THE EXCHANGE SEMESTER AT OVGU. SIMULATION WITH ANYLOGIC

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INTRODUCTION 1

GENERAL INFORMATION

Introduction to Simulation

Prof. Graham Horton

Dr. Claudia Krull

- English
- 1 lecture per week
- 1 exercise per week
- 5-6 final points

GOALS OF COURSE

- Show the need for Simulation and give some examples
- Give an introduction to two important areas of simulation:
  - Continuous simulation (ODEs)
  - Discrete- event stochastic simulation
- Learn to use the simulation software AnyLogic
- Solve some typical engineering problems using simulation
- Form the basis for further courses and thesis work

DEFINITIONS

Simulation [lat. "imitate"]:

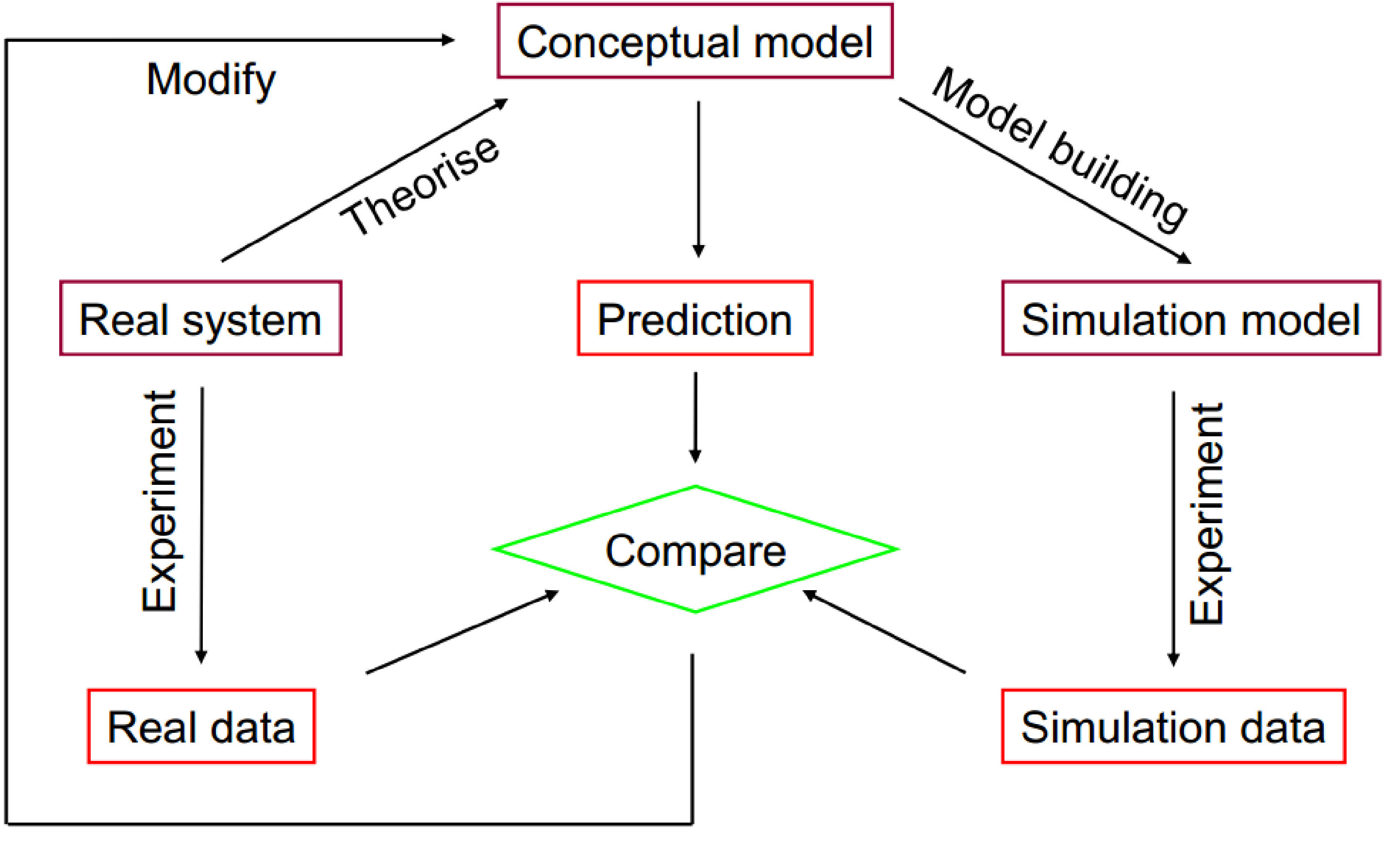
the representation or replication as a model of certain aspects of a real or planned cybernetic system, in particular of its behavior over time.

Model:

a representation of nature which emphasizes those properties that are considered to be important and ignores the aspects which are considered to be irrelevant.

Banks, "Discrete-event system simulation"

METHODS OF SCIENCE



APPLICATION FIELDS

Continuous simulation:

- All branches of (Natural) Science
- All branches of Engineering

Discrete simulation:

- Manufacturing and Automation
- Logistics and Transportation
- Reliability and Safety Engineering
- Operations Research

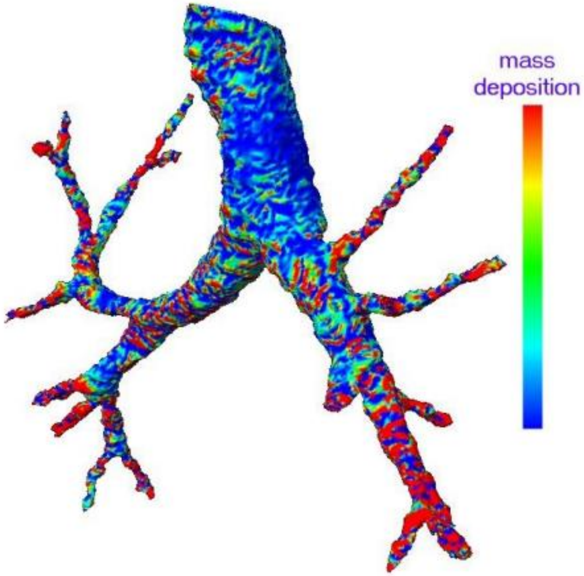
EXAMPLES

Automobile Production

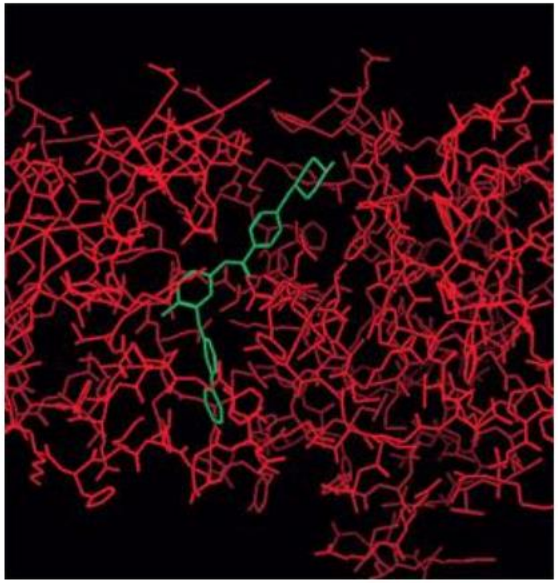
Digital Design

EXAMPLES

Medicine

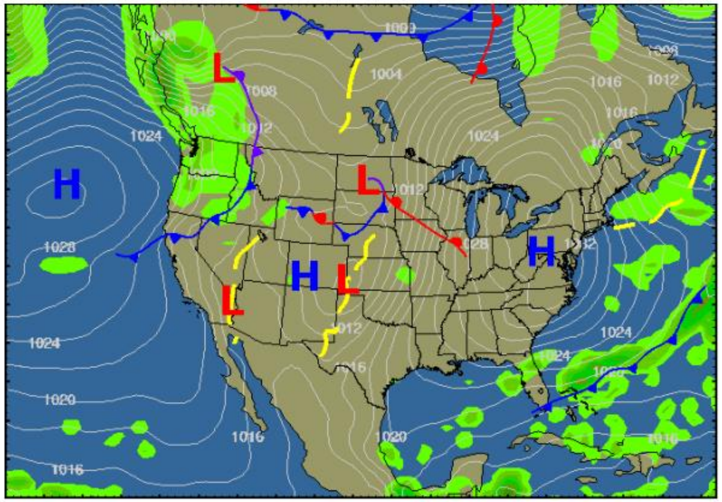


Pharmacology

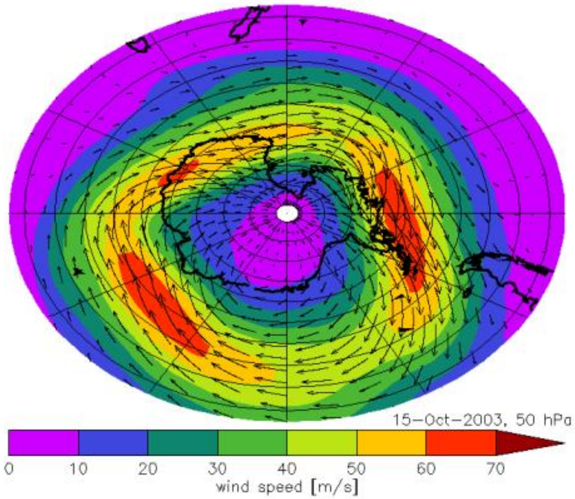


EXAMPLES

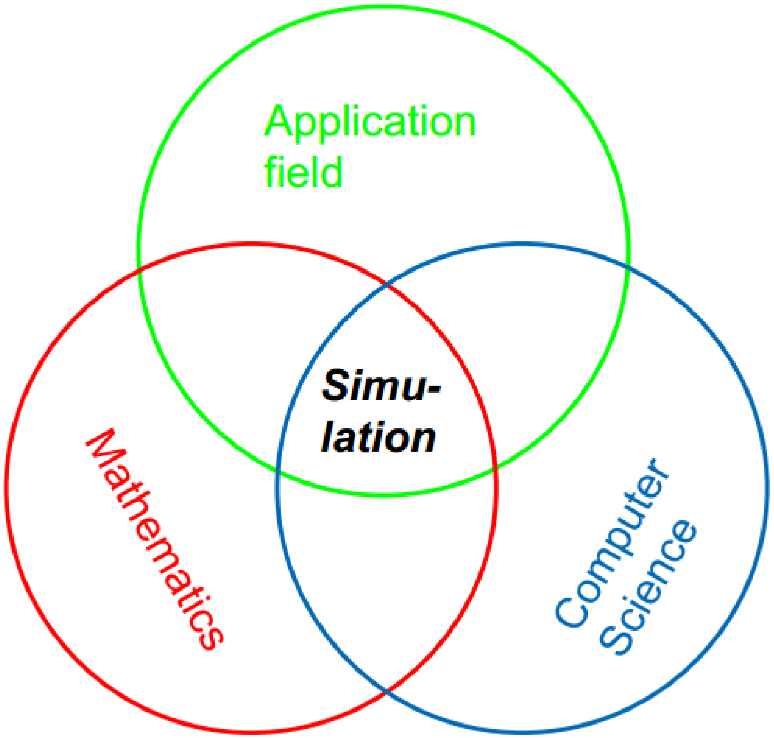
Weather Forecasting



Climate Changes



SIMULATION IS INTERDISCIPLINARY



PROS AND CONS

Advantages of Simulation :

+ Doesn't interrupt running system
+ Doesn't consume resources
+ Test hypotheses
+ Manipulate parameters
+ Study interactions
+ Ask "what if" questions

Difficulties of Simulation :

- Provides only individual, not general solutions
- Manpower: Time- consuming
- Computing: Memory - & time - intensive
- Difficult, experts are required
- Hard to interpret results
- Expensive!

WHEN TO USE?

When to use simulation

- Study internals of a complex system
- Optimize an existing design
- Examine effect of environmental changes
- System is dangerous or destructive
- Study importance of variables
- Verify analytic solutions (theories)
- Test new designs or policie
- Impossible to observe/influence/build the system

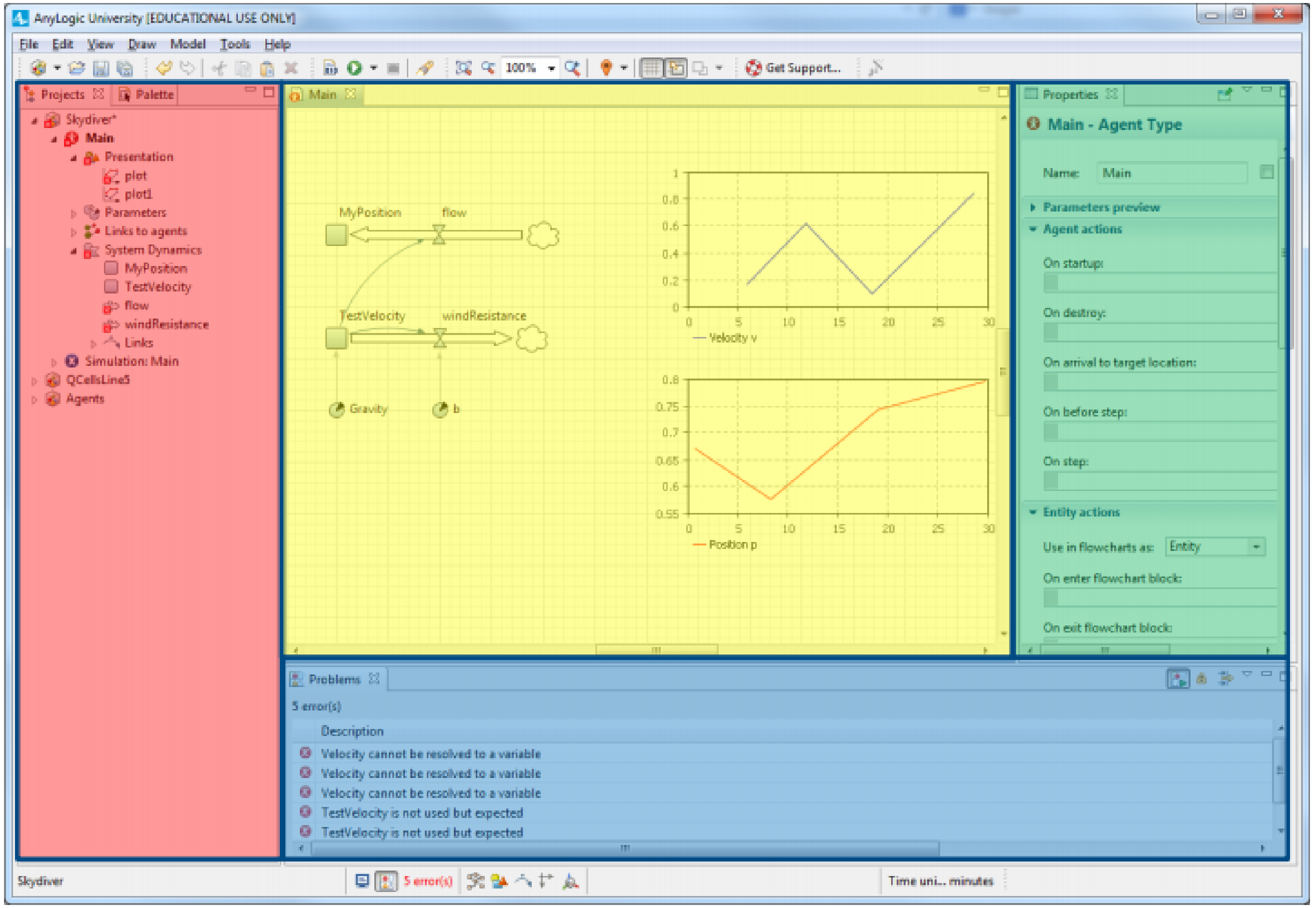
ANYLOGIC BY XJ TECHNOLOGIES

The simulation tool AnyLogic is available for Windows, Linux (x86 only), Mac OS.

Some Features

- Graphical modelling with only small Java code customizations
- Provides code completion (<ctrl>+<space>) and refactoring
- Graphical analysis of dynamic processes and simulation results
- Ability to export simulations as Java applets
- Supports multiple simulation paradigms, we‘ll use
  - Continuous simulation (system dynamics)
  - Discrete event - based simulation
- Extensive help system

THE ANYLOGIC WINDOW



THE ANYLOGIC PROJECT

An AnyLogic project has (at least) two parts:

- The simulation model
- One or more experiments

The model describes the system to be simulated.

The experiments describe what is to be done with the model.

The separation of model and experiment is very useful.

MODELS IN ANYLOGIC

The model consists of

- Parameters, variables, functions, events, …

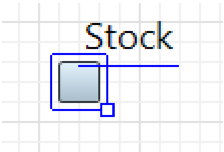
The model can contain visualizations

- Diagrams of model variable values
- Animation of model elements

These elements

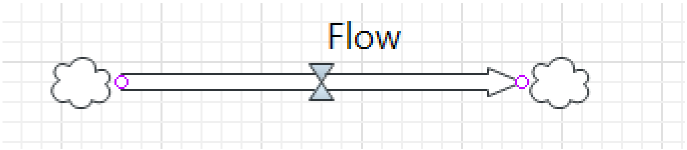
- can be moved and placed freely on a canvas
- can be named using normal Java conventions

BASIC ANYLOGIC ELEMENT TYPES



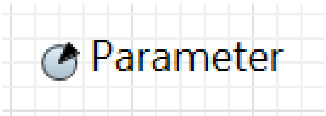
Stocks

- Describe the system dynamics using differential equations
- Need only an initial value and a first derivative, no explicit dynamics (mathematical description of behavior)



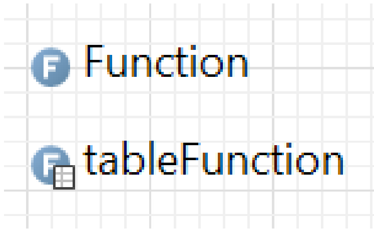
Flows

- Describes a rate of change of a stock (inflow / outflow)



Parameters

- Represent ordinary Java variables (int , float , …)
- Describe input parameters to the simulation



Functions

- Represent ordinary Java functions
- Return a value that is computed dynamically, potentially depending on the values of variables or parameters

EXPERIMENTS IN ANYLOGIC

There are different types of experiments (Educational Edition)

- Simulation

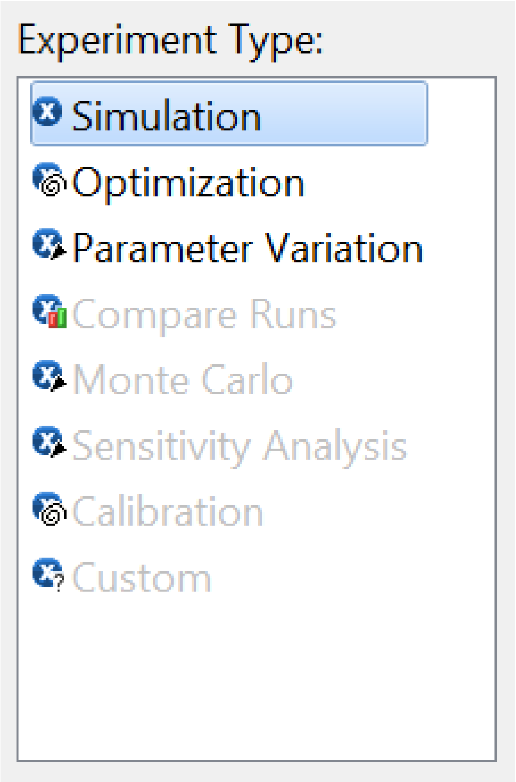
  (only one model run)

- Parameter Variation

  (outcomes for different parameter values)

- Optimization

  (automatically find suitable parameter values to minimize/maximize some expression)



CONTINUOUS SIMULATION

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DEFINITION

A continuous system is one in which the state variable(s) change continuously over time.

Banks, "Discrete-event system simulation"

EXAMPLES

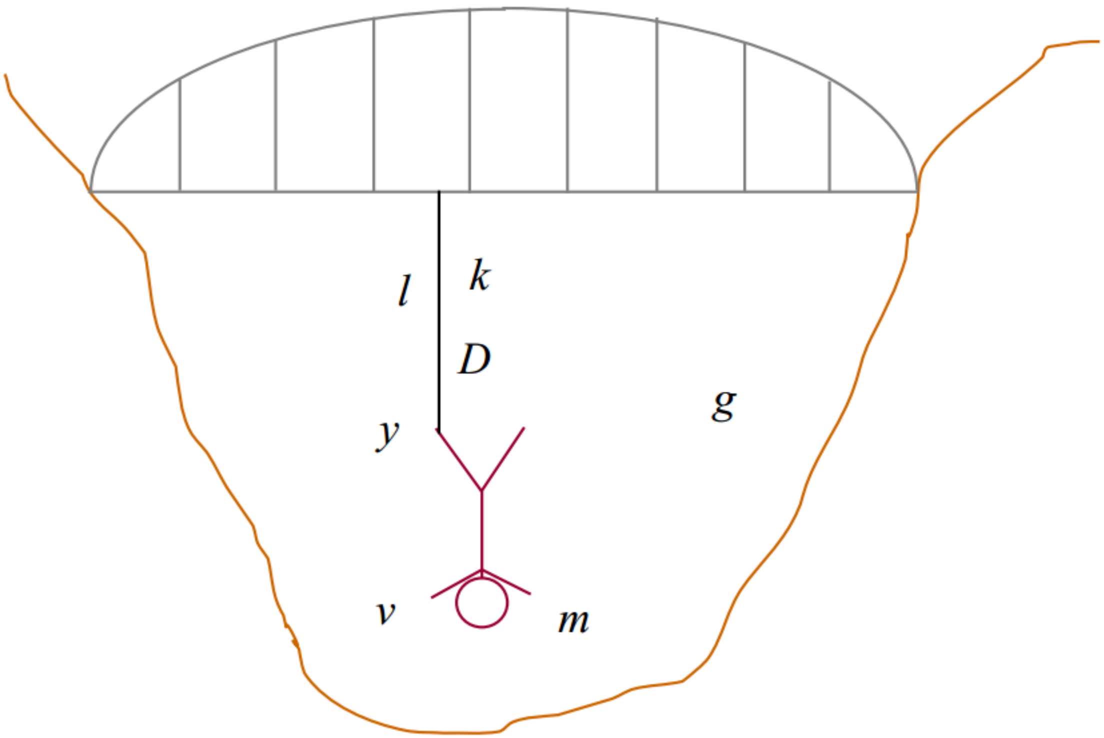
Continuous processes occur everywhere.

Some examples:

- The spread of a virus
- The motion of the planets orbiting the sun
- The current and voltage in an electrical circuit
- The populations of a predator and its prey

In almost all cases, the relationships between the variables are defined by an ODE.

THE BUNGEE JUMPER



THE BUNGEE JUMPER

Definition of relevant quantities:

Rope

- Spring constant: k [N/m] (=50.0 N/m)
- Damping constant: D [N · s /m] (=10.0 N · s /m)
- Length (relaxed): l [m] (=20 m)
- Length (momentary): y [m]

Jumper

- Downward velocity: v [m/s]
- Mass: m [kg] (=60.0 kg)

System

- Acceleration (gravity): g [m/s^2] (=9.81 m/s^2)

MODEL

We need equations for position y and velocity v

Position:

- Definition of speed: $v = \frac{dy}{dt}$

Speed:

- Definition of acceleration: $a = \frac{dv}{dt}$
- Newton's Law: acceleration = force / mass i.e. $a = \frac{F}{m}$

Result: $\begin{cases} \frac{dy}{dt} = v \\ \frac{dv}{dt} = g + \frac{F}{m} \end{cases}, F - ?$

SPRINGS AND DAMPERS

When taut, the rope exerts two downward (!) forces:

1) proportional to its length of extension:

$$F_{Spring} = -k * (y - l)$$

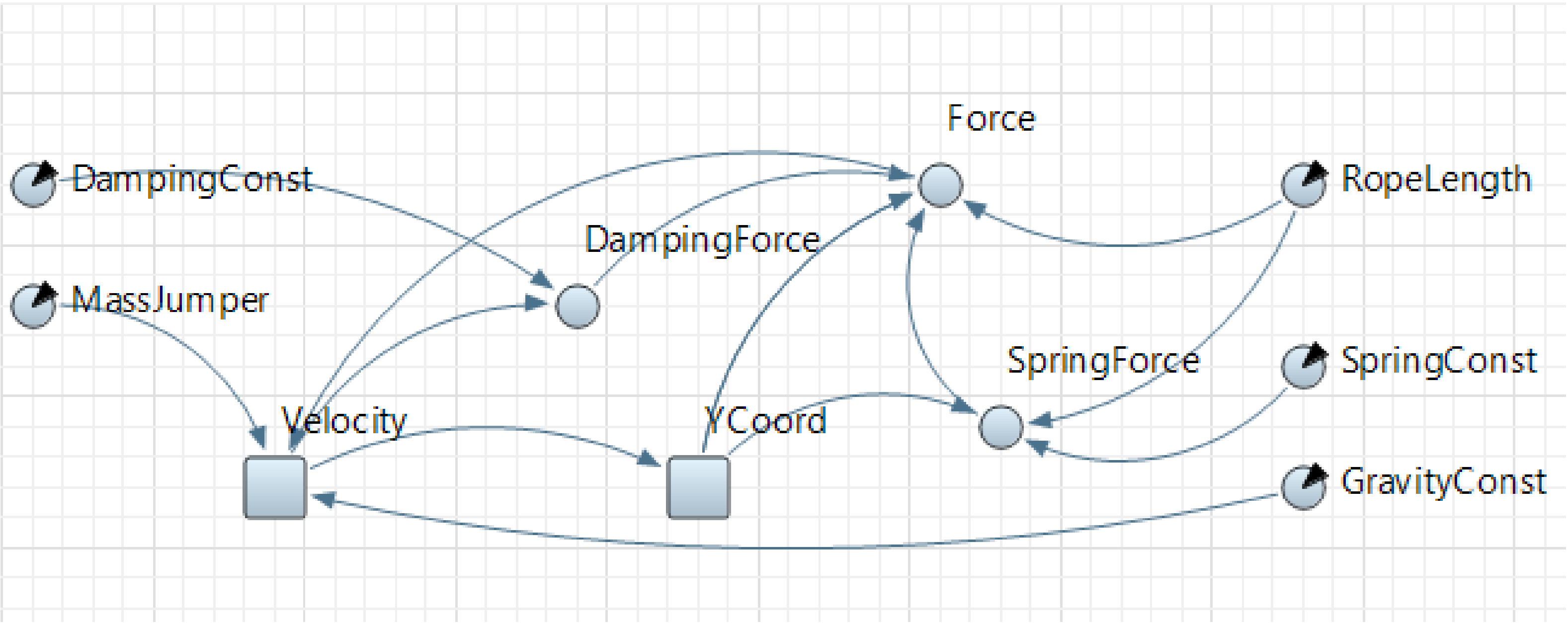
2) proportional to its speed of extension, iff the rope is extending (rate of extension > 0) !

$$F_{Damping} = -\max(D * v, 0)$$

Let F be the rope's downward force on the jumper:

$$\begin{cases} y > l, F = F_{Damping} + F_{Spring}, & the\ rope\ pulls\ up \\ y < l,\ F = 0, the\ rope\ is\ slack \end{cases}$$

ANYLOGIC MODEL



SIR MODEL

The SIR model is a classical model in epidemiology

- S – susceptible individuals (may get infected)
- I – infected/infectious individuals (spread the disease)
- R – recovered individuals (are healthy and cannot be infected)

The model can also incorporate

- Vaccinations
- Population dynamics

DEFINING THE EQUATIONS

Initial values:

- $S = 999, I = 1, R = 0$
- 10 contacts per day
- meeting an infected person one has an infection risk of 0.08
- 10 days to recover

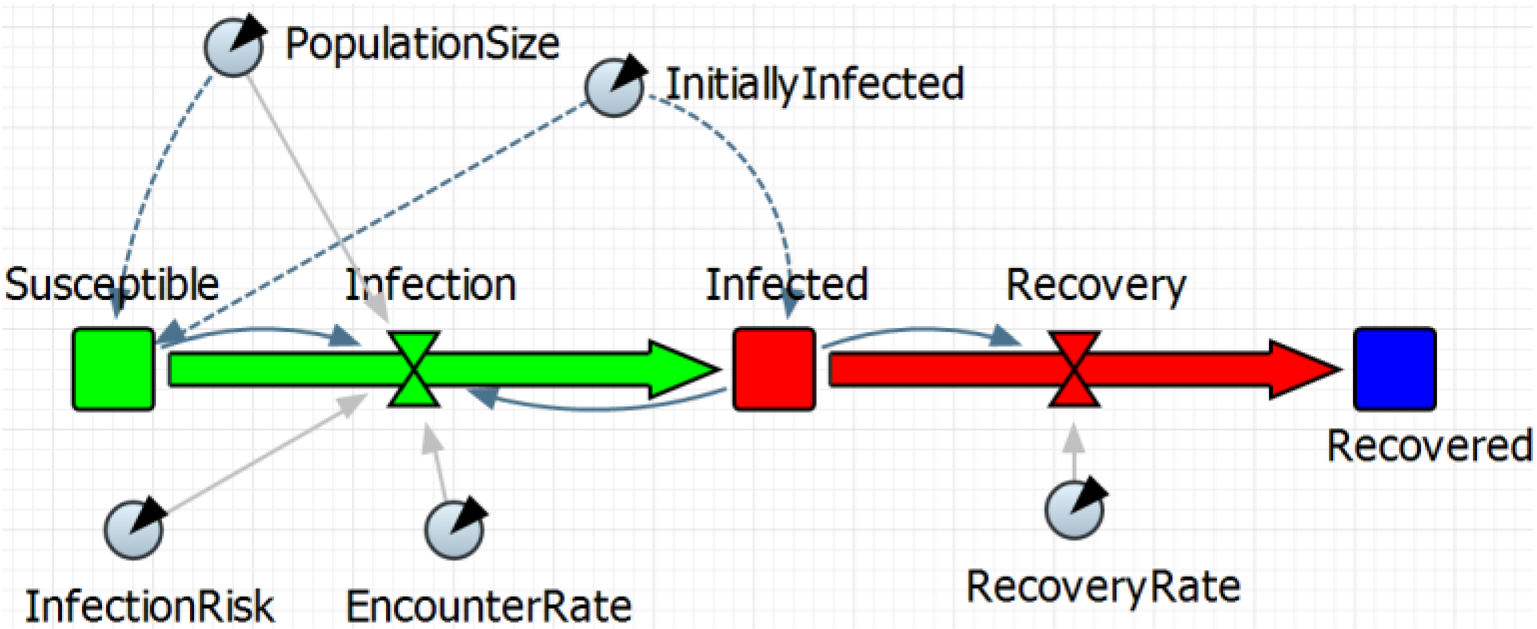
DEFINING THE EQUATIONS

- $InfectionRate = InfectionRisk * EncounterRate * S * \frac{1}{S+I+R}$
- $RecoveryRate = I * \frac{1}{DiseaseDuration}$

Differential Equations:

- $\frac{dS}{dt} = -InfectionRate$
- $\frac{dI}{dt} = InfectionRate - RecoveryRate$
- $\frac{dR}{dt} = RecoveryRate$

ANYLOGIC MODEL



DISCRETE-EVENT SIMULATION

3

DEFINITION

A discrete system is one in which the state variable(s) change only at a discrete set of points in time.

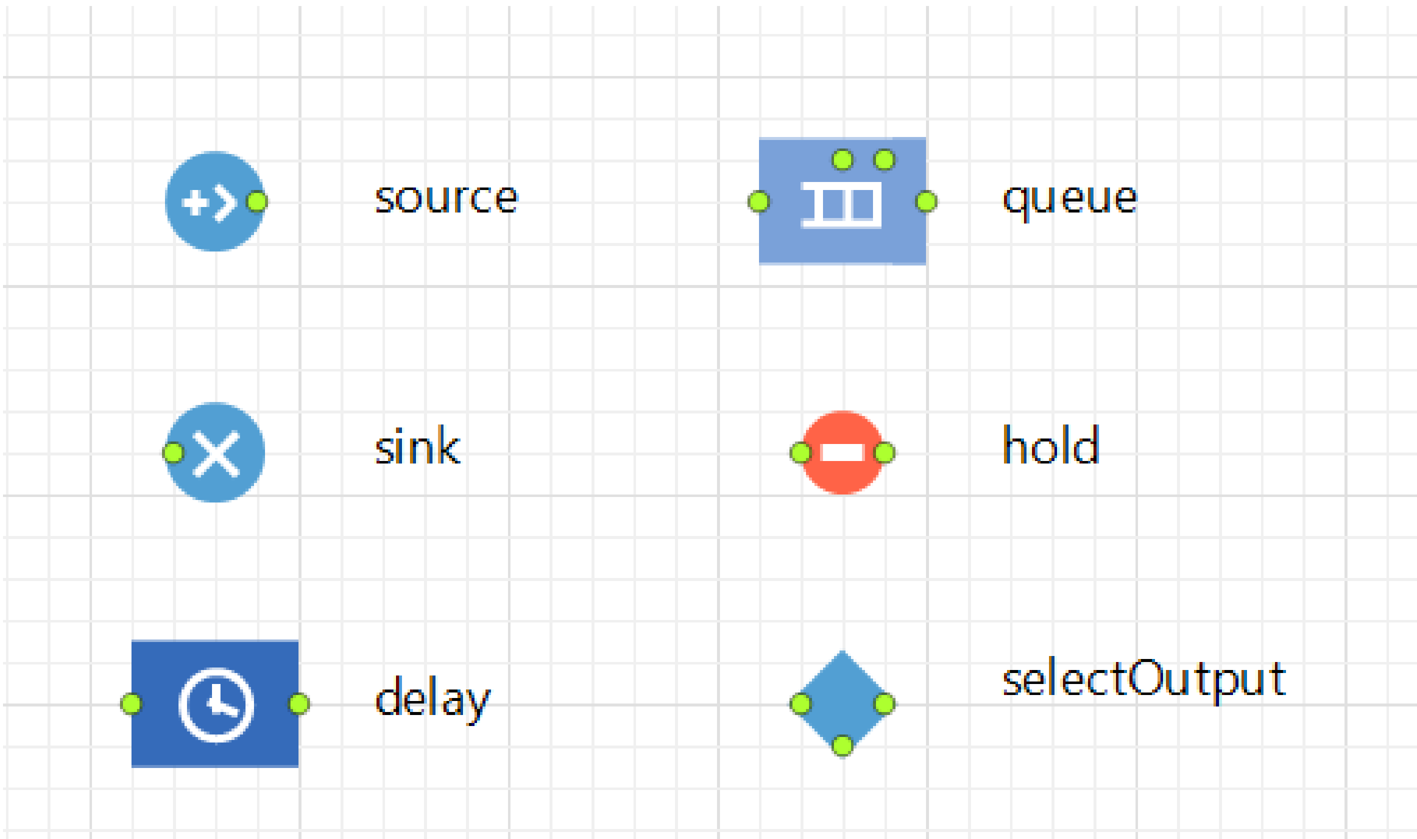
Banks, "Discrete-event system simulation"

WHY IMPORTANT?

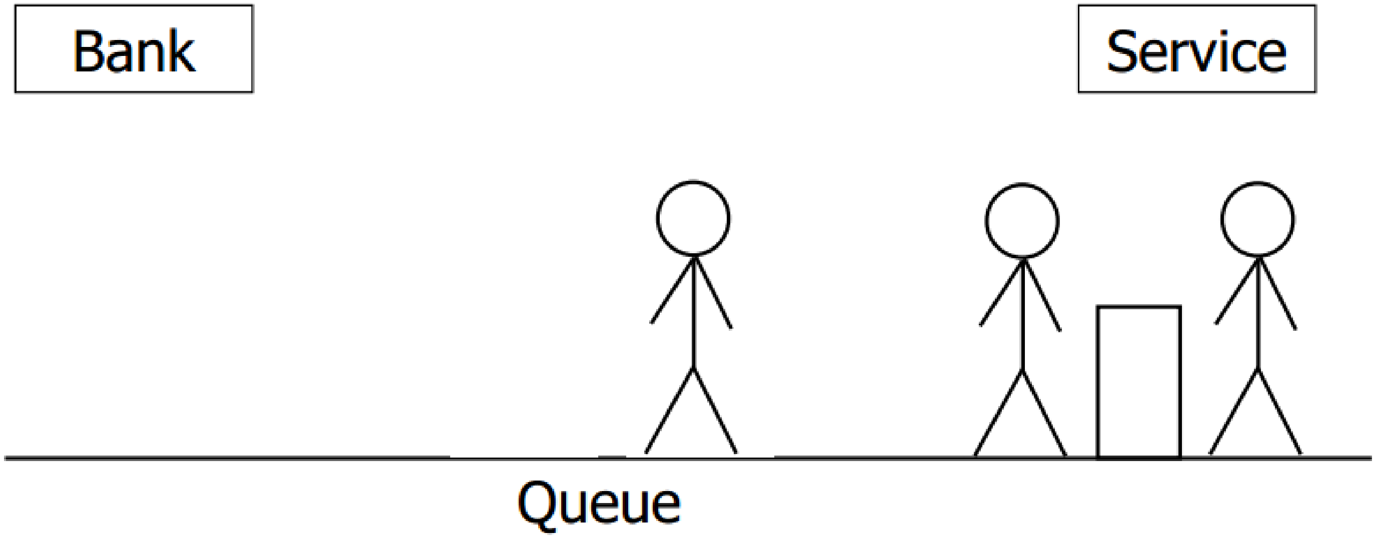
DES are everywhere:

- Factories
- Queues
- Warehouses
- Computer Networks

ANYLOGIC FOR DES

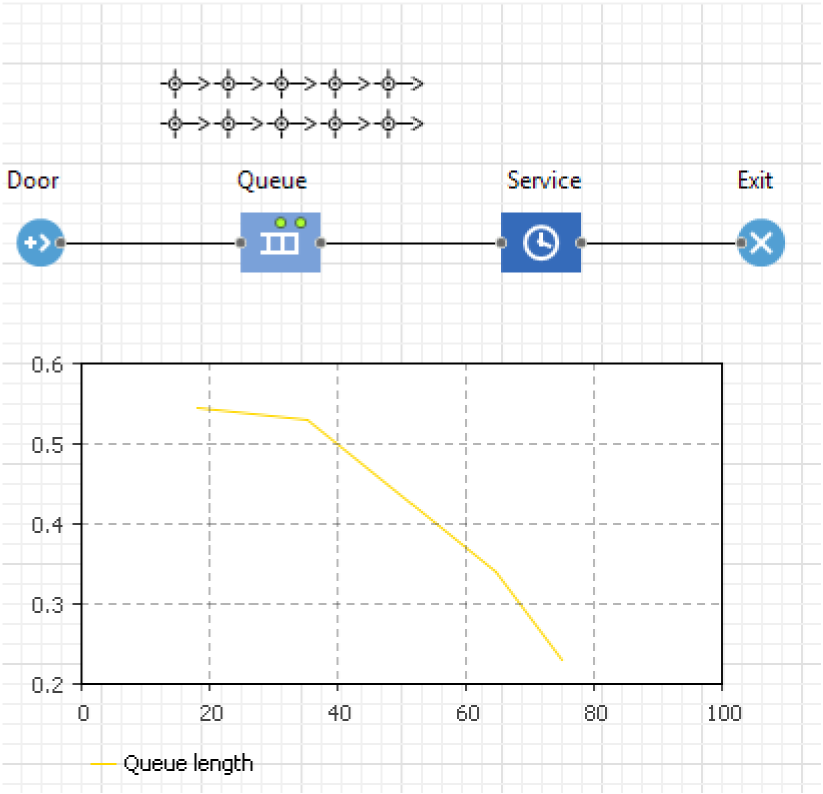


BANK EXAMPLE



BANK EXAMPLE

Few clicks and you are done!



THE MEDICAL PRACTICE

Patients:

- Arrive at the practice
- If there is a seat left
  - They wait in the waiting room
  - Otherwise, they leave at once
- They are treated by the doctor
- They pay and leave

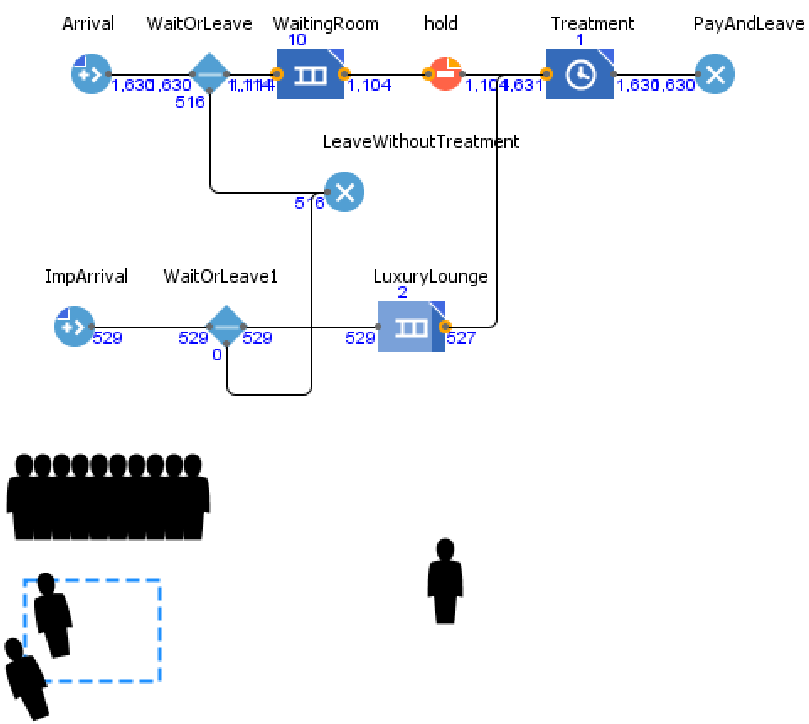
THE MEDICAL PRACTICE MODEL

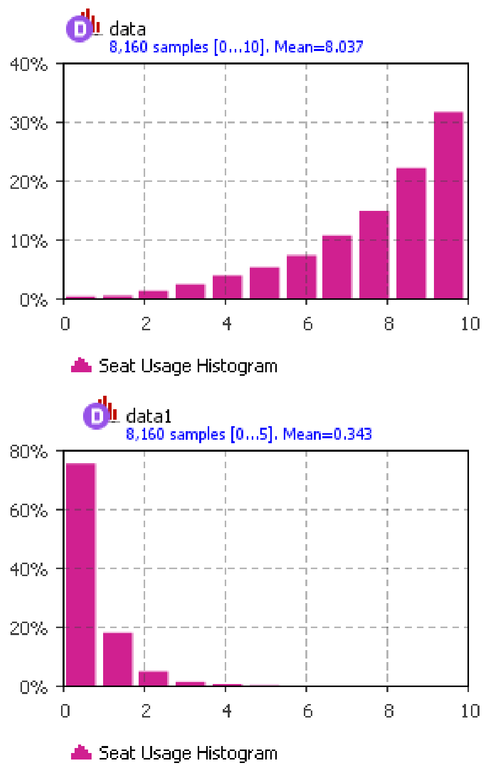
A MORE COMPLICATED PRACTICE

A two-class medical system:

- There are two types of patients: normal and important ones
- Important patients have a separate waiting room
- The doctor will not treat normal patients as long as important ones are waiting
- Treatment of important patients needs more time

A MORE COMPLICATED PRACTICE





INTRODUCTION IN AGENT-BASED SIMULATION

4

DEFINITION

An **agent-based model** (**ABM**) is one of a class of computational models for simulating the actions and interactions of autonomous agents (both individual or collective entities such as organizations or groups) with a view to assessing their effects on the system as a whole.

Wikipedia

MOTIVATION

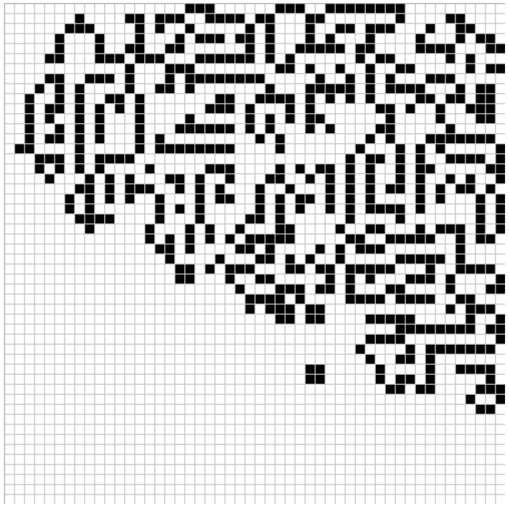
Why do we need agent-based simulation?

- Growing complexity in social-technical systems
- Distributed / agent based systems more frequent
- Interaction and self-organization
- Most natural populations are heterogeneous
- Individuals are adaptive and can learn
- …
- e.g. energy market, economy, societal dynamics

Traditional methods fail to capture that adequately

GAME OF LIFE

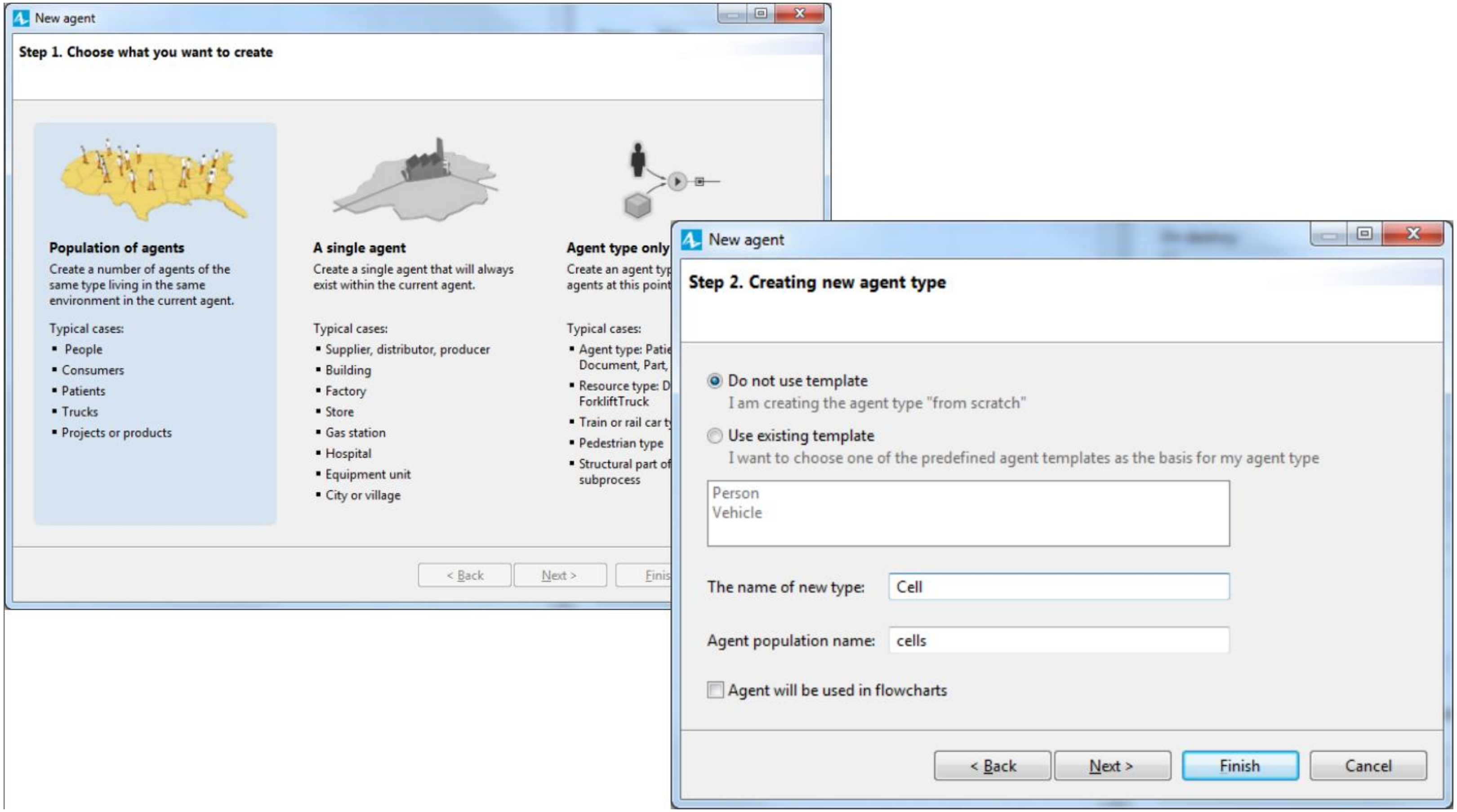
- Cellular automaton
- Each cell can be either alive or dead
- Next generation state depends of Moore-neighborhood



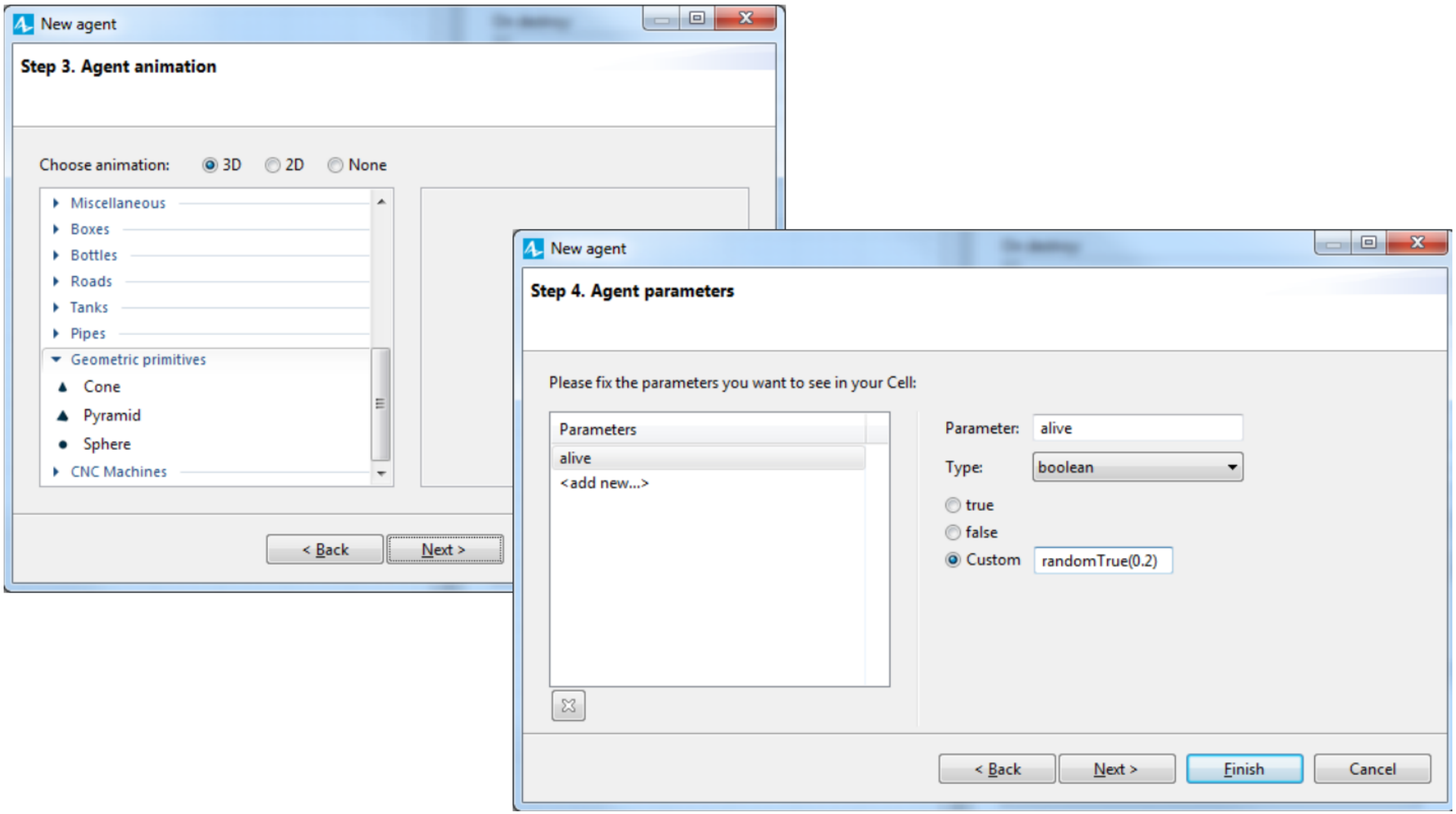
Rules

- A dead cell with 3 live neighbors comes alive
- A living cell with less than 2 live neighbors dies
- A living cell with 2 or 3 live neighbors stays alive
- A living cell with more that 3 live neighbors dies

GAME OF LIFE

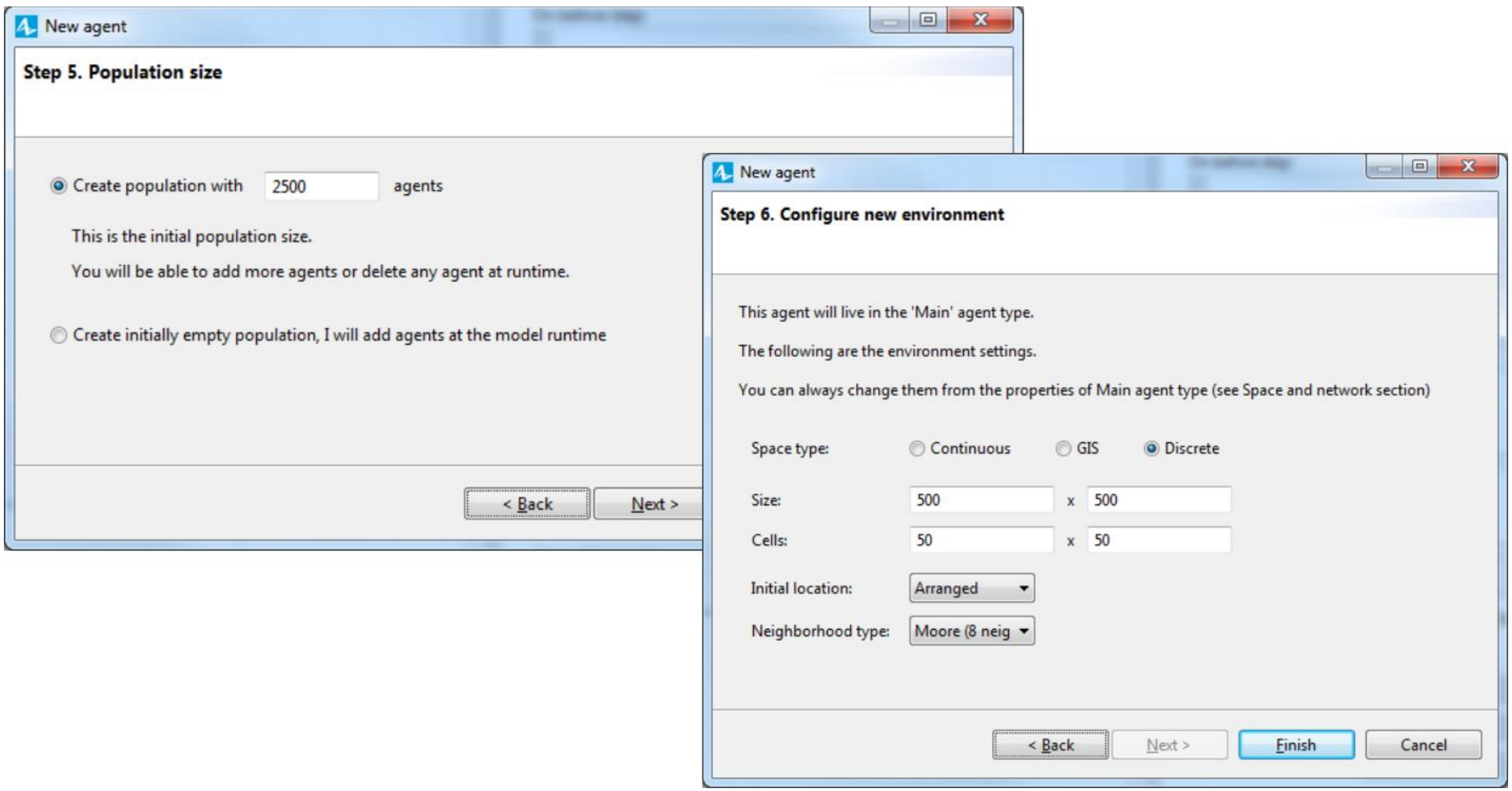

New agent
Step 1. Choose what you want to create
Population of agents
Create a number of agents of the same type living in the same environment in the current agent.
Typical cases:
People
Consumers
Patients
Trucks
Projects or products
A single agent
Create a single agent that will always exist within the current agent.
Typical cases:
Supplier, distributor, producer
Building
Factory
Store
Gas station
Hospital
Equipment unit
City or village
Agent type only
Typical cases:
< Back
Next >
New agent
Step 2. Creating new agent type
Do not use template
I am creating the agent type "from scratch"
Use existing template
I want to choose one of the predefined agent templates as the basis for my agent type
Person
Vehicle
The name of new type:
Cell
Agent population name:
cells
Agent will be used in flowcharts
< Back
Next >
Finish
Cancel

GAME OF LIFE

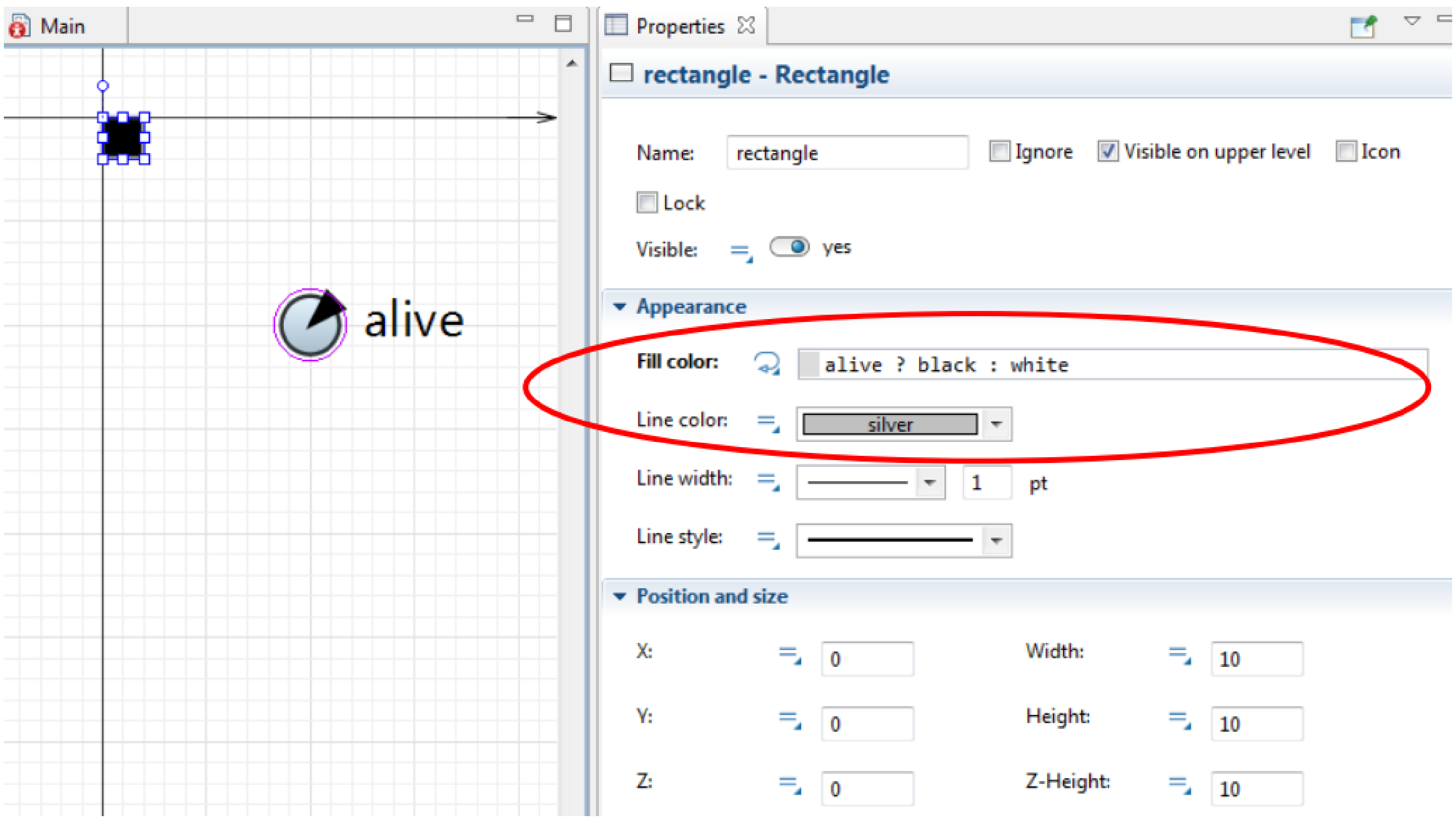


New agent
Step 3. Agent animation
Choose animation: 3D 2D None
Miscellaneous
Boxes
Bottles
Roads
Tanks
Pipes
Geometric primitives
Cone
Pyramid
Sphere
CNC Machines
< Back
Next >
New agent
Step 4. Agent parameters
Please fix the parameters you want to see in your Cell:
Parameters
alive
<add new...>
Parameter: alive
Type: boolean
true
false
Custom randomTrue(0.2)
< Back
Next >
Finish
Cancel

GAME OF LIFE


New agent
Step 5. Population size
Create population with
2500
agents
This is the initial population size.
You will be able to add more agents or delete any agent at runtime.
Create initially empty population, I will add agents at the model runtime
< Back
Next >
New agent
Step 6. Configure new environment
This agent will live in the 'Main' agent type.
The following are the environment settings.
You can always change them from the properties of Main agent type (see Space and network section)
Space type:
Continuous
GIS
Discrete
Size:
500
x
500
Cells:
50
x
50
Initial location:
Arranged
Neighborhood type:
Moore (8 neig
< Back
Next >
Finish
Cancel

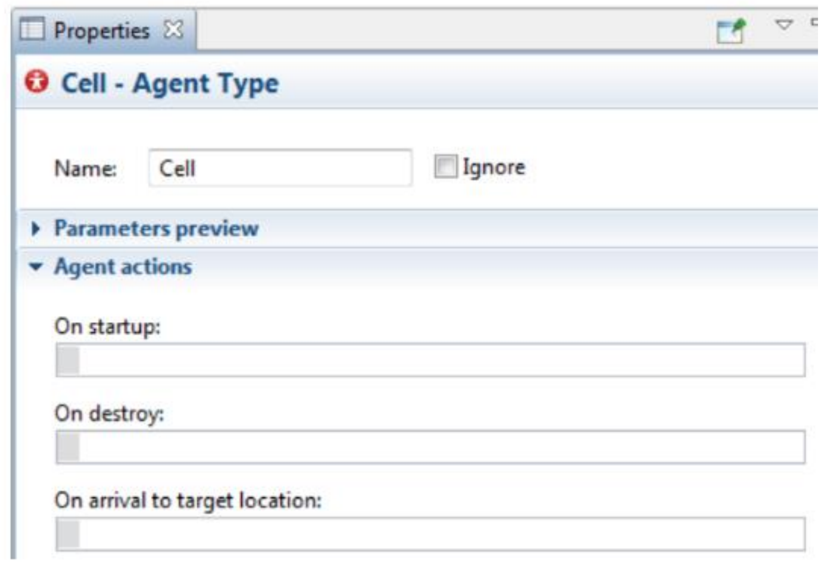
GAME OF LIFE



Main
alive
Properties
rectangle - Rectangle
Name:
rectangle
Ignore
Visible on upper level
Icon
Lock
Visible:
yes
Appearance
Fill color:
alive ? black : white
Line color:
silver
Line width:
1
pt
Line style:
Position and size
X:
0
Width:
10
Y:
0
Height:
10
Z:
0
Z-Height:
10

GAME OF LIFE

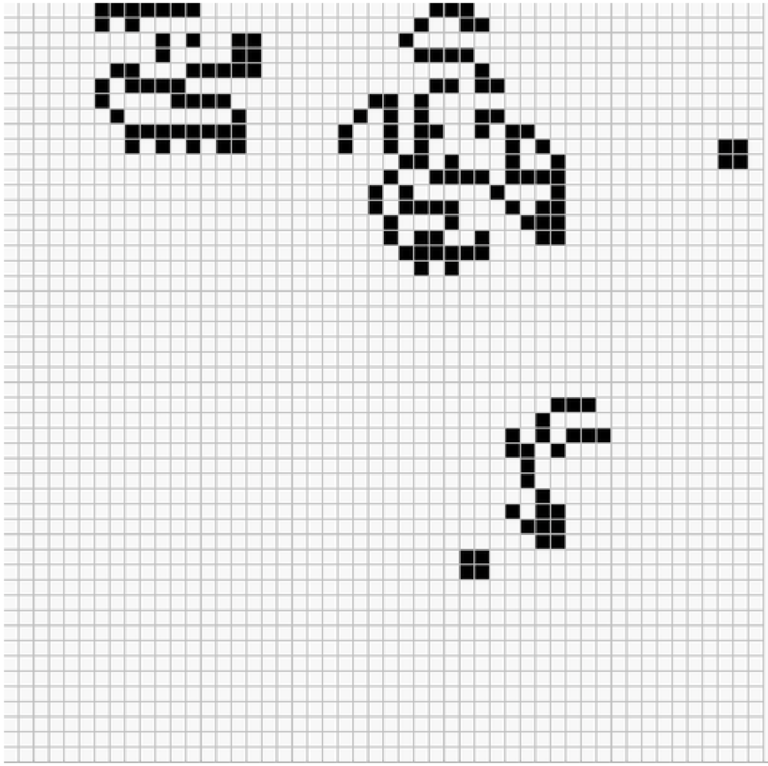
- A dead cell wit neighbors comes
- A living cell wit neighbors dies
- A living cell wit neighbors stays
- A living cell wit live neighbors di

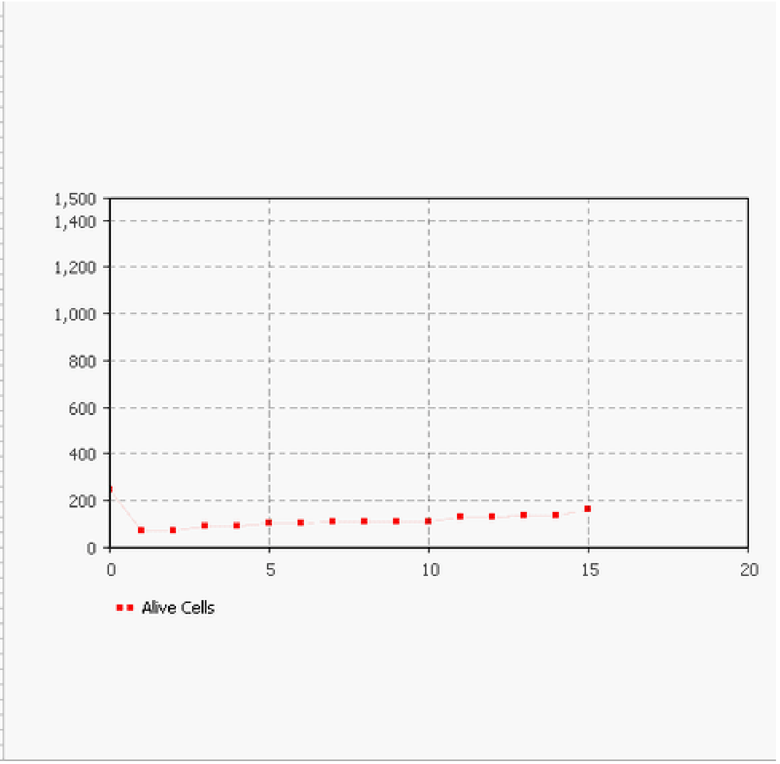


On step:

```
//count live neighbors
int liveNeighbors = 0;
for(Agent a : getNeighbors())
    if(((Cell)a).alive) liveNeighbors++;
//rule 1
if(!alive && liveNeighbors == 3)
    alive = true;
//rule 2 & 4
if(alive && (liveNeighbors < 2 || liveNeighbors > 3))
    alive = false;
```

GAME OF LIFE





FLOCKING BIRDS

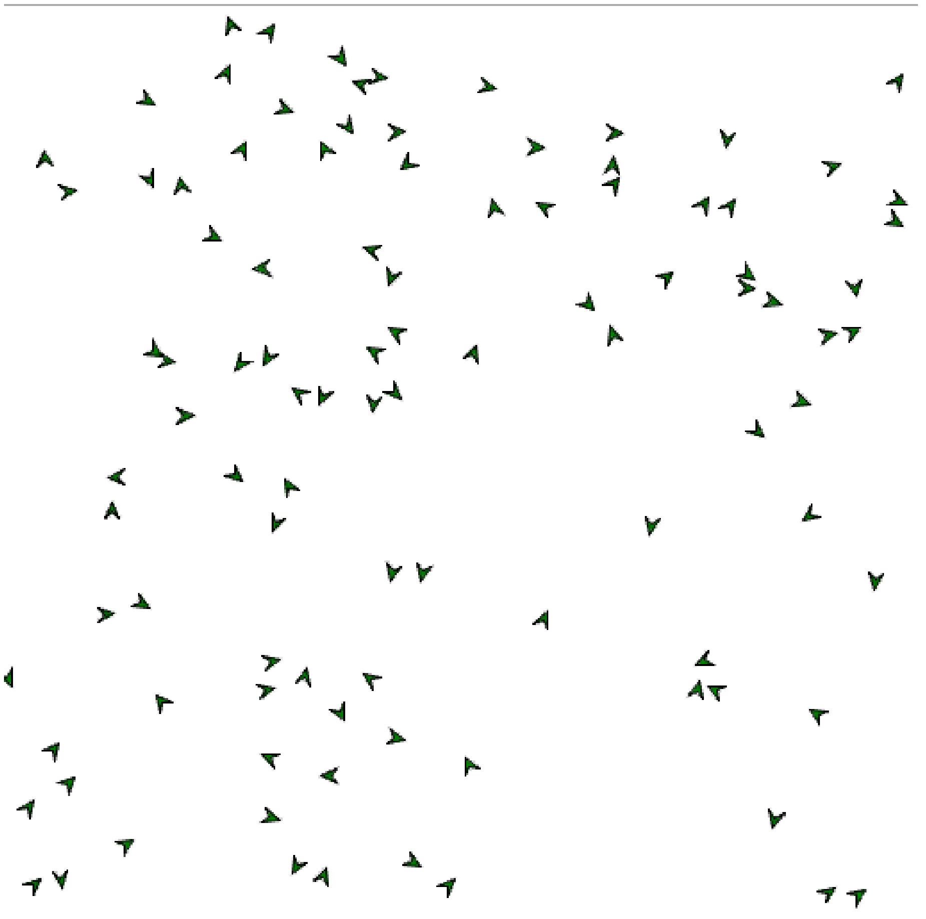
Flocking behavior of birds

- Continuous space and movement
- Birds adapt their flight pattern to other birds in their vicinity

Rules

- Separation – avoid crowding neighbors
- Alignment – steer towards average heading of neighbors
- Cohesion – steer towards average position of neighbors

FLOCKING BIRDS



HYBRID SIMULATION

5

SEMESTER ASSIGNMENT – THE SIMS

We are looking at a family of mom, dad and son.

Their moods depend on various factors:

- Mom's mood depends on her husband and son and on the family's savings.
- Dad's mood depends on his wife and on his employment status.
- The son's mood alternates between in love and heartbroken.

The family's peace is fragile:

They are often on the verge of falling apart by either the parents getting divorced or being broke.

SEMESTER ASSIGNMENT – THE SIMS

You are a family therapist.

- Keep the family peace until the son goes off to college.

Your suggestions are:

- Buy flowers for mom
- Have a drink
- Play the lottery
- Arrange a date for the son
- Work overtime
- Take a part - time job

SEMESTER ASSIGNMENT – THE SIMS

Create a simulation model for the described scenario.

- Use it to predict the family behavior .

Your task as a therapist is …

- to devise a strategy for applying the interventions.

The strategy must …

- maximize the probability of keeping the family together for seven years.

SEMESTER ASSIGNMENT – THE SIMS

Use your model to answer questions :

- For how long will the father be unemployed on average?
- How much money will be spent on damaged school property?

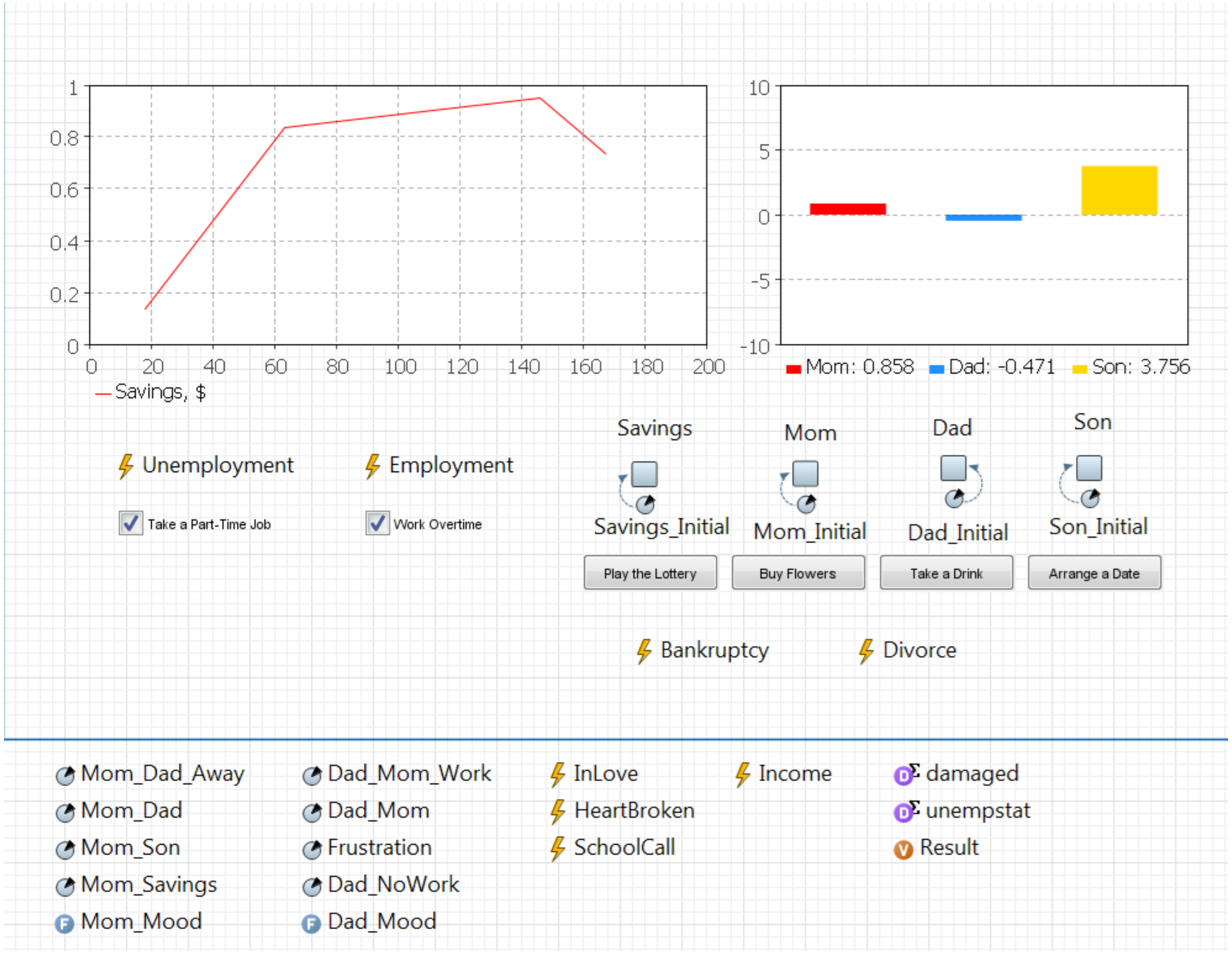
What is the probability that...

a) the family will be broke before college starts?

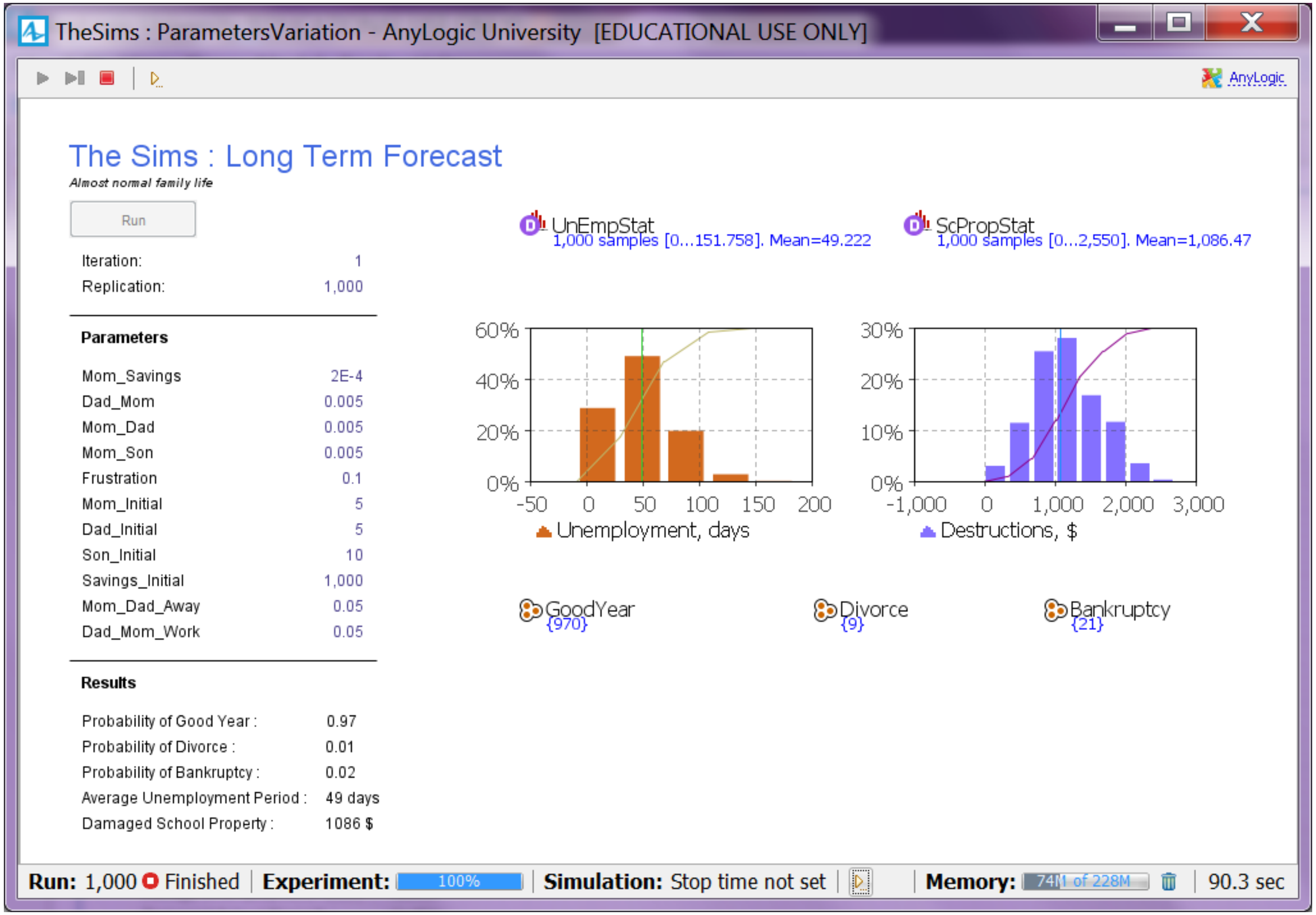
b) the parents will get a divorce?

c) they stay happy for seven years?

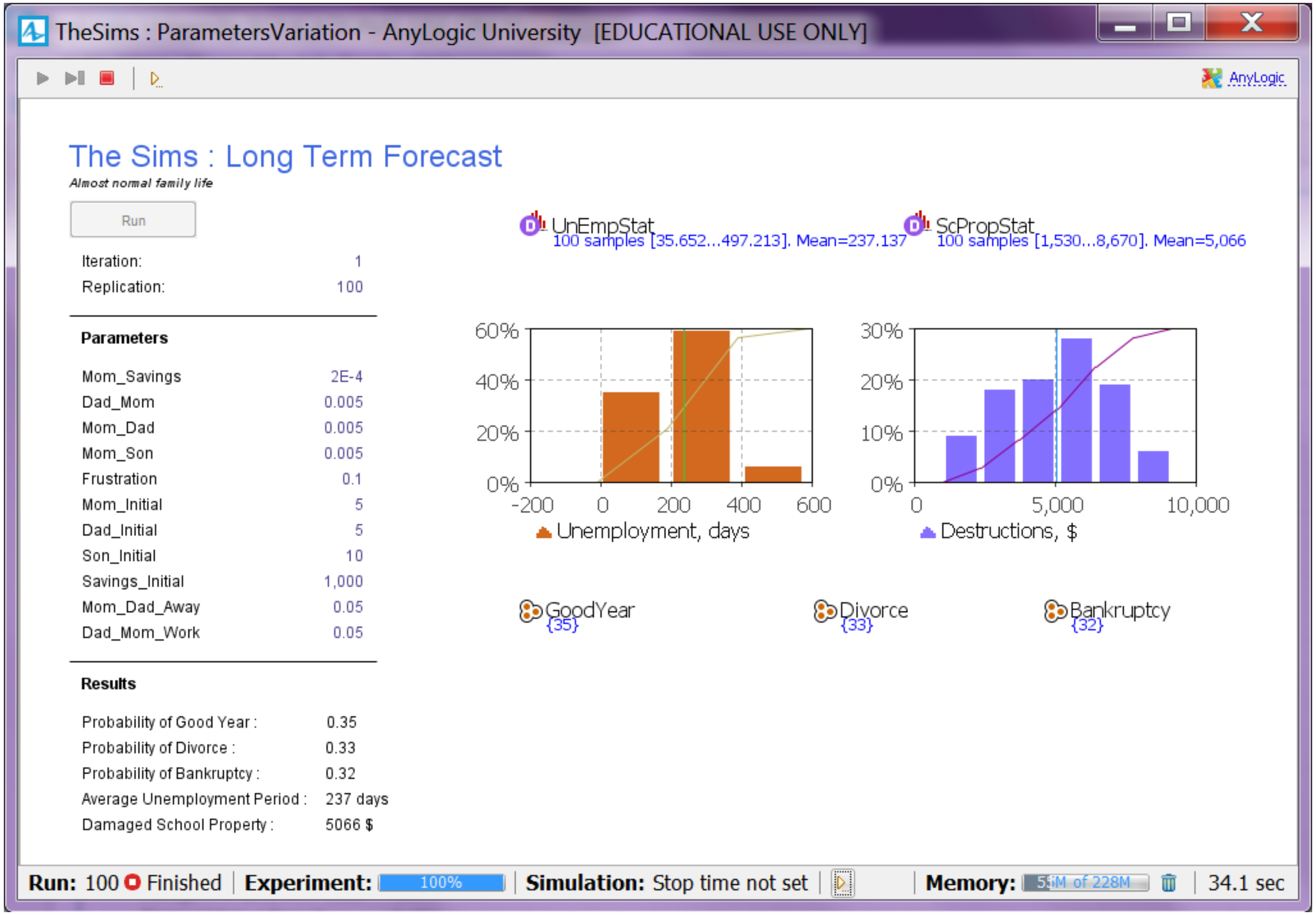
ANYLOGIC MODEL



1 YEAR PREDICTION



7 YEARS PREDICTION WITHOUT INTERVENTIONS



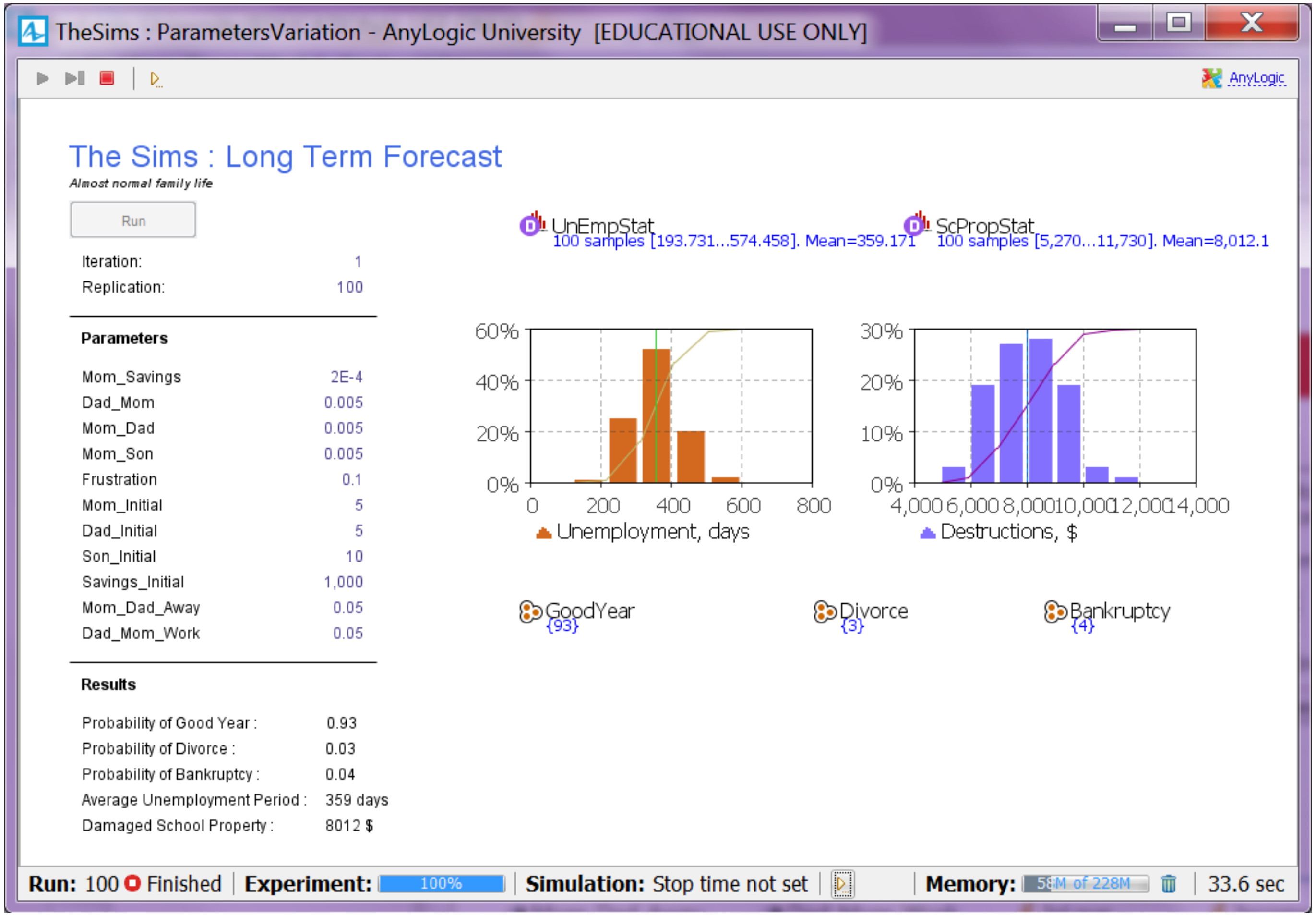
THERAPY

Overtime + part-time job

So that the main idea of the survival strategy is to earn as much money as they can. For example, our simulation starts and dad is employed, so he can work overtime else his wife may take a part time job to minimize the losses while her husband is unemployed.

THERAPY

Hardworking during 1.5 years:



THANK YOU FOR YOUR ATTENTION!