System Dynamics Modelling in NetLogo

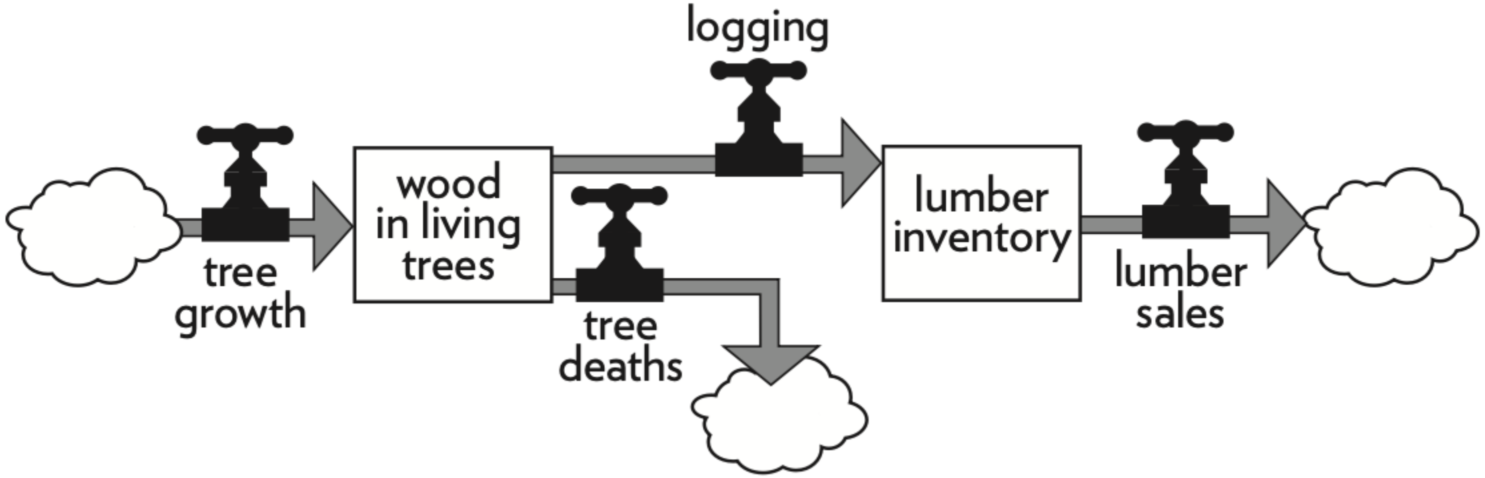
THE UNIVERSITY *of* EDINBURGH
informatics

Modelling of Systems for Sustainability
INFR10088

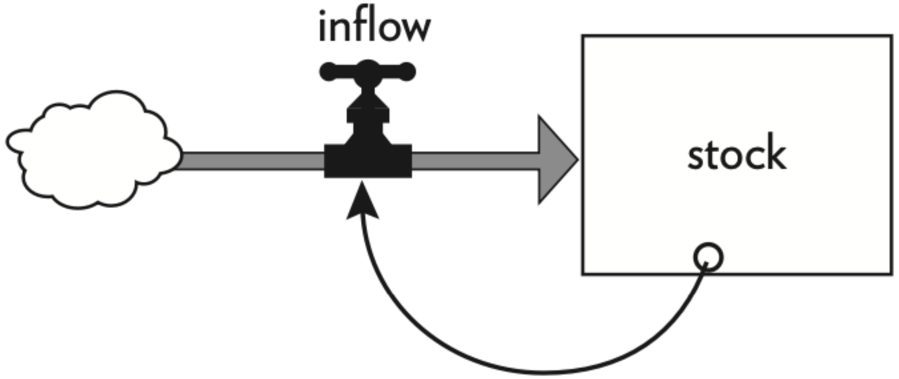
System Dynamics Concepts

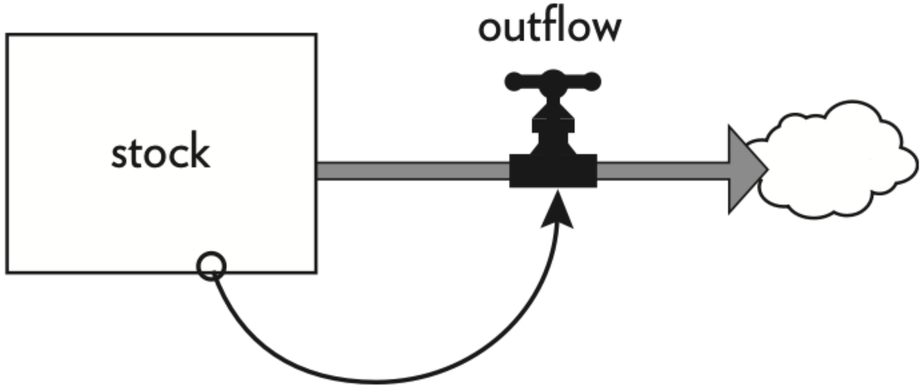
- Stocks – modified each timestep by flows
- Flows – rate of change
- Auxiliary variables – used for intermediate calculations
- Links from Stocks and Auxiliaries to Flows – to affect the flow
- Influence diagram with
  - Balancing (negative feedback) loops
  - Reinforcing (positive feedback) loops

Stocks and Flows

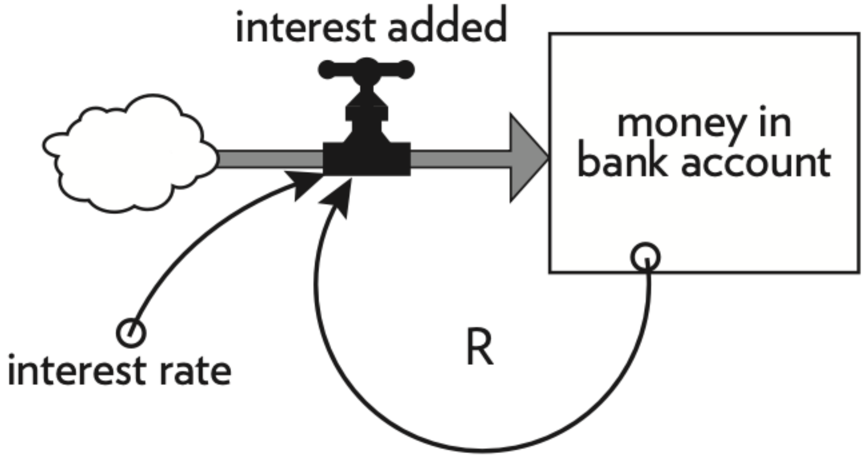


Feedback

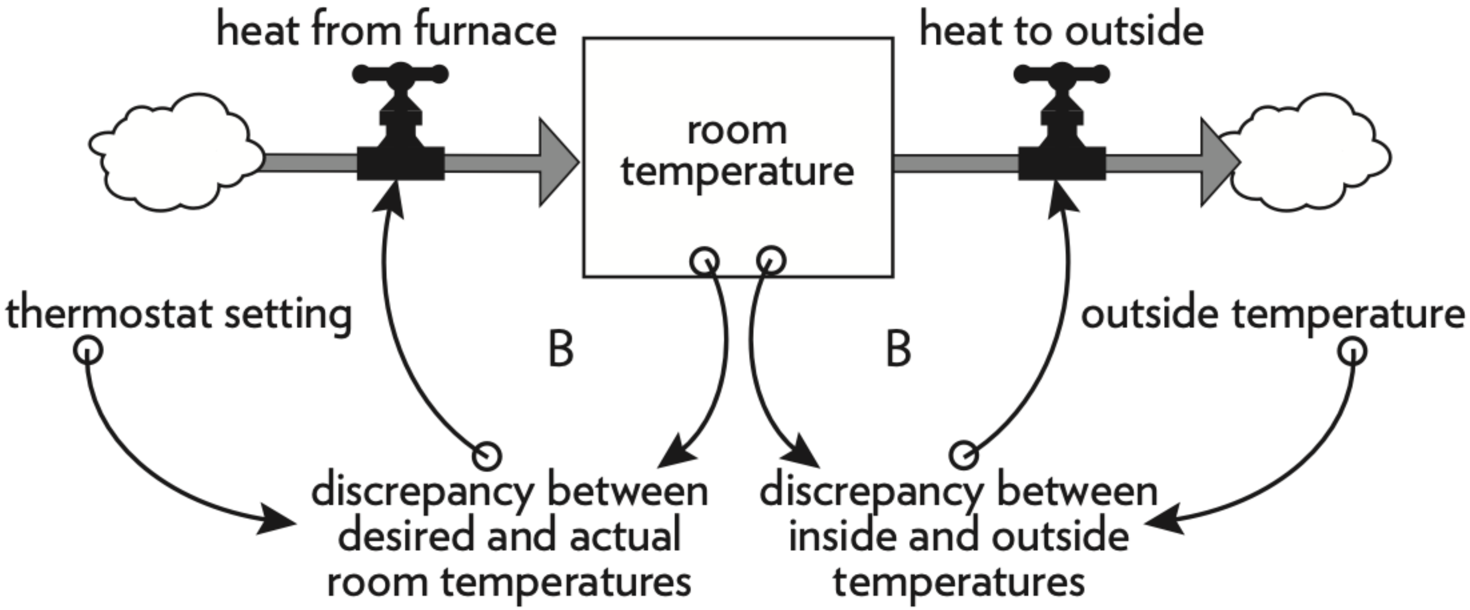




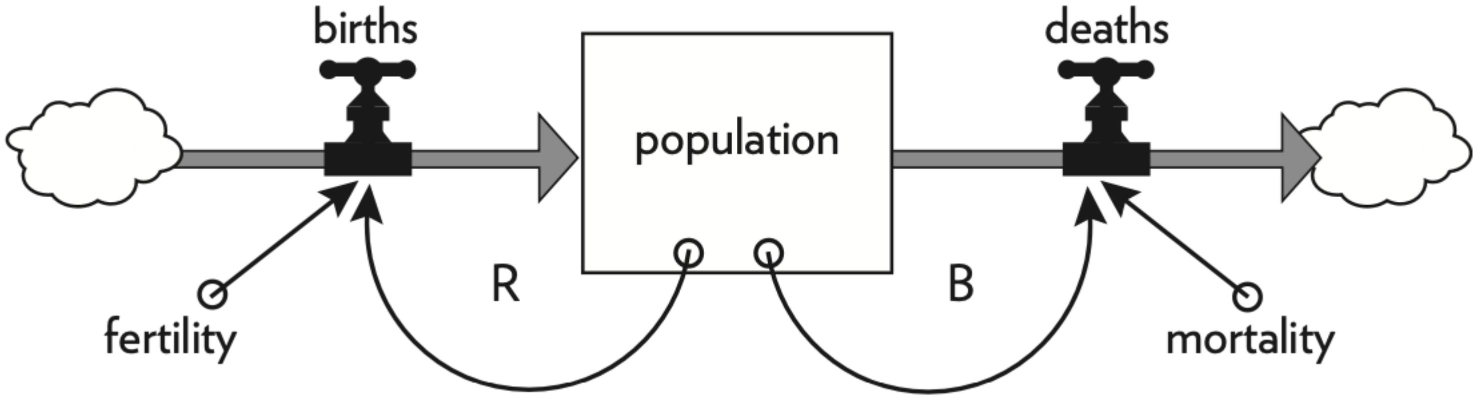
Reinforcing Feedback Loop



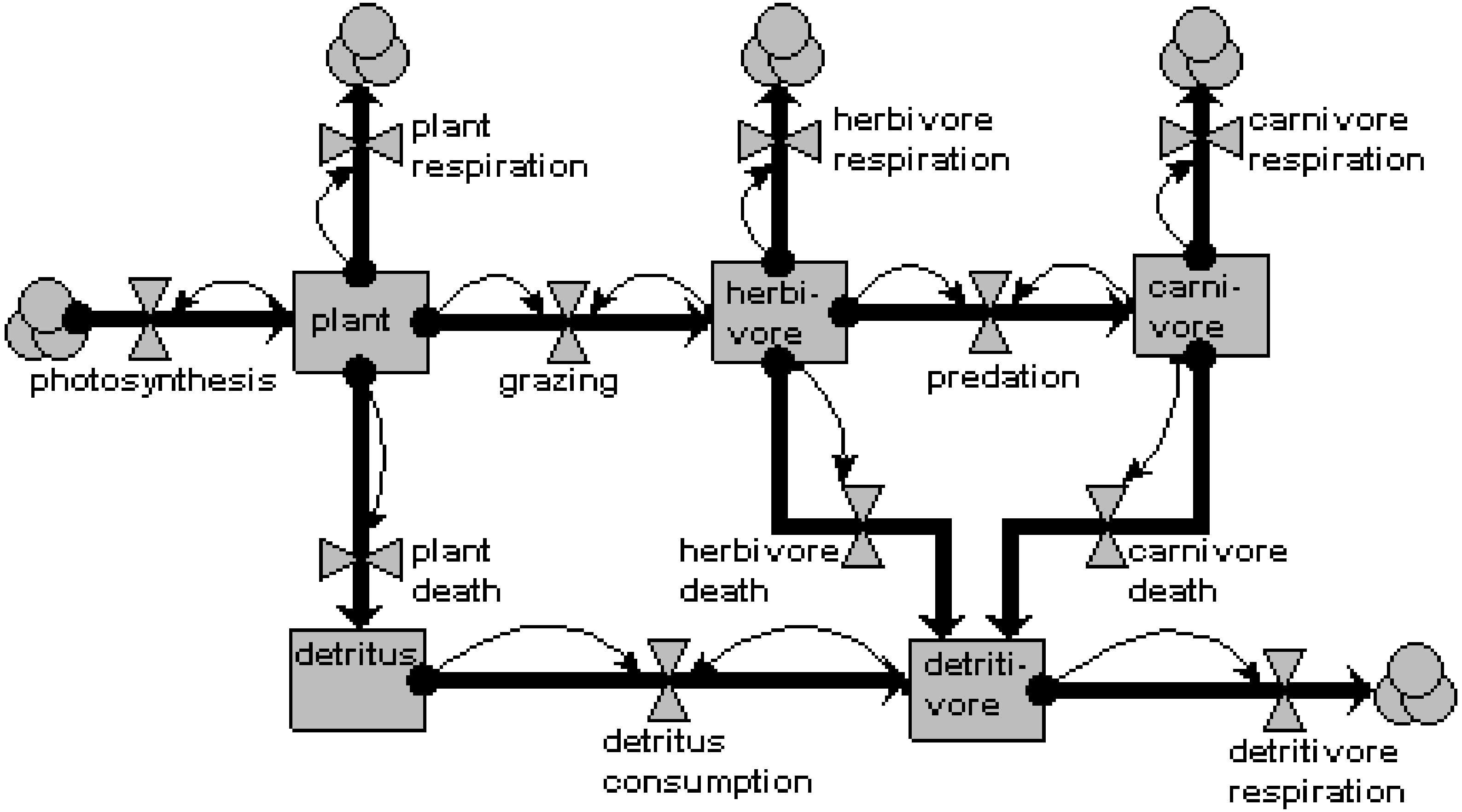
Balancing Feedback Loop



Balancing and Reinforcing



Ecosystem energy flow



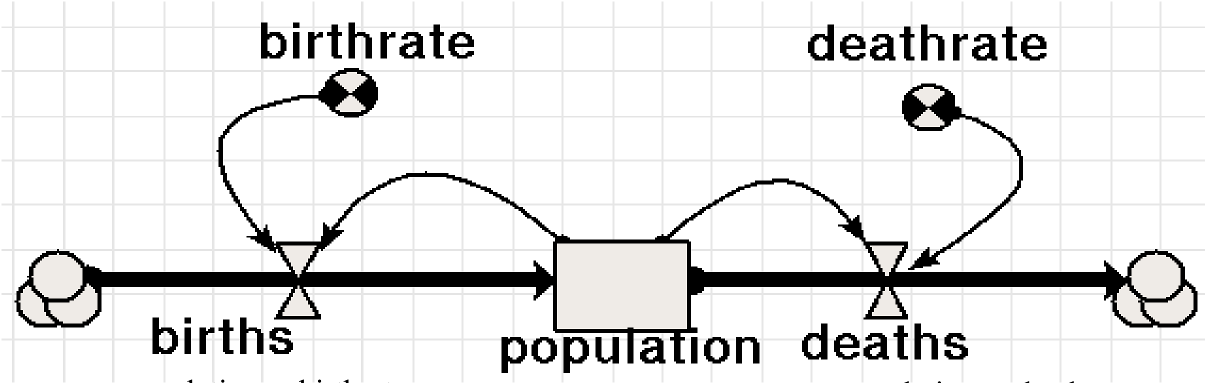
Population Dynamics
simple: statement

- The population is represented by a single state variable (stock), whose dynamics depend on two flows: a reproduction inflow and a mortality outflow. Both occur at a rate proportional to population size.

Population Dynamics *simple*: components

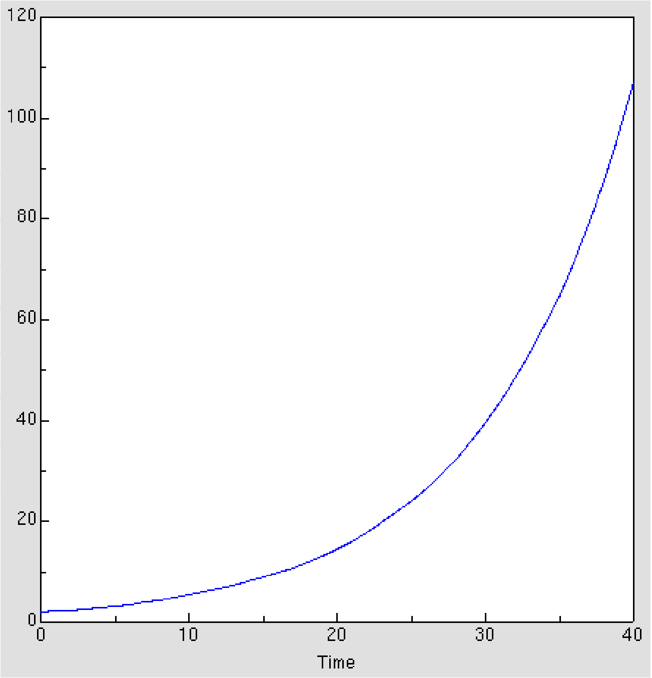
- stock: population
- flows: births, deaths
- parameters: birthrate, deathrate
- Equations (for flows):
  - births = population x birthrate
  - deaths = population x deathrate
- initial conditions:
  - Initial population size
  - birthrate
  - deathrate

Population Dynamics
simple: model



= population x birthrate

= population x deathrate

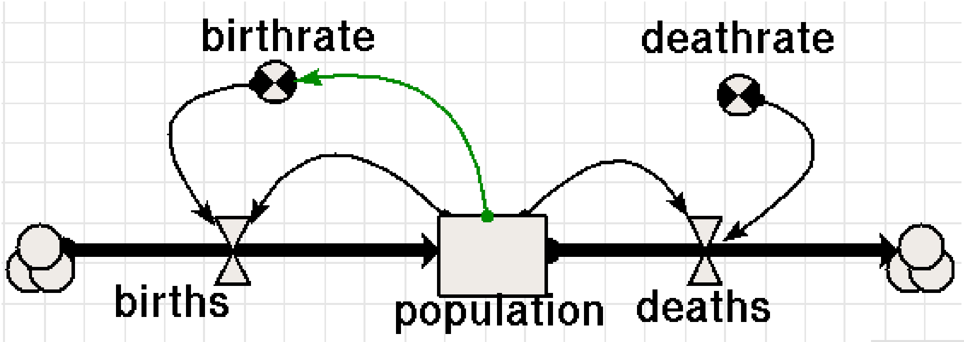


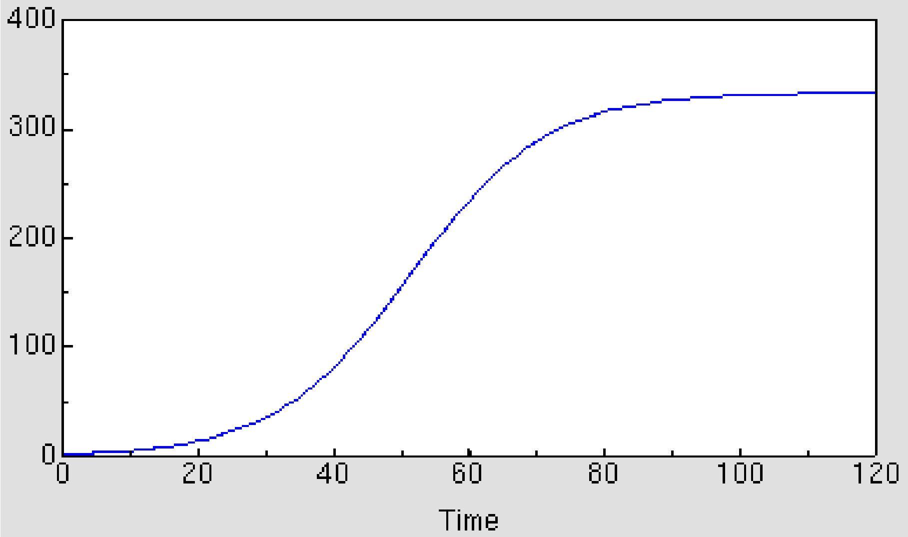
Simple Model in NetLogo

Population Dynamics *declining fertility*: statement

- The simple model is modified by making the reproductive rate per individual depend on population size, decreasing as population increases
- birthrate = 0.3 x (1000 – population)/1000
  - Now a variable!

Population Dynamics
declining fertility: model





Declining Fertility in NetLogo

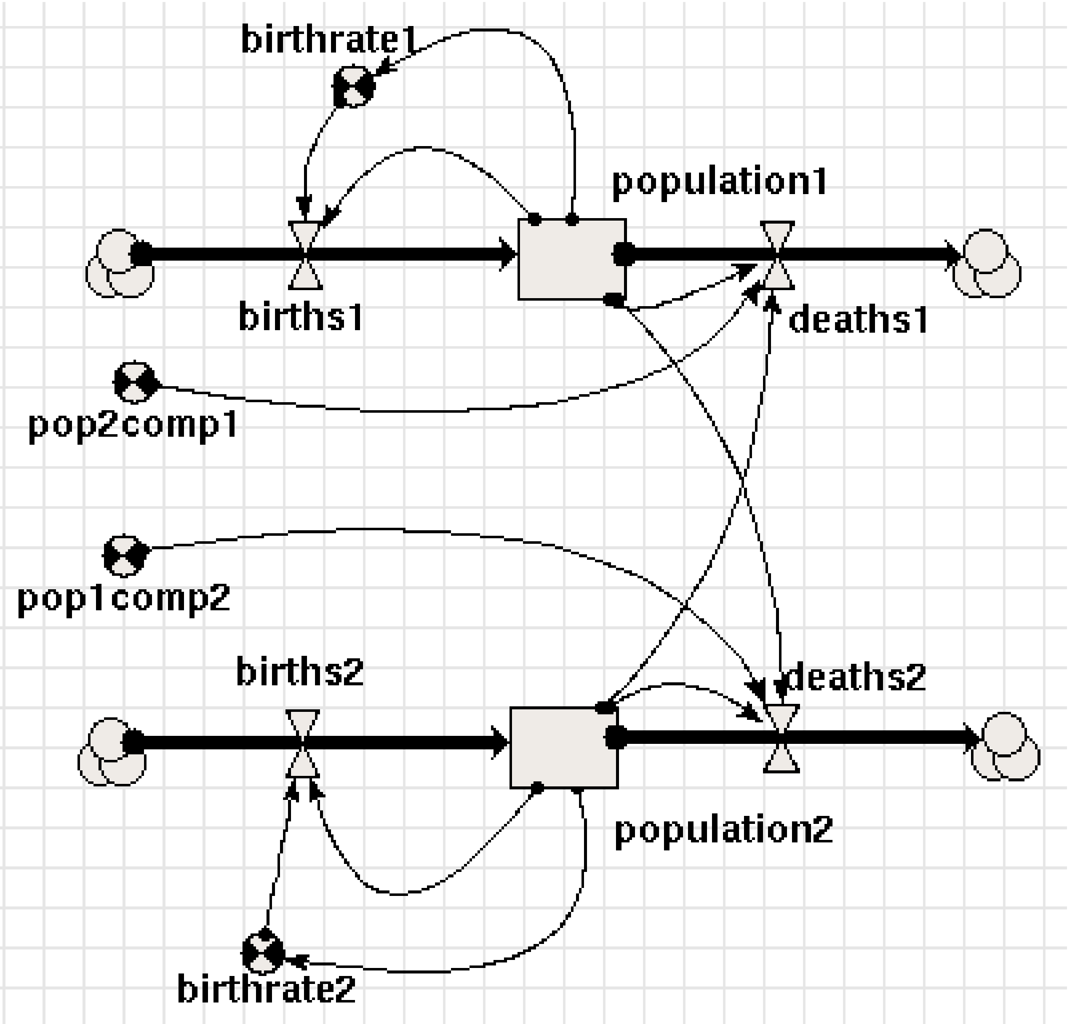
Population Dynamics *competition*: statement

- Two-species competition. Each population's growth rate is reduced as its population gets bigger (the *declining-fertility* model). When a competitor is present, then the growth of each population is further reduced by the other. The outcome depends on the relative strength of within- and between-species factors.

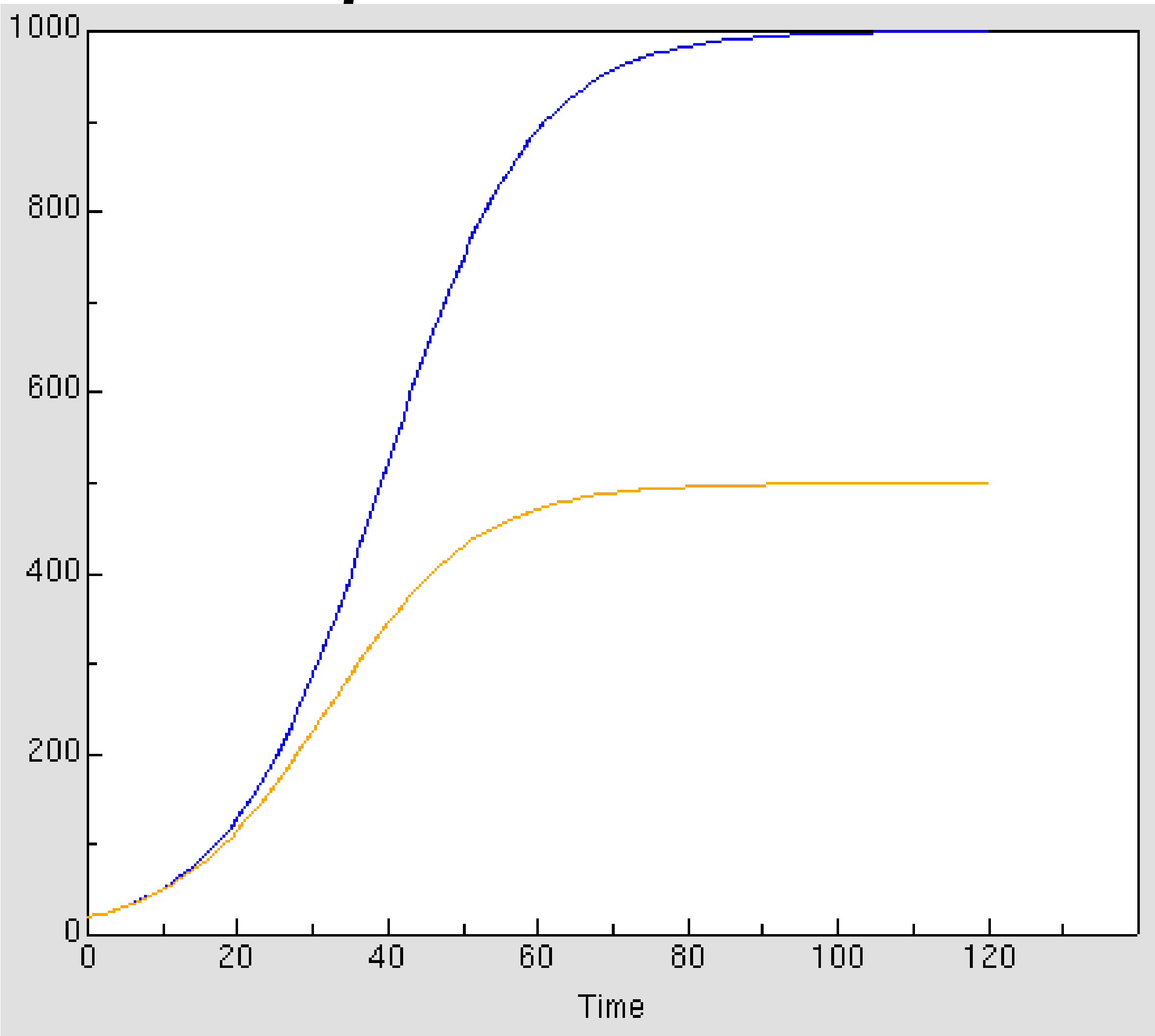
Population Dynamics *competition*: components

- Stocks: population1, population2
- Flows
  - each population as for *declining-fertility*
- Parameters
  - Additional parameters to reflect the increase in deaths due to the other species

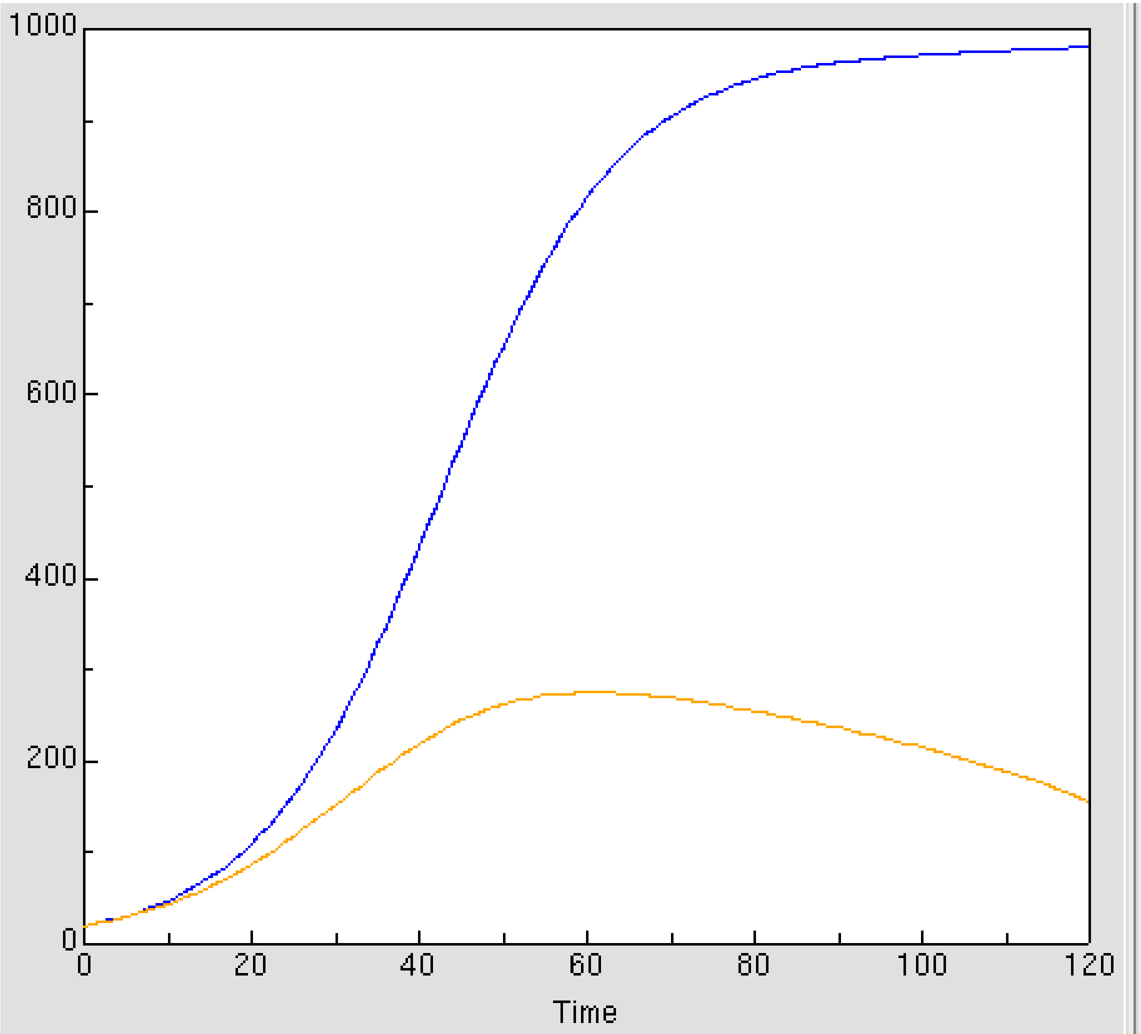
Population Dynamics *competition*: model



Population Dynamics
competition: none



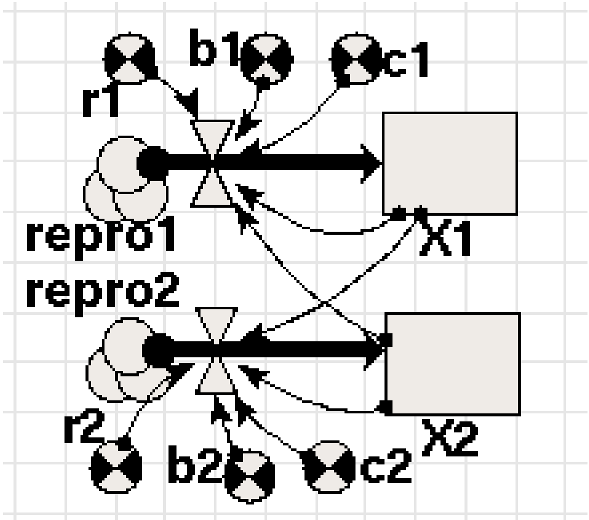
Population Dynamics
competition: suppression



Mathematical Formulation
competition: statement and model

$dX_1/dt = r_1.X_1.(1\text{-}b_1.X_1\text{-}c_1.X_2)$
$dX_2/dt = r_2.X_2.(1\text{-}b_2.X_2\text{-}c_2.X_1)$

X_1,X_2 are the populations sizes of the two species;
r_1,r_2 are the intrinsic rate sof increase of the two species;
b_1,b_2 are the self-inhibition coefficients for the two species;
c_1,c_2 are the competitor's inhibition coefficient for each species.



Lotka-Volterra equations

Competition in NetLogo

Predator-Prey Model

- Based on Simple Model
- Stocks: sheep, wolves
- Flows
  - Sheep births proportional to sheep population (birth-rate), deaths from wolves (predation-rate)
  - Wolf births proportional to fraction of sheep eaten (predator-efficiency), deaths by death-rate
- Parameters
  - Sheep birth rate, wolf death rate, predator-efficiency, predation-rate

When to use System Dynamics

- Group (as opposed to individual) behaviour is known
- Exploration of the influence of parts of the system on each other is a focus
- Often used for modelling:
  - Organisations and social structures
  - Ecosystems
  - Increasingly for economics

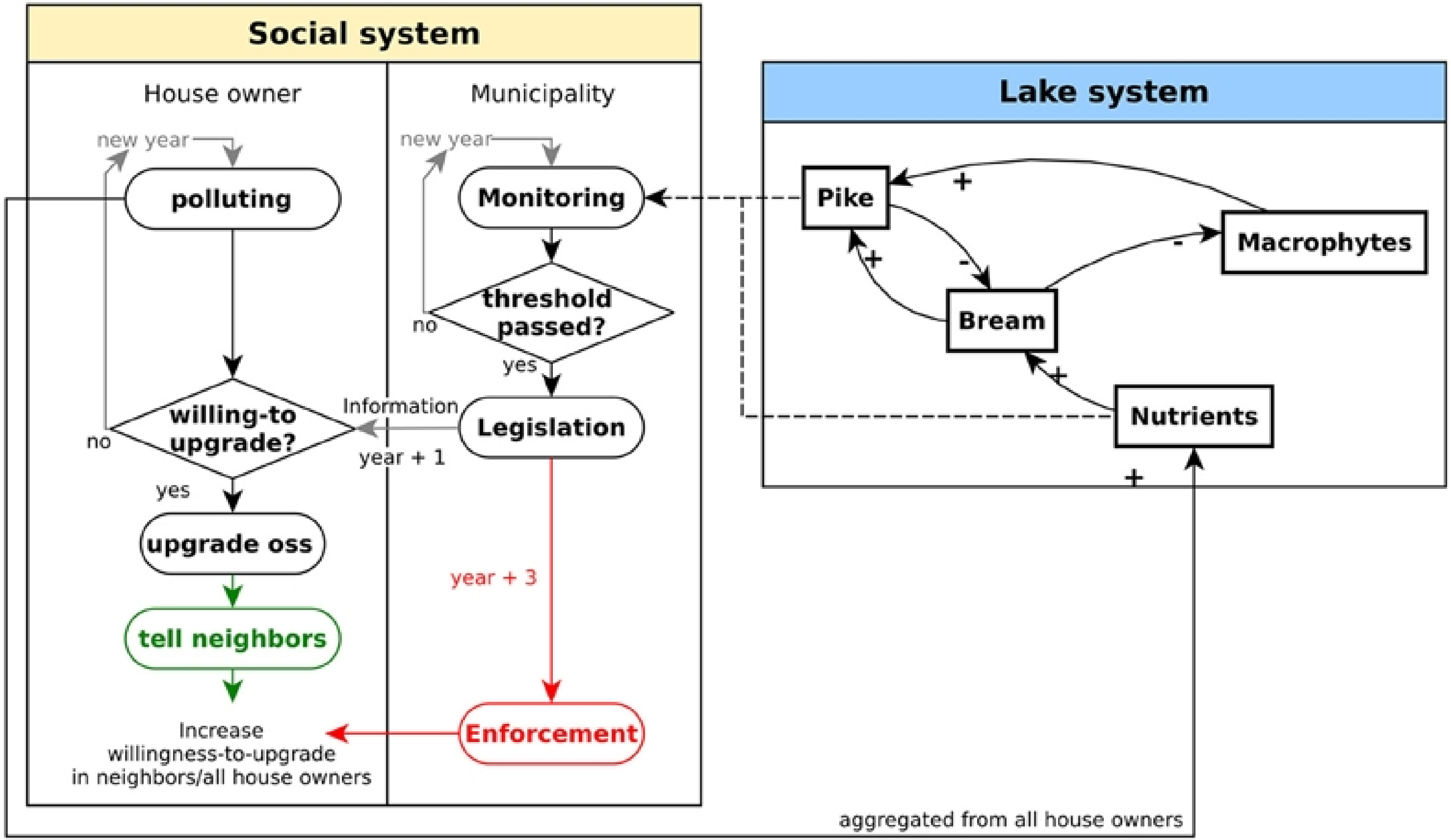
ODDs for System Dynamics Models

- Many features the same as for Agent Based (or any modelling framework)
- Entities: Stocks and Flows
- Variables: Auxiliaries
- Scheduling is only about discussion of the timestep used
- Should include an influence diagram labelling loops

Hybrid Agent-Based & System Dynamics Models

- Netlogo Predator-Prey comparison
- Socio-environmental systems (SES)

LIMNOSES hybrid AB+SD model



Limits to Growth World3

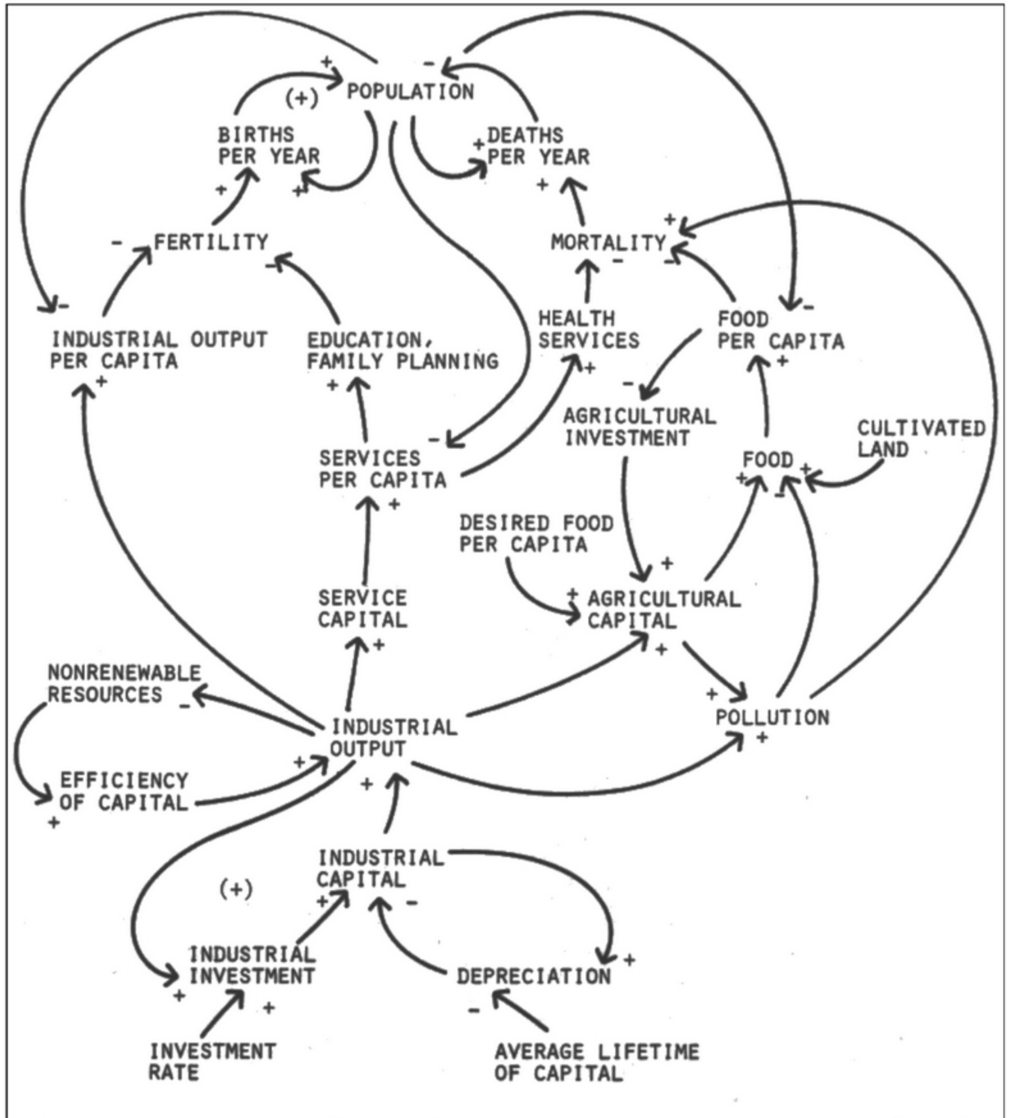


Figure 1-3 Causal-loop diagram of several important feedback loops in World3