UNIVERSITY OF LEEDS

Agent-based modelling

By Dr. Yannick Oswald

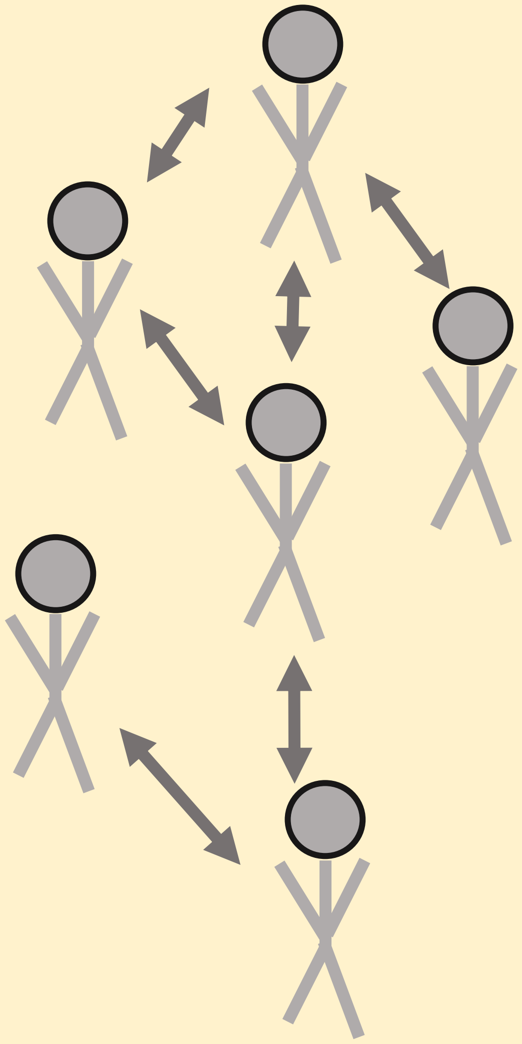
part of GEOG5927 Predictive Analytics March 2023, YO

Acknowlegment: Slide style I took, next to Dr. Jiaqi Ge, additional inspiration from Prof. Thomas Schmickl at the University of Graz

What are we doing today?

- Learning about agent-based modelling
  - What is it?
  - What are the key concepts?

- Applications to geography (GIS) and social sciences



How does this fit within the course (I)?

Predictive Analytics is more or less about

- What do people do?
- How do they behave?
- What do they want?

Tools used so far..

(Spatial) Microsimulation

Machine Learning:
Random Forests (Decision Trees)

How does this fit within the course (II)?

Microsimulation & Machine Learning	Agent-based modelling
Individual-based	*Agent*-based
Features of the individual predict behaviour or classification e.g. age gender neighbourhood salary	An agent is an "autonomous" entity There are rules of behaviour Rules of behaviour and interaction with others and environment determine outcomes

Growth of Geographical ABM

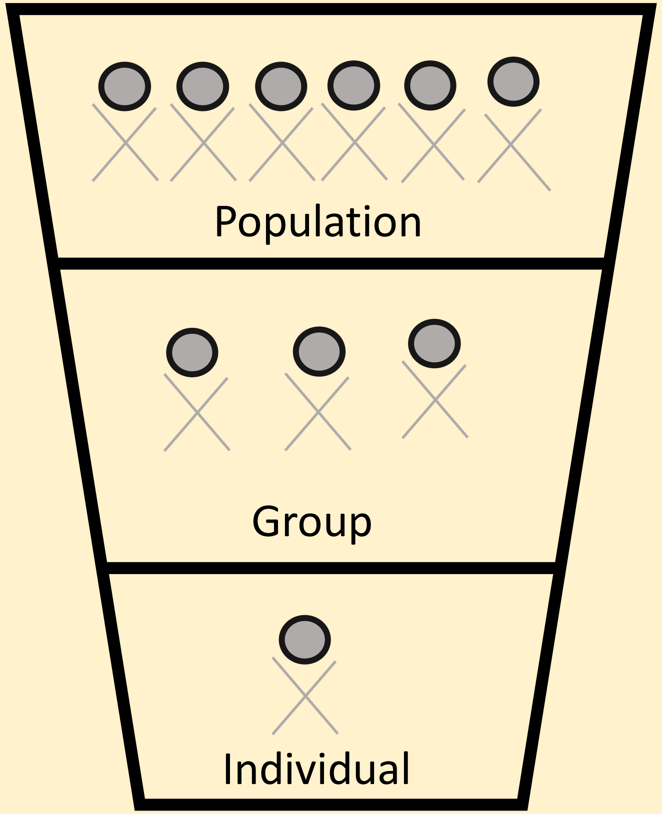
Time-table for this week

- 13:00 – 14:00 Monday 27th March, Today, **Lectures**
  - What is an ABM?
  - Key concepts in ABM
  - Big Data, Smart Cities and ABM
  - **Intro to Assignment 2**

- 11:00 – 13:00 & 13:00 – 15:00 Wednesday 29th March 2023: **Practical**
  - Introduction to Netlogo
  - Netlogo practicals – Programming the game of life and other model explorations
  - **Intro to Assignment 2**

So what is agent-based modelling?

“General” approaches to modelling systems



Top-down approach

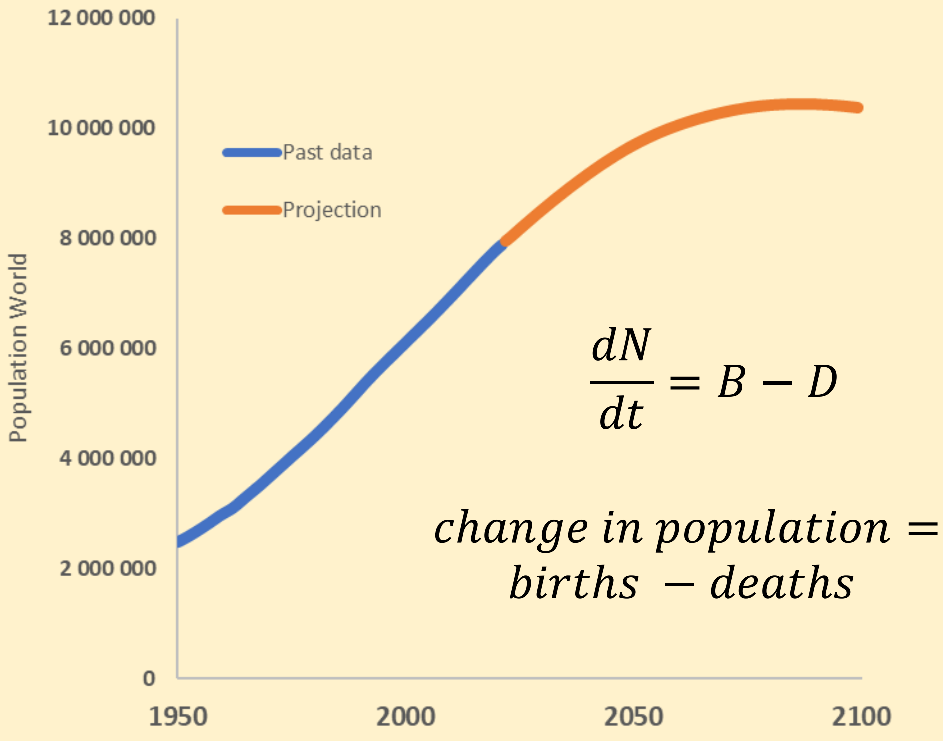
“Global” system description

Bottom-up approach

“Local” system description

Examples (I) Top-down approaches “One equation to rule them all”

Population dynamics

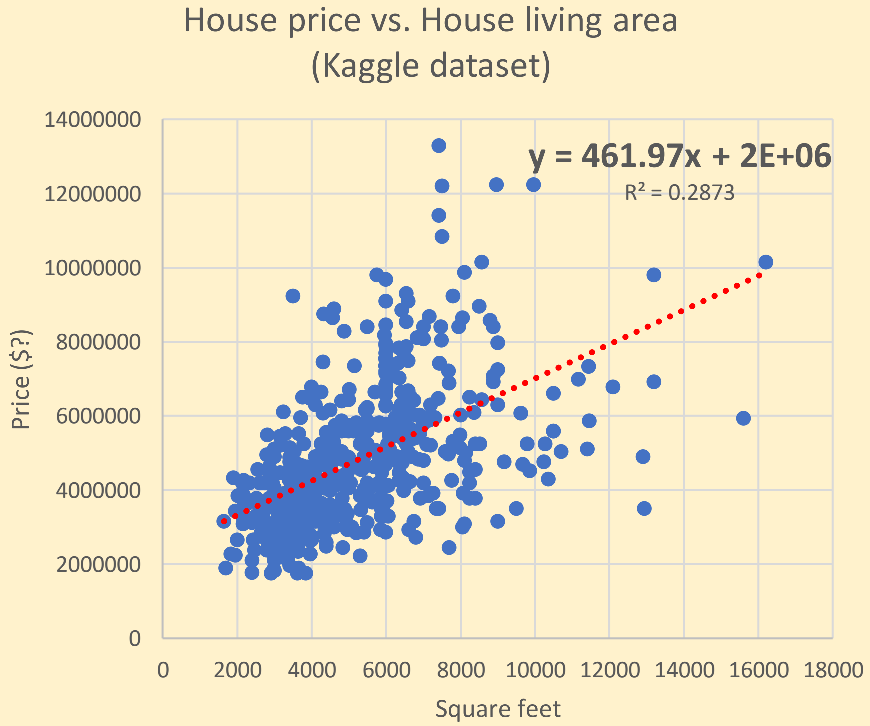


$$\frac{dN}{dt} = B - D$$

$$change\ in\ population = births\ - deaths$$

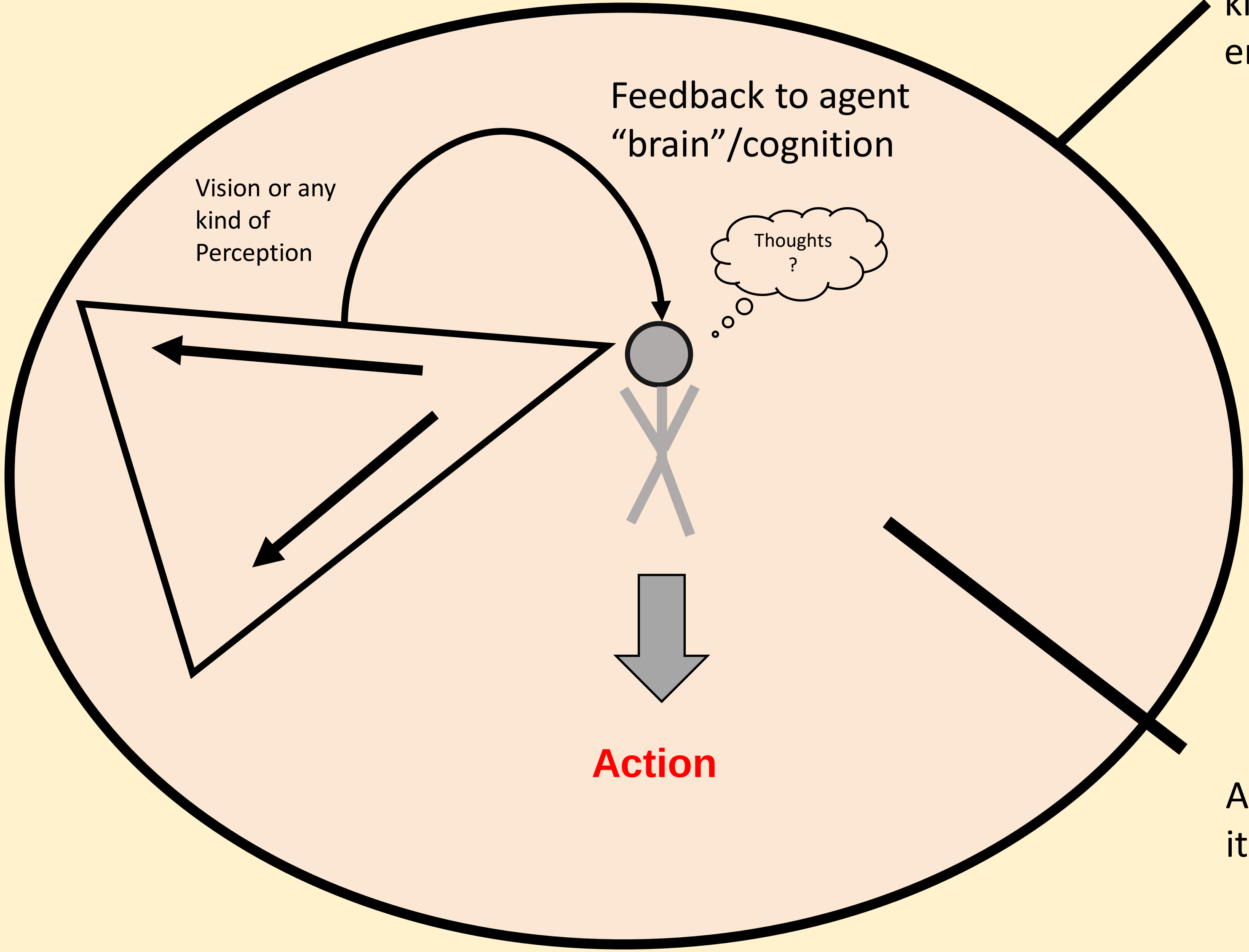
Source: https://population.un.org/wpp/Download/Standard/MostUsed/

Linear regression



Source: https://www.kaggle.com/datasets/yasserh/housing-prices-dataset

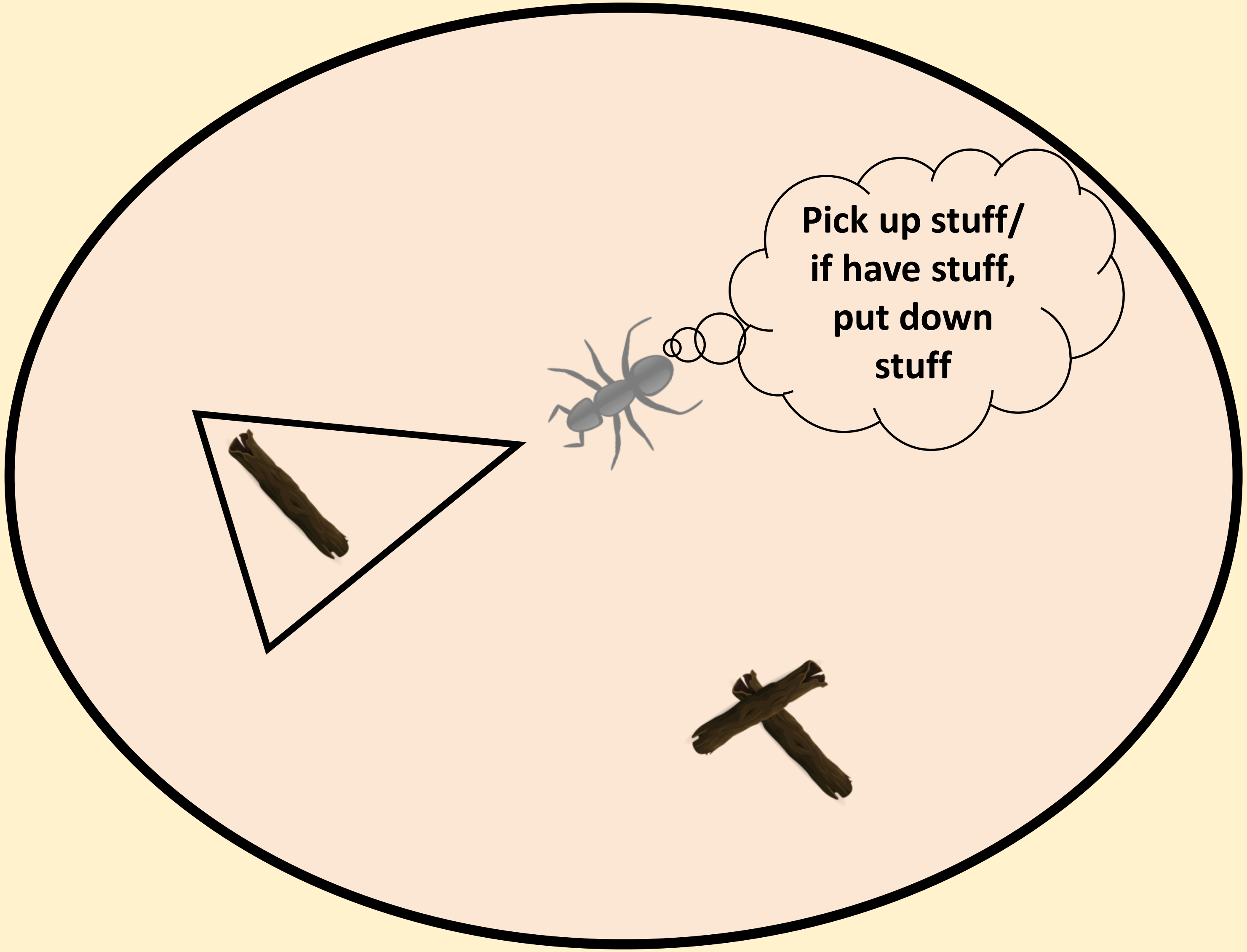
Agents



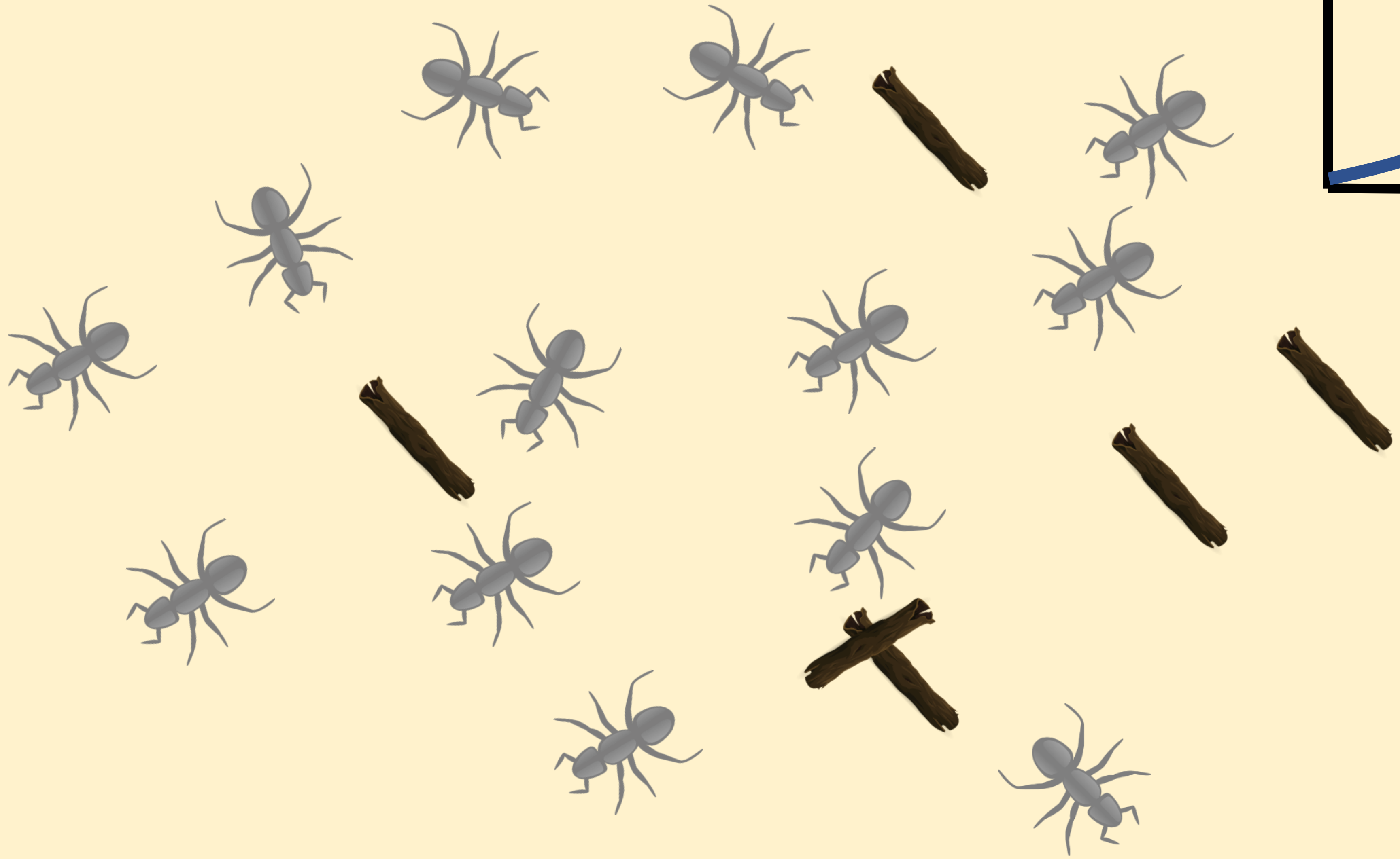
"Live" in some kind of environment

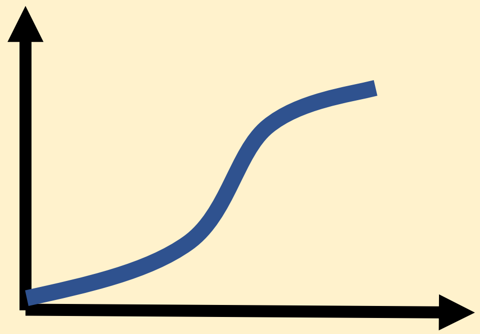
Agent knows only about its ***local*** environment

Agents Example (I) – The Termite



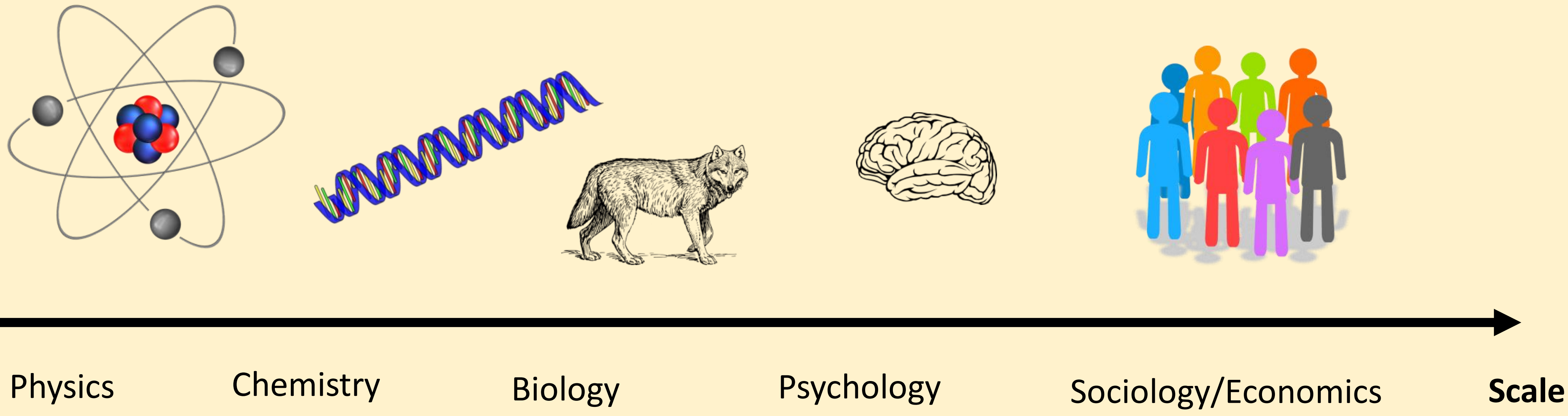
Agent-based model Example (I) – The Termites





Agent-based modelling is a universal approach across the sciences

– break down the system into its constituent parts and build it “bottom-up”



Universal phenomena that can be studied with ABMs

From a cross-science perspective Agent-based models are useful to study

- Complexity (complex systems)
- Self-organization
- Emergence
- Swarm-intelligence (or -stupidity)

Complex systems (I)

Citation from Wikipedia

(don’t do this in your homework or examinations):

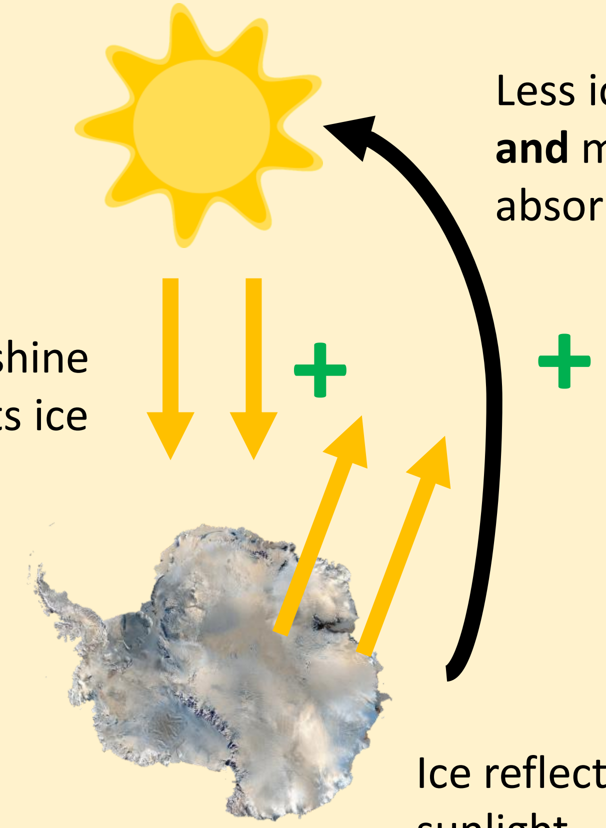
“A complex system is a system composed of many components which may interact with each other. Examples of complex systems are Earth's global climate, organisms, the human brain, infrastructure such as power grid, transportation or communication systems, complex software and electronic systems, social and economic organizations (like cities), an ecosystem, a living cell, and ultimately the entire universe.”

Complex systems (II) – Essential features

- **Feedback loops**
- **Non-linearity**
- **Chaotic behaviour (sensitivity to initial conditions)**
- **Many interconnected elements**
- **(maybe) Self-Organization (important in context of ABMs)**
- **(maybe) Emergence (important in context of ABMs)**
- (maybe) Adaptation

Complex systems (III) – Feedback loops (I): positive feedback

Example (I)



Less ice raises temperature **and** more sunlight is absorbed by ocean

Sunshine melts ice

Ice reflects less sunlight

Example (II)

+

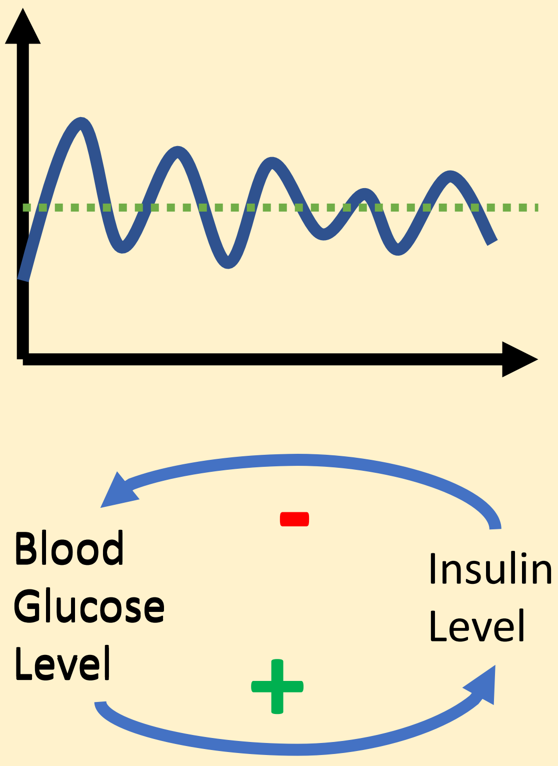
Bitcoin price

# of people interested

+

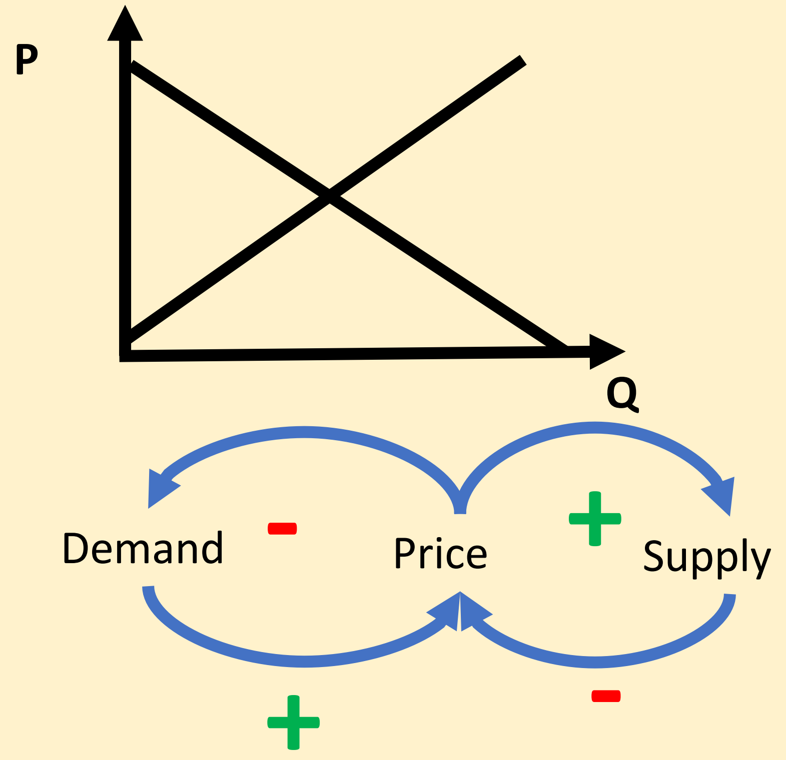
Complex systems (IV) – Feedback loops (II): negative feedback or, better, ***stabilizing*** feedback

Example (I) – Blood Glucose



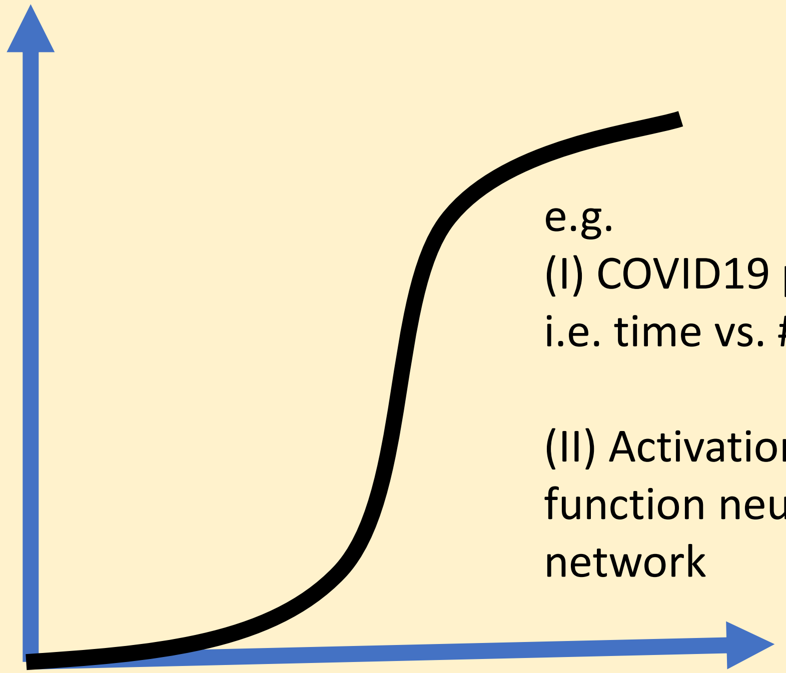
homeostasis

Example (II) – Demand and Supply in Economics



Complex systems (V)
Non-linearity / Chaos theory

Variable B



e.g.
(I) COVID19 pandemic
i.e. time vs. # of cases

(II) Activation
function neural
network

Variable A

Butterfly effect
(A butterfly can cause a tornado)

Self-organization (I)

- Self-organization is ***global*** ***pattern formation*** from ***local*** ***interactions***

Example **ant highway**

Ants leave pheromones wherever they go, other ants follow pheromones

No ant has information about the entire highway, there is no top-down design

Emergence (I)

- Related to self-organization
- A new "qualia/quality" emerges at a higher level of organization
- An entity is observed to have properties its parts do not have on their own – *"the whole is more than the sum of its parts"*

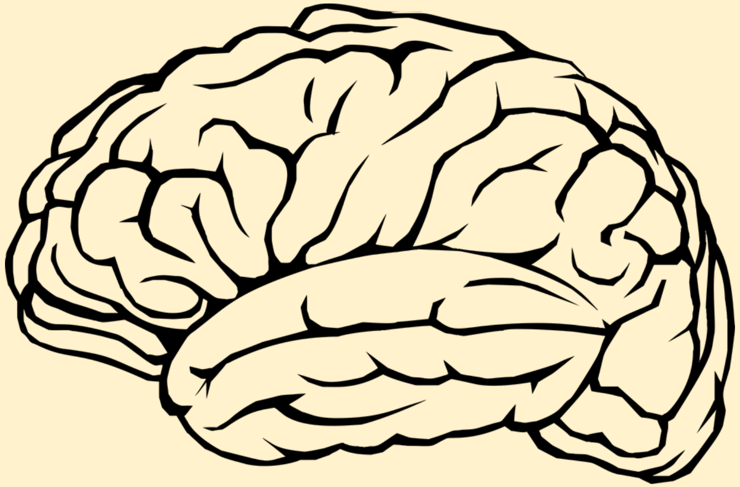
<u>IMPORTANT FOR UNDERSTANDING ABMs:</u>
SIMPLICITY LEADS TO COMPLEXITY
From simple rules on a "local" level, complex structures emerge at a "global" level.

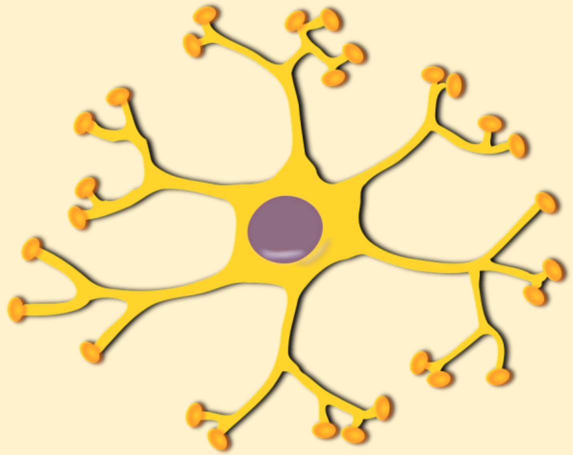
Water/Wetness

Bird flock patterns

Emergence (II) – Strong emergence

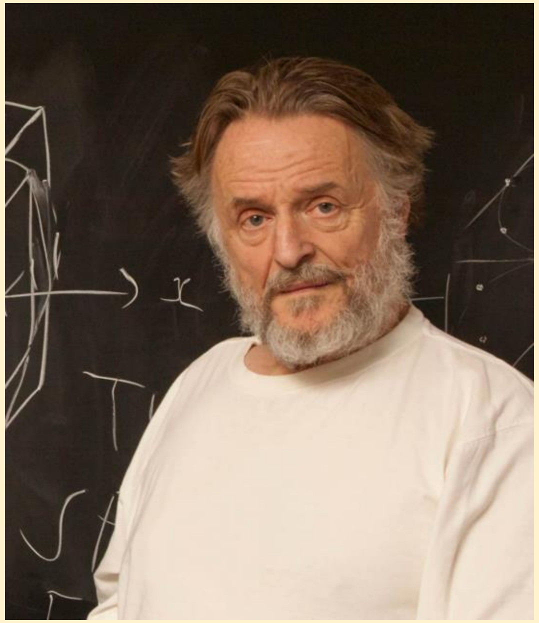
- *Strong* emergence is where self-organization becomes inexplicable.
- Cannot deduce higher-level properties anymore from low-level rules
- Consciousness is a good example of that: How does it emerge from the interaction of neurons? We do not know.





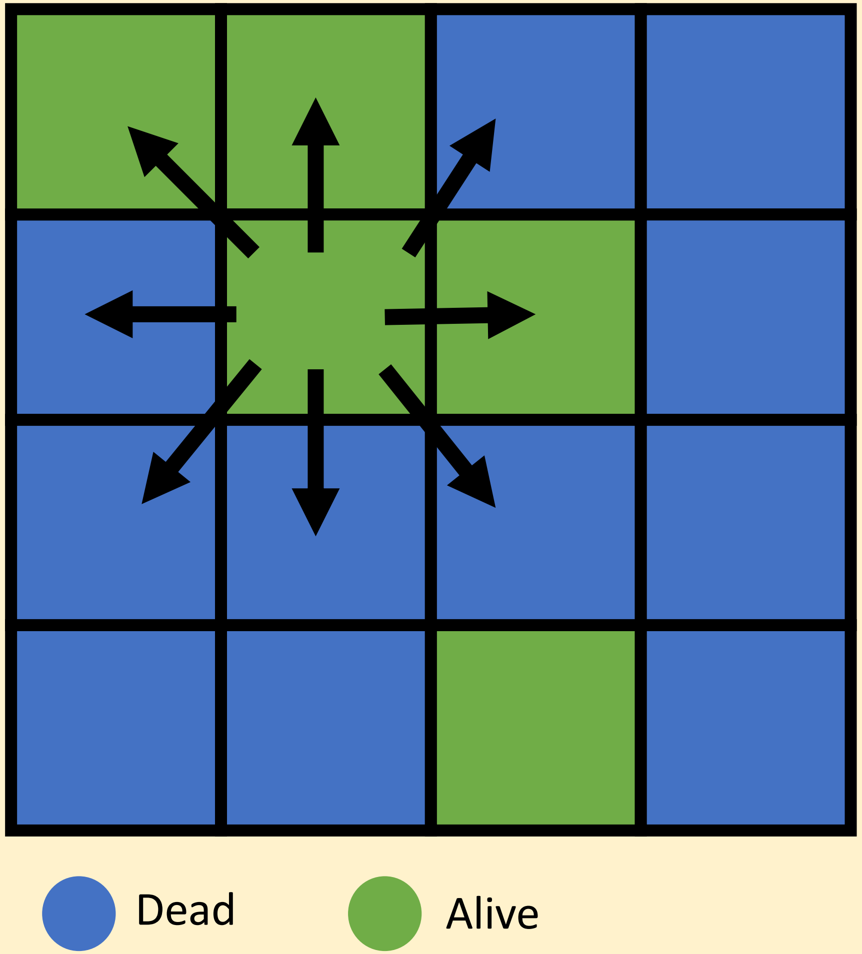
Emergence (III) – Conway's Game of Life (I)

- Perhaps most popular case of emergence, which anyone can study, and we are going to!
- **<u>It is a cellular automaton</u>**, so from computational theory.
- **We can consider it an extremely simple agent-based model**



John Conway
English mathematician at Cambridge and Princeton
1937 - 2020

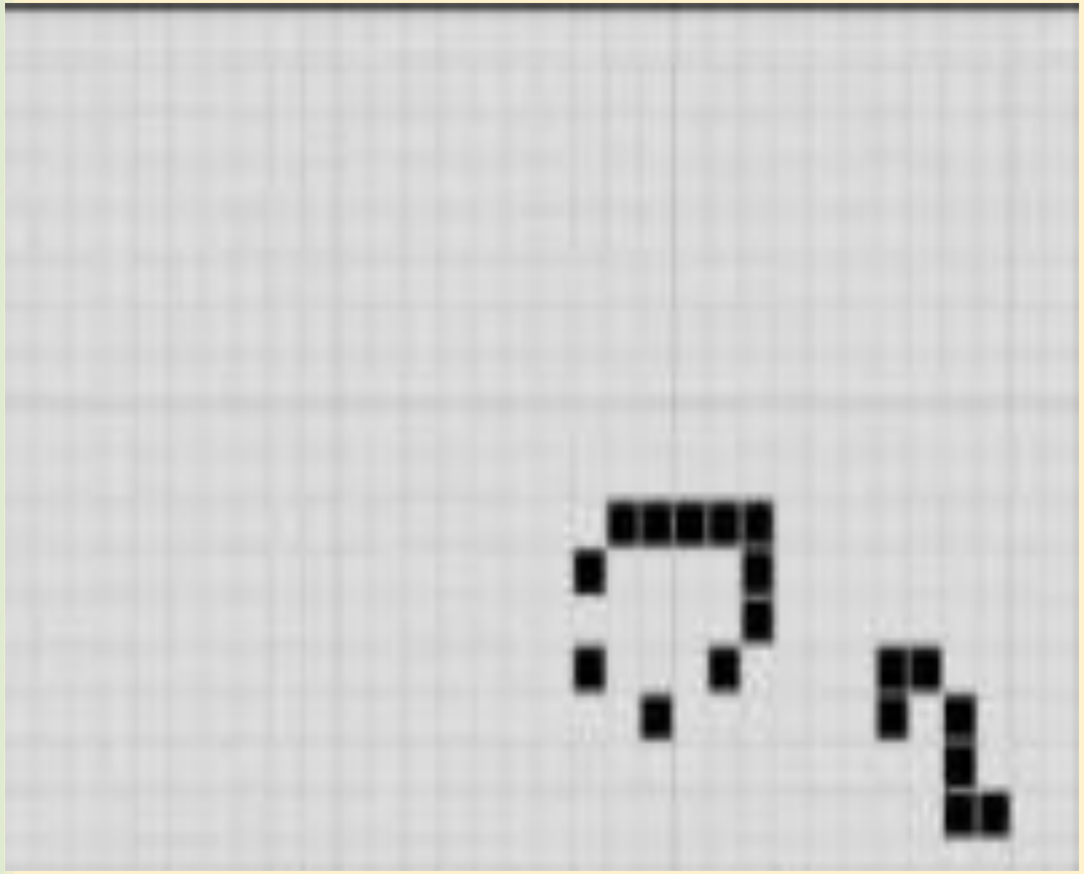
Emergence (IV) – Conway's Game of Life (II)

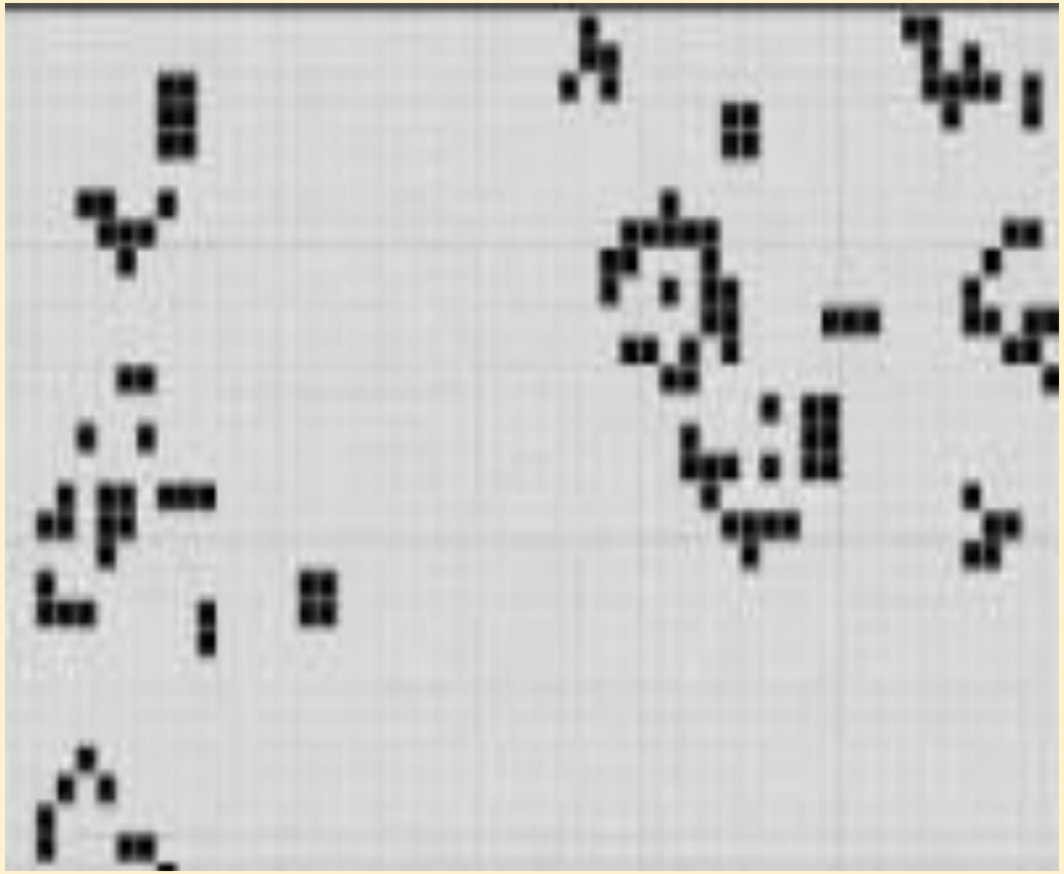


Cell/Agent rules (again from Wikipedia)

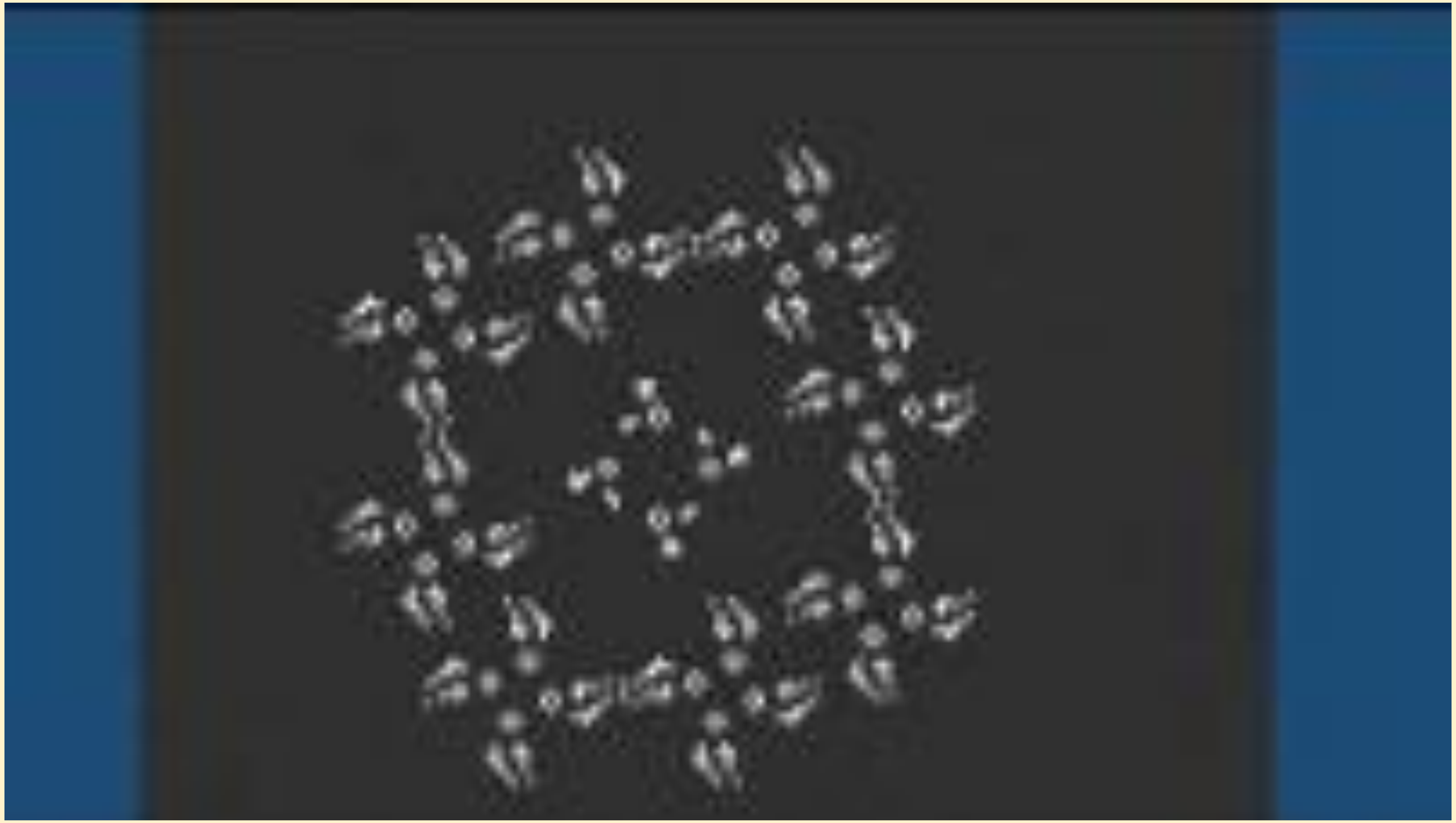
- Any live cell with fewer than two live neighbours dies, as if by underpopulation.
- Any live cell with two or three live neighbours lives on to the next generation.
- Any live cell with more than three live neighbours dies, as if by overpopulation.
- Any dead cell with exactly three live neighbours becomes a live cell, as if by reproduction.

Emergence (V) – Conway's Game of Life (II)





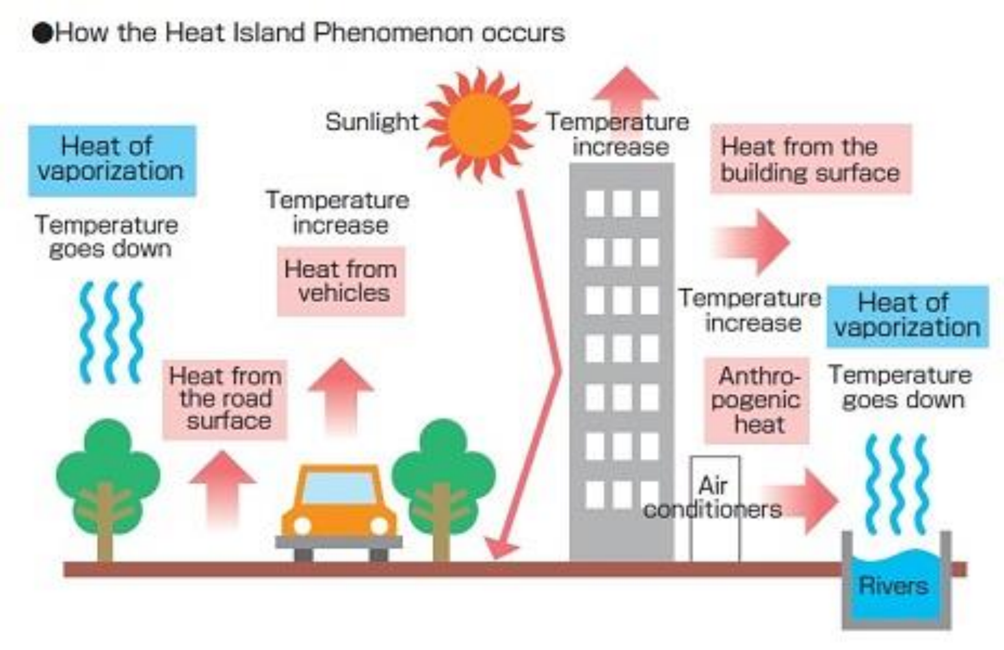
Emergence (VI) – Conway's Game of Life (III) – More crazy patterns



Emergence (VI) – Examples from Geographical Information Science

Traffic and traffic jams

Urban heat islands



Source: http://www.gardinergreenribbon.com/heat-island-effect/

Swarm intelligence (I) - Example

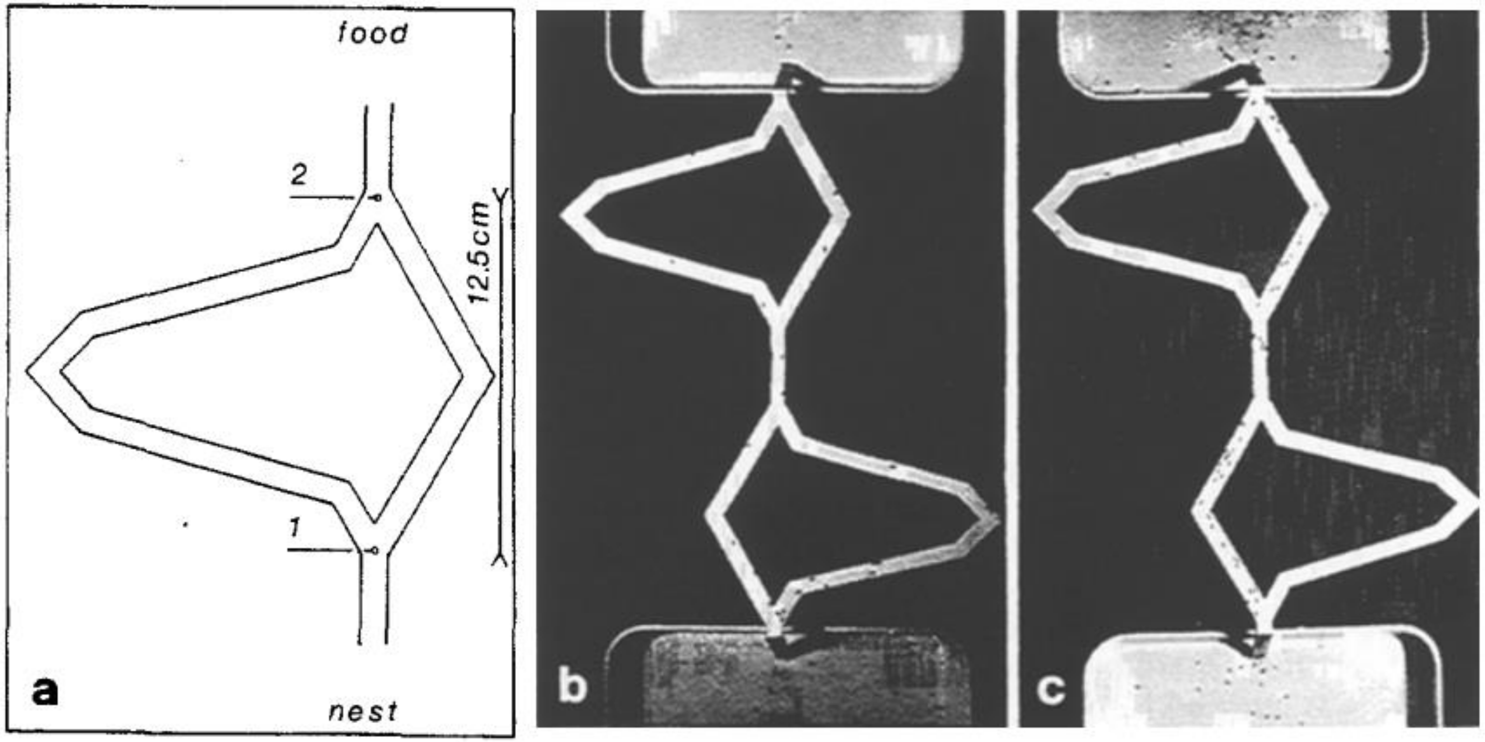


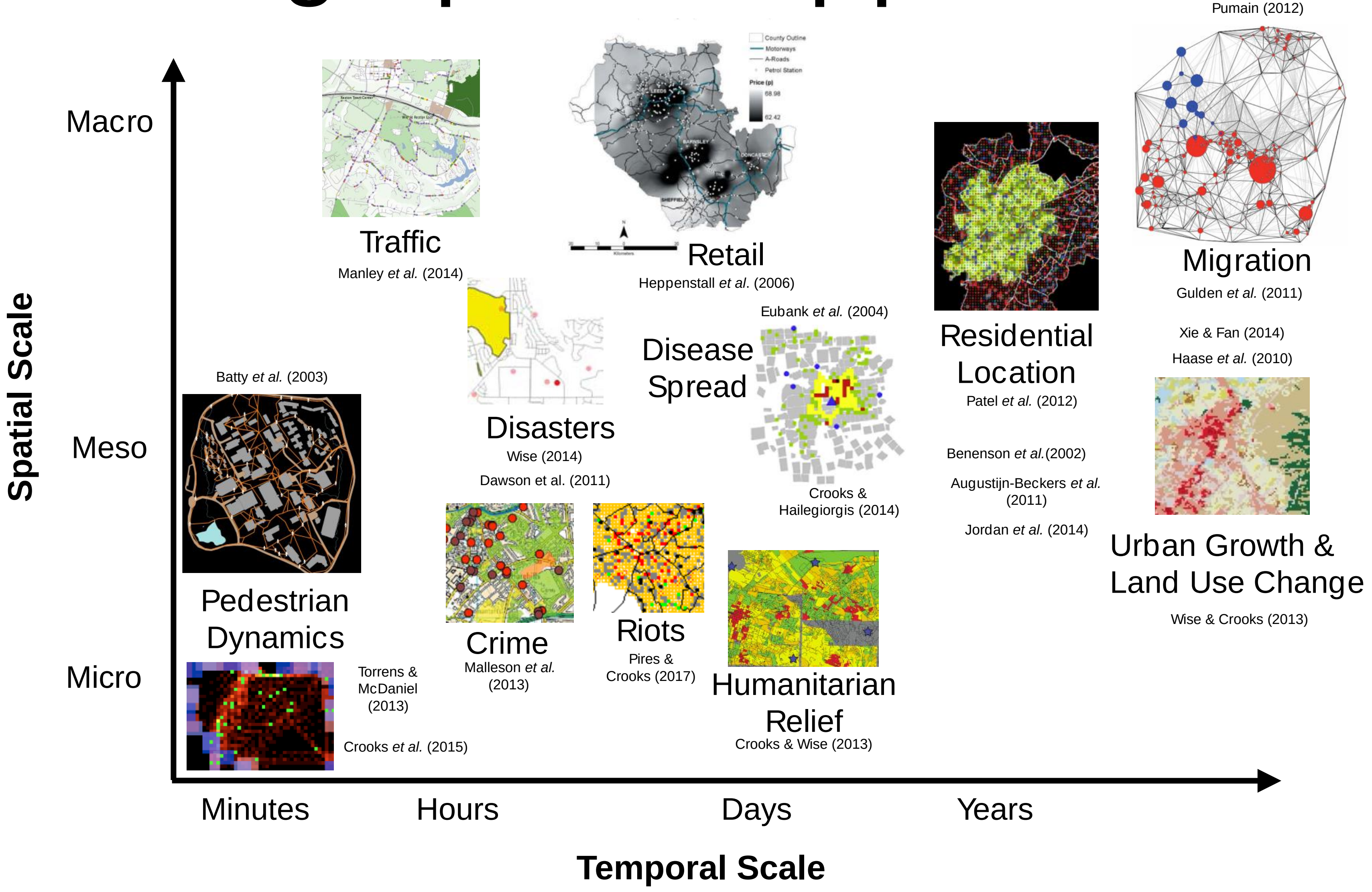
Fig. 1. A colony of *I. humilis* selecting the short branches on both modules of the bridge; a) one module of the bridge, b) and c): photos taken 4 and 8 min after placement of the bridge

- Ants always find the shortest path
- No single ant Knows anything about this
- But the swarm finds the optimum
- “Easy” to model with ABM

<u>**Picture from:**</u> Goss, S., Aron, S., Deneubourg, J.L. *et al.* Self-organized shortcuts in the Argentine ant. *Naturwissenschaften* **76**, 579–581 (1989). https://doi.org/10.1007/BF00462870

ABMs in Predictive Analytics and Geographical Information Science

Geographical Applications



Example 1:
Modelling Crime patterns (I)

Good for? Crime prevention and mitigation, Security of communities, Testing policy interventions

Behavioural model of agents

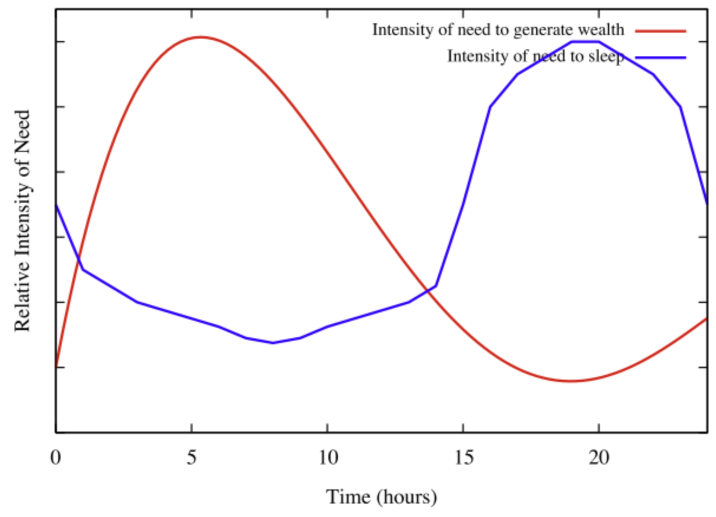


Fig. 2. Need intensities over time. How the time of day affects an agents need to generate wealth or sleep where Time $t = 0$ is defined as approximately 7am.

Neighborhood/spatial features

Table 3
The change from the default value for variables associated with different community types.

Type of area	Percentage change from default value	
	Attractiveness (%)	Security (%)
Default	–	–
Rich	150	150
Deprived	50	50
Student	150	50

Source pictures and content: Malleson, N., Heppenstall, A., & See, L. (2010). Crime reduction through simulation: An agent-based model of burglary. *Computers, environment and urban systems*, *34*(3), 236-250.

Example 1:
Modelling Crime patterns (II)

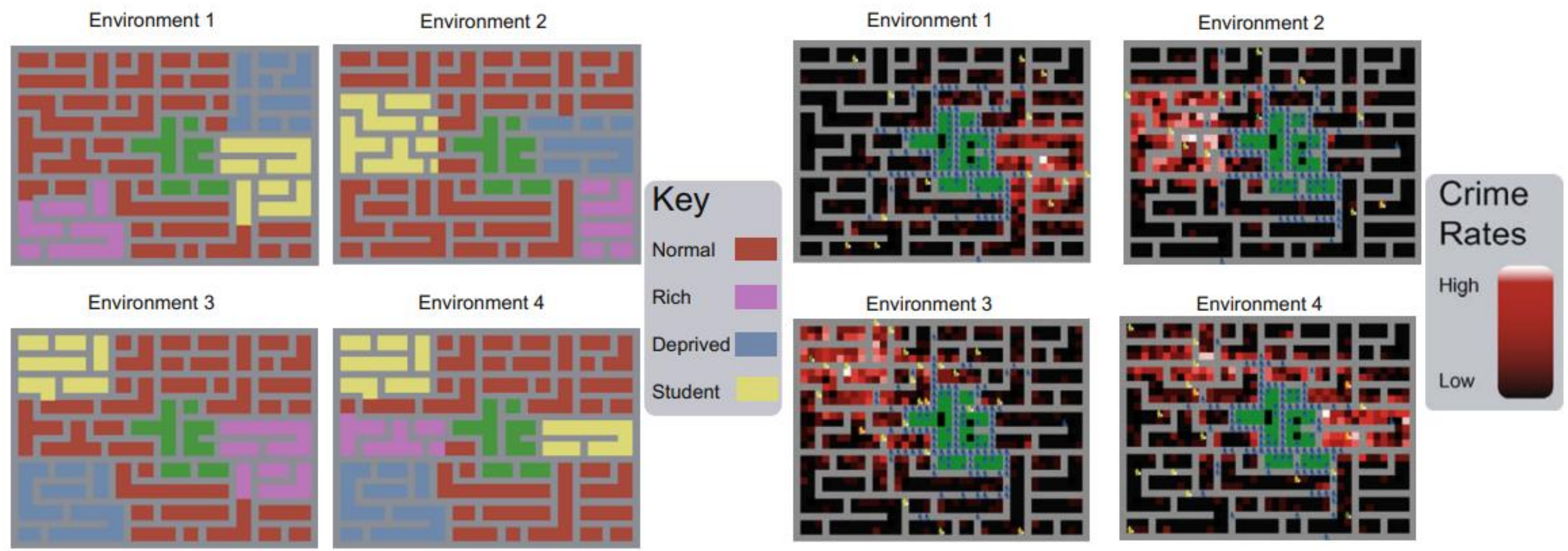
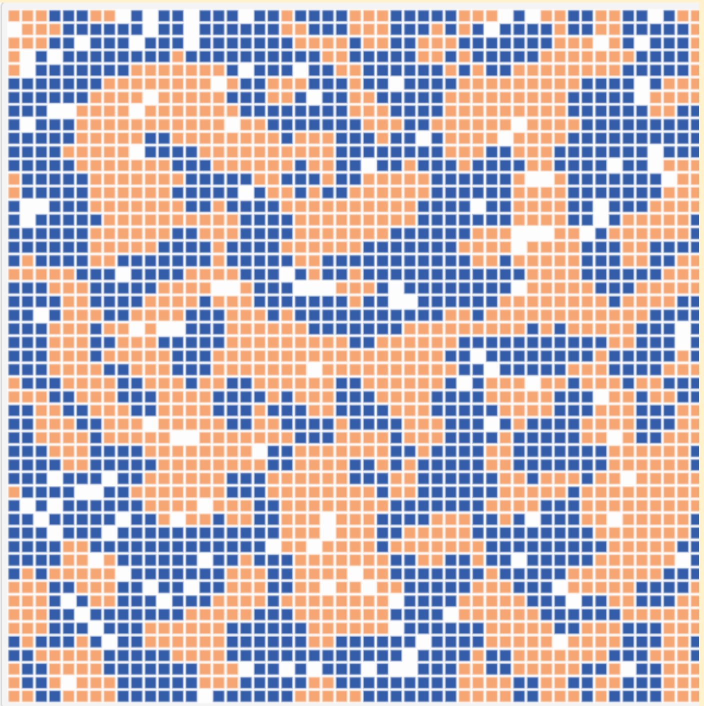


Fig. 8. Altering security and attractiveness. The layout of different environments altering the community type and burglary rates produced by day 50 using different community types.

Source pictures and content: Malleson, N., Heppenstall, A., & See, L. (2010). Crime reduction through simulation: An agent-based model of burglary. *Computers, environment and urban systems*, *34*(3), 236-250.

Example 2: Segregation Model by Schelling

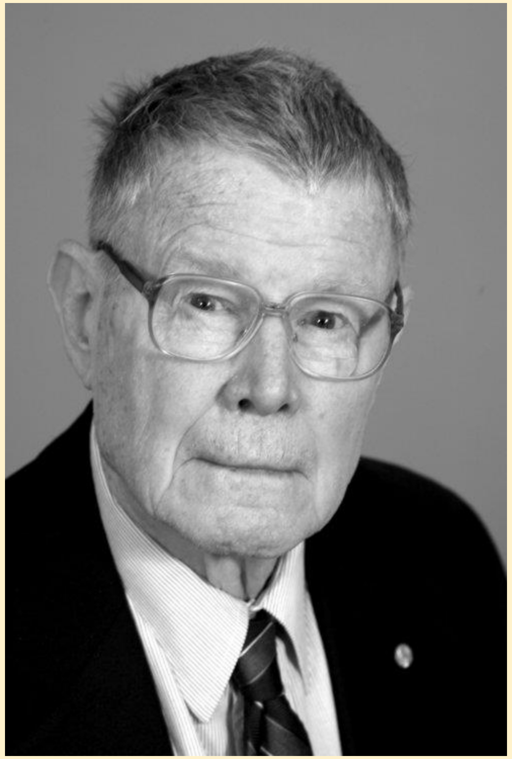
Even a small amount of in-group preference can form segregated societies.



Is my neighborhood sufficiently similar to me?

→ Is the fraction of neighbors similar to me more than I want it to be?

For ~30% similarity wanted segregation occurs already.



Thomas Schelling (1921 – 2016)
American economist
Nobel Prize recipient
Wrote the book "Micromotives and Macrobehaviour"

Schelling, T. C. (1971). Dynamic models of segregation. *Journal of mathematical sociology*, *1*(2), 143-186.

Example 2:
Segregation Model by Schelling
Is it true? Is it controversial?

- Schelling did actually not only think about racial separation in the US explicitly but also used it as one example.

- The model became more associated with that in the 1980s when the debate emerged.

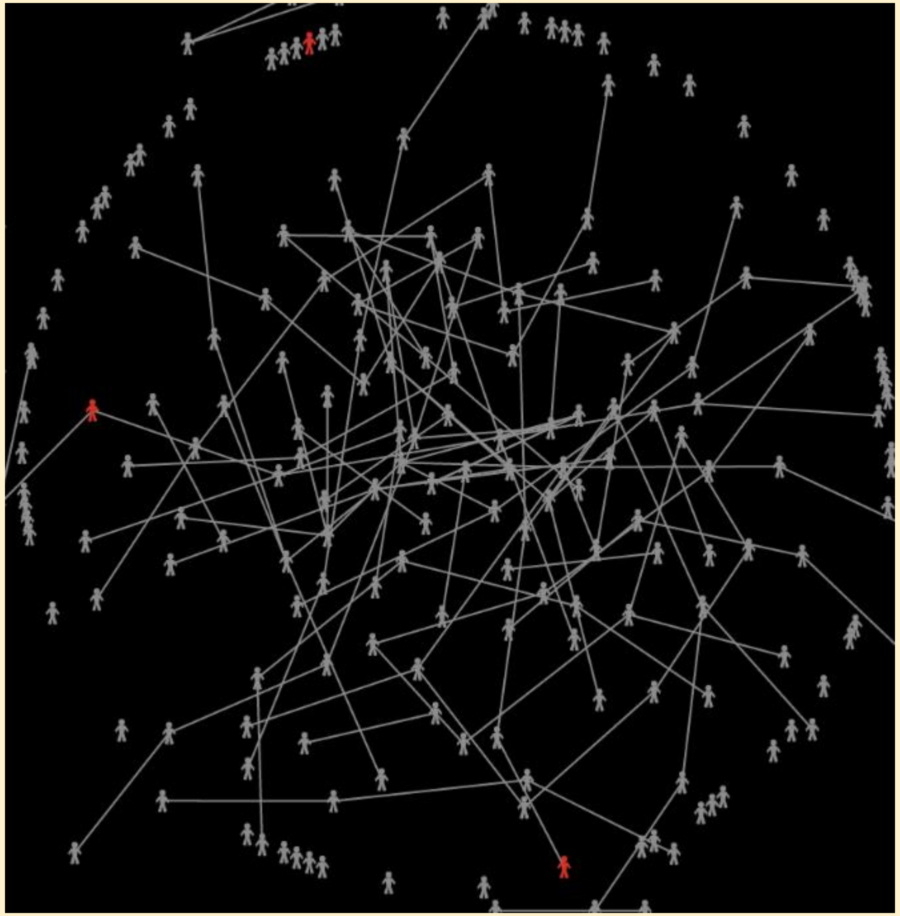
- *Not sure it is a good model for this:* It omits history and the state
  The United States e.g. the US was a fully racist state until ~1950s
  with laws dictating separation between black and white citizens.

- It also omits that income determines where you *can* live

- Still interesting from today's perspective, I would argue, not for residential/spatial separation but for social media and political polarization etc.

Example 3: Pandemics/ Epidemics

ABMs for this topic existed for a long time but became much more popular and important during the COVID19 pandemic



<u>**Good for?**</u>

Epidemology research in general

Crisis management

Testing policy interventions

Example in Netlogo

http://www.netlogoweb.org/launch#http://ccl.northwestern.edu/netlogo/models/models/IABM%20Textbook/chapter%206/Spread%20of%20Disease.nlogo

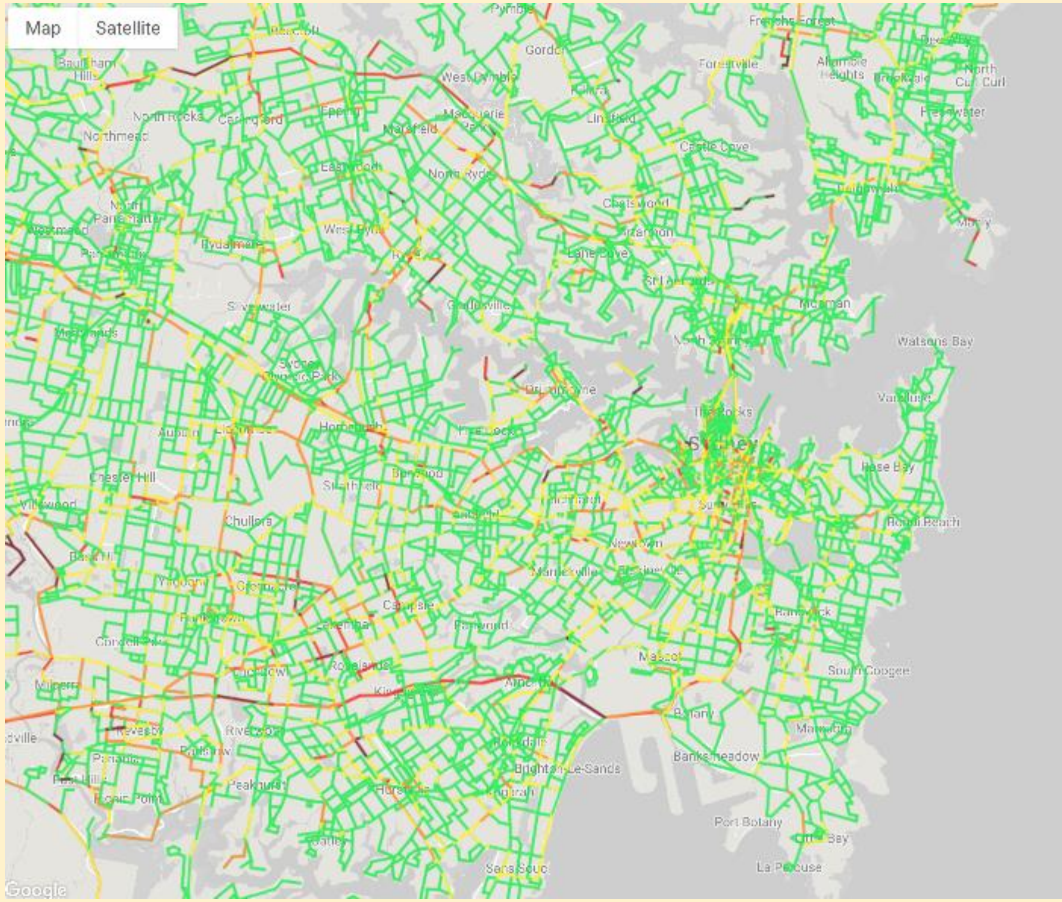
Example 4: Train Station simulation model

<u>Good for?</u>
Urban/Infrastructure planning

Crowd management

- https://urban-analytics.github.io/dust/p/2018-07-15-abmus-da.html#/StationSim-videos

Example 5: Large-scale simulation of urban traffic incidents



<u>Good for?</u>

Road/infrastructure planning

https://youtu.be/_wzuBVzpI1A

Project info:
http://adait.io/inno-pii.html

Limitations of ABMs and what to give thought to..

- Computationally expensive.
  - Lots of decisions!
  - Multiple model runs (robustness)
- Modelling "soft" human factors is challenging
  - Complex psychology?
  - But this is really hard!
- Potential to over-complicate (like in any model)
  - Need to think carefully about what to include

"As simple as possible and no simpler" –

Albert Einsteint (perhaps)
https://www.nature.com/articles/d41586-018-05004-4

- Rules are often probabilistic we guess/use heuristics
  - E.g. There is a 70% change of attending this morning's lecture, and 30% chance of staying in bed
- Models that use randomness like this are **probabilistic**
- They need to run many times to ensure robust results
- **Calibration and validation is a very important topic**

Netlogo and Practical planning

- There are many softwares to build agent-based models. They can for instance be build in Python.

- We will use **Netlogo**

- **Remember:**

You have been assigned to one Practical

- 11:00 – 13:00 & 13:00 – 15:00 Wednesday 29th March 2023: **Practical**
  - Introduction to Netlogo
  - Netlogo practicals – Programming the game of life and other model explorations
  - **Intro to Assignment 2**

- Bring Laptop or log-in stationary PC

Further resources for the interested

COMPLEXITY EXPLORER
SANTA FE INSTITUTE

- Full online-course on ABM – very introductory friendly. Also uses Netlogo. (unfortunately has a paywall now..)

https://www.complexityexplorer.org/