System Thinking and System Dynamics

Bayreuth Summer School

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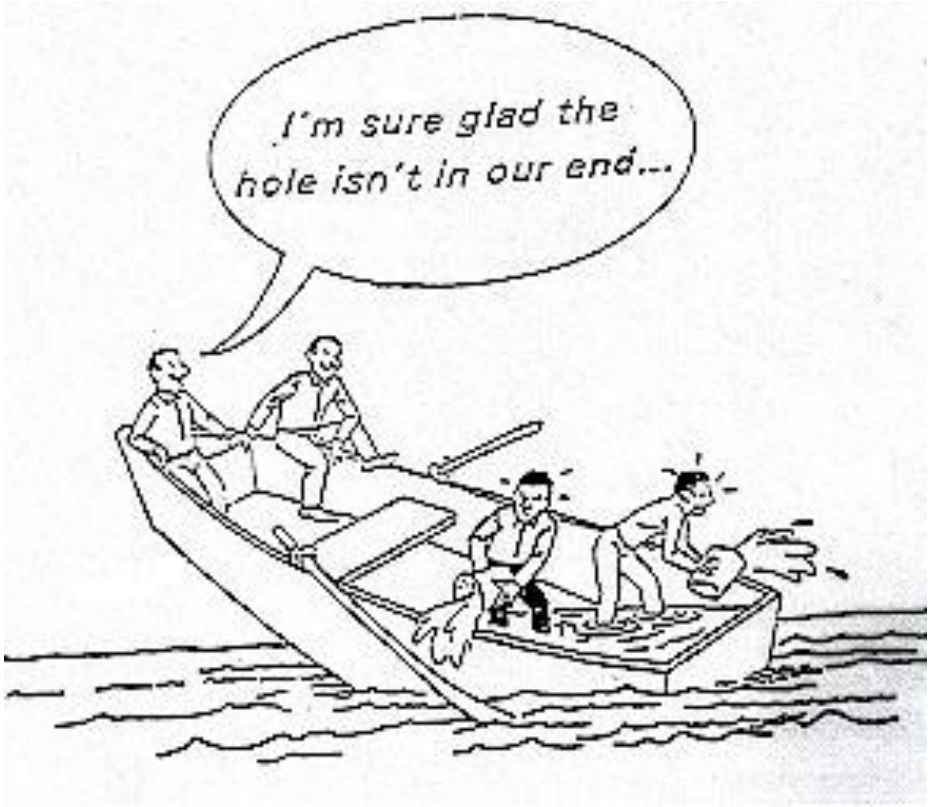
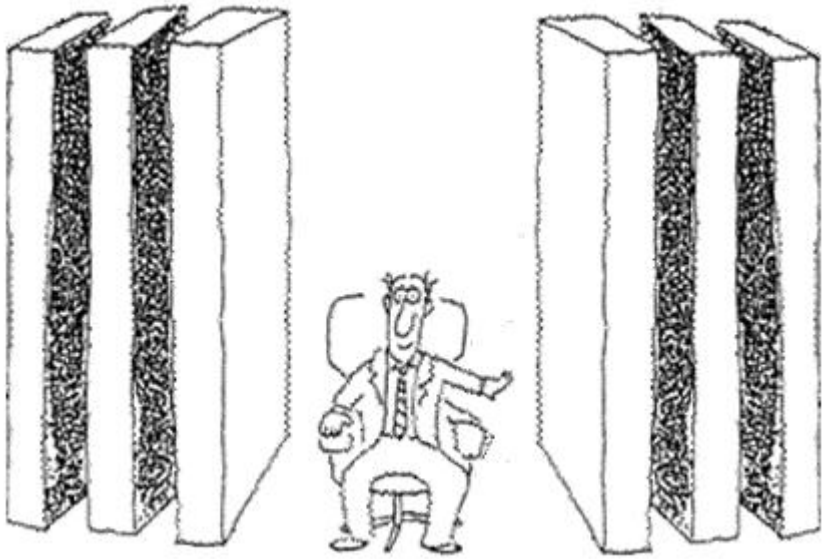
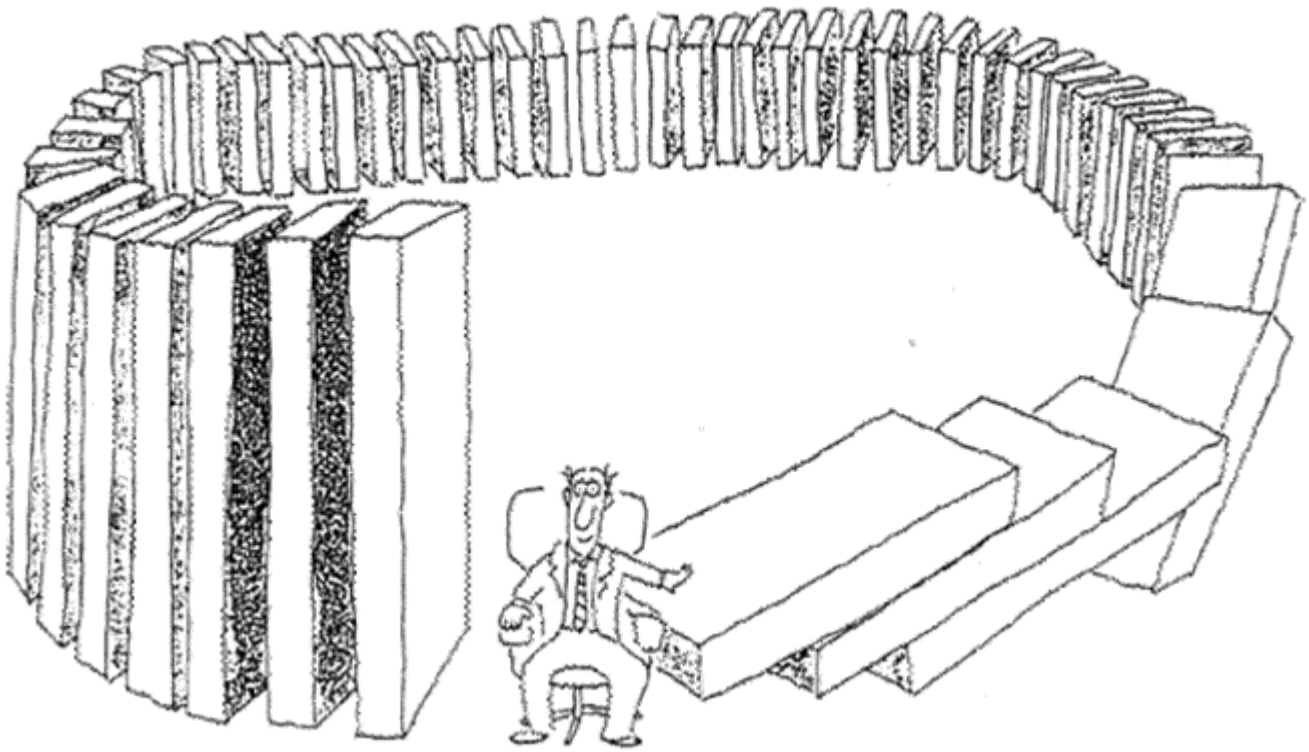
System Thinking



System Thinking



System Thinking



System Thinking

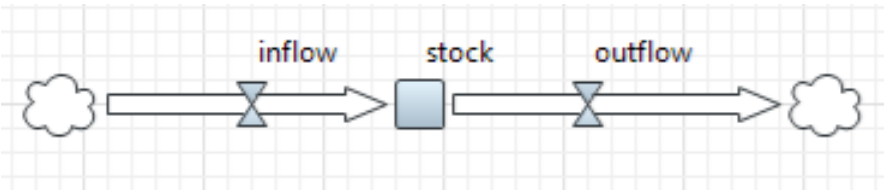
- A system can be complex (interacting multiple feedback loops, delay, etc.)
- We cannot look at everything
- Simplify using model
- Deciding system boundary is important
- Need a tool to analyse the interactions between multiple feedback loops in a (complex) system

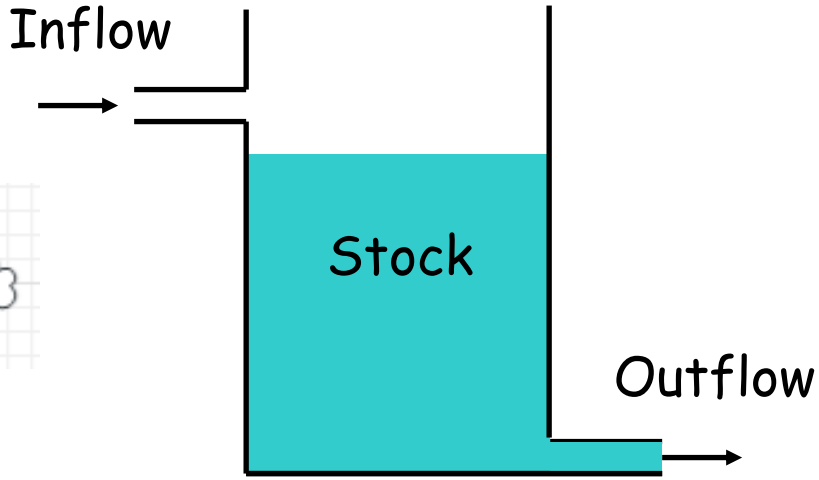
System Dynamics Modelling

- A simulation modelling paradigm that is used to explore complex feedback systems and to analyse the mutual interactions among factors over time (Forrester, 1961)

- View the world as a collection of stocks, flows and delays

Stocks and Flows



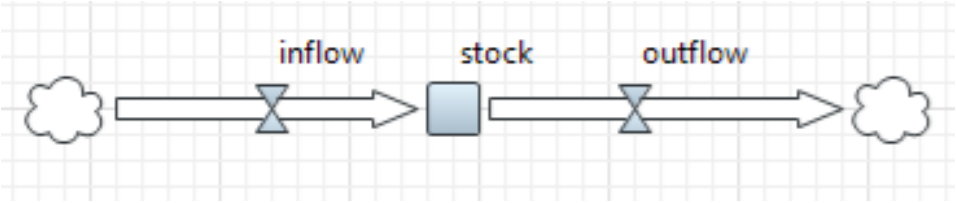


$$Stock(t) = Stock(t_0) + \int_{t_0}^{t} \left[Inflow(s) - Outflow(s) \right] ds$$

$$\frac{d(Stock)}{dt} = Inflow - Outflow$$

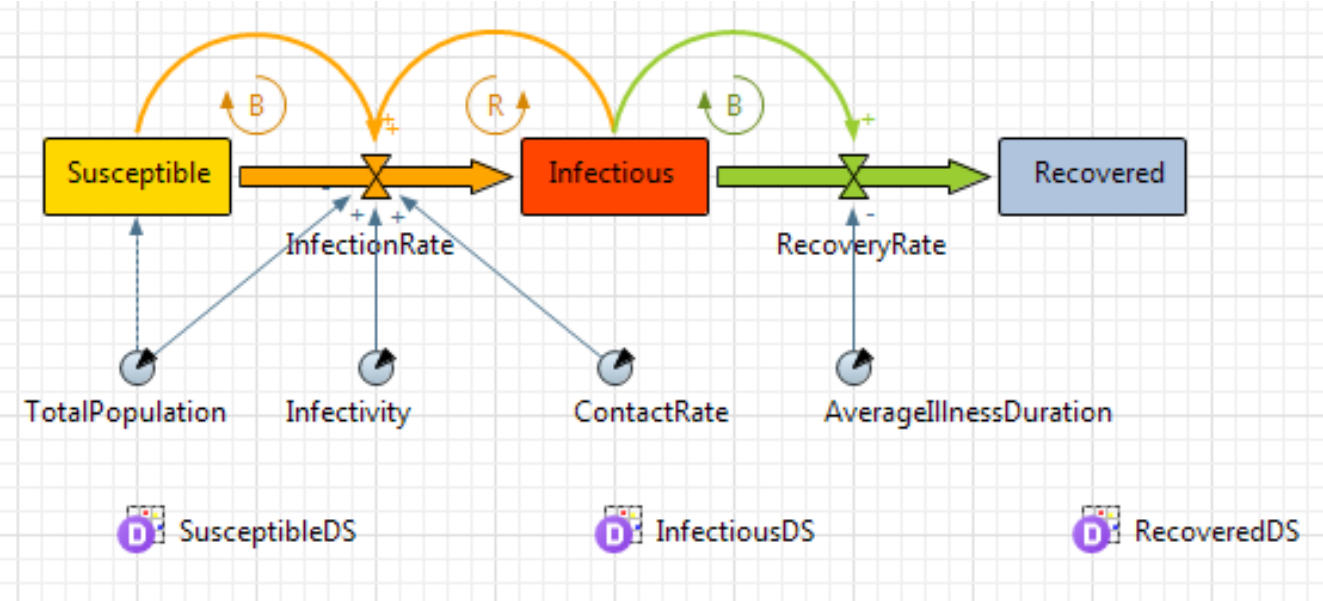
Stocks and Flows

- Stocks: physical and mental
- Snapshot test

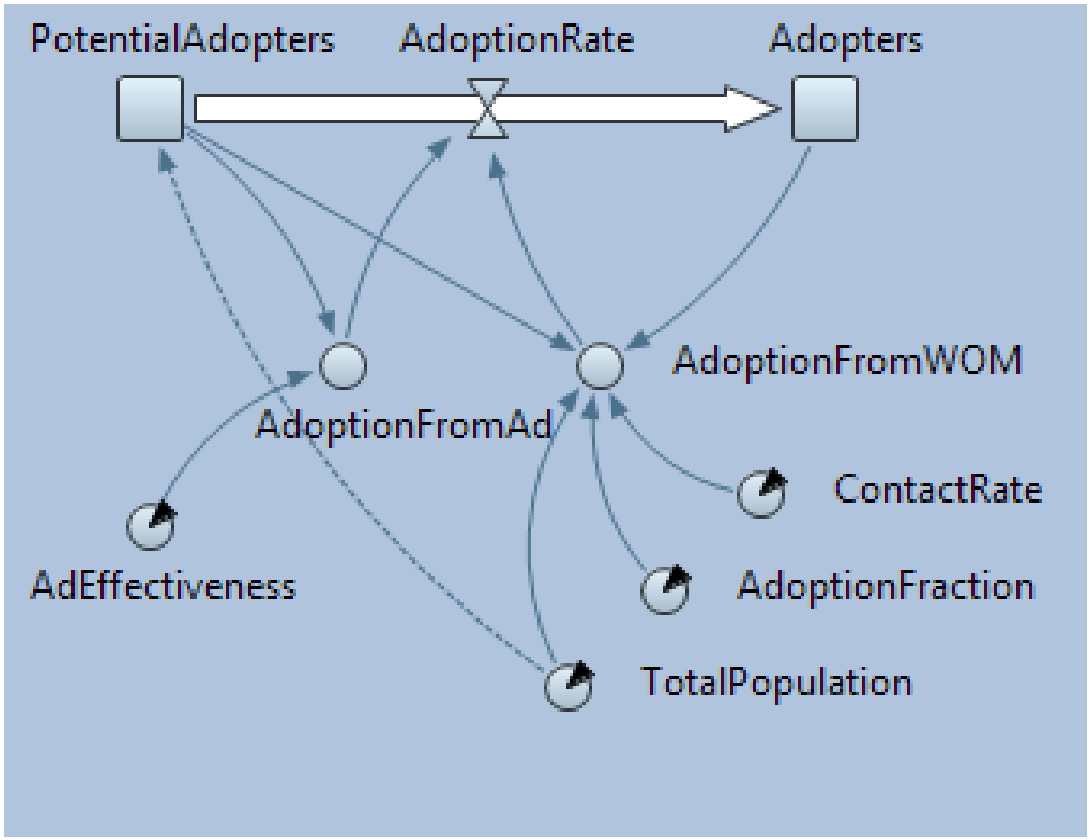


- Units
- Conservation of materials

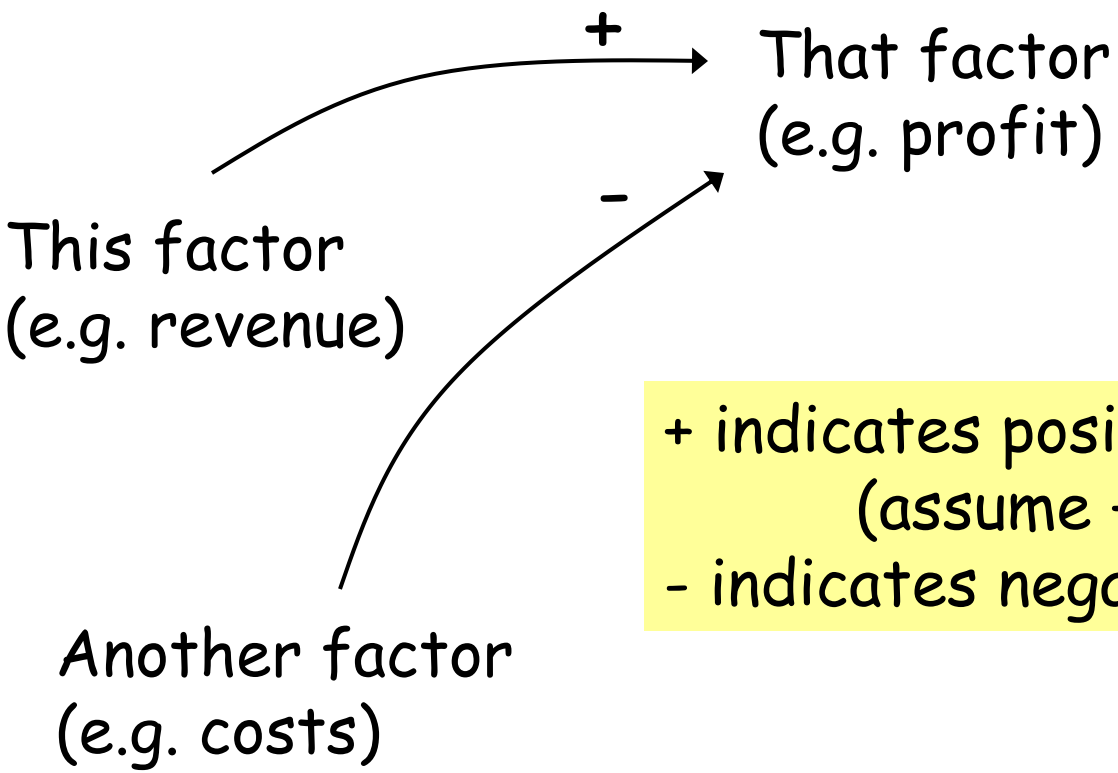
Example 1: SIR epidemic model



Example 2: Bass diffusion model



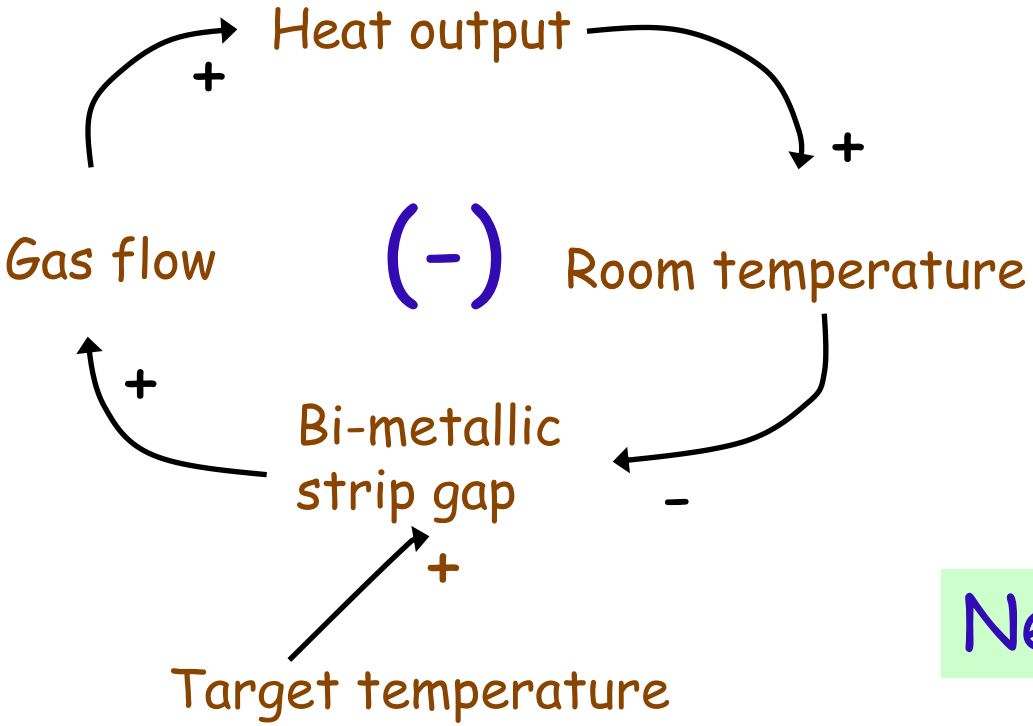
Causal Loop Diagram

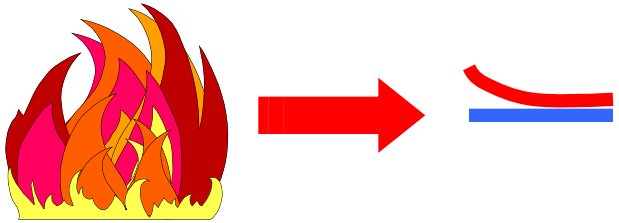


+ indicates positive causality
(assume + if none shown)
- indicates negative causality

Causal Loop Diagram

Thermostatically controlled gas-fired central heating system

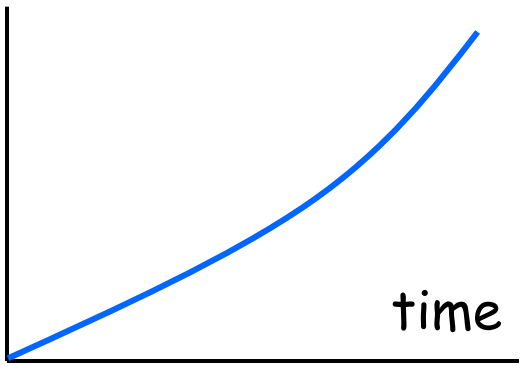


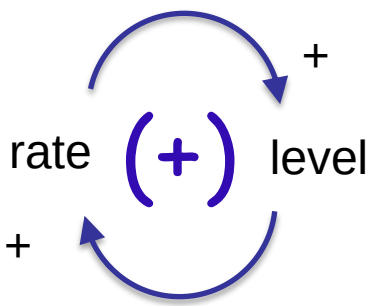


Negative feedback

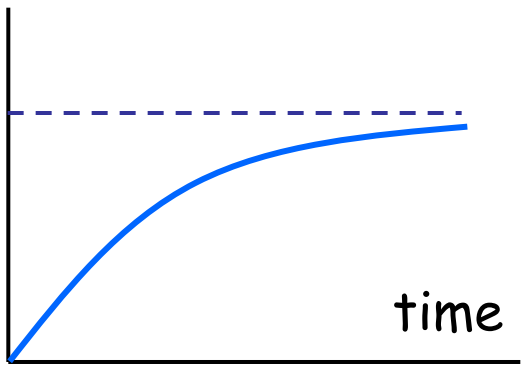
Structure creates behaviour

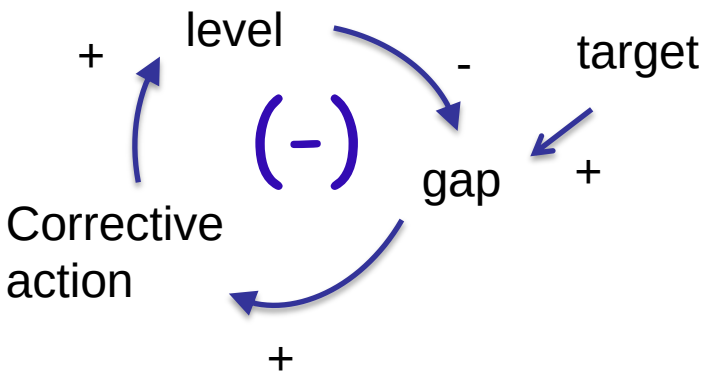
Exponential growth





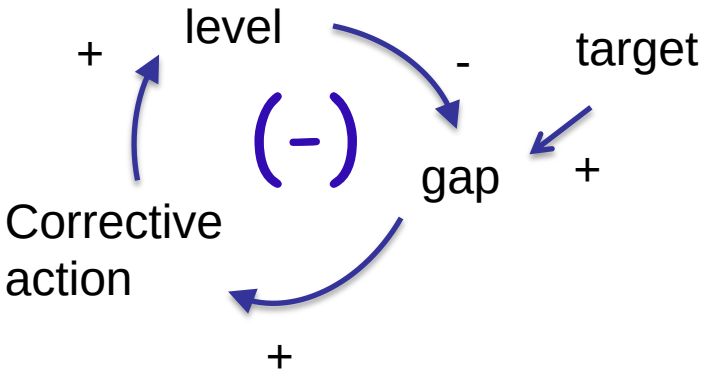
Goal seeking





Delays

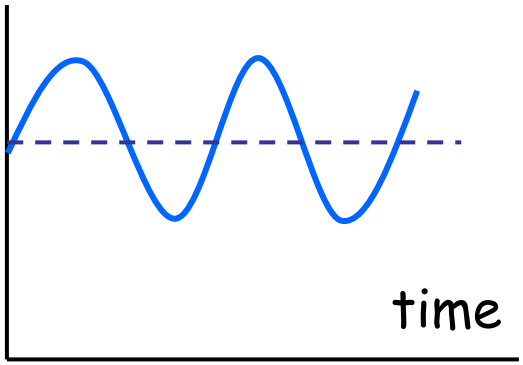
- What is the effect of delay?

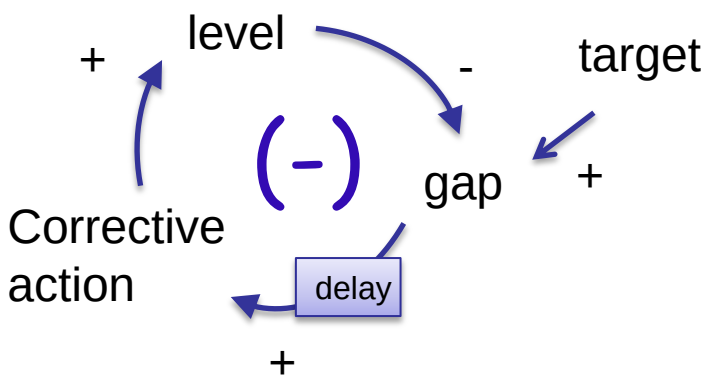


- Delays are pervasive – it takes time
  - To measure
  - To make a decision
  - For the decision to take effect

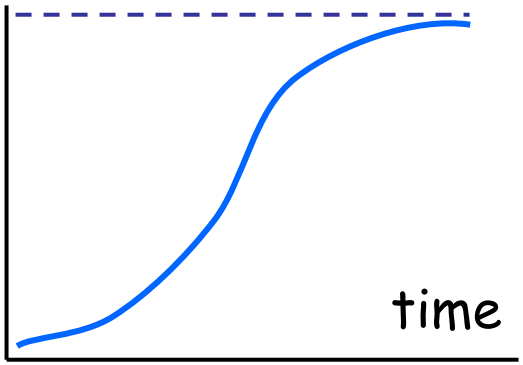
Structure creates behaviour

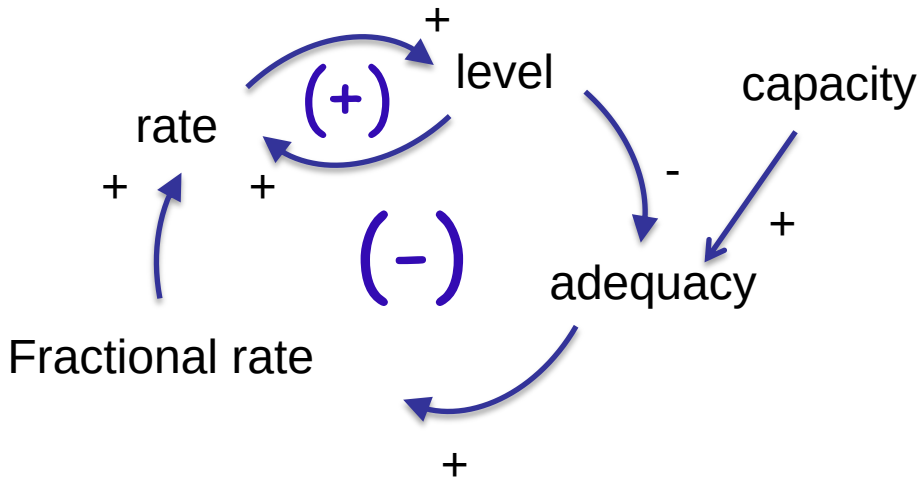
Oscillation





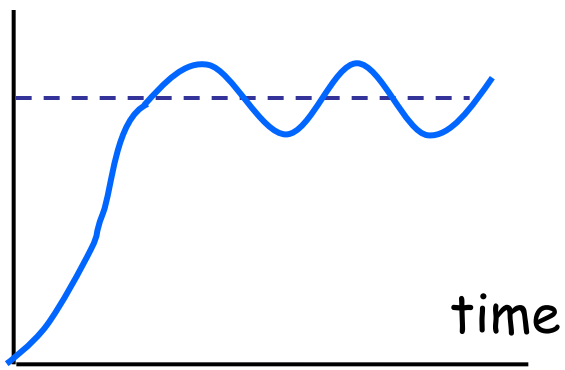
S-shaped growth

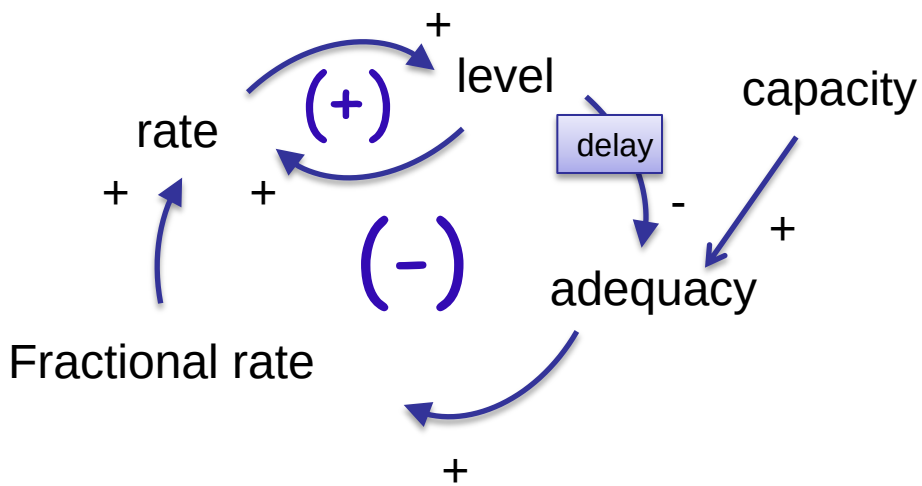




Structure creates behaviour

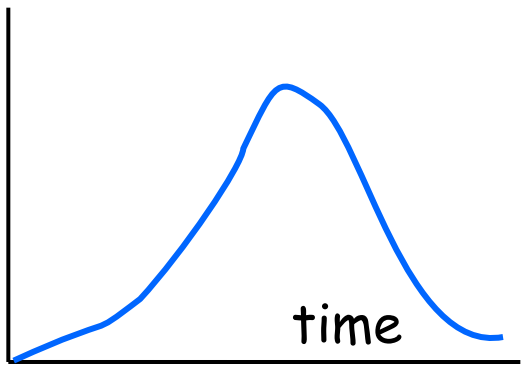
S-shaped with oscillation

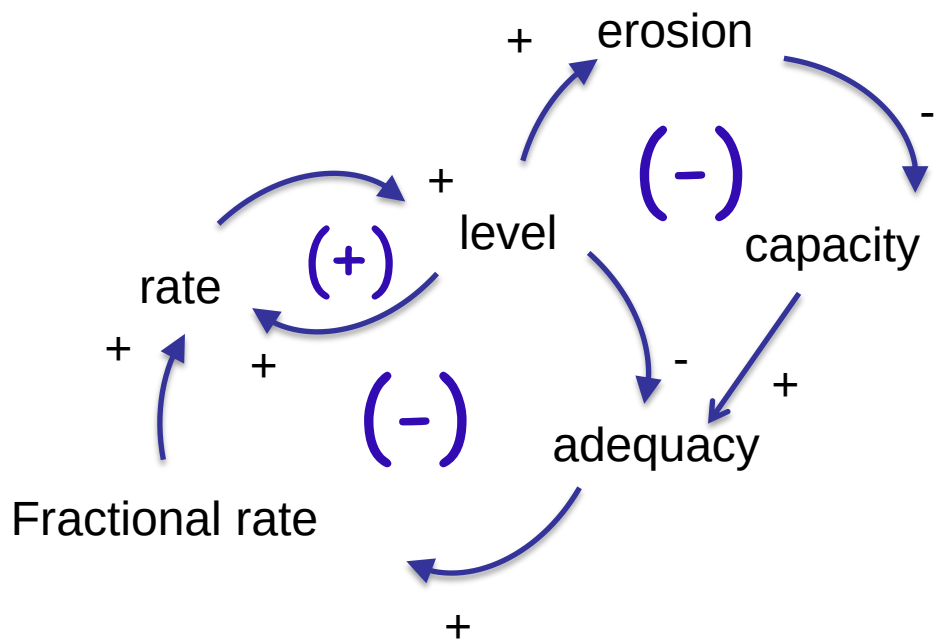




Structure creates behaviour

Collapse





Causal Loop Diagram

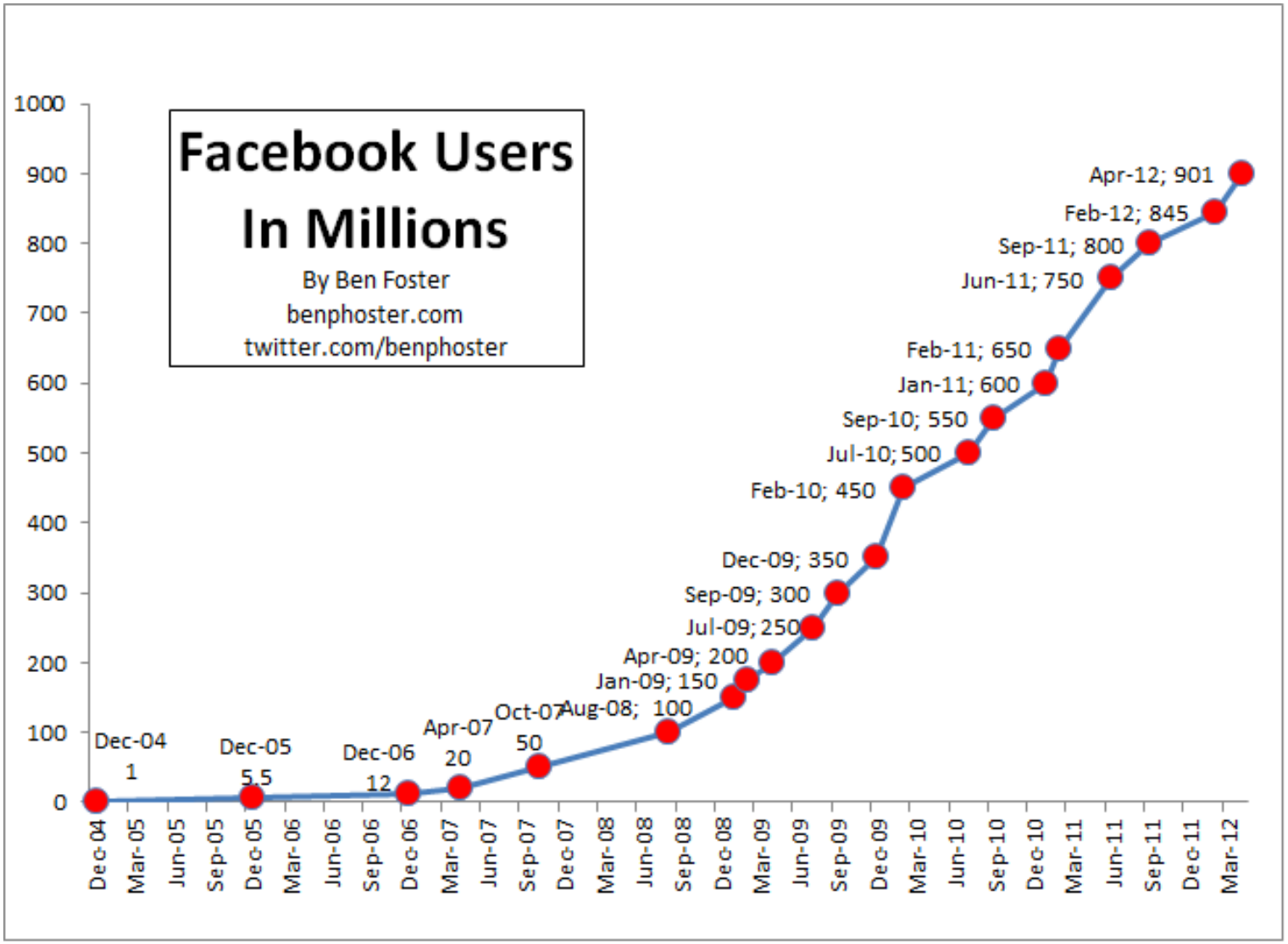
Price

Number of competitors

Profits

Market attractiveness

Production Cost


Facebook Users
In Millions
By Ben Foster
benphoster.com
twitter.com/benphoster
1000
900
800
700
600
500
400
300
200
100
0
Dec-04
1
Dec-05
5.5
Dec-06
12
Apr-07
20
Oct-07
50
Aug-08; 100
Jan-09; 150
Apr-09; 200
Jul-09; 250
Sep-09; 300
Dec-09; 350
Feb-10; 450
Jul-10; 500
Sep-10; 550
Jan-11; 600
Feb-11; 650
Jun-11; 750
Sep-11; 800
Feb-12; 845
Apr-12; 901
Dec-04
Mar-05
Jun-05
Sep-05
Dec-05
Mar-06
Jun-06
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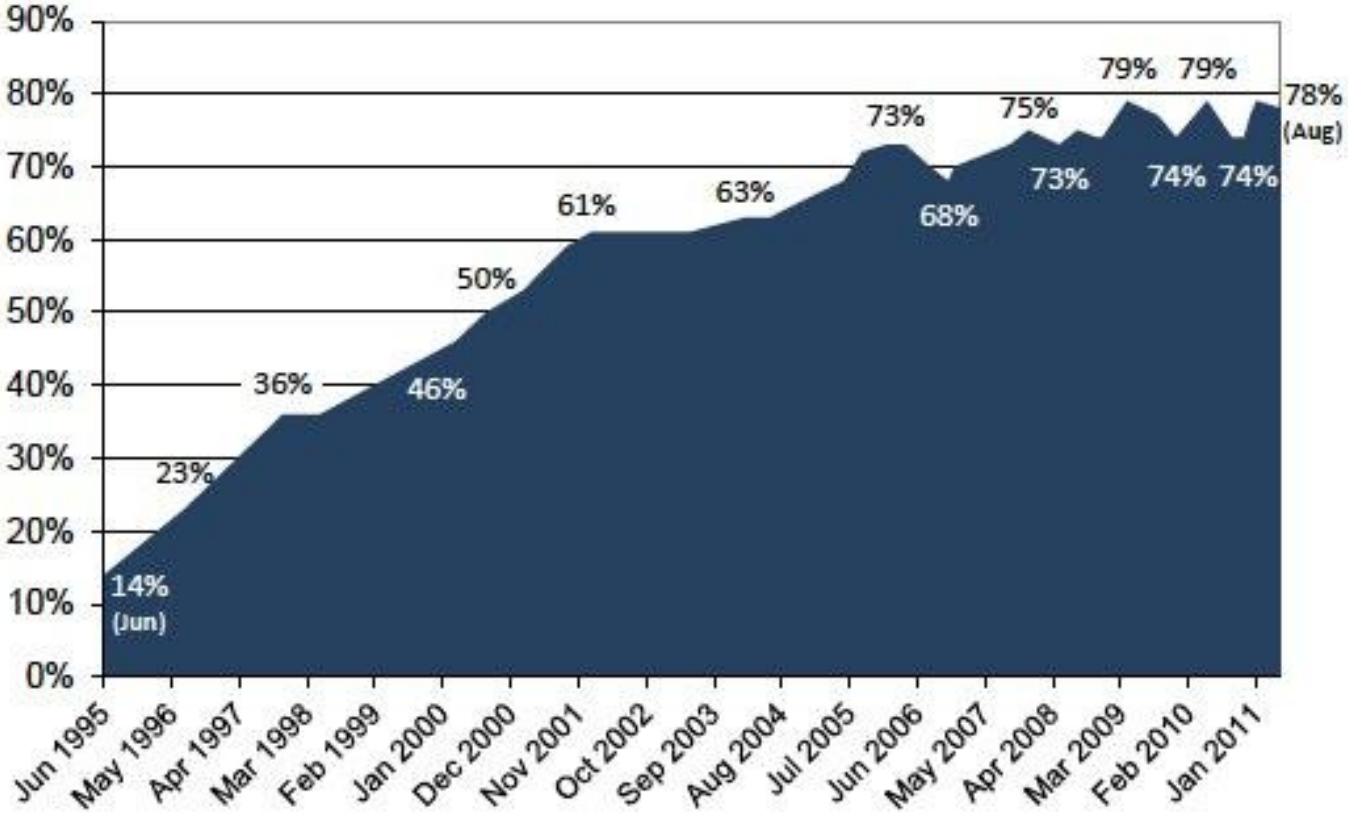
Dec-11
Mar-12

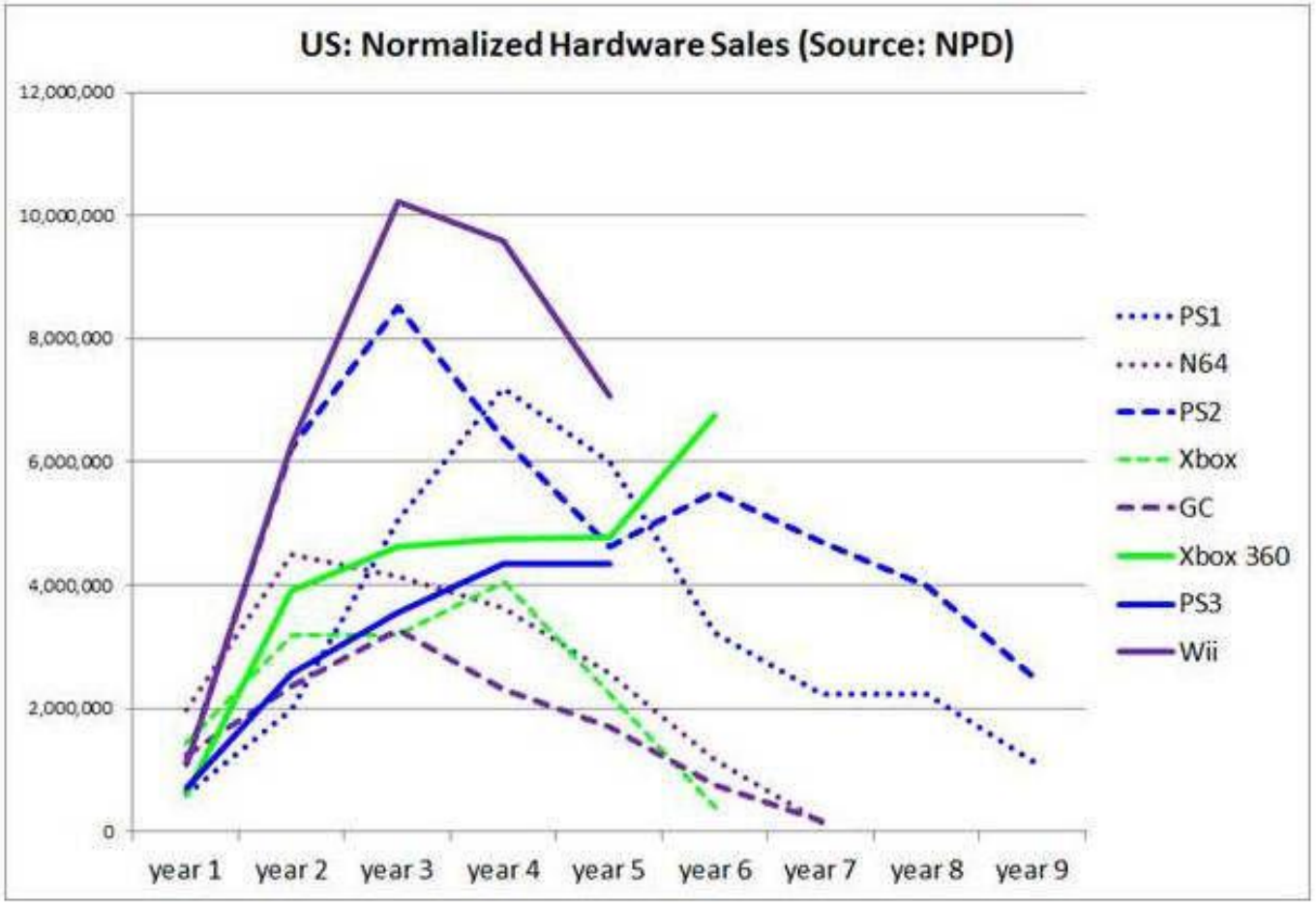
Internet adoption, 1995-2011

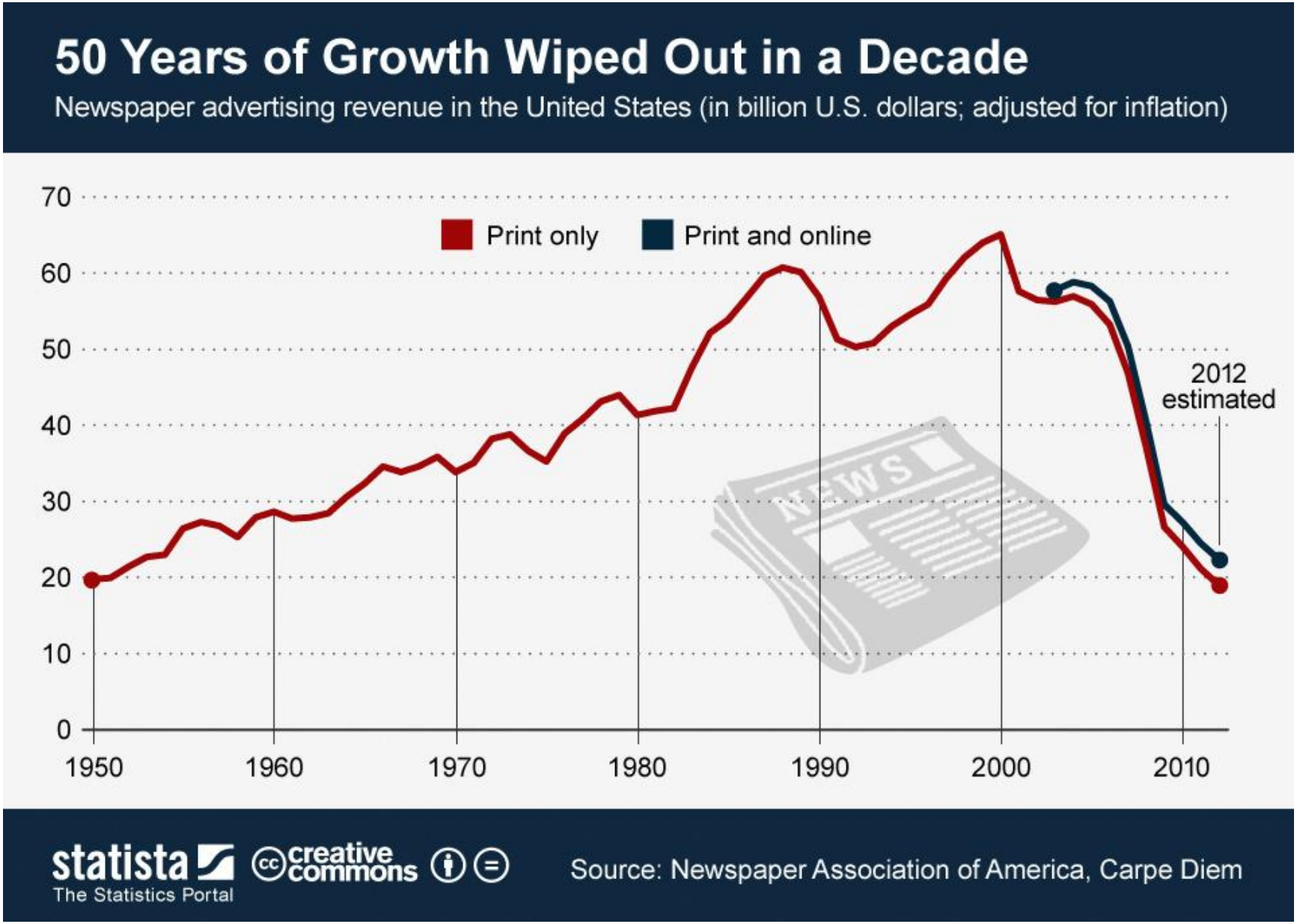
% of American adults (age 18+) who use the internet, over time. As of August 2011, 78% of adults use the internet.



Source: Pew Internet & American Life Project Surveys, March 2000-August 2011.

More: http://pewinternet.org/Trend-Data/Internet-Adoption.aspx


US: Normalized Hardware Sales (Source: NPD)
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
year 1
year 2
year 3
year 4
year 5
year 6
year 7
year 8
year 9
PS1
N64
PS2
Xbox
GC
Xbox 360
PS3
Wii


50 Years of Growth Wiped Out in a Decade
Newspaper advertising revenue in the United States (in billion U.S. dollars; adjusted for inflation)
Print only
Print and online
2012 estimated
70
60
50
40
30
20
10
0
1950
1960
1970
1980
1990
2000
2010
statista
The Statistics Portal
creative commons
Source: Newspaper Association of America, Carpe Diem

Sources of dynamic complexity

- Dynamic - Change in flows
- Multiple feedbacks
  - Difficult to isolate a component of the system
  - Circular causality – current decision will affect future decision
  - May reflect the ability to “adapt” or “learn”
- Nonlinear
  - Effect is not proportional to cause
  - Different level of sensitivity towards changes in the system

Sources of dynamic complexity

- Delays are troublesome
  - Reduce the ability to “learn”
  - Increase the tendency for system to oscillate
  - Better-before-worse / worse-before-better scenarios
- Cause and effect are distant in time and space
  - Action may have a long term effect
  - Some are difficult/impossible to undo
  - Expand the boundaries of our mental models
- Emergent behaviour – counter-intuitive

More notes on feedback system

- The meaning of feedback:
  - Positive ≠ Good
  - Negative ≠ Bad
- Intuition works well for simple isolated feedback
  - Hopeless when multiple feedbacks interact
- The dynamic complexity of a system arises from the interactions of multiple feedbacks over time
  - Does not have to be from thousands of interacting components
  - Beer game vs. optimization of airline operations

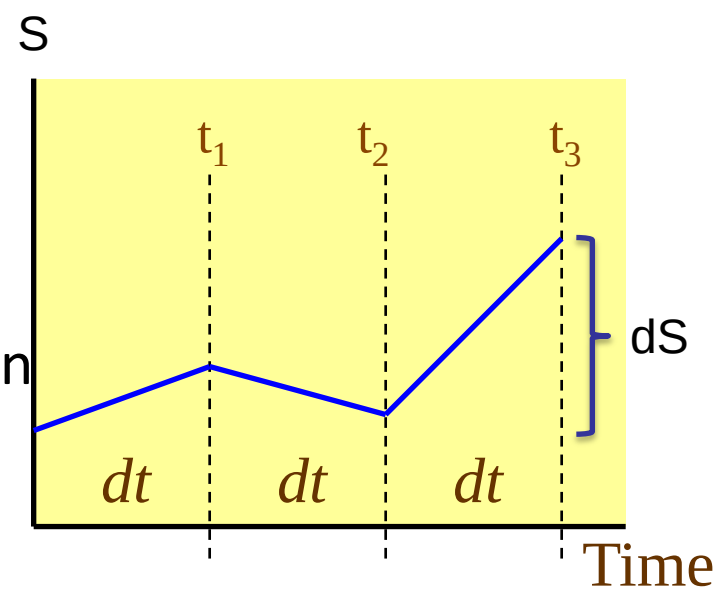
System dynamics software tools

- Building blocks: Stocks, Flows, Delays, Auxiliaries

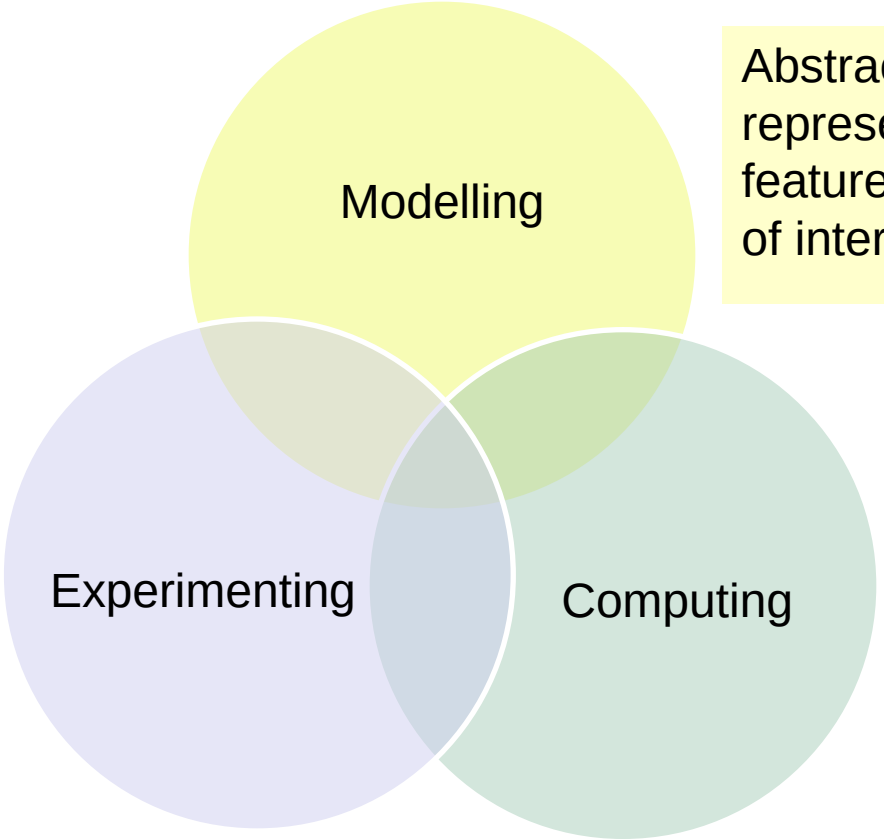
- Tools
  - Vensim
  - Powersim Studio
  - Stella & iThink
  - AnyLogic
  - And others (including many agent-based simulation tools)

System dynamics simulation

- Time slicing
- Stock equations
  - computed at each time point t_i
- Flow equations
  - computed after the level equation
  - held constant over dt
- At each time point
  - compute new stock levels
  - then compute new flow rates
- The software must apply numerical methods to solve the integrations – integration errors



Activities in computer simulation



Abstracting and representing the main features of the system of interest

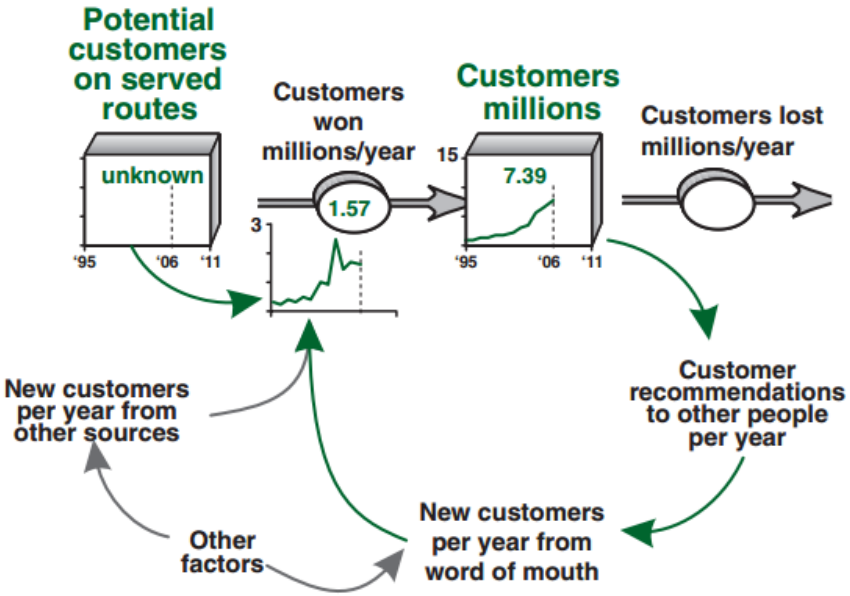
Using the model to explore options or gain understanding

Producing a model than can be run on a PC or other computer

It often becomes difficult to separate these

SD is no different, but …

- Reference modes & time horizon
  - Do not underestimate delay
  - The development of the problem over time
    - Break the short-term worldview
    - Define important concepts



SD is no different, but …

- Dynamics hypothesis
  - Working theories of how the problem arose
  - Endogenous explanation – scrutinize exogenous inputs
  - Broad boundary with key feedbacks vs. Narrow but detailed view

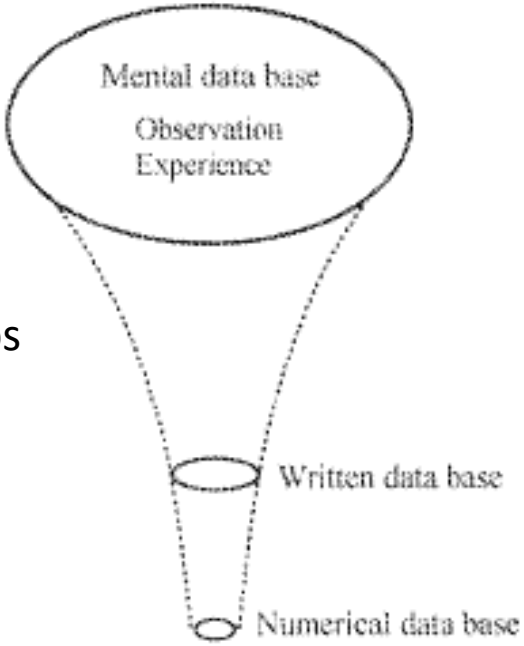
Data

- SD models = mathematical representations
  - Most information is not numerical

- Numerical data base
  - Use statistical analysis
  - Some analyses assume discrete time
  - SD numerical procedure may require smaller timesteps
  - Estimate with continuous distributions – robustness

- Written data base
  - Document-based research methodologies

- Mental data base
  - Method: observation, survey, interview, focus group, etc.
  - Analysis: Grounded theory, discourse analysis, ethnography, etc.



Further Reading

- Pidd, M. (any edition) Computer Simulation in Management Science. John Wiley & Sons, Chichester, UK – chapter 13, 14, and 15. These chapters provide you with a good introduction on System Dynamics.

- Sterman, J.D. (2000) Business Dynamics: Systems Thinking and Modeling for a Complex World. McGraw-Hill. If you want to know System Dynamics in greater detail, this book is for you.