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?

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Key dates

Session	Date	What
6	Thu 05 Nov	**Quiz 1**
7	Thu 12 Nov	Project topics published, allocation opens
9	Thu 26 Nov	Project kick-off
11, 12	Thu 10 and 17 Dec	Presentations of preliminary work (P1)
14	Thu 14 Jan	**Quiz 2**
16, 17	Thu 28 Jan, 08:30 and 10:00	Final presentations (P2)

Winter break between sessions 12 and 13.

How you are assessed

Five parts, 100 points in total

Part	Points
Quiz 1: basics	15
Quiz 2: analysis and LLMs	14
Group project	40
Individual final report	15
Participation	16

Grade	Points
1 (Excellent)	89 to 100
2 (Good)	77 to 88
3 (Satisfactory)	65 to 76
4 (Sufficient)	51 to 64
5 (Fail)	0 to 50

All points are added up: a weak part can be made up by the others.
One condition: the two quizzes together need at least 14 of their 29 points.

Quizzes and participation

15 + 14 points

Two quizzes

- On Moodle at the start of the session.
- Multiple choice and short open questions.
- Individual work. Closed book, no AI assistance.
- Quiz 1 covers sessions 1 to 5, quiz 2 sessions 6 to 13.

16 points

Participation

- Active contributions in sessions and on Moodle.
- Four assignments on Moodle, 3 points each.
- Several sessions start with coding questions: correct answers earn points (modalities will be explained later).

Took part? Come to me at the end of the session and I award you the points.

The group project

40 points, groups of 4 to 5

20 points

Model and code

A GitHub repository with working, documented code. Research question and approach count.

10 points

Final presentation

10 to 15 minutes plus 5 minutes of discussion. Sessions 16 and 17.

10 points

Group report

5 to 10 pages: question, methods, results, discussion.

Topics come from a given list and are allocated online before the kick-off in session 9. You present your preliminary work in session 11 or 12 (P1).

Individual report and AI tools

15 points

Individual final report

- 3 to 4 pages: your learning progress, your contribution to the group, your use of AI tools, and feedback on the course.
- It should be written by hand.
- Everyone submits their own PDF on Moodle. The deadline will be announced.

AI tools encouraged

Use them, and say how

- GitHub Copilot, ChatGPT and similar tools are allowed for ideas, code, texts and research.

You are responsible for correctness and for understanding your code. In the final presentation, I ask oral questions about it.

Attendance and staying connected

Attendance

- Attendance is **compulsory** in a proseminar.
- I will not check it as long as enough people come. If attendance drops, that changes.
- If you have to miss sessions, talk to me, a substitute assignment is possible.

Materials and communication

- Moodle: announcements, materials and the forum.
- Course website: slides, PDFs and cheatsheets.
- david.maier@uni-graz.at, office hours by appointment.

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 that way?

Feedback and emergence.

You are a fisher

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

0 to 5 fish

Catch

In every round, you choose how many fish you catch.

× 2 until the lake is full

Regrow

The fish left in your lake double. A full lake holds 6 fish per fisher: 24 in a lake of four.

8 rounds

Your goal

Catch as many fish as you can over all of them.

Your lake starts full. You see its fish, not what the others chose.

Our lakes

The game runs in the live session. Every student fishes on their own device, and the fish in each lake appear 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?

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

Why I caught as many fish as I did

Our reasons

In class, the answers appear here, grouped into themes.

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)

> *"Put simply, a system is a set of complementary, interrelated parts that does something as a whole that its parts can't do on their own."* Sillitto (2021)

Elements

The parts you can identify.

You, your lake mates and the fish.

Interconnections

How the parts affect each other.

Catches take fish out, the rest regrow, and your lake mates fish the same stock.

Function

What the system does, which can differ from what anyone wants.

Turned fish into catches, round by round.

Where does our lake end?

Inside our game

You and your lake mates, the fish, the catch limit and the regrowth.

Outside, for now

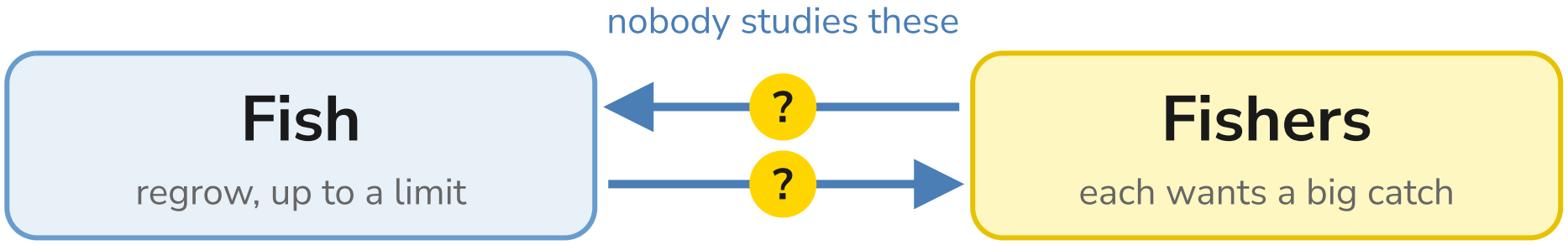
A regulator and a quota, the price of fish, other lakes, your need for income, the weather.

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

> *“Value-laden choices of what to include, and where the boundaries need to be articulated, are always involved and have consequences for how we understand the system.”* Sitas et al. (2022)

Our boundary holds people and fish together: a **social-ecological system**.

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?

What do the arrows between fish and fishers carry?

Think of a round after which your lake had fewer fish than before.

When your lake got emptier, what did you do?

1. I took more, before the fish were gone
2. I took less, to leave some fish
3. The same as before
4. My lake never got emptier

Why did it go that way? Feedback

B Restraint

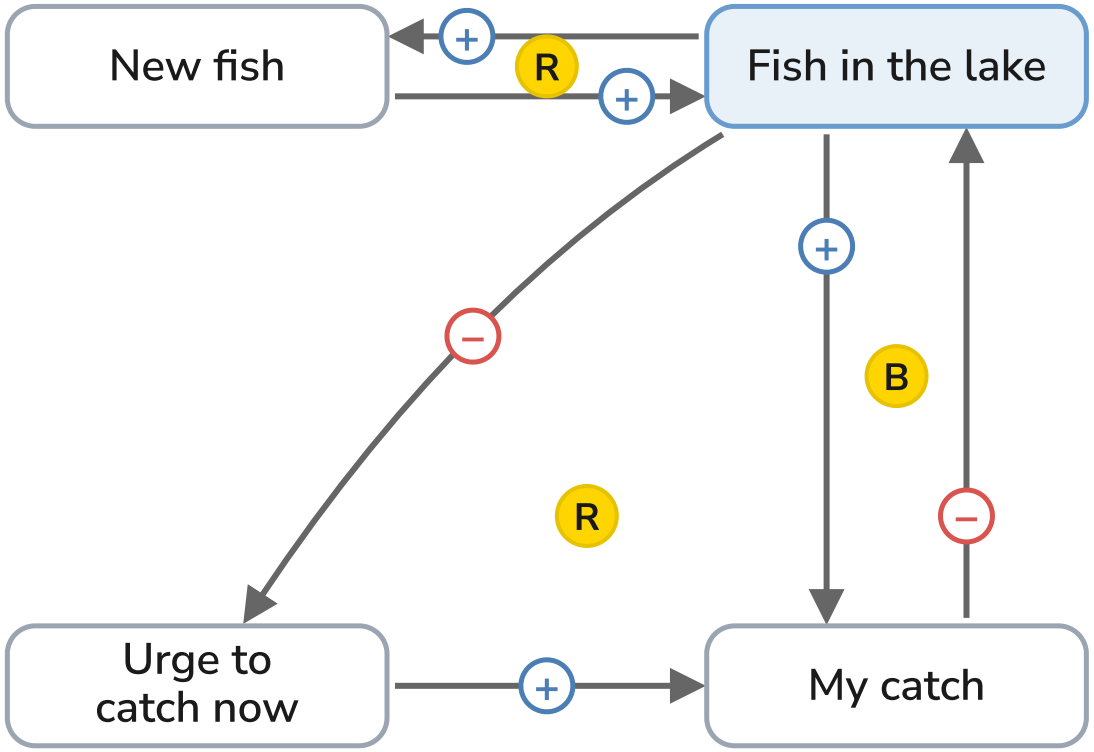
Fewer fish → I take less → more fish

R The race

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

R The collapse

Few fish → few new fish → even fewer fish



\+ moves the same way, – the opposite way

R is a reinforcing loop, B a balancing loop

Nobody chose the result

The rules fixed the catch limit and the regrowth, not which lakes survive.

Three tests for an **emergent** result

Not just a sum
When you fished mattered, and how the others reacted, not only how much.

A different kind of result
You each chose a number. A collapsed lake is not a number anyone chose.

Hard to predict
Same rules, same kind of people, different lakes. Could anyone have predicted it?

More emergence is not always better



All imposed
Often not interesting.
A simple equation may do.

In between
Often the best level of emergence.

All emergent
Too many complex behaviours can make it hard to learn from.

Railsback & Grimm (2019)

Our game was a model

The system: a real fishery

Fishers who choose | **A shared stock** | **Regrowth**

Several species | Boats and costs | Price of fish

Weather | Regulator and quota | Other lakes

Need for income | Decades of history

Gold: what our game kept. Dashed: left out.

keep only what the question needs

A model: our game

Fishers who choose

A shared stock

Regrowth

Four fishers, eight rounds

A model is not the system. It is a simplified stand-in, built for a question.

Ours: why do shared stocks collapse? Unlike the fishery, a model can be run again, changing one thing at a time.

Starfield et al. (1990)

Could simulated fishers do the same?

A second model of our dilemma, on a bigger lake

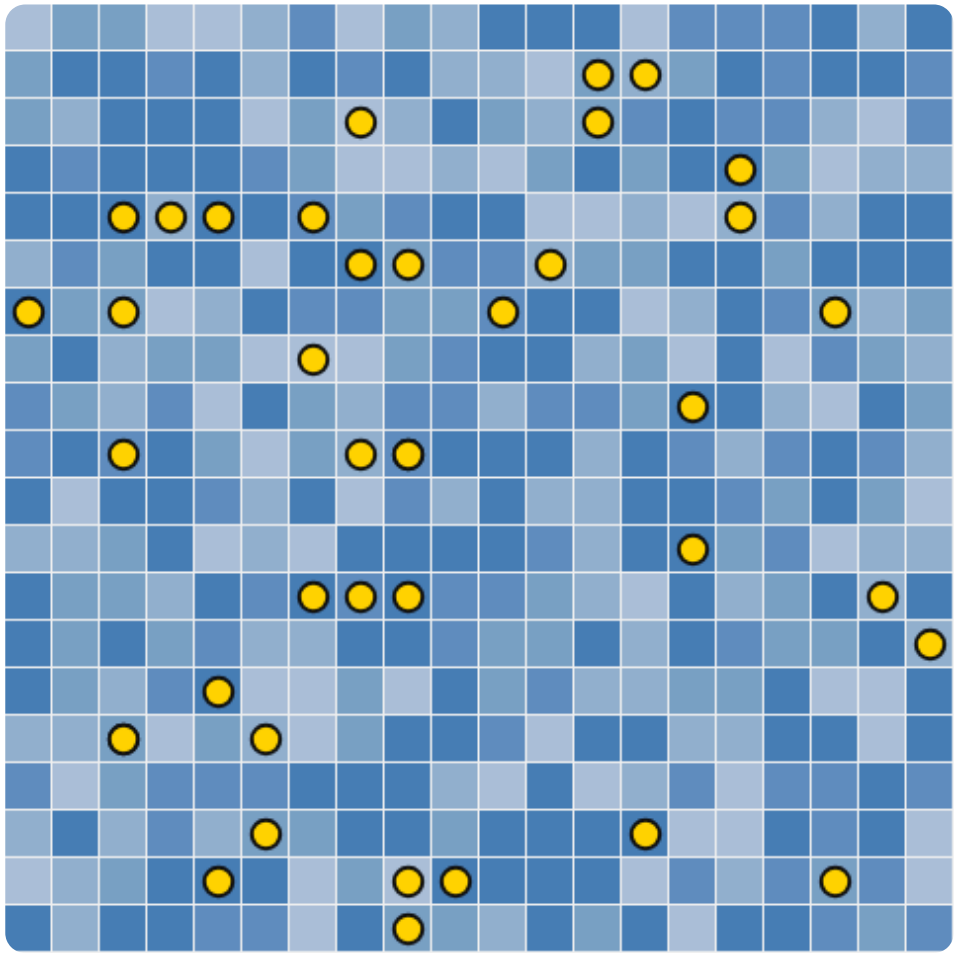
	Our game	The simulation
Fishers	You, 4 per lake	Boats on one lake
Space	No places	A grid of places
Catch	You chose 0 to 5	A boat takes up to 5 from the richest water nearby
Fish	Doubled, up to 24	Fish breed and spread to nearby water, up to a limit
Talking	From the break on	Nobody talks or plans

We made these rules up. Nobody measured them.

How many boats can fish this lake for ever?

1. About 10
2. About 20
3. About 35
4. More than 50

A lake with boats



Boats on the lake: **40**

Each boat catches at most **5** fish

▶ Run | Step | New start

Fish left in the lake, round by round

73%	0.0	0	0
of the fish left	fish per boat now	fish per boat so far	rounds

Fish, the darker the more Boats The second slider is your choice from our game.

Does it need people at all?

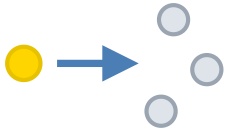
Starlings: three rules, no leader

The model: each bird reacts to its neighbours



Align

Fly the way your neighbours fly.



Cohere

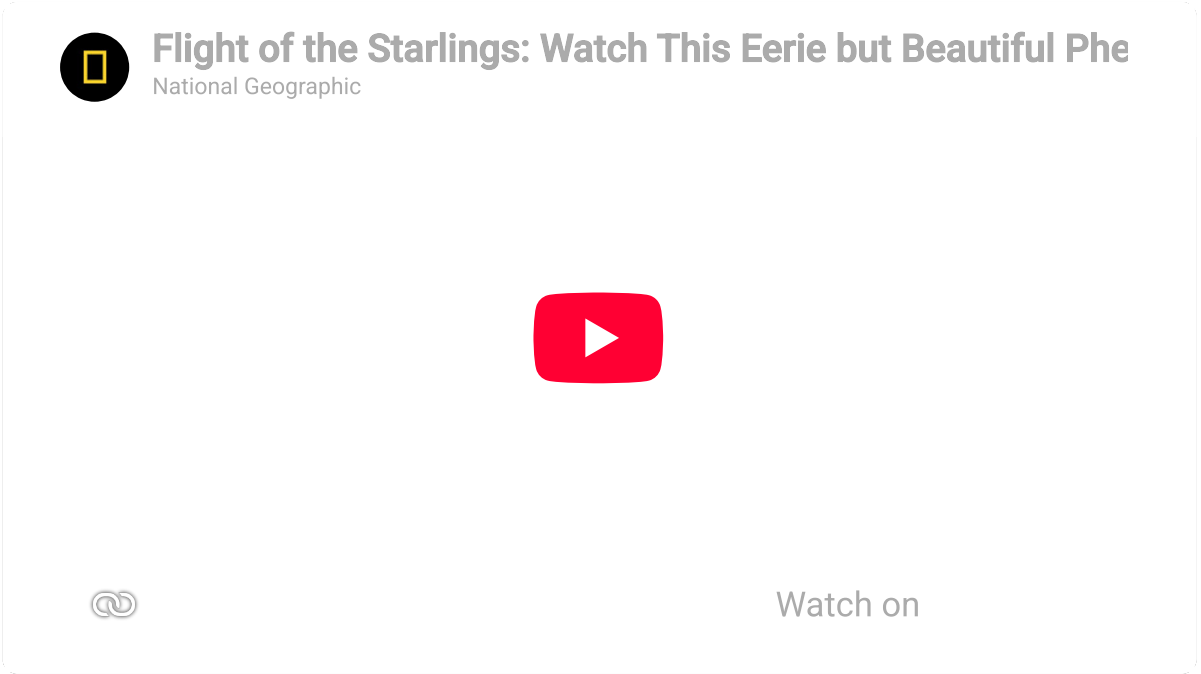
Move towards your neighbours.



Separate

Keep a minimum distance.

The system: real starlings



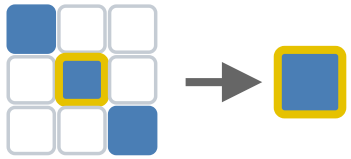
No bird knows the shape of the flock, and no rule mentions it.

Reynolds (1987)

Does it even need living things?

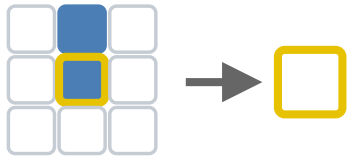
Conway's Game of Life: four rules, one grid

Every cell is alive or dead. In every step, for every cell:



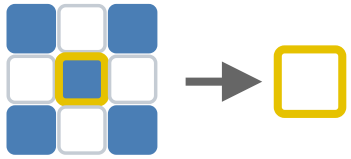
Survives

2 or 3 live neighbours



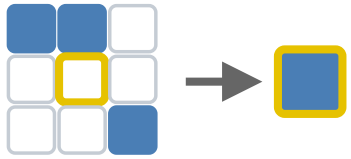
Dies of loneliness

fewer than 2



Dies of overcrowding

more than 3



Comes alive

a dead cell with exactly 3

What these rules do

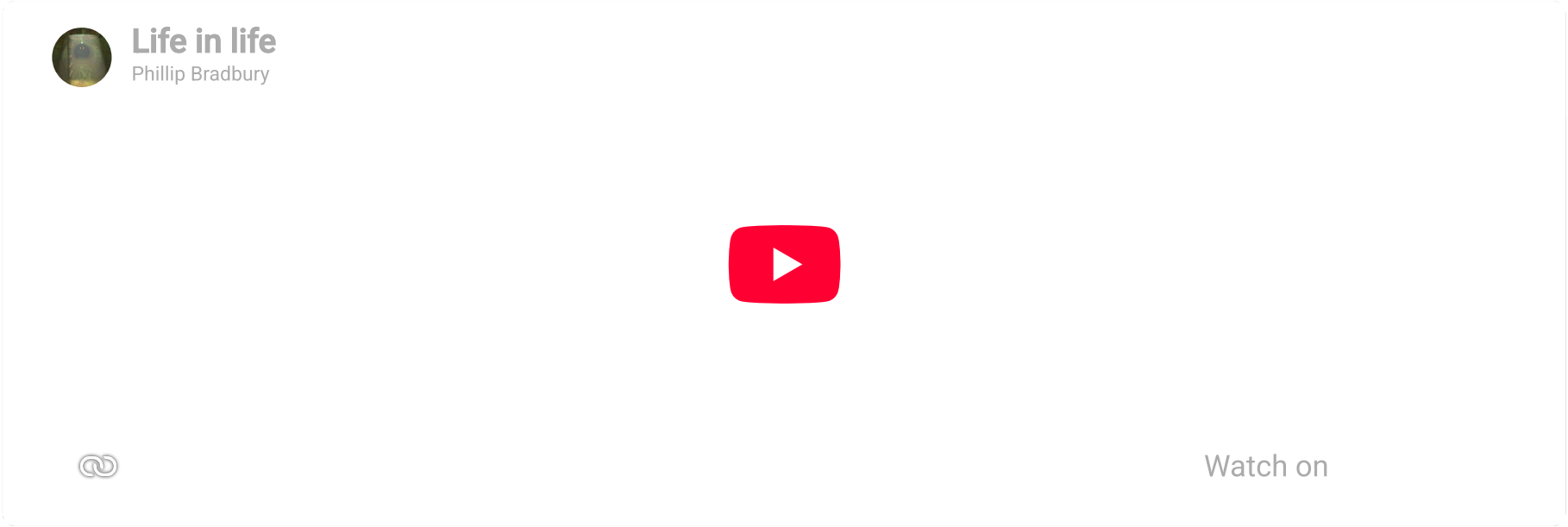
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Watch on YouTube

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

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

A system

Fishers and fish form one social-ecological system.

2

Feedback

Each catch changes the next: the fewer fish, the stronger the race.

3

Emergence

The collapse emerges from many reasonable choices. Nobody chose it.

Knowing the rules is not knowing the outcome. 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 lab

One rule to save the lake

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

One or two sentences. Which feedback loop does your rule weaken?

My rule, and why it would work

Our rules

In class, the answers appear here, grouped into themes.

Before lesson 4: 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 4:

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 four assignments. Each 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.*

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

Meadows, D. H. (2008). *Thinking in Systems: A Primer.*

Metcalf, G. S., Kijima, K. & Deguchi, H. (eds., 2021). *Handbook of Systems Sciences.*

Also: Mobus & Kalton (2015) · Jackson (2024) · Reynolds (1987) · Gardner (1970)