

LESSON 2 · 14 OCTOBER 2026

Applied Systems Sciences 1

Systems, feedback and emergence

Why do fish stocks collapse, even when no fisher wants them to?

David Maier

Department of Environmental Systems Sciences

University of Graz

Last week your choices made the teams

Today your choices share a lake

Why do fish stocks collapse, even when no fisher wants them to?

- 1 **What happens?** We fish a lake together.
- 2 **What was that?** A system.
- 3 **Why did it go that way?** Feedback and emergence.

You are a fisher

You share a small lake with about three others, chosen at random

1 Catch

In every round, choose on your phone how many fish you catch: 0 to 5.

2 Regrow

After each round, the fish left in your lake **double**, up to 6 per fisher: 24 in a lake of four. An empty lake stays empty.

3 Your goal

The game has **8 rounds**. Catch as many fish as you can over all of them.

Your phone shows your lake's number and its fish. You don't see what the others chose.

Our lakes

The game runs in the live session: every student fishes on their phone, and each lake's stock appears here round by round.

Why did you catch as many fish as you did?

One sentence: what did you think about when you chose your catch?

Why I caught as many fish as I did

For example: what you expected the others to do, what you saw in the lake, what you wanted to achieve.

What was that? A system

“A system is an interconnected set of elements that is coherently organized in a way that achieves something.”

Meadows (2008)

Elements

You, the fish, the lake.

The easiest part to see, and not what explains the curve.

Interconnections

Your catch, the regrowth, the stock everyone saw.

Change them and the curve changes.

Function

What the system did: turned a lake into catches, round by round.

Visible in its behaviour, not in anyone's plan.

Meadows (2008), Ch. 1 · Mobus & Kalton (2015), Ch. 1

Where does our lake end?

Inside our game

You, the fish, the rules of catching and regrowth.

Outside, for now

The price of fish, fishing rules, other lakes, your need for income, the weather.

The boundary depends on the question. To ask “would a fishing quota help?”, the rules move inside.

“The delineation between social and natural systems is artificial and arbitrary.” Berkes & Folke (1998)

Our lake was a **social-ecological system**: people and fish, changing each other.

Mobus & Kalton (2015), Ch. 1 · Biggs et al. (2022), Ch. 1, pp. 4 to 5

Why not study the parts?

A fish biologist

Knows exactly how fast the fish regrow.

Can't tell how much you will catch.

An economist

Knows that each of you wants a big catch.

Can't tell what that does to the lake.

Our curve came from **both, interacting**. Taking the system apart loses exactly what we want to explain.

What drives the fish stock?

Send **up to three causes and their effects** you noticed in our lake, one at a time. Say whether each effect goes up or down.

For example: “The fewer fish are left, the more I want to catch now.”

One cause and its effect

Why did it go that way? Feedback

B Balancing

Fewer fish → more room to regrow → more fish

R The race

“If I don't catch them, someone else will” → more catches → fewer fish → more reason to catch now

R The collapse

Few fish → few new fish → even fewer fish

Meadows (2008), Ch. 1 and 2

Nobody chose the result

Same rules, same kind of people: some lakes survived, some didn't. An outcome is **emergent** when it

- ① is not simply the sum of the individuals' properties,
- ② is a different type of result than individual decisions,
- ③ cannot easily be predicted from the individuals.

Could anyone have predicted which lakes would survive? Keep that question in mind.

Railsback & Grimm (2019), Ch. 8.1

Emergent or imposed?

Back to our lakes.

Imposed means: forced by the rules of the game, directly and predictably.

Which of these did the rules impose, rather than your choices produce?

1. That nobody could catch more than 5 fish per round
2. Which lakes survived
3. How many fish each lake had after round 3
4. Who caught the most fish

Railsback & Grimm (2019), Ch. 8.1

Our lake is a complex adaptive system

Relational

Each lake's fate came from how catches and regrowth interact.

Adaptive

You changed your catch after seeing the lake.

Non-linear

12 fish refill a lake; 4 fish barely recover.

Open boundaries

Prices, rules, other lakes: where we stop is our choice.

Context dependent

A catch of 5 is harmless in a full lake and fatal in a nearly empty one.

Emergent

Same rules, different lakes: nobody chose the result.

Preiser et al. (2018), in Biggs et al. (2022), Ch. 1, pp. 5 to 6, and Ch. 2

Does this only happen with fish?

Simulated people choosing where to live

Two groups of households on a grid.
Each household is **content** as long as at least **30%** of its neighbours are like it.
Otherwise it moves to a random empty place.

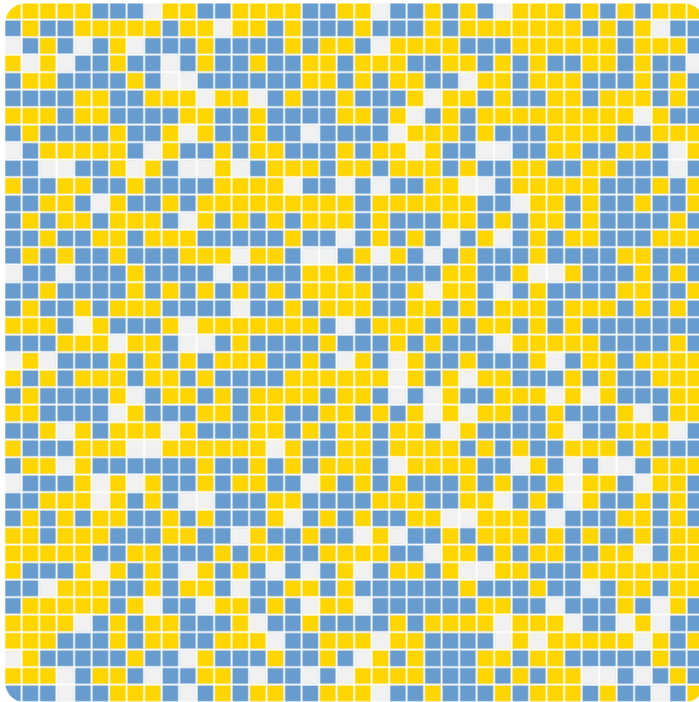
Nobody minds being in the minority. What will the neighbourhood look like after a while?

Schelling (1971)

What pattern do you expect after a while?

1. Mixed, roughly like the start
2. Somewhat clustered
3. Strongly segregated
4. Constantly changing, no stable pattern

Schelling's segregation model



Content if at least **30%** of neighbours are alike



▶ Run

Step

New start

49%

similar neighbours on average

261

households want to move

0

rounds

Schelling (1971) · Sakoda (1971) · one of the first agent-based models, Schlüter et al. (2022), Ch. 28

Does it need people at all?

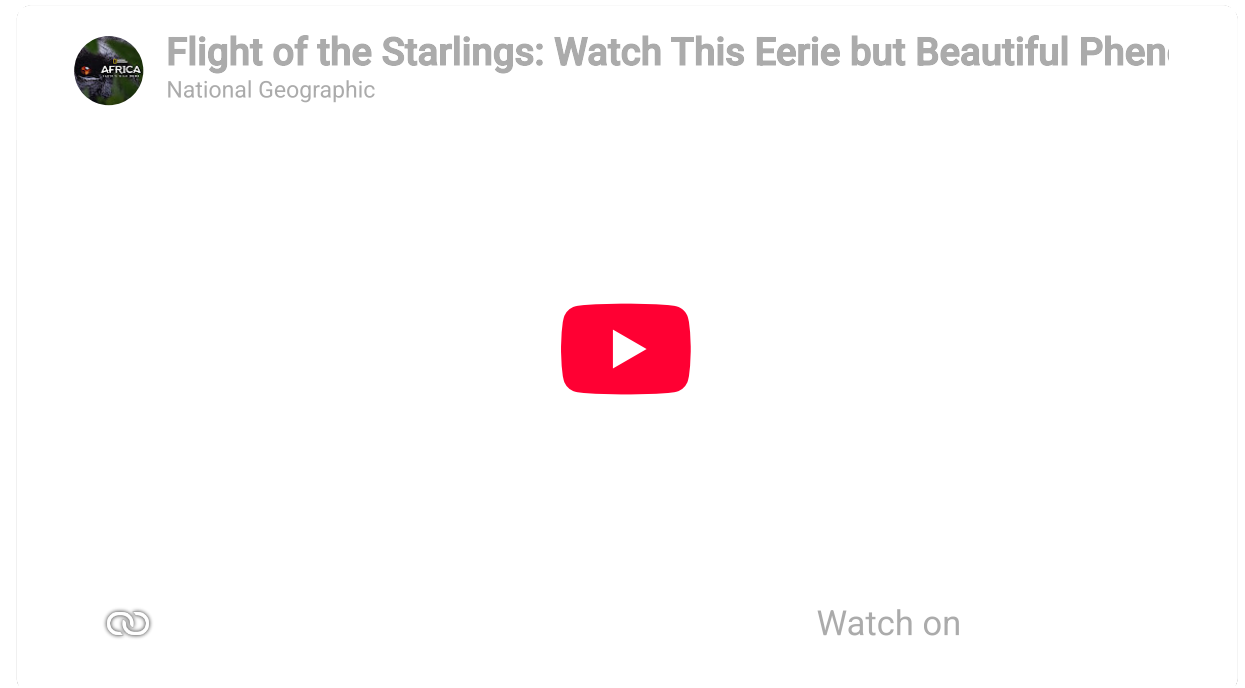
Starlings: three rules, no leader

Each bird only watches its nearest neighbours:

- ① **Align:** fly in the same direction.
- ② **Cohere:** move towards them.
- ③ **Separate:** keep a minimum distance.

No bird knows the shape of the flock.

Reynolds (1987) · Railsback & Grimm (2019), Ch. 8



Does it even need living things?

Conway's Game of Life (1970): four rules for cells on a grid

Each cell is alive or dead. In every step:

- 1 A live cell with 2 or 3 live neighbours survives.
- 2 With fewer than 2, it dies of loneliness.
- 3 With more than 3, it dies of overcrowding.
- 4 A dead cell with exactly 3 live neighbours comes alive.

No choices, no chance: everything is fixed by the rules.

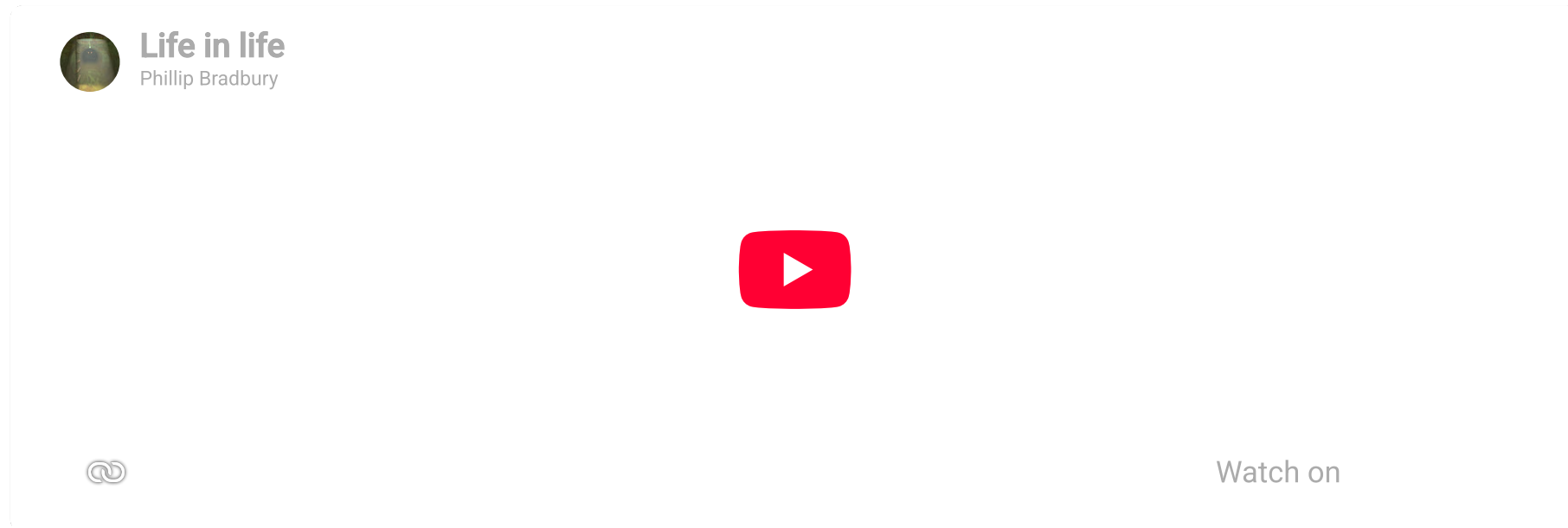


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Watch on YouTube

Knowing the rules is not knowing the outcome

The Game of Life simulates itself



Four rules that can compute anything. In general, nobody can tell what a pattern will do without **running it.**

Why do fish stocks collapse, even when no fisher wants them to?

- 1 Fishers and fish form one **social-ecological system**.
- 2 **Feedback** ties every catch to the next: the fewer fish, the stronger the race.
- 3 The collapse **emerges** from many reasonable choices; some lakes escape it, and nobody chooses which.

So how could we find out what saves the lake?

Next: Thursday 15 October · 08:30 to 09:45 · SR 35.K1 · models, agent-based models and LLMs, then the setup clinic

One rule to save the lake

Name **one rule** that could have saved our lake. Why would it work?

My rule, and why it would work

One or two sentences. It stays anonymous.

Before lesson 3: read about agent-based models

Read

Chapter 28, Agent-based modelling, in *The Routledge Handbook of Research Methods for Social-Ecological Systems* (Biggs et al., 2022), pp. 383 to 389. On Moodle.

About 30 minutes. Read it with our lake in mind.

Then write on Moodle

A short reflection (about 150 words), before lesson 3:

1. What does the chapter say an ABM is good for that an equation is not?
2. Which part of our lake game would you model as an agent, and why?
3. One thing you did not understand.

This is one of the four reading assignments; each reflection is worth 3 points of your participation grade.

Sources for this lesson

Biggs, R. et al. (eds., 2022). *The Routledge Handbook of Research Methods for Social-Ecological Systems.*

Biggs et al., Ch. 1: what SES are, Berkes and Folke, the six properties of complex adaptive systems. Schlüter et al., Ch. 28: reading assignment.

Railsback, S. F. & Grimm, V. (2019). *Agent-Based and Individual-Based Modeling: A Practical Introduction.* 2nd ed.

Ch. 8.1: emergence.

Meadows, D. H. (2008). *Thinking in Systems: A Primer.* Ch. 1 and 2.

Schelling (1971) · Reynolds (1987) · Mobus & Kalton (2015), Ch. 1