CSC2720: Systems Thinking for Global Problems

→ Last week:
- Why systems thinking?
- What sort of discipline is it?
- Defining a system

→ This week:
- Feedback Loops
- The idea of limits
- Multiple feedback loops
- Case Study: Feedbacks in the Climate System

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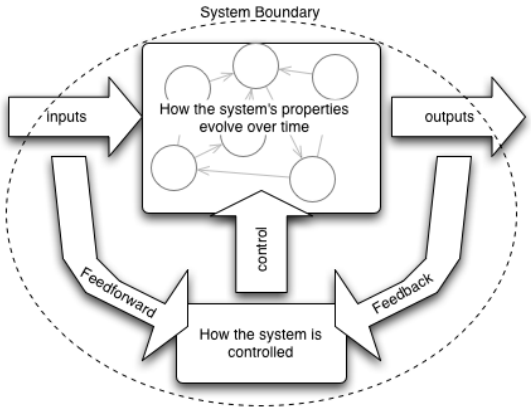
Elements of a System



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General Systems Theory

→ How scientists understand the world:
- Reductionism - break a phenomena down into its constituent parts
  - E.g. reduce to a set of equations governing interactions
- Statistics - measure average behaviour of a very large number of instances
  - E.g. gas pressure results from averaging random movements of zillions of atoms
  - Error tends to zero when the number of instances gets this large

→ But sometimes neither of these work:
- Systems that are too interconnected to be broken into parts
- Behaviour that is not random enough for statistical analysis

→ General systems theory
- Originally developed for biological systems:
  - E.g. to understand the human body, and the phenomena of 'life'
- Basic ideas:
  - Treat inter-related phenomena as a system
  - Study the relationships between the pieces and the system as a whole
  - Don't worry if we don't (yet) fully understand each piece

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Two approaches to study systems

1. Focus on the rules followed by individuals (bottom up)
   - Build simulations (agent models, physics models, etc)
   - Study the emergent behaviour
2. Focus on the patterns of behaviour of the system as a whole (top down)
   - Identify feedback loops, stocks, flows, etc
   - Build qualitative, causal models (eg system dynamics models)
   - Focus on holistic understanding (what-if questions), rather than quantifying behaviour

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Behaviour of Complex Systems

Simple rules

Many relationships

Large numbers of interactions

Complex Non-linear Systems

Self-organizing behaviour

Feedback Loops

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Feedback Loops

Reinforcing Loop
(positive loop)

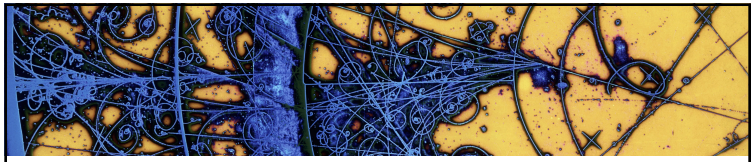
births per year — Population Growth — population

Balancing Loop
(negative or goal-seeking loop)

heat — Thermostat — temperature

temperature gap

target temperature



Systems Activity:

Living Loops

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Some Alternative Notations

(a)

Births + R + Population + B - Deaths +

(b)

Births → Population → Deaths

R B

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Example Stock'n'Flow Diagrams

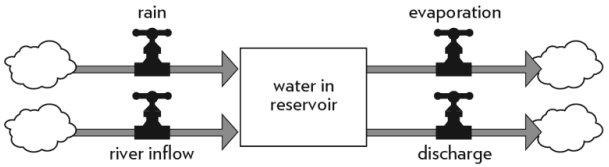

Figure 3. A stock of water in a reservoir with multiple inflows and outflows.

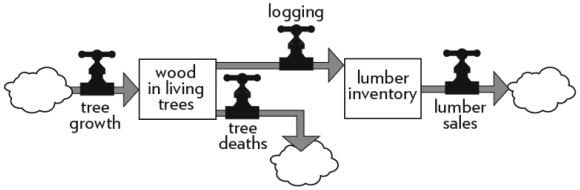

Figure 4. A stock of lumber linked to a stock of trees in a forest.

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Balancing Feedback Loops

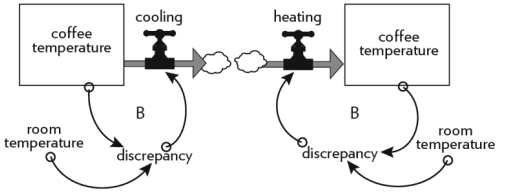

Figure 10. A cup of coffee cooling (*left*) or warming (*right*).

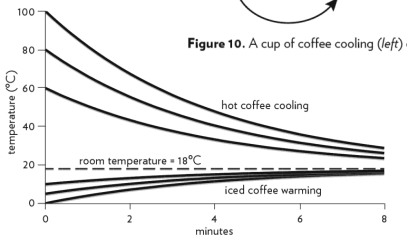

Figure 11. Coffee temperature as it approaches a room temperature of 18 °C.

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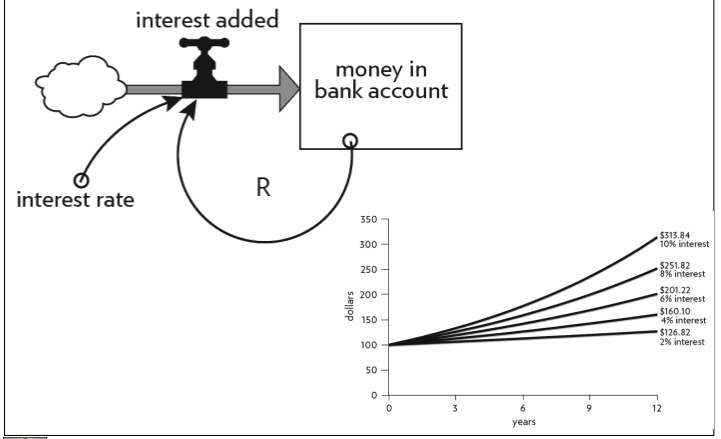
Reinforcing Loops



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House Thermostat

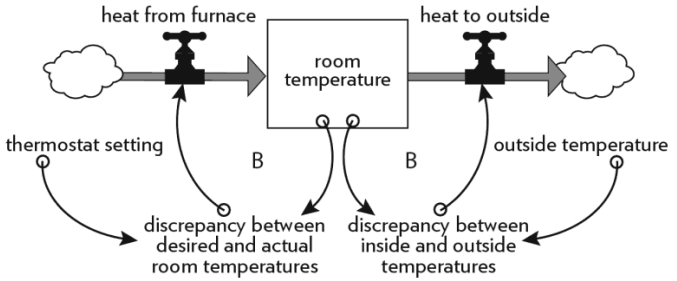

Figure 15. Room temperature regulated by a thermostat and furnace.

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But the room doesn't stay warm!

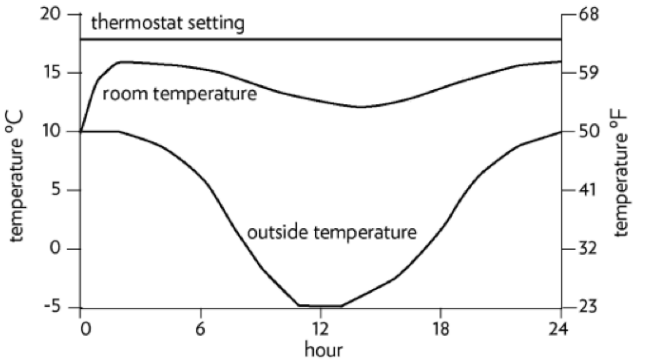

Figure 20. On a cold day, the furnace can't keep the room warm in this leaky house!

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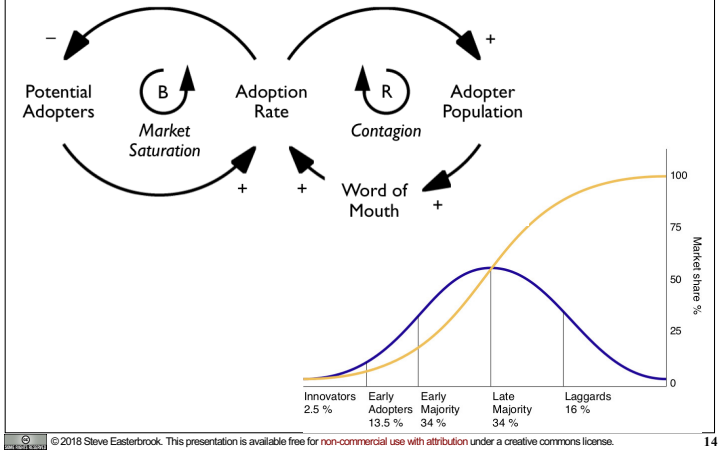
Multi-loop systems



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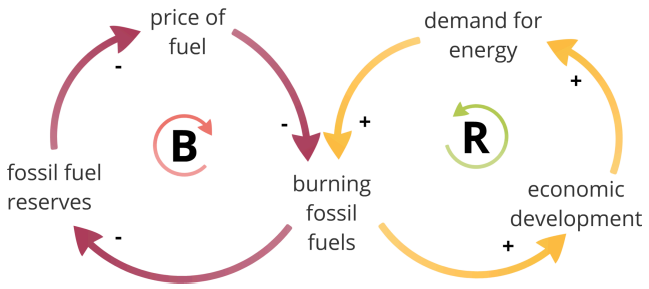
Rational markets?



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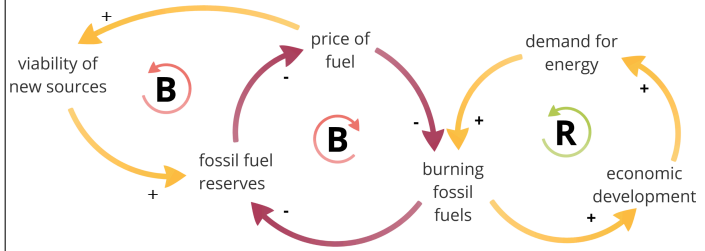
Substitutability



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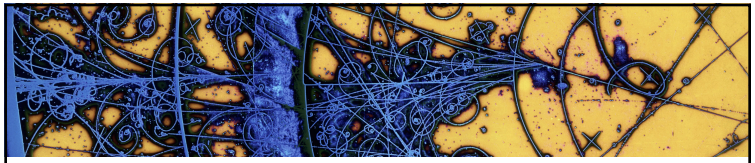

Systems Activity:

Postcard Stories

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Types of System

- **Natural Systems**
  - E.g. ecosystems, weather, water cycle, the human body, bee colony,…
  - Usually treated as hard systems
- **Abstract Systems**
  - E.g. set of mathematical equations, computer programs,…
  - Interesting property: system and its description are the same thing
- **Symbol Systems**
  - E.g. languages, sets of icons, street signs,…
  - Soft because meanings change
- **Designed Systems**
  - E.g. cars, planes, buildings, freeways, telephones, the internet,…
- **Human Activity Systems**
  - E.g. families, businesses, organizations, markets, clubs, …
  - E.g. any designed system when we also include its context of use
    - Same for abstract and symbol systems!
- **Information Systems**
  - Special case of designed systems
    - Part of the design includes the representation of the current state of some human activity system
  - E.g. MIS, banking systems, databases, …
- **Control systems**
  - Special case of designed systems
    - Designed to control some other system (usually another designed system)
  - E.g. thermostats, autopilots, …

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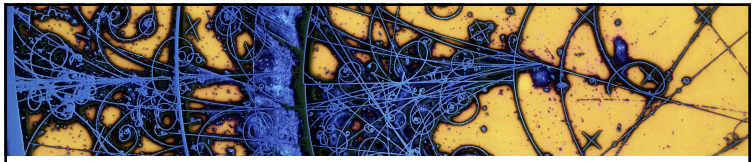
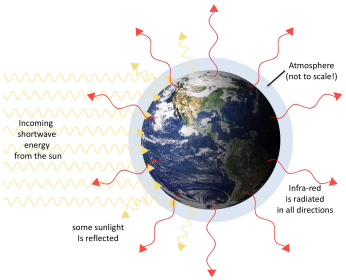


Case Study:

The Climate as a System



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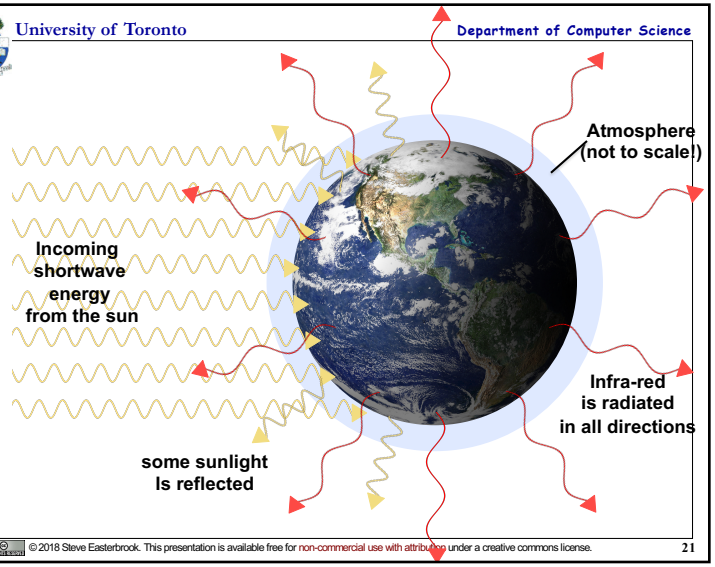

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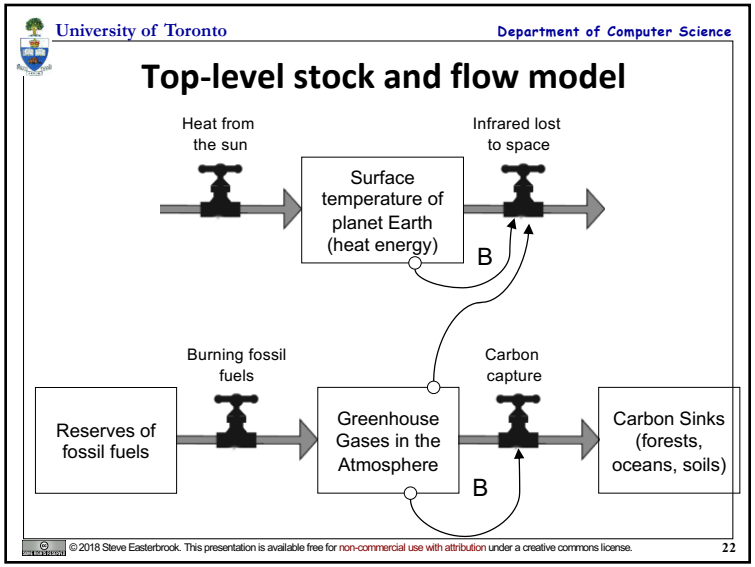
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Top-level stock and flow model
Heat from the sun
Infrared lost to space
Surface temperature of planet Earth (heat energy)
B
Burning fossil fuels
Carbon capture
Reserves of fossil fuels
Greenhouse Gases in the Atmosphere
Carbon Sinks (forests, oceans, soils)
B
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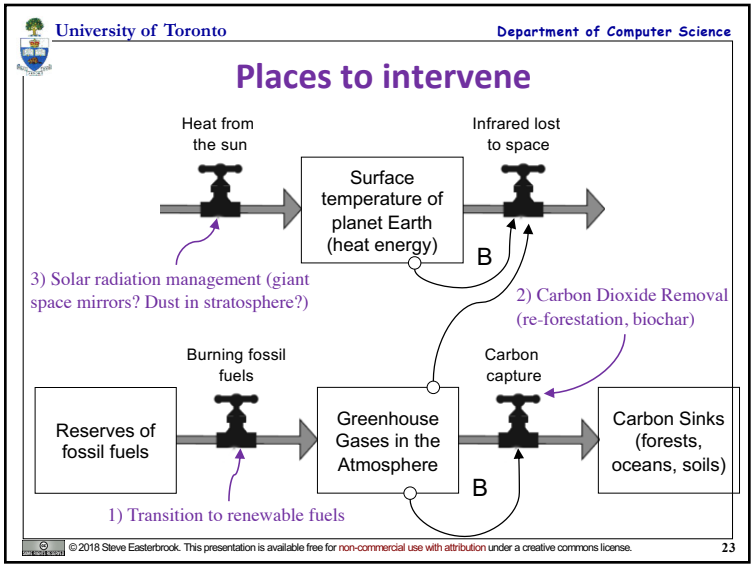
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Places to intervene
Heat from the sun
Infrared lost to space
Surface temperature of planet Earth (heat energy)
B
3) Solar radiation management (giant space mirrors? Dust in stratosphere?)
2) Carbon Dioxide Removal (re-forestation, biochar)
Burning fossil fuels
Carbon capture
Reserves of fossil fuels
Greenhouse Gases in the Atmosphere
Carbon Sinks (forests, oceans, soils)
B
1) Transition to renewable fuels
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