CT561: Systems Modelling & Simulation

1. Introduction to System Dynamics

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https://github.com/JimDuggan/SDMR

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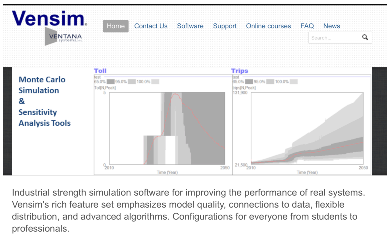
Overview

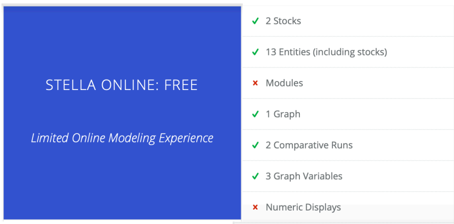
Structure

- Lectures, and Workshops/Tutorials
- 30% Continuous Assessment
  - MCQs
  - Assignment
  - Lab Exam



Software

- https://vensim.com/free-download/#ple
- https://www.iseesystems.com/store/products/stella-online.aspx



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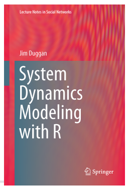
Lecturer – Jim Duggan



- Lectures in
  - Programming (R, MATLAB),
  - Modelling & Simulation
- Research interests:
  - System Dynamics
  - Computational Epidemiology
  - Data Science & Artificial Intelligence

System Dynamics

System dynamics is a modeling methodology used to build simulation models of social systems, and these computerized models can support policy analysis and decision making. This simulation method is based calculus, and models of real-world dynamic processes are constructed using integral equations. The models presented here illustrate the breadth of application of system dynamics, and include:

- **Epidemiology**, with a focus on the contagious disease SIR model, and an interesting extension of this to a disaggregate form, based on a vectorized R implementation.
- **Health Systems Design**, which provides a system-wide model comprising population demographics, a supply chain of general practitioners, and a demand-capacity model of general practitioner services to overall population.
- **Economics and Business**, ranging from simple customer model, and onto models of limits to growth, capital investment, and the impact of non-renewable resources on growth.

Models are implemented using R and Vensim. The model catalog is as follows:

- Chapter 1 contains the Vensim model of customer growth, with a single stock (Customers), and two flows, an inflow (Recruits) and an outflow (Losses)
- Chapter 2 has an implemention of the customer model in R
- Chapter 3 presents models of (1) S-Shaped growth, (2) Solow's Economic model and (3) a model of overshoot and collapse.
- Chapter 4 introduces a Vensim model for a health systems example, where the model is divided into three distinct sectors
- Chapter 5 contains the SIR model and a vectorised diffusion model.
- Chapter 6 shows how RUnit can be used to test system dynamics models
- Chapter 7 illustrates how statistical screening can be used to analyse system dynamics models

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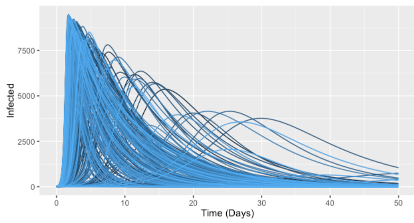
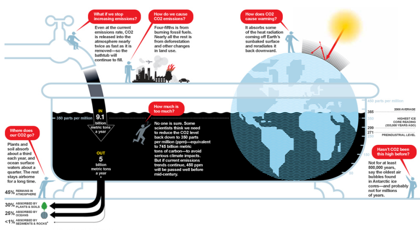
(1) What is a model?

- "An external and explicit representation of part of reality as seen by the people who wish to use that model to understand, to change, to manage and to control that part of reality." Pidd 1996.
- System Dynamics models are *dynamic models* (behaviour over time)





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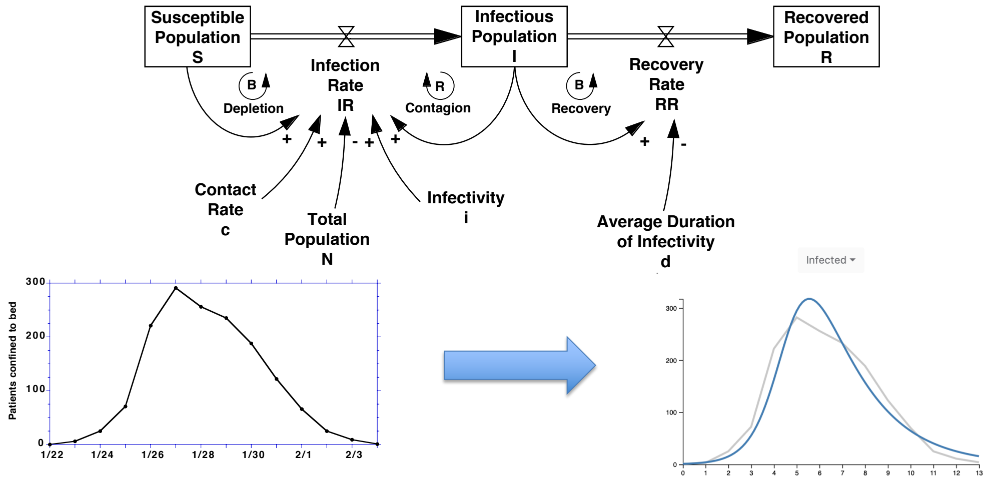
A Dynamic Model



Dynamics of epidemic disease

Sources: British Medical Journal, 4 March 1978, p. 587;.

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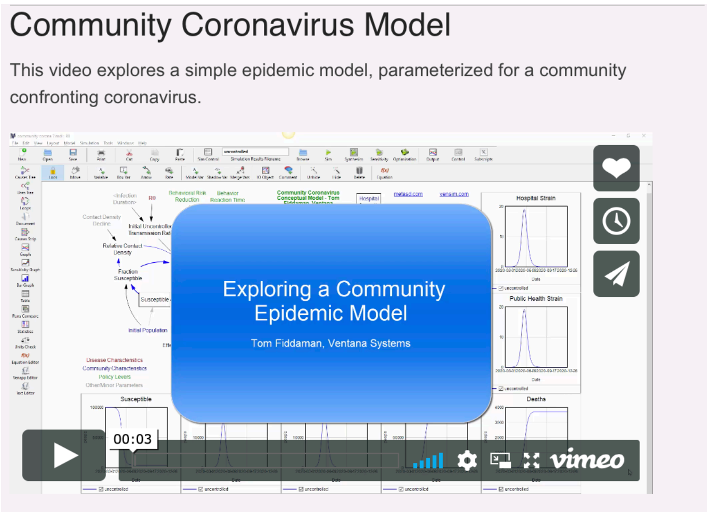
https://vensim.com/coronavirus/



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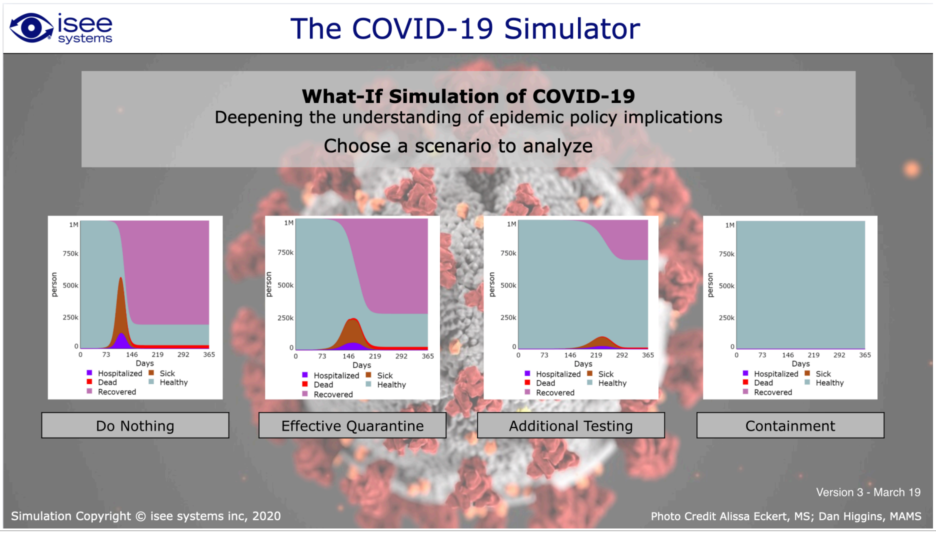
https://exchange.iseesystems.com/public/isee/covid-19-simulator/index.html#page1



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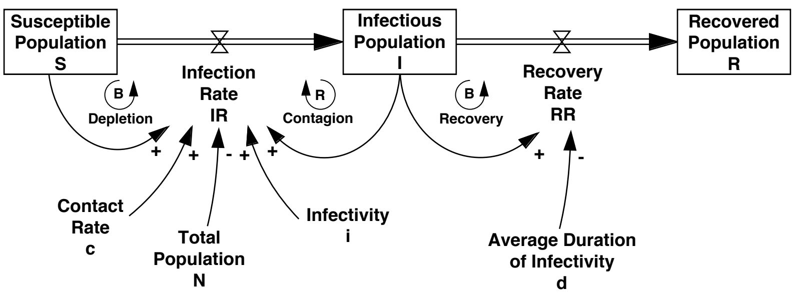
Stocks and Flows

- **Stock** and **flow** variables modeled with stock-flow diagrams
- The stock **accumulates** its inflows to it, less the outflows from it.



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(2) Stocks and Flows

- A **stock** is the foundation of any system.
- **Stocks** are the elements of the system that you can see, feel, count, or measure at any given time.
- A **system stock** is, an accumulation of material or information that has built up over time
- Dimensions are units (litres, people, lines of code)

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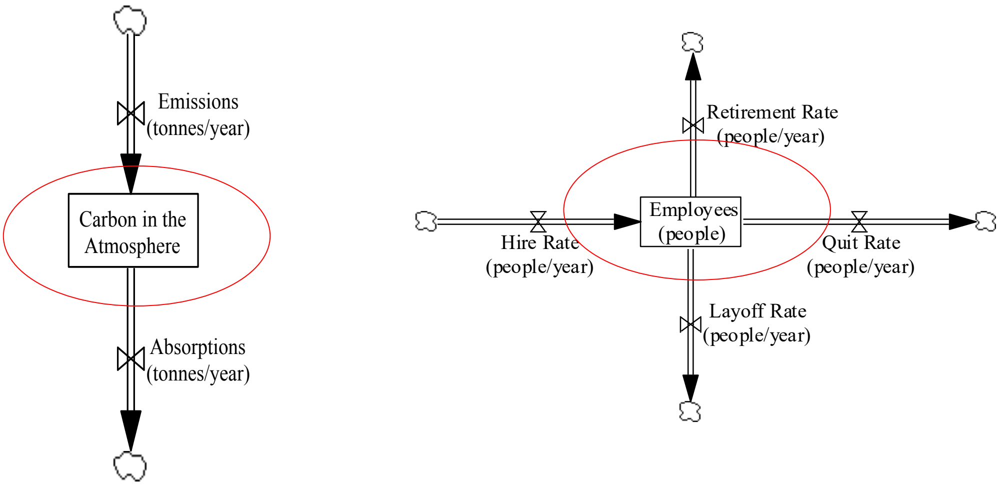
Models: **Stocks** and Flows



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Flows

- Stocks change over time through the actions of a **flow**.
- Flows are:
  - filling and draining,
  - births and deaths,
  - purchases and sales,
  - deposits and withdrawals
  - enrolments and graduations
- Dimensions are units/time period (litres/day, people/year)

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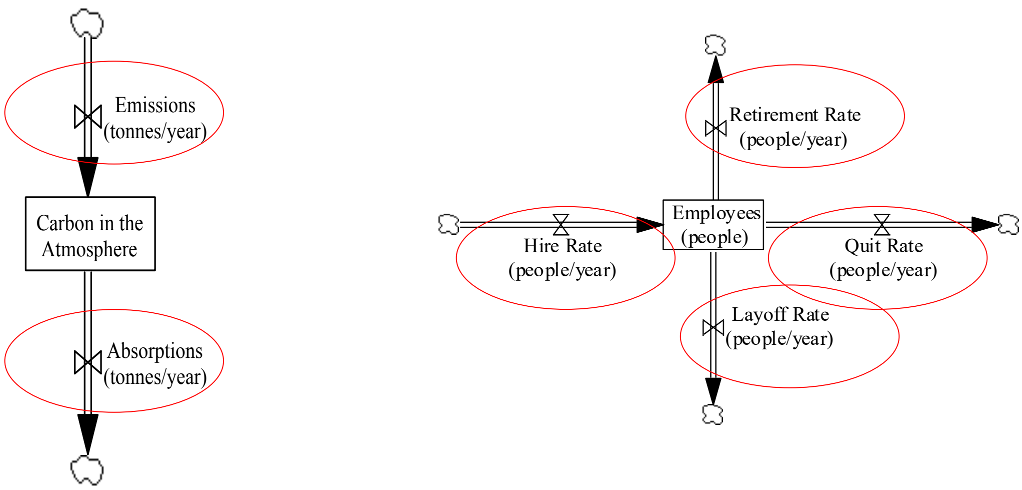
Models: Stocks and **Flows**



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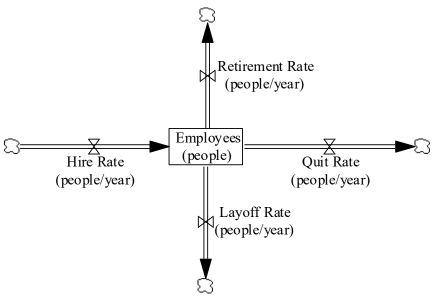
General Principle of Stock/Flow Systems

- From this simple bathtub model you can deduce **several important principles** that extend to more complicated systems:
- As long as the sum of all inflows exceeds the sum of all outflows, the level of the stock will **rise**.
- As long as the sum of all outflows exceeds the sum of all inflows, the level of the stock will **fall**.
- If the sum of all outflows equals the sum of all inflows, the stock level **will not change**; it will be held in dynamic equilibrium at whatever level it happened to be when the two sets of flows became equal.

Meadows, Donella H. *Thinking in systems: A primer*. Chelsea Green Publishing, 2008.



Year	Employees (Jan)	Hires (Jan-Dec)	Retires (Jan-Dec)	Layoff (Jan-Dec)	Quits (Jan-Dec)	Net Flow Jan-Dec
2018	1000	100	20	0	50	30
2019	1030	50	5	0	15	30
2020	1060	30	0	0	0	30
2021	1090					

The stock (Employees) ***accumulates*** *its inflows, less the outflows.*

Summary

- **Systems thinkers see the world as a collection of stocks along with the mechanisms for regulating the levels in the stocks by manipulating flows.**

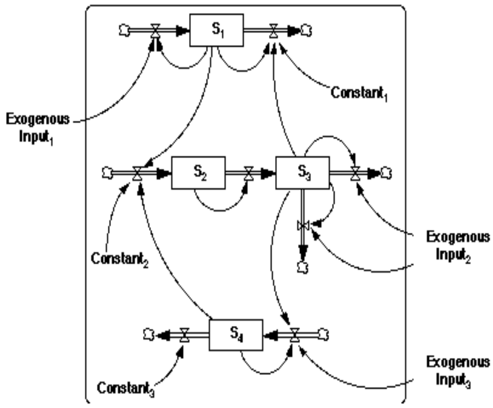
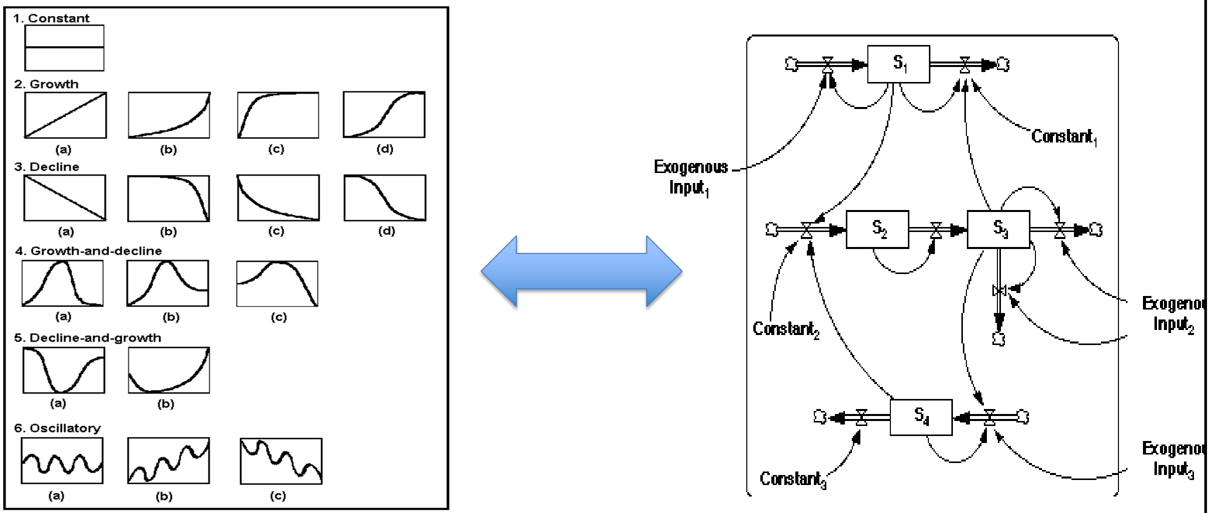


Diagram source: J.D. Sterman,Business Dynamics: Copyright © 2001 by the McGraw-Hill Companies

Challenge 1.1

- For each of the following variables, identify the stock, the flows (distinguish between inflows and outflows), the units for each variable, and the most likely time horizon for a simulation model representation.
  - Enrollments, Students, Graduations
  - Account Balance, Credits, Debits
  - Retirements, Staff, Recruitments, Total Staff Retired
  - Absorptions, Emissions, Carbon in the Atmosphere
  - People Entering, People Leaving, People in the Store
  - Water in the Lake, Rainfall, Evaporations
  - Customers Joining, Customers, Customers Leaving
  - People Infected, New Infections, People Recovering, People Recovered
- Build a simple model in Excel.

Categories of Dynamic Behaviour Patterns (Barlas 2019)



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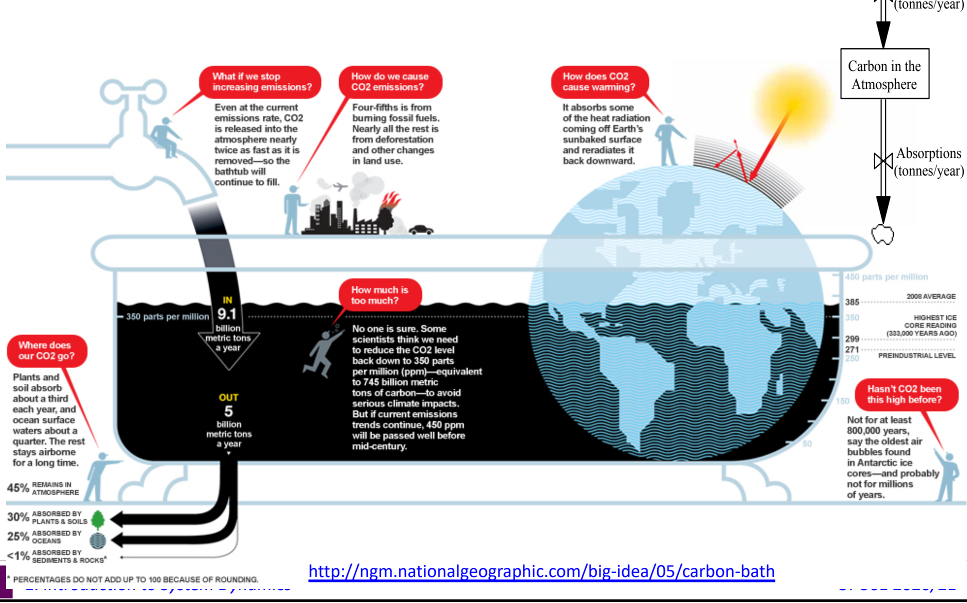
A "bathtub" Model of Carbon in the Atmosphere



http://ngm.nationalgeographic.com/big-idea/05/carbon-bath

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