Agent-based Modelling

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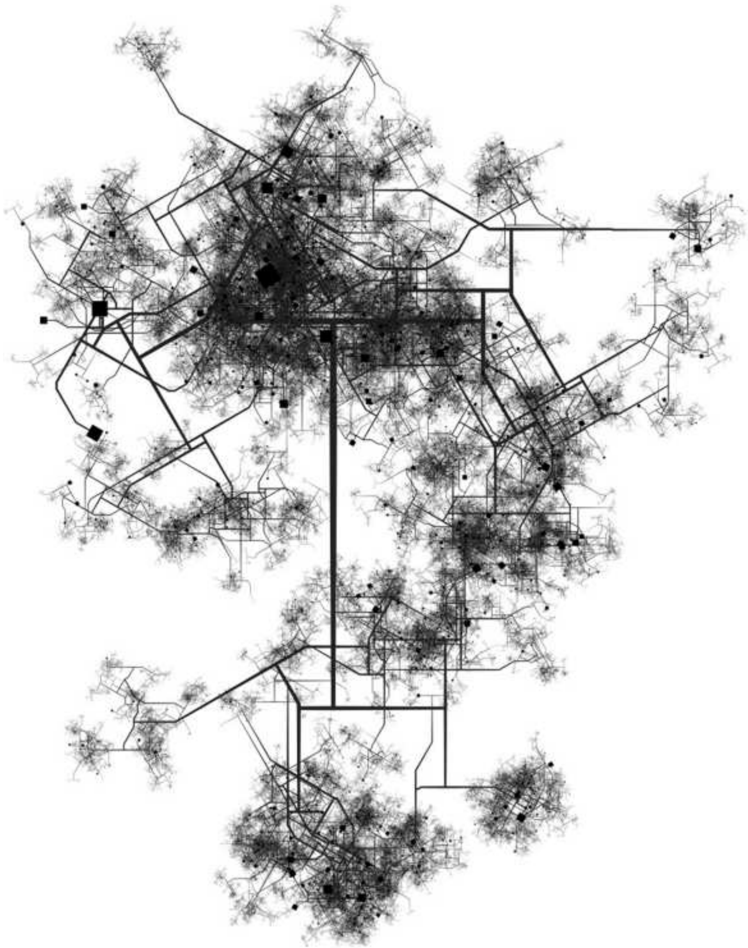
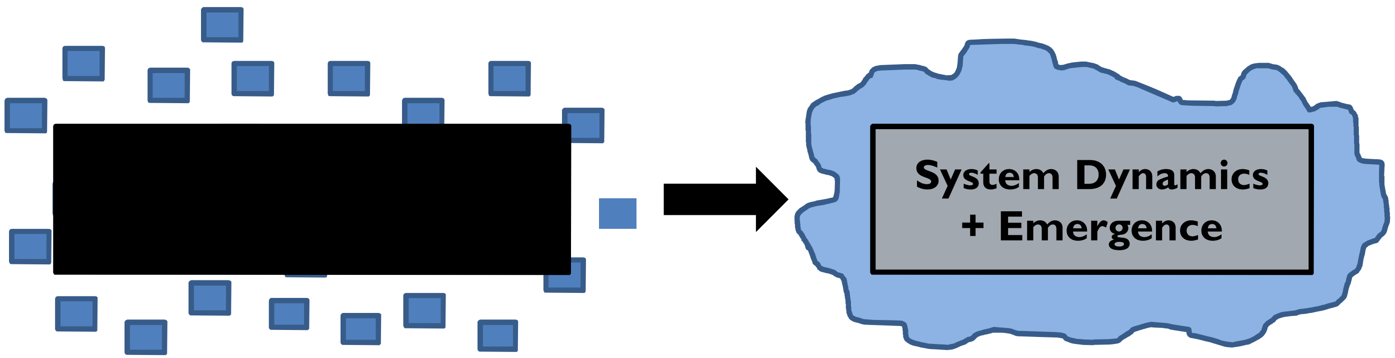
Today's Talk

- Complex Systems
- Agent-based Modelling
  - In Principle
  - By Example
  - My Research
  - The Possibilities
- Development of Agent-based Models
  - Design Principles
  - Software



Complex Systems

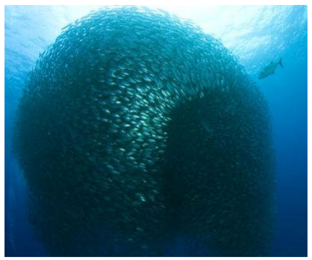
Complex Systems

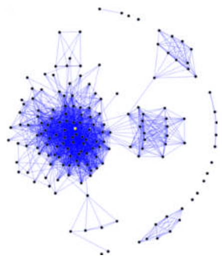


"Whole is greater than the sum of it's parts"





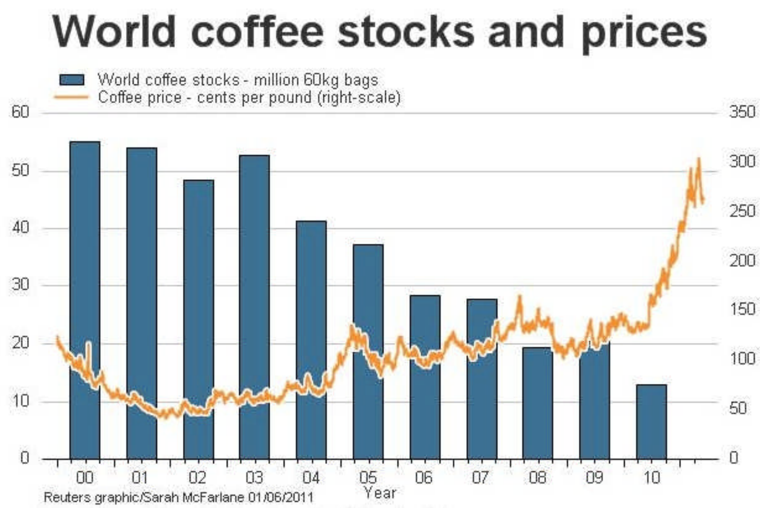


Complex Systems

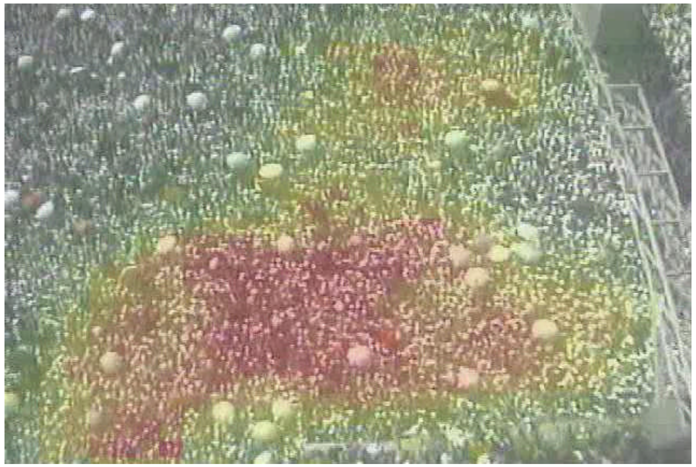
Non-Linear Behaviour

System behaviour is characterised by **non-linear** actions and interactions

Responses to actions may be **disproportionate**,
not easily predicted through examination of macroscopic dynamics only



"…increase in price speculation and deliberate hoarding"



Complex Systems

Self-Organisation

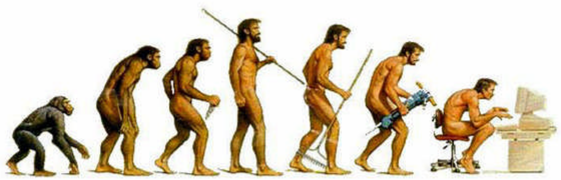
Development of **form** and **pattern** through behaviours of individuals, with **no centralised coordination**

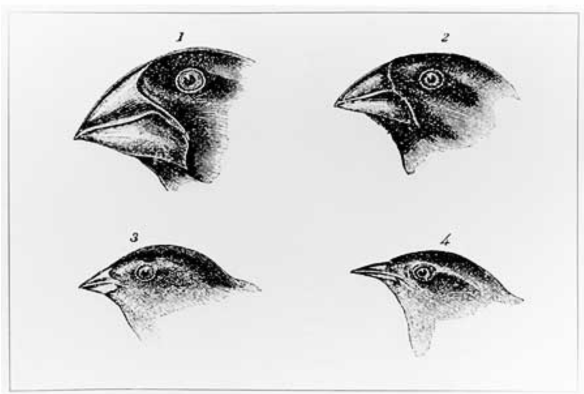
Complex Systems

Learning and Adaptation

Systems remembers past events and **adapts to change**

Nature of system evolves over time through learning better outcomes





Architectural adaptation in Abyaneh, Iran

Complex Systems
Cascading Behaviour

Certain behaviours can **cascade** across networks of individuals

Behaviour can **transfer** quickly between individuals, not allowing them enough time to adapt to the new conditions

Complex Systems

Inter-System Complexity

Systems do not sit in isolation, they **interact** with others at higher levels

A key challenge for understanding a complex system is identifying where the **boundary of influence** lies

What is the cause?

Social?
Political?
Technical?
Economic?

How far does it influence?

City-wide?
Nation-wide?
World-wide?

Complex Systems

Driven by Individual Behaviour

Complex phenomena are best understood through consideration of the behaviour of all interacting parts

- How does each individual play a part in the system?
- How does individual behaviour change reflect in the system?
- How do individuals and systems interact to cause change?
- How do interactions vary in respect to other conditions?

Macroscopic phenomena **emerge** through
Microscopic actions and interactions

Why Study Complex Systems?

- Many of today's most important global challenges are a product of interactions between individuals and systems

- Social, technological, economic, physical, environmental and political systems all can play a role

- Understanding these issues requires an insight into the complexity of interactions occurring within the system

Agent-based Modelling

Modelling Complex Systems

Traditional Methods

Traditional approaches – usually incorporating DEs – miss out much of the relevant detail, held within the interactions of individuals

Highly non-linear and non-equilibrium processes

High heterogeneity within the system

Individuals naturally adapt and change to new conditions

Modelling approaches must capture the full extent of behaviour, not constrain or smooth them through macroscopic equations

Modelling Complex Systems
Agent-based Modelling

Agent-based Modelling simulates from individual perspective, capturing emergent phenomena through agent behaviour

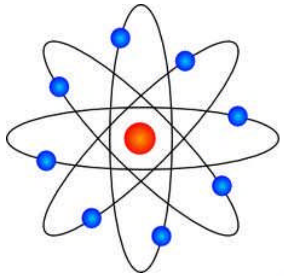
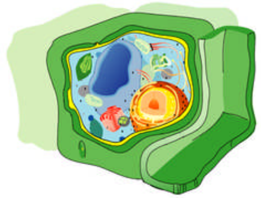
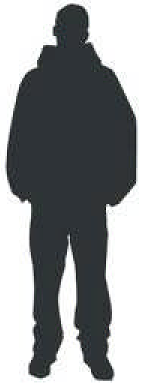
Individual agents are modelled on real-world entities, as autonomous decision-makers that act according to a set of rules

The behaviours and interactions of all agents results in collective phenomena reflecting system dynamics

Modelling Complex Systems

What is an agent?

- A distinct entity, actively involved in dynamics of the system
- Always autonomous
- May be human, animal, infrastructural, physical, technical, basically any kind of encapsulated individual
- Behaviour may be very simple, or quite complex
- May be heterogeneity among population, but not always


Modelling Complex Systems

Agent-based Modelling

Agent-based Modelling enables the exploration of how a system changes over space and time

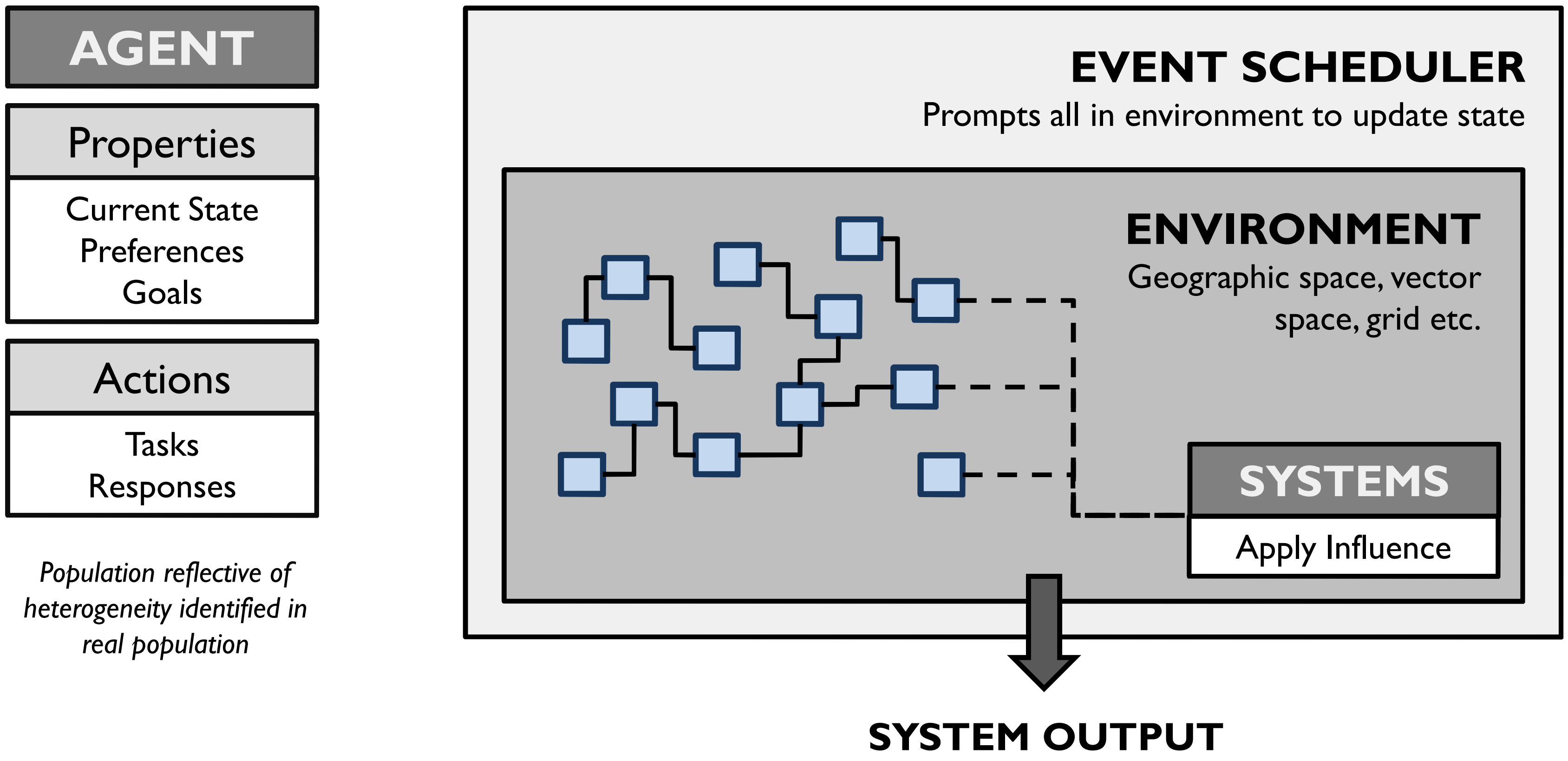
In many cases, spatial proximity is vital, and strongly influences agent behaviour.

The behaviour of a system usually changes over time – this is an explicit component of all agent-based models

Agent-based Modelling

In Principle

Agent Behaviour | **Simulation Environment**



Agent-based Modelling

Modelling Behaviour

- Agent behaviour may be simple or sophisticated
- However, this does not necessarily reflect in the degree of complexity viewed at the system level

- We'll now go through some examples of simple and complex agent behaviour, demonstrating how accumulated behaviour reflect in macroscopic phenomena
- Models developed in NetLogo software

Agent-based Modelling

By Example

Ant Nest Model

Simple ant foraging behaviour

Simple model demonstrating ant communication behaviours around food sources

Heterogeneity across population only lies in agents' actions – yet macroscopic patterns still resolve

Ants move randomly in search for food, once found they return to the nest, leaving a pheromone trail for other ants to follow

Other ants, on sensing the pheromone, follow it towards the food source to carry out the same procedure

AGENT
Properties
-
Actions
Move Randomly Return to Nest Leave Pheromone Follow Pheromone

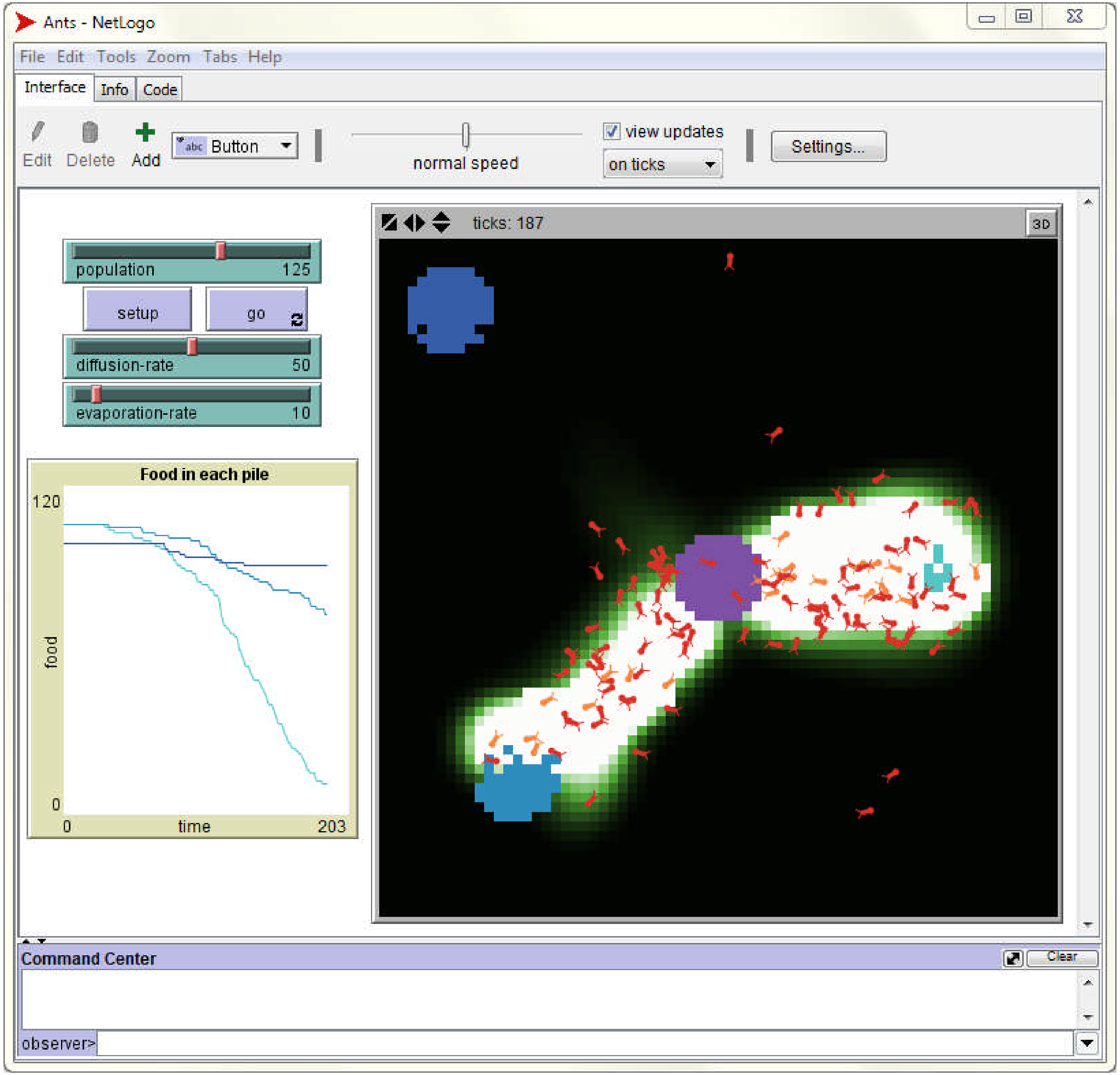
Agent-based Modelling

By Example

Ant Nest Model

Things to Notice:

- Route are established through the initial discovery by one single ant – this is **non-linear** and **self-organisational** behaviour
- Generally only one route is operating at a given time, with it being more difficult to establish other routes while most ants are preoccupied
- Altering the pheromone behaviours causes significant changes to rate at which food is found and transported back to nest


Ants - NetLogo
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Settings...
ticks: 187
3D
population 125
setup
go
diffusion-rate 50
evaporation-rate 10
Food in each pile
120
0
food
0 time 203
Command Center
Clear
observer>

Agent-based Modelling

By Example

Schelling's Segregation Model (1978)

The 'first' Agent-based Model

Model of evolution of racial segregation in American cities during 1970s

Two types of **simple** agents, behaviour leads to patterns developing in urban realm

Grid-based **spatial** representation of environment

System outputs showing % unhappy and % similar

AGENT

Properties

Agent Type
% Similar Wanted
Happy?
Similar Nearby %
Other Nearby %

Actions

Assess Area
Find Random Spot

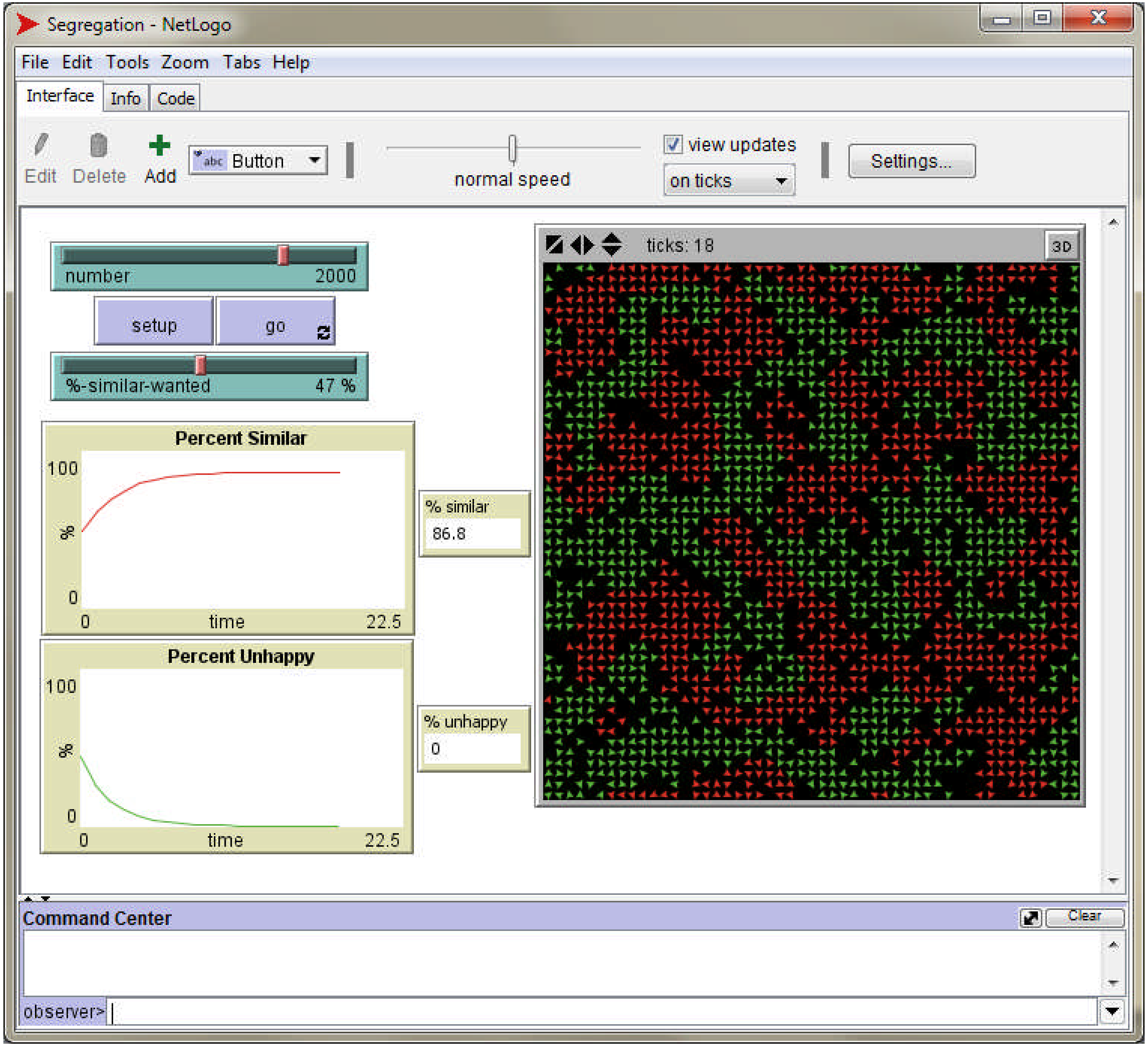
Agent-based Modelling

By Example

Schelling's Segregation Model (1978)

Things to Notice:

- Individuals move randomly, assessing each location independently, but yet order is established – **self-organisation**
- The random nature of movement means that the arrival of a single green agent may lead to the departure of a number of red agents – **non-linear** response to a simple action
- **Space** is very important – if space is available agents may cluster into completely homogenous groups, if not then allowances have to be made


Segregation - NetLogo
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Interface Info Code
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on ticks
Settings...
number 2000
setup
go
%-similar-wanted 47 %
Percent Similar
100
%
0
0 time 22.5
% similar
86.8
Percent Unhappy
100
%
0
0 time 22.5
% unhappy
0
ticks: 18
3D
Command Center
Clear
observer>

Agent-based Modelling

By Example

El Farol Bar (1994)

Exploring Agent Predictive Power

Popular bar in Sante Fe, New Mexico – Thursday night is Irish music night! However, the bar often gets uncomfortably crowded putting potential visitors off.

Agents use a **prediction strategy** to decide whether to go to the bar, prediction is based on a weighting of previous weeks' attendances

Agents utilise their best performing prediction strategies in deciding whether to attend or not.

AGENT

Properties

Strategies
Best Strategy
Current Prediction
Attend?

Actions

Create Strategy
Make Prediction
Go to Bar

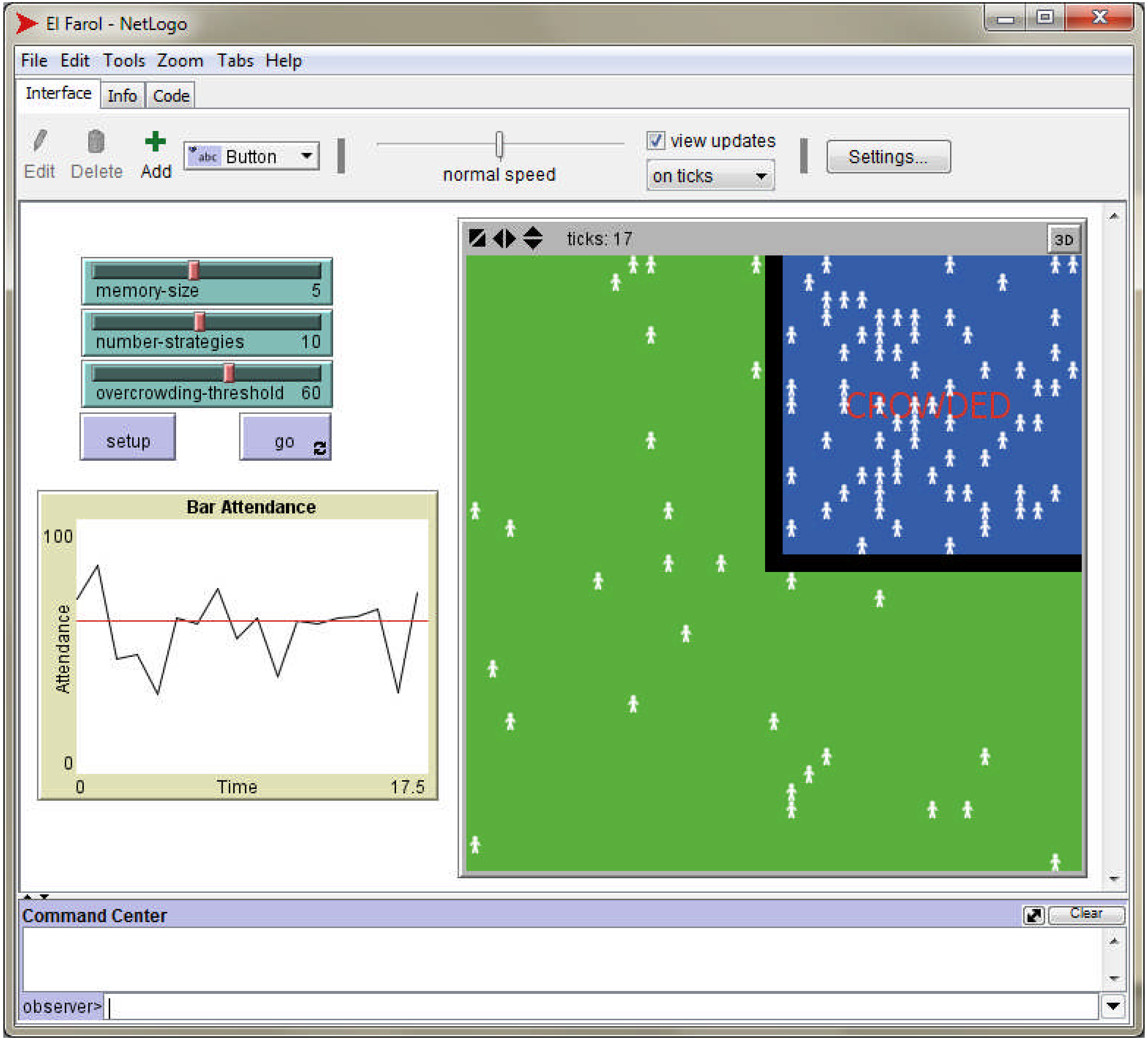
Agent-based Modelling

By Example

El Farol Bar (1994)

Things to Notice:

- Representation of inductive reasoning by agents, **bounded** in their knowledge of the problem
- **Game theoretic** representation of behaviour, predicting actions of others in order to select own behaviour
- Increased number of strategies leads to less variation in patterns
- When agents have memory of only previous week's attendance then the system descends into a chaotic loop of attendance and non-attendance


El Farol - NetLogo
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Settings...
memory-size 5
number-strategies 10
overcrowding-threshold 60
setup
go
Bar Attendance
100
Attendance
0
0
Time
17.5
ticks: 17
3D
CROWDED
Command Center
Clear
observer>

Agent-based Modelling

By Example

Virus Spreading Model

Cascading Virus Spreading through a Network

Abstract representation of virus spreading through a network, demonstrates the SIR (susceptibility, infected, resistance) model of epidemics

Virus spreads between network nodes, according to defined spread probabilities, with checks carried out every tick

Network configuration is vital in determining virus movement patterns

AGENT

Properties
Infected? Resistant?

Actions
Become Susceptible Become Infected Become Resistant Spread Virus

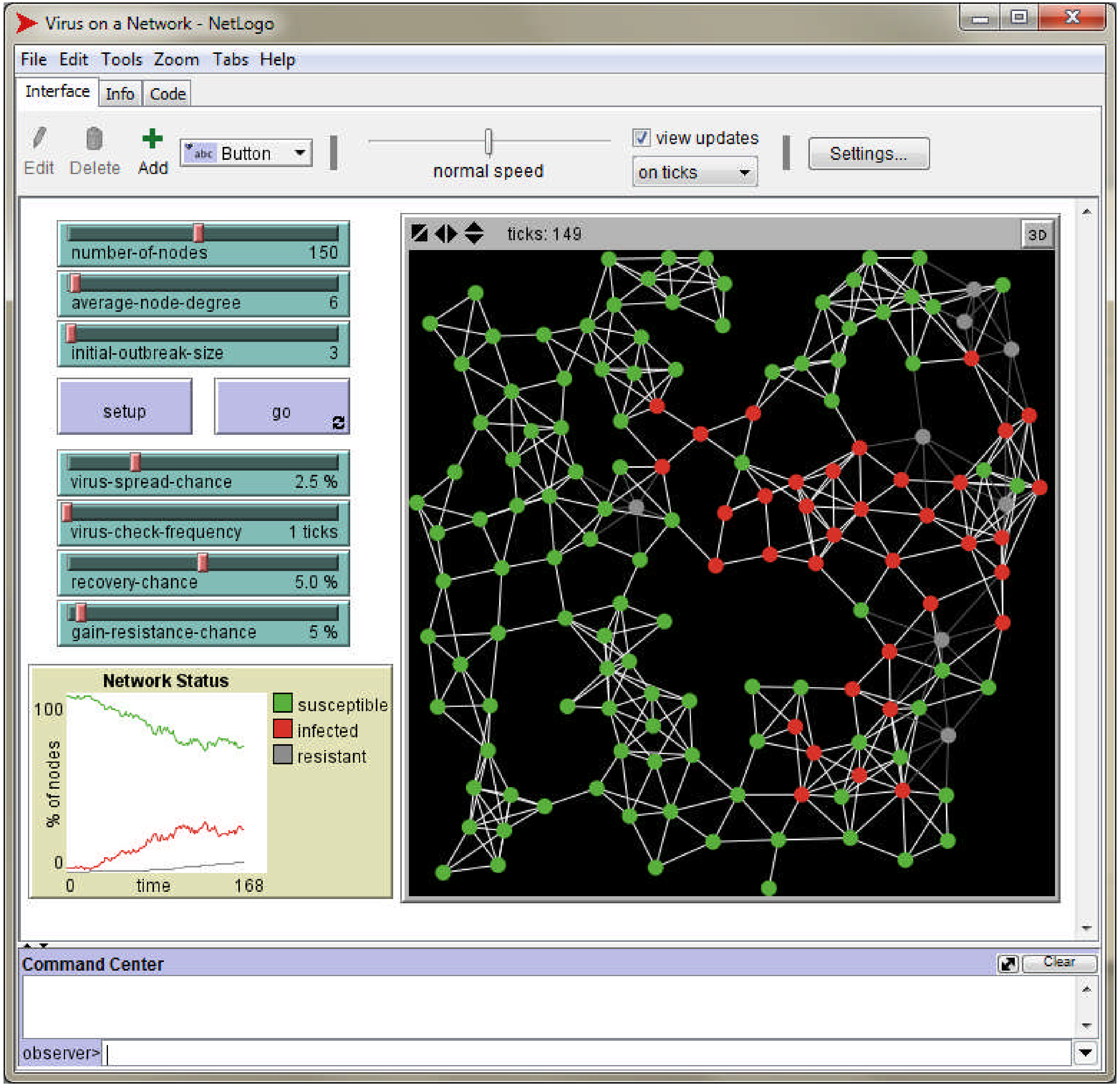
Agent-based Modelling

By Example

Virus Spreading Model

Things to Notice:

- Good demonstration of potential for problem to swiftly **cascade** through a network of agents
- But, some agents are able to **adapt** to the virus, causing it to eventually die out
- Networked model introduces a new element of systemic behaviour, demonstrating importance of **connectivity**
- Behaviour of virus – in terms of contagiousness – and agent behaviour – rate of recovery – are both vital in establishing infection patterns


Virus on a Network - NetLogo
File Edit Tools Zoom Tabs Help
Interface Info Code
Edit Delete Add
Button
normal speed
view updates
on ticks
Settings...
number-of-nodes 150
average-node-degree 6
initial-outbreak-size 3
setup
go
virus-spread-chance 2.5 %
virus-check-frequency 1 ticks
recovery-chance 5.0 %
gain-resistance-chance 5 %
Network Status
100
0
% of nodes
0
time
168
susceptible
infected
resistant
ticks: 149
3D
Command Center
Clear
observer>

Agent-based Modelling

By Example

Economic Disparity Land Use Model

Selection of Residence Area by Socio-Economic Status

More sophisticated model of land use development, incorporating four types of agent – representing human behaviour and influence of internal systems

‘Rich’ and ‘poor’ agents calculate the utility of a residential location by quality of land measure, cost of living and proximity to services

Service location and land squares considered agents too – behaving independently, impacting on system dynamics

Human Agents

AGENT

Properties

Type

Actions

Calculate Utility
Find New Location
Die

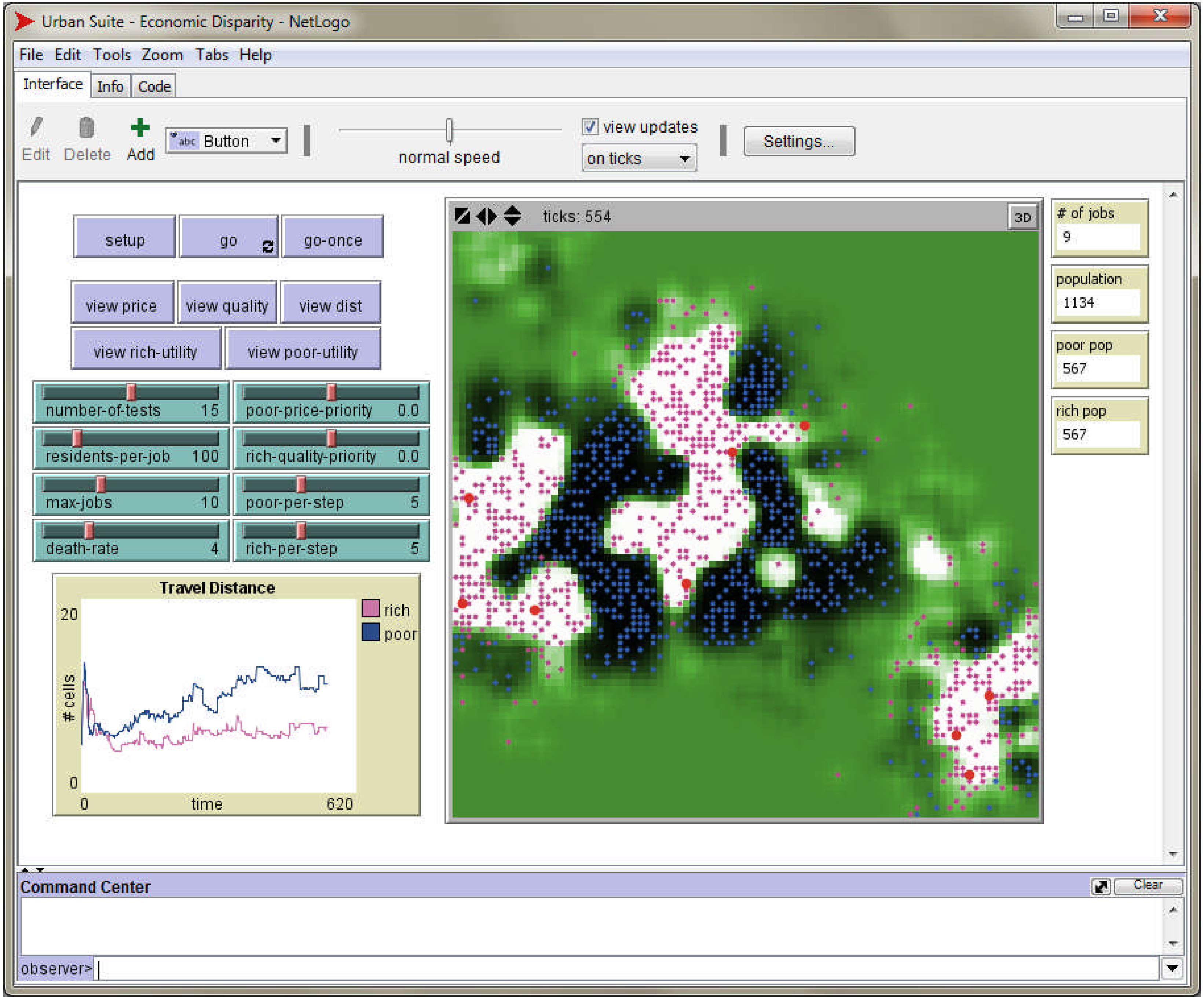
Agent-based Modelling

By Example

Economic Disparity Land Use Model

Things to Notice:

- Good demonstration of development of **spatio-temporal patterns** based on agent preference and behaviour
- Demonstrates **mixture of agents and systems** and their interactions – land value development, location of jobs, selection of residence
- Behaviour of agents leads to development of quite different urban structures – either sprawl or clustering
- Development of Schelling's segregation model, with more complex mechanisms driving dynamics



Urban Suite - Economic Disparity - NetLogo
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view quality
view dist
view rich-utility
view poor-utility
number-of-tests 15
poor-price-priority 0.0
residents-per-job 100
rich-quality-priority 0.0
max-jobs 10
poor-per-step 5
death-rate 4
rich-per-step 5
Travel Distance
20
0
cells
0
time
620
rich
poor
ticks: 554
3D
# of jobs
9
population
1134
poor pop
567
rich pop
567
Command Center
Clear
observer>

Agent-based Modelling

By Example

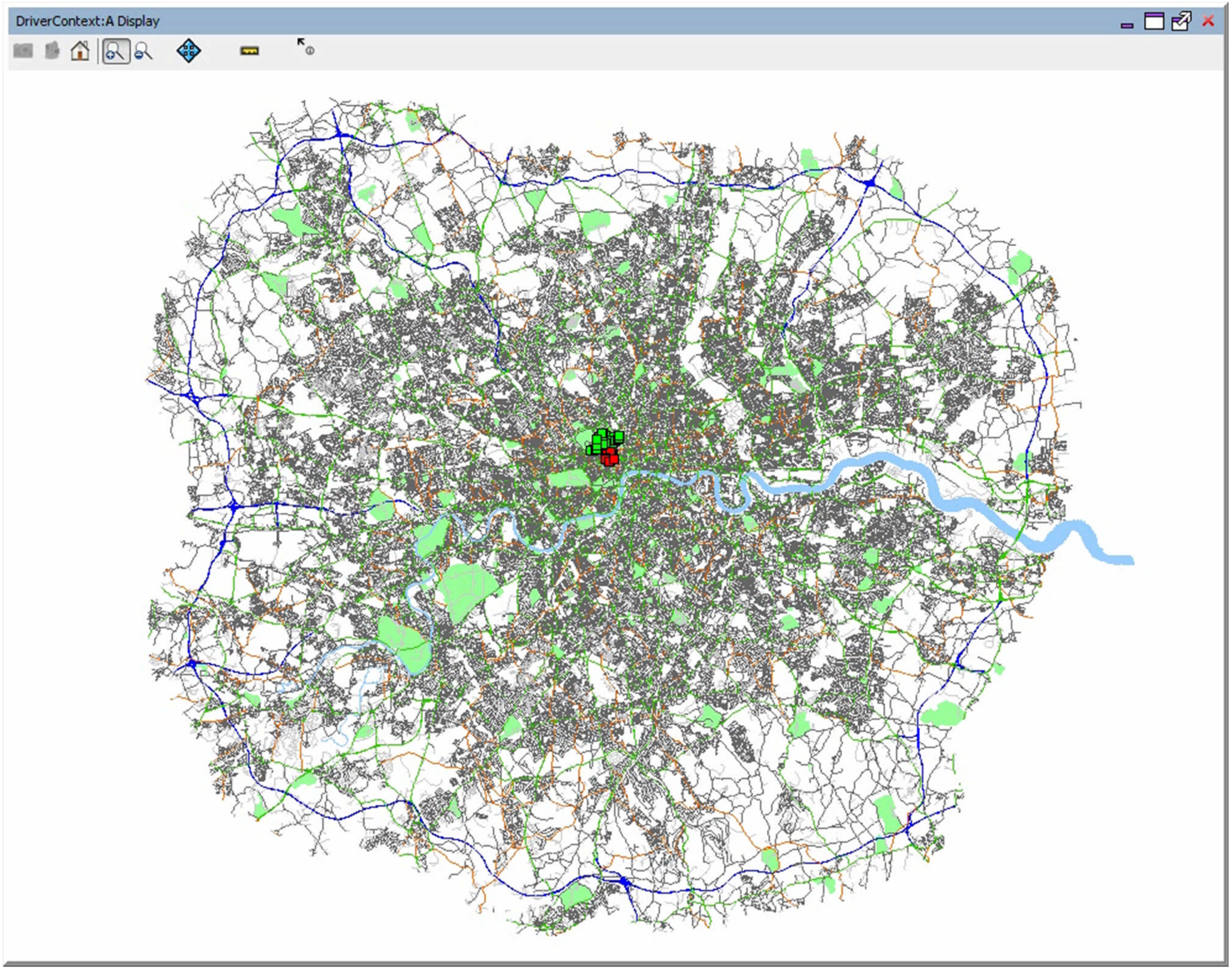
My Research

Evolution of Urban Traffic Systems in response to Unexpected Road Closures

Complex model of agent behaviour, developed using a more sophisticated modelling platform

Agent design incorporates heterogeneity in terms of spatial knowledge and route choice – based on analysis of movement data

Individual responses towards road closure and congestion by agents results in evolution of traffic patterns over space and time


DriverContext:A Display

Agent-based Modelling

The Possibilities

Recent Conference on ABM included some of the following themes:

- Pedestrian Simulation, indoor and outdoor
- Education Planning
- Housing Choice and Housing Policy
- Impact of forest composition on spread of disease in Red Colobus populations
- Operation of HVAC systems in commercial buildings
- Land-use change in the Elbow River watershed in southern Alberta
- Agent based model of urban retail system
- An Agent-Based Model for Analysing Conflict, Disasters, and Humanitarian Crises in East Africa
- Spatio-temporal Dynamics of Slum Formation in Mumbai, India
- Climate Change, Land Acquisition, and Household Dynamics in Southern Ethiopia
- An Agent-Based Understanding of City Size Distributions
- Simulating Residential Dynamics in London's Housing Market

A world of possibilities!

Development of
Agent-based Models

Development
Principles

1. Identify the most relevant actors and processes operating within your system of interest
   - Who is playing an active influence on system dynamics?
   - What behaviours need to be captured?
   - Where does the system end? Where are its boundaries?

2. Identify whether the relevant behaviours can be modelled
   - Do methods exist for the modelling of this behaviour?
   - Can behaviour be measured and quantified? Or reduced into a number of rules?
   - Can models reflecting this behaviour be easily validated?

Development

Principles

3. Over which kind of space and time will your agents interact?
   - Will they move over geographic space, or a vector space?
   - Will they connect through networks (social, physical) or only by proximity?
   - Can the space be readily discretised?
   - How long should the simulation run for? How long a time step?
4. Identify the system-level measures that will indicate the effectiveness of your model
5. Select the most appropriate platform on which to build your model based on your specification

Development

Principles

- **Keep it Simple!**

- Greater sophistication does not necessarily lead to a better model, but will lead to slower processing times
- Model only the key agents and key behaviours
- Build agent behaviour from data where possible
- Validate both agent behaviour and system patterns

- Get the design right: **Garbage In, Garbage Out!**

Development

Software

- Large number of frameworks, suitability for your work should depend on the following aspects:
  - Nature of model (size, complexity, desired output etc.)
  - Level of programming expertise
  - Established programming skills
  - Framework maturity (including access to resources, help)
  - (Maybe) Operating System
- Most available for free (open source), built within academia
- Many employ design frameworks, scheduling and simulation engine functionality

Development

Software

Name	Language	Maturity	Notes
NetLogo	Proprietary	High	Easy-to-use, highly flexible platform; Widely used; Great ‘toy’ model platform, but scalability issues.
Repast Simphony	Java and Groovy	High	Flexible, scalable platform; Excellent GUI with good GIS features; Includes ANN/GA implementations.
MASON	Java	Medium	Lightweight platform; Less feature-rich than Repast.
JADE	Java	High	Standardised development platform
Swarm	Objective-C	Medium	Similar design to Repast but with less functionality

Final Word

Final Word

Agent-based Modelling

- ABM is an excellent platform for modelling phenomena where individual behaviour is central to defining system characteristics
- Enables the prediction and examination of expected AND unexpected behaviours
- Applicable to a range of situations, able to incorporate human, technical and ecological agents

- Careful agent design is vital, and validation should be a priority
- The range of platforms available means ABM is open to all

Thank You

Questions?

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Project: http://standard.cege.ucl.ac.uk

Twitter: @EdThink

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