UNIVERSITY OF LEEDS

AGENT-BASED MODELLING

What are we doing today?

- Learn about agent-based modelling (ABM)
  - *What is it?*
  - *What are the key concepts?*
  - *What is it for? The strengths and weaknesses of the method*
- ABM Examples
- ABM tool - NetLogo

WHAT IS AGENT-BASED MODELLING?

Agent-Based Modelling (ABM) – All about the individual

Computer simulation of autonomous,

heterogeneous and interacting individual

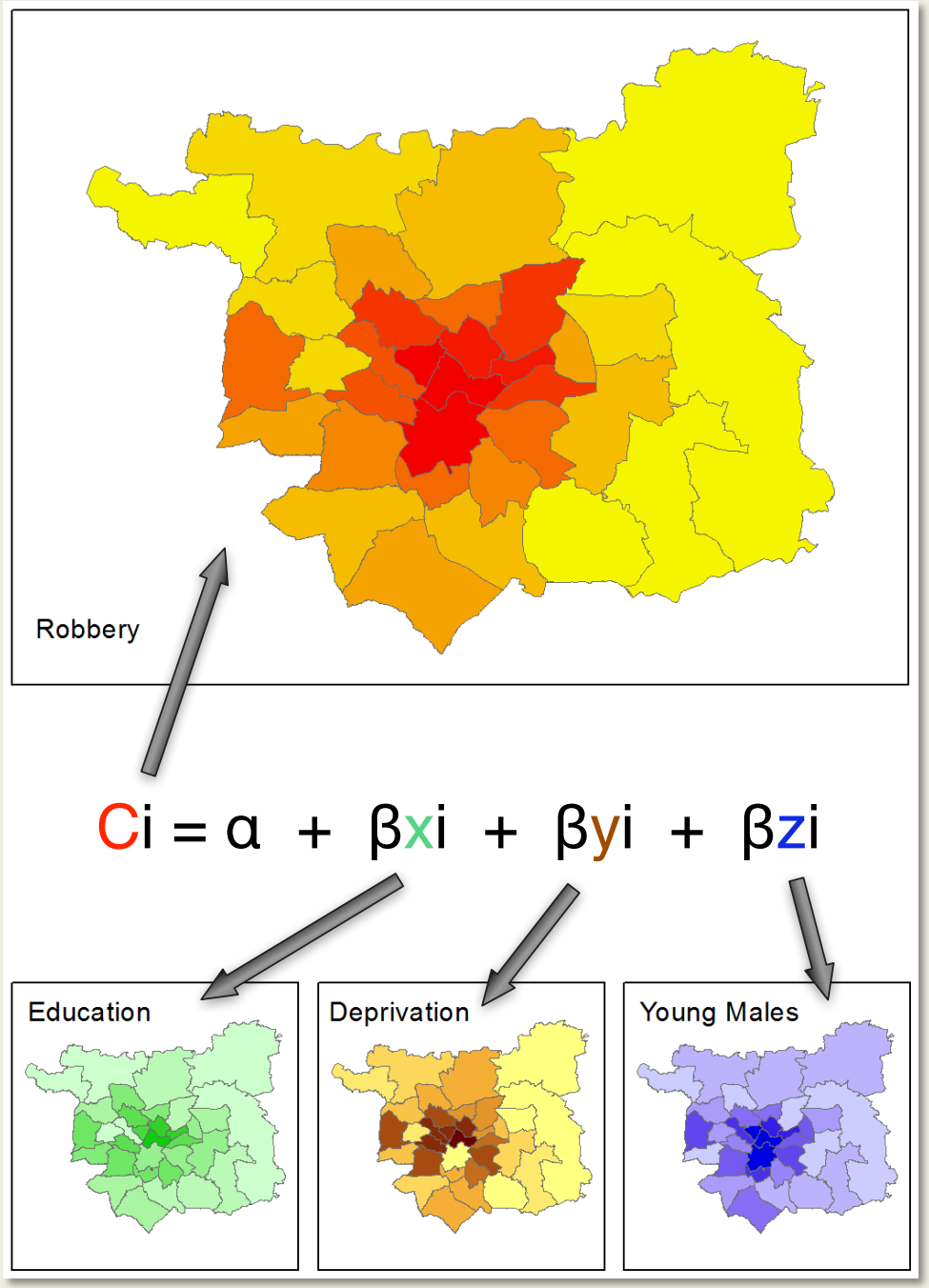
agents situated in a virtual environment

Example: SimCity

https://www.youtube.com/watch?v=vS0qURI_JJY

Aggregate vs Individual Level

- ‘Traditional’ modelling methods work at an aggregate level, from the **top-down**
  - *E.g. Regression, spatial interaction modelling, location-allocation, etc.*



Aggregate vs. individual-level

- Systems are driven by individuals
  - *(cars, people, ants, trees, whatever)*
- Not controlled by god
- **Bottom-up modelling**
  - *An alternative approach to modelling*
  - *Rather than controlling from the top, try to represent the individuals*
  - *Model the individual behaviour directly*
  - *Let the system evolve by itself*

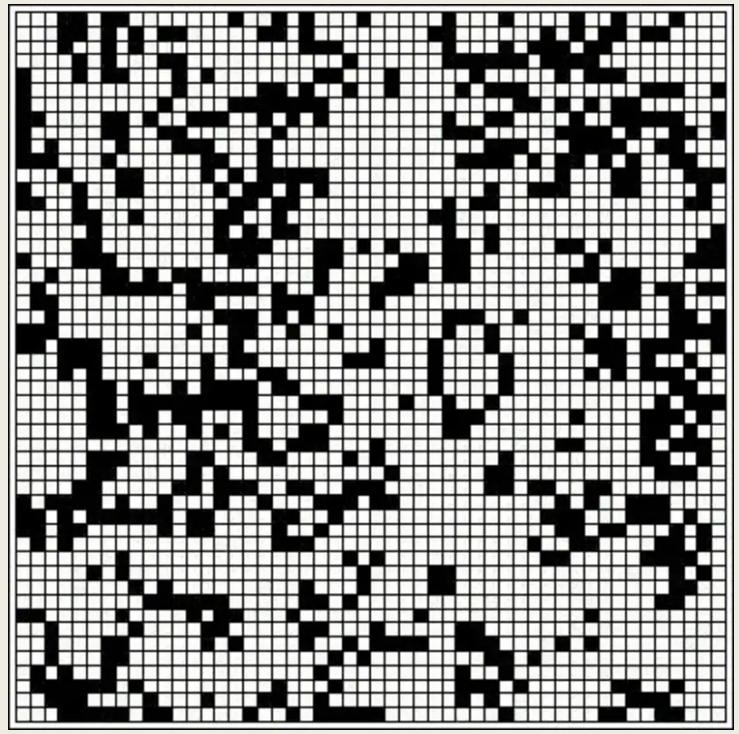
Picture by Wayan Vota
(http://www.flickr.com/photos/dcmetroblogger/)

Aggregate vs. individual-level

- Aggregate models work very well in some situations
  - *Homogeneous individuals*
  - *Interactions not important*
  - *Very large systems (movement of people)*
- But they miss some important things:
  - *Low-level dynamics, i.e. “smoothing out” (Batty, 2005)*
  - *Interactions (e.g. spread of COVID-19)*
  - *Emergence*
  - *Complex systems*

What is a complex system?

- Lots of individual components (individuals, organisations)
- Each have a relationship with other components
- Changes over space
- Changes over time
- Unknown what the outcome is (emergence)



Game of Life: Cellular Automata

What is an agent? (I)

- No universal definition
- But most people agree that agents should exhibit some of the following criteria

- **Autonomy**
  - *Act independently, free from central control*
  - *Control its own state and make independent decisions*

What is an agent? (II)

- **Heterogeneity**
  - *Agents should not normally be identical*
  - *Groups of similar agents are formed from the ground-up (e.g. by agents interacting with each other)*

- **Reactivity**
  - *Agents can sense their environment and respond to changes*
  - *Responses should be* ***goal-directed***

What is an agent? (III)

- **Bounded rationality**
  - *Agents should not have full knowledge of the world (this would be very unrealistic)*
  - *Environmental perception can be limited*
  - *Choices will not be perfectly rational – they can make mistakes*
- **Interactive**
  - *Agents can communicate with each other*
  - *Could be dependent on environment (e.g. distance)*

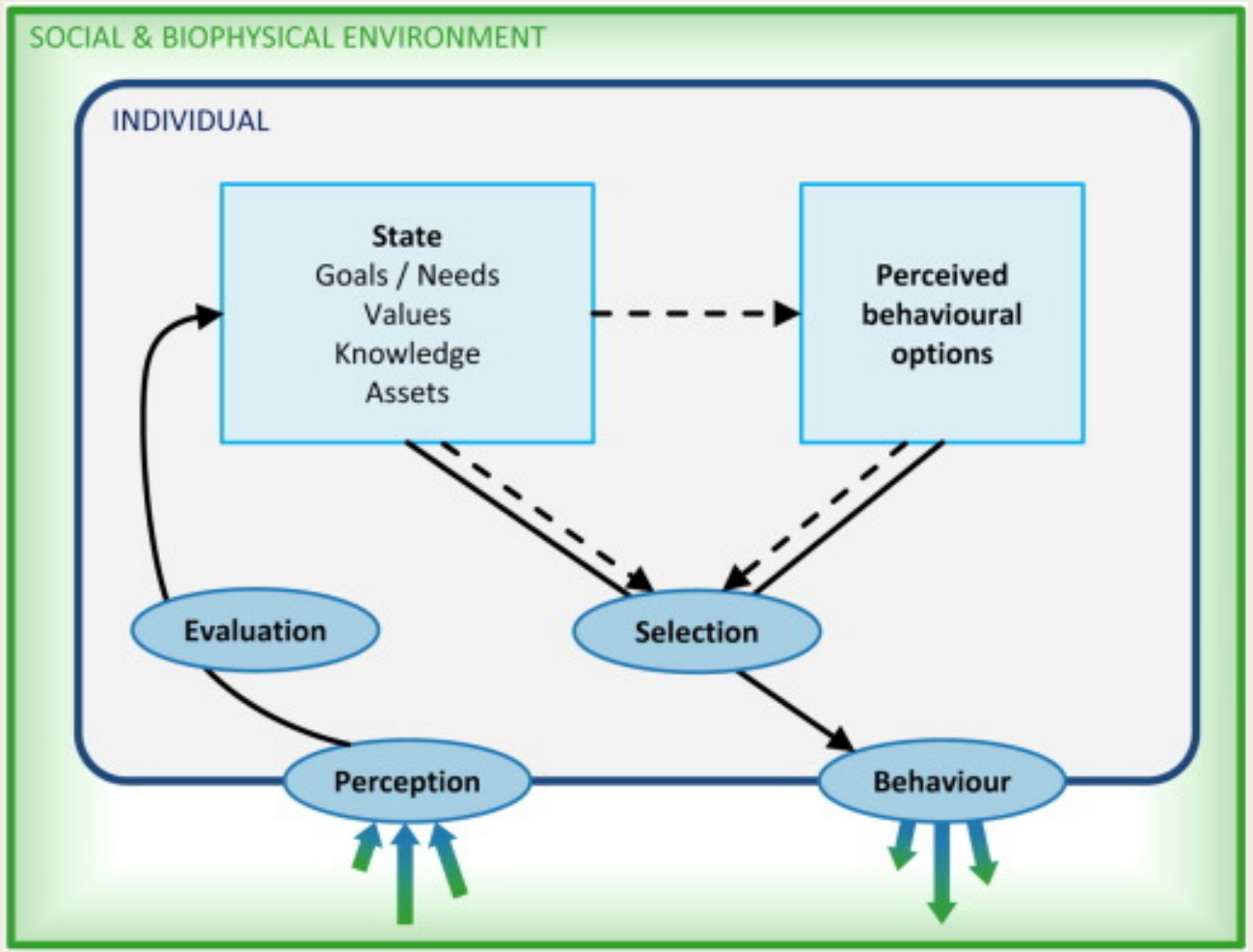
What is an agent? (IV)

- **Mobile**
  - *Often agents will be able to navigate a space.*
- **Learning / adaption**
  - *Agents should be able to adapt future decisions, based on past experiences*

Modelling human behaviour in ABM

- Simple rules, rule of thumb
- Rules from experts and practitioners in the systems (specialised systems, e.g. farming, electricity market, auction)
- Rational agent/optimisation
- Bounded rationality with limited information and cognitive capacity
- Psychological theories (e.g. Prospect Theory, Theory of Planned Behaviour)
- Data-driven machine learning approach
- AI models
  - *Belief–desire–intention*
  - *Learning*

Modelling human behaviour in ABM



Schlüter, Maja, et al. "A framework for mapping and comparing behavioural theories in models of social-ecological systems." *Ecological Economics* 131 (2017): 21-35.

How does ABM differ from microsimulation?

What is microsimulation?

- The generation of a population sample *P* made up of *n* individuals.
- Each individual has a set of attributes.
- Attributes can be updated over time.
- Initial population often taken from population samples in large scale surveys

How does ABM differ from microsimulation?

- **Microsimulation:**
  - *Individuals do not interact with each other*
  - *Individuals updated at end of each iteration.*
  - *More suitable for upscaling and population projections*
- **ABM:**
  - *Individuals interact with each other*
  - *Individuals can be updated asynchronously.*
  - *More suitable for modelling emergent phenomenon*

Appeal of ABM – Natural way of thinking

- Most '**natural**' way of thinking about systems
  - *Individual actions drive the system*
  - *Easier to communicate to others*
  - *Transparent assumptions*
  - *Behaviours confirmed by actual people in the system*

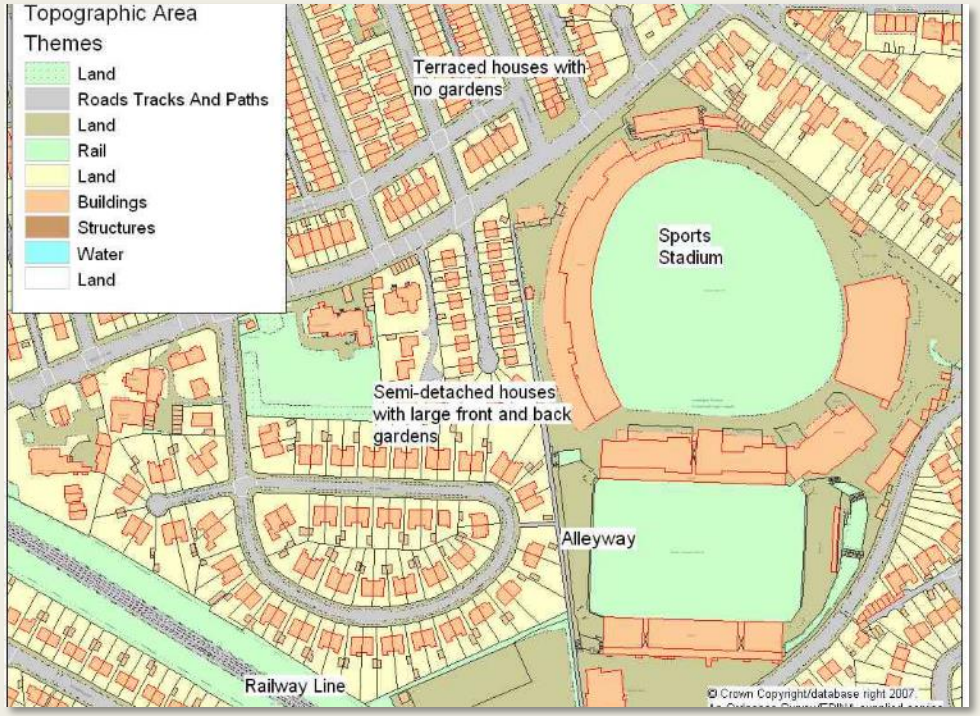
Appeal of ABM – Modelling emergence

- Emergence: The whole is greater than the sum of its parts
  - *Outcomes that are hard to derive (mathematically) from initial conditions*
  - *Path dependence (different outcomes from the same initial conditions due to stochasticity or randomness)*
  - *Unintended consequences*

> "A phenomenon is emergent when it can only be described and characterised using terms and measurements that are inappropriate or impossible to apply to the component units"
>
> - Gilbert (2004) page 3.

Appeal of ABM

- Can include both **physical space** and **social processes**
- Can represent **heterogeneous** agents
- Can represent individual-level decision making in a more realistic way
  - *Not limited to rationality*
  - *More complex and realistic behaviour*
  - *AI*
- Designed at abstract level: Easy to **change scale**



Disadvantages of ABM

- Known unknowns
  - *We don't know exactly what someone will do.*
  - *So we guess*
    - E.g. There is a 30% change of attending this lecture, and 70% chance of staying in bed
- Models that use randomness like this are **probabilistic**
- The need to run many times to ensure robust results
- Calibrating and validating

Disadvantages of ABM

- Computationally expensive.
  - *Complicated agent decisions*
  - *Lots of decisions!*
  - *Multiple model runs (robustness)*

- Modelling “soft” human factors
  - *Good that we can include complex psychology*
  - *But this is really hard!*

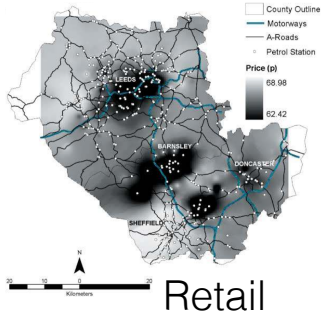
- Potential to over-complicate
  - *Need to think carefully about what to include*

Growth of Geographical ABM

Geographical Applications

Traffic

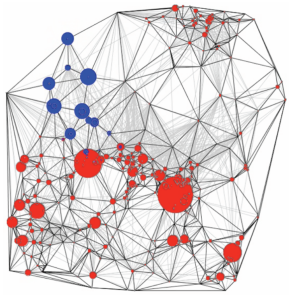
Manley *et al.* (2014)



Retail

Heppenstall *et al.* (2006)

Pumain (2012)

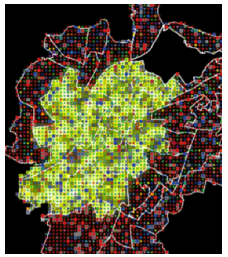


Migration

Gulden *et al.* (2011)

Xie & Fan (2014)

Haase *et al.* (2010)



Residential Location

Patel *et al.* (2012)

Benenson *et al.*(2002)

Augustijn-Beckers *et al.* (2011)

Jordan *et al.* (2014)

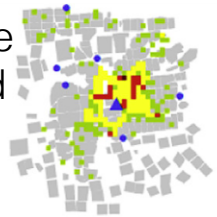
Disasters

Wise (2014)

Dawson et al. (2011)

Eubank *et al.* (2004)

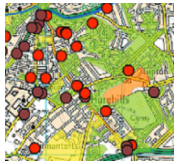
Disease Spread



Crooks & Hailegiorgis (2014)

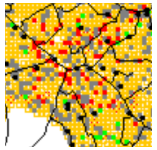
Batty *et al.* (2003)

Pedestrian Dynamics



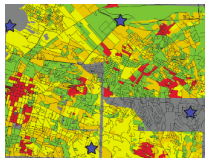
Crime

Malleson *et al.* (2013)



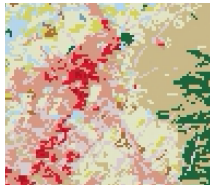
Riots

Pires & Crooks (2017)



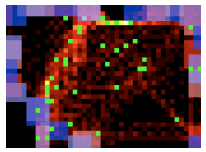
Humanitarian Relief

Crooks & Wise (2013)



Urban Growth & Land Use Change

Wise & Crooks (2013)



Torrens & McDaniel (2013)

Crooks *et al.* (2015)

Spatial Scale

Macro

Meso

Micro

Minutes

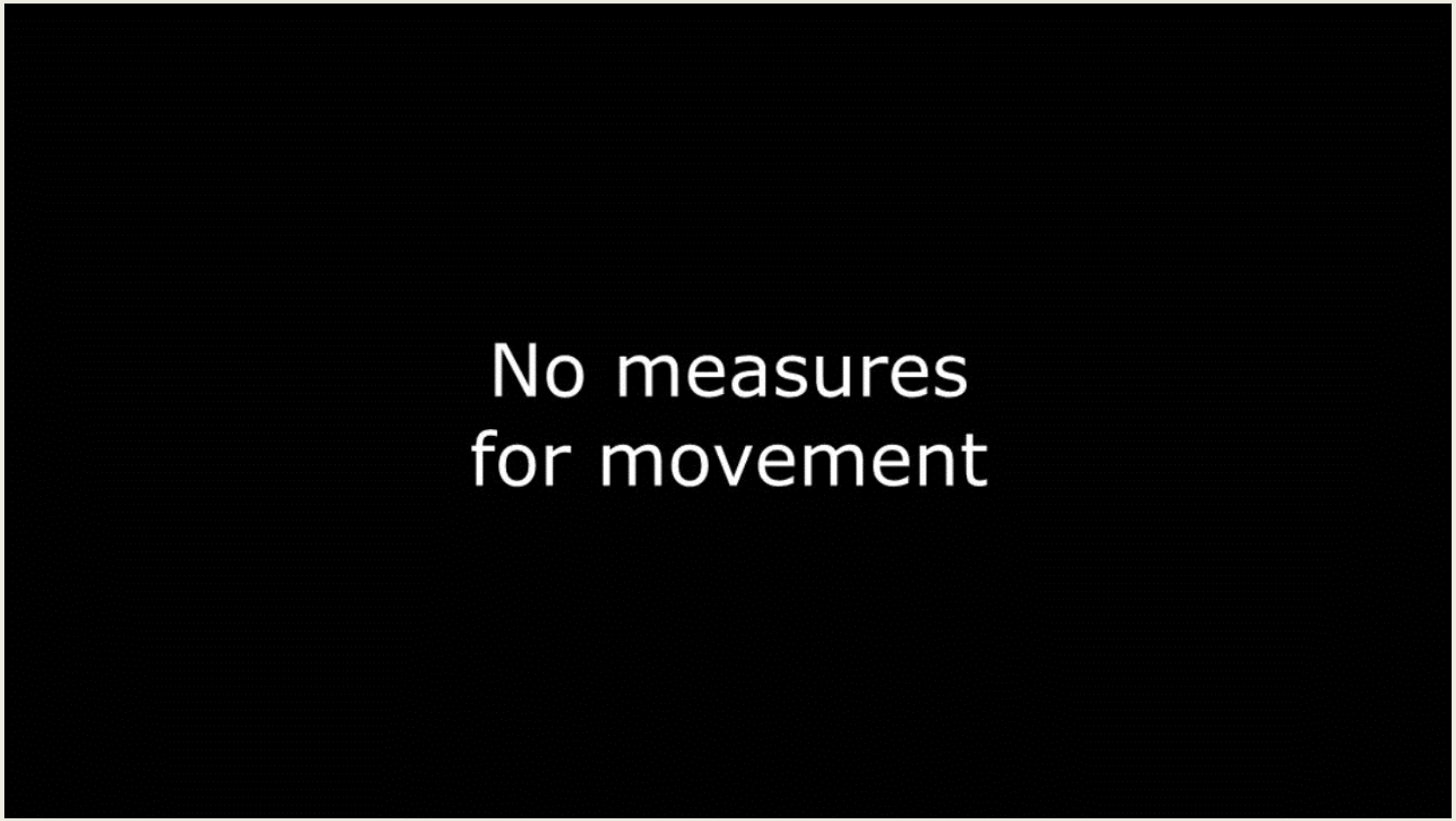
Hours

Days

Years

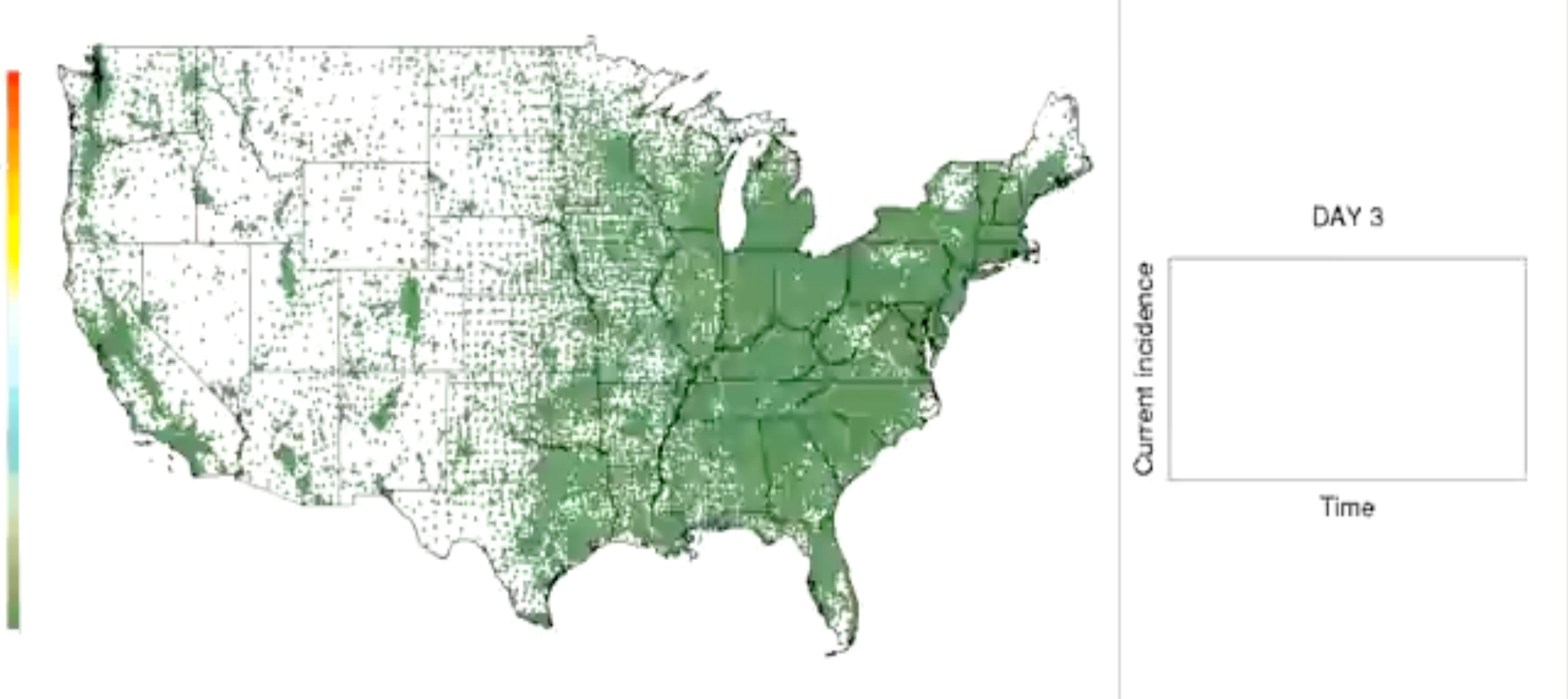
Temporal Scale

ABM Example: COVID-19 measures



Source: Washington Post https://www.washingtonpost.com/2020/world/corona-simulator/

Example 2: Simulation of a flu pandemic outbreak in the continental United States, initially introduced by the arrival of 10 infected individuals in Los Angeles



Each dot represents a Census tract and changes color from green to red as more people in that tract become infected

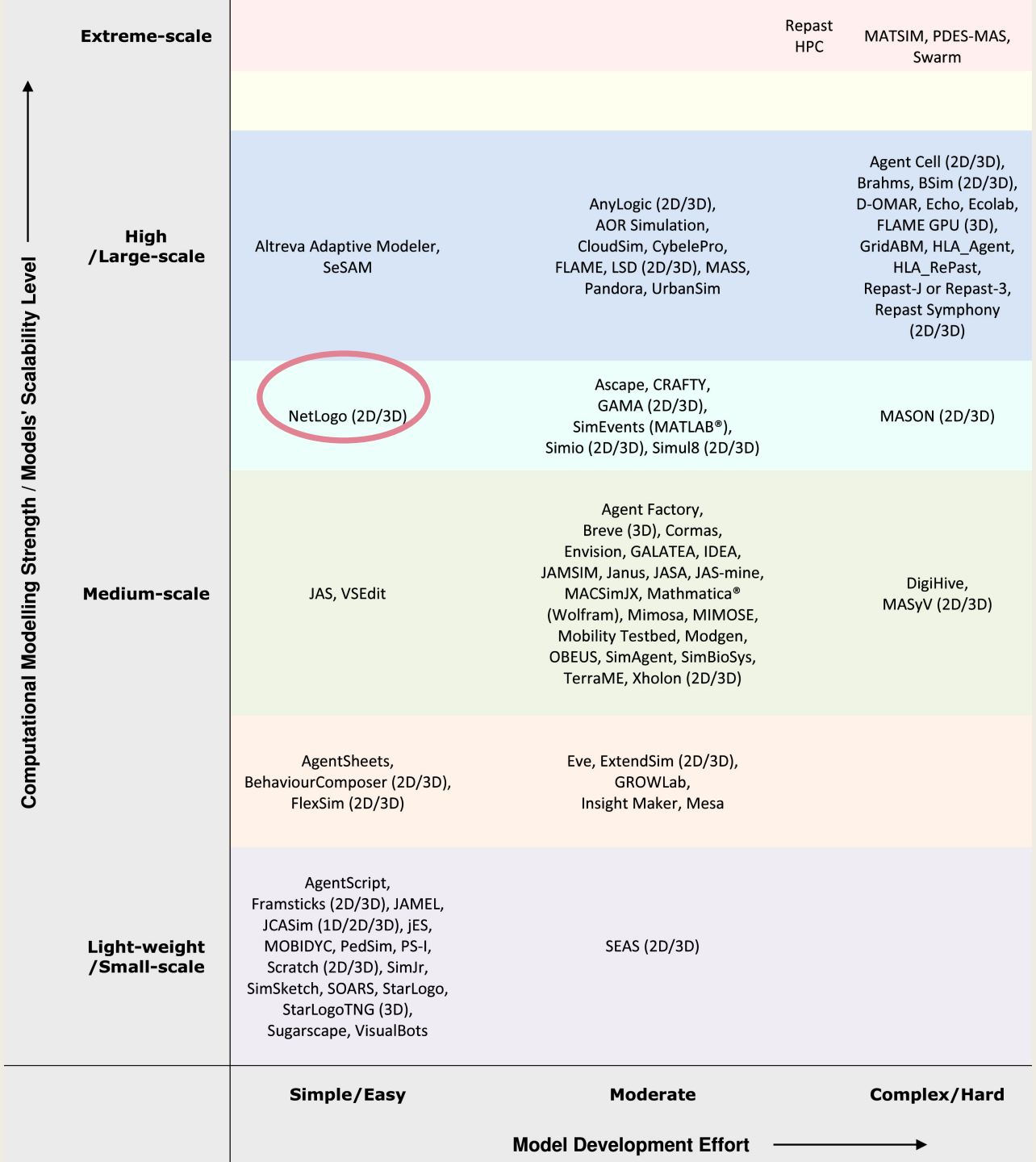
Source: http://tinyurl.com/4oxxx3l & http://tinyurl.com/4lerjwv

When to use ABM

- Interactions between agents and multiple systems are important
- Human behaviour is important in a natural system
- Heterogeneous agents and behaviour (land patches, species, humans, social groups…)
- Complex system and emergent outcomes
- Rich individual-level data or network data are available

Available ABM software tools

Abar, Sameera, et al. "Agent Based Modelling and Simulation tools: A review of the state-of-art software." *Computer Science Review* 24 (2017): 13-33.



Netlogo

- Advantage
  - *Free*
  - *Easy to learn, nice GUI, immediate results*
  - *Large active community*
  - *Extensive model library*
  - *Quite efficient, multiprocessing*
  - *Behaviour space for calibration and sensitivity analysis*
  - *Rnetlogo, PyNetlogo – to call from R and Python*
- Disadvantage
  - *Limited debug functionality*
  - *Limited upscaling for very big models*

NetLogo Example – Basic traffic simulation

http://www.netlogoweb.org/launch#http://www.netlogoweb.org/assets/modelslib/Sample%20Models/Social%20Science/Traffic%20Basic.nlogo

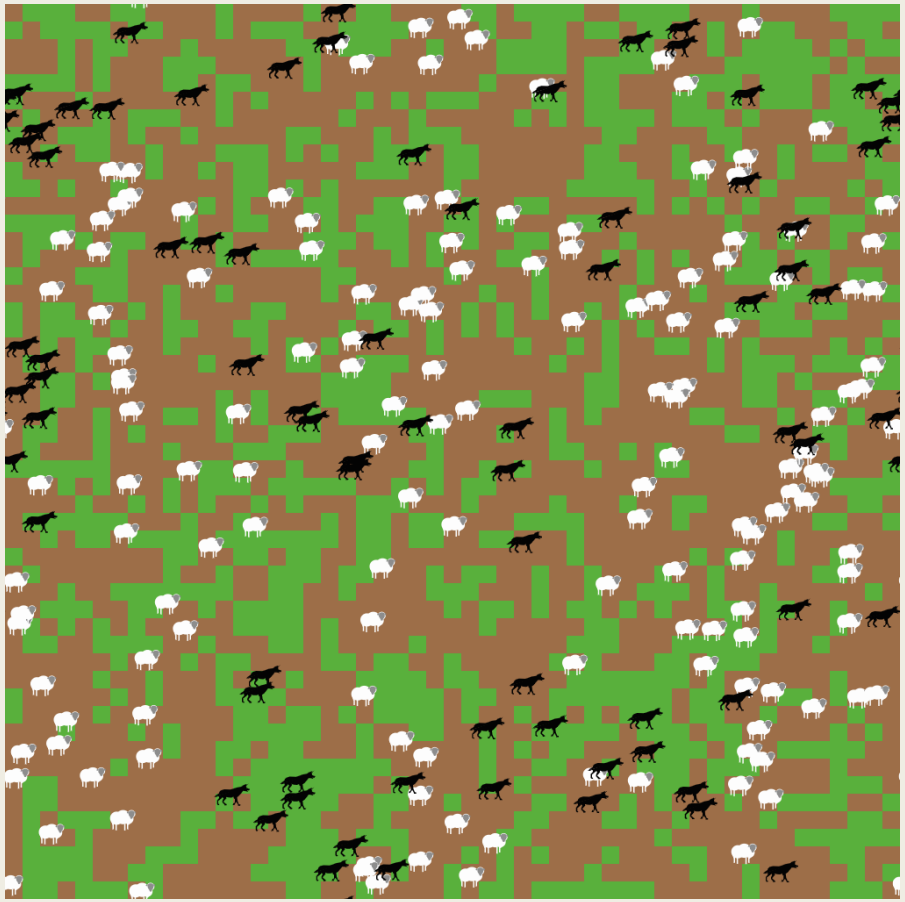
Think about: How does a traffic congestion form?

Netlogo example: Wolf sheep predation

http://www.netlogoweb.org/launch#http://ccl.northwestern.edu/netlogo/models/models/Sample%20Models/Biology/Wolf%20Sheep%20Predation.nlogo

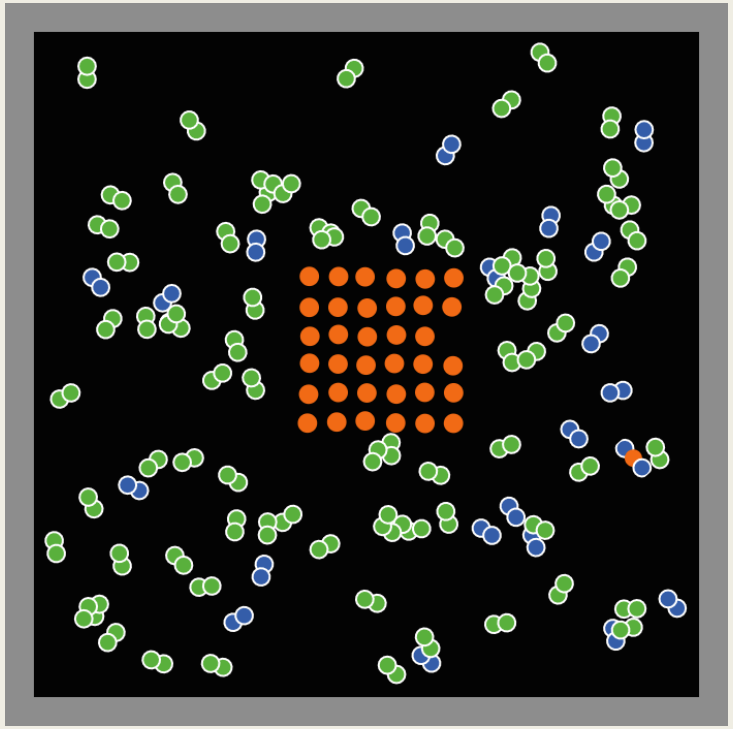
Think about

- Is the wolf-sheep-grass system stable?
- Under what conditions is the system stable?
- Under what conditions will the wolf go extinct?

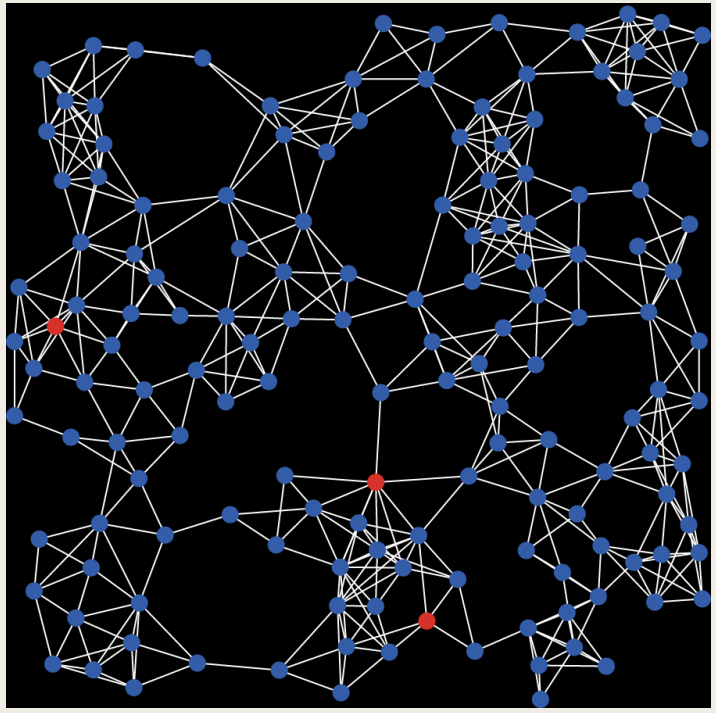


Have a go at NetLogo yourself!

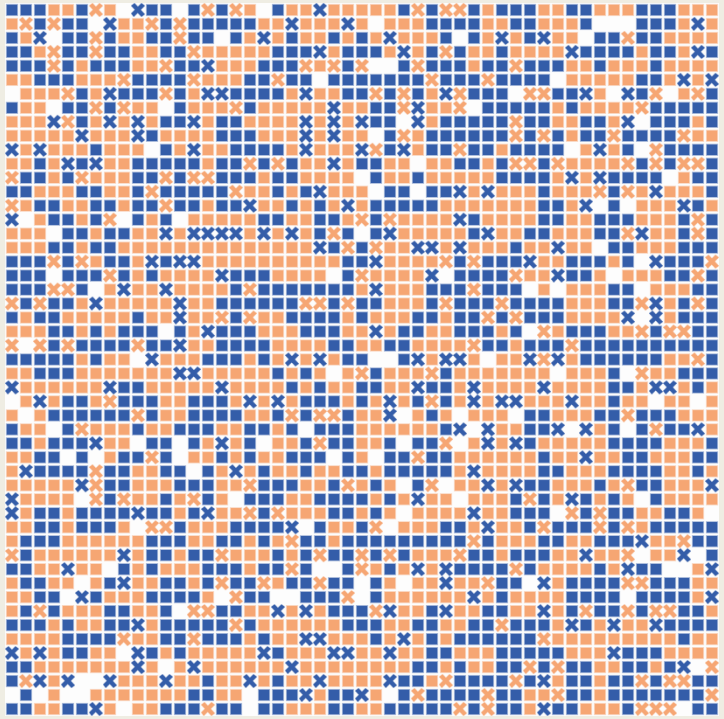
https://ccl.northwestern.edu/netlogo/ and go to ***NetLogo Web***



Combustion reaction



Virus spread network



Neighbourhood segregation

PRACTICAL SESSION: USING NETLOGO TO BUILD AN ABM

Reading list

- Crooks, A., Malleson, N., Manley, E., & Heppenstall, A. (2018). *Agent-based modelling and geographical information systems: a practical primer*. Sage.
- Brunsdon, C. and Singleton, S. (2015) Geocomputation: a practical primer, p392 pages, SAGE. Edmonds, B., Meyer, R., 2013. *Simulating social complexity : a handbook* . Springer-Verlag, Heidelberg.
- Gilbert, G.N. and Troitzsch, K.G. (2005) *Simulation for the social scientist* . Open University Press, Maidenhead, England; New York, NY.
- Heppenstall, A.J., Crooks, A.T., See, L.M. and Batty, M. (2012) *Agent-based models of geographical systems* . Springer.
- O'Sullivan, D. and Perry, G.L. (2013) *Spatial simulation : exploring pattern and process* . John Wiley & Sons Inc, Chichester, West Sussex, UK.
- Tesfatsion, L., & Judd, K. L. (Eds.). (2006). *Handbook of computational economics: agent-based computational economics (Vol. 2)*. Elsevier.
- Hamill, L., & Gilbert, G. N. (2016). *Agent-based modelling in economics*. UK: John Wiley & Sons.
- Gilbert, N., & Terna, P. (2000). *How to build and use agent-based models in social science*. Mind & Society, 1(1), 57-72.