Why it works

- R1 and B1 meet at one variable, the electric cars on the road, and share no effect
- No – effect makes the recommendations' loop reinforcing
- One – effect makes the queues' loop balancing
- The delay sits on queues at public chargers → electric cars on the road, where months pass before buyers hear
- The public chargers lie outside both loops and act on the balancing loop through the queues

Step by step

1. Electric cars on the road, drawn first: the number the situation begins and ends with.
2. Owners' recommendations, with a + effect each way to the cars, closing R1, word of mouth: the growth, drawn before anything holds it back.
3. Queues at public chargers, with a + effect from the cars and a – effect back, delayed by the months before word of hour-long waits reaches buyers, closing B1, put off by queues.

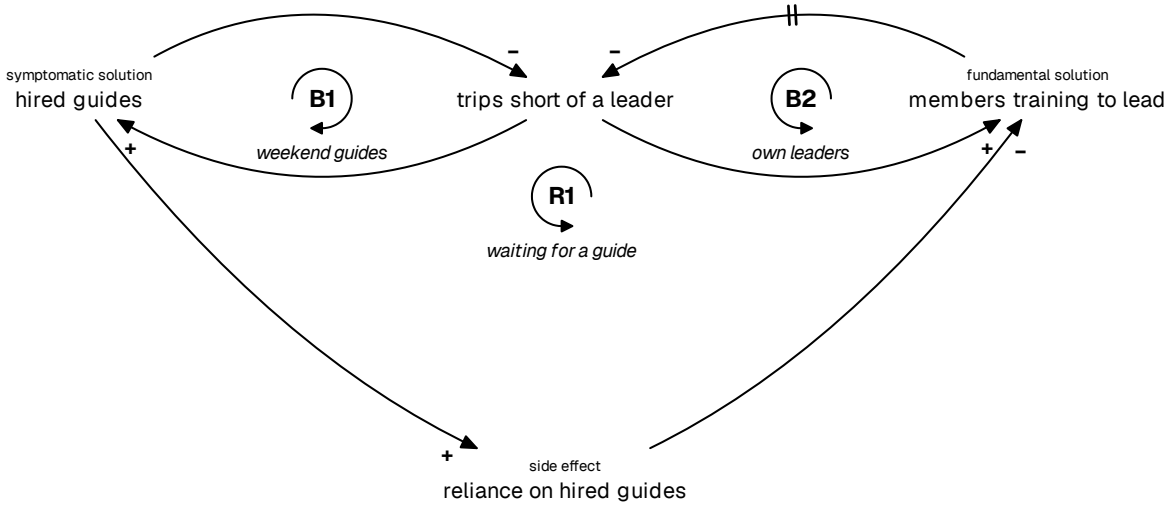
4. Public chargers, with a – effect on the queues, drawn last of the variables: no effect in either loop changes how many there are.
5. Limits to growth, declared once B1 is drawn: with R1 alone, the growth has nothing to limit it, and the drawing matches no archetype.

What another defensible answer might vary

Another defensible answer might name the queues as their opposite, a free charger when one is wanted, with the polarity of each effect into and out of it reversed: B1 stays balancing, and the match holds. Drawing the purchases as a variable both loops pass through would make them share an effect, and the structure would no longer match limits to growth. What stays the same is a reinforcing loop and a balancing loop that meet at one variable, with the chargers outside both.

AR 03 A climbing club that hires guides for its trips

Archetype: shifting the burden



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The more trips short of a leader, the more hired guides (+), and the more hired guides, the fewer trips short of a leader (–): one – effect, so B1 is balancing. The more trips short of a leader, the more members training to lead (+), and a season later, the more members training, the fewer trips short of a leader (–, with a delay): B2 is balancing too. The more hired guides, the more the club relies on them (+), and the more it relies on them, the fewer members train (–): R1 runs from the shortage through the hired guides, the reliance and the training back to the shortage, with two – effects, so it is reinforcing. Hired guides are the symptomatic solution, members training to lead the fundamental solution and the reliance on hired guides the side effect; the declared archetype is shifting the burden, which the structure matches with its delay, and fixes that fail within it.

Why it works

- Both balancing loops pass through the trips short of a leader, the shortage the hired guides and the training each relieve
- The delay sits on members training to lead → trips short of a leader, where a season passes
- Two – effects make R1, through the reliance, reinforcing
- The reliance on hired guides reaches the shortage only through the training, so the training's loop is the one it weakens
- Each role is written above its variable

Step by step

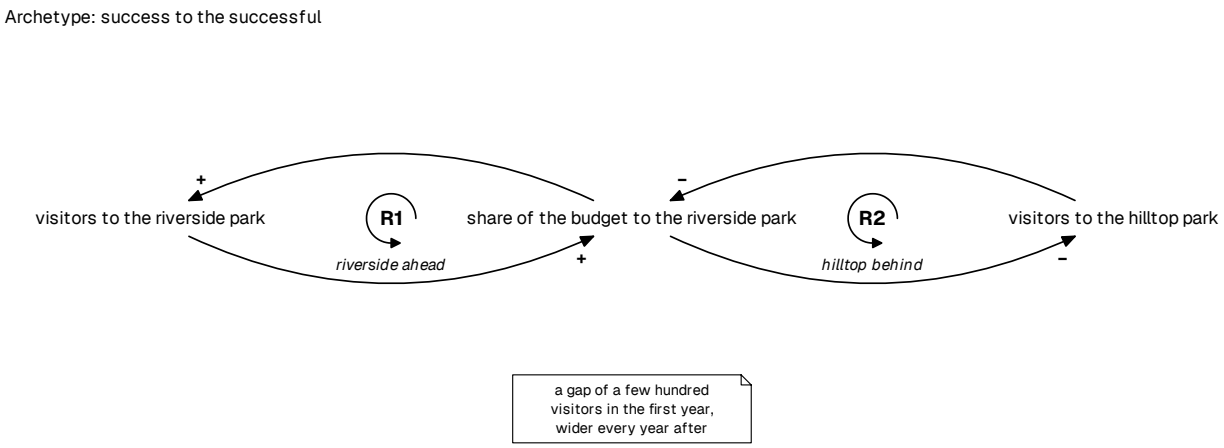
1. Trips short of a leader, drawn first: the club meets the shortage before it hires a guide or trains anyone.

2. Hired guides, the symptomatic solution, with a + effect from the shortage and a – effect back, closing B1, weekend guides: a guide hired for the weekend lets that trip go ahead.
3. Members training to lead, the fundamental solution, with a + effect from the shortage and a – effect back, delayed by the season of courses and logged climbs, closing B2, own leaders.
4. Reliance on hired guides, the side effect, with a + effect from the guides and a – effect into the training, closing R1, waiting for a guide, which runs through B2's delayed effect and so comes after it.
5. Shifting the burden, declared last, once R1 is drawn: without it, the club has two ways to close the shortage, and nothing shifts the burden to the guides.

What another defensible answer might vary

Another defensible answer might draw the training as a chain, members training to lead → qualified leaders → trips short of a leader, with the delay on either effect, or name the side effect the club's self-reliance, with – effects into and out of it: a variable named as its opposite, which keeps R1 reinforcing and still matches shifting the burden. What stays the same is two balancing loops through the shortage, the slower one with its delay, and a reinforcing loop from the hired guides through the training.

AR 04 Two parks and one maintenance budget



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The more visitors to the riverside park, the larger its share of the budget (+), and the larger that share, the more visitors to the riverside park (+): no – effect, so R1 is reinforcing. The more visitors to the hilltop park, the smaller the riverside park's share (–), and the larger that share, the fewer visitors to the hilltop park (–): two – effects, so R2 is reinforcing too. Two reinforcing loops sharing one variable match success to the successful: the park ahead draws the larger share, and the gap of a few hundred visitors in the first year widens every year after.

Why it works

- The split of the budget is one variable, so both loops pass through it
- R2 has two – effects, an even number, so it is reinforcing as drawn
- The two loops mirror each other across the share, one for each park
- The note names the first year's small gap and its widening

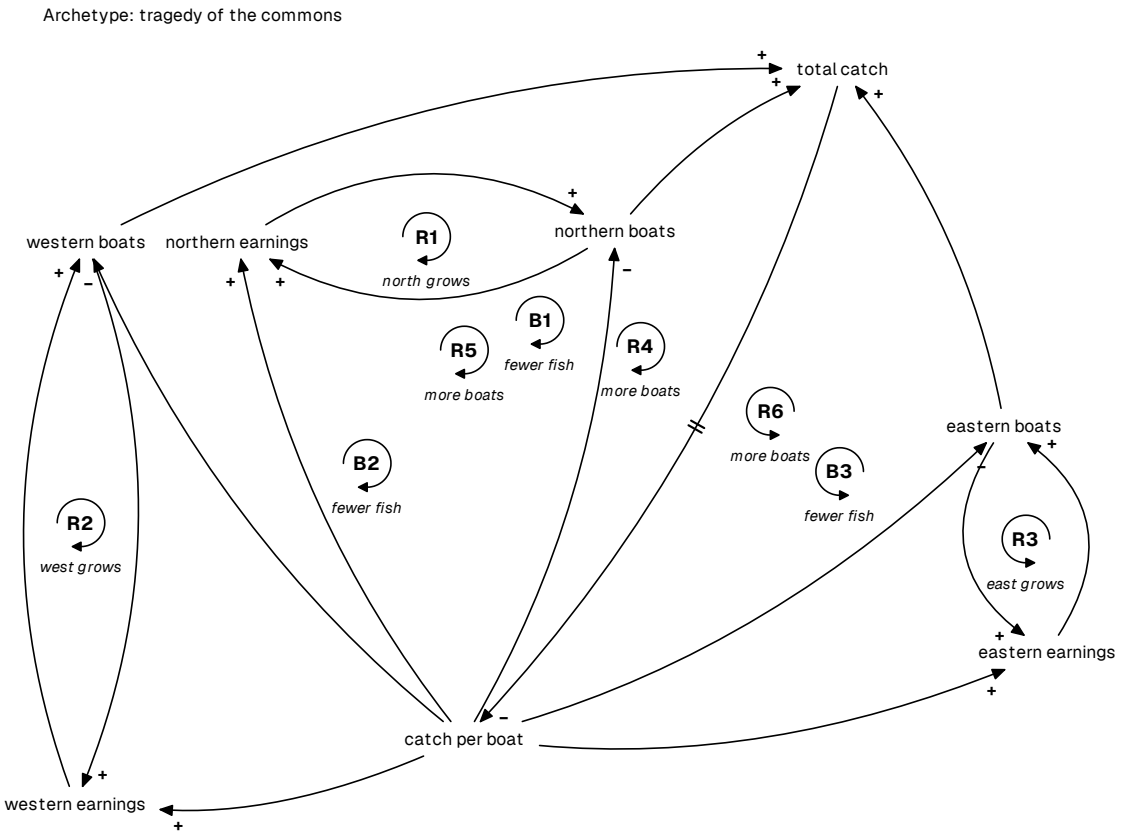
Step by step

1. Share of the budget to the riverside park, drawn first: the council sets it each spring, and both parks' visitors depend on it.
2. Visitors to the riverside park, with a + effect each way to the share, closing R1, riverside ahead: the park ahead in the first year, so its loop comes first.
3. Visitors to the hilltop park, with a – effect each way to the share, closing R2, hilltop behind: the larger the riverside park's share, the less the hilltop park is mowed, cleaned and repaired.
4. The behavior note under the share, written once both loops are drawn: the gap it names is between the visitors R1 adds and those R2 takes away.
5. Success to the successful, declared last, once R2 holds the hilltop park back by the same split: R1 alone is one park's growth.

What another defensible answer might vary

Another defensible answer might draw the share as the hilltop park's share of the budget, with the polarity of each effect reversed: both loops stay reinforcing, and the match holds. Or it might draw each park's upkeep between the share and its visitors, as a chain of two effects. What stays the same is one variable for the split and two reinforcing loops through it.

AR 05 Three countries' fleets on one fishing ground



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The more northern boats, the more northern earnings (+), and the more northern earnings, the more northern boats (+): no – effect, so R1 is reinforcing, and R2 and R3 are the western and eastern fleets' loops. Each fleet's boats add to the total catch (+); the larger the total catch, the smaller the catch per boat, years later (–, with a delay); and the larger the catch per boat, the more each fleet earns (+): B1, B2 and B3 run through one fleet's boats and earnings each, with one – effect, so each is balancing. The smaller the catch per boat, the more boats each fleet sends (–): R4, R5 and R6 run from one fleet's boats through the total catch and the catch per boat, with two – effects, so each is reinforcing. Each pair of fleets matches tragedy of the commons, so the structure matches it three times, once for each pair, each with its delay.

Why it works

- One total catch and one catch per boat are shared by every fleet's balancing loop
- Each balancing loop's one – effect is the total catch's on the catch per boat; each loop back to a fleet's boats from the catch per boat adds a second, so it is reinforcing
- The delay sits on total catch → catch per boat, where the missing young fish take years to show
- Three fleets make three pairs, and each pair is one match of tragedy of the commons
- The fleets sit around the shared pair of variables, so no effect crosses another

Step by step

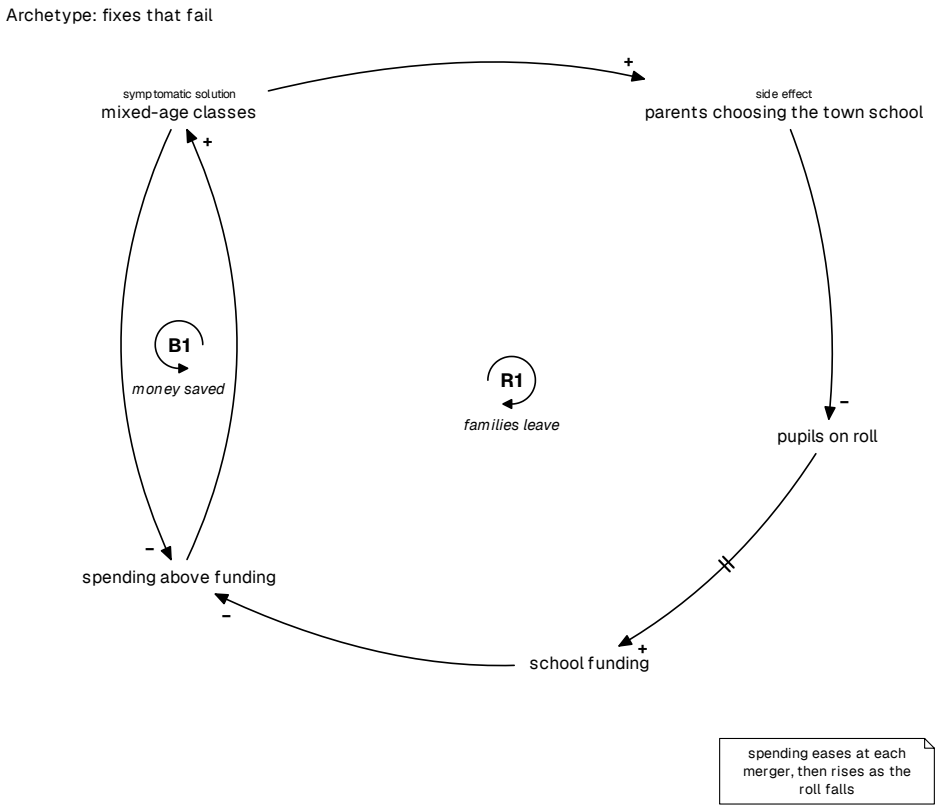
1. Northern boats and earnings, with a + effect each way, closing R1, north grows: the owners spend what they earn on more boats.

2. The western and eastern boats and earnings, closing R2, west grows, and R3, east grows: each fleet growing on its own until something the three share holds them back.
3. Total catch, with a + effect from each fleet's boats: the one place the three fleets' growth meets, drawn once.
4. Catch per boat, with a – effect from the total catch, delayed by years, and a + effect to each fleet's earnings, closing B1, B2 and B3, fewer fish.
5. A – effect from the catch per boat to each fleet's boats, closing R4, R5 and R6, more boats: drawn after the balancing loops, as a fleet sends more boats only once its catch per boat has fallen.
6. Tragedy of the commons, declared last: no one fleet's loops match it; two fleets' loops drawing on the one catch per boat do.

What another defensible answer might vary

Another defensible answer might draw the fish left to breed between the total catch and the catch per boat, as a chain of two effects with the delay on either, or name each fleet's earnings as its losses, with the polarity of each effect into and out of them reversed: every loop keeps its kind, and the three matches hold. What stays the same is one total catch fed by all three fleets, one catch per boat falling from it after a delay, and two reinforcing loops for each fleet.

CS 10 Kelsham Primary School: merging classes to balance the budget



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The more spending above funding, the more mixed-age classes (+), and the more mixed-age classes, the less spending above funding (–): one – effect, so B1 is balancing, and the saving comes at once. The more mixed-age classes, the more parents choosing the town school (+), the fewer pupils on roll (–), the less school funding a year later (+, with a delay), and the more spending above funding (–): R1 has two – effects, so it is reinforcing. Mixed-age classes are the symptomatic solution and parents choosing the town school the side effect; the declared archetype is fixes that fail, which the structure matches with its delay.

Why it works

- Both loops pass through spending above funding, the change the governors merge classes to undo
- One – effect makes the saving balancing; two make the families' leaving reinforcing
- The delay sits on pupils on roll → school funding: each October's count sets the next school year's funding
- Each role is written above its variable: the merged classes' and the parents' choice
- The note names the saving at each merger and the spending that comes back

Step by step

1. Spending above funding, drawn first: it is what the governors act on when they merge classes.
2. Mixed-age classes, the symptomatic solution, with a + effect from spending above funding and a – effect back, closing B1, money saved: merging Years 3 and 4 in 2023 saved £52,000 a year at once.
3. Parents choosing the town school, the side effect, then pupils on roll and school funding, with a + effect, a – effect, a + effect delayed by the October count and a – effect back to spending above funding, closing R1, families leave: drawn after B1, since the funding falls a year after the pupils leave.

4. The behavior note, written once both loops are drawn, since each half of it comes from one: spending eases at each merger, from B1, and rises as the roll falls, from R1.
5. Fixes that fail, declared last: until R1 is drawn, merging classes only saves money, and nothing fails.

What another defensible answer might vary

Another defensible answer might draw the school's reserve in place of spending above funding, with the polarity of each effect into and out of it reversed: a variable named as its opposite, which keeps both loops' kinds and still matches fixes that fail. Or it might draw teachers between spending above funding and mixed-age classes, or put a second delay on parents choosing the town school → pupils on roll, since families move at the end of a school year. What stays the same is a balancing loop of saving and a reinforcing loop, through the side effect and a delay, that returns to spending above funding.

Chapter 11 · Diagnosing Tangled Situations

Two street musicians, Ines and Kofi, play on one corner, and each plays louder when the other drowns them out. A diagram shows Ines's volume → Ines against Kofi +, Ines against Kofi → Ines's volume –, Kofi's volume → Ines against Kofi –, and Ines against Kofi → Kofi's volume +. Its loops match escalation and eroding goals. Which story is it, and why?

a Escalation: the shared variable sets one musician's volume against the other's
Yes. Both archetypes are two balancing loops sharing one variable, so the loops match both. Ines against Kofi compares one side's position with the other's, as escalation's relative position does. A gap would be a target less actual performance: the volume Ines wants less Ines's volume.

b Eroding goals: Kofi's volume is the target Ines's volume closes on
Not quite. Kofi's volume moves with the shared variable, as eroding goals' target moves with the gap, so the loops fit. But nobody chose it as a value to stay near: it is the other side's position, and that makes the story escalation.

c Either: the loops match both, so both declarations are equally right
Not quite. The loops match both because matching reads loops and their kinds, not what a variable is. The stories differ in what the shared variable is: here it compares the two musicians, so the declaration is escalation.

A pottery studio's evening classes fill by word of mouth, and its waiting list grows. A diagram of the studio shows two leverage points: the wheels in the studio, and the waiting list the owner treats as normal. Its author judges the waiting list the better place to act. How does the diagram show that?

a A ranking written beside it: the waiting list first, the wheels second, each with its reason
Yes. No mark ranks leverage points: each is the same box with its question marks. The order and the reasons go beside the diagram in words, where a reader can test each reason against the loops.

b A heavier box around the waiting list
Not quite. Every mark is drawn in pencil in one weight, so a heavier box carries nothing a reader can read. A leverage point's box marks a hypothesis about where to act, not its rank.

c Only the waiting list boxed, the wheels left plain
Not quite. That drops the second proposal, and the comparison with it. Both boxes stay, and the ranking, with its reasons, goes beside the diagram.

Sam and Jo share a flat and take turns cooking dinner for both, which leaves each of them free evenings. Short of time in the week, each starts cooking a week's lunches on Sunday afternoon. Sam's cooking takes the oven and every pan when Jo comes to cook, and Jo's leaves a sink of washing-up that Sam clears before starting. Which archetype's story is this?

a Accidental adversaries

Yes. Their turns at cooking free each other's evenings: the partnership loop. Each Sunday's cooking eases its cook's own week, a balancing loop for each, and gets in the other's way; the two together close the adversaries' loop. Kemeny puts the leverage in each partner learning what the other needs.

b Escalation

Not quite. Escalation's two sides act on one comparison, each against the other's lead. Neither flatmate measures their week against the other's: each Sunday's cooking is for its cook's own week, and it gets in the other's way as it goes.

c Fixes that fail, once for each flatmate

Not quite. A drawing of the flat does match fixes that fail, one flatmate's Sunday cooking as the symptomatic solution and its side effect running through the other's week. But each such match lies within accidental adversaries, and read alone it leaves out the partnership loop that ties the two weeks together.

QUESTION 1 OF 3

Which variable is eroding goals' target, and what brings it down?

a Staffing need, lowered by community care.

Not quite. Staffing need is the gap: the staffing goal raises it and provider retention lowers it. Community care reaches the need only by lowering the staffing goal, around B10 and B11.

b Staffing goal, lowered by veterans sent to community care (B10) and by the downsizing of rural services that follows (B11).

Yes. A higher staffing need sends more veterans to community care, and each – effect into the staffing goal brings the goal down, closing the gap from the target's side. Here the target moves, and recruitment and retention, B9, are left less to close.

c Provider retention, lowered by provider burnout.

Not quite. Provider retention is actual performance, the side recruitment raises through B9. Burnout lowers it around R1, but no variable sets it as a target is set.

QUESTION 2 OF 3

Its authors count R1, the burnout spiral, in their drifting goals (eroding goals). With B9, R1 matches another archetype, coupled with eroding goals. Which?

a Shifting the burden, with community care as the symptomatic solution.

Not quite. Community care relieves the staffing need only by lowering the staffing goal, eroding goals' second loop, and R1 doesn't pass through it. No shifting the burden matches here.

b Escalation, between provider recruitment and provider burnout.

Not quite. Escalation is two balancing loops sharing one variable, and R1 is reinforcing. The escalation that matches here is eroding goals' own shape: B9 with B10 or B11.

c Fixes that fail: B9 brings retention back as the need rises, and R1 drives it down through patients per provider and burnout.

Yes. With provider retention named as its opposite, provider loss, as the problem symptom, B9 is the fix and R1 the side effect's loop, its delay not drawn. B9 is eroding goals' corrective action too, so the two matches share the staffing need, recruitment and retention: coupled archetypes.

Ranked by what Kim finds of eroding goals, which leverage point comes first?

a Provider recruitment, pushed harder.

Not quite. Recruitment corrects through B9, after a delay, while a lowered staffing goal closes the gap at once; and R1's burnout drives out the providers recruited. While the goal can fall, a recruitment push closes the gap no sooner.

b Veterans sent to community care, cut back.

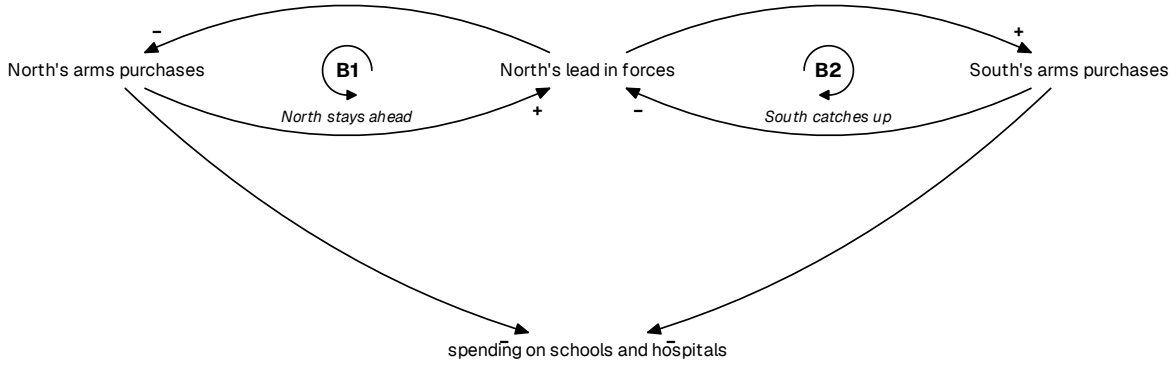
Not quite. Community care reaches veterans who would otherwise drive far for care, and it lowers the target only through its effect on the staffing goal. Holding the goal itself stops B10 and B11 with no veteran sent back to the road.

c The staffing goal, set from outside the facilities and held there.

Yes. Kim finds that targets set from outside the situation drift less. Held, the staffing goal no longer falls with the community care sent, so B10 and B11 stop, and the gap stays open until B9 closes it.

AR 06 An arms race between two neighboring countries

Archetype: escalation



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The more arms North buys, the larger North's lead in forces (+), and the larger that lead, the fewer arms North buys (–): one – effect, so B1 is balancing. The more arms South buys, the smaller North's lead (–), and the larger North's lead, the more arms South buys (+): B2 is balancing too. Traced as a figure 8 through both loops, each country's purchases lead to the other's: the spiral of escalation. Both countries' purchases lower the spending on schools and hospitals (–), which acts on neither loop. The declared archetype is escalation, which the structure matches; the same two loops also match eroding goals, since both archetypes are two balancing loops sharing one variable. What tells the two stories apart is what each loop changes: here each changes one country's arms, pushing the shared lead its own way; in eroding goals one loop changes what is achieved and the other lowers the target.

Why it works

- One variable, North's lead in forces, is read by both countries, so both loops pass through it
- Each loop has one – effect, so both are balancing
- The spending on schools and hospitals is reached from both countries' purchases and returns to neither loop
- The declaration names escalation, since both loops change arms and neither lowers a target

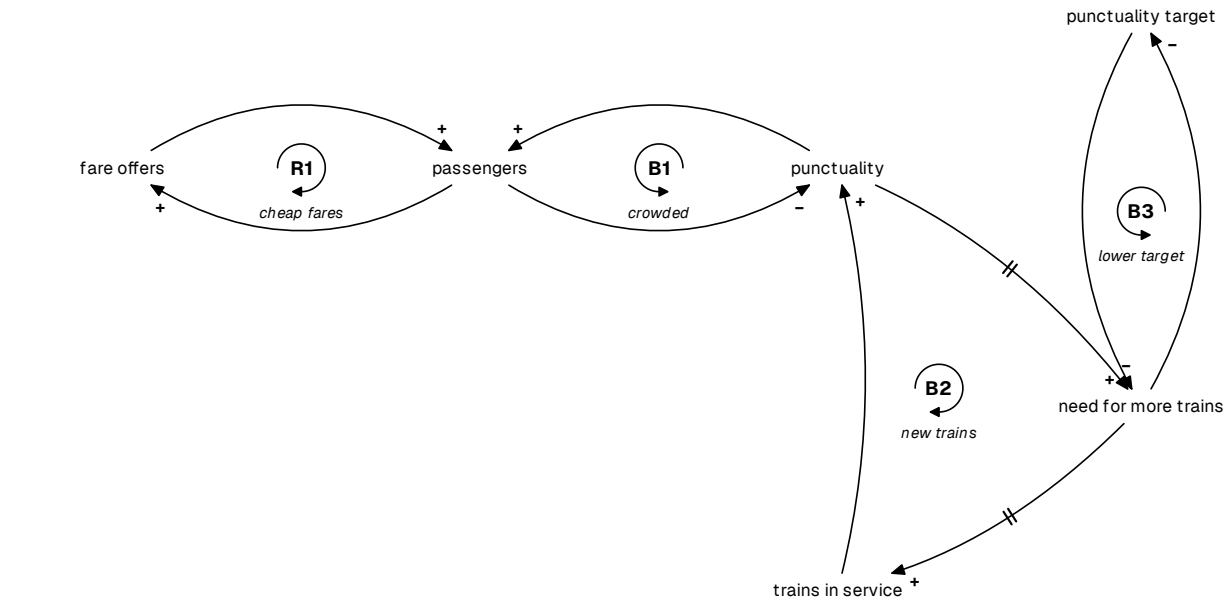
Step by step

1. North's lead in forces, drawn first: each country judges its safety by it before buying anything.
2. North's arms purchases, with a + effect to the lead and a – effect back, closing B1, North stays ahead: North buys until it is well ahead.
3. South's arms purchases, with a – effect to the lead and a + effect back, closing B2, South catches up: each of South's purchases shrinks the lead that North's loop restores.
4. Spending on schools and hospitals, with a – effect from each country's purchases, drawn after both loops: it comes out of the same budgets and changes no purchase.
5. Escalation, declared last, once both countries' loops are drawn: with North's alone, there is no one to escalate against.

What another defensible answer might vary

Another defensible answer might name the comparison South's lead in forces, with the polarity of each effect into and out of it reversed: both loops stay balancing, and the match holds. Or it might draw a delay on each country's purchases, since arms take years to arrive. What stays the same is one comparison read by both countries, two balancing loops through it, and the spending on schools and hospitals outside both.

AR 07 A country's railways



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The more passengers, the more fare offers (+), and the more fare offers, the more passengers (+): no – effect, so R1 is reinforcing. The more passengers, the lower the punctuality (–), and the higher the punctuality, the more passengers (+): one – effect, so B1 is balancing. The lower the punctuality, the greater the need for more trains (–, with a delay); the greater the need, the more trains in service (+, with a delay); and the more trains in service, the higher the punctuality (+): B2 is balancing. The higher the target, the greater the need (+), and the greater the need, the lower the target (–): B3 is balancing. The declared archetype is growth and underinvestment, which the structure matches with its delay, and limits to growth sits within it: R1 held back by B1. B3 and B2 also match eroding goals, with the need for more trains as the gap: each time the target is lowered, the need it reads is smaller, and fewer trains are ordered.

Why it works

- R1, B1 and B2 meet at the passengers and the punctuality, as growth and underinvestment's three loops do
- One delay sits where the operator reads the need, the other where new trains arrive
- The punctuality target acts on the need for more trains, and B3 lowers it as the need grows
- Each loop's kind follows its count of – effects

Step by step

1. Passengers and fare offers, with a + effect each way, closing R1, cheap fares: the growth the operator starts from.
2. Punctuality, with a – effect from the passengers and a + effect back, closing B1, crowded: crowding holds the growth back before any train is ordered.
3. Need for more trains and trains in service, with a delay where the year's figures come in and another for the four years a train takes to build, closing B2, new trains.

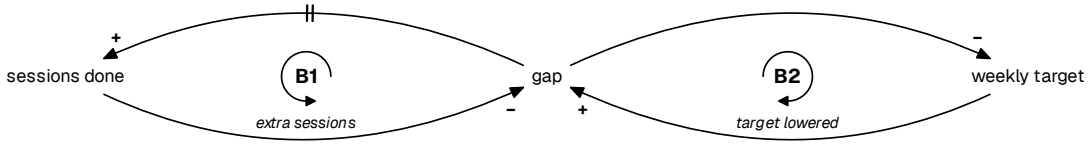
4. Punctuality target, with a + effect on the need and a – effect back, closing B3, lower target: drawn after B2, as the operator lowers the target only when the need is already large.
5. Growth and underinvestment, declared last: its template's three loops are R1, B1 and B2, and its delay is the four years of building, not the year of figures.

What another defensible answer might vary

Another defensible answer might draw the target's effect on the need through a gap, punctuality target → punctuality below the target → need for more trains, or name the punctuality as the lateness of trains, with the polarity of each effect into and out of it reversed: every loop keeps its kind, and the match holds. What stays the same is a reinforcing loop of passengers, two balancing loops meeting at the punctuality, two delays, and the target acting on the need.

AR 08 Knee exercises after an operation

Archetype: eroding goals



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The larger the gap, the more sessions done a week later (+, with a delay), and the more sessions done, the smaller the gap (–): one – effect, so B1 is balancing. The larger the gap, the lower the weekly target (–), and the higher the target, the larger the gap (+): B2 is balancing too. Both close the gap: B1 by raising the sessions done a week later, B2 by lowering the target as soon as it is reset. The declared archetype is eroding goals, which the structure matches with its delay. In the match, the weekly target and the sessions done are interchangeable: swapped, every loop keeps its kind, so the loops alone don't settle which is the target; only the target is set by Priya each Sunday.

Why it works

- The gap is a variable of its own, between the weekly target and the sessions done
- Each loop has one – effect, so both are balancing
- The delay sits on the gap's effect on the sessions done, where extra sessions wait for the next week
- B2 is named target lowered: the gap closes without more sessions

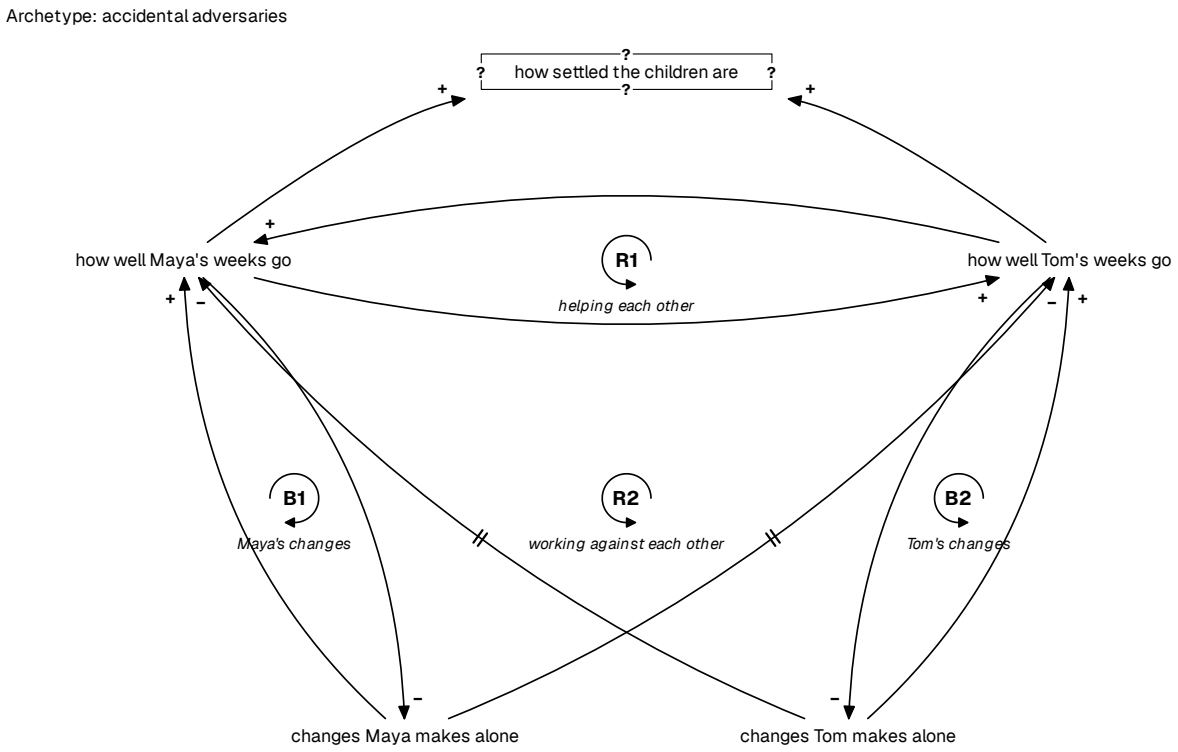
Step by step

1. Weekly target, sessions done and the gap, with a + effect from the target and a – effect from the sessions: Priya's count each Sunday, before she acts on it.
2. A + effect from the gap to the sessions done, delayed by the week before extra sessions fit in, closing B1, extra sessions.
3. A – effect from the gap to the weekly target, closing B2, target lowered: drawn after B1, as Priya lowers her target only after a busy week when she falls short.
4. Eroding goals, declared last: B1 alone is a target worked toward, and B2's lowered target is what makes it erode.

What another defensible answer might vary

Another defensible answer might name the sessions done as the sessions skipped, with the polarity of each effect into and out of it reversed: both loops stay balancing, and the match holds. Or it might draw extra sessions planned between the gap and the sessions done, as a chain of two effects with the delay on either. What stays the same is one gap between the target and the sessions done, two balancing loops through it, and the delay on the loop through the sessions done.

AR 09 Two parents sharing care after a separation



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The better Maya's weeks go, the better Tom's (+), and the better Tom's, the better Maya's (+): R1 is reinforcing. The worse Maya's weeks go, the more changes she makes alone (–), and the more changes, the better her weeks go (+): one – effect, so B1 is balancing, and B2 is Tom's. Each parent's changes make the other's weeks worse, after a delay (–): R2 runs from Maya's weeks through her changes, Tom's weeks and his changes back to Maya's weeks, with four – effects, so it is reinforcing. The declared archetype is accidental adversaries, which the structure matches: each parent's changes ease their own weeks at once and, weeks later, the other's get worse, which brings on the other's changes. How settled the children are, reached from both parents' weeks, is the leverage point: it is the one measure both parents see, and a change that eases one home and unsettles the other shows in it.

Why it works

- R1, the help each parent gives the other, and R2, their changes working against each other, both pass through both parents' weeks
- B1 and B2 are each parent's changes, easing their own weeks
- The delays sit on the effects from each parent's changes to the other's weeks, where the children carry them between homes
- The leverage point is how settled the children are, a measure both parents see

Step by step

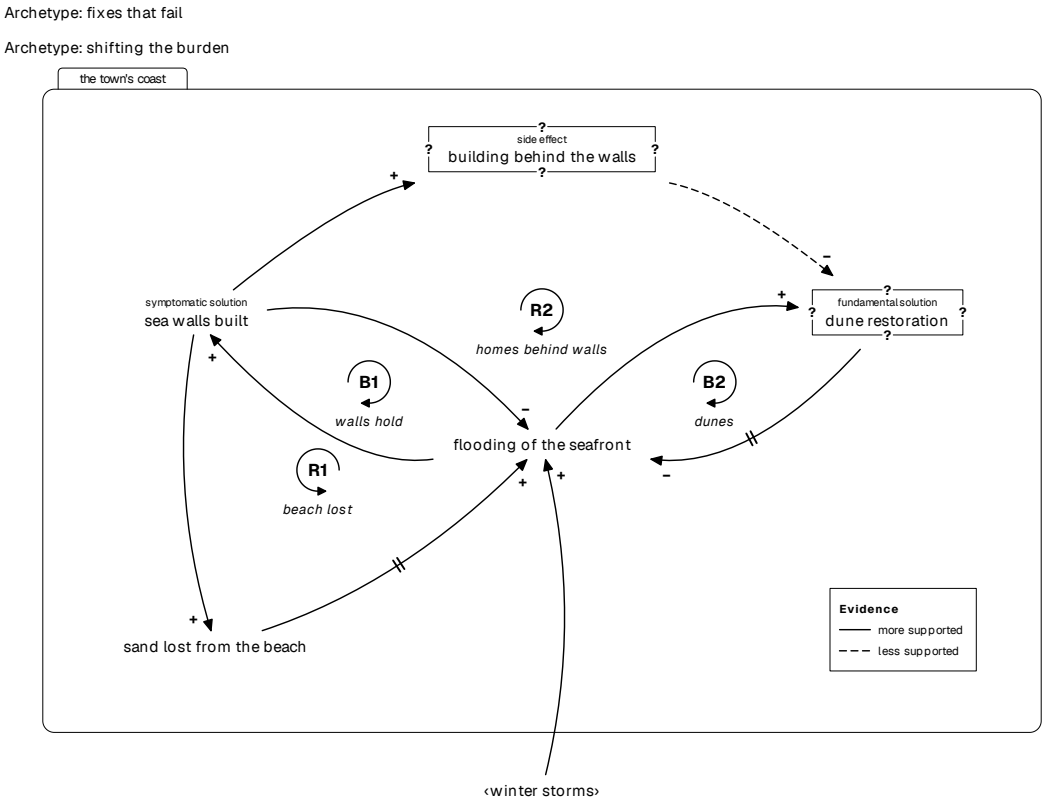
1. How well Maya's and Tom's weeks go, with a + effect each way, closing R1, helping each other: the lifts to football and the shared homework rules the situation starts with.

2. Changes Maya makes alone, with a – effect from her weeks and a + effect back, closing B1, Maya's changes: a new bedtime that eases her own week.
3. Changes Tom makes alone, with the same two effects on his side, closing B2, Tom's changes: a swapped weekend that eases his.
4. A – effect from each parent's changes to the other's weeks, each delayed by the week or two before the children bring them over, closing R2, working against each other.
5. How settled the children are, the leverage point, with a + effect from each parent's weeks: drawn last of the variables, as it is reached from both homes and acts on neither loop.
6. Accidental adversaries, declared last, once R2, the loop the delayed effects close, is drawn.

What another defensible answer might vary

Another defensible answer might draw the two further loops the structure holds, Maya's changes worsening Tom's weeks and so the help he gives her (and Tom's likewise), each reinforcing, or name each parent's weeks as how hard they go, with the polarity of each effect into and out of them reversed: every loop keeps its kind, and the match holds. It might also mark the leverage point on a shared calendar of both homes' rules, drawn as a variable acting on both parents' changes. What stays the same is the help between the two parents' weeks, each parent's changes easing their own weeks, those changes reaching the other's weeks after a delay, and one leverage point.

AR 10 A coastal town and its sea walls



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Winter storms, outside the town's coast, raise the flooding of the seafront (+). The more flooding, the more sea walls built (+), and the more walls, the less flooding (–): one – effect, so B1 is balancing. The more walls, the more sand lost from the beach (+), and the more sand lost, the more flooding, years later (+, with a delay): R1 runs from the flooding through the walls and the sand back to the flooding with no – effect, so it is reinforcing. The more flooding, the more dune restoration (+), and the more restoration, the less flooding, after a delay (–): B2 is balancing. The more walls, the more building behind them (+), and the more building, the less dune restoration (–, coded as a hypothesis): R2 runs from the flooding through the walls, the building and the restoration back to the flooding, with two – effects, so it is reinforcing. B1 and R1 match fixes that fail, with its delay; B1, B2 and R2 match shifting the burden, with its delay. The two archetypes are coupled through the sea walls built and the flooding of the seafront: each wall relieves the flooding at once, loses sand from the beach, and makes the restoration that would last for decades costlier.

Why it works

- The sea walls built are one variable, the symptomatic solution in both archetypes, which share it and the flooding
- The delays sit where the lost sand brings flooding back and where restored dunes lower it, years after each change
- The building's effect on dune restoration is dashed, and the legend shows the coding
- The winter storms act on the flooding from outside the town's coast, and nothing inside acts on them

- Leverage, ranked first: dune restoration, the fundamental solution, which lowers the flooding without losing sand from the beach; its delay of years means it starts long before the flooding it prevents
- Ranked second: building behind the walls, whose limit keeps dune restoration affordable and weakens R2
- The sea walls built are no leverage point: each wall adds to both R1 and R2

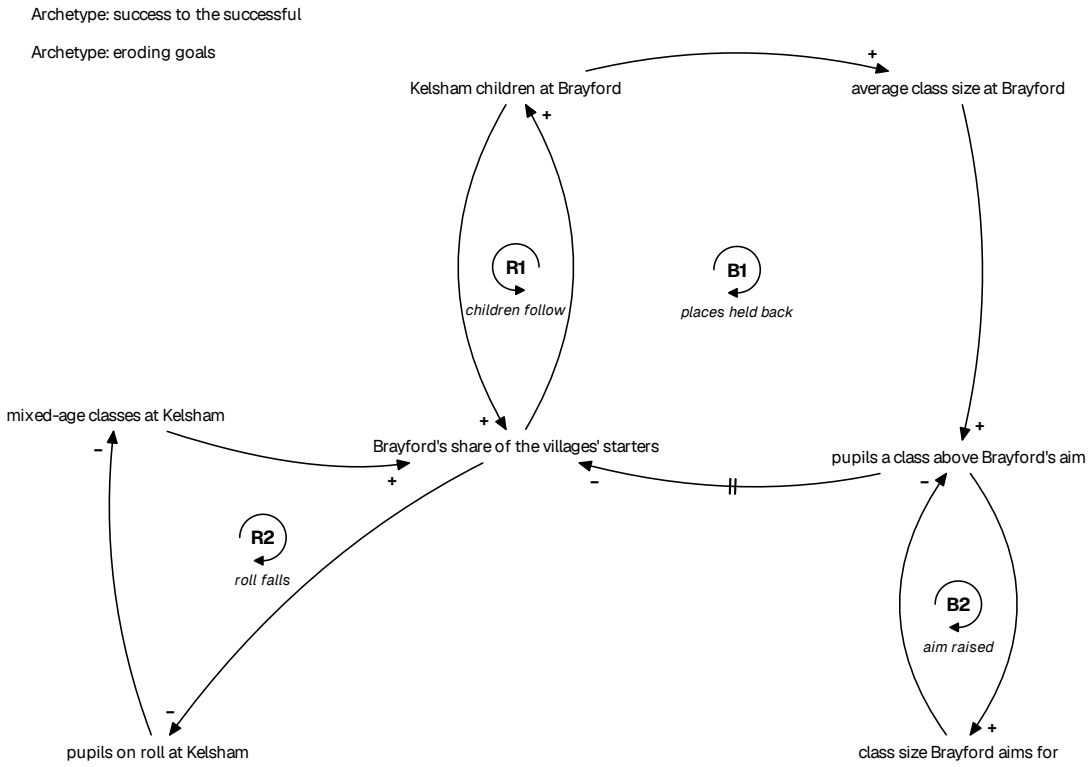
Step by step

1. The town's coast as a boundary, the flooding of the seafront inside it and winter storms outside, with a + effect: the situation opens with the storms that flood the town.
2. Sea walls built, the symptomatic solution, with a + effect from the flooding and a – effect back, closing B1, walls hold: a wall stops the sea at once.
3. Sand lost from the beach, with a + effect from the walls and a + effect to the flooding, delayed by the years before the sea reaches the walls with more force, closing R1, beach lost.
4. Dune restoration, the fundamental solution and a leverage point, with a + effect from the flooding and a – effect back, delayed by the years new dunes take to grow, closing B2, dunes.
5. Building behind the walls, the side effect and the other leverage point, with a + effect from the walls and a dashed – effect, the engineers' hypothesis, to the dune restoration, closing R2, homes behind walls, with the legend for the dashed line.
6. Fixes that fail and shifting the burden, declared last: B1 and R1 matched fixes that fail from step 3, and shifting the burden matched only once B2 and R2 were drawn.

What another defensible answer might vary

Another defensible answer might name the sand lost as the sand on the beach, with the polarity of each effect into and out of it reversed: every loop keeps its kind, and both matches hold. Or it might draw rising sea level beside the winter storms, a second external driver acting on the flooding, or mark the sand lost from the beach as the side effect of fixes that fail. What stays the same is one variable for the sea walls built, shared by both archetypes, the two delays, the building's effect on the restoration coded as a hypothesis, and a ranking written beside the diagram, not drawn.

CS 11 Kelsham Primary School: the town school's pull and its rising class size



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Brayford's share of the villages' starters sits on three of the four loops. The larger the share, the more Kelsham children at Brayford (+), and the more of them, the larger the share (+): R1 is reinforcing. The larger the share, the fewer pupils on roll at Kelsham (–), the more mixed-age classes there (–), and the larger the share (+): two – effects, so R2 is reinforcing too. R1 and R2 match success to the successful, the share as the allocation: Brayford gains what Kelsham loses. The more Kelsham children at Brayford, the larger its average class size (+) and the more pupils a class above its aim (+), which holds places back the next September (–, with a delay): one – effect, so B1 is balancing. The more pupils above the aim, the higher the aim (+), and the higher the aim, the fewer pupils above it (–): B2 is balancing. B1 and B2 match eroding goals with its delay. The two archetypes are coupled through the share and the Kelsham children at Brayford: each rise in the aim closes the gap before B1 holds places back, so the share goes on growing and the pupils on roll at Kelsham go on falling.

Why it works

- Brayford's share of the villages' starters is one variable: the allocation in success to the successful, and on B1's path from the gap to the class size
- R2 has two – effects, an even number, so it is reinforcing
- The gap is a variable of its own, between Brayford's average class size and its aim, named by the pupils above the aim
- The delay sits on the gap's effect on the share: places are held back only from the next September
- B2 is named aim raised: the gap closes without a place held back
- Each rise in the aim lets Brayford take more of the villages' starters, so the pupils on roll at Kelsham fall faster

Step by step

1. Brayford's share of the villages' starters, drawn first: three of the four loops pass through it.
2. Kelsham children at Brayford, with a + effect from the share and a + effect back, closing R1, children follow: brothers, sisters and friends follow the children already there.
3. Pupils on roll at Kelsham and mixed-age classes at Kelsham, with a – effect from the share, a – effect between them and a + effect back to the share, closing R2, roll falls: Brayford's gain seen from Kelsham's side.
4. Average class size at Brayford, with a + effect from the Kelsham children there, then the class size Brayford aims for and the gap, with a + effect from the class size and a – effect from the aim: Brayford compares the two before it acts.
5. A – effect from the gap to the share, delayed until the next September, when places are held back, closing B1, places held back.
6. A + effect from the gap to the aim, closing B2, aim raised: drawn after B1, since the governors raise the aim only after a year above it.
7. Success to the successful and eroding goals, declared last: the first matched from step 3, the second only once B2 was drawn, coupled through the share and the Kelsham children at Brayford.

What another defensible answer might vary

Another defensible answer might name the gap the places left in Brayford's classes, with the polarity of each effect into and out of it reversed: both balancing loops keep their kinds, and the match holds. Or it might draw Kelsham's share of the villages' starters in place of Brayford's, which reverses the polarity of each effect into and out of it and leaves all four loops' kinds as they are. What stays the same is one share on both archetypes, two reinforcing loops through it, two balancing loops through the gap, and the delay on the places held back.

Chapter 12 · Choosing the Diagram

A family of five fills its laundry basket in a day or two. Each evening one parent looks in, and runs a wash if the clothes are above a line marked inside the basket; the machine washes at most one basketful a day. The parents' question: does one look each evening keep the basket from overflowing? Which diagram answers it?

a A feedback control diagram
Yes. The marked line is a target the parents chose, the evening look a measured value, the clothes above the line a gap, the washes run a corrective action, and the clothes in the basket the controlled variable: a stock with roles written above its names. Whether the washing keeps up turns on the reading once a day and the one basketful a day at most.

b A stock & flow diagram
Not quite. The clothes in the basket are a stock, filled as clothes are worn and drained by washes, so this diagram holds half the answer. The marked line and the evening look are a target and a measured value; written above its names as roles, they make it a feedback control diagram.

c A causal loop diagram
Not quite. It would show the loop, more clothes in the basket, more washes, fewer clothes, but not that the clothes accumulate, nor the line the parents chose to keep them under.

d A system context map
Not quite. It would show the household's boundary and what passes across it, such as clothes bought and given away, and nothing inside it, where the basket is.

A causal loop diagram of a town's night buses shows R1, riders → fares collected → buses running → riders, all +, and B1, riders → standing passengers +, standing passengers → riders –. It is opened in an archetype lab and declared limits to growth. What changes in the drawing?

a One line is added: Archetype: limits to growth
Yes. The diagram opens with every variable, effect and loop as drawn. A reinforcing loop and a balancing loop sharing riders match limits to growth, and the declaration is the one line added. Limits to growth has no symptomatic solution, fundamental solution or side effect, so no role is written.

b The variables are redrawn as stocks and flows
Not quite. That conversion is into a stock & flow diagram, by hand, and no archetype is declared on one. In an archetype lab the causal loop diagram's marks stay as they are.

c Roles are written above riders, fares collected and standing passengers
Not quite. Roles are written only where an archetype has them: symptomatic solution, fundamental solution and side effect. Limits to growth has none, so the declaration is the only line added.

d Nothing: the match is listed, so no declaration is written
Not quite. The matches are listed after every change, but a declaration is written by whoever draws the diagram: a hypothesis about its loops, checked against the matches.

A chess club's treasurer is asked three things. Which one can the treasurer answer without a diagram?

a How many weeks until the club's fund, €200 now and €40 added a week, reaches the €680 that new clocks cost
Yes. The answer is one quantity reached by arithmetic, (680 – 200) ÷ 40 = 12 weeks, and a sentence carries it. Nothing comes back around, and no boundary is in question.

b Why more members bring more volunteers to teach beginners, and more teaching brings more members
Not quite. That change comes back around, from members to volunteers to members: a loop, which a causal loop diagram shows with its kind.

c Whom the club deals with, from the hall it rents to the league it plays in, and what passes each way
Not quite. Several parties, each with something passing each way, are what a system context map shows. A list would name the parties and leave out what passes.

QUESTION 1 OF 3

Which question does this part of the slide, drawn as a stock & flow diagram, answer?

a Why people move toward the government or toward the insurgents.
Not quite. One auxiliary sets every flow, attractiveness of the government's path, after a delay. What makes that path attractive is drawn in the slide's other clusters, about a hundred variables left out here.

b How many people hold each of five stances, and how fast they move between neighboring stances.
Yes. Five stocks of people, filled and drained by four flows, each from one stance to the next: what accumulates, and how fast it changes. No one moves from active insurgent supporter to government sympathizer without passing through the fence.

c Whether the coalition's actions shift popular support.
Not quite. No loop closes in the part: no stock reaches attractiveness of the government's path, so no change in support comes back around to the flows. Any action reaches the flows through the slide's other clusters, not drawn here.

QUESTION 2 OF 3

The slide comes from a brief for planning a counterinsurgency: which actions shift popular support toward the government, and how fast. Which drawing would answer that?

a The whole slide, since every variable is on it.
Not quite. About 110 variables and the lines among them are on it, and no path through them can be followed by eye, so it answers no question by itself. The brief's own pages take it a cluster at a time, then one loop at a time.

b An influence map, with popular support as its central outcome.
Not quite. An influence map answers what bears on one outcome before anyone knows which way each acts, and the slide's lines carry no + or –, as a map's influence claims don't. But an influence map has no stock or flow, so it can't show how many people move, or how fast.

c A stock & flow diagram of the five stocks with the few loops through their flows that the plan acts on.
Yes. Support accumulates in stocks of people, and an action shifts it by changing how fast people move, through loops that close back on the flows: chapter 7's stocks inside feedback. Drawn a few loops at a time, each can be followed.

Would a sentence do in place of this part?

a No: five stocks are too many for a sentence.
Not quite. A sentence holds the five in order. What a sentence can't hold is a change coming back around through several variables, and in this part none does.

b No: a sentence can't carry the delays.
Not quite. A sentence carries a delay in words, after a delay, as a behavior note does; the mark adds nothing a reader of the sentence lacks.

c Yes: no loop closes in it, and one sentence holds what it shows.
Yes. People move one stance at a time between active government supporter and active insurgent supporter, toward the government's side as its path grows more attractive, after a delay, and relative support is read from the four stocks off the fence. Nothing comes back around. Joined to the slide's loops, the part would have to be drawn again.

CD 01 Which diagram?

What does Ines draw, or write, to answer her question?

a A system context map
Yes. Whom the team deals with is the parties outside one boundary, the team's, and what passes each way is the exchanges, each a named one-way line between a party and the boundary. Callouts from the police and rescue reports to them are two exchanges, one each way.

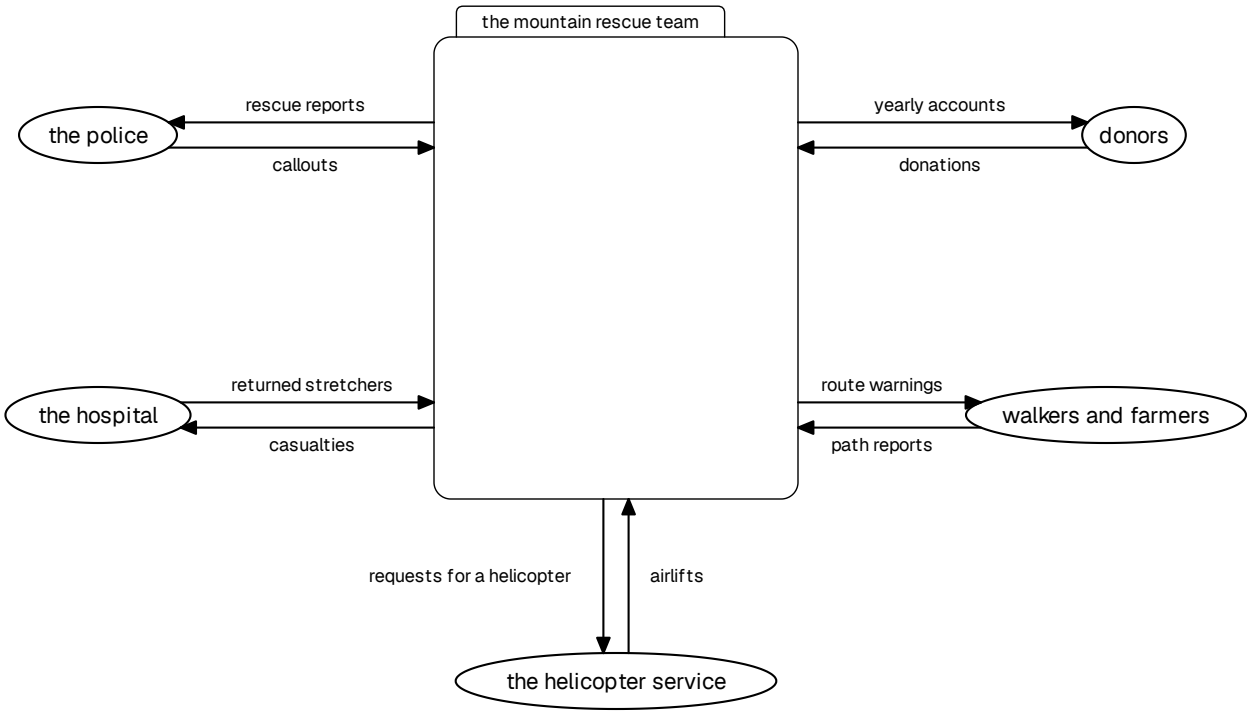
b No diagram: a list
Not quite. A list names the five parties but not what passes each way: the police, on a list, carry neither the callouts they send nor the rescue reports they receive.

c A causal loop diagram
Not quite. A causal loop diagram shows how a change in one variable produces a change in another, and where those changes come back around in loops. Ines is after who sends what to whom, not what changes what.

d An influence map
Not quite. An influence map shows what bears on one outcome, ranked. Ines names no outcome: she is after the parties and what passes between them and the team.

e A stock & flow diagram
Not quite. A stock & flow diagram shows what accumulates and what fills and drains it: money in the team's account, filled by donations. The police, the hospital and the walkers have no place in it.

CD 01 A mountain rescue team



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One boundary, the mountain rescue team, with five parties outside it: the police, the hospital, the helicopter service, donors, and walkers and farmers. Ten named exchanges cross it, one each way with every party: callouts in and rescue reports out; casualties out and returned stretchers in; requests for a helicopter out and airlifts in; donations in and yearly accounts out; path reports in and route warnings out.

Why it works

- One boundary, named for the team, so the volunteers are the system and none of them is drawn as a party
- The helicopter service outside the boundary: the team requests its helicopter and doesn't run it
- Walkers and farmers drawn as one party, since they send the same reports and read the same warnings
- Each exchange names one thing, so callouts and rescue reports are two lines, not one with two arrowheads
- Every party both gives and receives, which a list of the five leaves out

Step by step

1. The mountain rescue team as the boundary, drawn alone: every exchange Ines asks about crosses it.
2. The police, with callouts in and rescue reports out: every rescue starts with their callout.
3. The hospital, with casualties out and returned stretchers in: where each carry down the hill ends.
4. The helicopter service, with requests for a helicopter out and airlifts in: called only for a serious injury or a long carry.
5. Donors, with donations in and yearly accounts out: the money behind the rescues, which reaches the team apart from any callout.
6. Walkers and farmers, with path reports in and route warnings out: exchanges that run between rescues, before any call.

What another defensible answer might vary

Another defensible answer might draw walkers and farmers as two parties, or leave out the returned stretchers. The casualties the helicopter service flies to the hospital pass between two parties outside the team, so no exchange of the team's carries them. What stays the same is one named boundary, the parties outside it, and one thing per exchange.

CD 02 Which diagram?

What does Mateus draw, or write, to answer his question?

a A causal loop diagram
Not quite. A causal loop diagram gives every effect a + or – and shows the loops they close. Mateus can give a + or – only to the salary's effect: drawn there, the other effects would carry guesses as findings, and no loop runs through his wish to move.

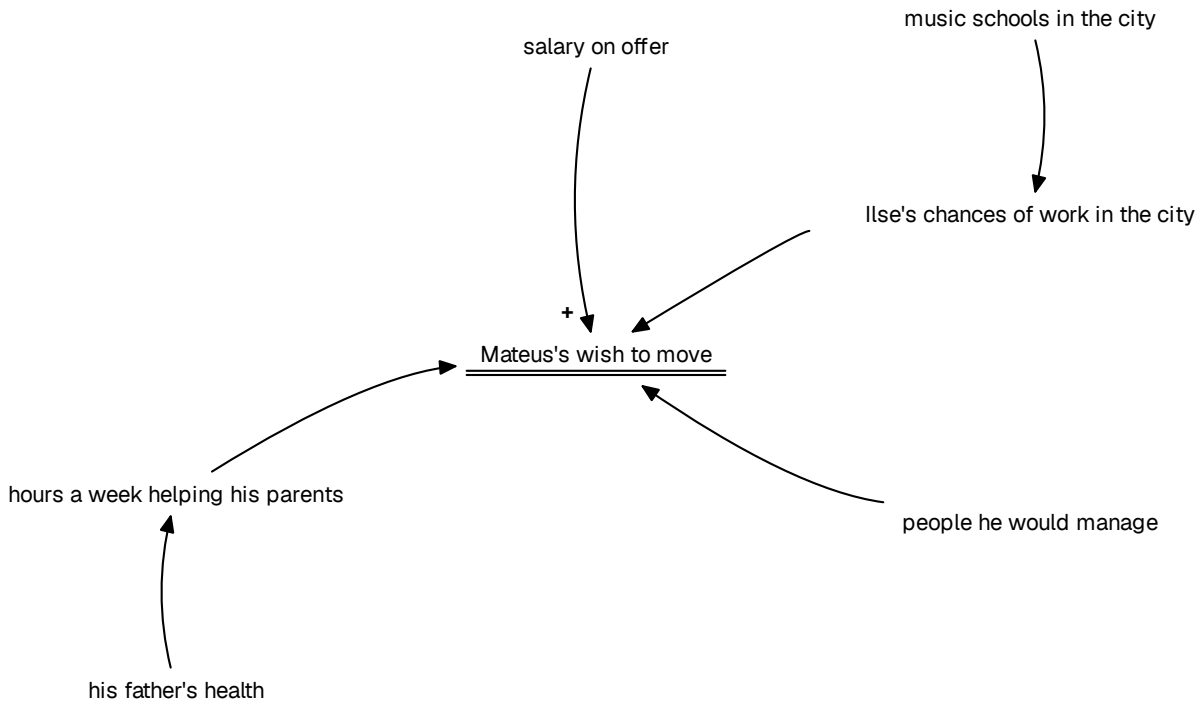
b No diagram: a list
Not quite. A list names the salary, Ilse's chances, the hours with his parents and the team he would lead, but not that the music schools reach his wish to move only through Ilse's chances, or his father's health only through the hours he helps.

c An influence map
Yes. What bears on his wish to move is one central outcome and the variables that act on it. That he can't yet say which way most of them push makes each an influence claim, with no + or –; the salary's claim alone is upgraded, with a +.

d A system context map
Not quite. A system context map shows the parties outside a boundary and what passes each way: Mateus's household, his parents, the new employer. Who sends what to whom leaves out what draws him to the city and what holds him at home.

e A stock & flow diagram
Not quite. A stock & flow diagram shows what accumulates and what fills and drains it: Mateus's savings, filled faster by the higher salary. His question is what bears on one wish, and a wish fills from no flow.

CD 02 Moving to another city for a job



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Mateus's wish to move as the central outcome, with four direct influences: the salary on offer, Ilse's chances of work in the city, the hours a week he spends helping his parents, and the people he would manage. The salary's claim is a causal claim with a +; the other three are influence claims, since he can't yet say which way they push. Music schools in the city reach his wish through Ilse's chances, and his father's health through the hours he helps, each an influence claim too.

Why it works

- One central outcome, a quantity: how strong his wish to move is
- One causal claim, the salary's, the only direction Mateus can say
- The hours with his parents and the team he would lead left as influence claims: each could push either way
- Music schools and his father's health drawn to the variables they act on, not to his wish

Step by step

1. Mateus's wish to move, the central outcome, drawn alone: his question names it, and every claim drawn after ends at it or reaches it.
2. Ilse's chances of work in the city, the hours a week helping his parents and the people he would manage, each with an influence claim on his wish: plain lines, since an influence claim is where every claim starts.
3. Music schools in the city and his father's health, each with an influence claim on the direct influence it acts through, drawn once those are there.
4. The salary on offer, its claim upgraded to a causal claim with a +, drawn last of the claims: a third above what he earns now, it is the pull Mateus is sure of.

What another defensible answer might vary

Another defensible answer might add rent in the city, or draw Ilse's wish to move as a variable of its own between her chances and his wish. What stays the same is one central outcome, Mateus's wish to move, one causal claim, the salary's, and every other claim an influence claim.

CD 03 Which diagram?

What does Halima draw, or write, to answer her question?

a A causal loop diagram
Not quite. A causal loop diagram shows that more emissions bring more carbon dioxide in the air, a + effect, but not that the carbon dioxide accumulates. Read as an effect, steady emissions give steady carbon dioxide, which is wrong here.

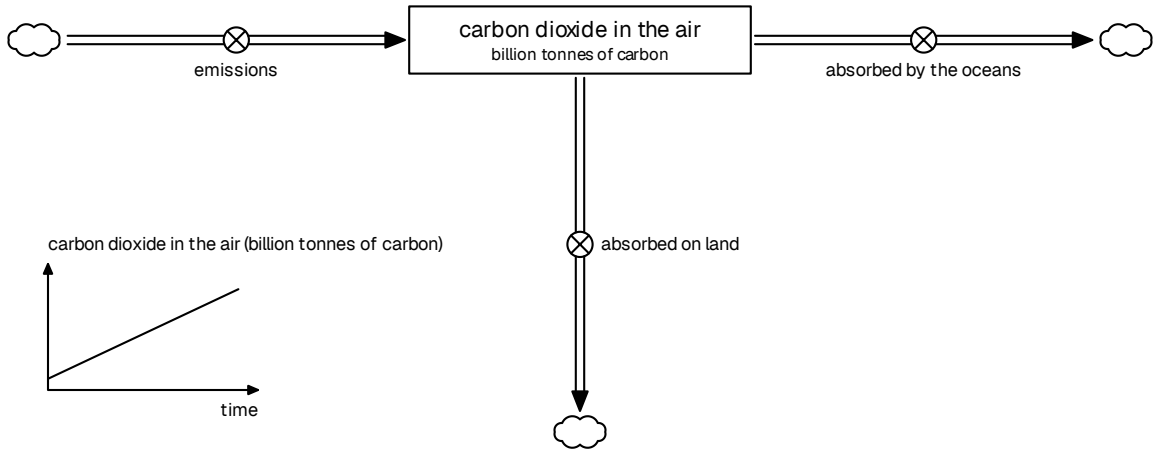
b A stock & flow diagram
Yes. Whether the carbon dioxide in the air stops rising is a question about how an amount changes over time: it is a stock, filled by emissions and drained by what the oceans and vegetation on land absorb. Holding emissions steady fixes the inflow, not the stock: with about 11 in and about 5 out each year, the stock goes on rising.

c No diagram: a sentence
Not quite. The sentence is what Halima writes once the stock is drawn: while emissions exceed what the oceans and vegetation on land absorb, the carbon dioxide in the air rises. Without the stock, most adults Sterman and Booth Sweeney tested expected it to hold steady once emissions did.

d An influence map
Not quite. An influence map shows what bears on one outcome, ranked. What bears on the carbon dioxide in the air is known here: emissions and what is absorbed. Halima's question is how much of it there is as the years pass.

e A feedback control diagram
Not quite. A feedback control diagram shows a target, a measured value and a correction that closes the gap between them. Nothing here holds the carbon dioxide in the air to a target; Halima's question is what steady emissions do to it.

CD 03 Carbon dioxide in the atmosphere



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One stock, carbon dioxide in the air, counted in billion tonnes of carbon, filled from a cloud by emissions and drained to two clouds by what the oceans and vegetation on land absorb. The time unit is a year, so each flow is counted in billion tonnes of carbon a year. Held steady, emissions of about 11 still exceed the about 5 absorbed, so the stock gains about 6 a year: it goes on rising, and stops rising only when emissions fall to what is absorbed.

Why it works

- The carbon dioxide in the air is the stock: an amount there at any moment, changed only by its flows
- Emissions held steady fix the inflow, not the stock, which rises while the inflow exceeds the outflows
- One outflow for the oceans and one for vegetation on land, each to a cloud outside what the model holds
- The graph rises: Halima's answer is no

Step by step

1. Carbon dioxide in the air, the stock, counted in billion tonnes of carbon, drawn first: Halima asks how much of it there will be as the years pass.
2. Emissions, the inflow, from a cloud: about 11 billion tonnes of carbon a year, which Halima supposes will hold steady.
3. Absorbed by the oceans and absorbed on land, two outflows to clouds, about 3 and 2 billion tonnes a year: drawn after the inflow, to be set against it.
4. The behavior-over-time graph of the stock, drawn last, since its shape follows from the flows: a straight line rising while they hold as they are.

What another defensible answer might vary

Another defensible answer might draw one outflow for what the oceans and vegetation on land absorb together, or a graph that rises and flattens, taking the oceans and vegetation to absorb more as the carbon dioxide in the air rises. What stays the same is one stock, emissions flowing in, at least one outflow, the time unit a year, and a graph that rises.

CD 04 Which diagram?

What does their father draw, or write, to answer his question?

a A causal loop diagram
Not quite. A causal loop diagram shows the two reinforcing loops through Noor's share of the turns, and no archetype. The same loops drawn there and opened in an archetype lab, with the archetype they match declared, are the diagram that answers whether others have seen this story.

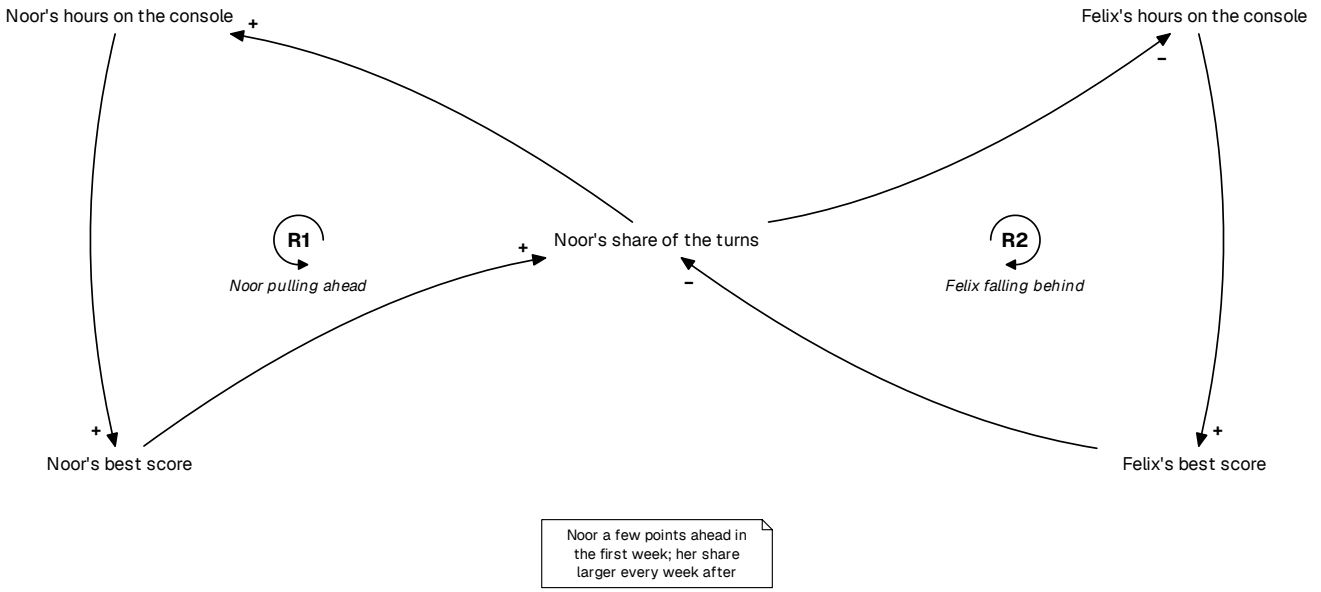
b An influence map
Not quite. An influence map shows what bears on one outcome, its directions left open until measured. The father's rule fixes every direction here, and the effects close two loops, which no one declares on an influence map.

c A system archetype
Yes. The father asks after a recurring loop structure with a name: a story others have seen, and how it usually runs. The two reinforcing loops, one through each child's hours, share Noor's share of the turns, and that structure matches an archetype, declared in one line; how the split usually runs is that archetype's known course.

d A stock & flow diagram
Not quite. A stock & flow diagram shows what accumulates and what fills it, such as each child's hours played. The father's question is whether the two loops through the split are a story with a name, which no stock or flow carries.

e No diagram: a sentence
Not quite. A sentence states the father's rule and Noor's lead in the first week. Whether the story recurs elsewhere is read from its loops: two reinforcing loops through one split, matched to an archetype.

CD 04 Two siblings and one games console



Archetype: success to the successful

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Noor's share of the turns sits on both loops. In R1, a larger share gives Noor more hours on the console (+), more hours a higher best score (+), and a higher score a larger share (+). In R2, a larger share for Noor gives Felix fewer hours (–), fewer hours a lower best score (+), and a higher score for Felix a smaller share for Noor (–): two – effects, so R2 is reinforcing too. The father declares success to the successful, which the structure matches with the share as the allocation: which child ends ahead depends on who started ahead as much as on what each could do with an equal share, so Noor's lead of a few points grows every week.

Why it works

- The father's rule is one variable, Noor's share of the turns, so both loops pass through it
- Each child's hours on the console sit between the share and that child's score, a chain the archetype's match allows
- R2 has two – effects, an even number, so it is reinforcing
- The declaration names the archetype in one line, which a causal loop diagram of the same loops lacks
- The note names Noor's first-week lead and its growth

Step by step

1. Noor's share of the turns, drawn first: it is the father's rule, set each Sunday, that both children's play depends on.
2. Noor's hours on the console and her best score, with three + effects from the share through both and back to it, closing R1, Noor pulling ahead: the child the rule favors from the first week.
3. Felix's hours and best score, with a – effect from the share, a + effect to his score and a – effect back, closing R2, Felix falling behind: the father's rule seen from Felix's side.
4. The behavior note under the share, written once both loops are drawn: the week-by-week course the father asks about.

5. Success to the successful, declared last in one line: the name of the story the father asks after, given once the loops it names are drawn.

What another defensible answer might vary

Another defensible answer might draw Felix's share of the turns instead, which changes the polarity of every effect into and out of it and leaves both loops reinforcing, or draw each score straight to and from the share, leaving out the hours. What stays the same is one variable for the split, two reinforcing loops through it, and success to the successful declared.

CD 05 Which diagram?

What does Ruth draw, or write, to answer her question?

a A stock & flow diagram

Not quite. A stock & flow diagram shows the water in the stretch, the water from the hill lake and the water drawn by the locks: the same stock and flows a feedback control diagram of the stretch holds, without its roles. With no target, gap or corrective action written, it shows neither the depth Ruth holds the stretch to nor that her morning reading arrives late.

b A causal loop diagram

Not quite. A causal loop diagram shows the balancing loop through the depth and the water let in, but not what accumulates, nor which variable is the target and which the reading. Ruth's question turns on both.

c A system context map

Not quite. A system context map shows the parties outside the canal, such as boaters and the lake's owners, and what passes each way. It leaves out how the depth is held, and where that falls short.

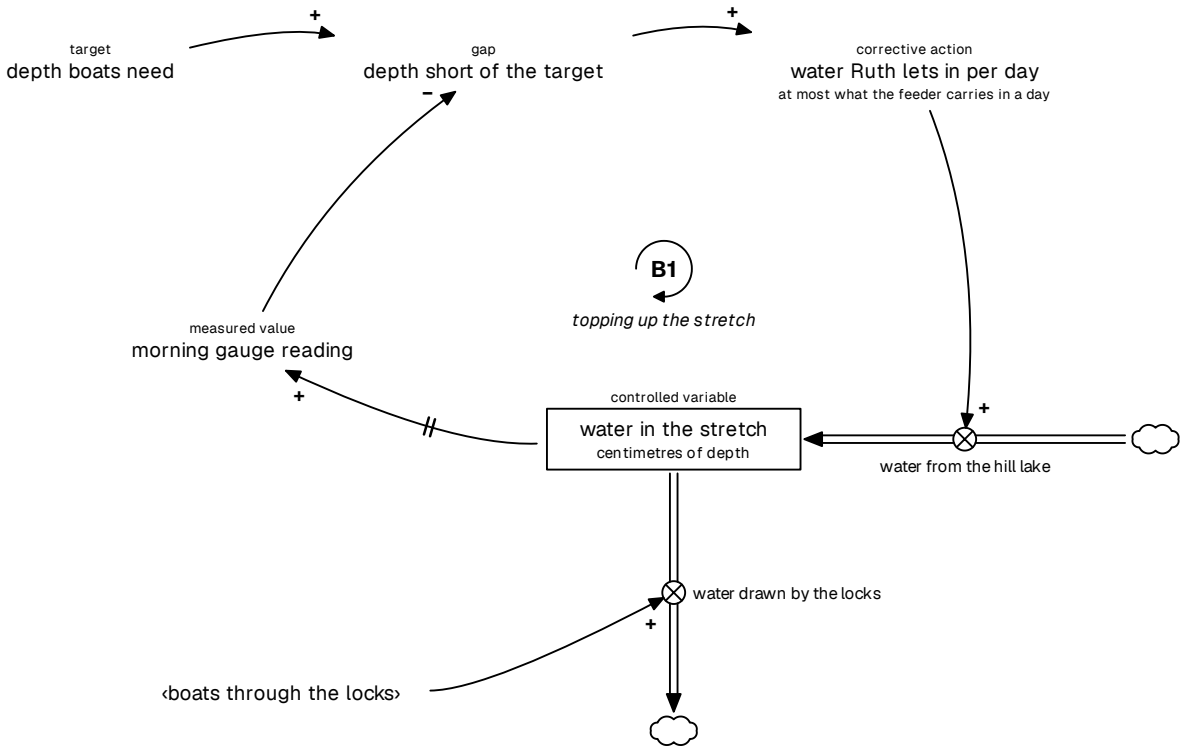
d A feedback control diagram

Yes. Ruth holds the stretch at the depth boats need: that depth is a target, and her morning reading a measured value, up to a day behind the water in the stretch. The gap between them sets the water she lets in, which the feeder limits: one control loop, its roles written over the stretch's stock and flows.

e No diagram: a sentence

Not quite. A sentence states Ruth's rule: the further the depth reads below what boats need, the more water she lets in. Where that falls short, between one morning's reading and the next and at the feeder's limit, shows on the loop drawn with its delay and its limit.

CD 05 A canal through a dry summer



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One stock, water in the stretch, counted in centimetres of depth: the controlled variable. Water from the hill lake fills it from a cloud and water drawn by the locks drains it to a cloud, both in centimetres a day. Depth short of the target is the gap, read from the depth boats need (+) and the morning gauge reading (–); it sets the water Ruth lets in per day (+), at most what the feeder carries in a day, whose signal reaches the valve of water from the hill lake (+). The reading follows the water in the stretch with a delay, one reading a morning. B1 has one – step, so it is balancing. Boats through the locks act at the valve of water drawn by the locks. A busy day of boats lowers the stretch between readings, and when the locks draw more in a day than the feeder carries, the stretch falls however large the gap.

Why it works

- The target, the depth boats need, has no signal into it: Ruth sets it
- The once-a-morning reading is a delay between the water in the stretch and the reading: the return path
- What the feeder carries in a day is written as the limit beneath the water Ruth lets in
- The boats act on the controlled variable at the valve of water drawn by the locks, never on the gap
- The one – step, from the reading to the gap, makes the loop balancing

Step by step

1. Water in the stretch, the controlled variable, a stock counted in centimetres of depth: the amount Ruth keeps deep enough for boats, drawn first.
2. Morning gauge reading, the measured value, with a + signal from the water in the stretch, delayed: water drawn at noon shows on the board only the next morning.

3. Depth boats need, the target, and depth short of the target, the gap, with a + signal from the target and a – signal from the reading: what Ruth works out each morning.
4. Water Ruth lets in per day, the corrective action, limited by what the feeder carries in a day, with a + signal from the gap and a + signal to the valve of water from the hill lake, the inflow, closing B1, topping up the stretch.
5. Boats through the locks, an external driver, with a + signal to the valve of water drawn by the locks, the outflow: drawn last, as what Ruth's loop has to keep up with, dozens of boats on a busy day.

What another defensible answer might vary

Another defensible answer might count the water in cubic metres, with the target and the reading in cubic metres too, or add evaporation as a second outflow in a dry summer. What stays the same is one stock with water from the hill lake flowing in and water drawn by the locks flowing out, one balancing control loop with the target off it, a delay on the morning reading, and the feeder's limit on the water Ruth lets in.

CS 12 Which diagram?

What does David Brennan draw, or write, to answer his question?

a A causal loop diagram
Not quite. In a causal loop diagram, homes lived in at Mill Lane → pupils on roll is a + effect, which reads as more homes, more pupils for good. The homes bring their 15 children once, as they are first lived in; whether the roll goes on falling afterwards turns on what fills it and what drains it each year.

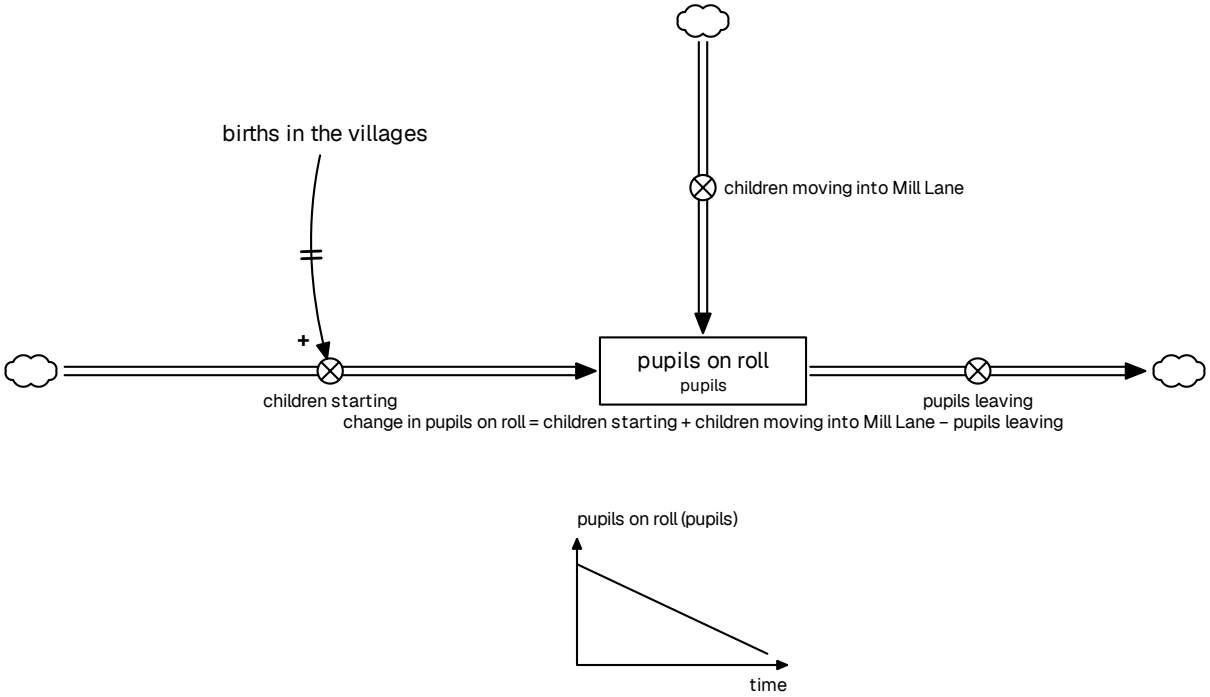
b A stock & flow diagram
Yes. Whether the roll goes on falling is a question about how an amount changes over the years: the pupils on roll are a stock, filled by the children starting and the children moving into Mill Lane, and drained by the pupils leaving. The inflow from Mill Lane stops once the last home is lived in, and the children starting, fewer than the births four years before, are fewer each year than the pupils leaving.

c An influence map
Not quite. An influence map shows what bears on one outcome, ranked, its directions left open. Here every direction is known: the births, the homes and the pupils leaving each fill or drain the roll. David Brennan's question is how many pupils are left as the years pass.

d A feedback control diagram
Not quite. A feedback control diagram shows a target, a measured value and a correction that closes the gap between them. Nothing here holds the roll to a target; the question is where the roll goes once the homes are lived in.

e No diagram: a sentence
Not quite. The sentence is what David Brennan writes once the roll is drawn as a stock: after 2029 only the children starting fill it, and fewer start than leave each year, so it goes on falling. Without the stock, Tom Hale's reading, that the homes turn the roll around, goes unchecked.

CS 12 Kelsham Primary School: the council's question



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One stock, pupils on roll, counted in pupils, a year at a time. It is filled from clouds by the children starting each September, set by the births in the villages four years before through a delayed signal, and by the children moving into Mill Lane, 15 in all from 2027 to 2029; it is drained to a cloud by the pupils leaving. Once the last home is lived in, the inflow from Mill Lane stops, and the children starting, fewer than the 11 or 12 born each year since 2023, are fewer than the pupils leaving, 16 in the year to October 2026: the stock goes on falling. David Brennan's answer is yes: the homes slow the fall while they fill, and don't turn the roll around.

Why it works

- The pupils on roll are the stock: an amount there each October, changed only by its flows
- The Mill Lane homes fill the roll only while they are first lived in, 15 children in all, and not after
- The births set the children starting four years later through a delayed signal, so the starters to 2029 are known now
- The graph falls: once the homes are lived in, fewer children start than pupils leave

Step by step

1. Pupils on roll, the stock, counted in pupils with its stock equation, drawn first: David Brennan asks how many there will be as the years pass.
2. Children starting, an inflow from a cloud: each September's starters, 9 in the year to October 2026.
3. Births in the villages, with a + signal to the children starting, delayed by the four years before a child starts: the births to 2025 set the starters to 2029.

4. Children moving into Mill Lane, a second inflow from a cloud: 15 in all, as the 60 homes are first lived in from 2027 to 2029.
5. Pupils leaving, the outflow to a cloud, drawn after both inflows to be set against them: 16 in the year to October 2026.
6. The behavior-over-time graph of the stock, drawn last, since its direction follows from the flows: falling once the last home is lived in.

What another defensible answer might vary

Another defensible answer might draw the homes lived in at Mill Lane as an auxiliary with a signal to the children moving into Mill Lane, or the pupils leaving as two outflows, for secondary school and for Brayford Primary School. Or its graph might fall and flatten, as smaller years reach Year 6 and fewer pupils leave. What stays the same is one stock, two inflows, one outflow, the births' delay, and a graph that falls once the homes are lived in.