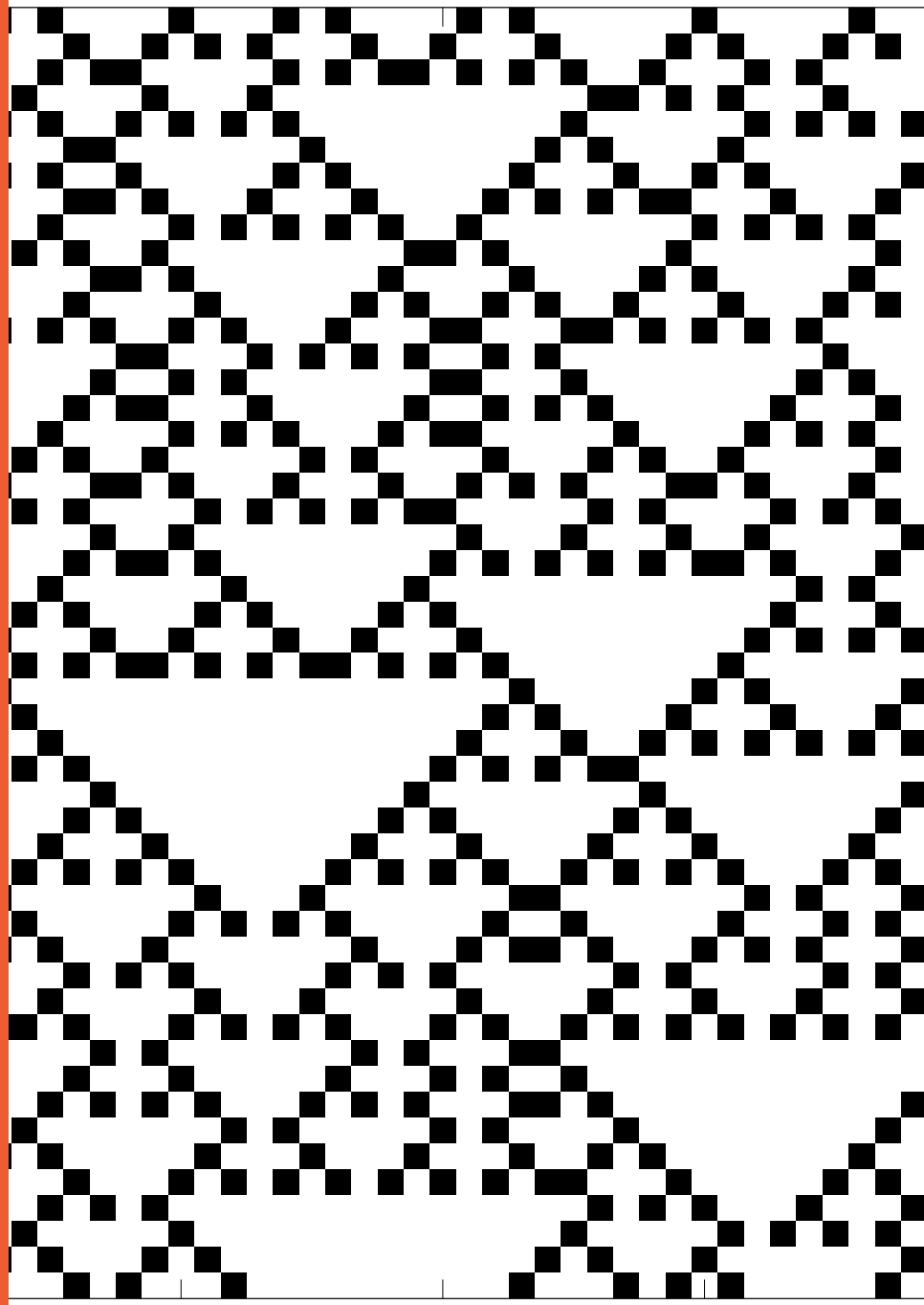
# CSYS5010 Introduction to Complex Systems

## Week 1c Complex systems modelling

Dr. Joseph Lizier



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# Complex Systems modelling – Session outcomes

- Understanding and ability to discuss of the modelling loop process
- Able to apply modelling techniques to examples of complex systems
- Ability to run and analyse pre-defined models in NetLogo

- Primary references:
  - H. Sayama, "*Introduction to the Modeling and Analysis of Complex Systems*", Geneseo, NY: Open SUNY Textbooks, 2015 – chapter 2, "Fundamentals of Modeling"

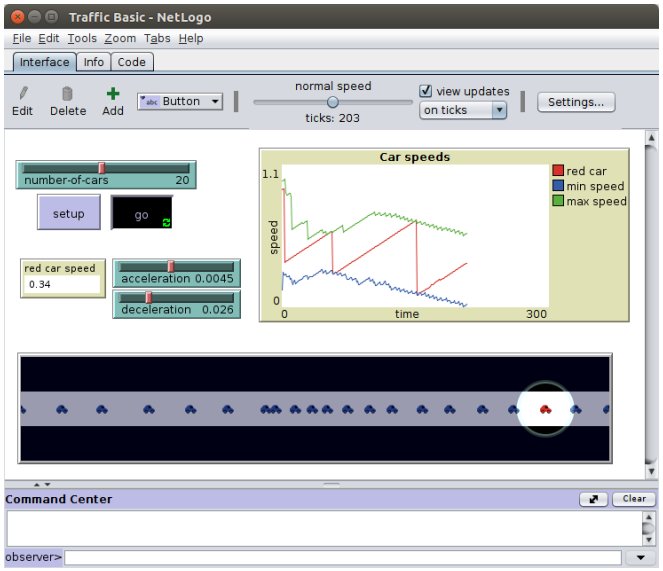
# Modelling traffic

1. Everybody on the floor!
2. You are all driving a “car” in a ring around the room
3. Rules:
    1. No overtaking
    2. Avoid collisions
4. One volunteer to monitor a segment of road on sidelines

# "Live" traffic modelling – reflection

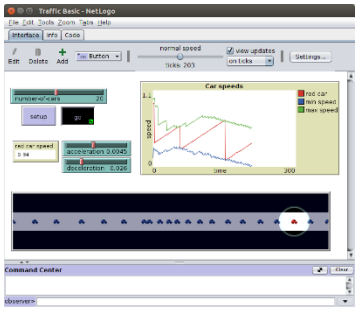
- How might we model traffic? What types of models could we use?
  - At which level do these models operate?
  - How might our volunteer model the traffic?
- Why might we want to model individual drivers?
- How did you behave as a driver?
  - How would you model individual driver behaviour?
  - What assumptions have you made?
  - Are we forgetting anything …?

# Let's do it in NetLogo



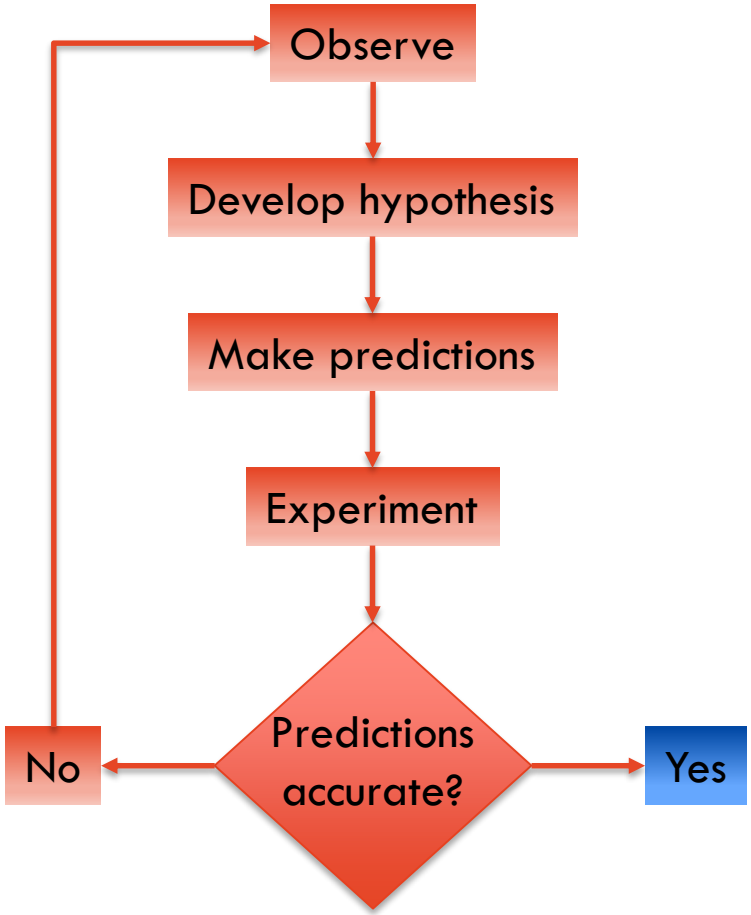

1. Start NetLogo
2. Open the Models Library (`File | Models Library`) then browse to `Sample Models | Social Science | Traffic Basic` and click `Open`
3. Click "`setup`" button.
4. Take note of the UI and parameters
   a. Are there any parameters we didn't consider before?
   b. What do you think will happen when you click "`Go`"?
   c. Click "`Go`" and observe – is it what you expected?

# Let's do it in NetLogo



5. Observe what is happening in the model:
   a. Try again with a new random initial condition – do the results persist?
   b. How would you qualitatively describe the dynamics here? What are the important aspects? Is there emergent behaviour here?
   c. How would you quantitatively characterise the dynamics? How would you do it statistically, and is this appropriate?
6. Try changing the number of cars slider, and the acceleration/deceleration sliders – how does behaviour change?
   **a. Challenge**: try to work out how the parameters inter-relate to create shockwave jams or free-flow?
7. Is this a good model of traffic? Why / why not? Is it better than what you had in mind before?
   a. What else could we include / change?
   b. How might you check whether the model was an accurate representation of reality?

# Scientific method




Issues:

- Is your hypothesis proven?
- Is diagram complete?

H. Sayama, "*Introduction to the Modeling and Analysis of Complex Systems*", Geneseo, NY: Open SUNY Textbooks, 2015; pp. 11-13

# Models

- Sayama, p. 13: "*all science can do is just build models of nature*"
  - "***A model is*** *a simplified representation of a system. It can be conceptual, verbal, diagrammatic, physical, or formal (mathematical).*"

- Why model?
  - Understanding
  - Prediction
  - Design/control

Science

Engineering

H. Sayama, "*Introduction to the Modeling and Analysis of Complex Systems*", Geneseo, NY: Open SUNY Textbooks, 2015; pp. 11-13

# Types of models

- Descriptive models:

  *In this approach, researchers try to specify the actual state of a system at a given time point (or at multiple time points) in a descriptive manner. Taking a picture, creating a miniature (this is literally a "model" in the usual sense of the word), and writing a biography of someone, all belong to this family of modeling effort. This can also be done using quantitative methods (e.g., equations, statistics, computational algorithms), such as regression analysis and pattern recognition. They all try to capture "what the system looks like."*

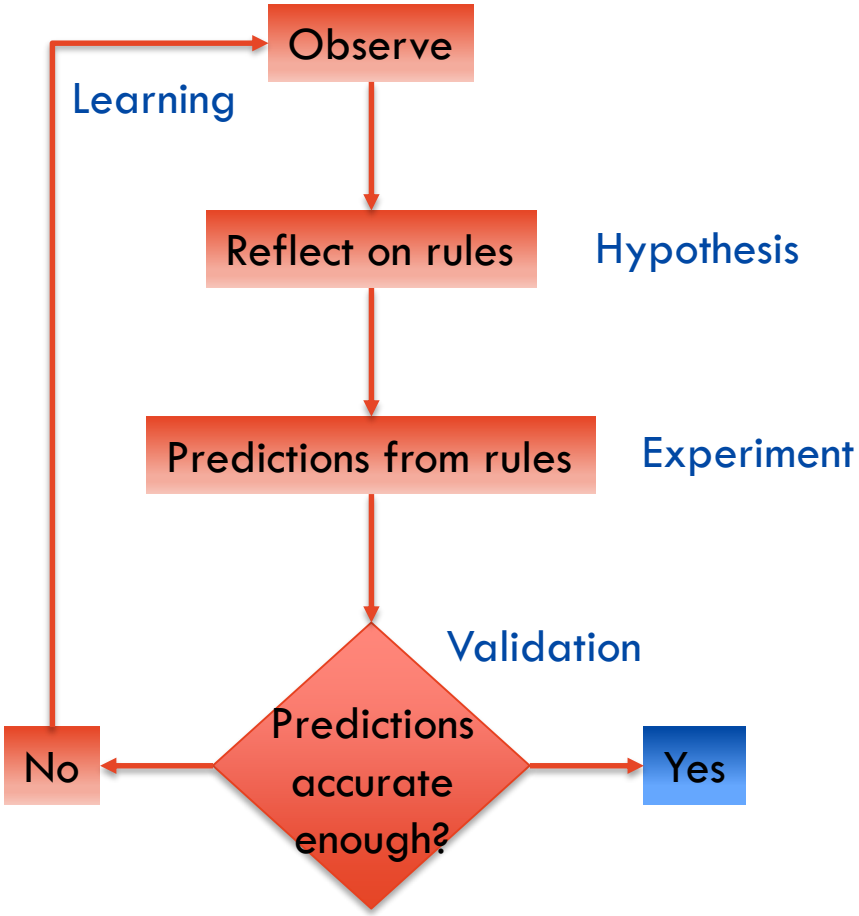
- Rule-based models:

  *In this approach, researchers try to come up with dynamical rules that can explain the observed behavior of a system. This allows researchers to make predictions of its possible (e.g., future) states. Dynamical equations, theories, and first principles, which describe how the system will change and evolve over time, all belong to this family of modeling effort. This is usually done using quantitative methods, but it can also be achieved at conceptual levels as well (e.g., Charles Darwin's evolutionary theory). They all try to capture "how the system will behave."*

Passages quoted from:
H. Sayama, "*Introduction to the Modeling and Analysis of Complex Systems*", Geneseo, NY: Open SUNY Textbooks, 2015; p. 14

# Modelling process

Sayama:




It's a modelling loop

Can be expressed various ways

E.g. Kristian Lindgren to me: "*model development, implementation, analysis, feedback*"

Helbing adds considerations:

- What is the purpose of the model?
- Hypotheses should be valid in the domain of the model

H. Sayama, "*Introduction to the Modeling and Analysis of Complex Systems*", Geneseo, NY: Open SUNY Textbooks, 2015; p. 14

D. Helbing and S. Balietti, "Agent-Based Modeling", in D. Helbing (ed.), Social Self-Organization, Springer, Berlin, 2012, pp. 35-36

# How to create a (rule-based) model

1. What questions do you want to address?
   - Helbing: understanding, accurate description, prediction, new situations
2. For this, at what scale should you describe the system?
   - Helbing: "*one should not put into the model assumptions what one wants to explain. The mechanisms on which … simulations are based should be (at least) one level more elementary than the evidence to be understood.*"
3. How is the system structured?
   - What are the components and how do they interact (networks!)
4. What are the possible states of the system and/or components?
5. How does the state of the system change over time?
   - Defining dynamical rules

Sayama: "*You will likely need to loop through these questions several times until your model successfully produces behaviors that mimic key aspects of the system you are trying to model.*"

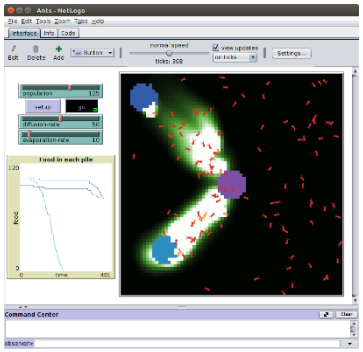
H. Sayama, "*Introduction to the Modeling and Analysis of Complex Systems*", Geneseo, NY: Open SUNY Textbooks, 2015; p. 20
D. Helbing and S. Balietti, "Agent-Based Modeling", in D. Helbing (ed.), Social Self-Organization, Springer, Berlin, 2012, pp. 35-36

# Creating a model – important considerations

- Sayama p. 21 *"A good model is simple, valid, and robust"*
  - Simplicity:
    - Occam's razor; Helbing: too many parameters are difficult to calibrate, suffer from overfitting.
  - Validity
    - Of predictions against observed reality
    - Of assumptions, e.g. Helbing: use meaningful parameters that can be operationally measured where possible
    - Trade-off between simplicity and validity, avoiding overfitting
  - Robustness
    - to variations in assumptions and parameter settings (which may be slightly inaccurate or subject to noise)

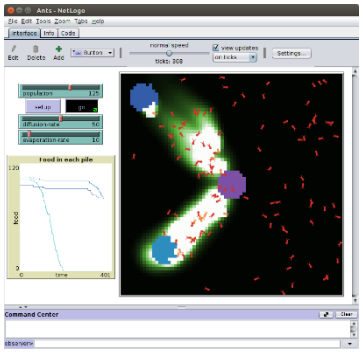
H. Sayama, "*Introduction to the Modeling and Analysis of Complex Systems*", Geneseo, NY: Open SUNY Textbooks, 2015; pp. 21-2
D. Helbing and S. Balietti, "Agent-Based Modeling", in D. Helbing (ed.), Social Self-Organization, Springer, Berlin, 2012, p.37

# Ant foraging – NetLogo



1. Start NetLogo
2. Open the Models Library (`File | Models Library`) then browse to `Sample Models | Biology | Ants` and `Open`
3. Click "`setup`" button.
   a. What do you think will happen when you click "`Go`"?
   b. Click "`Go`" and observe
4. Click the `Info` tab and read in detail about the model
5. Come back to the `Interface` tab, try different parameter settings, different initial conditions (as guided by your reading) and observe.
6. What observations of real ant foraging might such a model be used to predict?
7. Go back to Sayama's 5 steps for creating a model on slide 12 – what would the model designers have done at each step here? (PIs detail)
8. Is the model: Simple? Valid? Robust? Justify your thoughts!

# Ant foraging – NetLogo



**Further thinking /challenges** (*post-class*):

- Revisit the definition of complex systems from Lecture 1b – is the ant foraging a complex system? Why/why not?
- Does this model display: emergence? Self-organisation? Order-chaos interplay?
- Is this a good model – why/why not? What might be useful to add to it?

Play with other models in the NetLogo model library, and talk through some of the same questions we've posed about the Ants model. Remember the `Info` tab will help!

# Summary

- We've looked at what modelling is, considered modelling as a loop process, and how to create a good model.
  - (*Implicit?*) Why modelling is important for studying complex systems
- *Next week*: Let's learn how to conduct agent-based modelling …

# Questions

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