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)


EUGENE FAMA

Efficient market hypothesis

Everybody is **perfectly rational**

Efficient market hypothesis

Everybody is **perfectly rational**

Price reflects all **available information**

Efficient market hypothesis

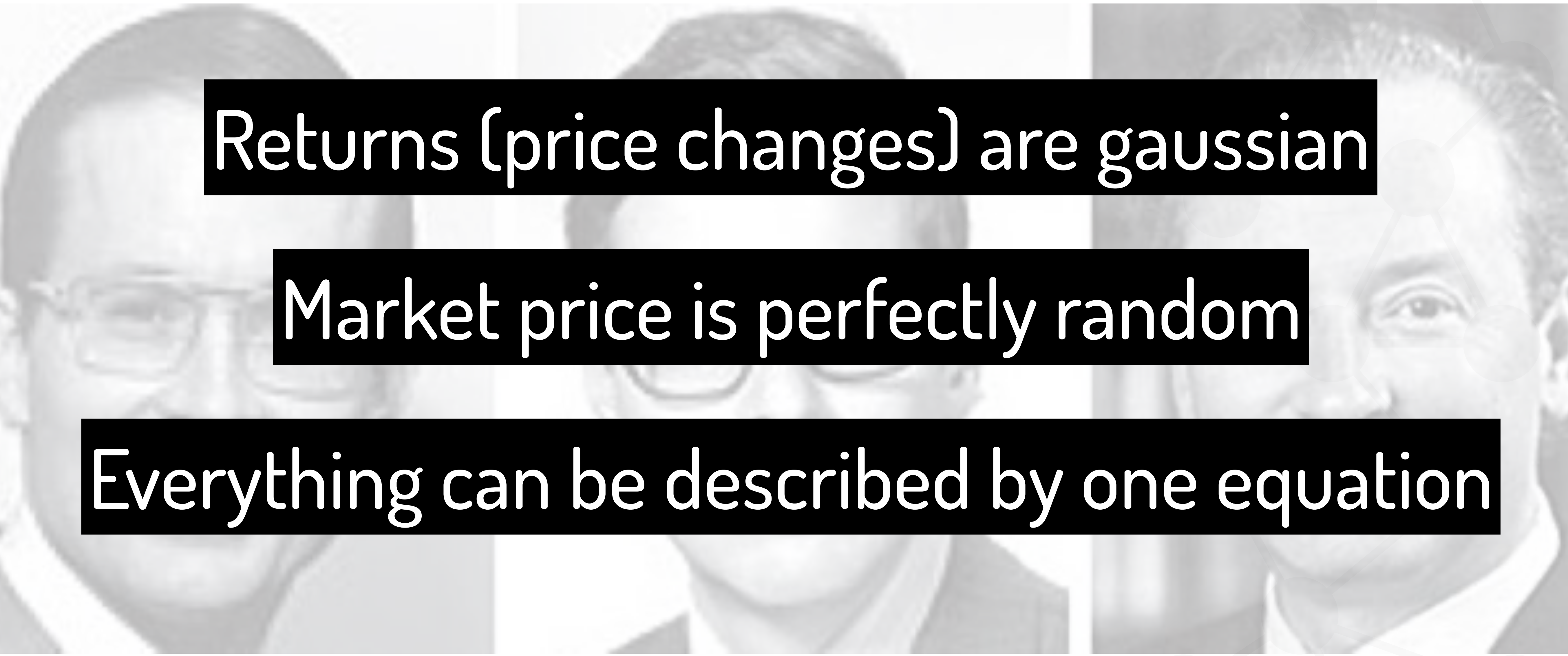
Everybody is **perfectly rational**

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

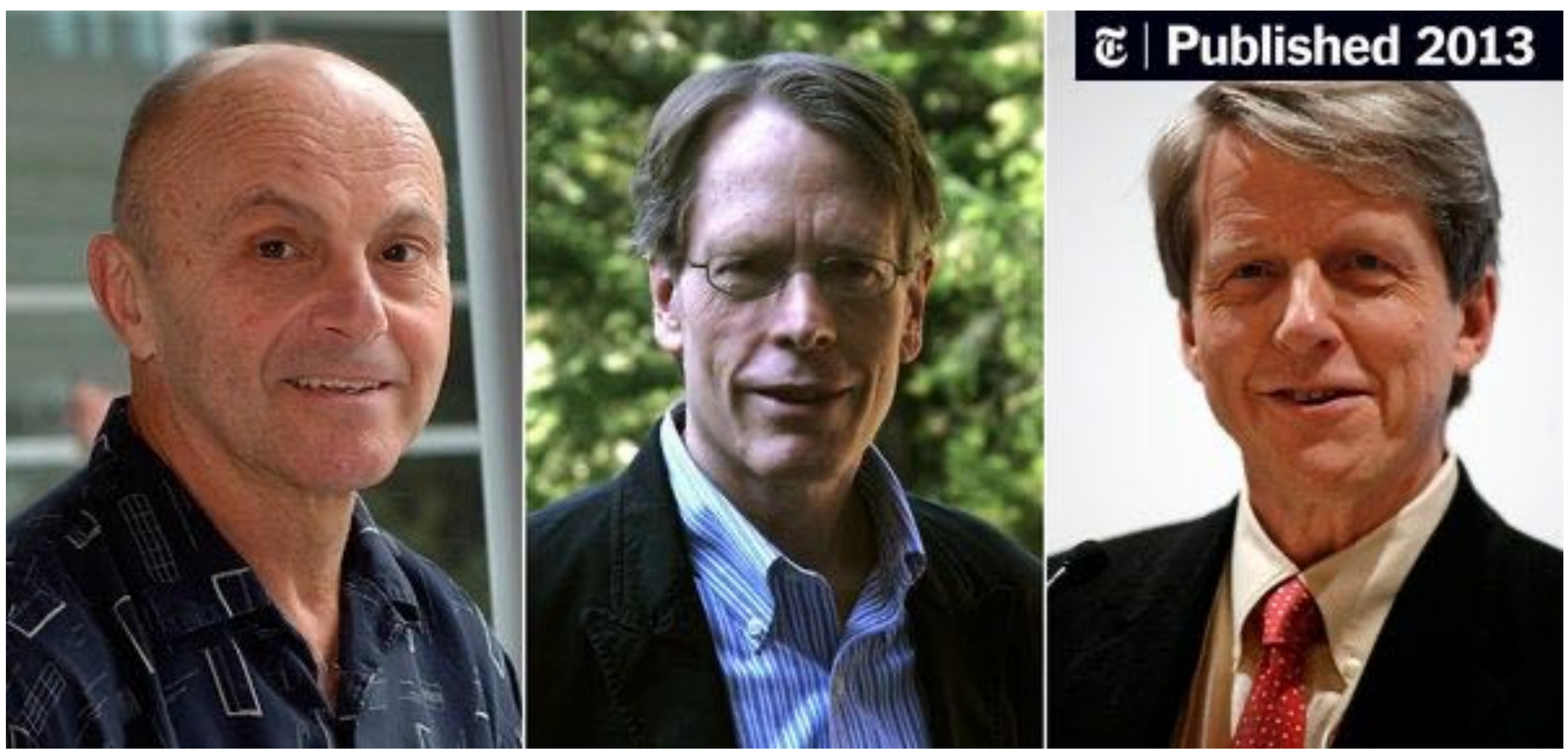
15,000,000,000,000,000,000,

000,000,0 **Years** 0,000,000,

000,000,000,000,000,000,

000,000,000,000,000

3,500
3,000
2,500
2,000
1,500
1,000
500
250
1950
2000


Published 2013


ALFR·
NOBEL
NAT·
MDCCC
XXXIII
OB·
MDCCC
XCVI
shed 2013

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

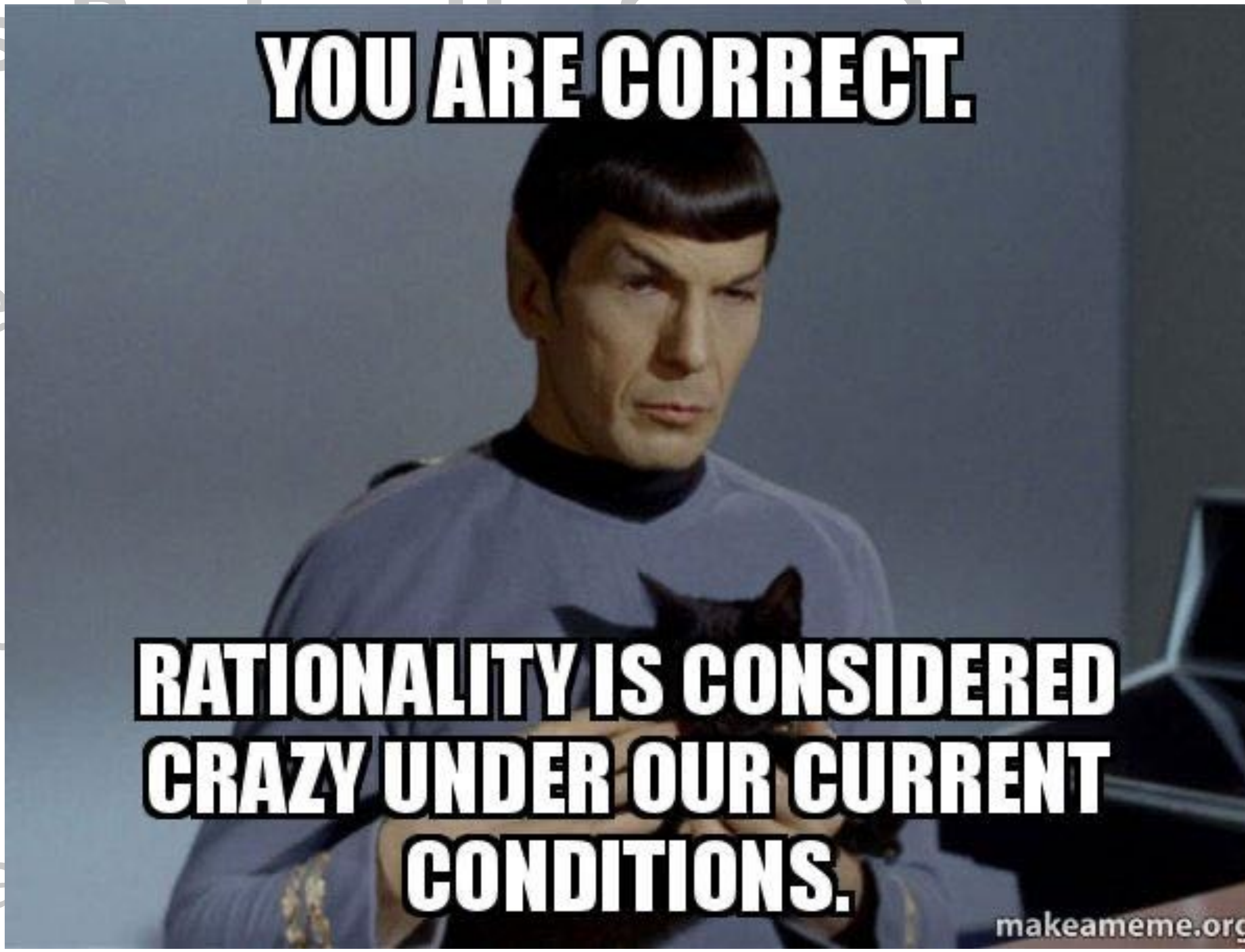
Why use abm

Bonus ... ptions

Agents are ... putational

Equilibriu ... condition

Intera ... noise



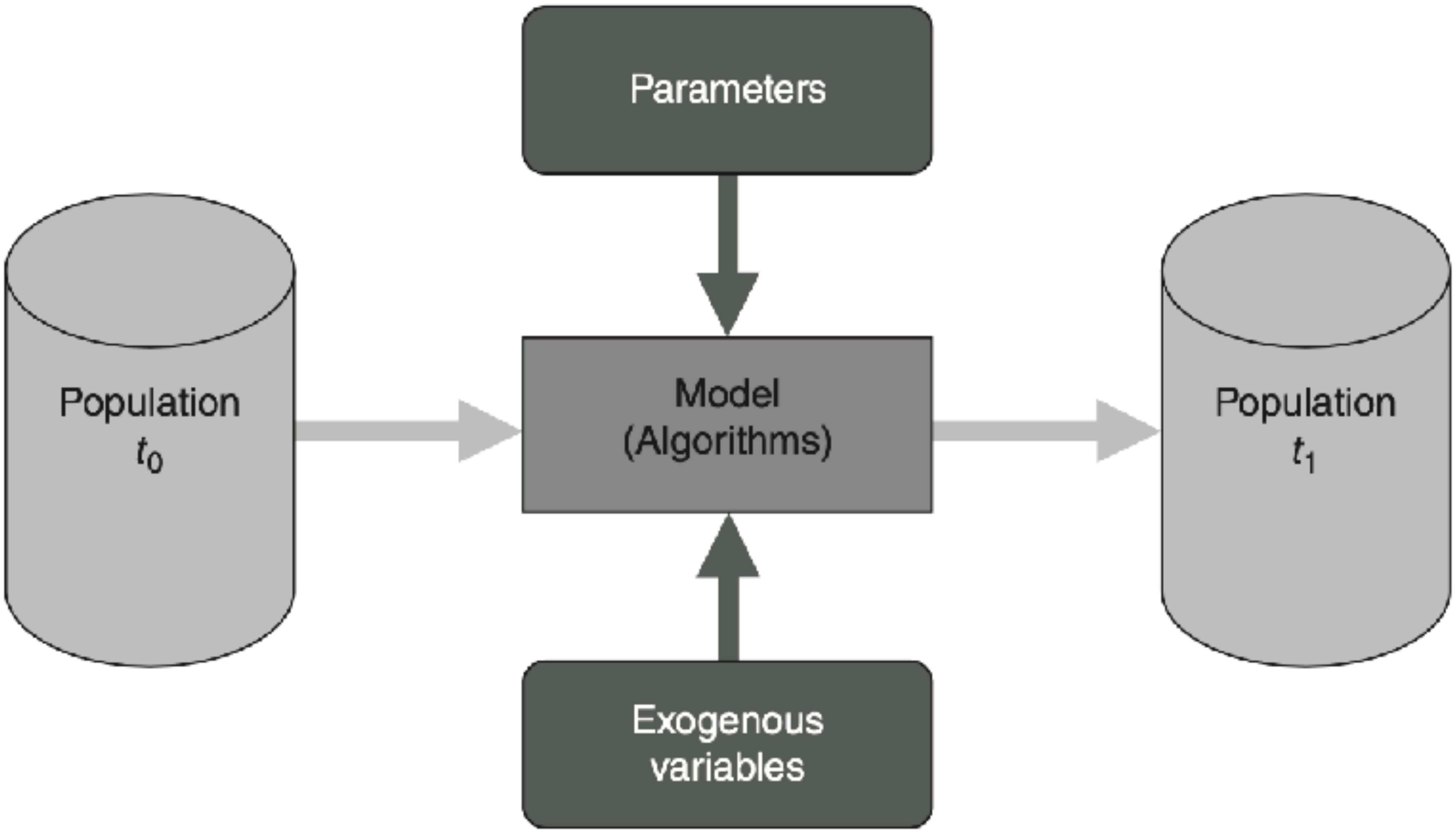
Discrete vs continuous time

Discrete event simulations (DeS)	Continuous simulations/ system dynamics (sd)
Given state at given time	Stock/flows/delays
Move between states between t and t+1	Differential equations

ABM vs DES

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

The structure of abms



The structure of abms

$$\boldsymbol{x}_{i,t+1} = f_i(\boldsymbol{x}_{i,t}, \boldsymbol{x}_{-i,t}, \boldsymbol{\theta}_i, \boldsymbol{\xi}_{i,t})$$

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**

$$\boldsymbol{x}_{i,t+1} = f_{\boldsymbol{i}}(\boldsymbol{x}_{i,t}, \boldsymbol{x}_{-i,t}, \boldsymbol{\theta}_i, \boldsymbol{\xi}_{i,t})$$

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 all other agents at time **t**

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

Function of agent **i**

The structure of abms

State of agent **i** at time **t**

Parameters of agent **i**

$$\boldsymbol{x}_{i,t+1} = \boldsymbol{f_i}(\boldsymbol{x}_{i,t}, \boldsymbol{x}_{-i,t}, \boldsymbol{\theta}_i, \boldsymbol{\xi}_{i,t})$$

State of all other agents at time **t**

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

Function of agent **i**

The structure of abms

State of agent **i** at time **t**

Parameters of agent **i**

Stochastic terms of agent **i** at time **t**

$$\boldsymbol{x}_{i,t+1} = f_{\boldsymbol{i}}(\boldsymbol{x}_{i,t}, \boldsymbol{x}_{-i,t}, \boldsymbol{\theta}_i, \boldsymbol{\xi}_{i,t})$$

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

$$y_t = m(X_t, \kappa_t)$$

Measurement errors

Aggregate variables at time **t**

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