Introduction to Agent-based modeling

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Outline

- "An agent-based model of group decision making in baboons"
- Some theory
- Some models
- Take home message

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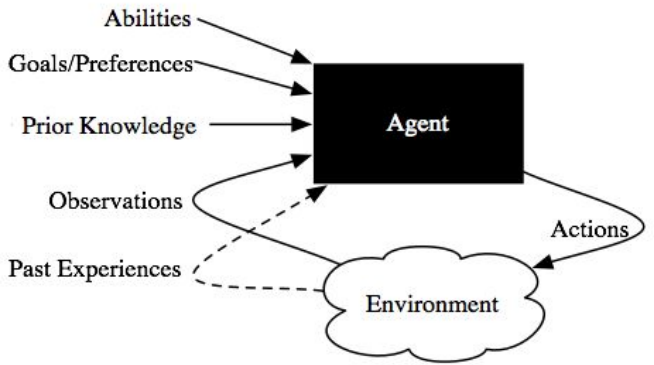

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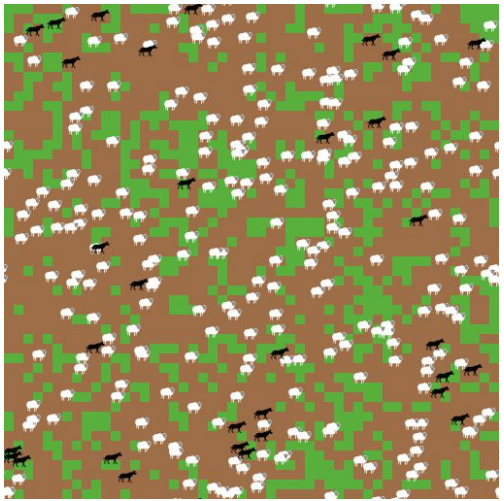

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- Which is the difference between "combined decisions" and "consensus decisions" in group-living animals?
- Which is the definition of "agent" provided in the paper?
- How can we overcome Maynard-Smith's criticism of agent-based modelling belonging to the category of "fact-free science"?

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- How well the model is able to **duplicate** the observed **activity patterns** of the animals
- The long-term aim is a **robust model of baboons behaviour** which is valid across a wide range of habitats and baboons species (included **extinct species**)

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- How well the model is able to duplicate the observed activity patterns of the animals
- **Combined decisions** refer to the situation where animals decide individually, but in a manner that is dependent on other group members (e.g., fission-fusion dynamics)
- **Consensus decisions** are made by spatially cohesive groups and concern issues such as movement direction, travel destination, and activity timing (i.e., they require mechanisms for groups to arrive at agreements - e.g., voting)

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- How well the model is able to duplicate the observed activity patterns of the animals
- **Combined decisions** refer to the situation where animals decide individually, but in a manner that is dependent on other groups
- An agent is a **"software system that perceives its environment and acts in that environment in pursuit of its goals"** (situated, embodied, intentional agents)

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- **Combined decisions** refer to the situation where animals decide individually, but in a manner that is dependent on other groups
- An agent is a "software system that perceives its environment and acts in that

- The models produced must be **tested** by using them **to predict behaviours in a given population** and comparing the predictions with field observations (i.e., **validation** of the model(s))

Some Theory First

Definition of "Model"

def. of "model":

" # 3 - a **simplified description**, especially a mathematical one, **of a system or process**, to **assist calculations** and **predictions** "
(Oxford Dictionary, OUP 2011)

$$y = mx + b$$

Definition of "Model"

Many possible "models"

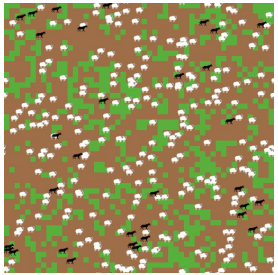
- **Model Organism** (e.g., a mouse to better understand a human pathogen's behaviour)
- **Mathematical model** (e.g., a system of equations to describe the dynamics of a predator-prey system - Lotka-Volterra Model)
- **Computational model** (e.g., an agent-based model)

$$\frac{dP}{dt} = -Pm + bHP$$

$$\frac{dH}{dt} = Hr - aHP$$

$$\begin{cases} P = P(t) & \text{Number of Predators} \\ H = H(t) & \text{Number of Prey} \end{cases}$$

$$\begin{cases} r > 0 & \text{Birth Rate of Prey} \\ m > 0 & \text{Death Rate of Predators} \\ a > 0 & \text{Death Rate of Prey/Predator} \\ b > 0 & \text{Birth Rate of Predators/Prey} \end{cases}$$



What a model is

A model is a **representation** of the fundamental **structure** of a real phenomenon or event

Such a representation may be:

- a **physical representation** (e.g., a 1:N scale model of an airplane or a building; a robot; another animal species)
- a **symbolic representation** (e.g., a system of equations; a series of words; a computer software or program)


```
; It simulates a communication. It increases the energy consumption
; as the number of links to reach the target
to communicate
  ; Get source and target
  let source random count turtles
  let target random count turtles
  ask turtle source[
    let dist nw:distance-to turtle target
    ifelse dist = false
      [set num-failures num-failures + 1]
      [  set energy-consumption energy-consumption + dist
         if success = -1
           [set success 0]
         set success success + 1
         foreach nw:turtles-on-path-to turtle target
           [transmit-msg]
      ]
    set communications communications + 1
  ]
end
```

What a model is

"**Incompleteness**" of a model:

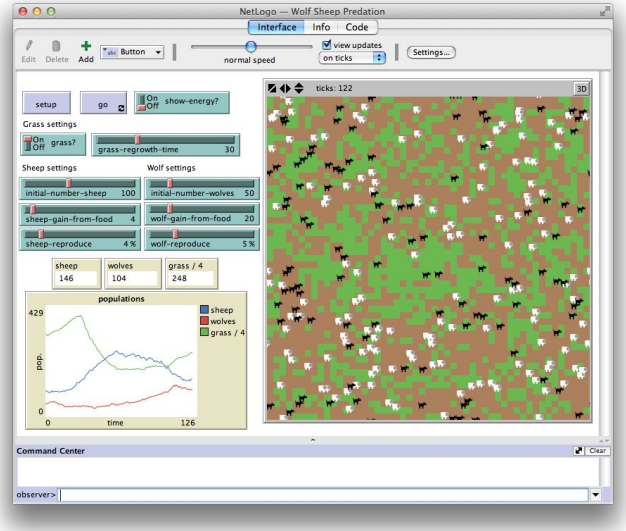
Models are **necessarily incomplete**:

Since a model is a **representation**, there is no model incorporating **all aspects of a real system** (in such a case, we would have a "**copy**" and not a model anymore).

This means that the implementation of a model implies a (series of) **assumption(s)** about the real system's:

- essential structure,
- parts,
- events,
- relationships between parts and events

Usefulness of a Model



To be useful a model must be easily **changed** and **modified**

The model user must be able to modify the model and to observe the effects of such changes

Changing or modifying the real system could be:

- difficult
- Ethically wrong
- Essentially, impossible (because of time-space constraints)

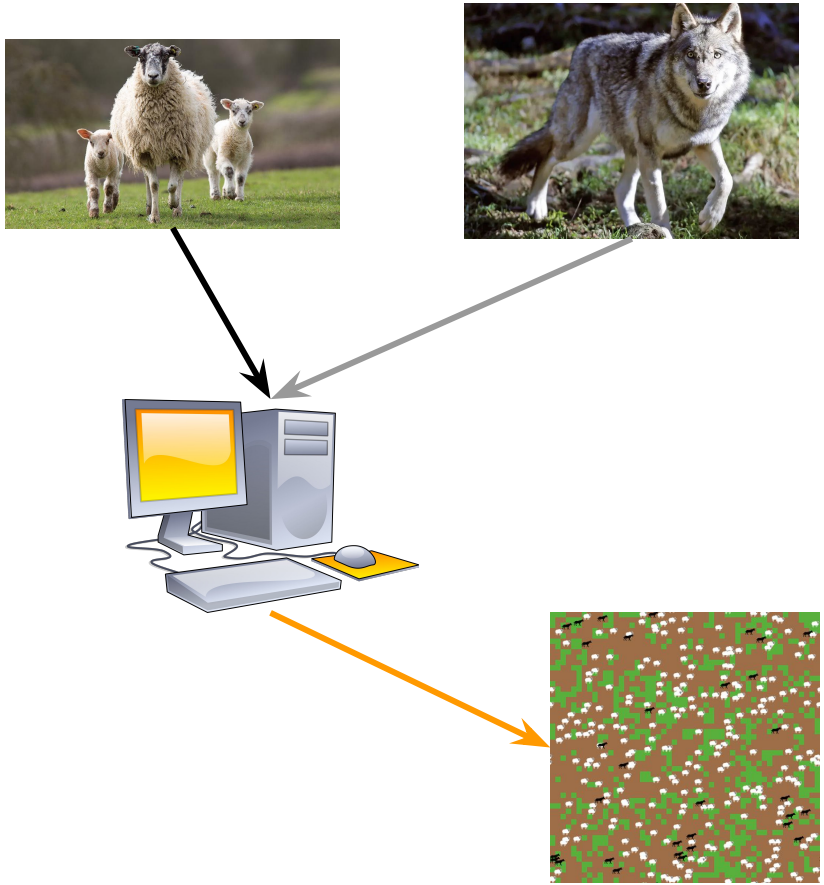
What a Computational Model is

A **computational model (CM)** consists in the **translation in operational terms** of the conceptual model of a real phenomenon or system

The model can be defined as the **set of systems' processes occurring over time**

The operational nature of the model allows us (hopefully) to better **understand the functioning** of the real system

Simulations (S) are a subset of CMs; and, **Agent-Based Modelling (ABM)** represents a particular class of techniques that can be used to implement a simulation S.

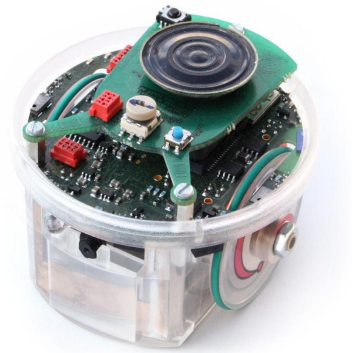


What an agent is

*"An (intelligent) **agent** is a device that **interacts** with its **environment** in flexible, **goal-directed** ways, recognizing important states of the environment and acting to achieve desired results."* (The MIT Encyclopedia of Cognitive Sciences, 1999)

The agent **can** be:

- Embodied
- Situated
- Intentional



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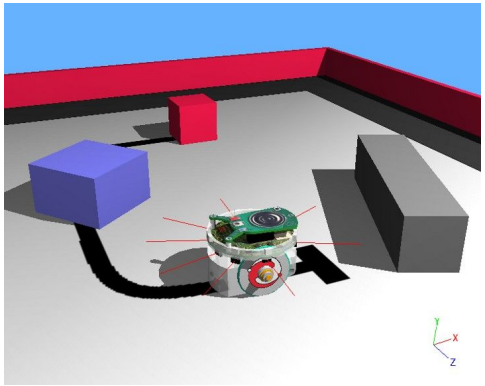

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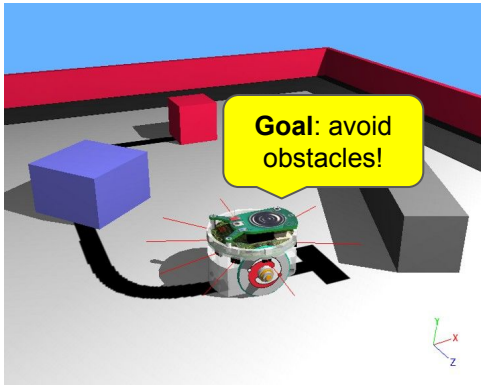
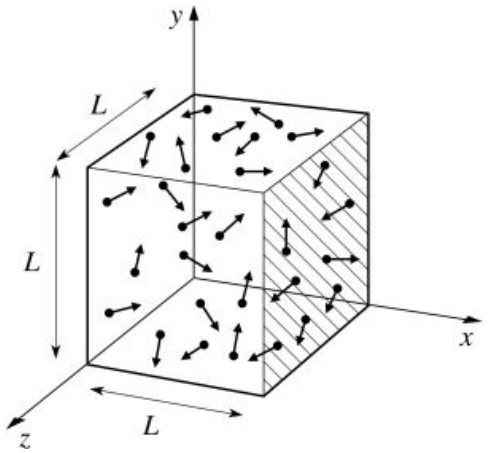


What an agent is

An Agent **can** be equipped with a **control system**:

- **No control system** (e.g., statistical mechanics particles)
- Rule-based control system
- Symbolic Vs. subsymbolic approach
  - BDI (Belief-Desire-Intention)
  - Artificial Neural Network (ANN)
- Any **modular architecture** you may think of



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if x >= X
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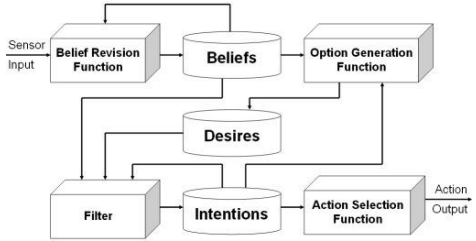
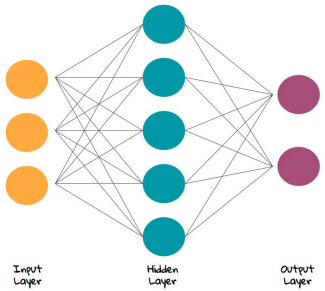


Vs.



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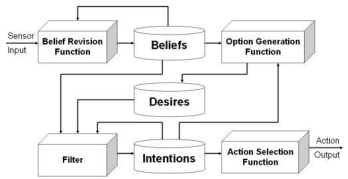

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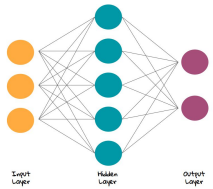

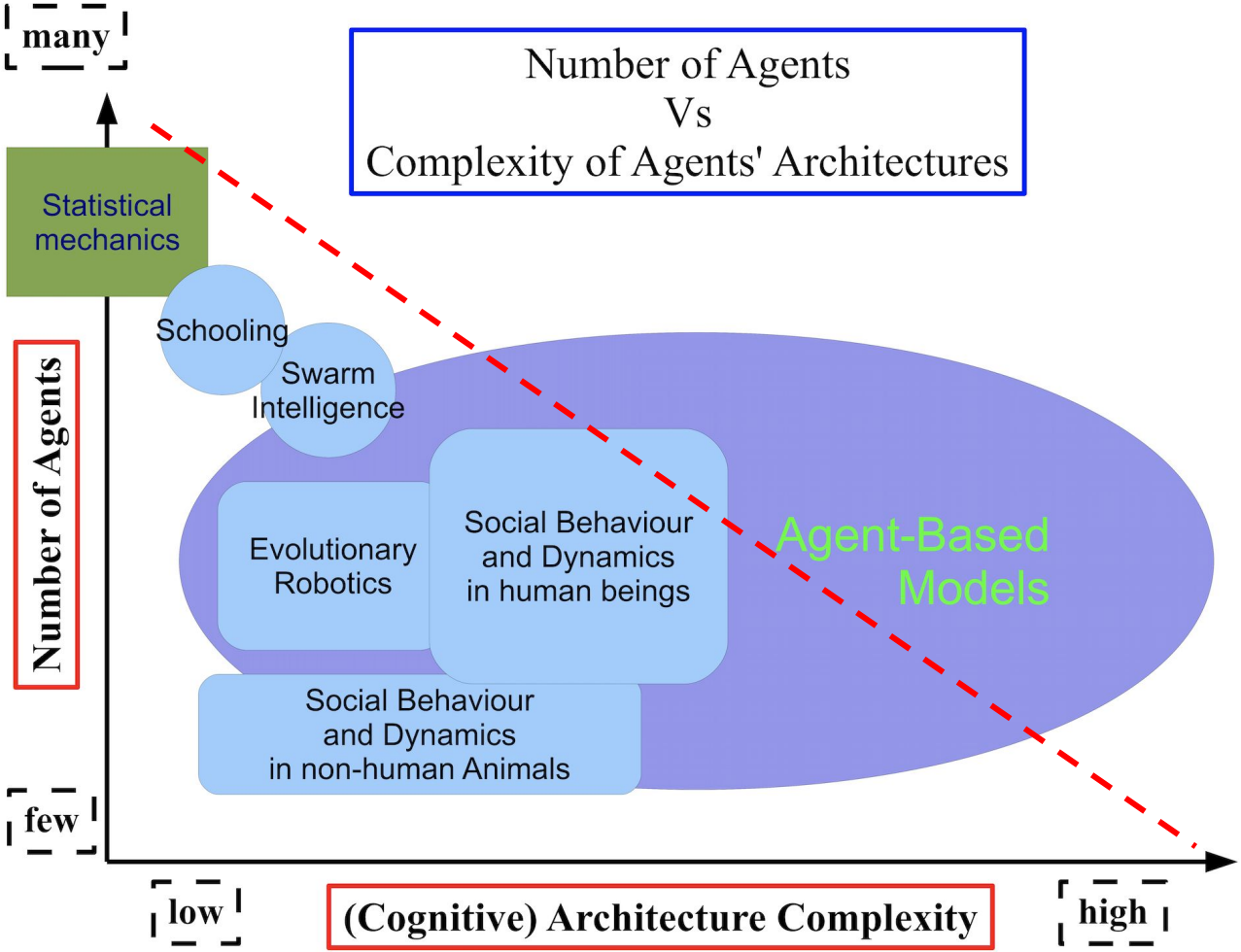
many
Number of Agents
Vs
Complexity of Agents' Architectures
Statistical mechanics
Schooling
Swarm Intelligence
Evolutionary Robotics
Social Behaviour and Dynamics in human beings
Agent-Based Models
Social Behaviour and Dynamics in non-human Animals
Number of Agents
few
low
(Cognitive) Architecture Complexity
high

Standard protocol in presenting an ABM

The **ODD protocol** is becoming more and more the **standard** way to present an ABM and it is organized around the three main components to be documented about a model:

1. Overview
2. Design concepts
3. Details

References:

- Grimm, Volker, et al. "A standard protocol for describing individual-based and agent-based models." *Ecological modelling* 198.1-2 (2006): 115-126.
- Grimm, Volker, et al. "The ODD protocol: a review and first update." *Ecological modelling* 221.23 (2010): 2760-2768.

Standard protocol in presenting an ABM

These components encompass seven sub-elements that must be documented in sufficient depth for the model's purpose and design to be clear and replicable for a third party:

1. *Purpose,*
2. *State Variables and Scales,*
3. *Process Overview and Scheduling,*
4. *Design Concepts,*
5. *Initialization,*
6. *Input, and*
7. *Submodels.*

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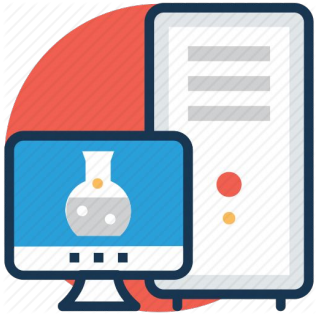
Advantages in using ABM



An **ABM**

- Obliges us to **formulate a theory**
- Allows us to use a sort of **virtual lab** where we can
  - **Observe the behaviour of the system** under controlled conditions
  - **Manipulate those conditions** without any risk
- Leads us **to identify relevant components** of the real systems and relations between those components
- Frees up from **time-space constraints**

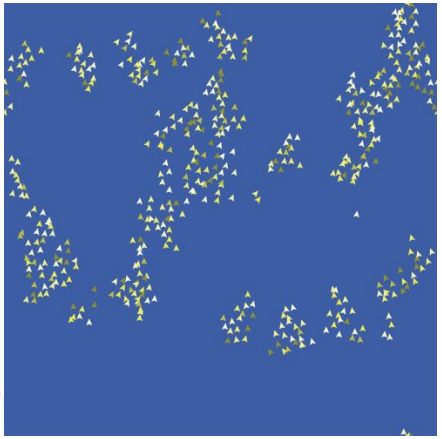
Limits Of ABM

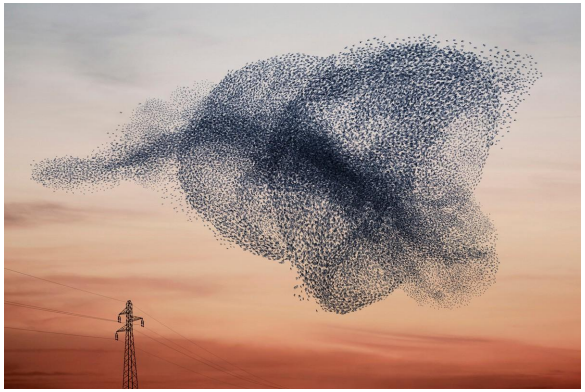
- The **Implementation** of an ABM depends on:
  - The **Availability of computational resources**
  - The necessity of using a specific level of **abstraction** (the model is a "Map" and not a "Copy")
  - The fact that the model must **be designed, developed** and **implemented by an Individual** and this **process requires time, experience**, and the formulation of a series of **arbitrary assumptions**
- **Interpretation** and **validation** of model results may be **challenging**

Some Models

Some models:

- Flocking behaviour
- Fireflies synchronization
- Wolf-sheep predator-prey s





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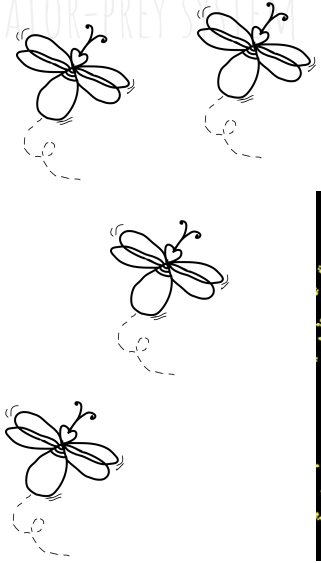

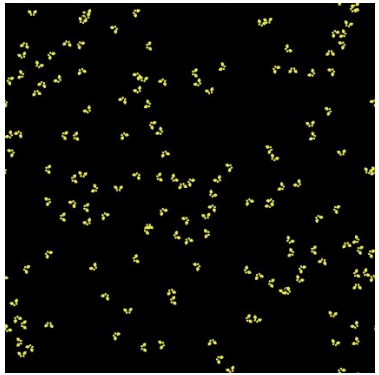

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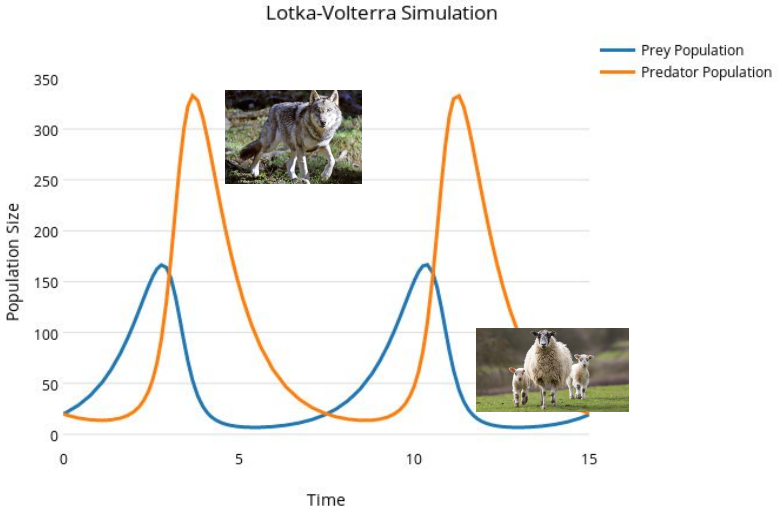

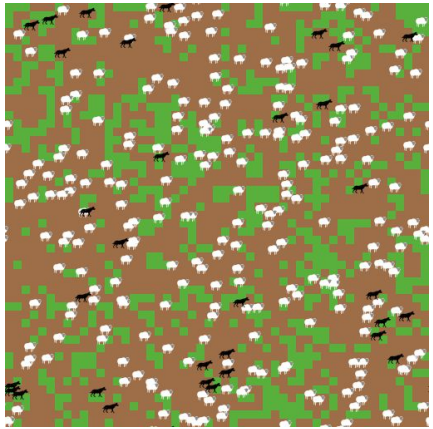

Take-Home Message

A simple but crucial set of Reminders:

- An **ABM** is **not the particular language, platform, software** used to implement it!
  - An ABM could even be implemented using a pen and a piece of paper…
- The main idea is that the **behaviour** of the system can **emerge** from the interactions between units or agents at another (lower) level:
  - We define the properties and the behaviours of those units and not the behaviour of the whole system
- A correct use of ABM requires **experience**, **experience**, and **experience**
  - There is **no single way** to implement an ABM, and there is **no right nor wrong way** to do it
- ABM may be an alternative to mathematical modelling, but ultimately it represents the ideal complement of it
- ABM and Mathematical models may investigate the same system, but they definitely produce different outputs:
  - ABM is a bottom-up approach, while
  - Mathematical Modelling is a Top-down approach
- An ABM can be parametrized using empirical data
- Empirical data can be used to validate ABM results
- ABM results can be used by researchers collecting empirical data to optimize the collection process or to properly define the type of data to collect (e.g., a particular measure)
- In an Ideal world the combination of empirical data and simulated ones may represent the best option; but, unfortunately, we do not live in an Ideal world…

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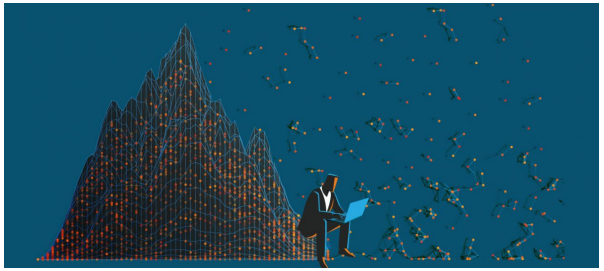
My very **personal interpretation** of ABMs:

- **Generators of in-silico** (big amount of) **data** that can be used to test scientific hypotheses;
- But, also **useful tools** that can be used **to teach** many different and interesting things (e.g., physics, chemistry, biology, social behaviours and dynamics, ...);
- Ultimately, the best and safest option to run **what-if analysis**...



Useful Links and References

IABM textbook(s)

- Railsback, S. F., & Grimm, V. (2019). *Agent-based and individual-based modeling: A practical introduction*. Princeton University Press
- Wilensky, U., & Rand, W. (2015). *An introduction to agent-based modeling: modeling natural, social, and engineered complex systems with NetLogo*. MIT Press.
- Epstein, J. M. (2006). *Generative social science: Studies in agent-based computational modeling*. Princeton University Press.

- R packages for Social-Network Analysis (SNA):
  - igraph (http://igraph.org/redirect.html)
  - Tidygraph
  - Ggraph (ggplot2 sort of extension…)
  - Statnet (http://www.statnet.org/)
  - RSiena (https://www.stats.ox.ac.uk/~snijders/siena/)

ABM using Python

- MESA: ABMs using Python
  https://mesa.readthedocs.io/en/master/

ABM using NetLogo

- https://ccl.northwestern.edu/netlogo/

- Marco Smolla: ABM using R
https://marcosmolla.wordpress.com/2015/07/16/an-introduction-to-agent-based-modelling-in-r/

- simecol: R script to show some model http://simecol.r-forge.r-project.org/

- SpaDES: https://cran.r-project.org/web/packages/SpaDES/vignettes/i-introduction.html
http://spades.predictiveecology.org/
https://github.com/PredictiveEcology/SpaDES

- Very complete Intro to SNA using R: https://www.jessesadler.com/post/network-analysis-with-r/

If you want to know more about ABM,
Have any question or
Simply need any clarification,
Do not hesitate to email me:

Marco Campenni', PhD
M.Campenni@exeter.ac.uk
Human Behaviour and Cultural Evolution Group
College of Life and Environmental Sciences
University of Exeter