G54SIM

Lecture 3

Simulation Methods: System Dynamics Simulation

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1. Systems Thinking

- We are quick problem solvers. We quickly determine a cause for any event that we think is a problem. Usually we conclude that the cause is another event.
  - Example: Sales are poor (event) because staff are insufficient motivated (cause); staff are insufficient motivated (event) because ...

- Difficulty: You can always find yet another event that caused the one that you thought was the cause. This makes it very difficult to determine what to do to improve performance.

Systems Thinking

- Idea of Systems Thinking:
  - Move away from looking at isolated events and their causes
  - Look at the organisation as a system made up of interacting parts
  - Internal structure of the system is often more important than external events in generating the problem

- If we shift from the event orientation to focussing on the internal system structure we improve our possibility of improving system performance as the system structure is often the underlying source of the difficulty.

2. System Dynamics

- Definition: System Dynamics (SD) is a methodology and computer simulation modelling technique for framing, understanding, and discussing complex issues and problems.
- The basis of the methodology is the recognition that the structure of any system is just as important in determining its behaviour as the individual components themselves.
- It is mostly used in long-term, strategic models and assumes high level of aggregation of the objects being modelled.
- The range of applications includes business, urban, social, ecological types of systems.

System Dynamics

- Norbert Wiener (1940s) studied how biological, engineering, social, and economic systems are controlled and regulated ➔ Cybernetics
- Jay Forrester (1950s) applied the principles of Cybernetics to industrial systems ➔ Industrial Dynamics
- John Collins (1970s) and John Sterman (1980s) applied the principles of Industrial Dynamics to urban, business, social, and ecological types of systems ➔ System Dynamics

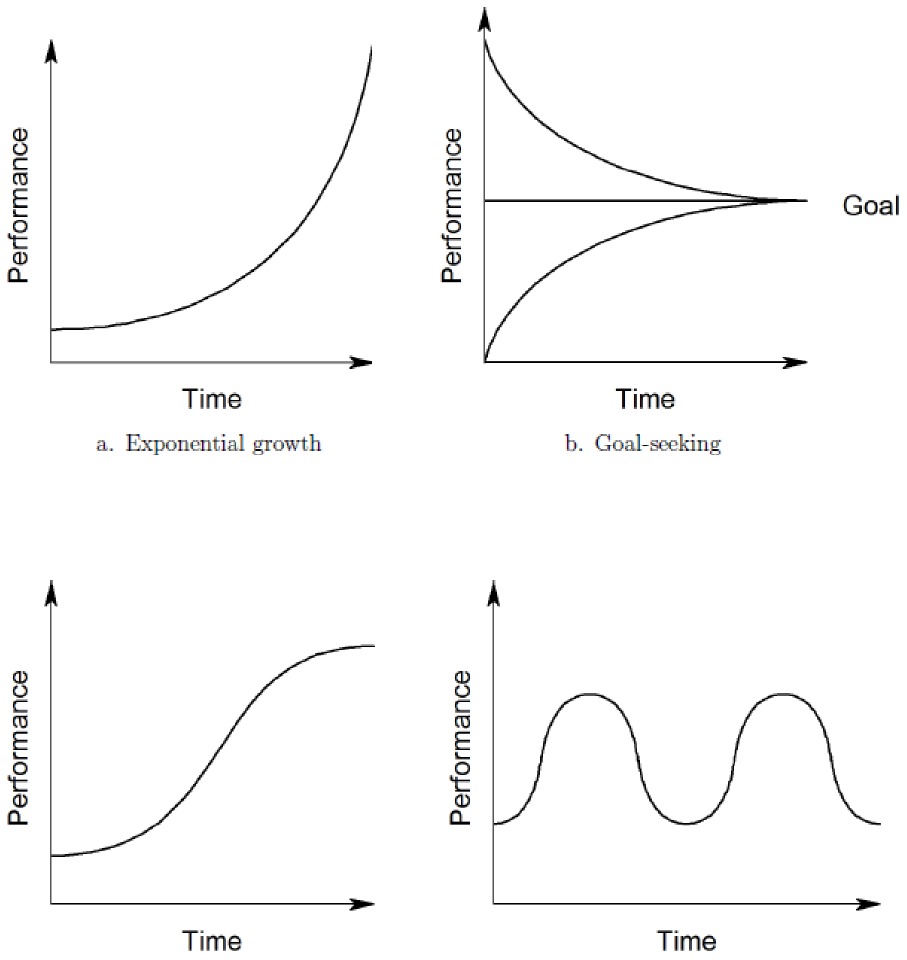
Jay Forrester

3. Patterns of Behaviour

- Generalise from the specific events to consider patterns of behaviour that characterise the situation
- Once we have identified a pattern of behaviour that is a problem, we can look for the system structure that is known to cause this pattern
- By finding and modifying this system structure you have the possibility to permanently eliminate the problem pattern of behaviour.

Patterns of Behaviour

- Common patterns that show up either individually or combined



a. Exponential growth

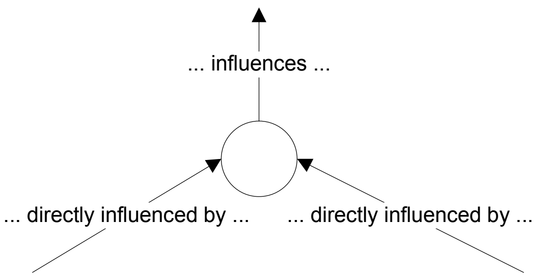
b. Goal-seeking

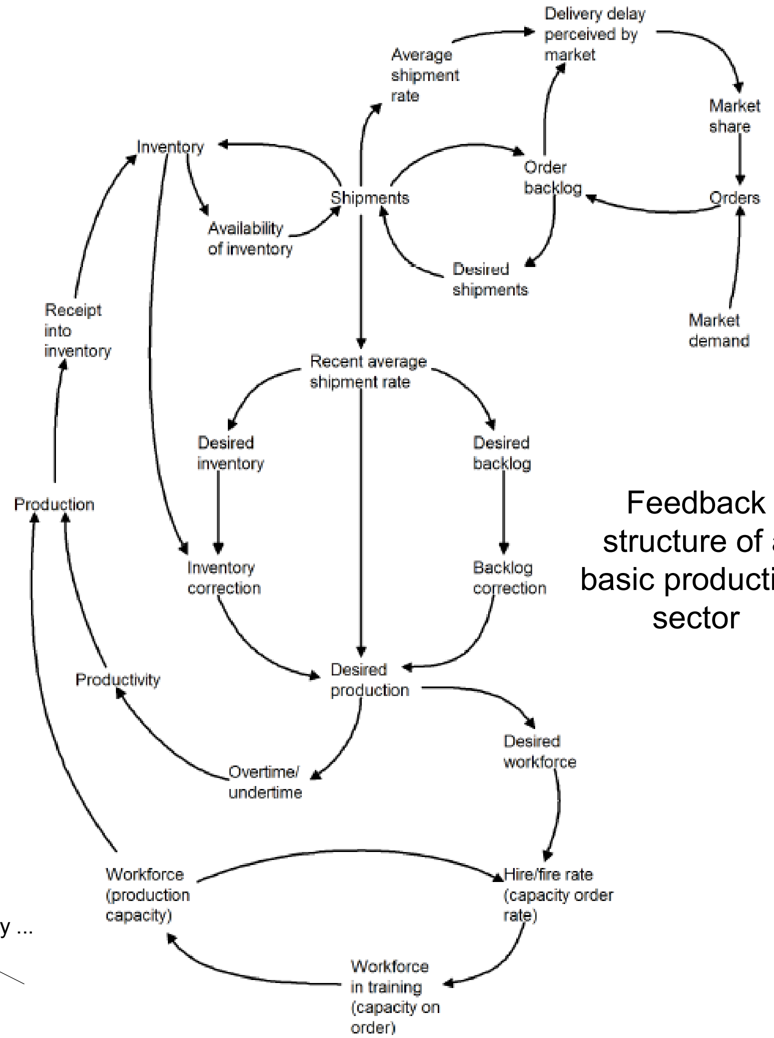
c. S-shaped

d. Oscillation

4. Feedback and Causal Loop Diagrams

- Notation for presenting system structures
  - Short descriptive phrases represent the elements which make up the sector.
  - Arrows represent causal influences between these elements

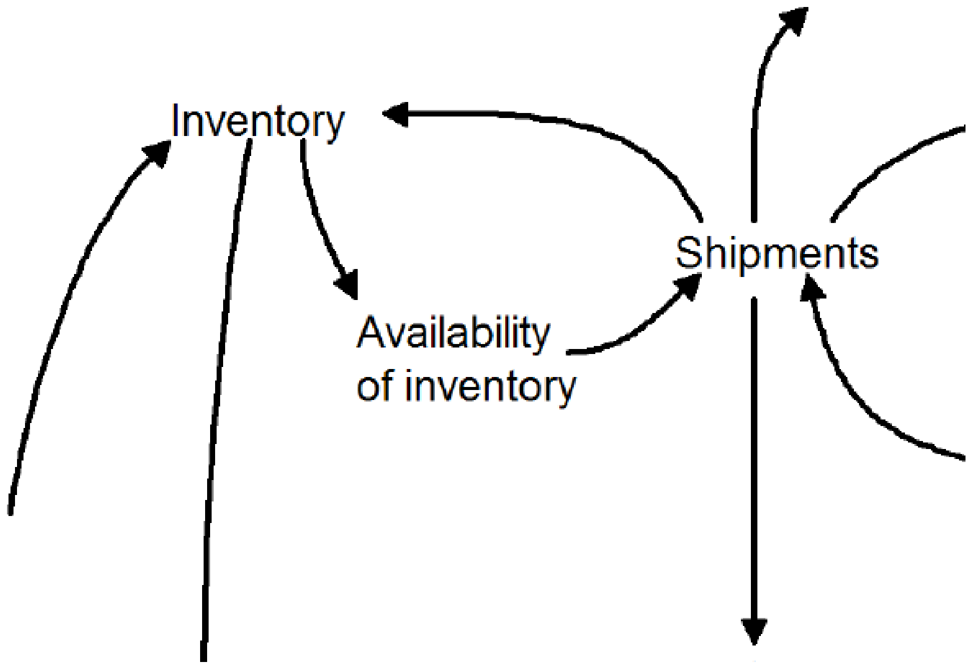




Feedback structure of a basic production sector

Feedback and Causal Loop Diagrams

- Feedback loop or causal loop: Element of a system indirectly influences itself



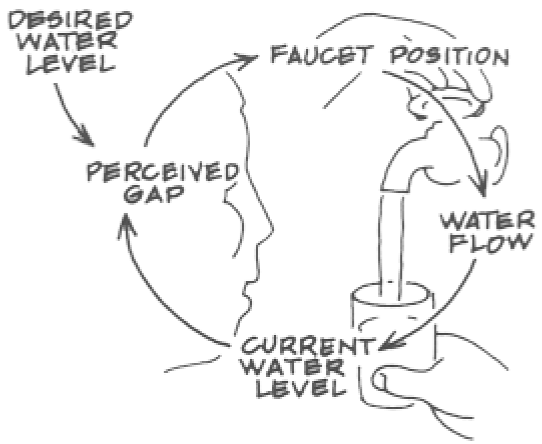
Feedback and Causal Loop Diagrams

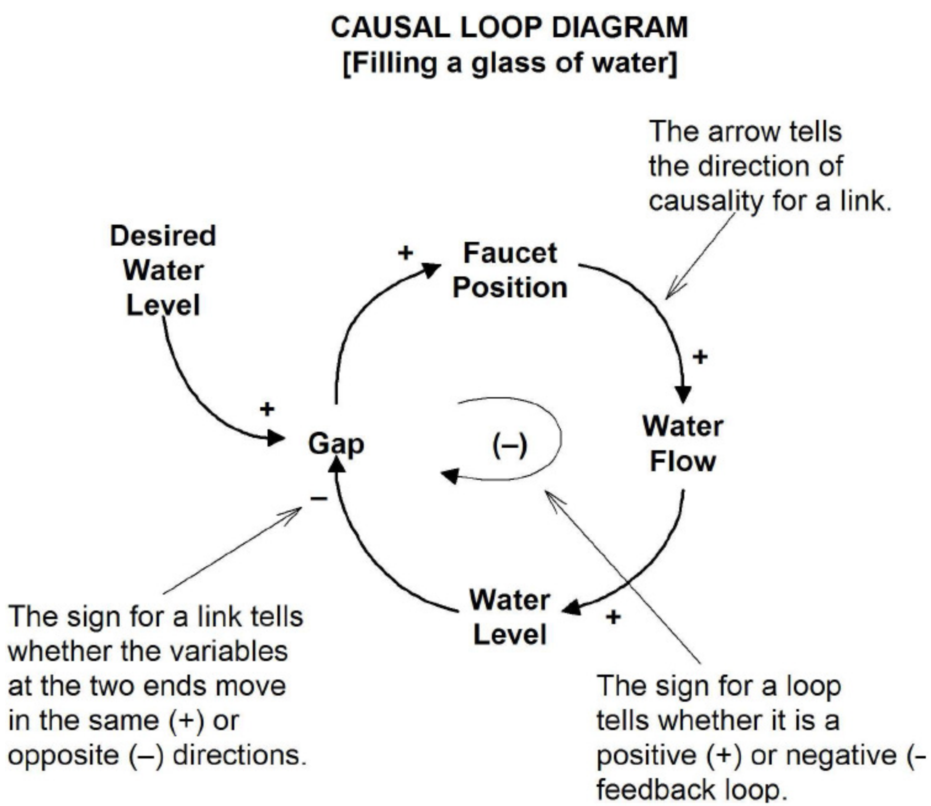
- Causal link
  - Causal link from element A to B is positive (+ or s) if either A adds to B or a change in A produces a change in B in the same direction
  - Causal link from element A to B is negative (- or o) if either A subtracts from B or a change in A produces a change in B in the opposite direction

- Feedback loop
  - A feedback loop is positive (+ or R) if it contains an even number of negative causal links
  - A feedback loop is negative (- or B) if it contains an uneven number of negative causal links

s=same; o=opposite; R=reinforcing; B=balancing

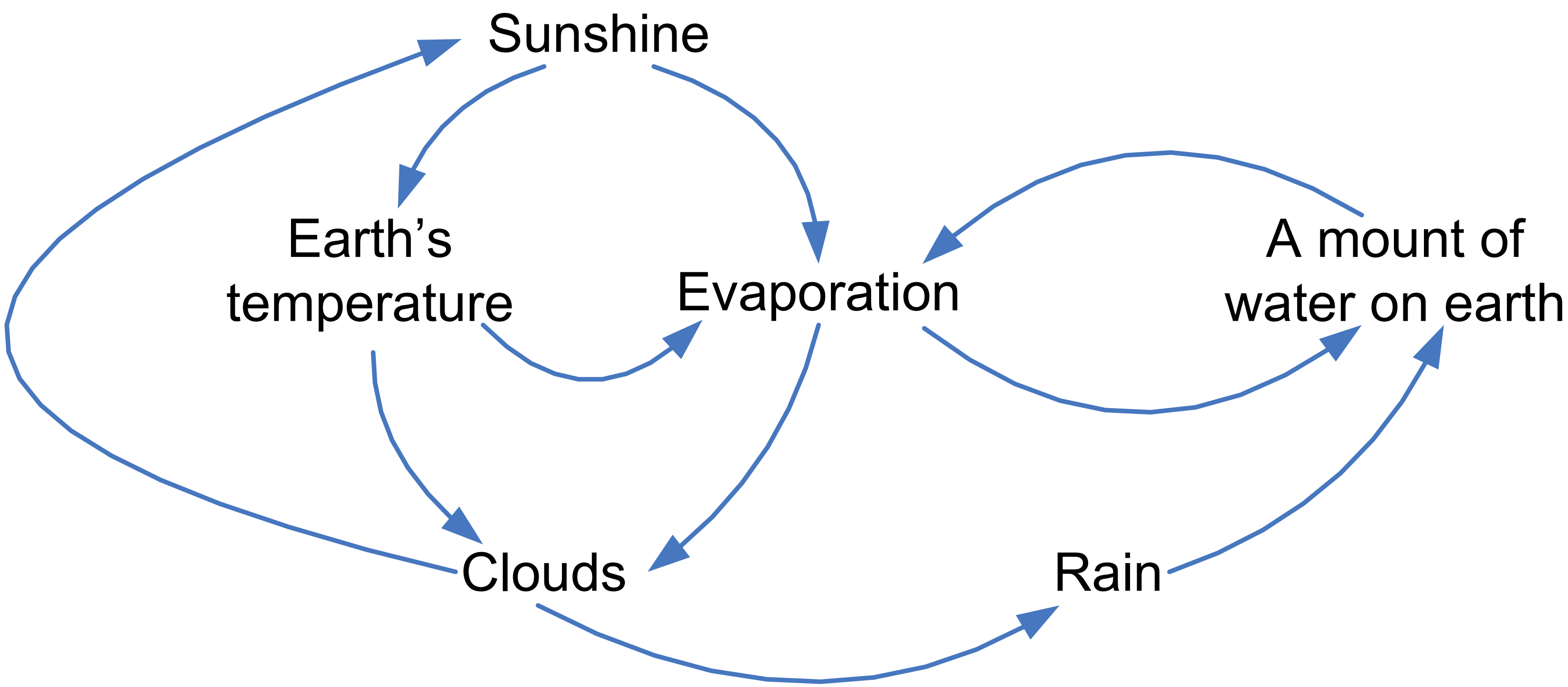
Feedback and Causal Loop Diagrams





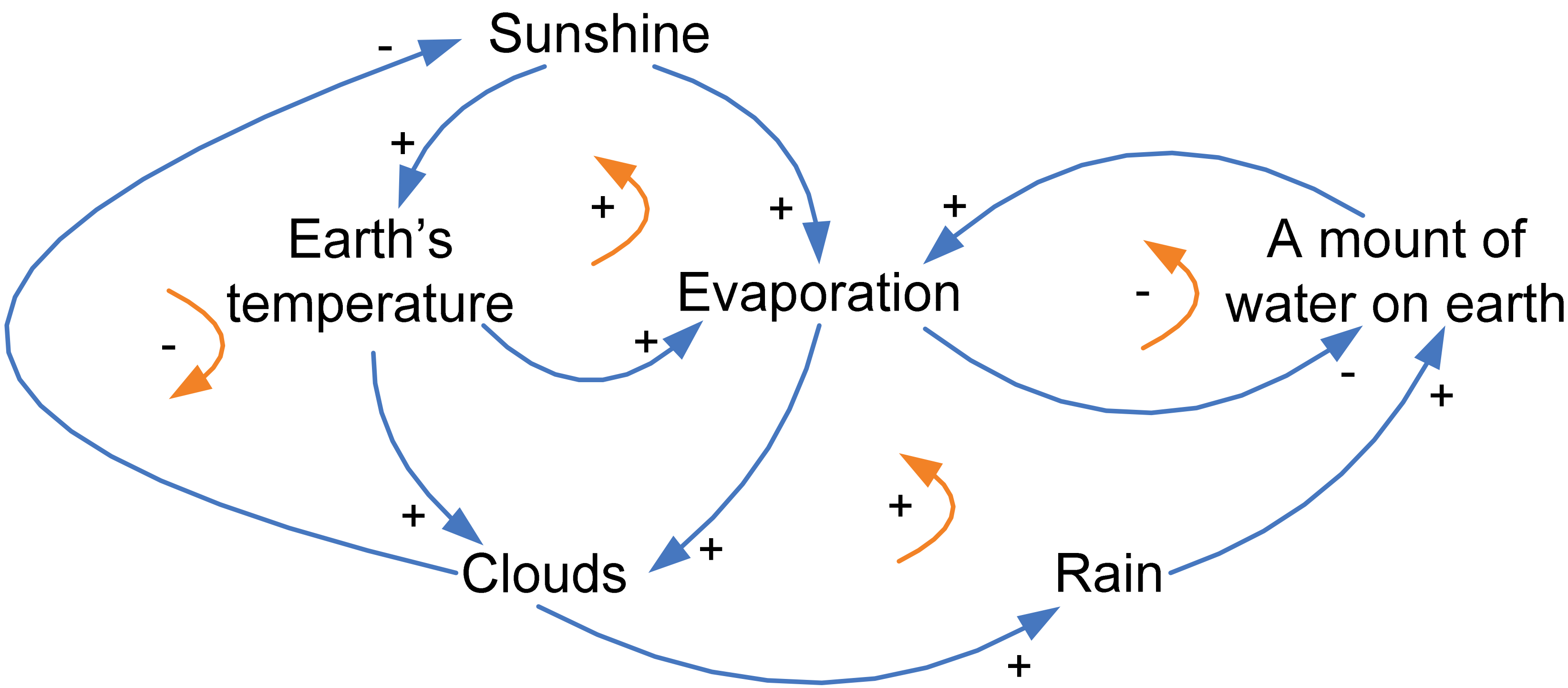
Feedback and Causal Loop Diagrams

- Self regulating biosphere



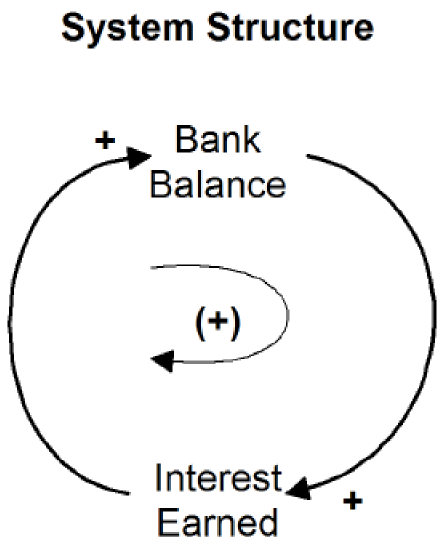
Feedback and Causal Loop Diagrams

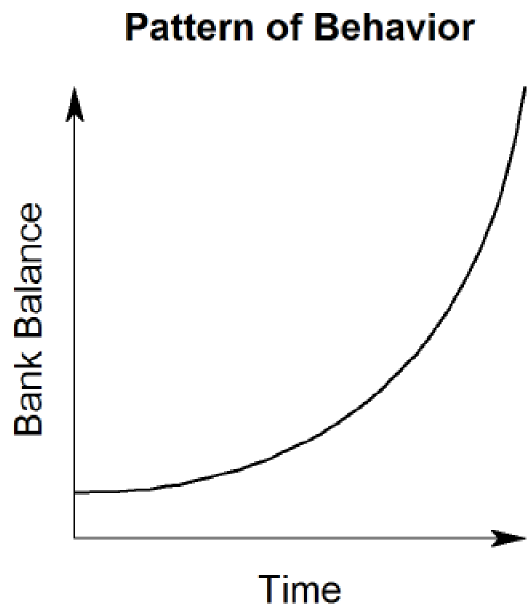
- Self regulating biosphere



5. System Structures and Patterns of Behaviour

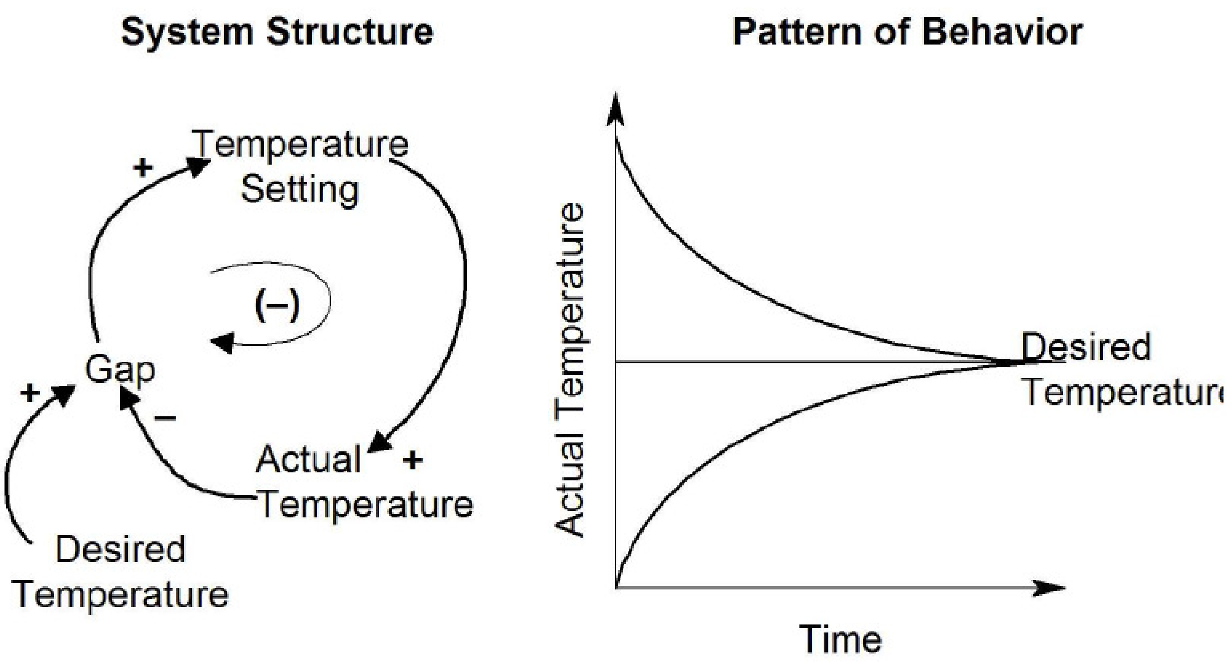
- Positive (reinforcing) feedback loop





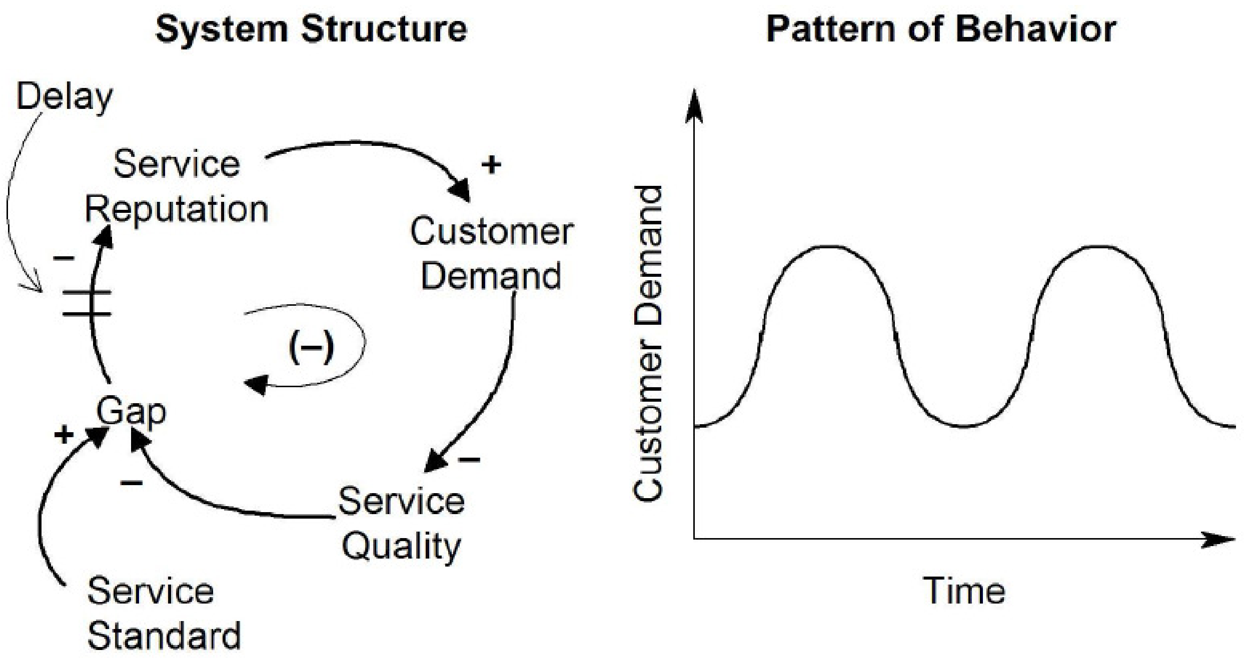
System Structures and Patterns of Behaviour

- Negative (balancing) feedback loop



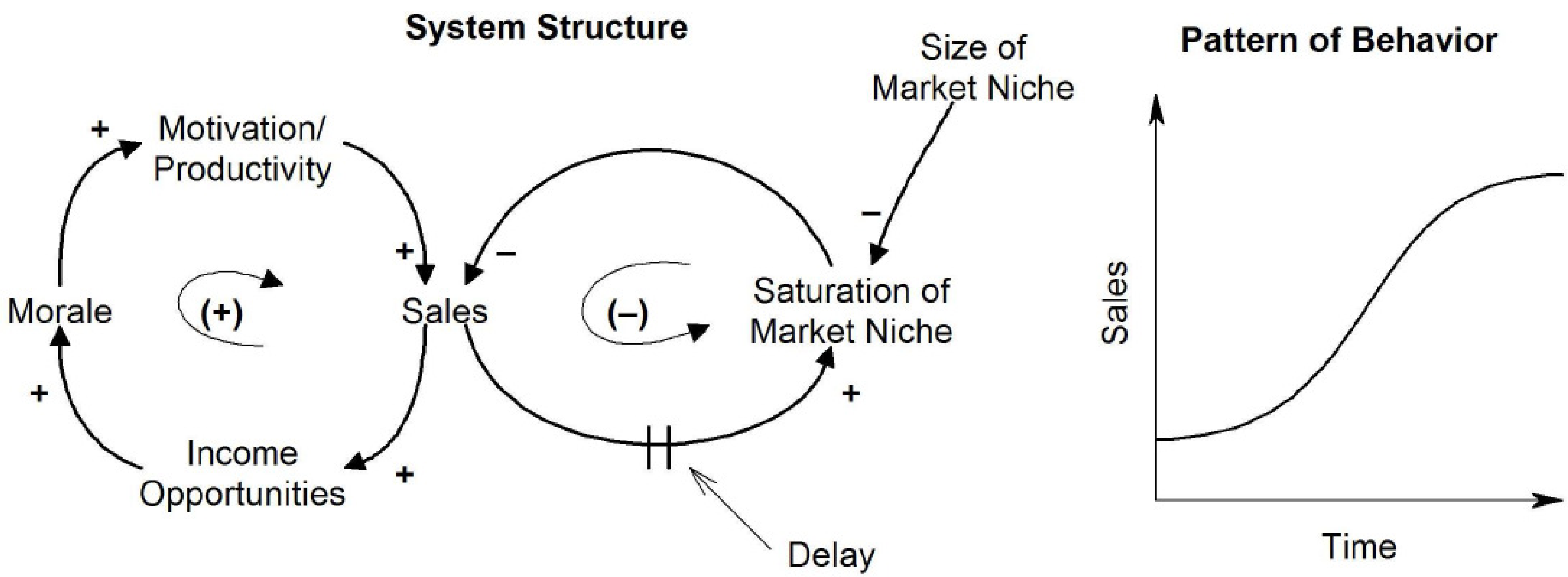
System Structures and Patterns of Behaviour

- Negative feedback loop with delay



System Structures and Patterns of Behaviour

- Combination of positive and negative loop

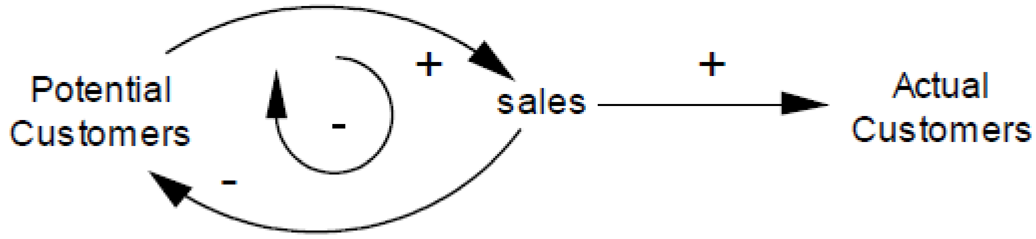


Break

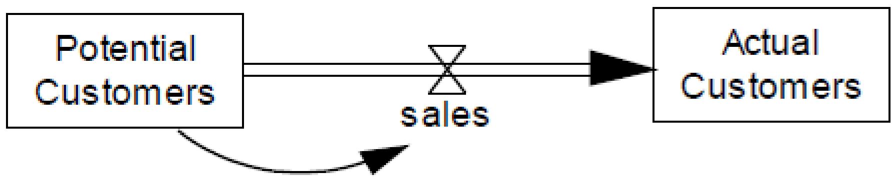
- See you back in 10 minutes ...

6. Stock and Flow Diagrams

- Example: Advertising for a durable good



a. Causal loop diagram



b. Stock and flow diagram

Stock and Flow Diagrams

- Stock and flow diagram:
  - Shows relationships among variables which have the potential to change over time (like causal loop diagrams)
  - Distinguishes between different types of variables (unlike causal loop diagrams)

- Basic notation:
  - Stock (level, accumulation, or state variable) {Symbol: Box}
    - Accumulation of "something" over time
    - Value of stock changes by accumulating or integrating flows
    - Physical entities which can accumulate and move around (e.g. materials, personnel, capital equipment, orders, stocks of money)

Stock and Flow Diagrams

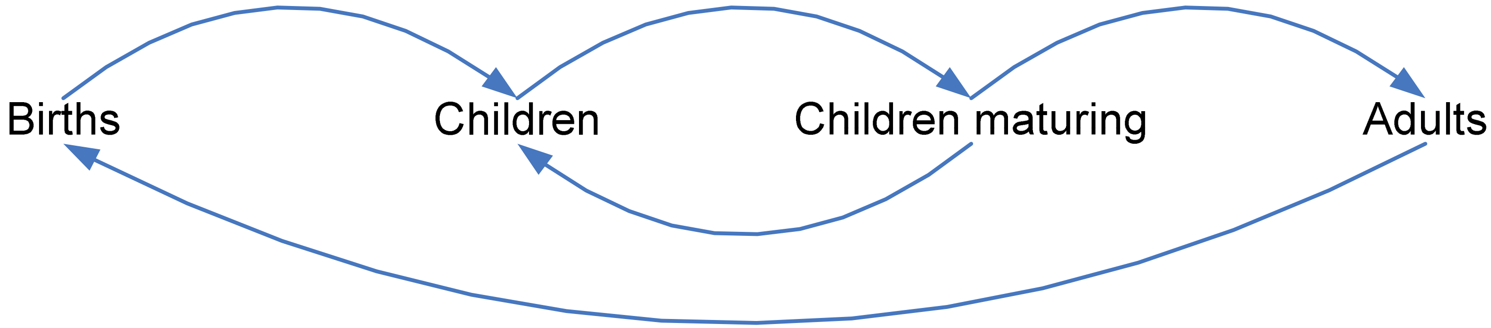
- Basic notation (cont.)
  - Flow (rate, activity, movement) {Symbol: valve}
    - Flow or movement of the "something" from one stock to another
    - The value of a flow is dependent on the stocks in a system along with exogenous influences
  - Information {Symbol: curved arrow}
    - Between a stock and a flow: Indicates that information about a stock influences a flow

Stock and Flow Diagrams

- Additional notation (e.g. VenSim)
  - Auxiliary {Symbol: Circle}
    - Arise when the formulation of a stock's influence on a flow involves one or more intermediate calculations
    - Often useful in formulating complex flow equations
  - Source and Sink {Symbol: Cloud}
    - Source represents systems of stocks and flows outside the boundary of the model
    - Sink is where flows terminate outside the system

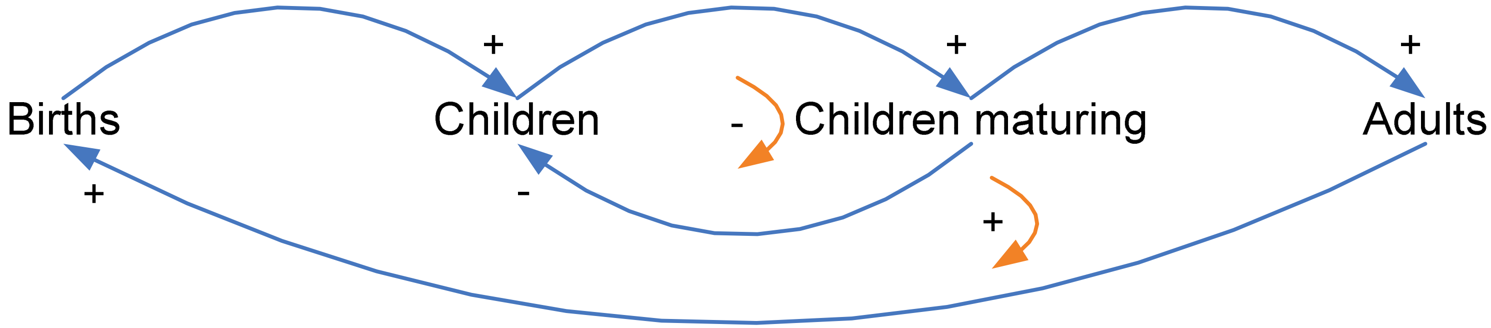
Stock and Flow Diagrams

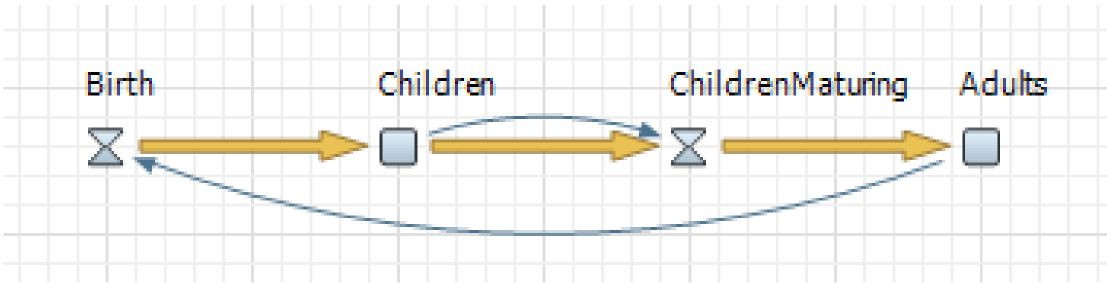
- Growth of population through birth



Stock and Flow Diagrams

- Growth of population through birth





7. System Dynamics Simulation

- Can a stock and flow diagram help you to answer the following question: How will the number of potential customers vary with time? No!
- We need to consider the quantitative features of the process
  - Initial number of potential and actual customers
  - Specific way in which sales flow depends on potential customers
- Simplifying assumptions for SD simulation modelling:
  - Aggregate approach is sufficient
  - Flows within processes are continuous
  - Flows do not have a random component

System Dynamics Simulation

- Analogy: Plumbing system
  - Stocks are tanks full of liquid
  - Flows are pumps that control the flow between the tanks

- To completely specify the process model
  - Initial value of each stock
  - Equation for each flow

System Dynamics Simulation

- Number of potential customers at any time t

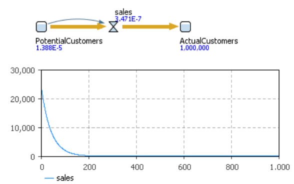
$$\text{Potential Customers}(t) = 1{,}000{,}000 - \int_0^t \text{sales}(\tau)\, d\tau.$$

- Number of actual customers at any time t

$$\text{Actual Customers} = \int_0^t \text{sales}(\tau)\, d\tau.$$

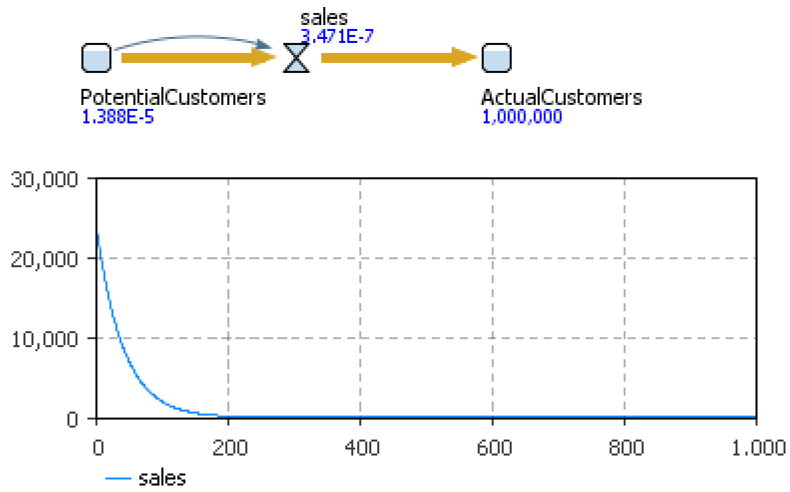
- Many possible flow equations! It is up to the modeller to choose a realistic one

$$\text{sales}(t) = 0.025 \times \text{Potential Customers}(t)\text{rs}(t) > 0$$
$$\{\, 0, \qquad \text{otherwise}$$

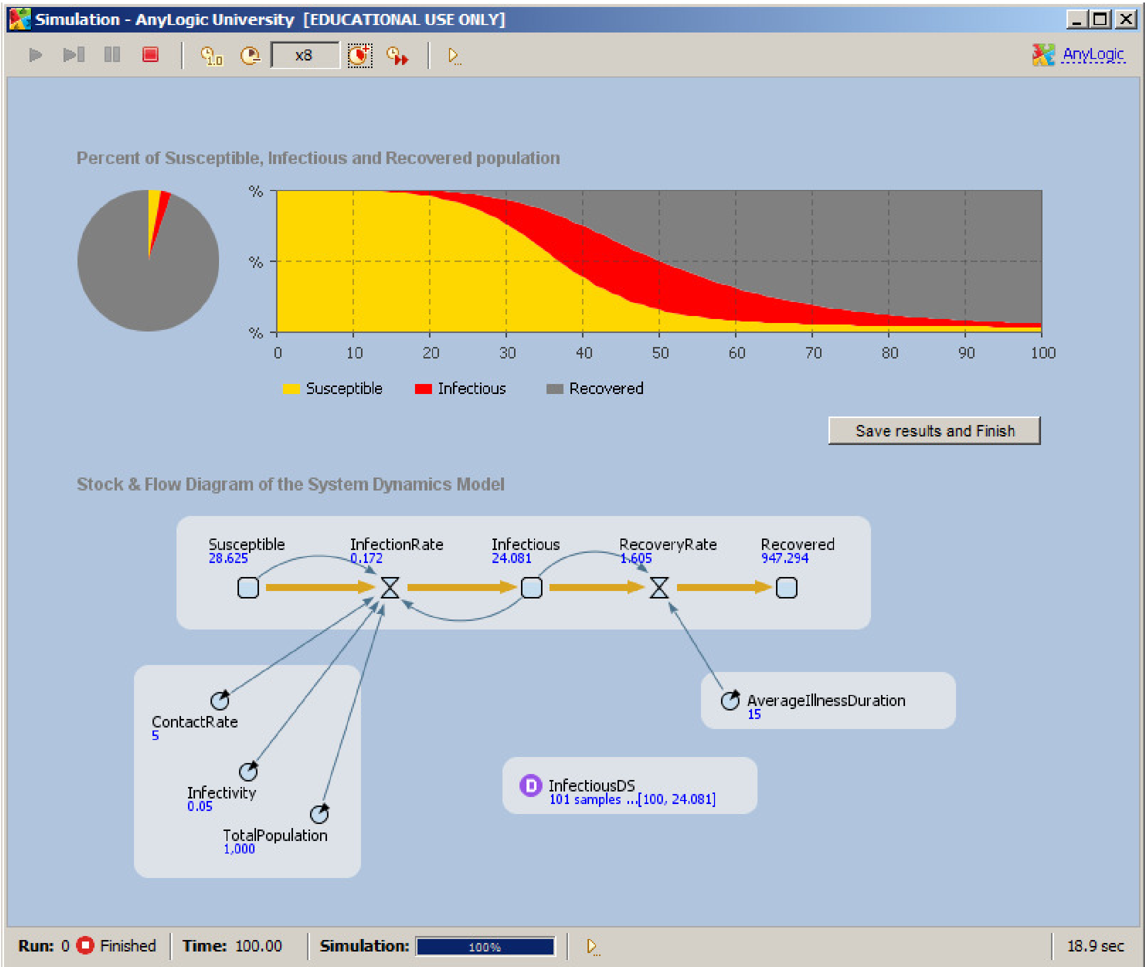


System Dynamics Simulation

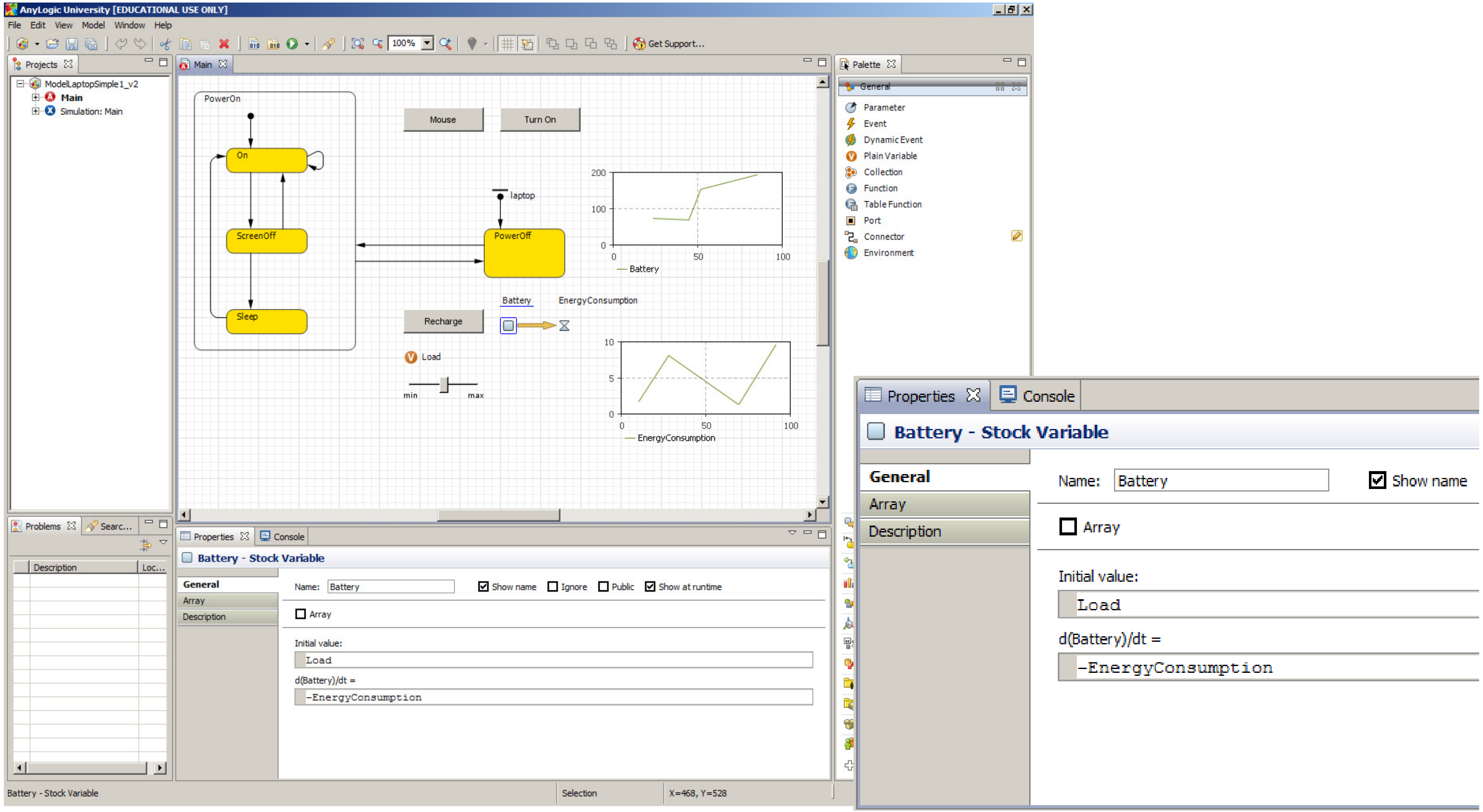
- Simulation output



System Dynamics Simulation



8. Multi-Method Simulation



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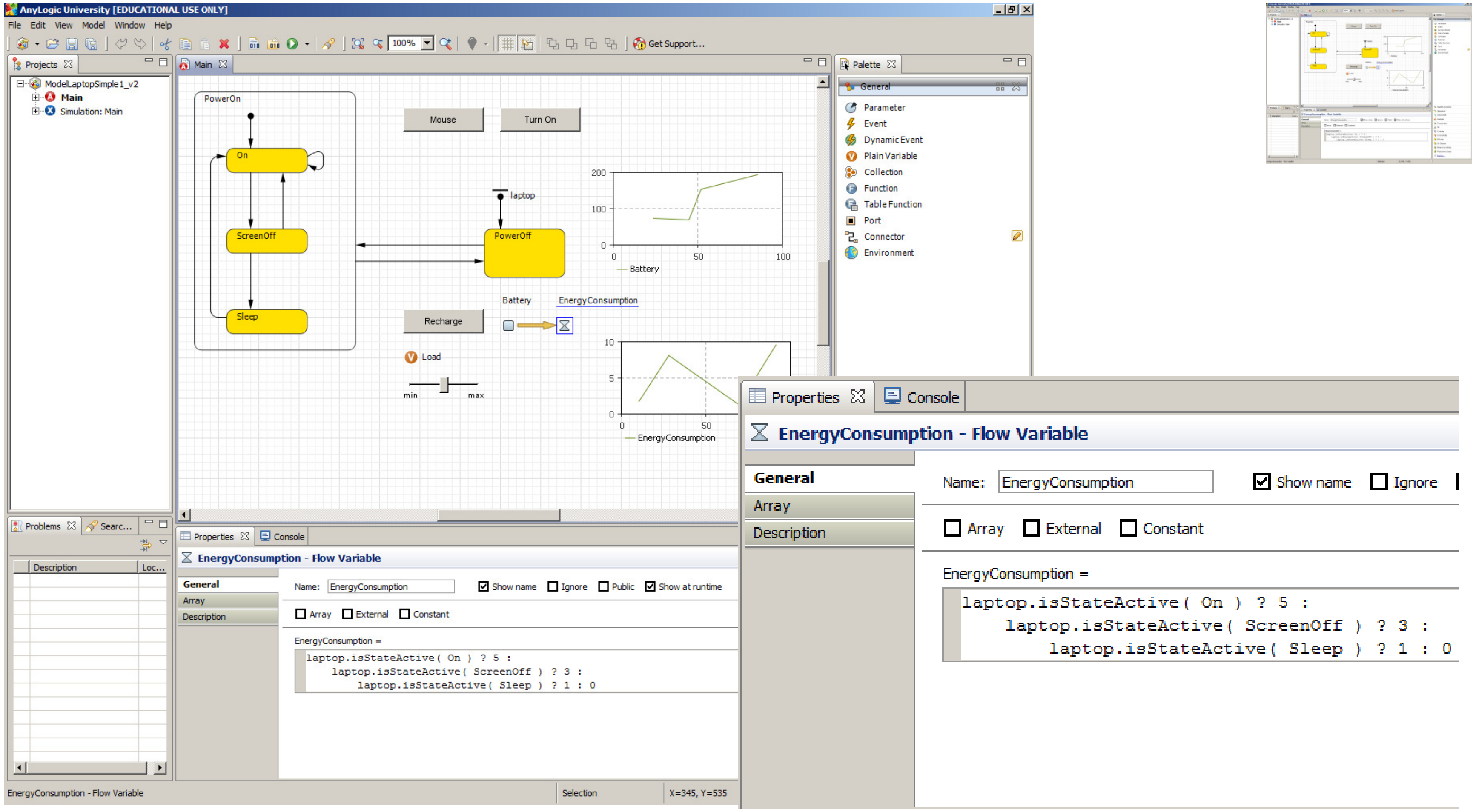
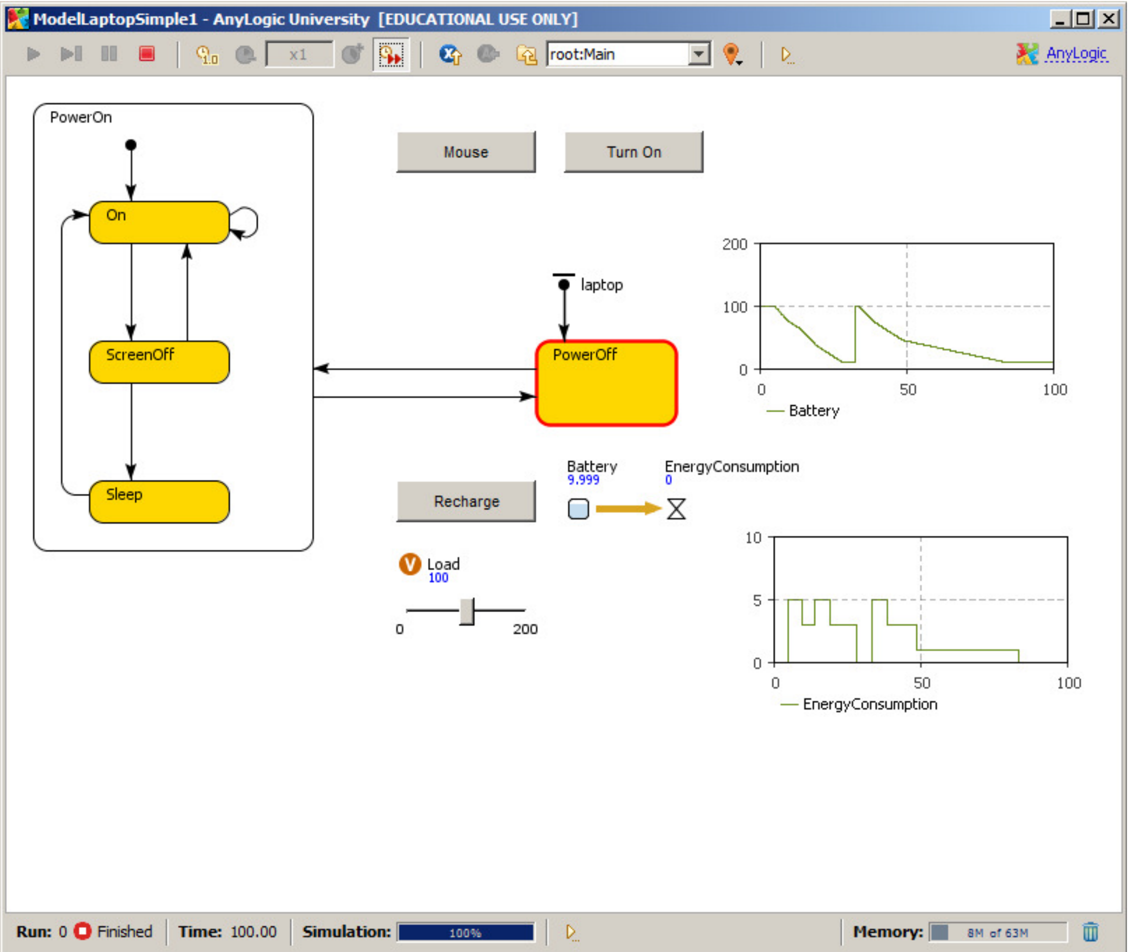
Multi-Method Simulation



Multi-Method Simulation



9. Summary: How to build SD simulation models

- Conceptualisation
  - Define the purpose of the model
  - Define the model boundaries and identify key variables
  - Describe the behaviour of the key variables
  - Diagram the basic mechanisms (feedback loops) of the system
- Formulation
  - Convert diagrams to stock and flow equations
  - Estimate and select parameter values
  - Create the simulation model

Summary: How to build SD simulation models

- Testing
  - Test the dynamic hypothesis (the potential explanation of how structure is causing observed behaviour)
  - Test model behaviour and sensitivity to perturbations
- Implementation
  - Test model's responses to different policies
  - Translate study insight to an accessible form

Further Reading & Acknowledgement

- Further reading:
  - Kirkwood (1998) Chapter 1-5
  - Sterman (2000)
    - All simulation models in this book are available as AnyLogic sample models (see AnyLogic Help)

- Acknowledgement:
  - Slides are based on Kirkwood (1998) an most diagrams are direct copies from this manuscript

Comments or Questions?

References

- Kirkwood CW (1998) System Dynamics Methods: A Quick Introduction (http://www.public.asu.edu/~kirkwood/sysdyn/SDIntro/SDIntro.htm)
- Sterman JD (2000) Business Dynamics: Systems Thinking and Modeling for a Complex World