Introduction to agent-based modelling
Learning outcomes

Learn what an agent is
Distinguish between different types of agents
Understand when agent-based modelling can be applied
A tale of rationality

Everybody is perfectly rational
A tale of rationality

Everybody is perfectly rational
We always make the best decision
We always know how to make the best decision
A tale of rationality

The efficient market hypothesis (EMH)
Efficient market hypothesis

Everybody is perfectly rational
Efficient market hypothesis

Everybody is perfectly rational

Price reflects all available information
Efficient market hypothesis

Everybody is perfectly rational

Price reflects all available information

Forms: Weak, semi-strong, strong
Black-Scholes
Black-Scholes

Returns (price changes) are gaussian

Market price is perfectly random

Everything can be described by one equation
A game of probabilities

Struck by lightning: 1 in 70,000
A game of probabilities

Struck by lightning: 1 in 70,000

Getting hit by asteroid: 1 in 1,068,820
A game of probabilities

Struck by lightning: 1 in 70,000

Getting hit by asteroid: 1 in 1,068,820

Winning the jackpot (UK lottery): 1 in 45,057,474
A game of probabilities

Struck by lightning: 1 in 70,000

Getting hit by asteroid: 1 in 1,068,820

Winning the jackpot (UK lottery): 1 in 45,057,474

Financial crisis: 1 in $10^{72}$
Should happen once every $15,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000$ years.
The century of complexity

“I think the next century will be the century of complexity.”
Stephen Hawking

From 2008 complexity started to permeate economics/finance/business research and decision making
What is an abm?

objects interact with each other and/or with the environment
What is an abm?

Objects interact with each other and/or with the environment.

Objects are autonomous (bottom-up approach).
What is an abm?

Objects interact with each other and/or with the environment.

Objects are autonomous (bottom-up approach).

The outcome of their interactions is numerically computed.
What is an agent?

Individual or group
What is an agent?

Individual or group

Interact with environment
What is an agent?

Individual or group

Interact with environment

Act/react
Scope of abms

Explanation and replication
Prediction

Describe the elements
Describe the system
Scope of abms

WHAT IF scenarios
The whole is more than the sum of its parts
Characteristics of ABM

- Heterogeneity
- Explicit space
- Local interactions
- Scalability
- Non-equilibrium dynamics
When to use ABMs

Model complex systems

Get quick intuition of the dynamics of the system
Why use ABM

Numerical computation of analytical models
Testing robustness of analytical models
Stand-alone simulation models
Why use ABM

Numerical computation of analytical models

Model is not analytically soluble for some variable

empirical distribution of variable needs to be compared with theoretical

Out of equilibrium solutions not possible analytically
Why use ABM

Testing robustness of analytical models

Changing assumptions or values often leads to no solution or intractability
Why use ABM

Stand-alone simulation models
Substitute, not complementary, to mathematical analysis
Problems are analytically intractable
Analytical solution bears no advantage
Why use ABM

Bonus: Replace the (crazy) assumptions of neoclassical economics

Agents are fully rational with unbounded computational skills

Equilibrium defined by re and no-arbitrage condition

Interactions and heterogeneity only add noise
Why use abm

Agents are fully rational with unbounded computational skills

Equilibrium defined by re and no-arbitrage condition

Interactions and heterogeneity only add noise

Bonus: Replace the (crazy) assumptions of neoclassical economics

YOU ARE CORRECT.

RATIONALITY IS CONSIDERED CRAZY UNDER OUR CURRENT CONDITIONS.
Discrete vs continuous time

Discrete event simulations (DeS)
- Given state at given time
- Move between states between t and t+1

Continuous simulations/system dynamics (sd)
- Stock/flows/delays
- Differential equations
## ABM vs DES

<table>
<thead>
<tr>
<th>Discrete-event simulations</th>
<th>Agent-based models</th>
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<tbody>
<tr>
<td>Process oriented (top-down modelling approach); the focus is on modelling the system in detail, not the entities.</td>
<td>Individual based (bottom-up modelling approach); the focus is on modelling the entities and interactions between them.</td>
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<tr>
<td>One thread of control (centralised).</td>
<td>Each agent has its own thread of control (decentralised).</td>
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<tr>
<td>Passive entities, i.e., something is done to the entities while they move through the system; intelligence (e.g., decision-making) is modelled as part in the system. Queues are a key element.</td>
<td>Active entities, i.e., the entities themselves, can take on the initiative to do something; intelligence is represented within each individual entity.</td>
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<tr>
<td>Flow of entities through a system; macro behaviour is modelled.</td>
<td>No concept of queues.</td>
</tr>
<tr>
<td>Input distributions are often based on collect/measured (objective) data.</td>
<td>No concept of flows; macro behaviour is not modelled, it emerges from the micro decisions of the individual agents.</td>
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<tr>
<td></td>
<td>Input distributions are often based on theories or subjective data.</td>
</tr>
</tbody>
</table>
The structure of abms
The structure of abms

\[ x_{i,t+1} = f_i(x_{i,t}, x_{-i,t}, \theta_i, \xi_{i,t}) \]

State of agent \( i \) at time \( t+1 \)
The structure of abms

\[ x_{i,t+1} = f_i(x_{i,t}, x_{-i,t}, \theta_i, \xi_{i,t}) \]

State of agent \( i \) at time \( t+1 \)

Function of agent \( i \)
The structure of abms

State of agent $i$ at time $t$

$$x_{i,t+1} = f_i(x_{i,t}, x_{-i,t}, \theta_i, \xi_{i,t})$$

State of agent $i$ at time $t+1$

Function of agent $i$
The structure of abms

\[ x_{i,t+1} = f_i(x_{i,t}, x_{-i,t}, \theta_i, \xi_{i,t}) \]

State of agent \( i \) at time \( t \)

State of all other agents at time \( t \)

State of agent \( i \) at time \( t+1 \)

Function of agent \( i \)
The structure of abms

\[ x_{i,t+1} = f_i(x_{i,t}, x_{-i,t}, \theta_i, \xi_{i,t}) \]

- State of agent \( i \) at time \( t \)
- Parameters of agent \( i \)
- State of all other agents at time \( t \)
- Function of agent \( i \)
The structure of abms

\[ x_{i,t+1} = f_i(x_{i,t}, x_{-i,t}, \theta_i, \xi_{i,t}) \]

- State of agent \( i \) at time \( t \)
- Parameters of agent \( i \)
- Stochastic terms of agent \( i \) at time \( t \)
- State of all other agents at time \( t \)
- State of agent \( i \) at time \( t+1 \)
- Function of agent \( i \)
The structure of abms

Transition equation

\[ X_{t+1} = F(X_t, \theta, \Xi_t) \]
State-space representation

Transition equation

\[ X_{t+1} = F(X_t, \theta, \Xi_t) \]

Measurement equation

\[ y_t = m(X_t, \kappa_t) \]
Measurement equation

\[ y_t = m(X_t, \kappa_t) \]

Aggregate variables at time \( t \)

Measurement errors
Random seed

Transition equation

\[ X_{t+1} = F(X_t, \theta, s) \]

Measurement equation

\[ y_t = m(X_t, s) \]
End of lecture exercise

Provide an example of a system which could be described by an agent-based model
Summary

Why agent-based modelling
What agents are
Structure of ABMs