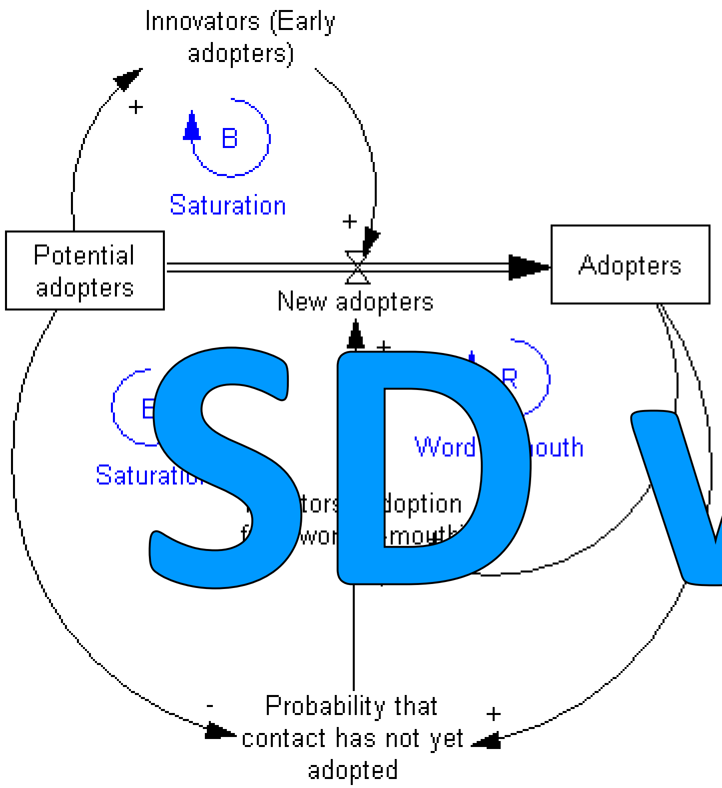
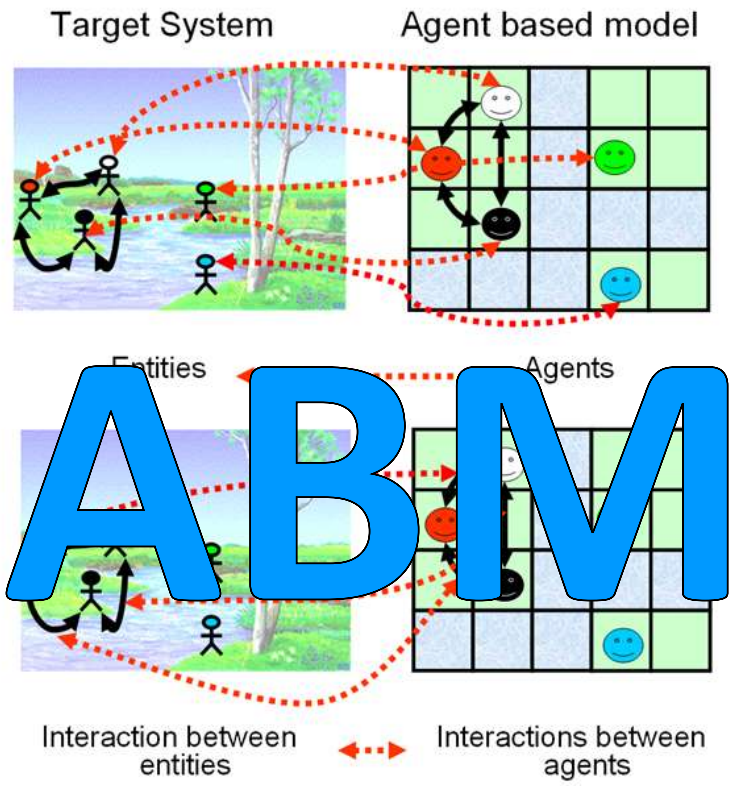


SD vs. ABM



ESM504 – System Dynamics for Business Policy

Dénes CSALA

12.06.2012

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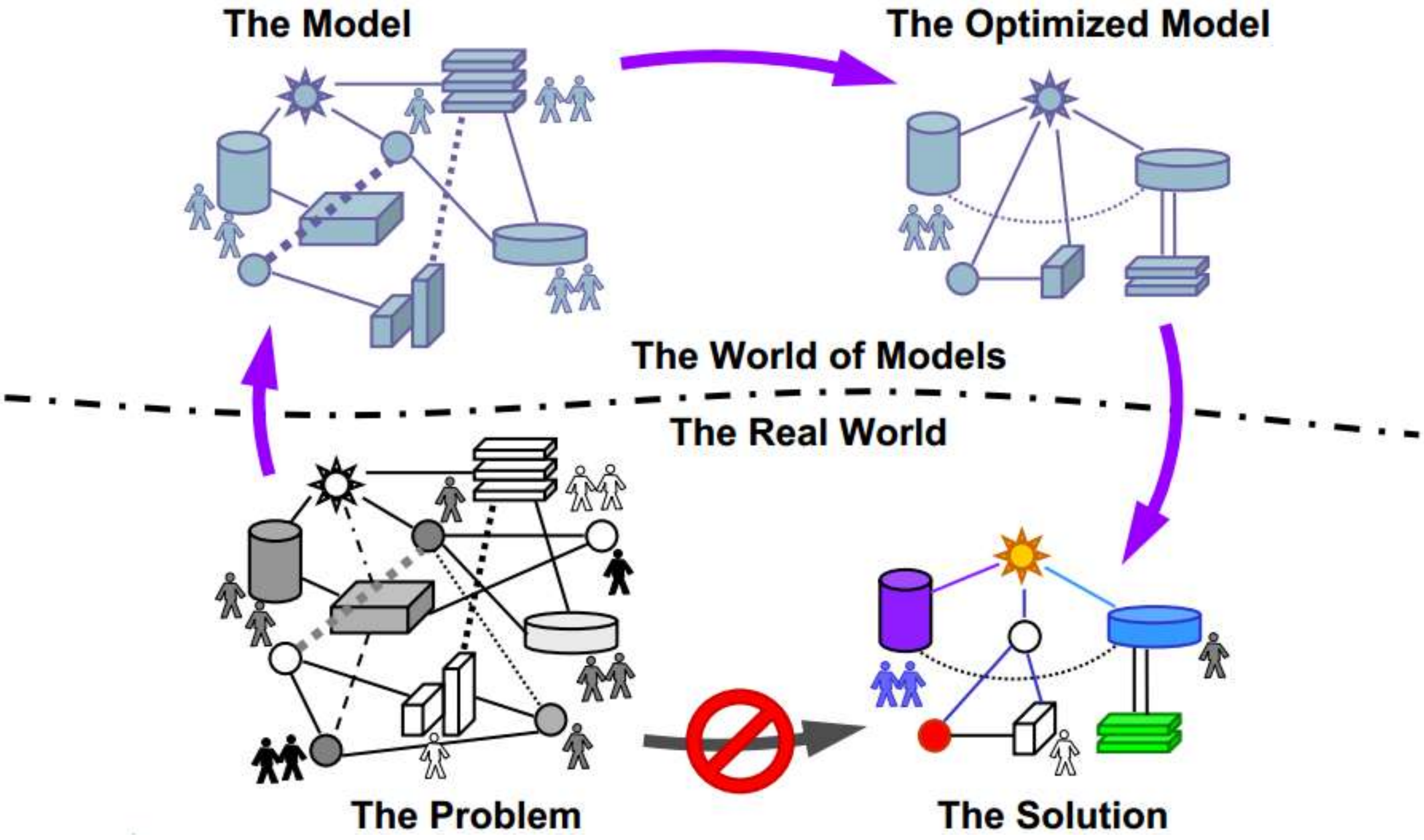
Overview

1. **Why model?**
   - The Modeling Cycle
2. **The family of simulation modeling**
   - System Dynamics
   - Dynamic Systems
   - Discrete Event
   - Agent Based
   - Hybrid
3. **ABC of ABM**
   - The agent
   - Common concepts
4. **SD vs. ABM**
   - Comparison
   - Pros and cons
   - Example models
5. **Modern methods**

Modeling: what and why?



Modeling: what and why?

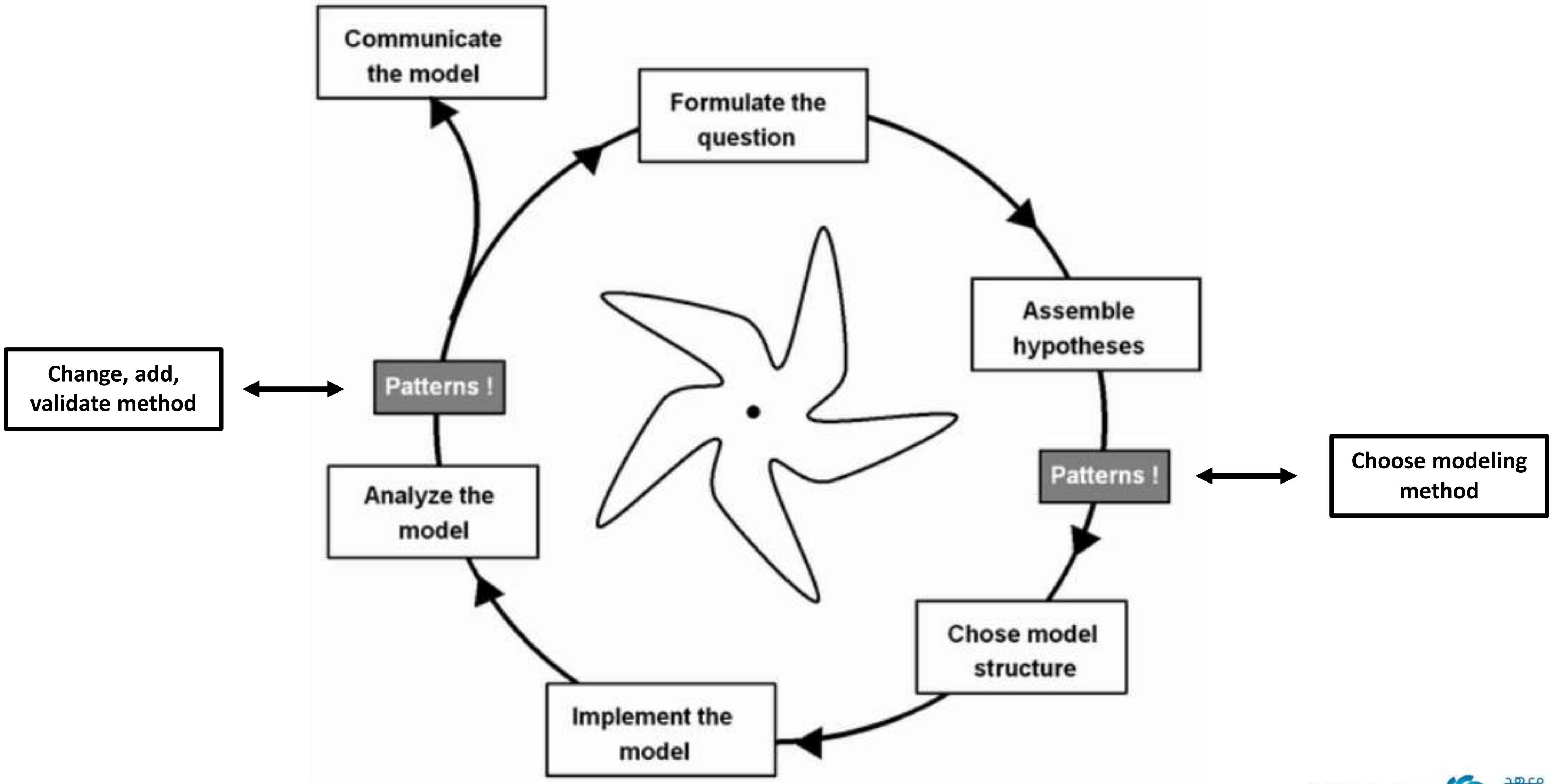
- A model is a simplified representation of the reality

- Why model? The reality is too complex to study!
  - Problem solving under constraints: time, information, money, etc.
  - Not all variables are of equal importance to the researcher
  - Reflect the 'implicit' assumptions, rules, and strategies we use to solve problems 'explicit' in the model

- Modeling is so cool, it's like a computer game! "Let us model the system first and think about the problems we want to answer"

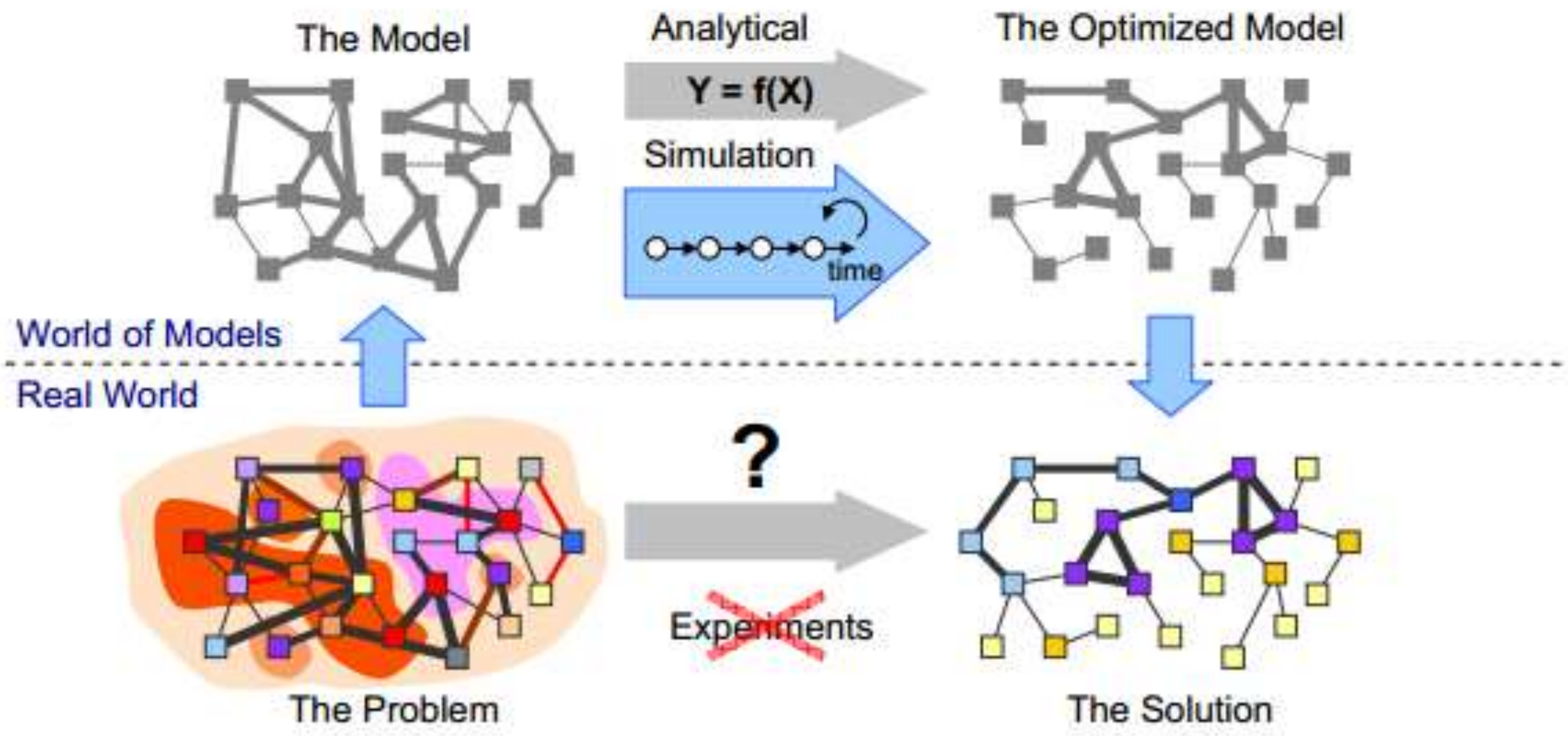
DOES NOT WORK!

The Modeling Cycle



Source: U. Berger

Modeling Approach



1. Try to solve the problem analytically
2. Try using experimental methods
3. Try using computer simulated numerical models

Source: A. Borshchev

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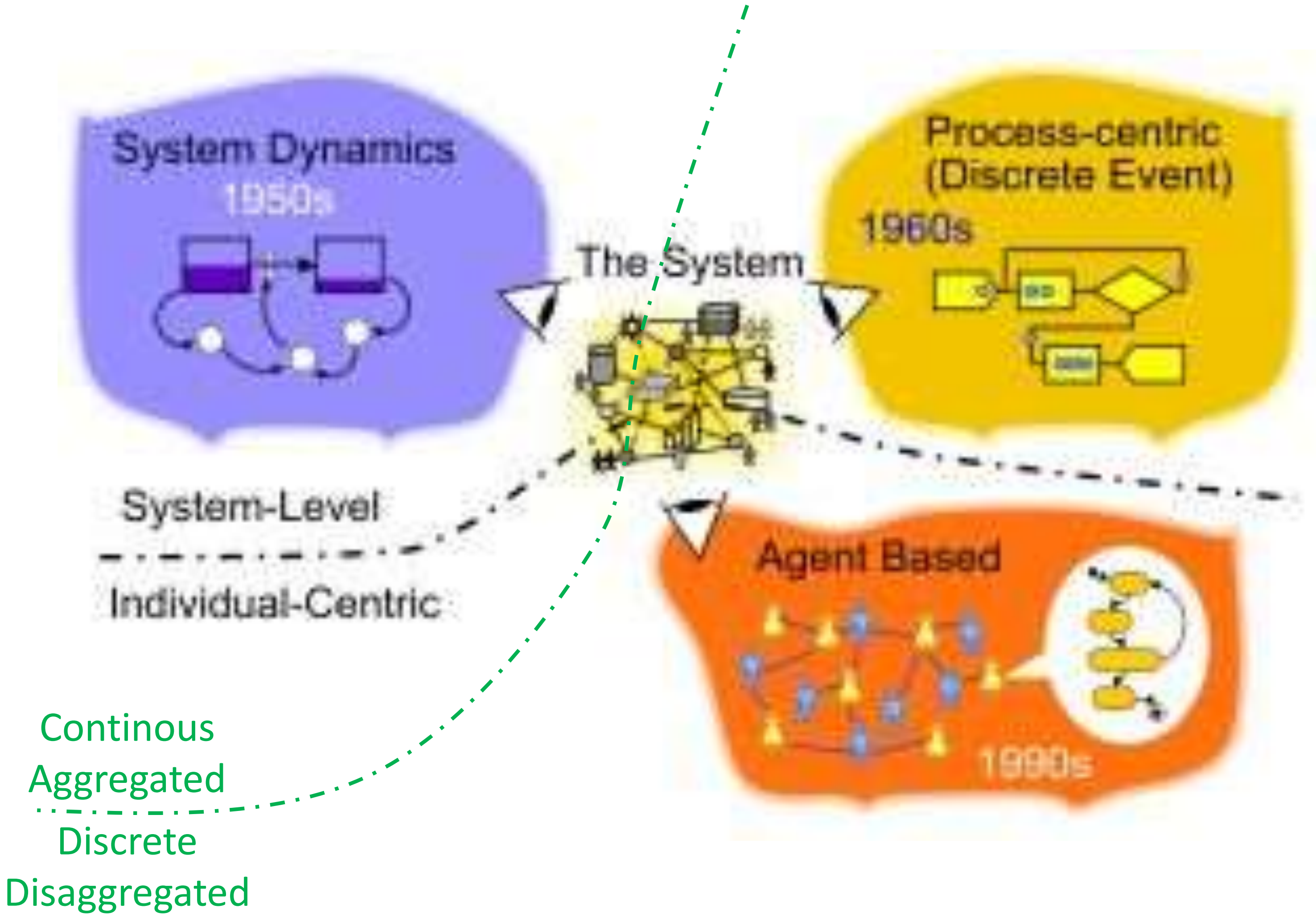
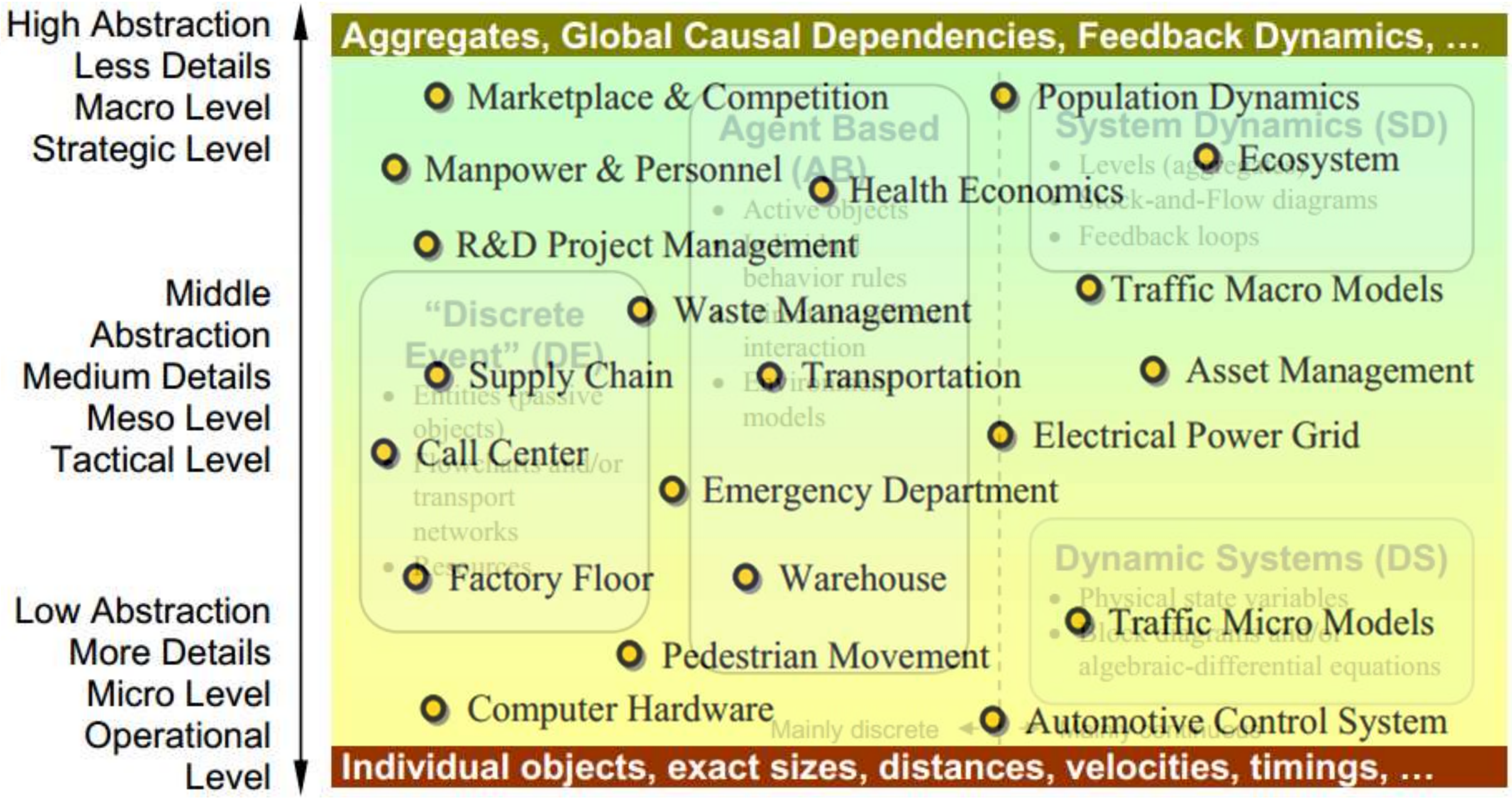
The family of simulation modeling



Source: AnyLogic

The family of simulation modeling



Source: A. Borshchev

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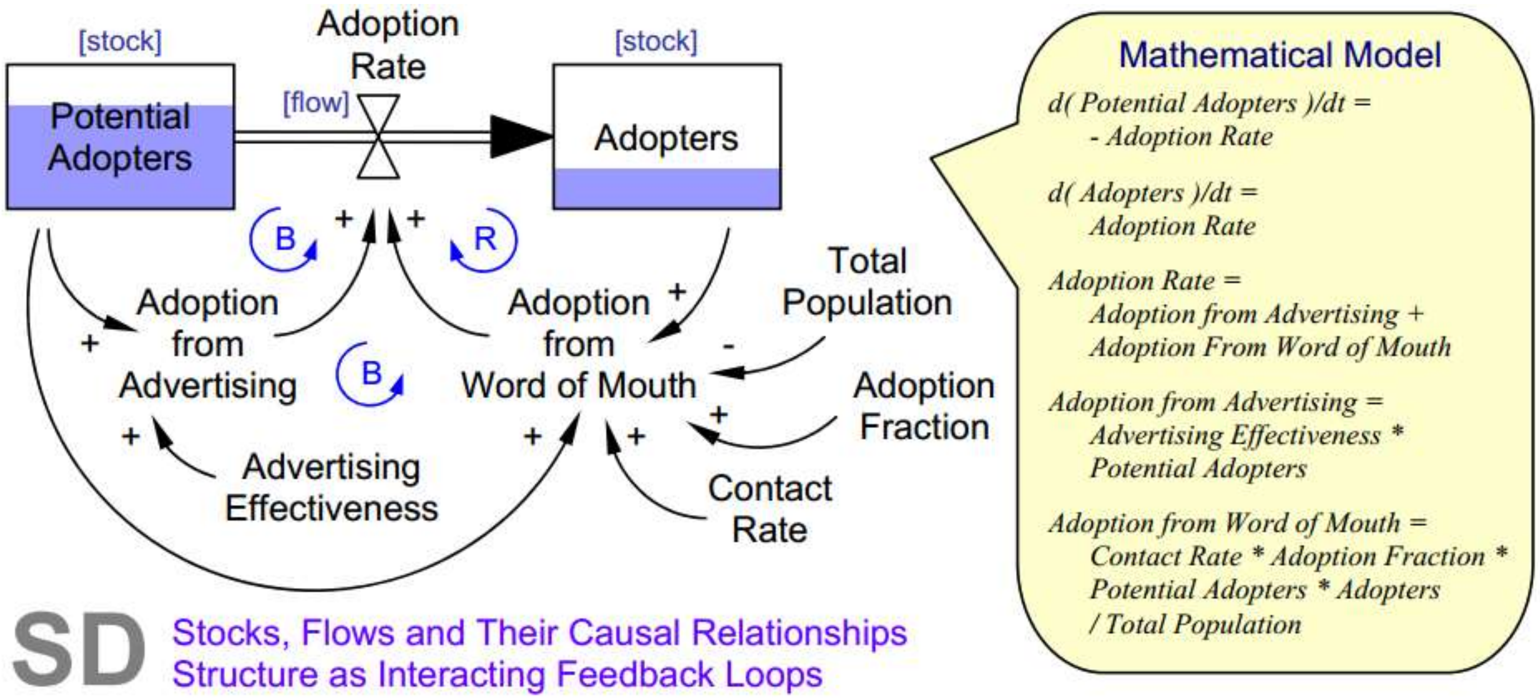
System Dynamics

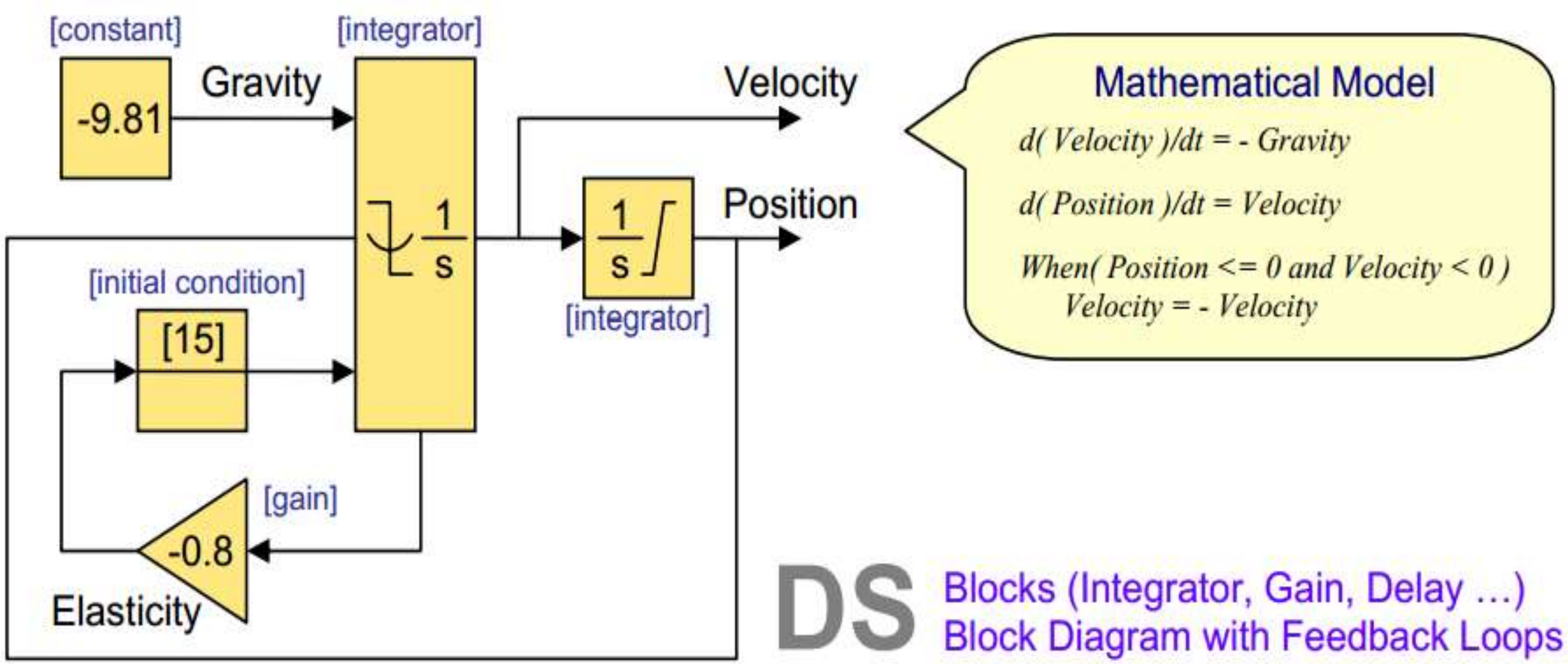


- Top-down approach
- Aggregate view, strong explanatory power – reflect mental models
- Uses stock, flows, loops and delays to represent the real world
- Widely applied in (but not limited to) managerial and policy studies

"System dynamics is a perspective and set of conceptual tools that enable us to understand the structure and dynamics of complex systems. System dynamics is also a rigorous modeling method that enables us to build formal computer simulations of complex systems and use them to design more effective policies and organizations. Together, these tools allow us to create management flight simulators-microworlds where space and time can be compressed and slowed so we can experience the long-term side effects of decisions, speed learning, develop our understanding of complex systems, and design structures and strategies for greater success."

Source: A. Borshchev, AnyLogic

Dynamic System



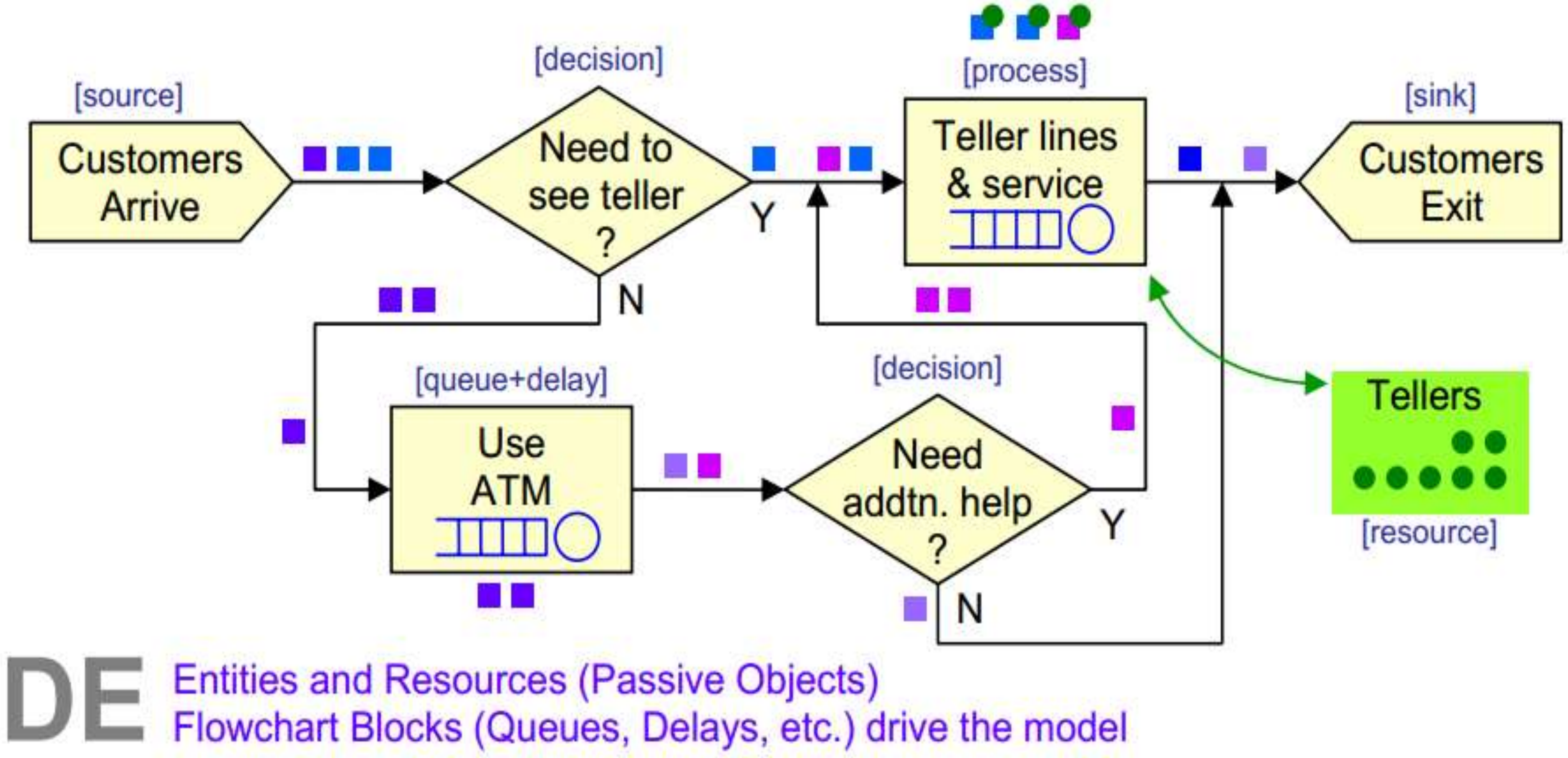
DS Blocks (Integrator, Gain, Delay …)
Block Diagram with Feedback Loops

- Used in electrical, mechanical, chemical and other engineering disciplines
- Variables have direct 'physical' meaning
- State variables linked by algebraic differential equations
- More accurate but also more complex than SD
- Think of it as an "exact" SD approach

"Dynamical systems theory is an area of mathematics used to describe the behavior of complex dynamical systems, usually by employing differential equations or difference equations. This theory deals with the long-term qualitative behavior of dynamical systems, and the studies of the solutions to the equations of motion of systems that are primarily mechanical in nature; although this includes both planetary orbits as well as the behavior of electronic circuits and the solutions to partial differential equations that arise in biology. Much of modern research is focused on the study of chaotic systems."

Source: A. Borshchev, Wikipedia

Discrete Event

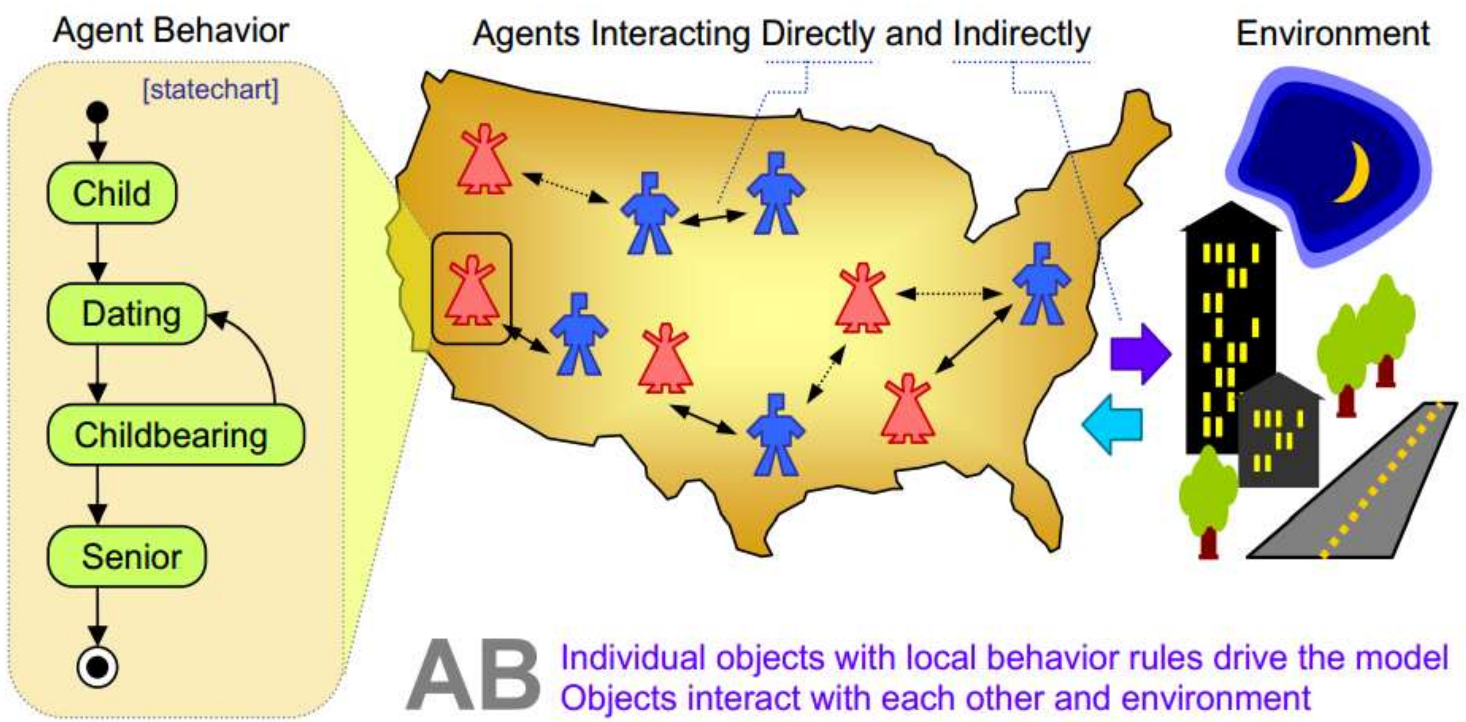


In discrete-event simulation, the operation of a system is represented as a chronological sequence of events. Each event occurs at an instant in time and marks a change of state in the system. For example, if an elevator is simulated, an event could be "level 6 button pressed", with the resulting system state of "lift moving" and eventually (unless one chooses to simulate the failure of the lift) "lift at level 6".

- Based on the concept of entities, resources and block charts describing entity flow and resource sharing
- Passive entities
- The focus is on the 'processes' not the 'agents'

Source: A. Borshchev, AnyLogic, Wikipedia

Agent Based

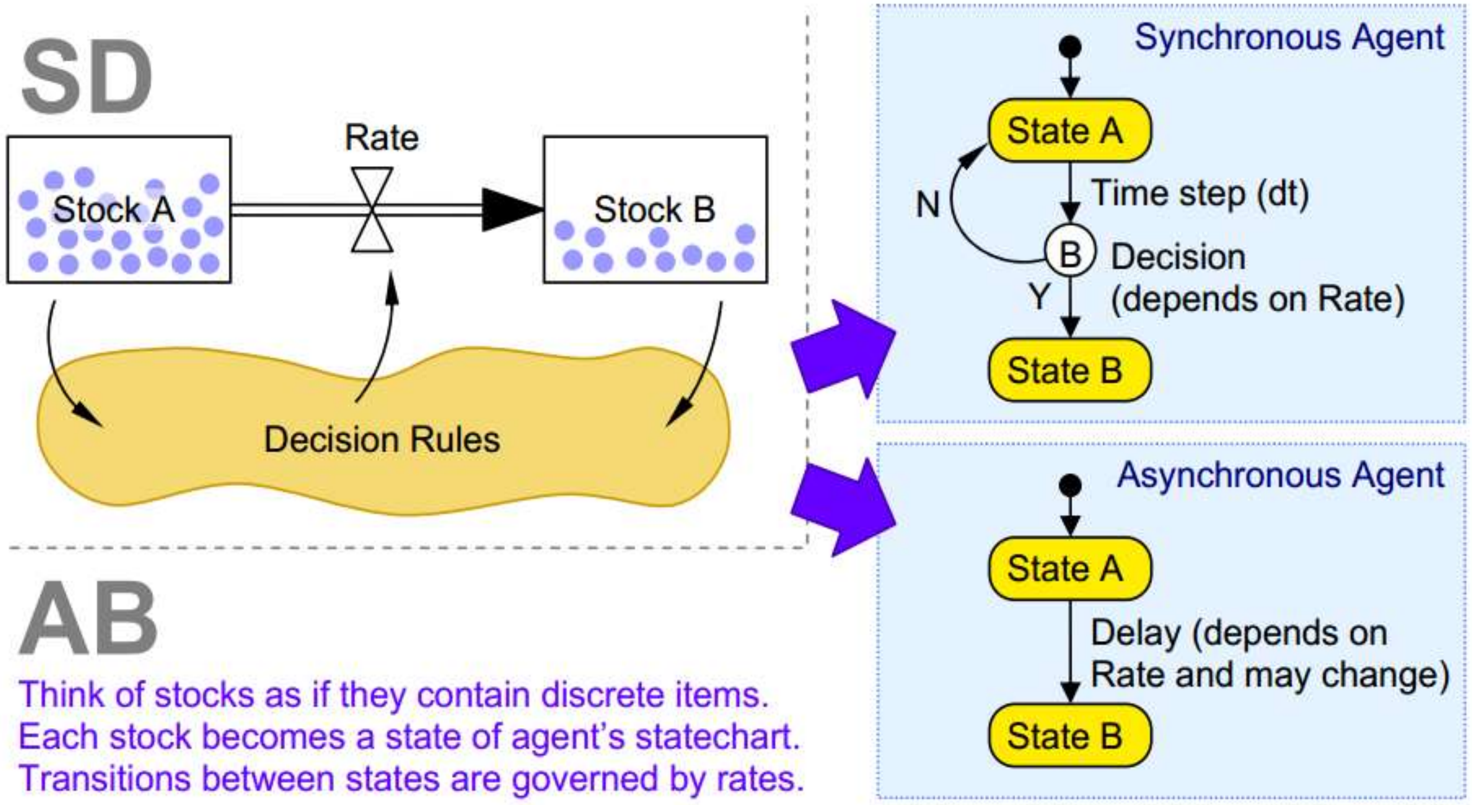


"Agent Based Modeling (also sometimes related to the term multi-agent system) is an essentially decentralized, individual-centric (as opposed to system level) approach to model design. When designing an agent based model the modeler identifies the active entities, the agents (which can be people, companies, projects, assets, vehicles, cities, animals, ships, products, etc.), defines their behavior (main drivers, reactions, memory, states, ...), puts them in a certain environment, establishes connections, and runs the simulation. The global behavior then emerges as a result of interactions of many individual behaviors. It combines elements of game theory, complex systems, emergence, computational sociology, multi-agent systems, and evolutionary programming."

- Bottom-up approach
- Consist of agents that are autonomous, pro-active, reactive, spatial aware, able to learn and have social abilities, that 'live' in an environment and are driven by behavior rules defined by 'state charts'

Source: A. Borshchev, AnyLogic

Multimethod approach – Hybrid models

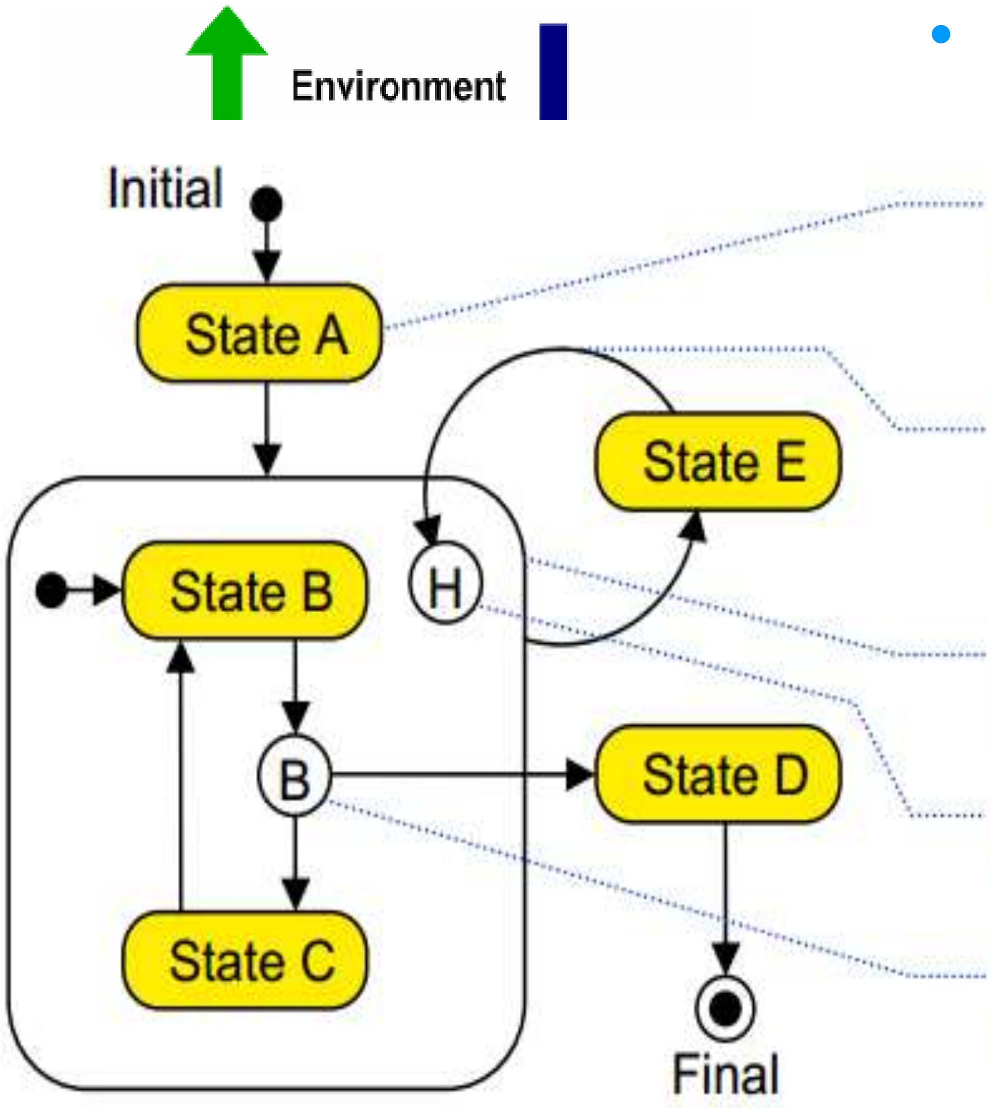


- Many problems can be models using both SD and ABM
- It is possible to 're-conceptualize' an SD model into ABM
- ABM allows us sometimes to refine the model and make it more 'realistic' and 'useful'

Source: A. Borshchev

ABC of ABM

- Building block: Agent



Simple State
Control is always located in one of the simple states. States have Entry and Exit actions

Transition
Can be triggered by an external or internal event, condition or timeout. Has Action

Composite State
A group of states with common behavior

History Pseudo State
Denotes last visited state in the composite state

Branch Pseudo State
Specifies conditional branching of transitions

ABC of ABM

- A ... ng ag... be... pa...

- Ex... si...
  - ... ving
  - ... rd
  - ...
- Th...

Common concepts in ABM

- Emergence: from chaos comes order!
  - ABMs with few or no emergent outcomes tend to be less useful (and less interesting!)
  - However, don't try to 'impose' emergence. Instead, look for the adaptation rules that might lead to it.
- Adaptation: what decisions do agents make?
  - Direct objective seeking: decisions maximize explicit estimates of an agent's future condition
  - Indirect objective seeking: agents are given rules that mimic observed behavior, which are presumably contribute to their objectives

Common concepts in ABM

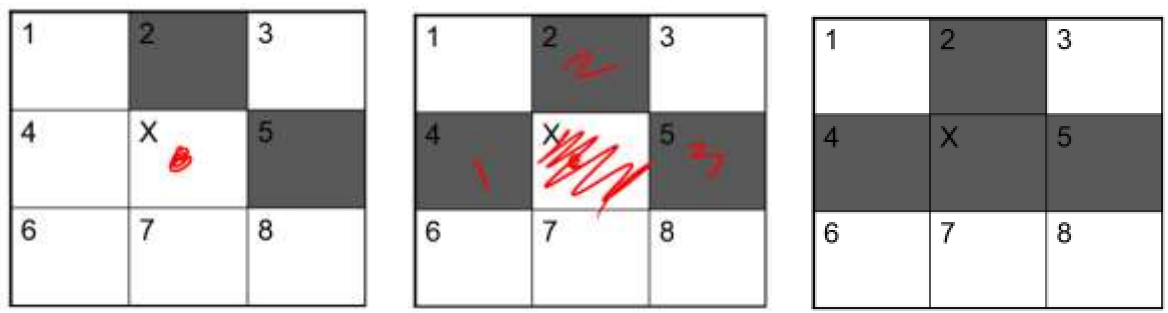
- Interaction: local NOT global interaction
  - Direct interaction: (example: wolf-sheep interaction in the predator-prey model)
  - Indirect interaction: through the environment (competition between sheep for grass)

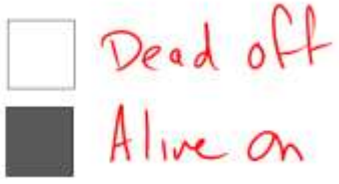
- Sensing: what information do agents have?
  - Is it realistic to assume that the agent knows a certain piece of information? Under what conditions?
  - What is the effect of this “partial knowledge”?

Game of Life

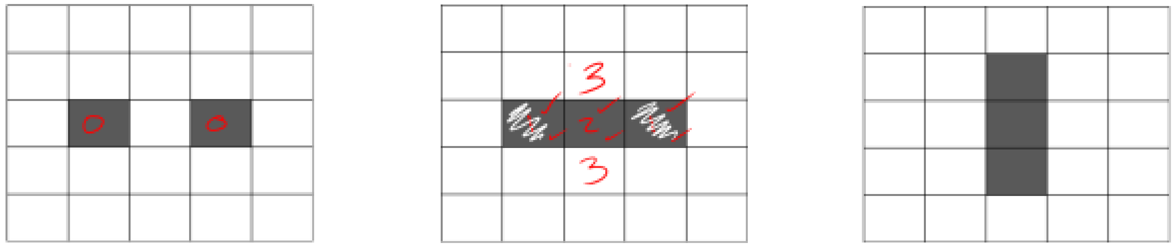
- The Game of Life, is a **cellular automaton** devised by the British mathematician John Horton Conway in 1970.

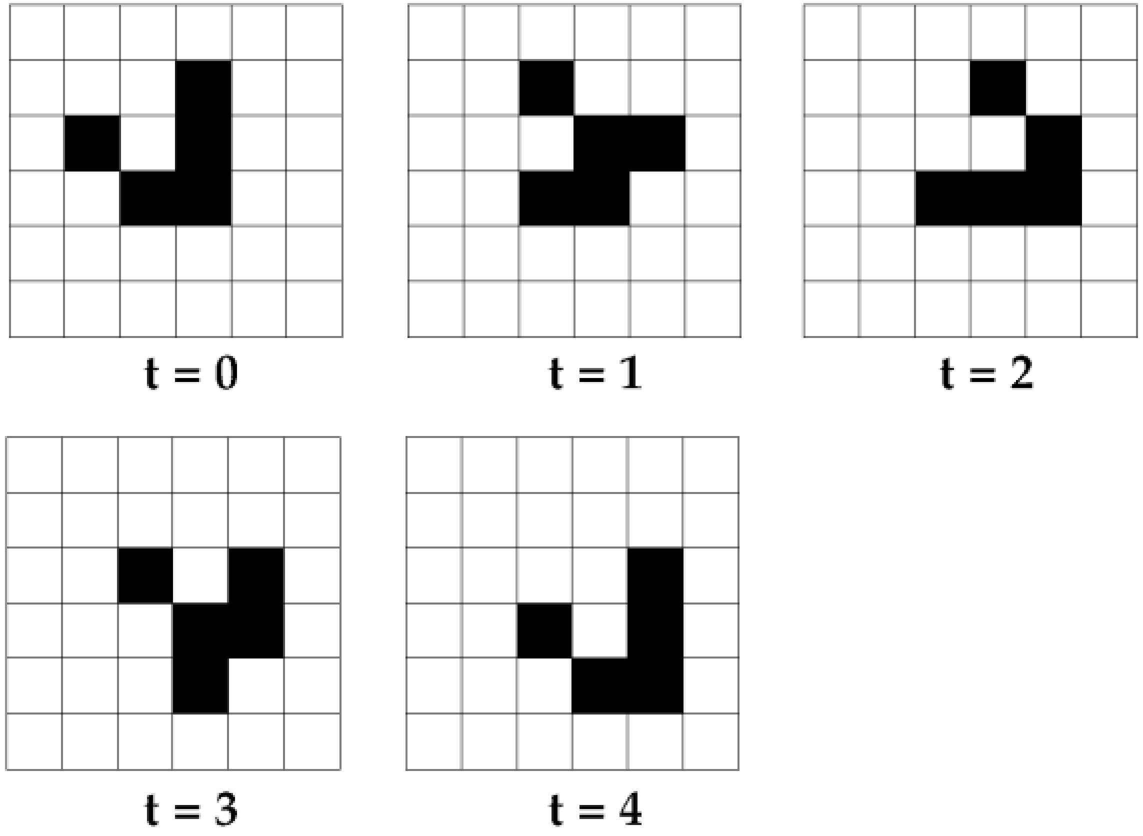
- 2 simple rules lead to emergence of unpredictable, complex patterns





If **off** you turn **on** if 3 neighbors **on**
If **on** stay **on** if 2 or 3 neighbors **on**





Source: Scott E. Page

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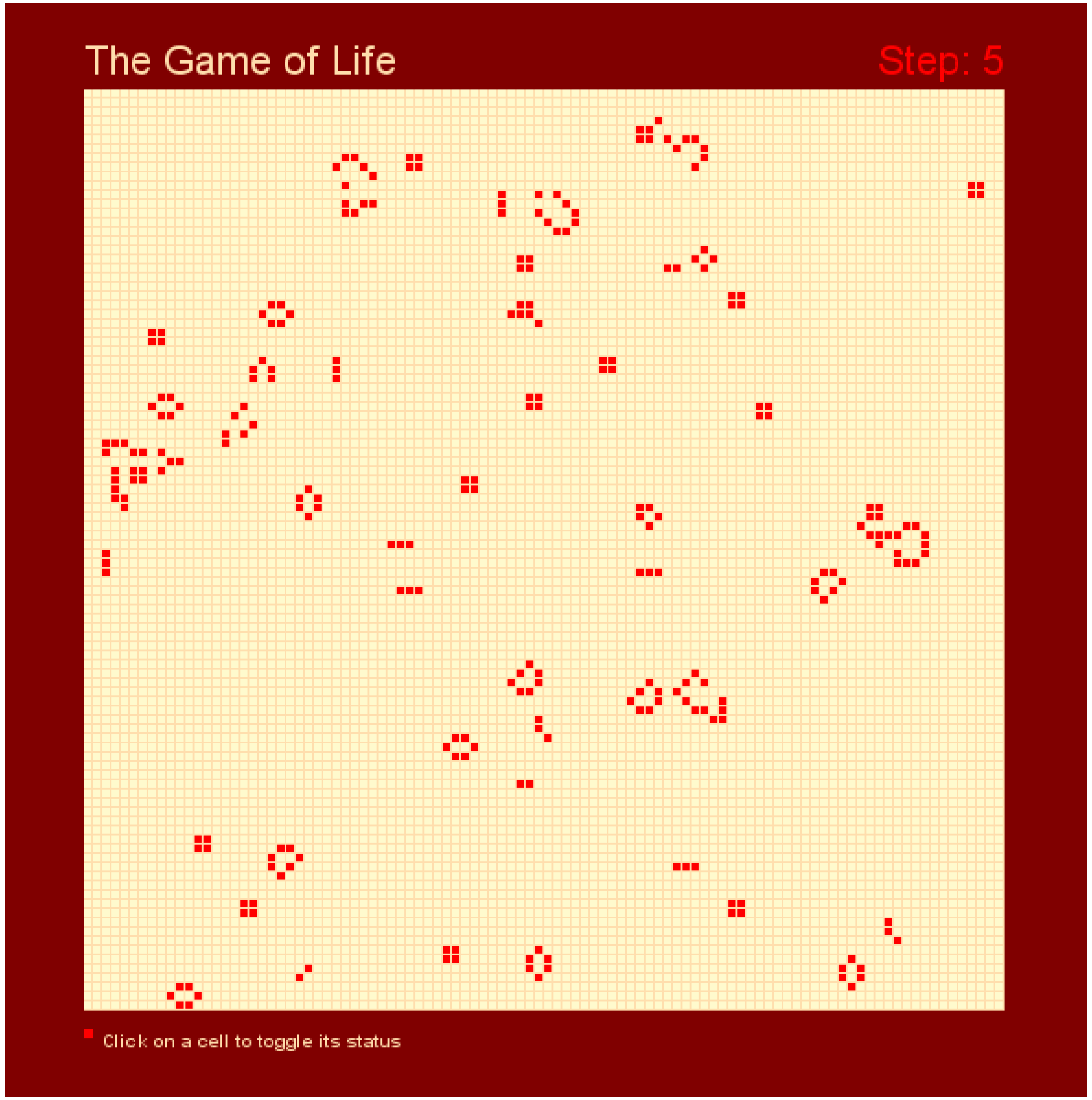
Game of Life



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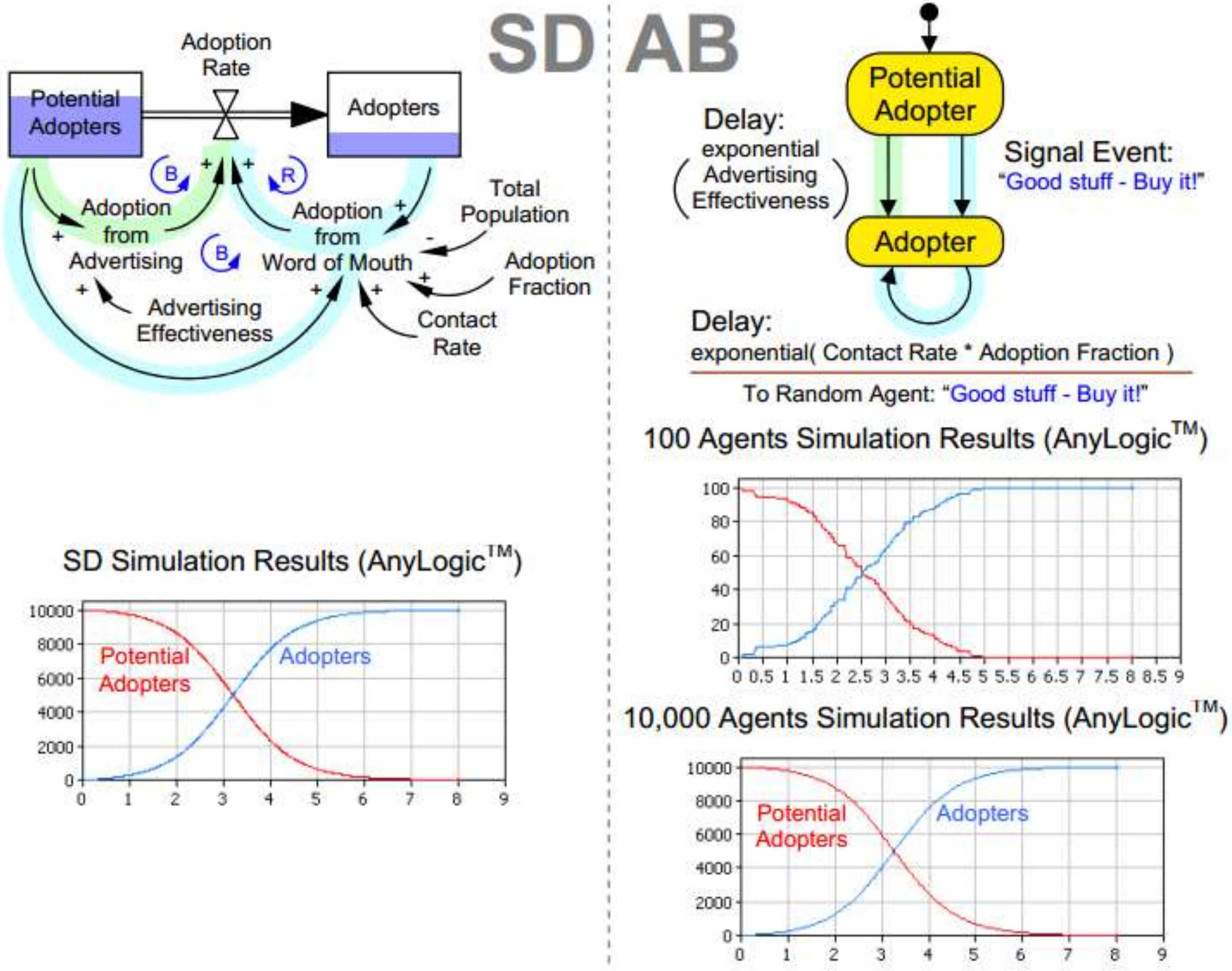
SD vs. ABM: Bass Diffusion model



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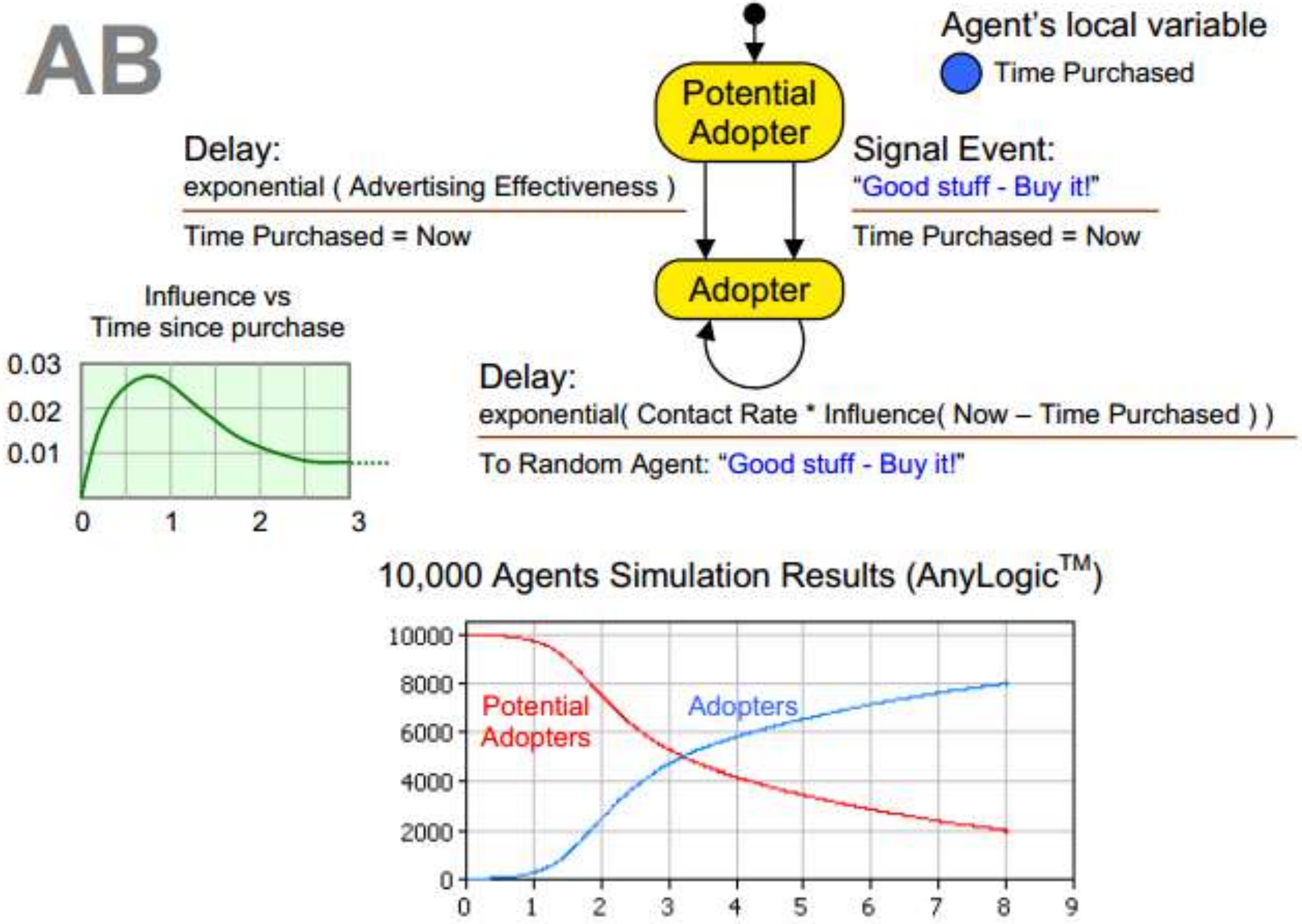
SD vs. ABM: Bass Diffusion model



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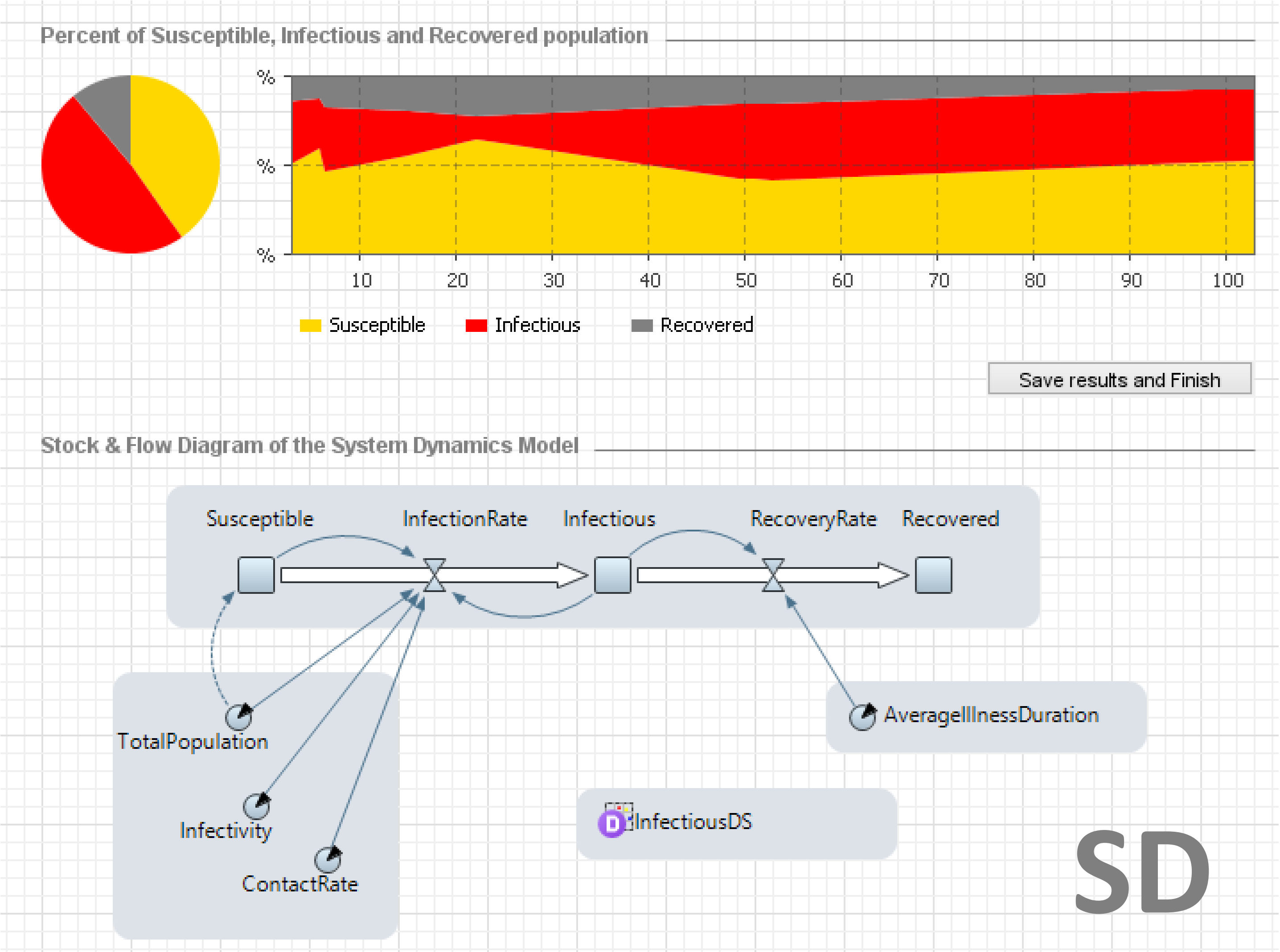
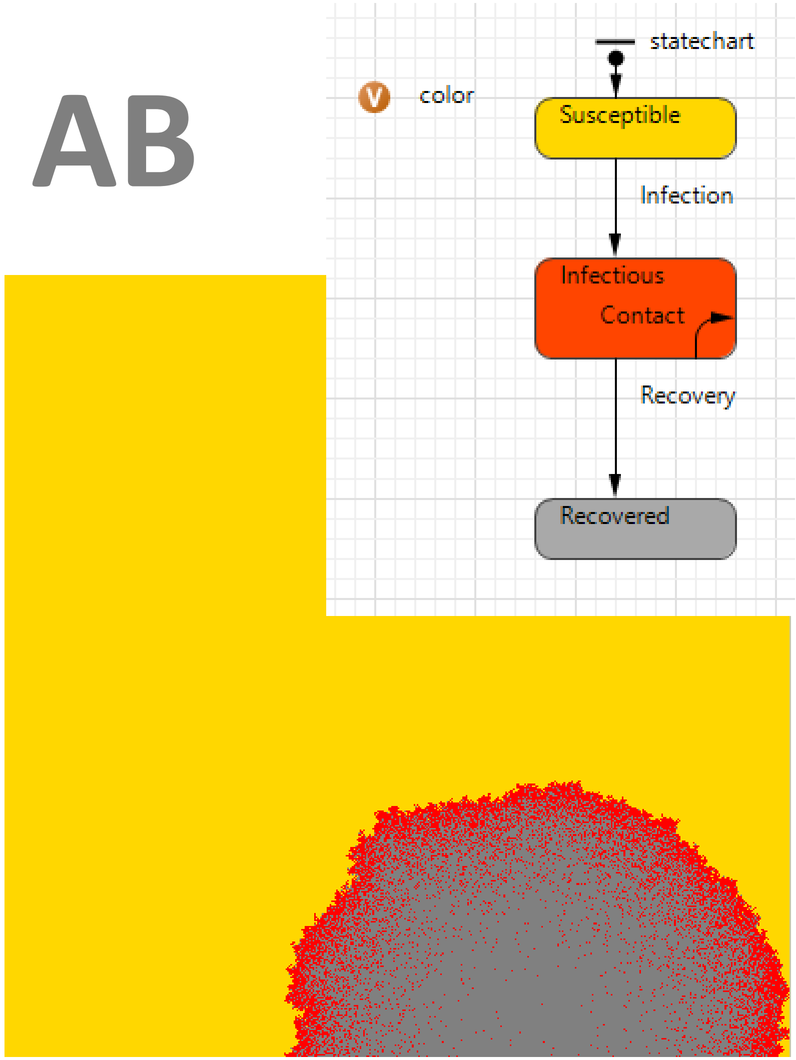
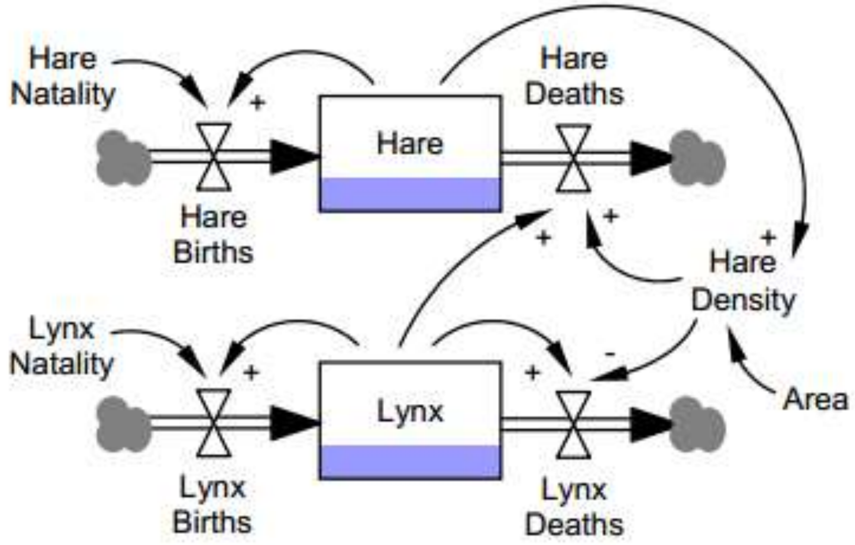
SD vs. ABM: SIR model

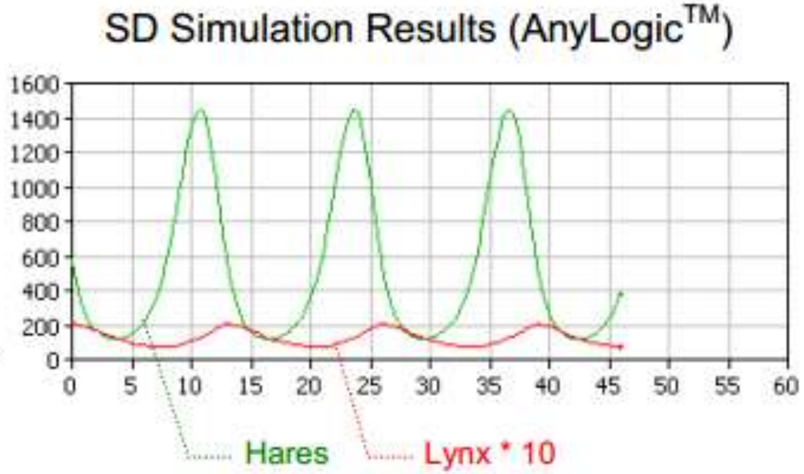




SD vs. ABM: Predator-Prey model

SD





d(Hares)/dt = Hare Births – Hare Deaths

*Hare Births = Hares * Hare Natality*

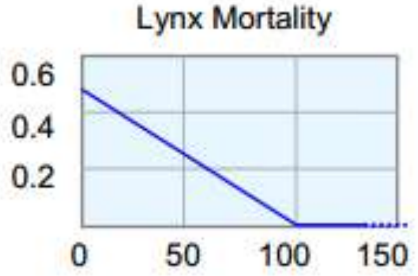
*Hare Deaths = Hare Density * Lynx*

Hare Density = Hares / Area

d(Lynx)/dt = Lynx Births – Lynx Deaths

*Lynx Births = Lynx * Lynx Natality*

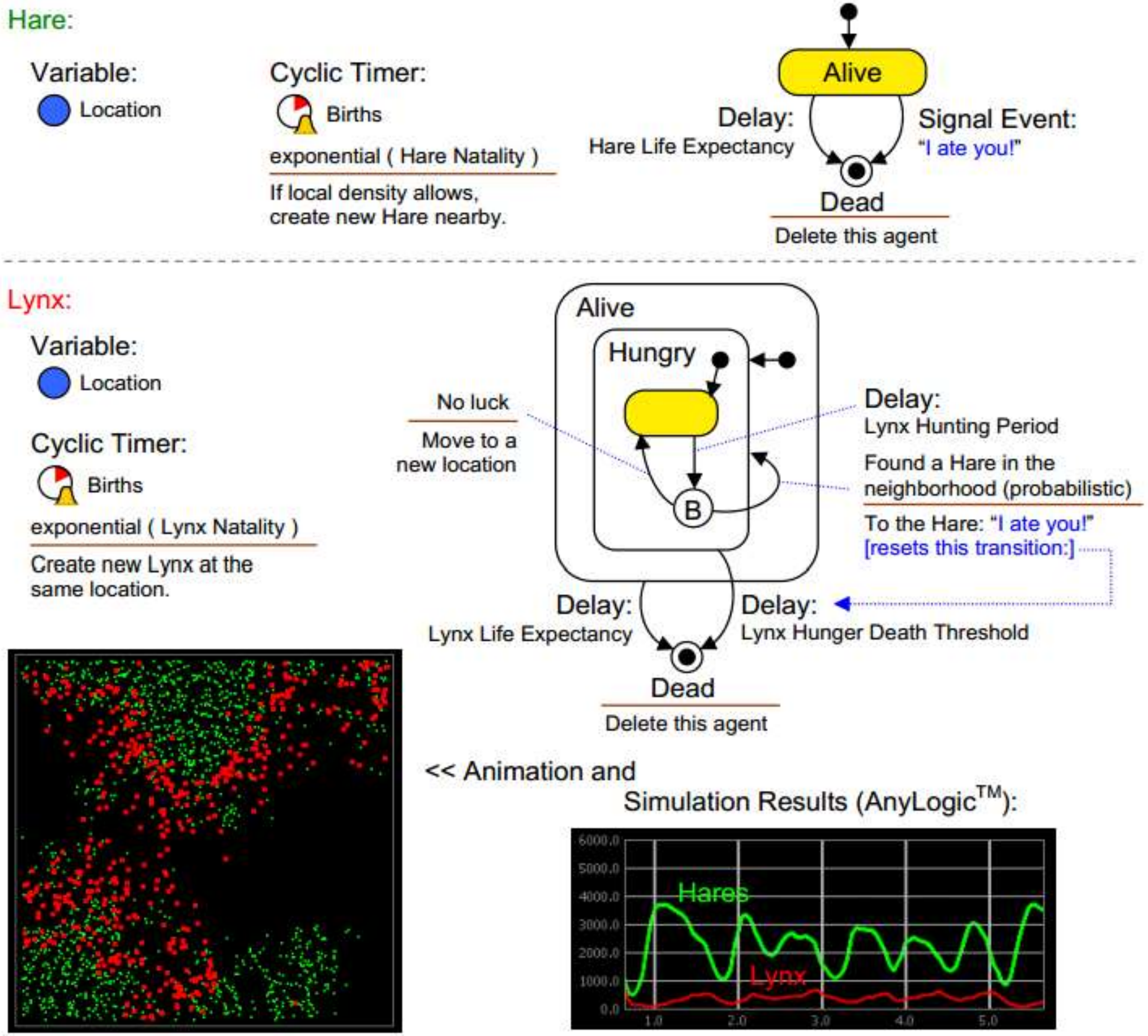
*Lynx Deaths = Lynx * Lynx Mortality(Hare Density)*



Assumptions:

- Prey population have unlimited resources and die only when eaten
- Predators only die because of starvation and prey is their only source of food
- Predators can consume infinite number of prey
- No environmental complexity (homogeneity)

SD vs. ABM: Predator-Prey model



AB

By using ABM, some of these assumptions can be avoided!

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Which approach to use when?

- No ‘clear-cut’ answer exists. It depends on your objective and expected ‘resolution’.
- Agent based models are often harder to develop, verify, validate and document, need more computational power to simulate and their results are more difficult to interpret.
- Why bother? Remember: sometimes our objective is to (describe the **behavior, variability and the interactions among organisms, not merely the quantity of** whole populations).

	System Dynamics	Agent-Based Modeling
Perspective	Top-down	Bottom-up
Main Building block	Causal loops	Agent entities
Unit of Analysis	System structure	Rules of agent behavior
Level of Modeling	Aggregate system behavior	Individual agent behavior
System Structure	Pre-determined	Evolvable
Time Handling	Continuous	Continuous or discrete

Source: S. Sgouridis

When to choose ABM?

- When you have discrete, identifiable and decentralized agents
- When the agents are different or the environment is heterogeneous
- When interaction between agents is local
- When agents are adaptive (and adapt their adaptation rules)
- When individual behaviors (and destiny) matters
- When agents have spatial presence

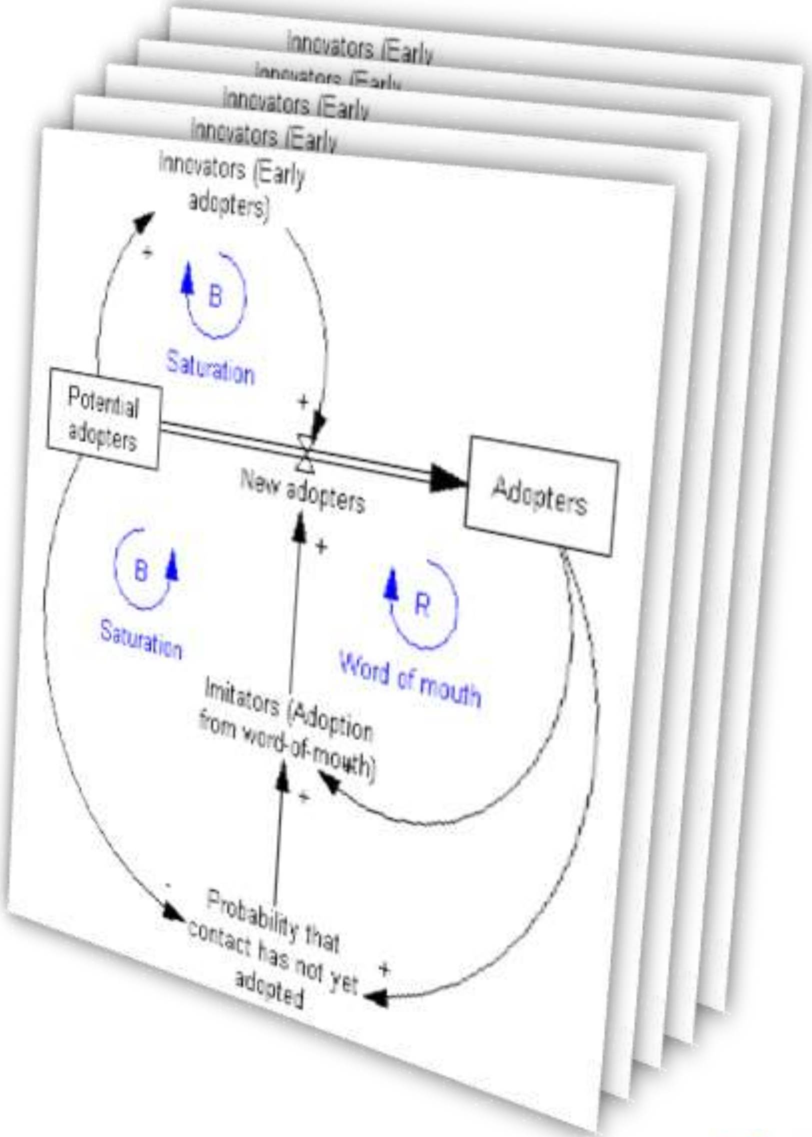
Some applications of ABM

- Complex Markets (stock, commodity, power, etc.)
- Epidemiology
- Social networks
- Supply chain management
- Ecological systems
- Biology and evolution
- Politics and war simulation

Modern methods

- Modern simulation environment allows for creation of hybrid models and overcome the limitations of the individual methods

- System-dynamics implemented in object-oriented programming languages (such as JAVA) allows for creation of Object Oriented System Dynamics models and gives birth to the concept of "Dynamic System Dynamics".
- The model structure is not necessary rigid anymore – can be controlled programmatically, it can expand and shrink!
- A complete SD model can be used as an Agent in an ABM model.



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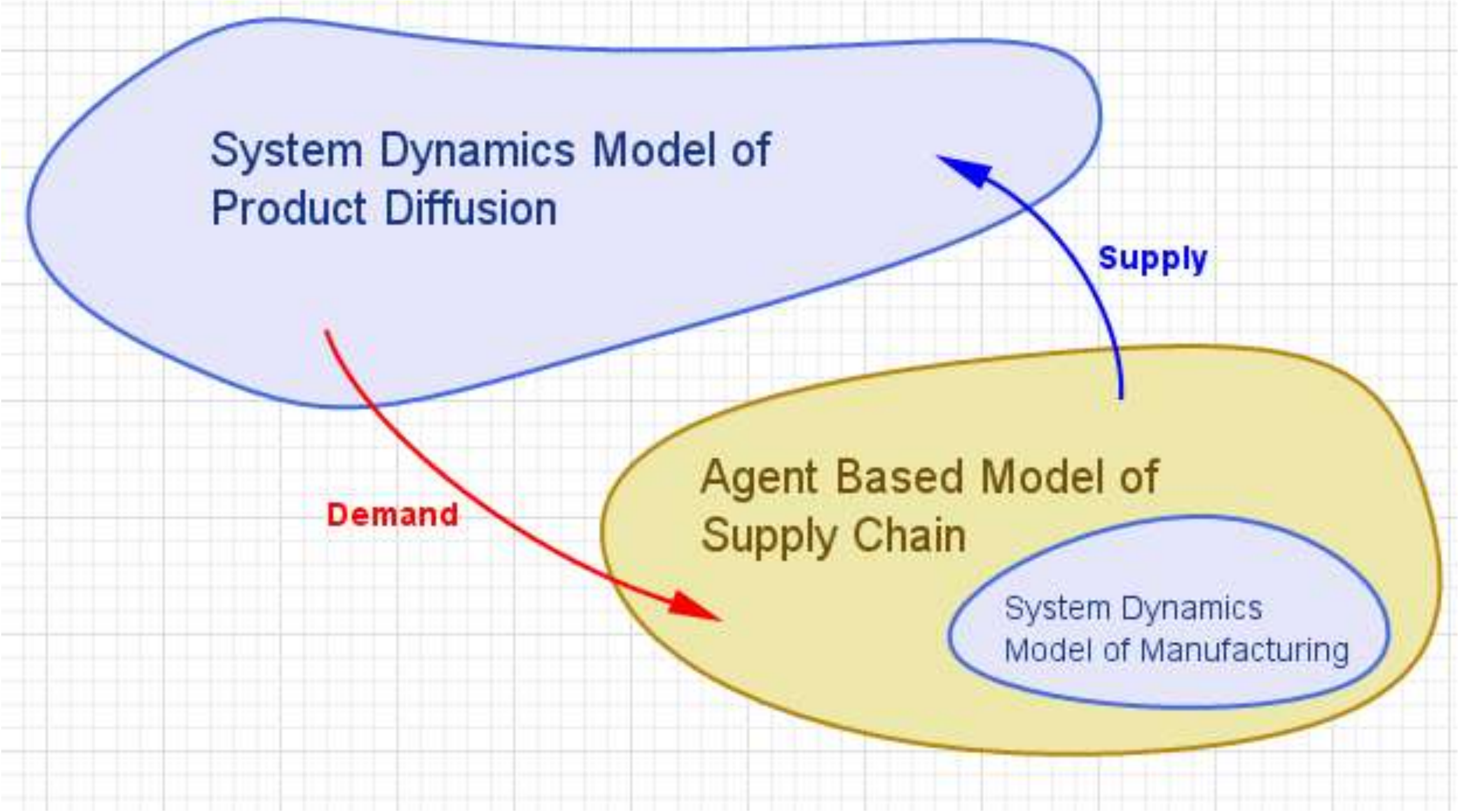
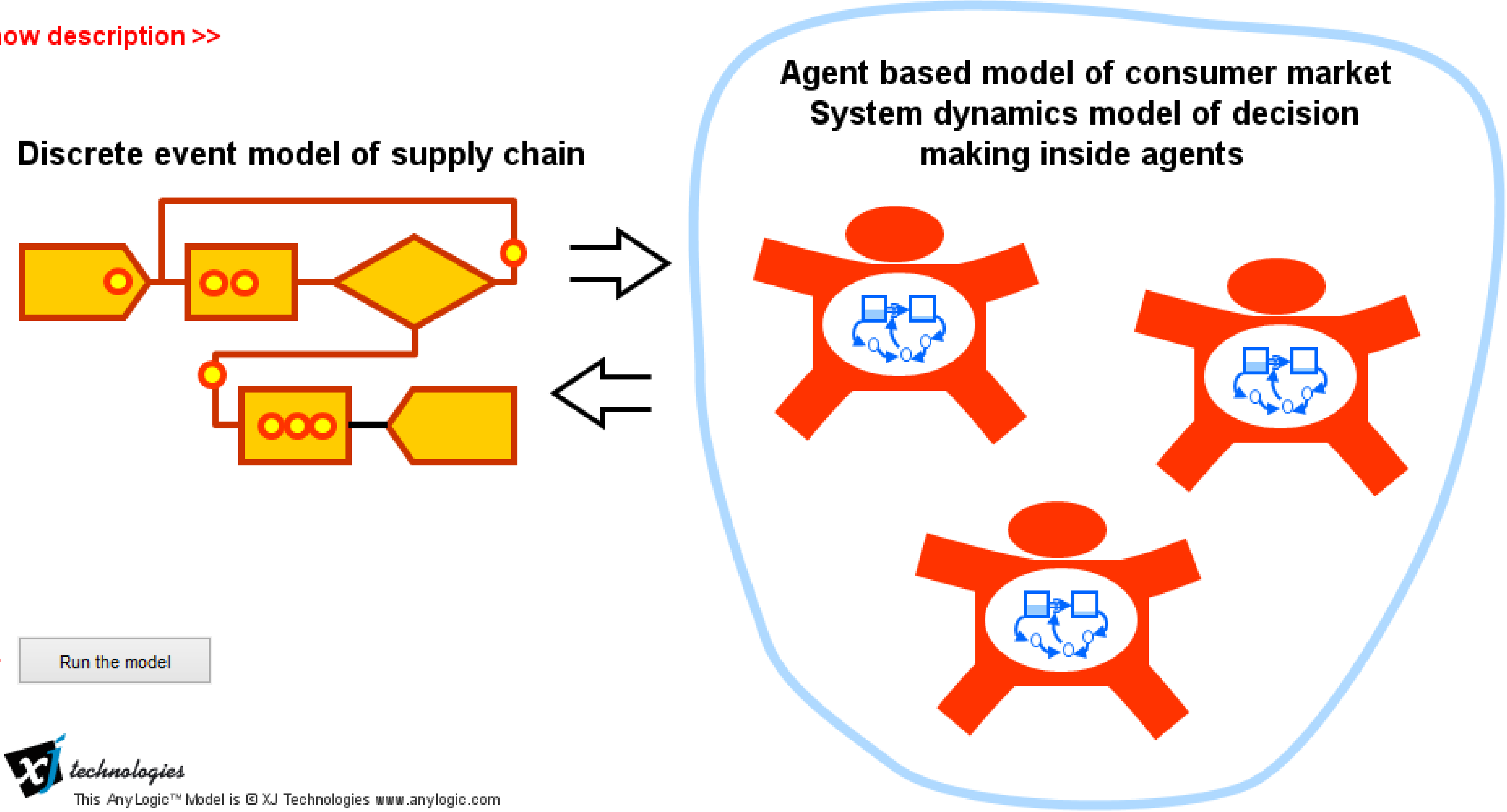
Multimethod Hybrid Model



Multimethod Hybrid Model

The Three Modeling Methods Work Together: Consumer Market and Supply Chain Model

Show description >>



Run the model

xj technologies
This AnyLogic™ Model is © XJ Technologies www.anylogic.com

Conclusion ?!

- **ABM** is another tool in your toolkit as a **Systems Engineer**

Experiment with other modeling approaches and use the one that fits best for or a combination of them – **smartly**!

Challenge model boundaries and resolution and usual thinking by creating **hybrid models**!

Other useful resources

- MIT System Dynamics self-study course
- MIT System Dynamics 1 course
- MIT System Dynamics 2 course
- MIT Agent-Based Modeling course
- MIT Agent-Based Modeling course –AnyLogic version
- TU Delft Agent-based Modeling course
- MIT Dynamic Systems 1 course
- MIT Dynamic Systems 2 course
- University of Michigan Model Thinking course on Coursera
- runthemodel.com – AnyLogic's proprietary online simulation model repository
- Forio Simulate – Cross-platform online simulation model repository

This presentation is based on "**Agent Based Modeling – An Overview**" by Ahmed Saif, Masdar Institute, 2010 and "**From System Dynamics and Discrete Event to Practical Agent Based Modeling: Reasons, Techniques, Tools**" by Andrei Borshchev & Alexei Filippov, XJ Technologies & St. Petersburg Technical University, 2004