CASA0011: Agent-Based Modelling for Spatial Systems

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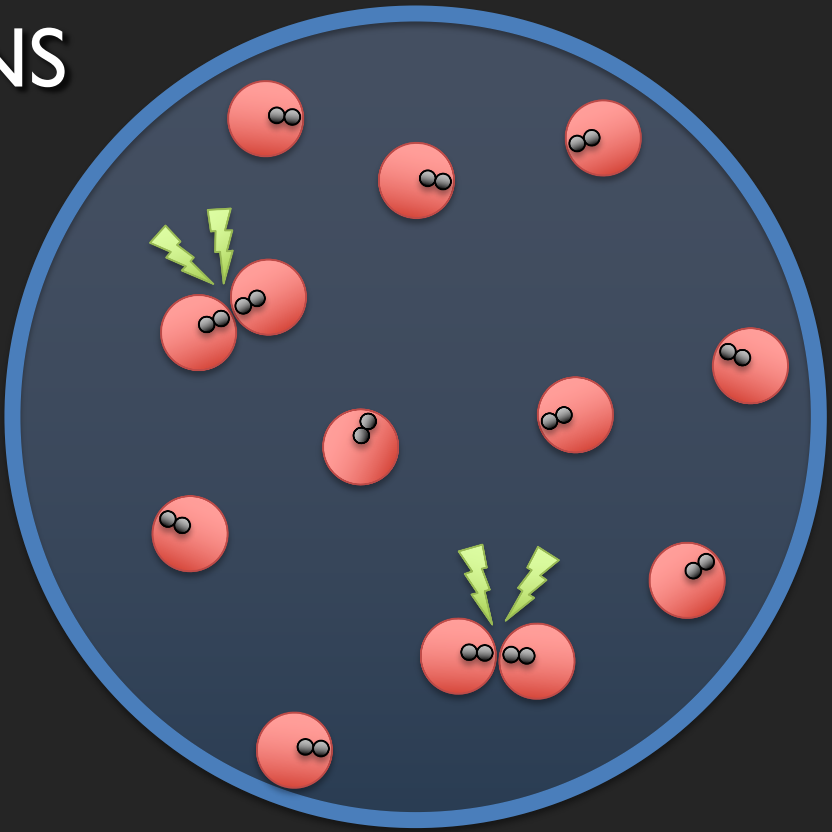


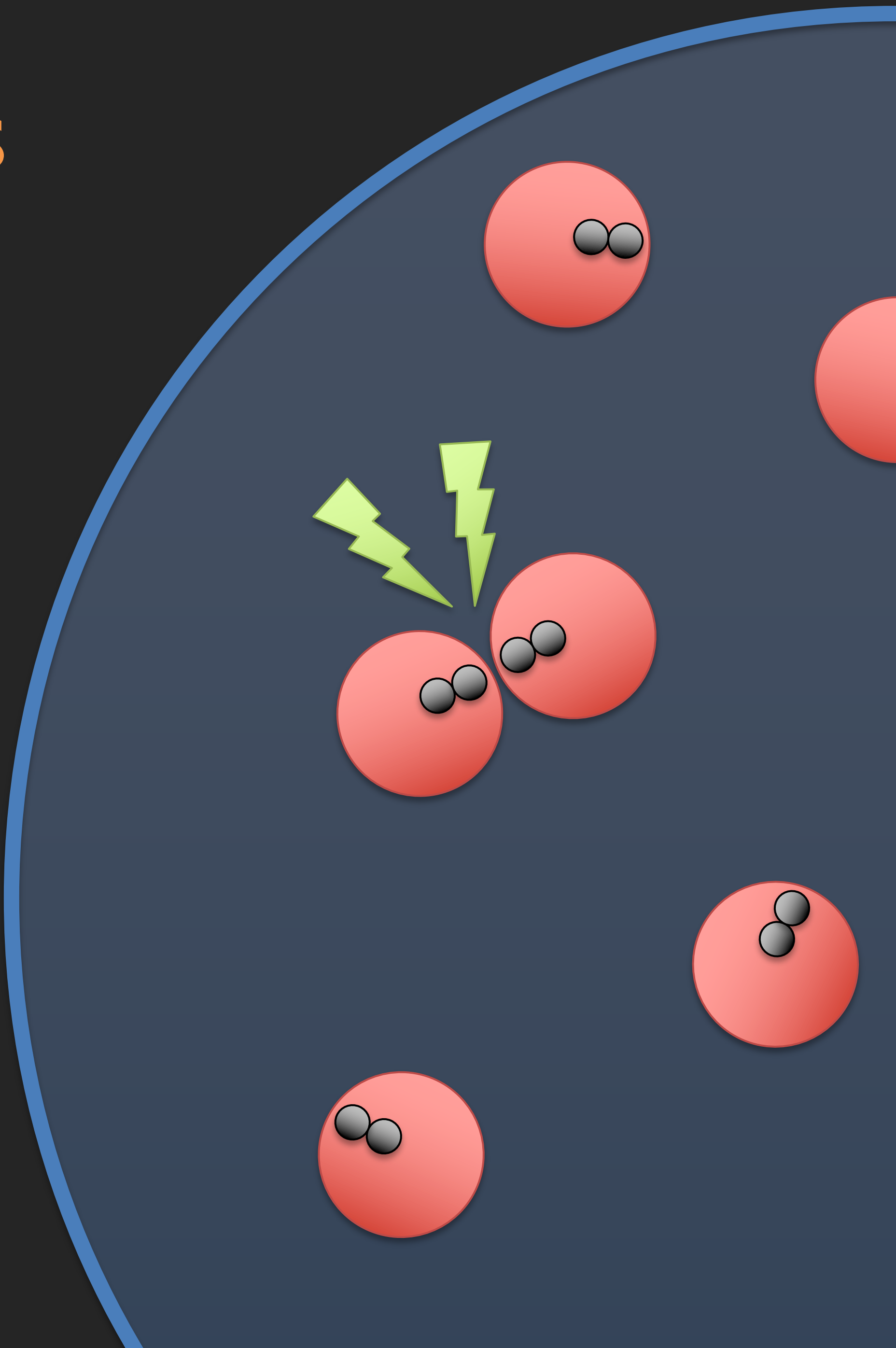
Session Objectives

You should...

1. Know the origins of the field of ABM

2. Be able to name and describe alternative kinds of modelling

3. Be able to describe current trends in modelling



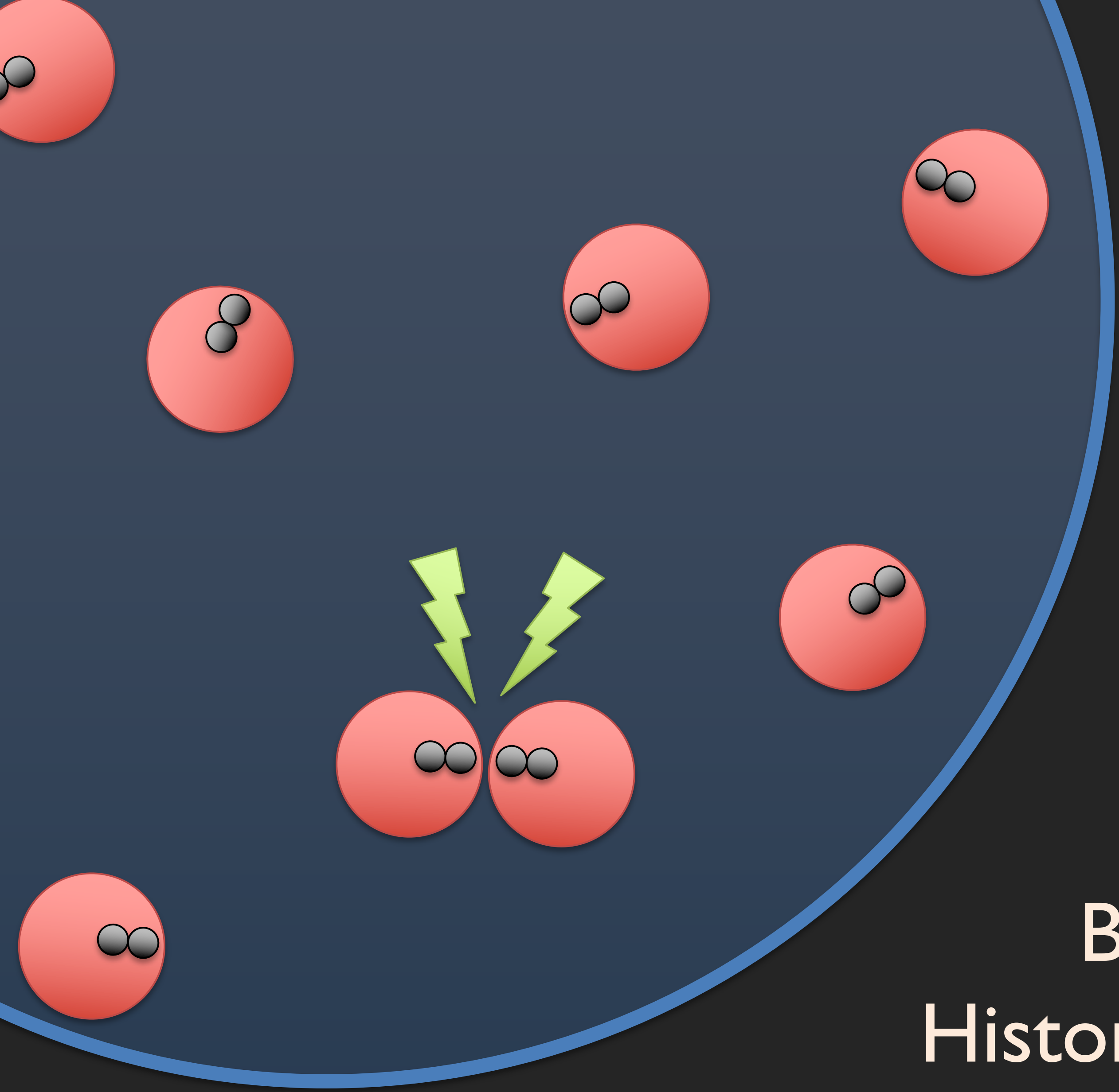
Last Week

- Course basics
- Define and understand complexity
- Define ABM

We enjoy feedback! It helps us teach!

Let us know about any issues, concerns, requests, etc. on:

- MOODLE!
- SLACK!



LECTURE 2

Background and History of Modelling

A brief history of simulating

- Really kicks off with first use of computers in university research, early 1960s
  - Discrete event simulations (e.g. "typical throughput" - e.g. waiting time)
  - System dynamics gets implemented (more on that later)
  - Also "Simulmatics" (Sola Pool and Abelson, 1962) JFK Reelection's version of 538. Basically a multi-agent simulation
- 1970s: microsimulation
- 1980s: more work in other fields
- 1990s: cross pollination from nonlinear dynamic researchers, AI researchers
  - Physicists invade with CA models: magnetic materials, fluid dynamics, crystal growth, soil erosion
  - Multilevel modelling also comes over from physics
  - After the growth of WWW throughout the 1980s, interest in distributed cognition/computation grows
  - Complexity science really gets going
- Subsequently: explosion and specialisation back into target fields!

Where did it come from?

Biology

- John von Neumann: self-reproducing automata (‘50s)
- John Conway: game of Life (‘60s)
- Chris Langton: artificial life (late ‘80s)

Computer Science

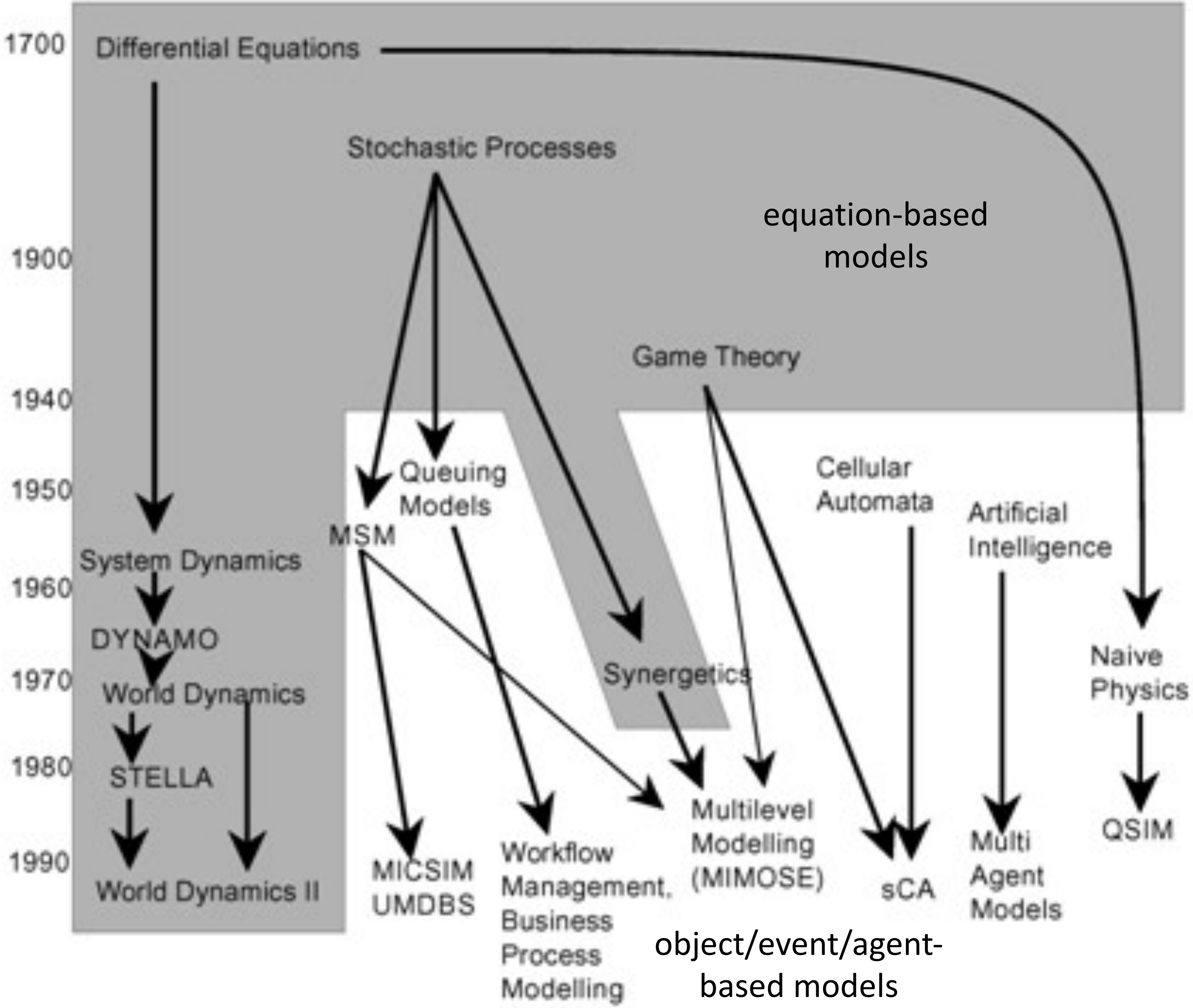
- artificial intelligence (AI)
- robotics
- distributed AI (DAI)
- multi-agent systems (MAS)
- object-oriented programming (OOP)

Social Science

- Simon, March and Cyert: the ‘behavioral school’ and simulation of few agent systems (‘50s and ‘60s)
- Tom Schelling: tipping model of segregation (late ‘60s)

Physics

- magnetic materials
- fluid dynamics
- crystal growth
- soil erosion



G&T 2005; after Troitzsch, 1997

Original slide by Rob Axtell

Contrasting Mindsets

Post WWII

- Global information, centralized control
- Math. programming: scalar value function
- Firm as rational actor
- Neoclassical utility: constrained maximization
- Arrow-Debreu markets: single price vector
- Decision theory
- Conventional AI

Now

- Local info, networks, distributed control
- Diverse representations: competing world views
- Many-agent firms
- Behavioural economics: multiple selves
- Decentralised markets: heterogeneous prices
- Game theory
- DAI and MAS

Subject	Number of Levels	Communication between Agents	Complexity of agents	Number of agents
System dynamics	1	No	Low	1
Microsimulation	2	No	High	Many
Queuing models	1	No	Low	Many
Multilevel simulation	2+	Maybe	Low	Many
Cellular automata	2	Yes	Low	Many
Multi-agent models	2+	Yes	High	Few
Learning models	2+	Maybe	High	Many

Taken from G&T 2005, Table 1.1

Example of Mathematical Equations: Differential Equations

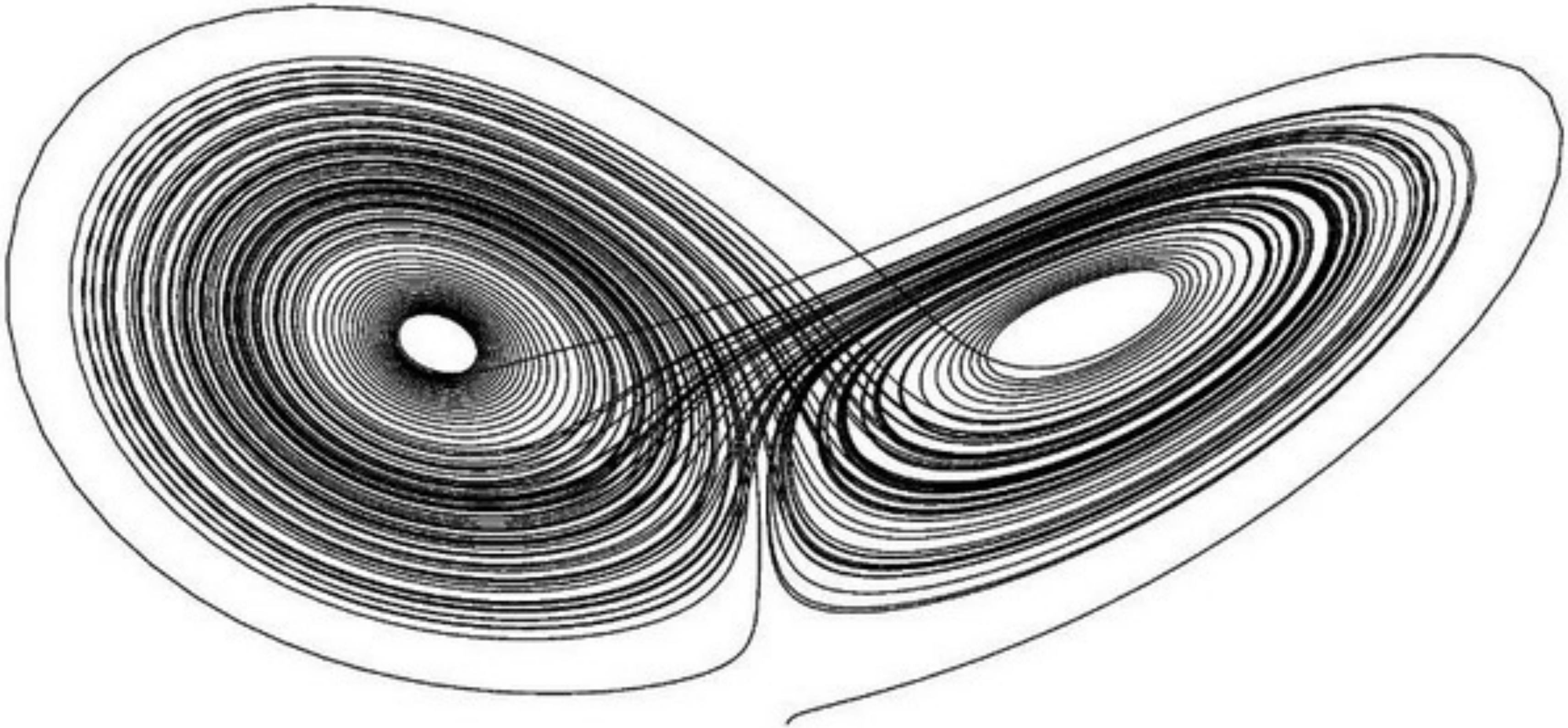
An equation in which a function is related to its derivatives

- solved in closed form (in simplest cases) OR numerically approximated through computation
- Example: motion of a body is described by position and velocity
- Other examples: fluid dynamics, heat equation, radioactive decay, **Lotka-Volterra predator-prey**

$$\frac{dy}{dx} = f(x)$$

$$\frac{dy}{dx} = f(x, y)$$

$$x_1 \frac{\partial y}{\partial x_1} + x_2 \frac{\partial y}{\partial x_2} = y$$



$$\frac{dx}{dt} = \alpha x - \beta xy$$

$$\frac{dy}{dt} = \delta xy - \gamma y$$

x = # of prey

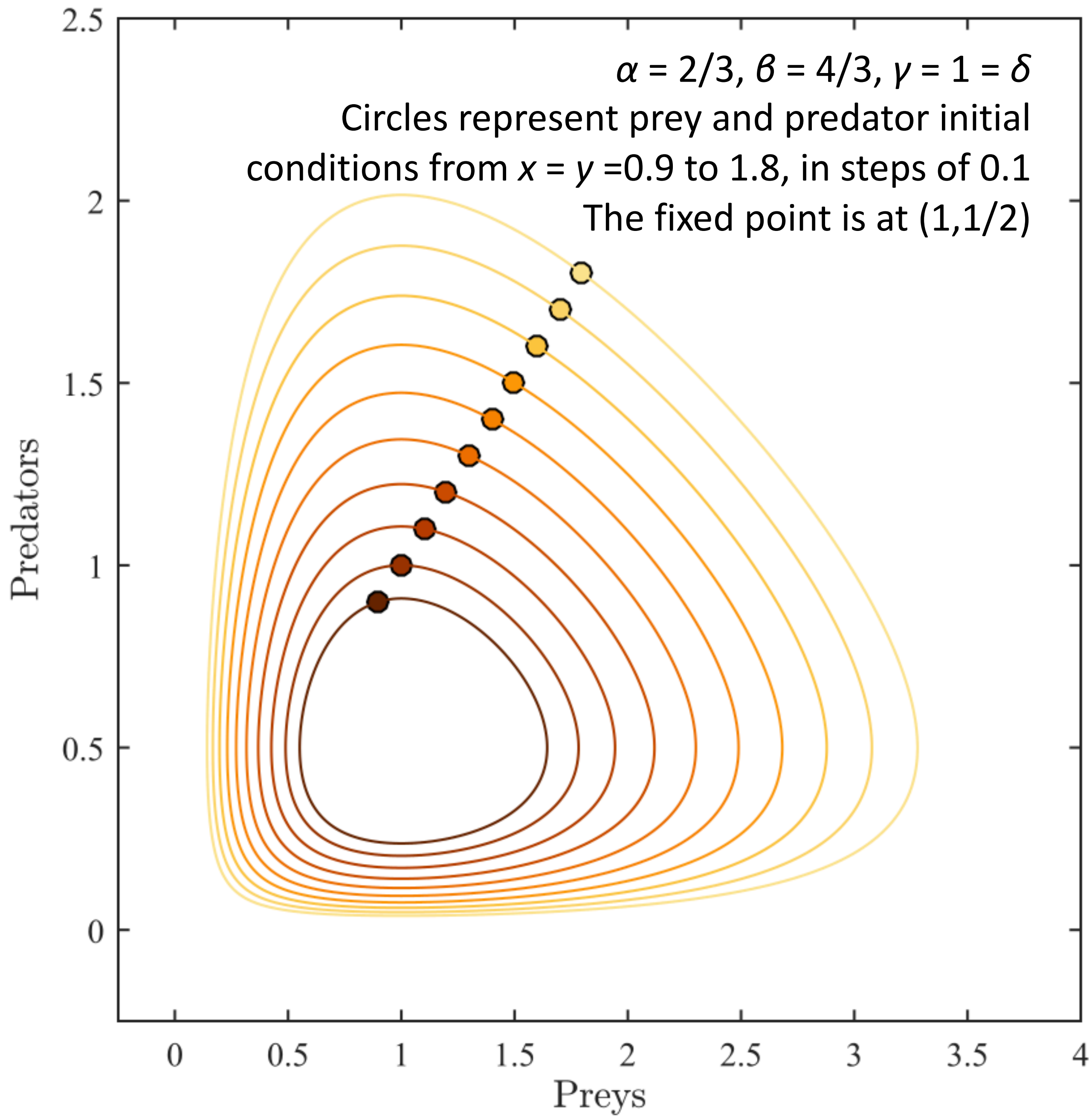
y = # of predators

$^{dy}/_{dt}$ and $^{dx}/_{dt}$ are the instantaneous growth rates of the two populations

t = time

α, β, γ, δ are positive real parameters describing the interaction of the two species.

Lotka–Volterra Equations


α = 2/3, β = 4/3, γ = 1 = δ
Circles represent prey and predator initial conditions from x = y =0.9 to 1.8, in steps of 0.1
The fixed point is at (1,1/2)
Predators
Preys
0
0.5
1
1.5
2
2.5
3
3.5
4

System Dynamics

"a target system, with its properties and dynamics, is described using a system of equations which derive the future state of the target system from its actual state."

- G&T 2005, p 28

- Based in differential equations, created by Jay W. Forrester at MIT in 1950s
- Deals with macro level – focus on the behavior of an agent **population**
- breaks systems down into **interconnected components** (blocks) and connects their outputs and inputs via links to one another. Blocks have an internal state with associated state variables
- Benefits:
  - captures dynamic behavior of systems over time
  - allows for feedback and cross-connectivity between different system elements
  - blocks allow the system to be modelled to whatever level of detail is computationally tractable

Wolf-Sheep Predation

EXAMPLE

NETLOGO > MODELS LIBRARY > WOLF-SHEEP PREDATION (SYSTEM DYNAMICS)

Microsimulation

"it seems reasonable to expect that our predictions would be more successful if they were based on knowledge about these **elemental decision-making units.**"
(Orcutt, 1957)

- Grew out of **economic modeling** practices
- Deals with **large, random samples of a population**
  - Populations can be made up of any kind of functional unit (e.g. persons, households, companies)
  - units have attributes such as age, income, gender, or employment status
  - multiple levels of aggregation may be measured (e.g. household made up of individual units)
- **Transition probabilities** are applied to units based on their individual attributes
  - **deterministic** (e.g. a person ages every year)
  - **stochastic** (e.g. a household potentially increasing in size)
- Estimates **future aggregate and distributional properties** of the population. (International Microsimulation Association, 2011)
- **shift in focus** from the **aggregate** to the **individual** – one of the earliest attempts to approach modeling from an individualistic orientation
- Examples:
  - Euromod: 15-country Europe-wide tax model
  - Transims: analyzes the transportation system in the United States

Household model

EXAMPLE

Household	1	2	3	4	5	6
time t	27 f job 27 m job	31 m job 30 f job	38 f job	37 m job 36 f childcare 5 m child 3 f child	65 m job 80 f pension	83 f pension

Cellular Automata

A series of cells with internal states and identical rules, which are stepped through time and updated based on their own attributes and their surroundings

- Cells' behavior depends on own and neighbors' behaviors at last time step, resulting in **local** interactions. CA produces a **macro-scale result of micro-scale decisions**
- A given cell can be in any one of several states
- At time step t each cell's state is updated by a universal set of rules
- Examples:
  - SLEUTH model developed by Clarke and his Santa Barbara Group
  - Metranomica by White and Engelen at the Research Institute for Knowledge Systems (RIKS)
  - DUEM model out of our own University College London's CASA. (Batty et al, 1999)

Fire

EXAMPLE

NETLOGO > MODELS LIBRARY > FIRE

Some Current Threads of Research

- We have the computing power to include things like data, which allows:
  - Spatially explicit models
  - Open Data
  - Now-casting
  - More complicated/realistic networks
- Behaviours
  - Exploration of learning, decision-making, belief, etc.
  - Movement and routing
- We can combine different kinds of modelling!

CONCLUSION

Today we covered…

- The history of simulation in the age of computing
- A brief introductions to different kinds of simulation and modelling
- A light introduction to current trends in research

A NEW (OPTIONAL) ACTIVITY!

Presenting an ABM to the Class

1. Why was this model built?
2. What question is it looking to solve?
3. What are the different kinds of agents, and how do they interact with one another?
4. What is the environment, and how do agents interact with it?
5. What metrics do the authors use to measure the behaviour/performance of the system?
6. How do the authors attempt to validate their model?
7. What conclusions did the authors draw from the results of running the model?
8. ***Bonus:*** how might you expand upon the model, given the results the authors present here?

Butterfly Hill-topping model

PRACTICAL/TUTORIAL!