Introduction to Agent-based modeling

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

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NetLogo 6.0:

2D models:

- Networks: Virus on Network
- Biology: Fireflies
- IABM textbook

3D model:

- Preferential attachment

R model:

- Simple foraging model
- PD's game (evo)

- using NetLogo to generate network data and
- R to analyze them
- 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/)

- (Social) Networks in R
- Theoretical ecology: from spatstat (R) to NetLogo and back
- MESA: ABMs using Python
- (https://mesa.readthedocs.io/en/master/)

- 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

- tidyverse, ggplot2, tidygraph, ggraph

- https://www.jessesadler.com/post/network-analysis-with-r/

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)

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)

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)
- symbolic (e.g., a system of equations; a series of words; a computer software or program)

"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

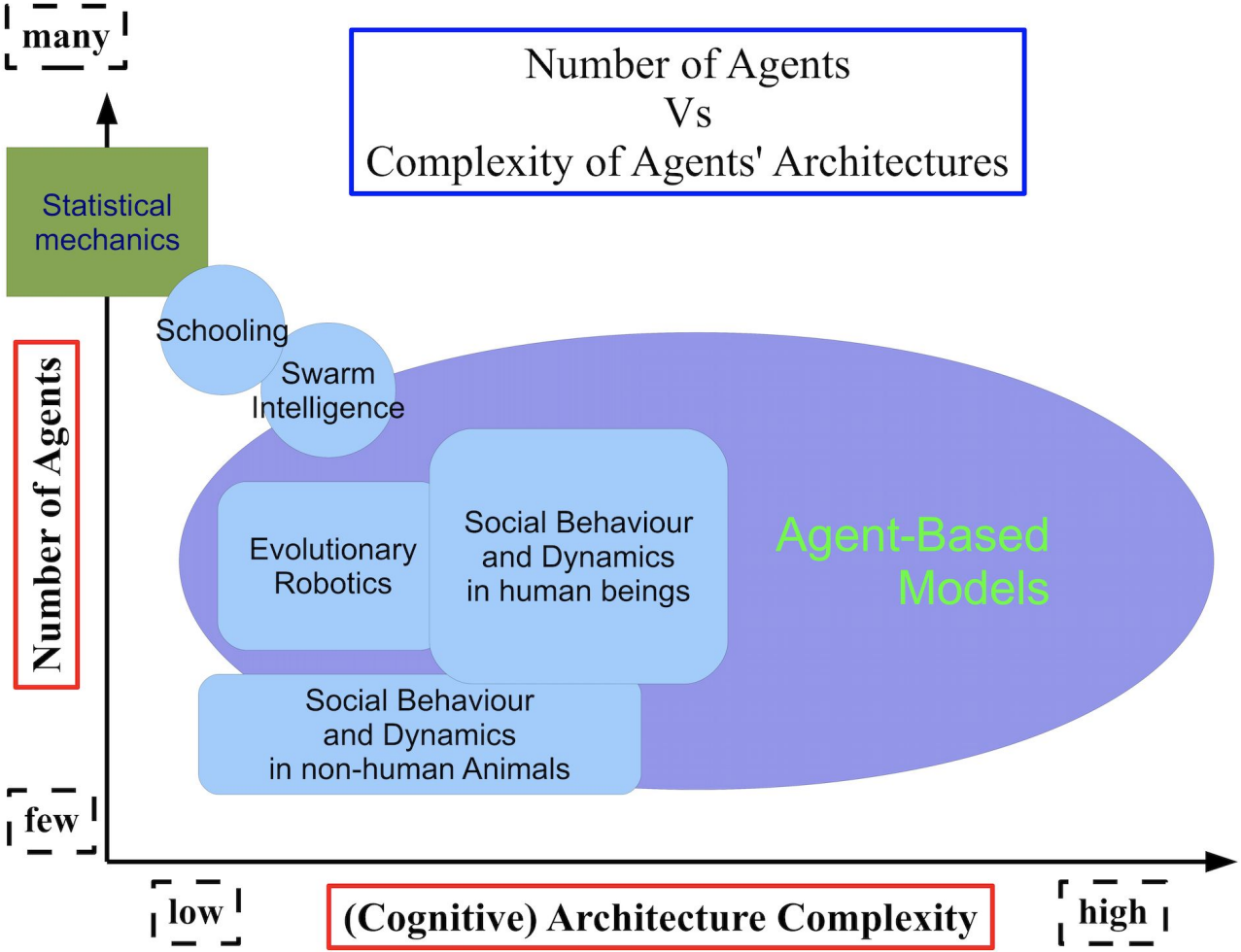
"An (intelligent) agent is a device that interacts with its environment in flexible, goal-directed ways, recognizing important states of the environment and acting to achieve desired results." (The MIT Encyclopedia of Cognitive Sciences, 1999)

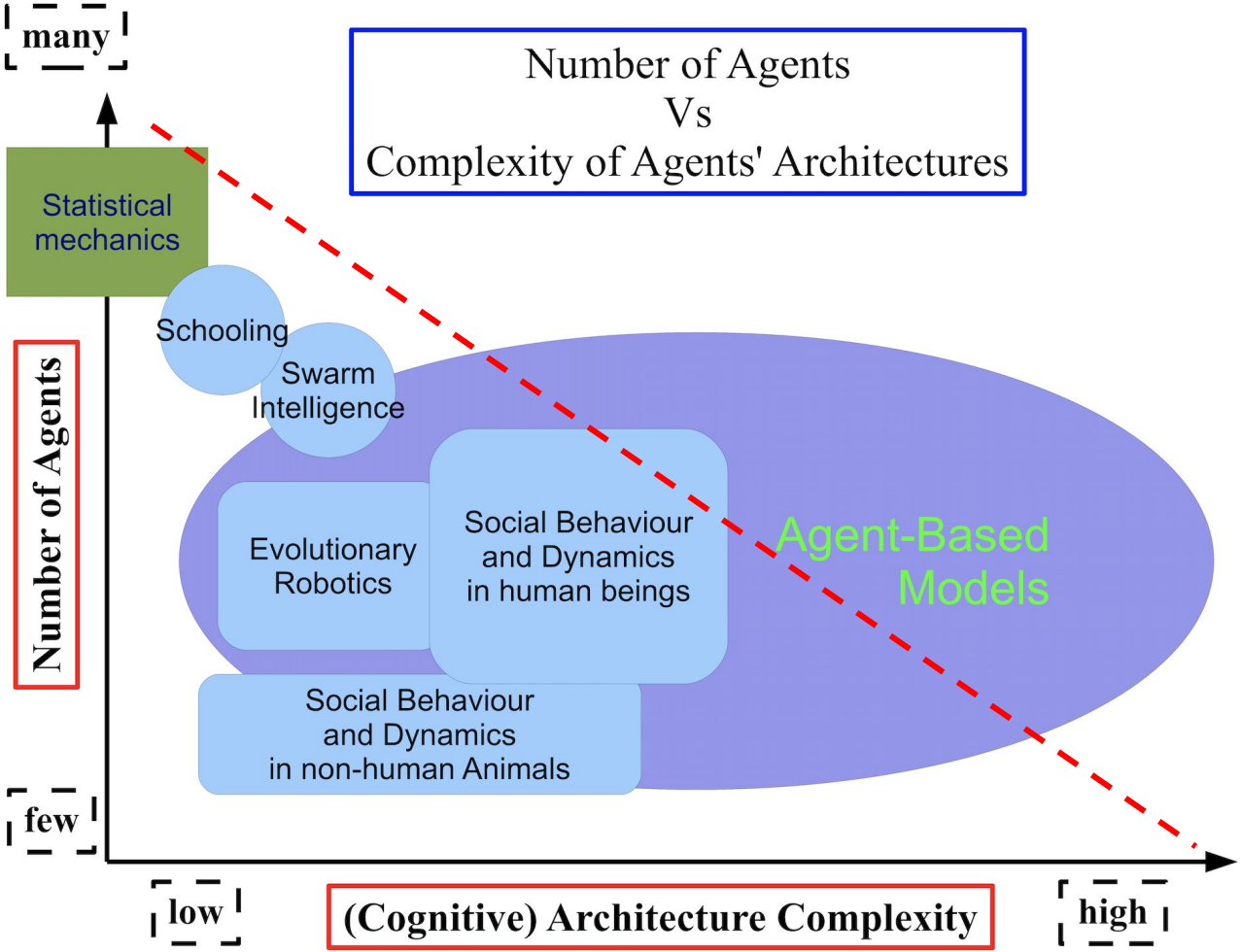
The agent **can** be:

- Embodied
- situated

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


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

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

Standard protocol in presenting an ABM

The ODD protocol became 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

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*.

- 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.

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 here being 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...

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**...