Simulation

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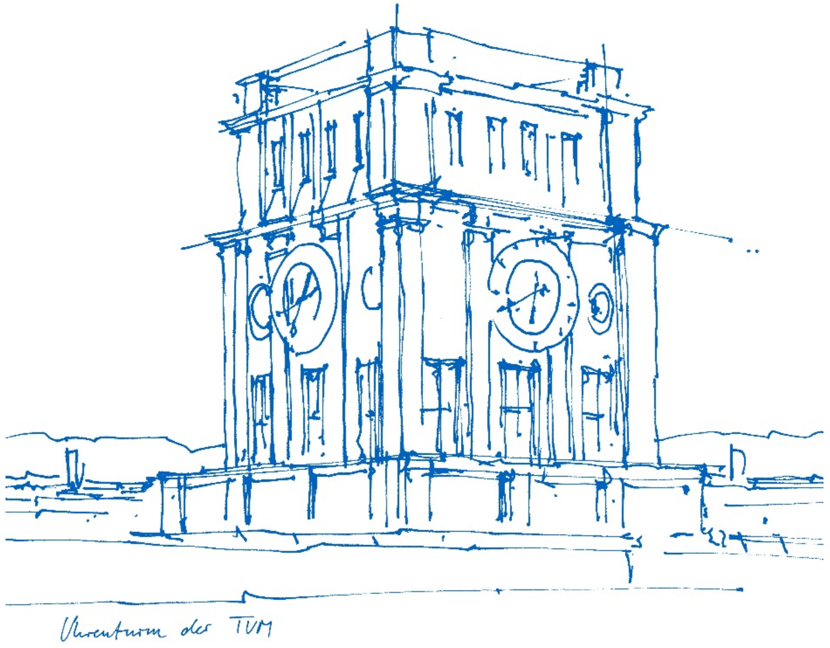
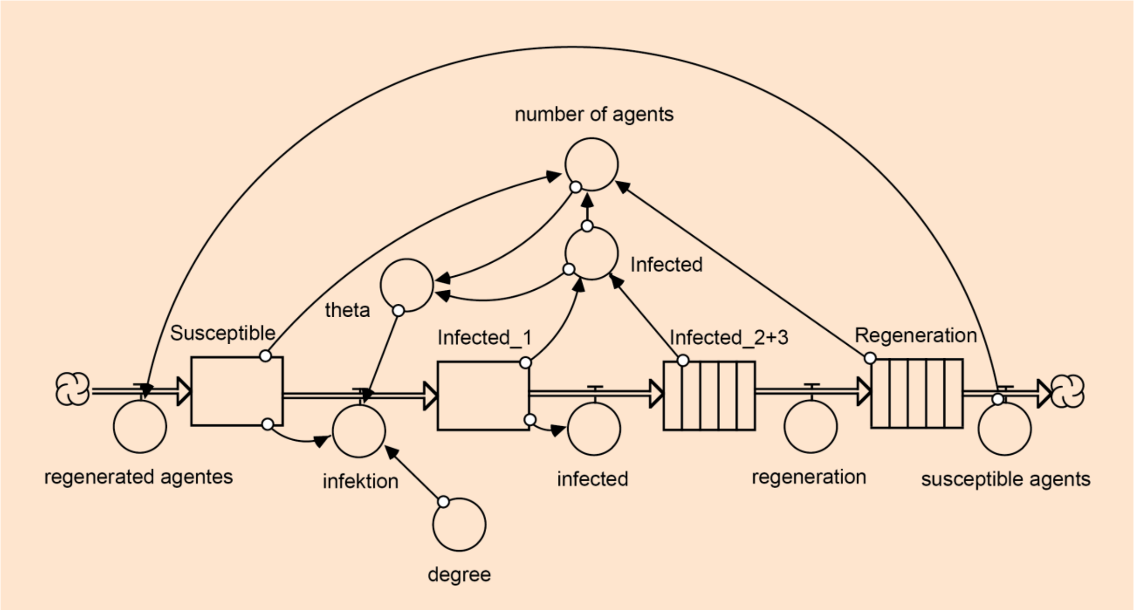


Agenda

Event simulation

Causal-loop diagrams

System dynamics



Simulation Paradigms

	Event Simulation	System Dynamics	Agent-Based Simulation
Modeling Objects	Events	Stocks and flows	Agents
Describing…	Dependences of elements	Impact of elements on each other	Behavior of agents
Type	Event-discrete	Continuous	Time-discrete
Level	Local	Global	Local

Event Simulation

System changes when events occur

Examples: Company models (e.g. warehousing, front desk activities)

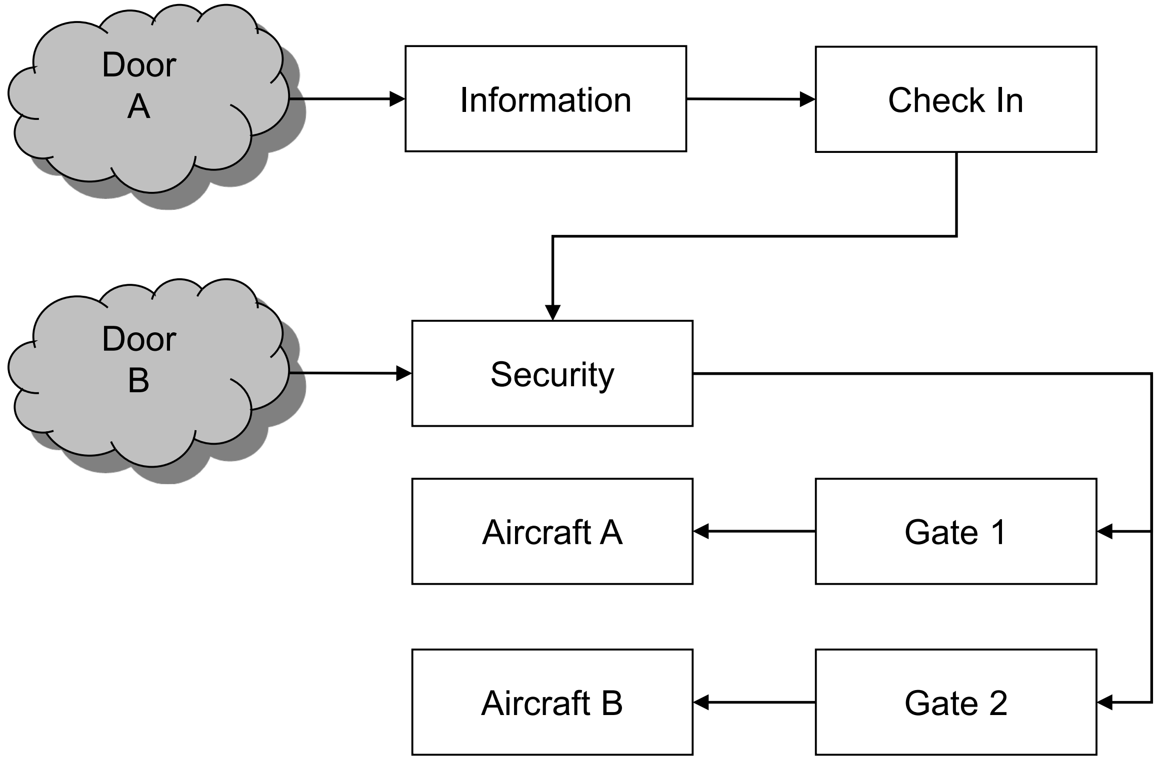
External events: customer enters the shop, truck arrives at the warehouse

Internal events: finalizing one process starts the next one

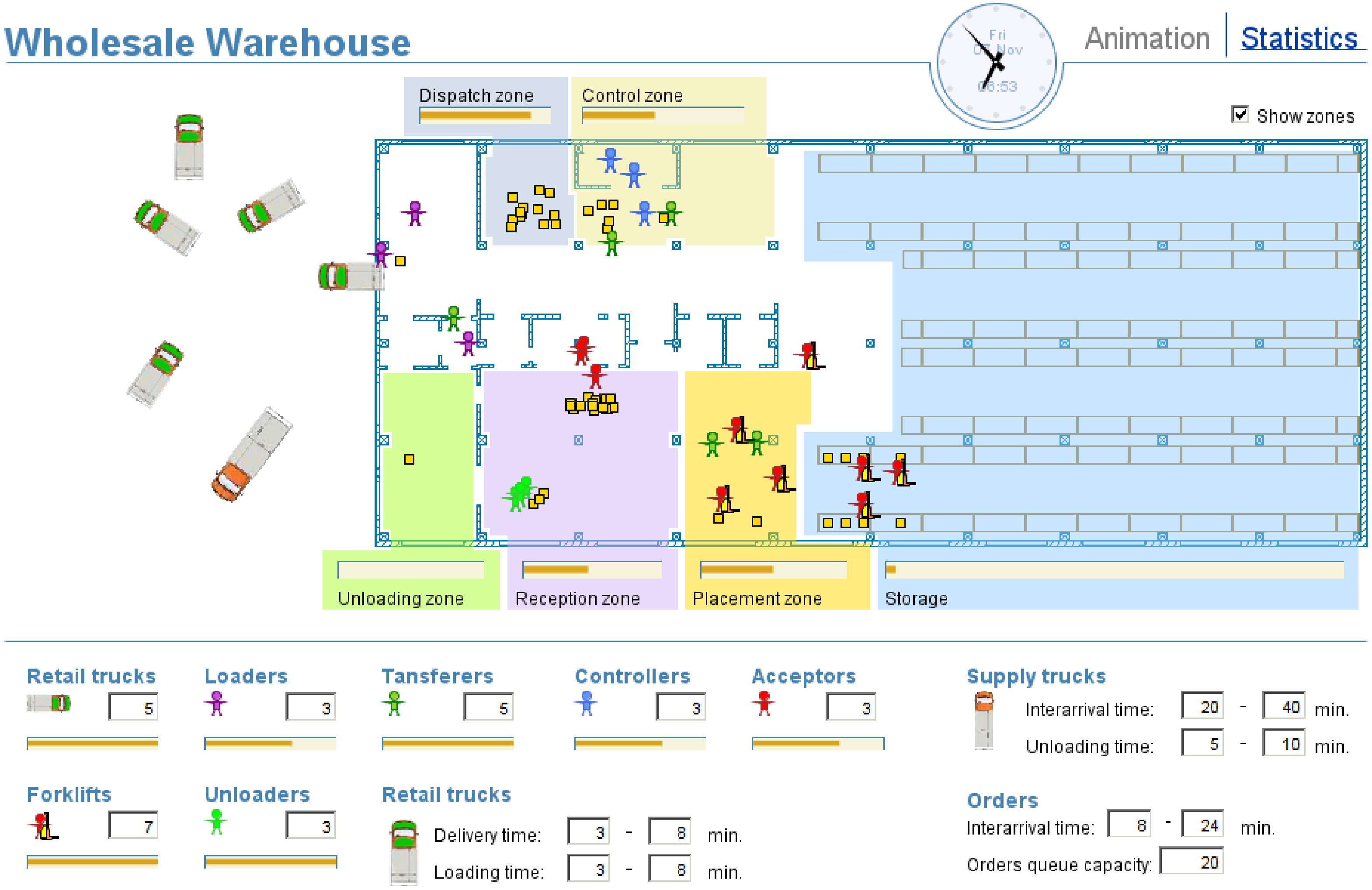
Actions are not time-discrete (opp. to ABM)

Implementation: queuing models, petri nets

Event Simulation



Event Simulation



System Dynamics

Developed by Jay Wright Forrester in the 1950s at MIT

Analyzing dynamic systems on macro level

Originally used for automated regulation of antiaircraft defense

Industrial Dynamics (1961): Models of business processes

Urban Dynamics (1969): Models of social problems in cities

World Dynamics (1973): Models of global economic and ecologic development

Vensim

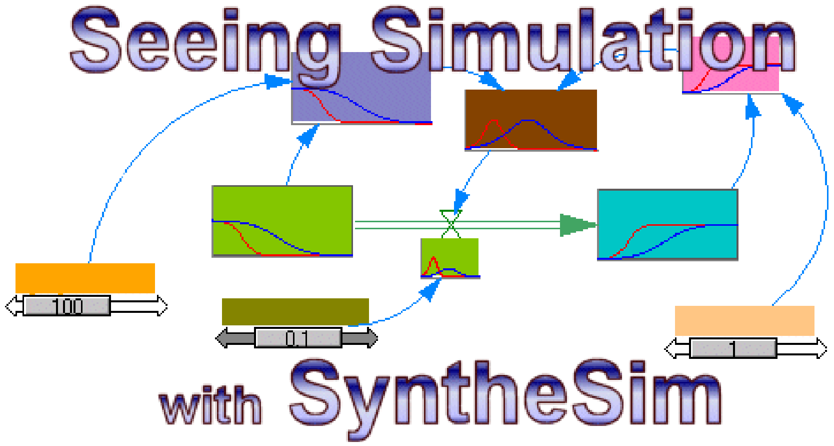
Tool for visual construction of System Dynamics models

Vensim = Ventana Simulation Environment

Plus: Causal loop diagrams, large systems, great help files and introductions, user friendly

Current version: 5.11A (Windows/Mac)

Vensim PLE version is free for academic use



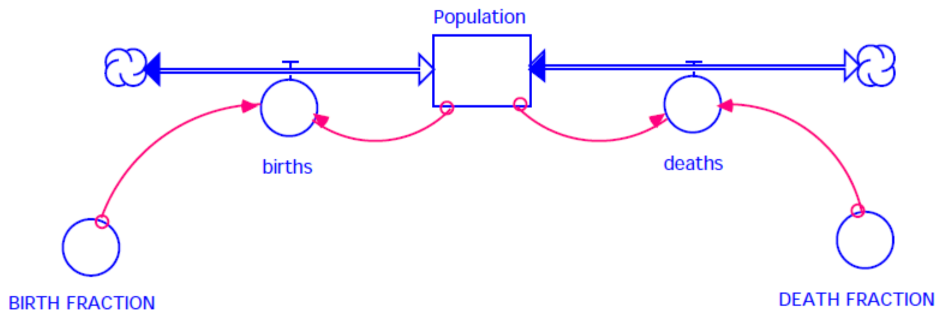
System Dynamics

A **system** is a collection of elements that continually interact over time to form a unified whole

The **structure** of the system is described by the relationships between the elements

Dynamics refers to change over time

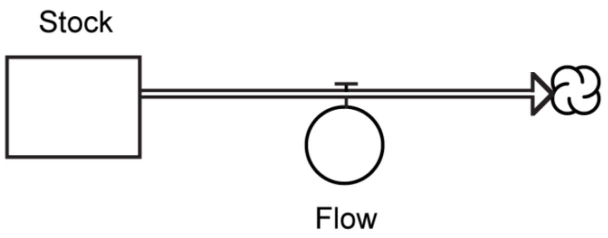
System Dynamics tries to describe the behavior of the system



Elements

Stock (Level): A generic symbol for anything that accumulates or drains. E.g. water accumulates in your bathtub.

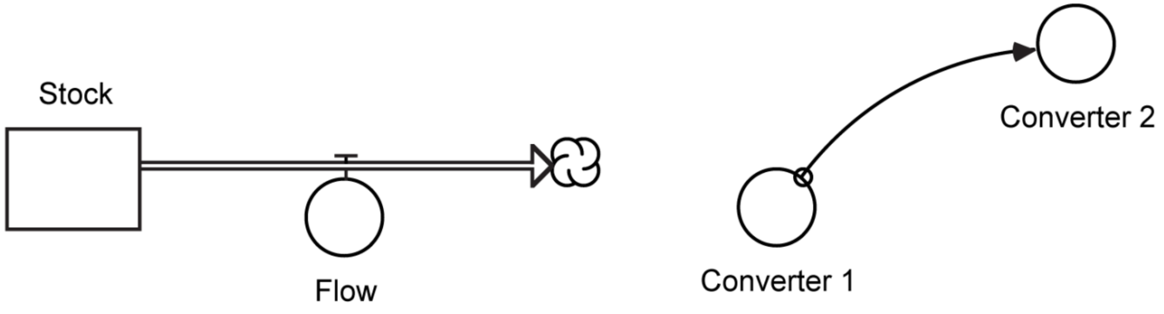
Flow: The rate of change of a stock. E.g. the water coming into the bathtub through the faucet and the water leaving the bathtub through the drain.



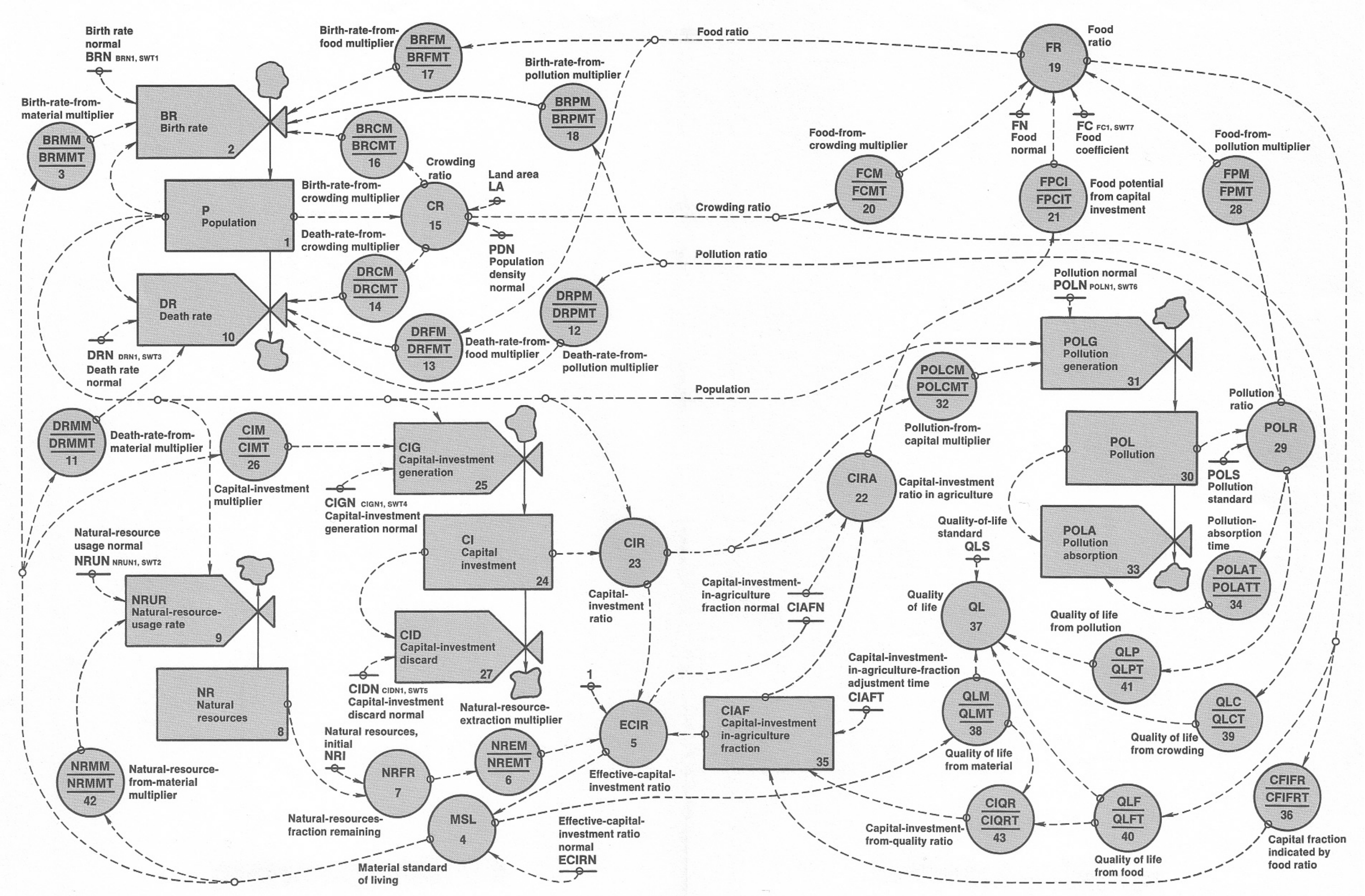
Elements

Converter: Is used to take input data and manipulate or convert that input into some output signal. E.g. the converter takes as an input your action on the valve and converts that signal into an output reflecting the flow of water.

Connector: An arrow that allows information to pass between converters, stocks, and flows.



4 Elements to Describe the World



Math Behind System Dynamics

System Dynamics is based on…

Difference equations (recurrence relations) recursively define time-discrete sequences of change:

$$x_{t+1} = x_t \, \alpha$$

Differential equations describe continuous dependences (change) between variables:

$$F = m \frac{dv}{dt}$$

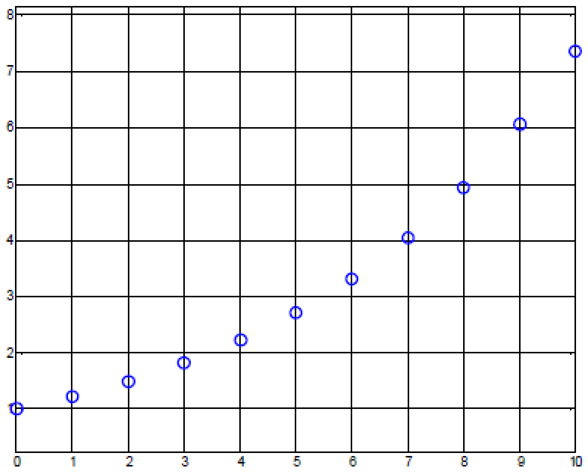
Newton’s second law of motion – acceleration

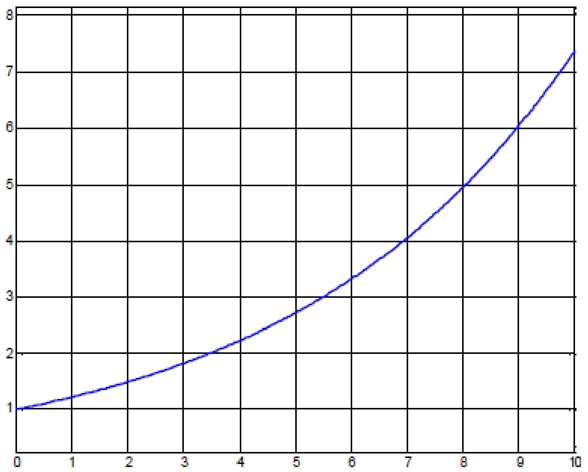
Math Behind System Dynamics

Continuous change: biology, physics, economy, etc.

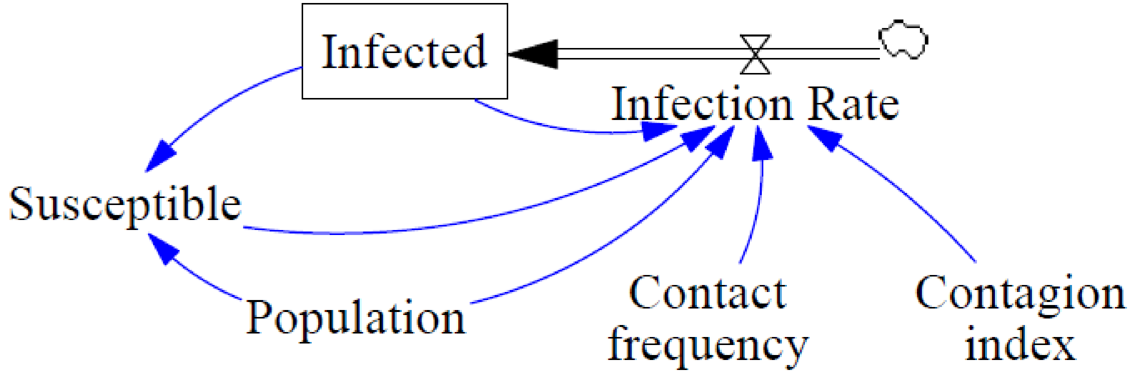
Problem: A lot of differential equations can not be solved mathematically

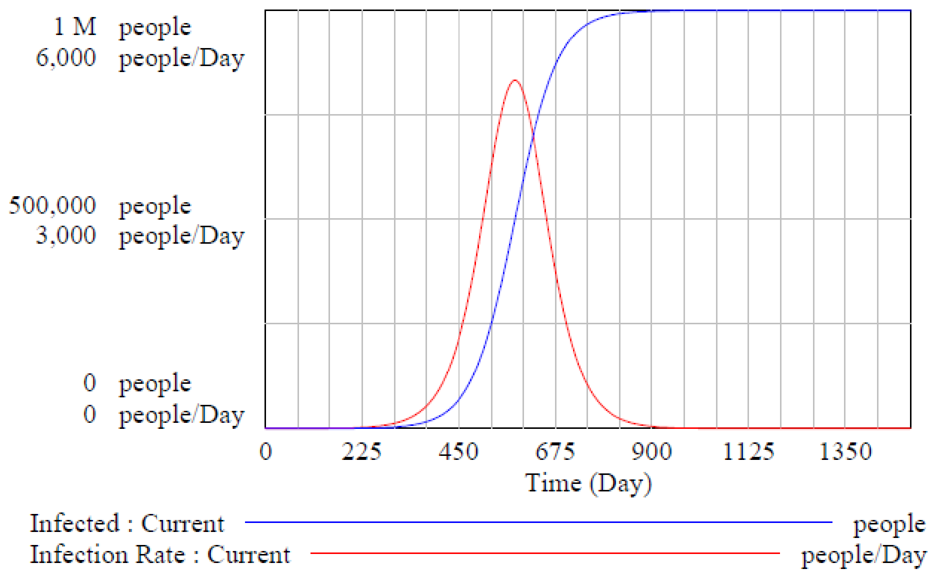
System Dynamics tools transfer continuous differential equations to difference equations, which can be solved iteratively





Epidemic Diffusion





US Population

Census: Population [2010]

- 0-17: 78,347,000
- 18-44: 112,807,000
- 45- : 121,757,000

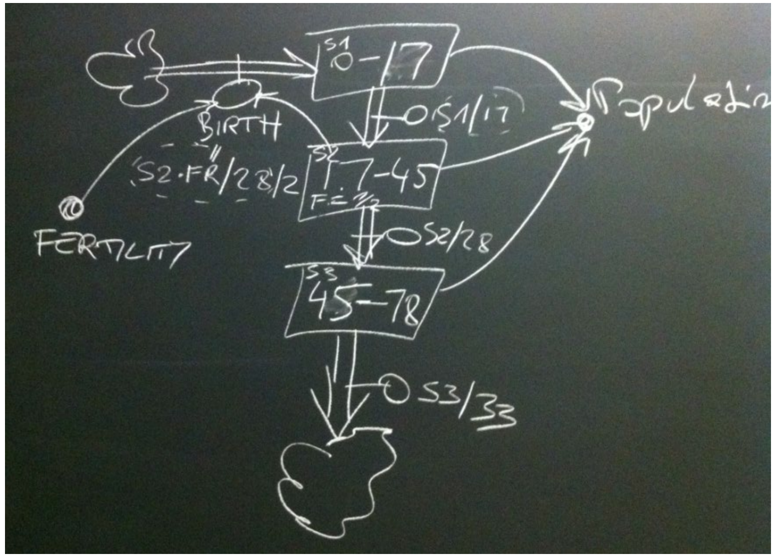
Fertility rate: 2.01 [2009]

Live births: 4,248,000 [2008]

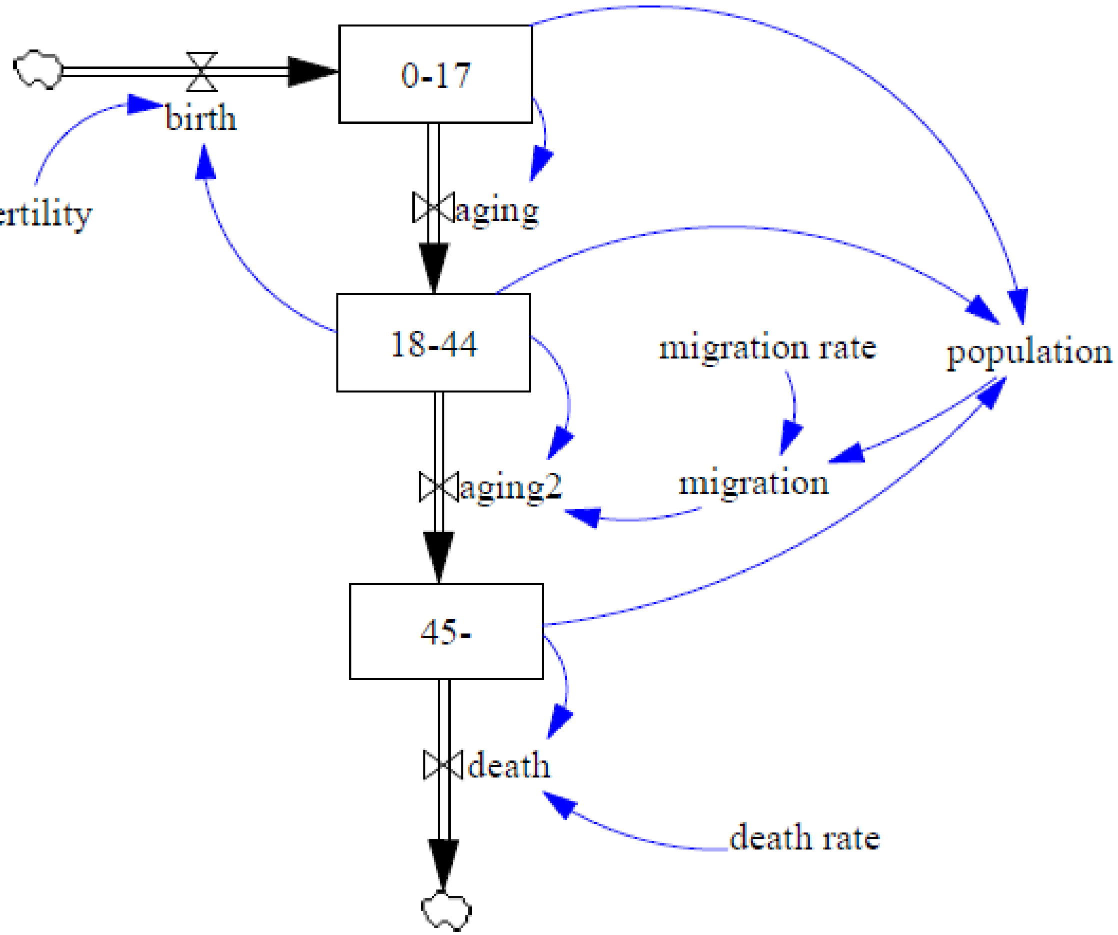
  – 112M * 2.01 / 2 / 26 = 4.32M

Deaths: 2,473,000 [2008]

Net migration rate: 4.32/1,000 population [2010]

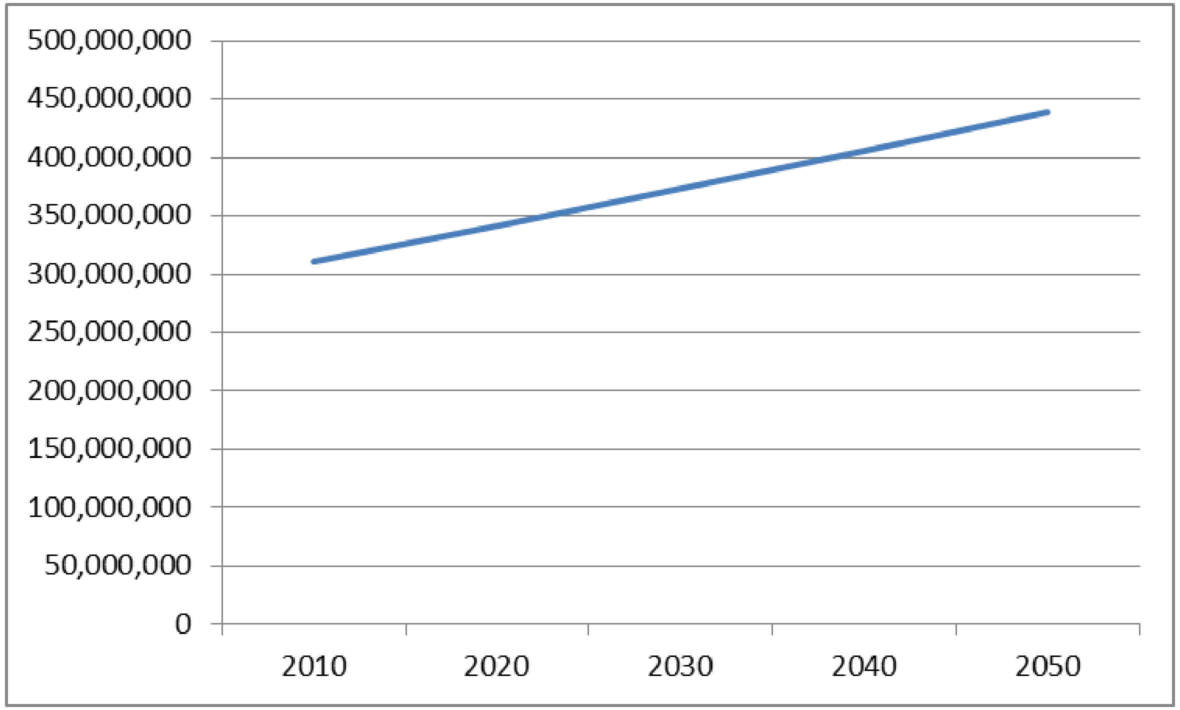


US Population



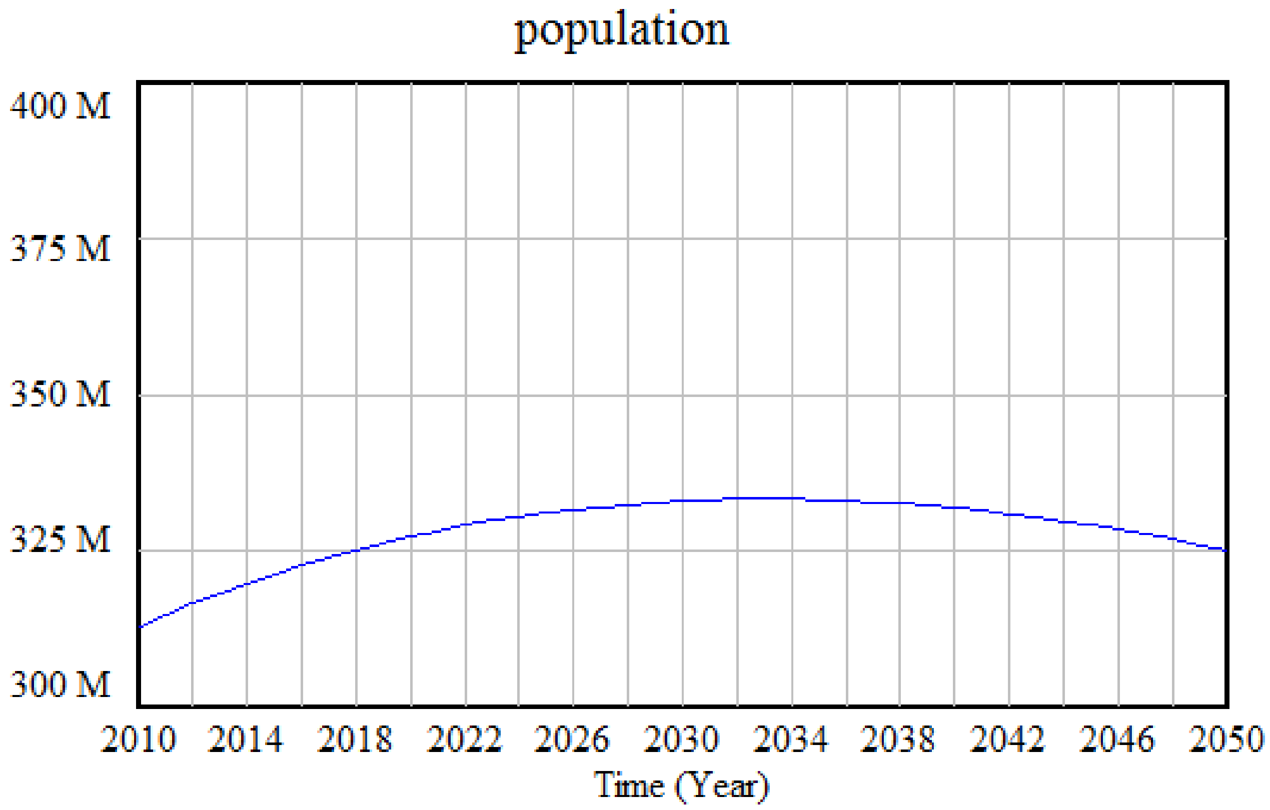
US Population

In 2008, the US Census Bureau projected future censuses as follows [Wikipedia]:



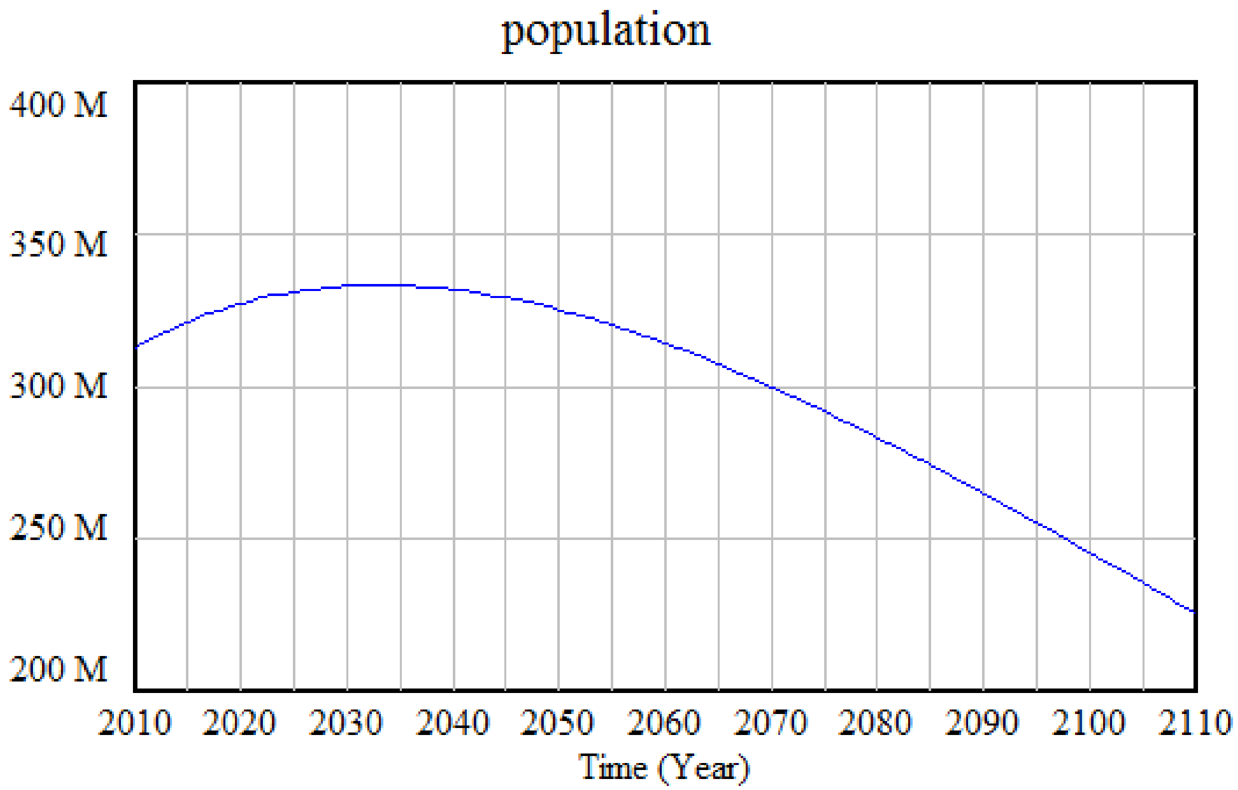
US Population

Our model:

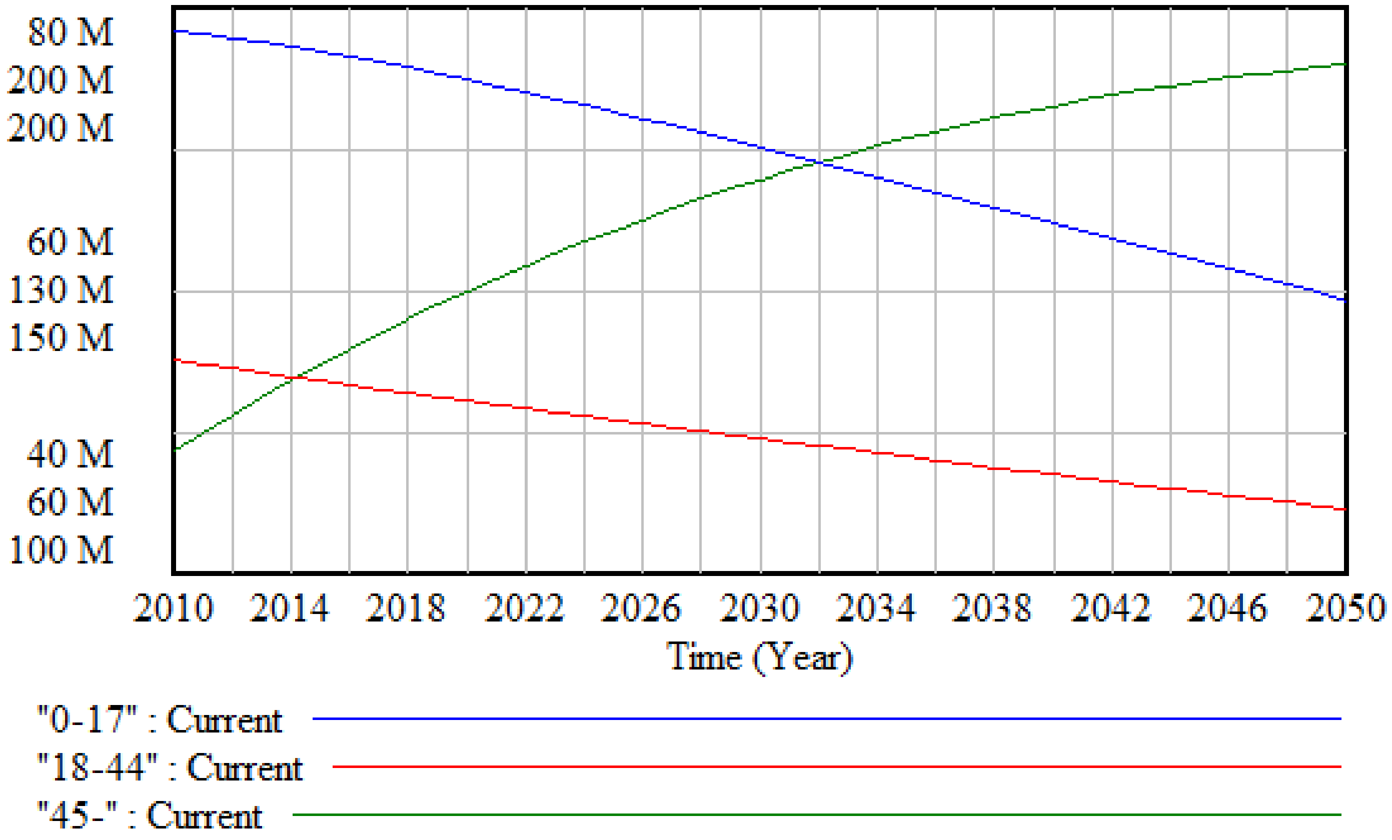


US Population

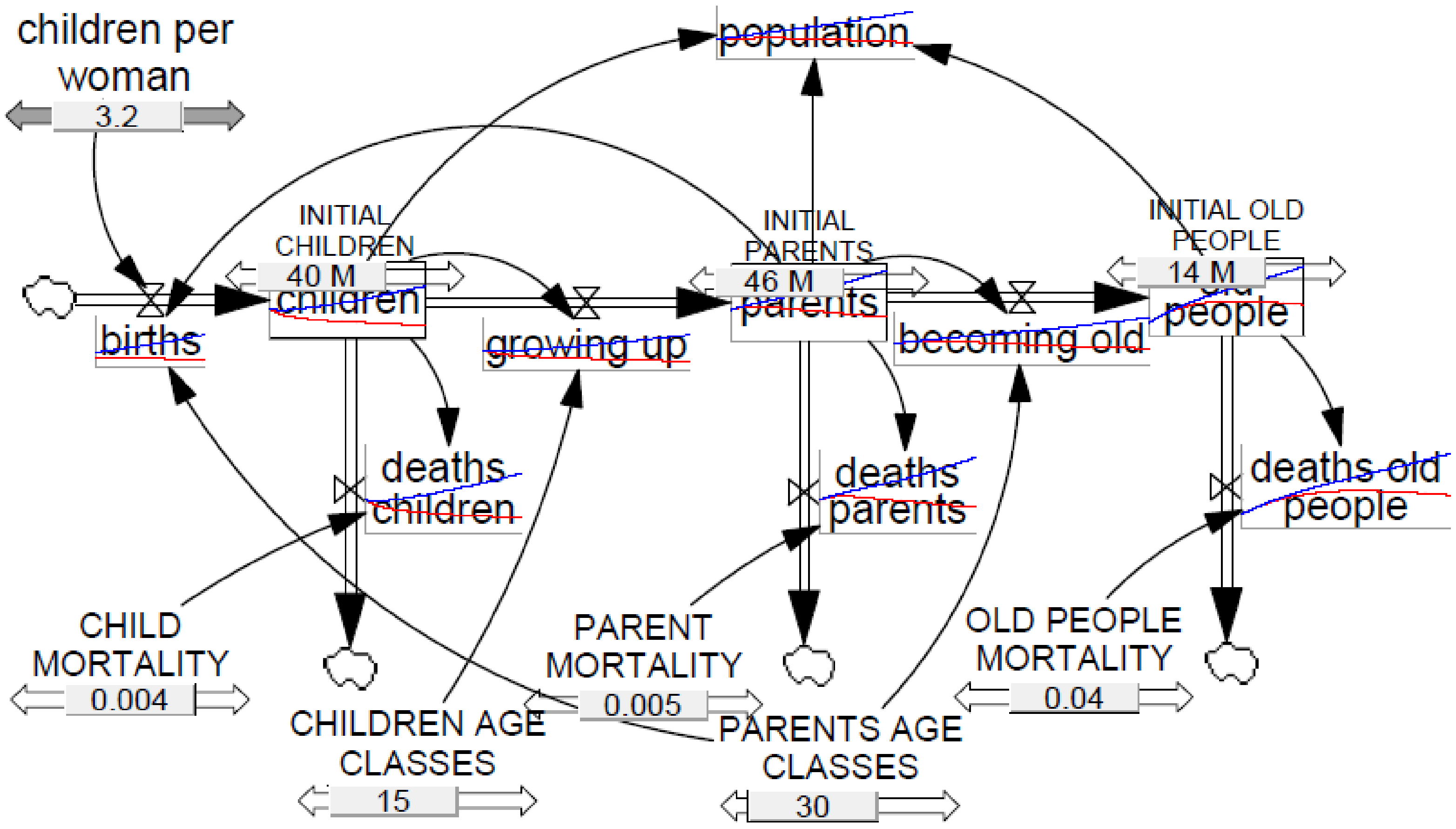
Our model:



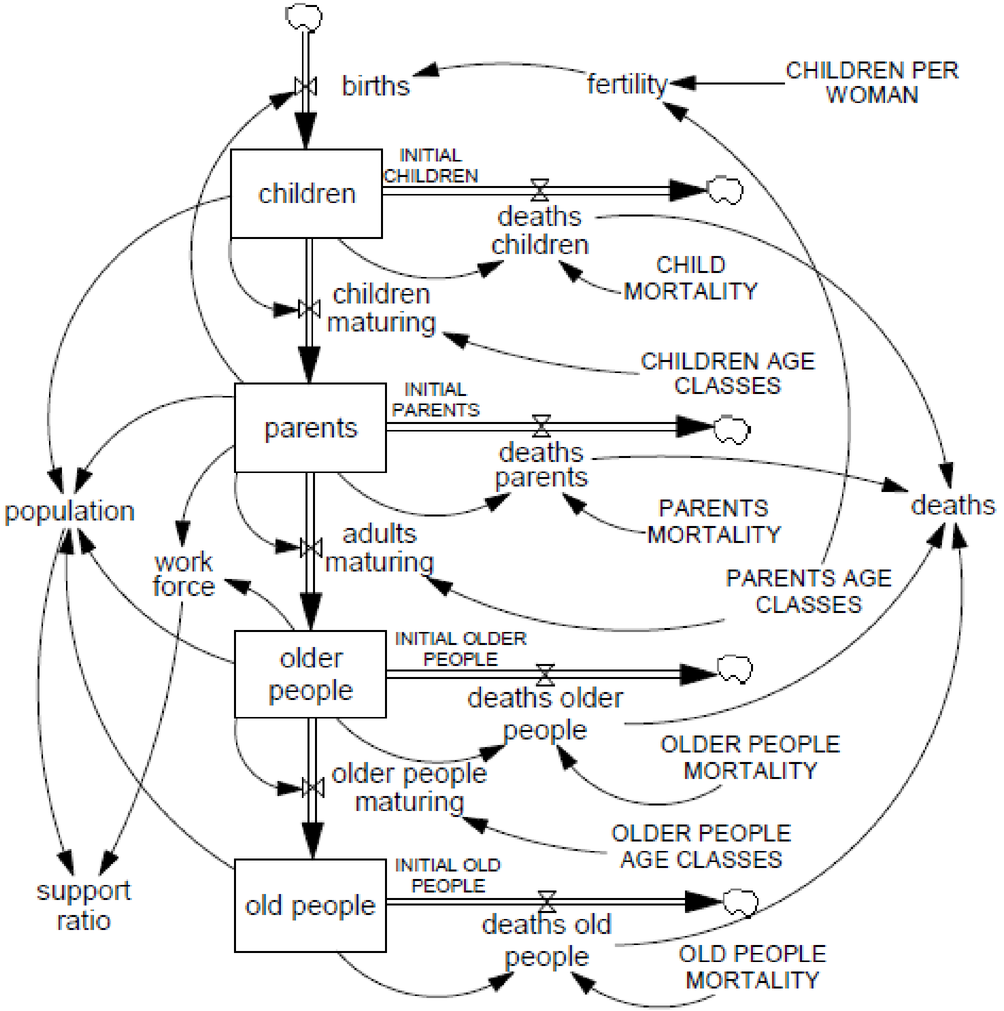
US Population



Population with 3 Generations



Population with 4 Generations



Price and Market

Prices on a free market:

Supply of gods and price of gods are a function of demand and costs (production, taxes, profits)

If the demand is higher than the supply, prices increase

Companies produce more products

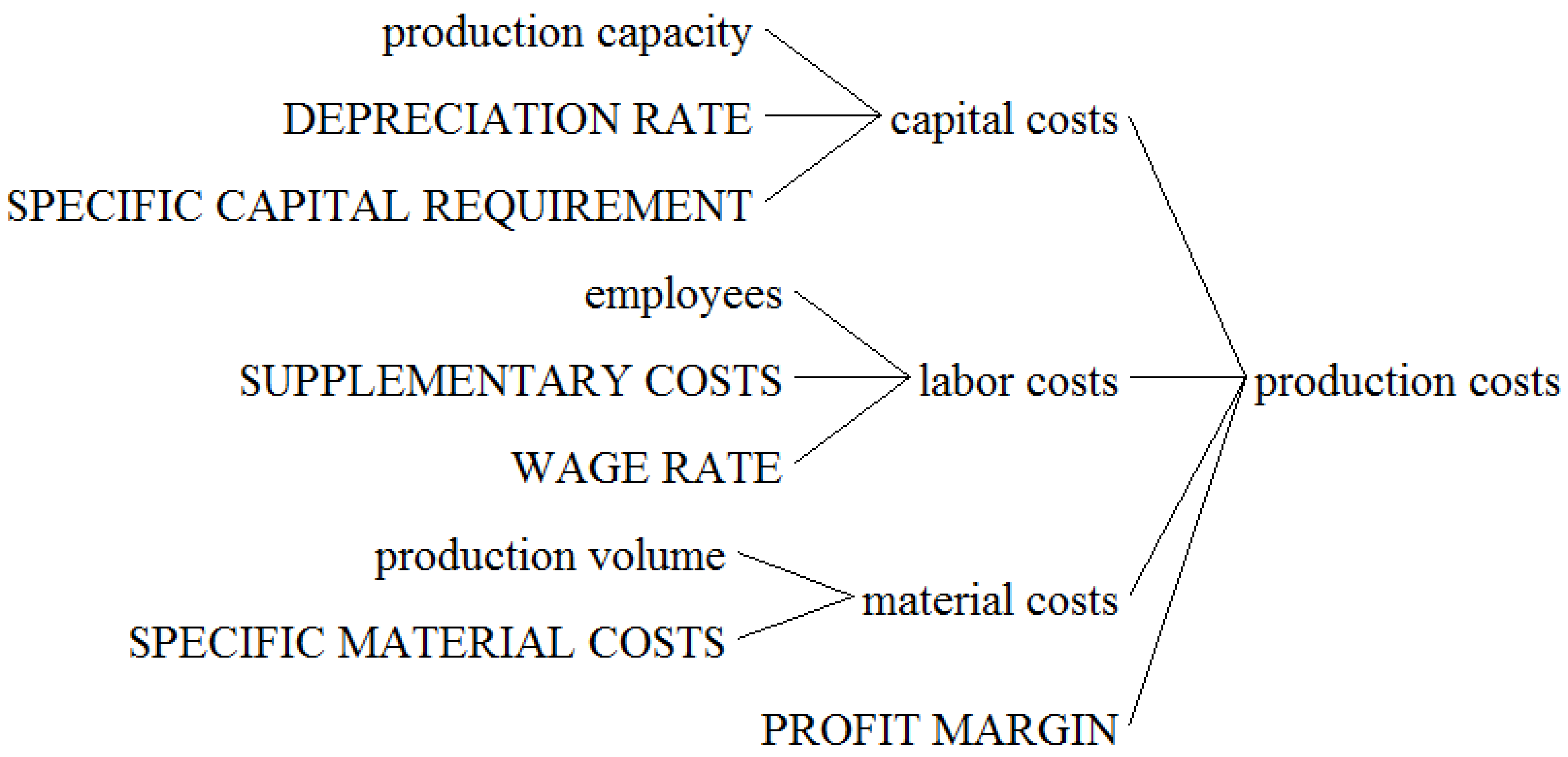
The supply increases

Prices decrease

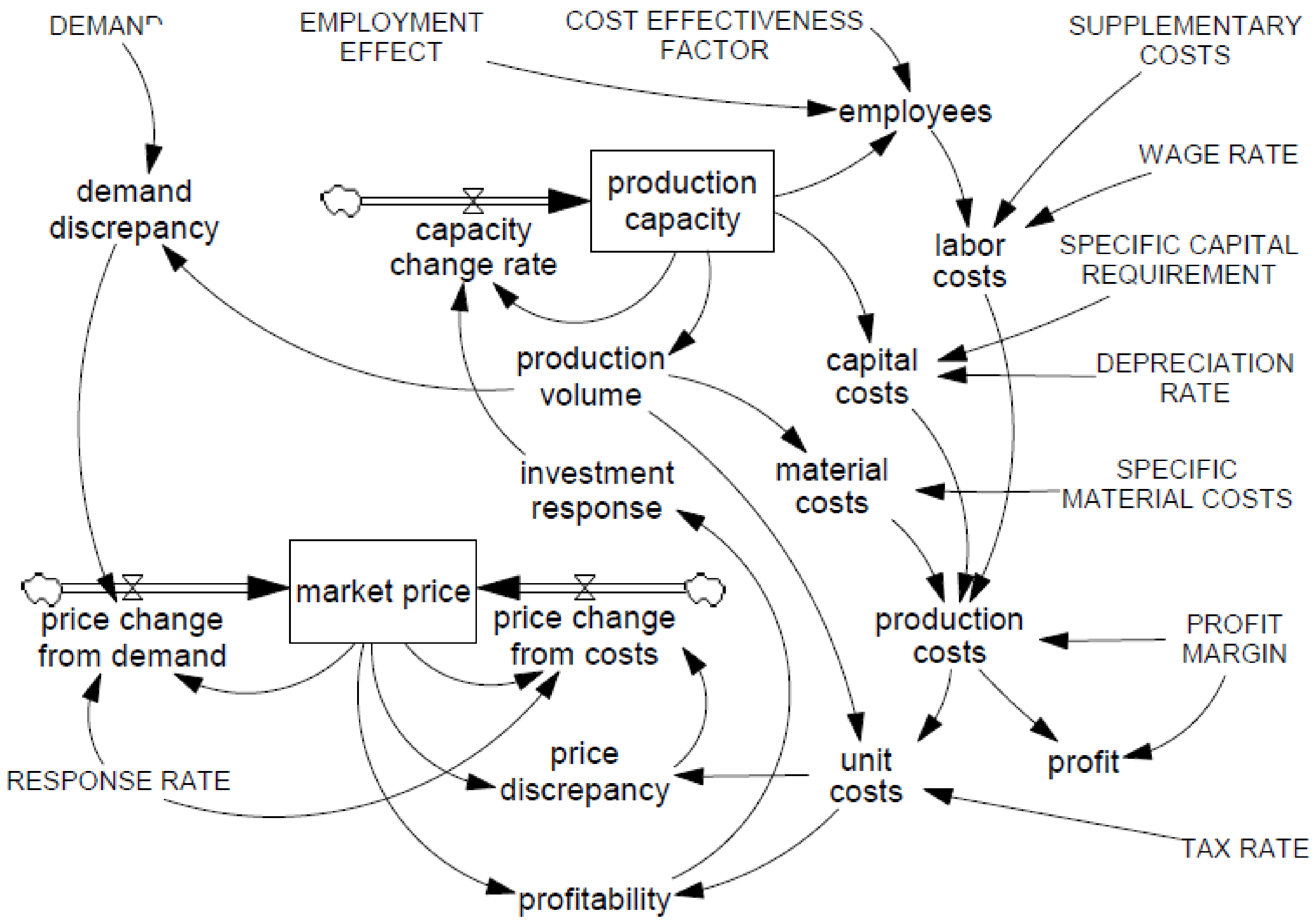
Companies start to produce less products

Damped periodic system that converges to a market price

Production Costs



Price and Market



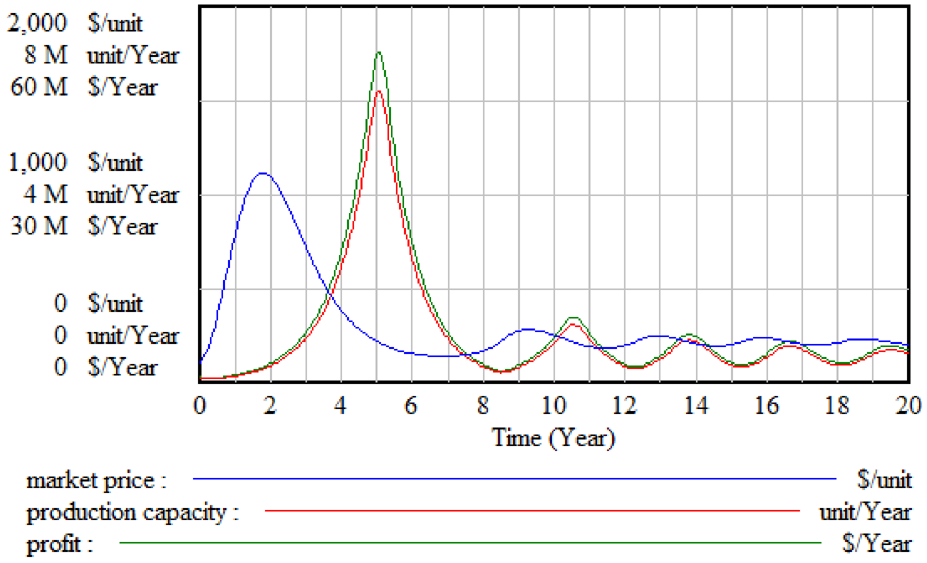
Results

Initial production volume is much lower than demand

Shortage of goods leads to increase of price

High profit increases production

Overproduction etc.



Aggression Model

Ethnic and cultural differences (e.g. religion) can lead to disputes

Dynamic processes:

- Unfamiliarity of other culture
- Tolerance
- Hate
- Restraint threshold for violent actions
- Etc.

Why is this (almost) impossible to model?

Why is this impossible?

Hate, tolerance, restraint threshold, etc. qualitative and subjective items

These items are almost impossible to measure

Connections and dependences cannot be described in detail

Individuals can act unforeseeable

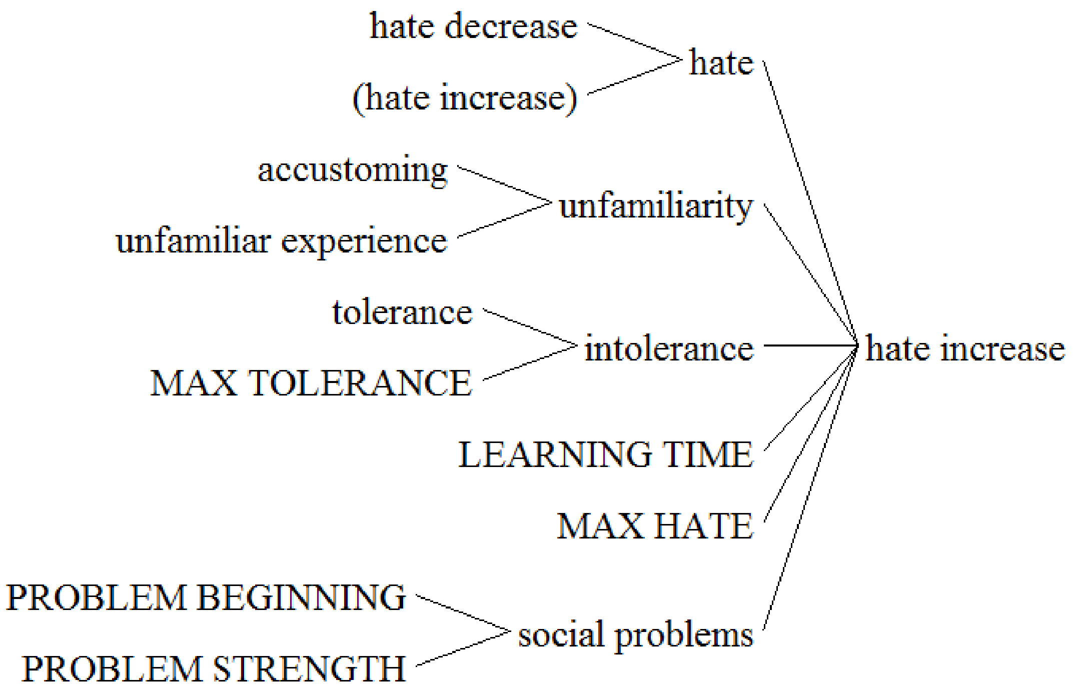
Population has ‘average’ behavior, but individuals can matter

What can we do?

Connect broadly accepted conceptions

Gentle quantification of qualitative concepts

Fuzzy approximation of dynamics



What do we get?

A vague idea of the structure and the dynamics

One model out of many possible models

Try to model a complex system can help to better understand the structure and dynamics of the system

Model as part of theory building

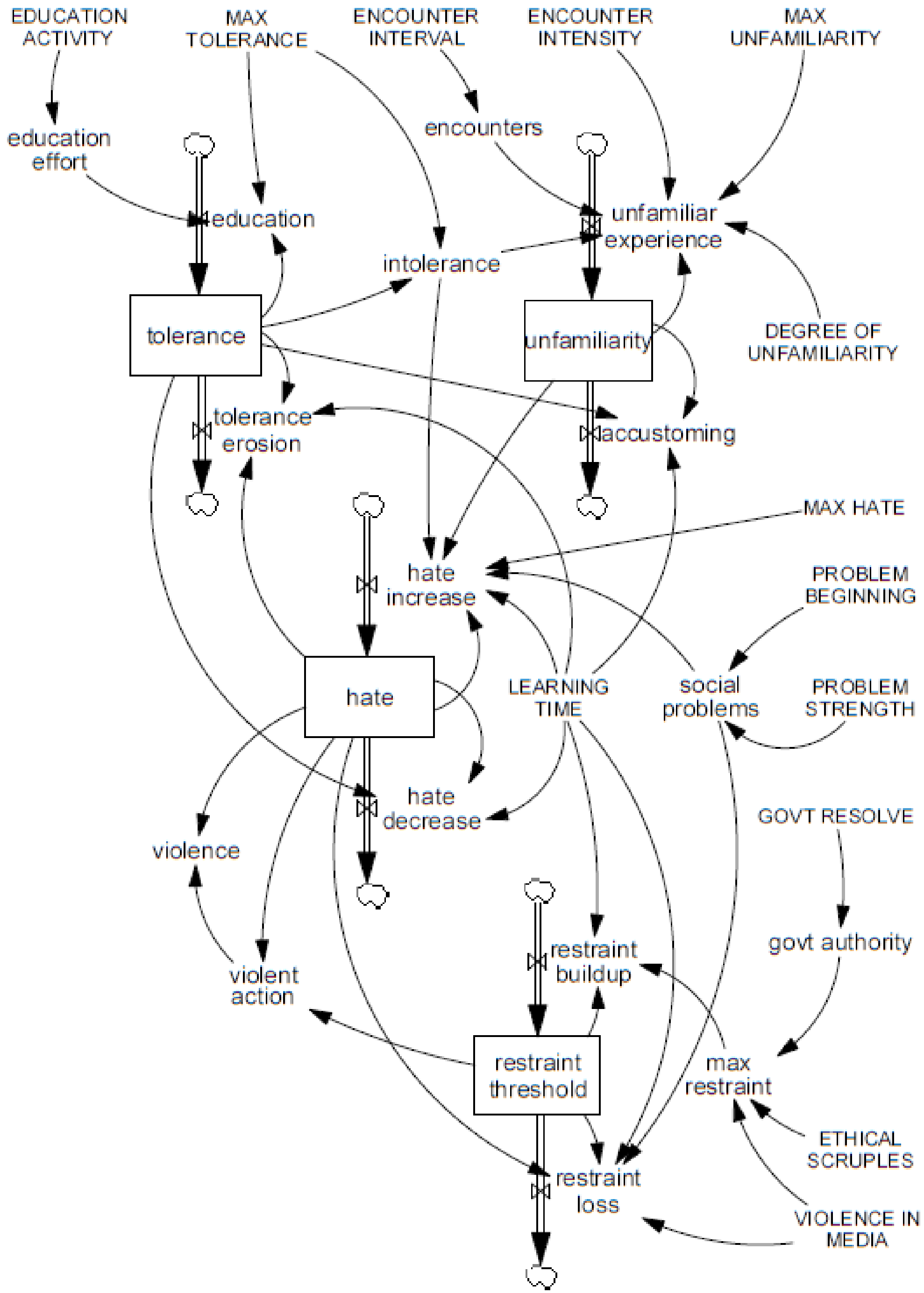
Aggression Model

Hate increases with intolerance and social problems

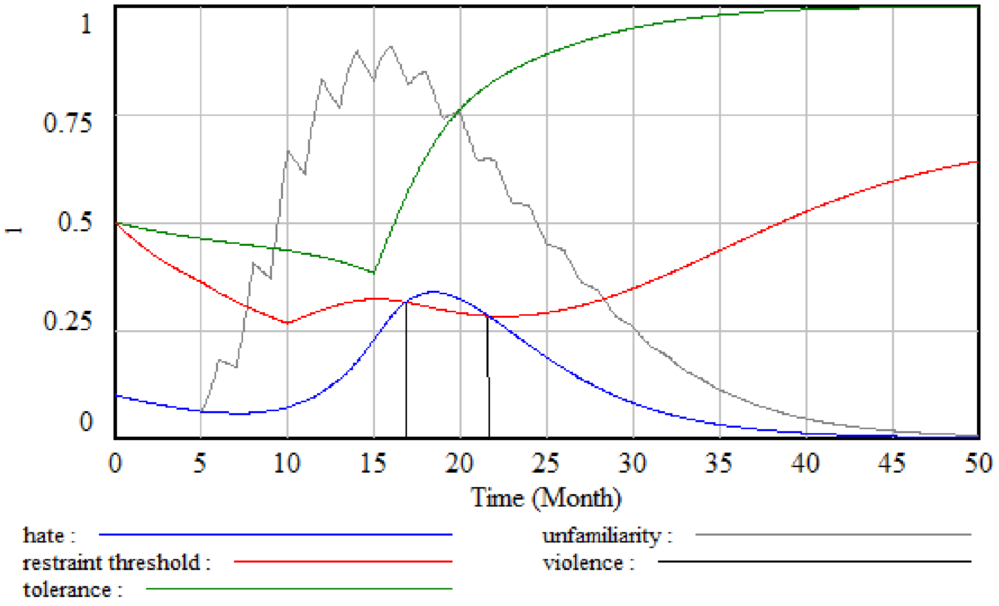
Violence breaks out if hate is higher than restraint threshold

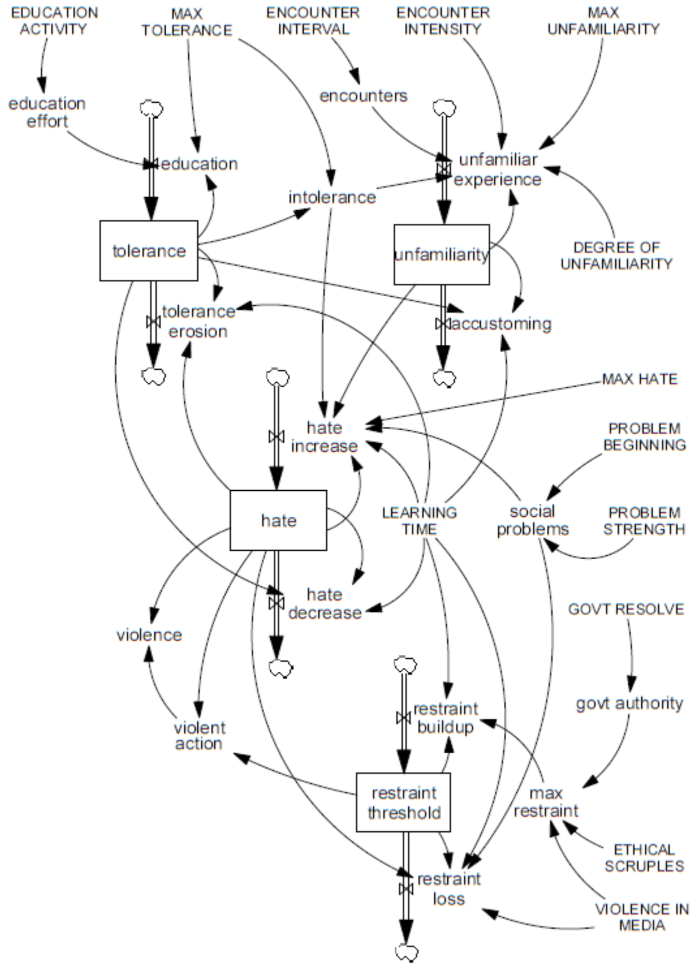
Hate, social problems and violence in media decrease restraint threshold for violence

Etc.



Aggression Model





System Zoo

3 Books by Hartmund Bossel:

System Zoo 1 Simulation Models. Elementary Systems, Physics, Engineering

System Zoo 2 Simulation Models. Climate, Ecosystems, Resources

System Zoo 3 Simulation Models. Economy, Society, Development

100 System Dynamics models, made public by University of Kassel

Zip file at Blackboard/Course Content/Data

ABM vs. System Dynamics

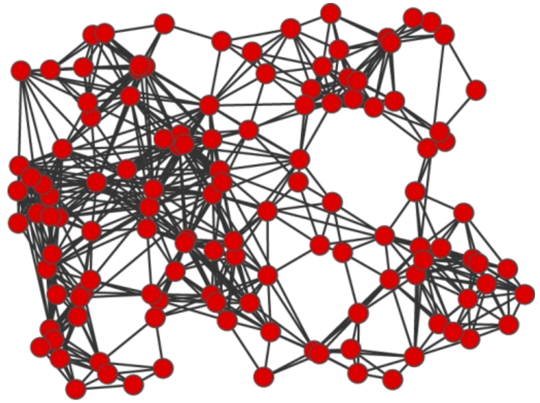
Different ways to describe the same system

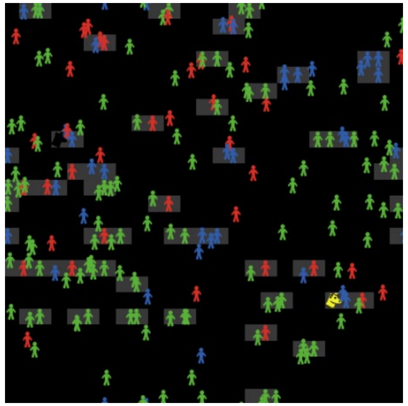
Micro level:

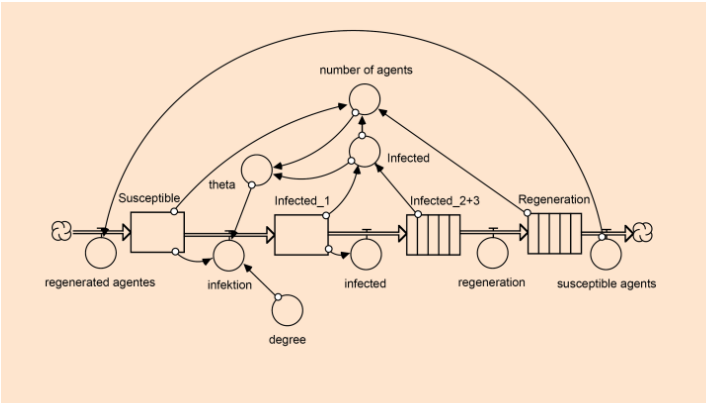
- Networks - Focus on connections and structure
- Agent Based Simulations - Focus on behavior of agents

Macro level:

- System Dynamics - Focus on system behavior







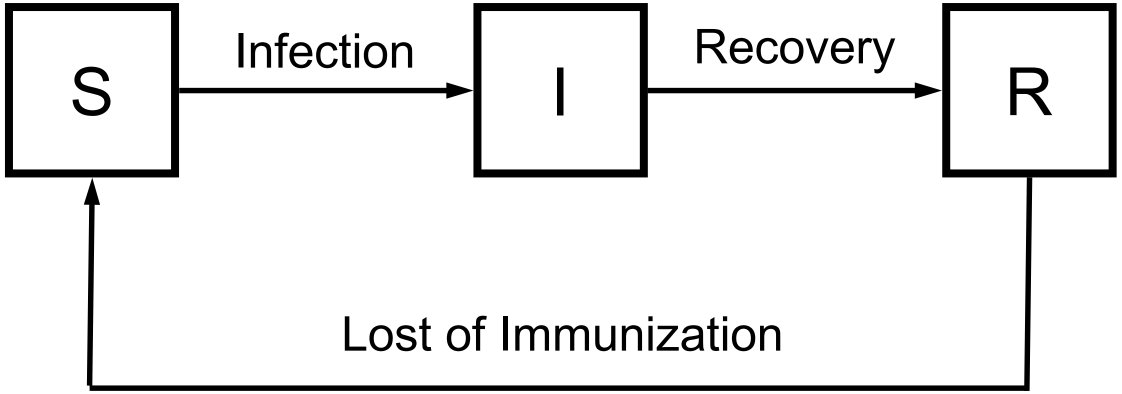
SIRS - Model

Susceptible elements get infected

Infected recover and become immune

After a time period elements become susceptible again

E.g. influenza



SIRS - Model

Agent-based network simulation

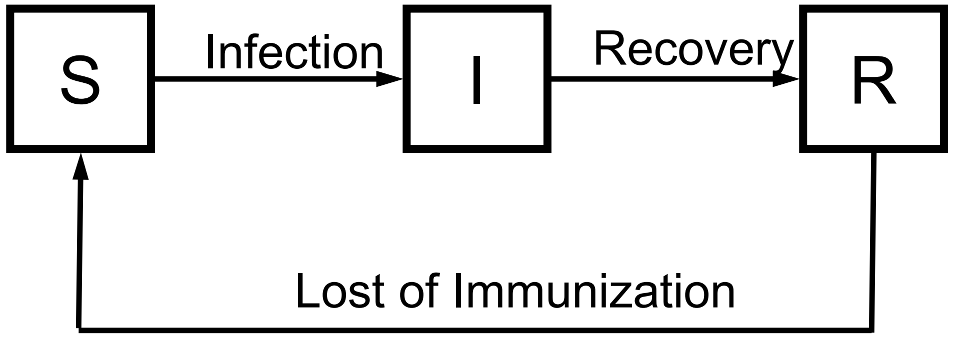
- Infection remains 3 time units, 4 in refractory state

State of an element in t = f(state t-1, state of neighbors in t-1)

1,000 nodes, random network, avg. degree 6

- 10 initially infected nodes

Contagion 0.5 index for every edge in network

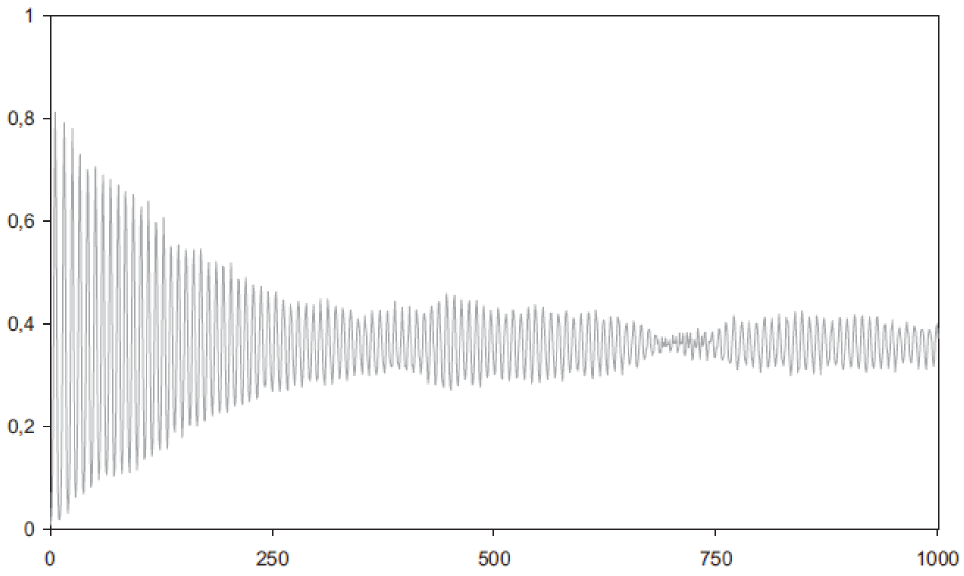


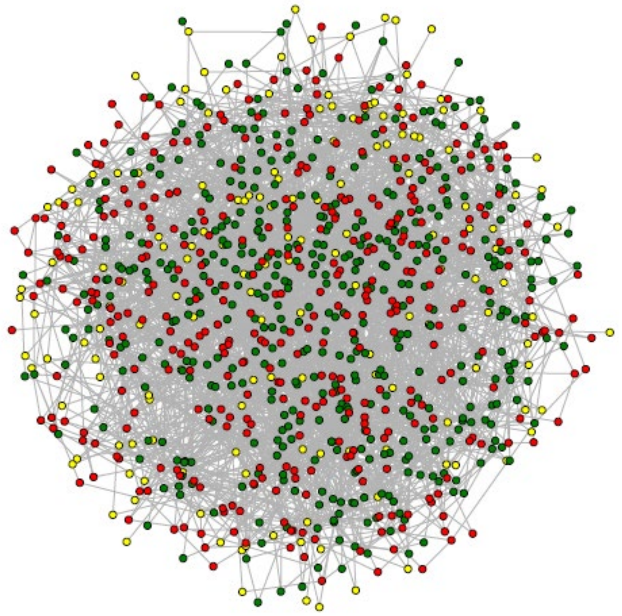
Agent-Based Simulation

Heavy oscillations

Every simulation run looks slightly different

Average of last 100 steps = 0.36 with +/- 0.004 (!)





System Dynamics

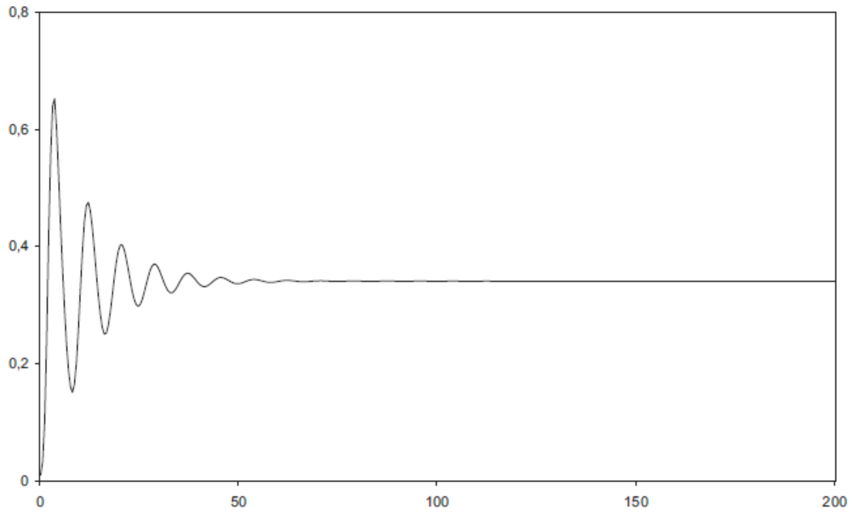
Fast stabilization

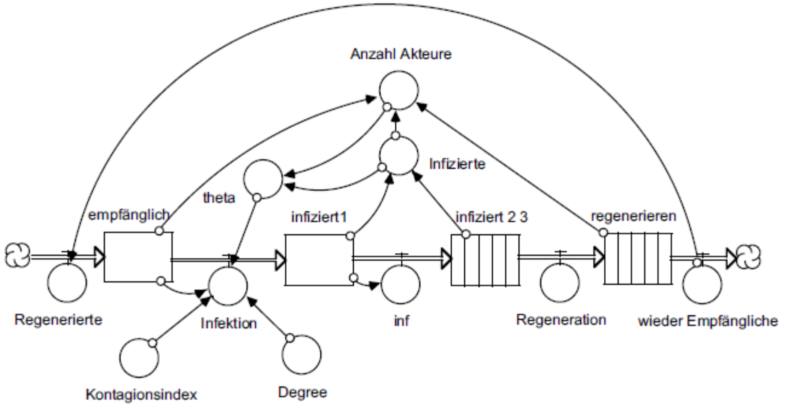
Every run is identical

Expected number of infected nodes:

$$p_{\text{inf}} = 1 - (1 - \theta)^k \qquad \theta = \frac{I}{S + I + R}$$

New infected = $p_{inf} \cdot S \cdot c^*$





ABM vs. System Dynamics

Agent-Based Simulation

SIR(S) model for every agent

Individual behavior and decisions

Include individuality (e.g. network structure)

Unpredictable in details (e.g. who is when infected)

Fuzzy “real-world” behavior

System Dynamics

SIR(S) model on macro level

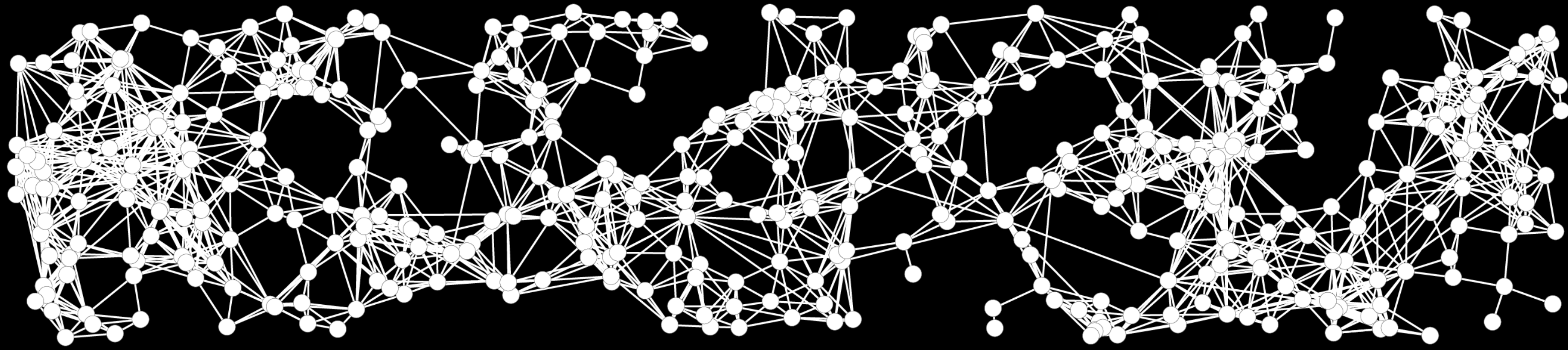
Average behavior as expected values

Aggregated structure with no or little individuality

One result which can be reproduced exactly

Mathematical clarity

“Our mission is to go forward, and it has only just begun.
There's still much to do, still so much to learn. Engage!”
Jean-Luc Picard, Star Trek TNG, Season 1 Episode 26



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