CT561: Systems Modelling & Simulation

Lecture 1: Introduction to Stocks and Flows

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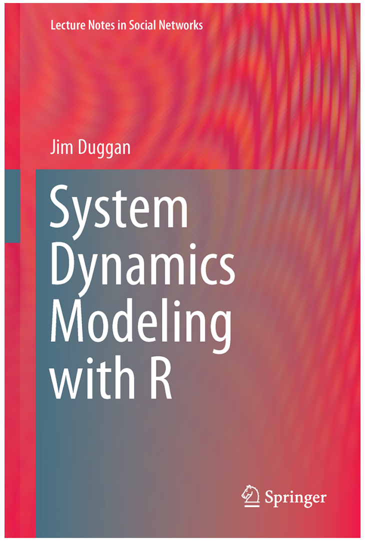
https://github.com/JimDuggan/SDMR

https://twitter.com/_jimduggan



Overview

Structure

- Lectures Tues, 2-4
- Labs (from week 6) & 3 Assignments
- MCQ – each week

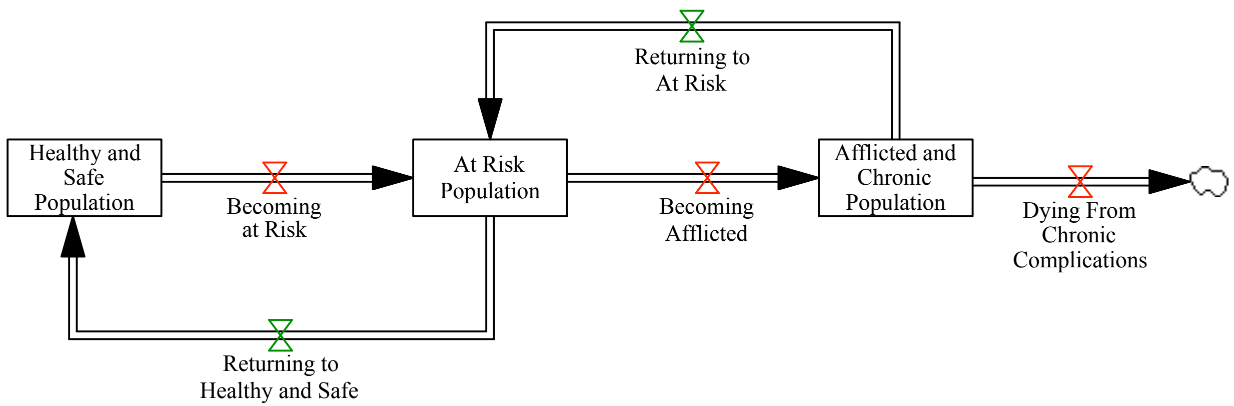
Tools

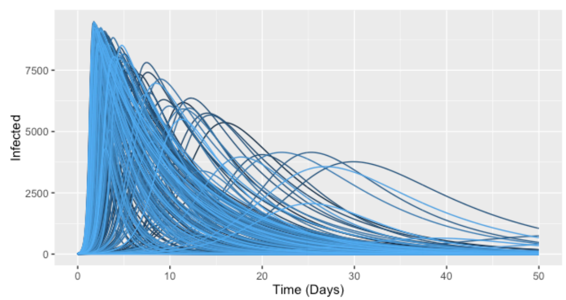
- Vensim PLE
- R & R Studio

Motivation

"A model should always be created for a purpose"
Jay W. Forrester, Urban Dynamics (1969), p.113.

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.

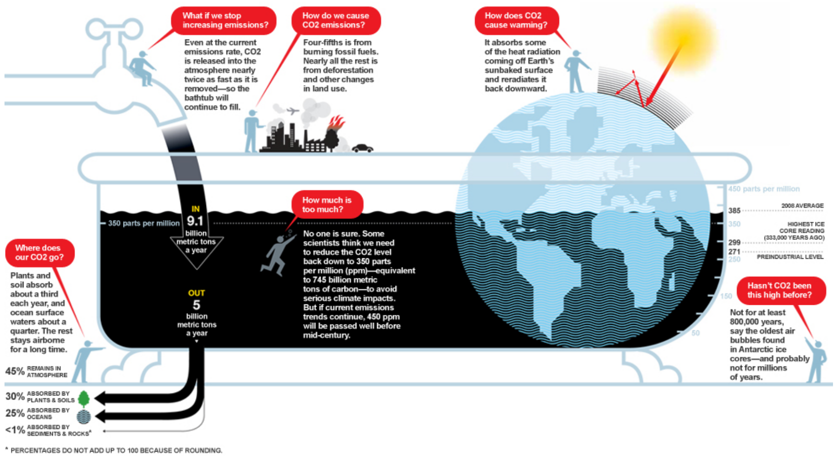




What is a model?

"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.

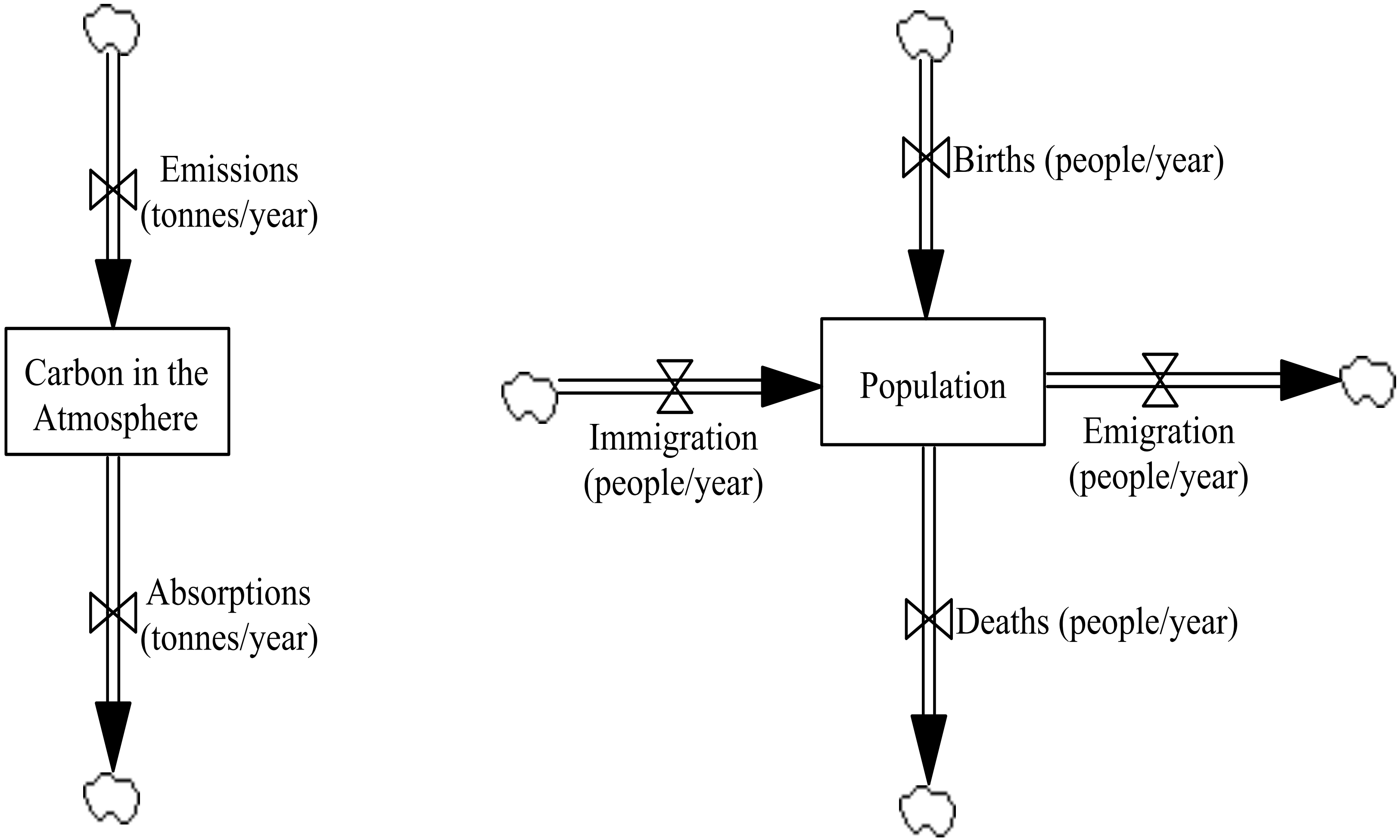
- Reality:
  - Declining student numbers
  - Increasing carbon in the atmosphere



Model types (Meadows 1974)

- ***Absolute, precise predictions***, for example, when and where will the next solar eclipse be observable?
- ***Conditional, precise predictions,*** for example, if a cooling systems fails in a nuclear power plant, what will be the maximum pressure exerted on the reactor's containment vessel?
- ***Conditional, imprecise projections of dynamic behavior***, for example, if an infectious disease spreads through a population, what is the likely future burden of demand on intensive care facilities one month from the outbreak date?

Models: Stocks and Flows



Stocks

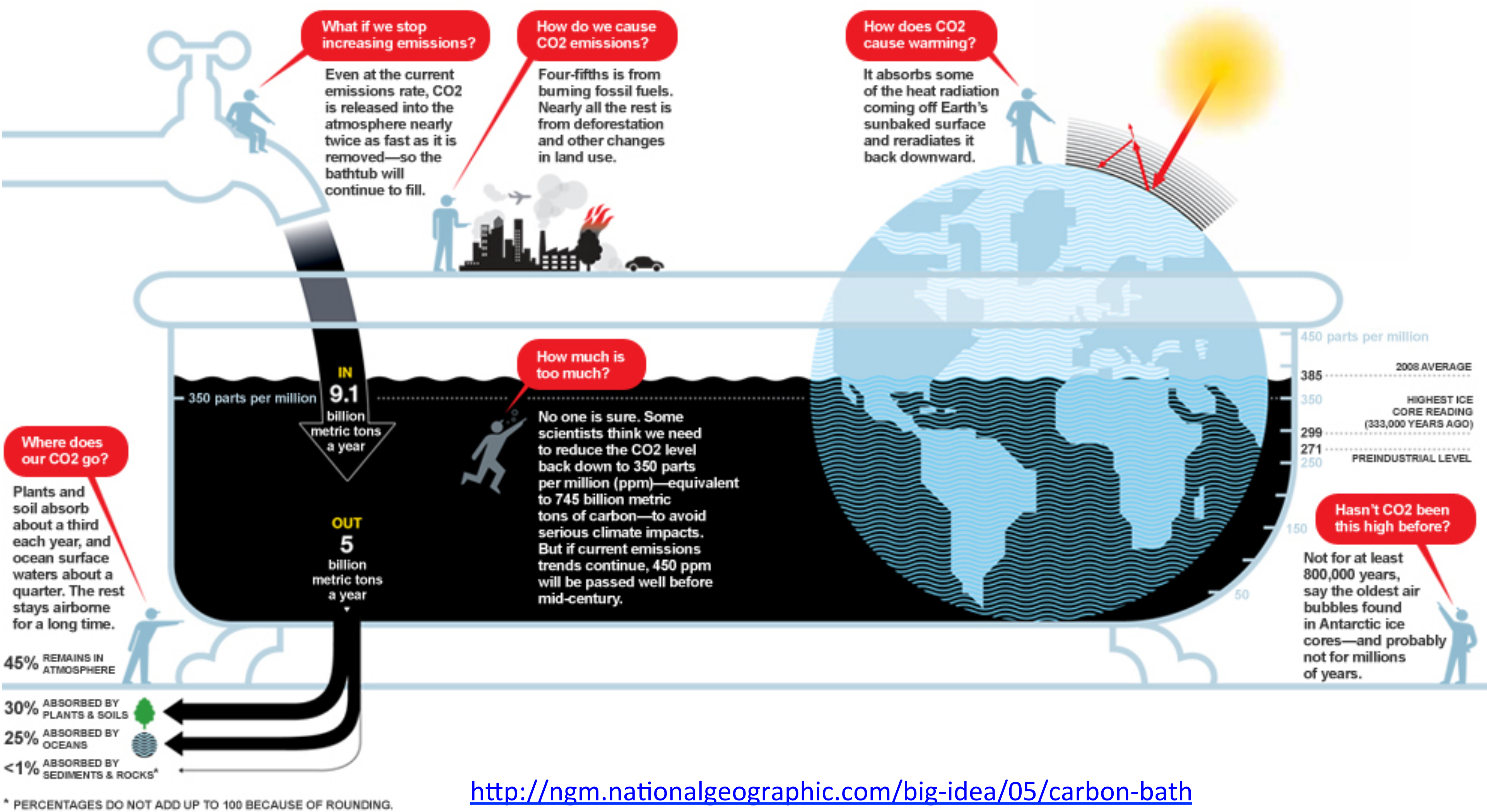
- A **stock** is the foundation of any system.
- **Stocks** are the elements of the system that you can see, feel, count, or measure at any given time.
- A **system stock** is, an accumulation of material or information that has built up over time
- Dimensions are units (litres, people, lines of code)

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

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)

A Stock and Flow Model of Carbon in the Atmosphere

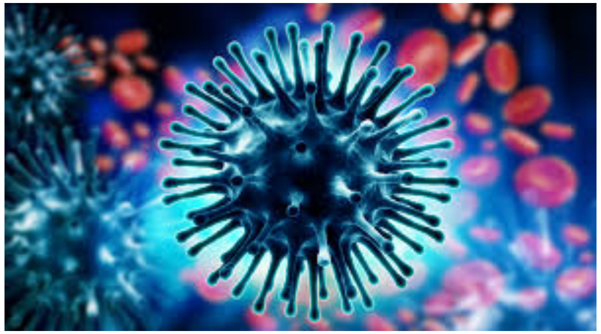


http://ngm.nationalgeographic.com/big-idea/05/carbon-bath

Challenge 1.1

Identify one stock and associated inflows and outflows for the following systems:

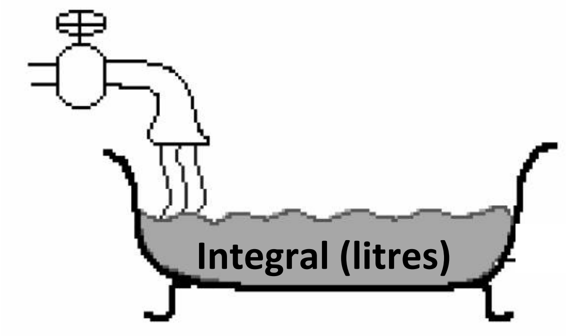
- A Warehouse.
- Employees in an organization.
- Illness in a population (e.g. influenza).

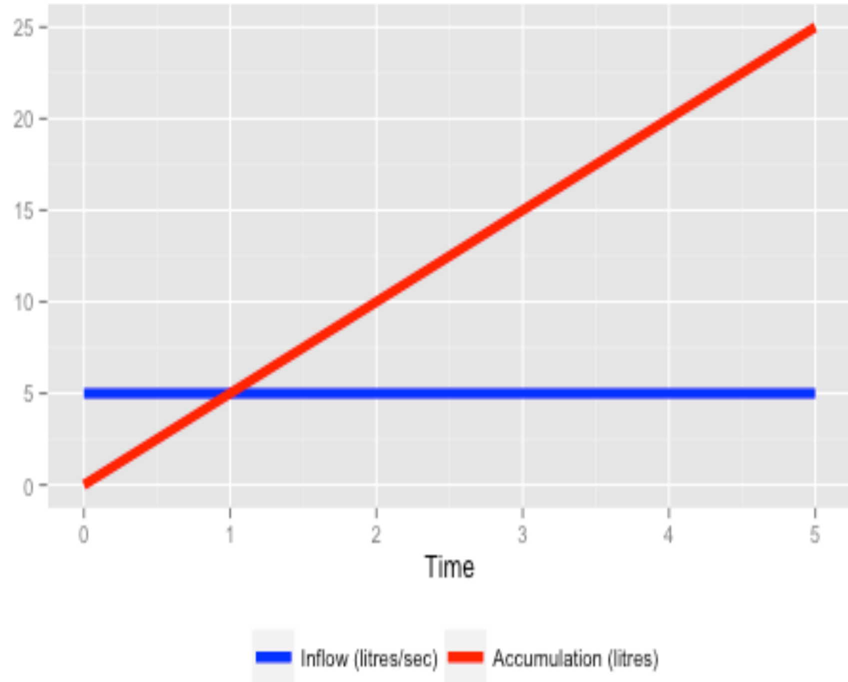


Integration

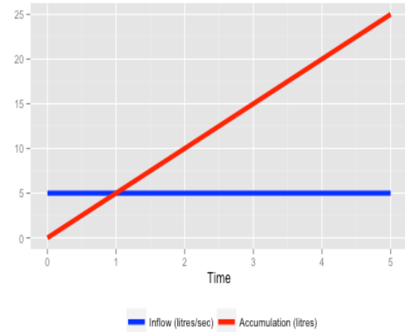
- Calculus is the study of how things **change over time**, and is described by Strogratz (2009) as *"perhaps the greatest idea that humanity has ever had."*
- Integration is the mathematical process of calculating the area under the net flow curve, between initial and final times.

Derivative (litres/minute)





Analytical Solution



$$\int x^n \, dx = \frac{1}{n+1} x^{n+1} + c$$

$$f(x) = 5\,x^0$$

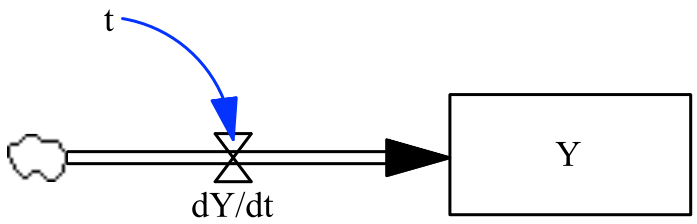
$$\int 5\,x^0\,dx = 5 \int x^0\,dx = \boxed{5x^1 + c}$$

$$\int_0^5 5x^0 dx = 5(5) - 5(0) = 25$$

$$\int_0^{1000} 5x^0 dx = 1000(5) - 5(0) = 5{,}000$$

Challenge 1.2

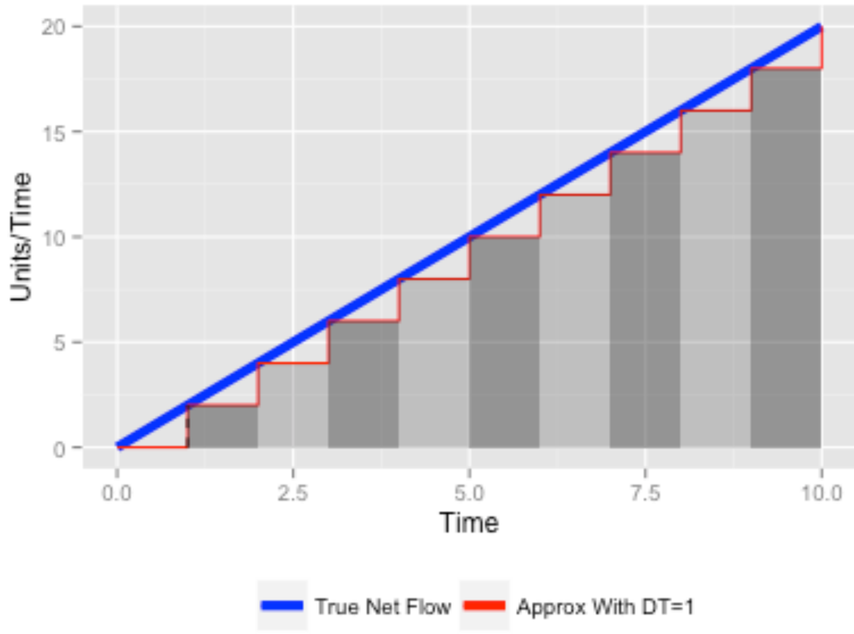
$$\frac{dy}{dt} = 2t$$



- Given this net flow, calculate the value in the stock after 10 time units.
- Verify the result using graphical integration.

Numerical Integration

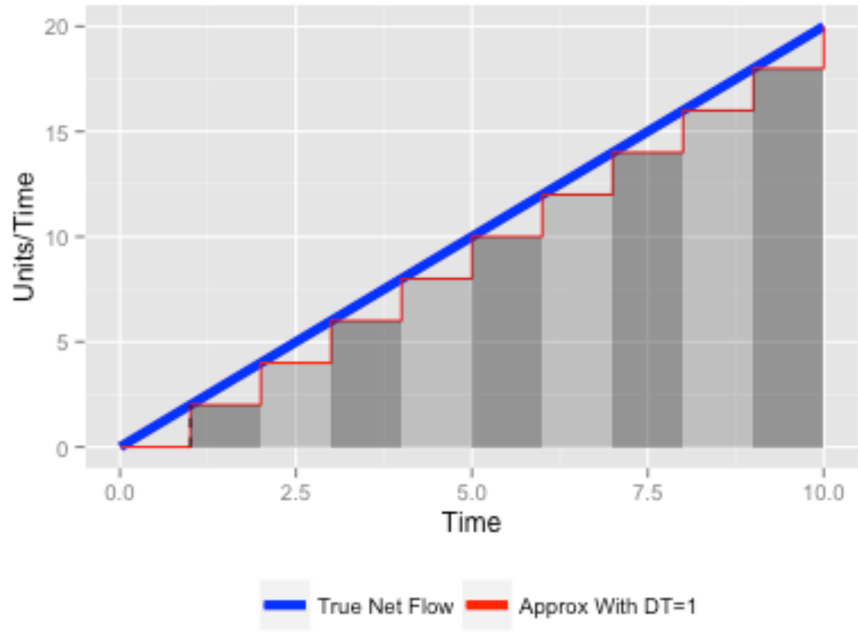
- Euler Method
- Approximate area under the net flow curve as a summation of rectangles, of width DT
- The smaller DT, the more accurate the result



$$S_t = S_{t-dt} + NF_{t-dt} \times DT$$

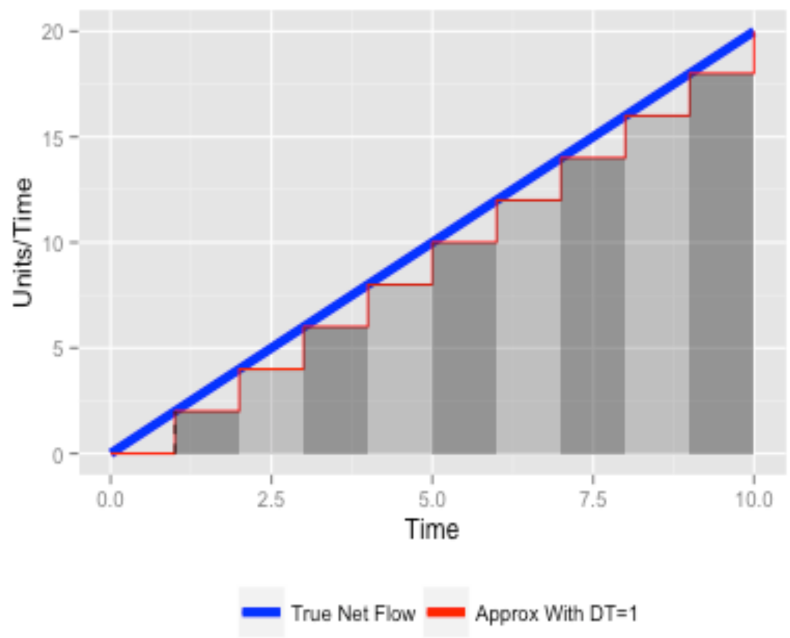
The Algorithm

- Set Time = START
- Initialise Stocks
- Calculate Flows
- Time = Time + DT
- While (Time <= END)
  - Calculate Stocks
  - Calculate Flows
  - Time = Time + DT



Solution, DT=1

Time	$Stock_t$	Net Flow
0	0	0
1	0+0=0	2
2	0+2=2	4
3	2+4=6	6
4	6+6=12	8
5	12+8=20	10
6	20+10=30	12
7	30+12=42	14
8	42+14=56	16
9	56+16=72	18
10	72+18=90	20



$$S_t = S_{t-dt} + NF_{t-dt} \times DT$$

Note: Stock only depends on previous stock and net flows

Challenge 1.3

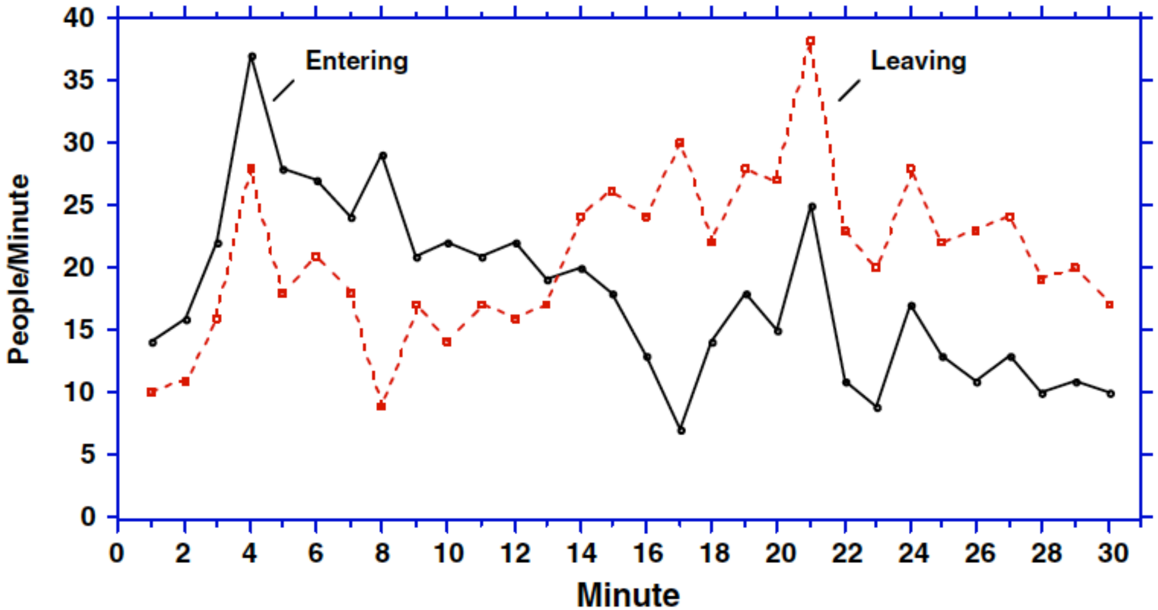
- Solve numerically, the following derivative. Assume the integral has an initial value of 100, and the time interval is [0-5]. Set DT = 0.5 for the numerical solution.

$$\frac{dy}{dt} = 4t$$

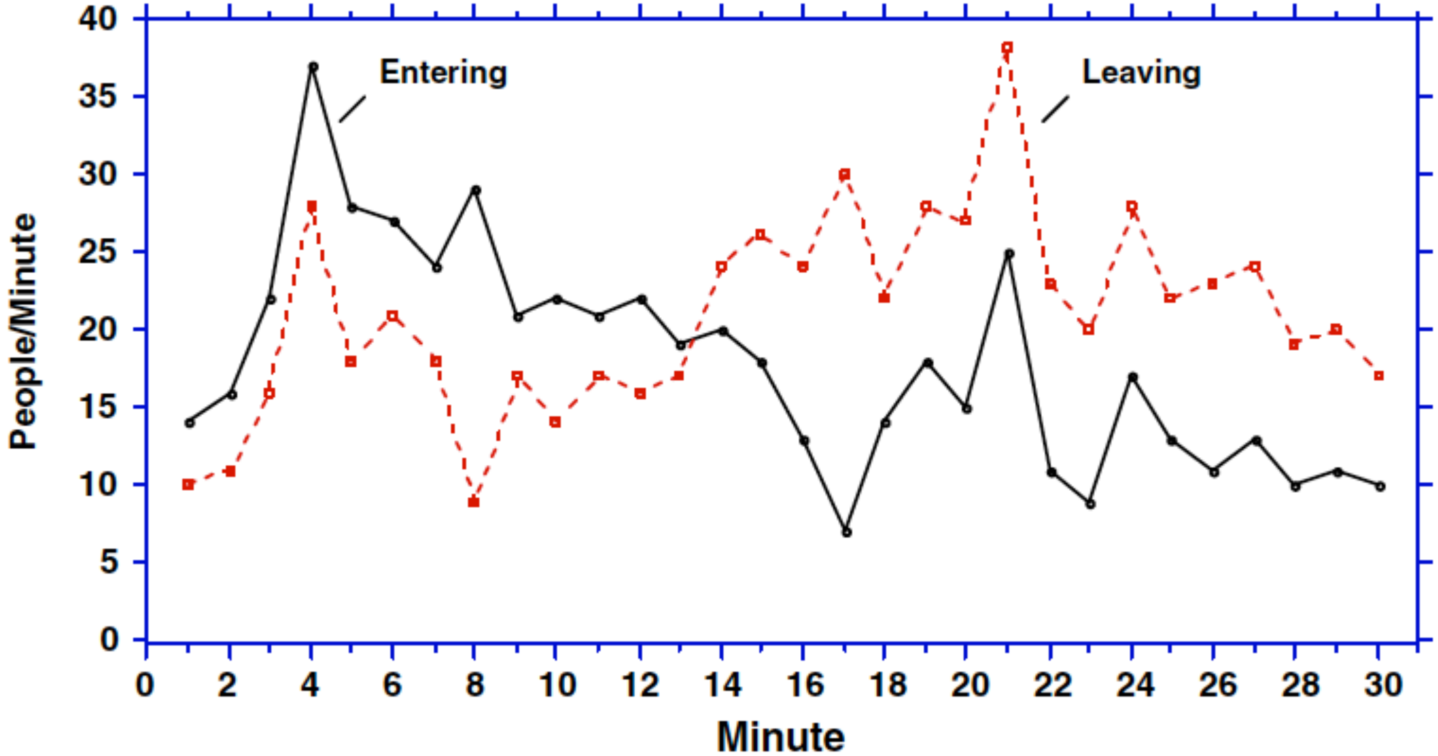
- Find the error term for this numerical solution.

Challenge 1.4

The Department Store problem (Cronin et al. 2009)



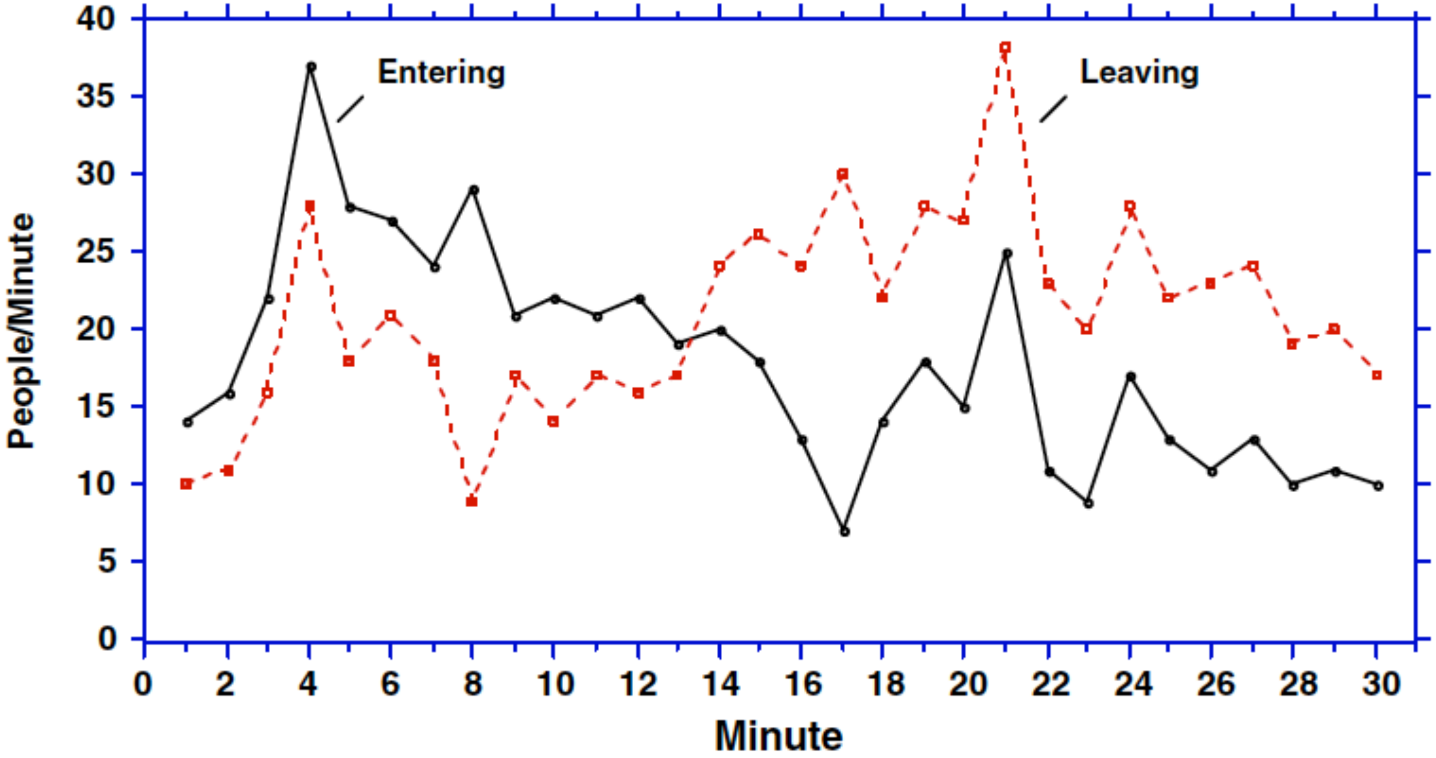
Question 1



1. During which minute did the most people enter the store?

Minute ________ ❑ Can't be determined

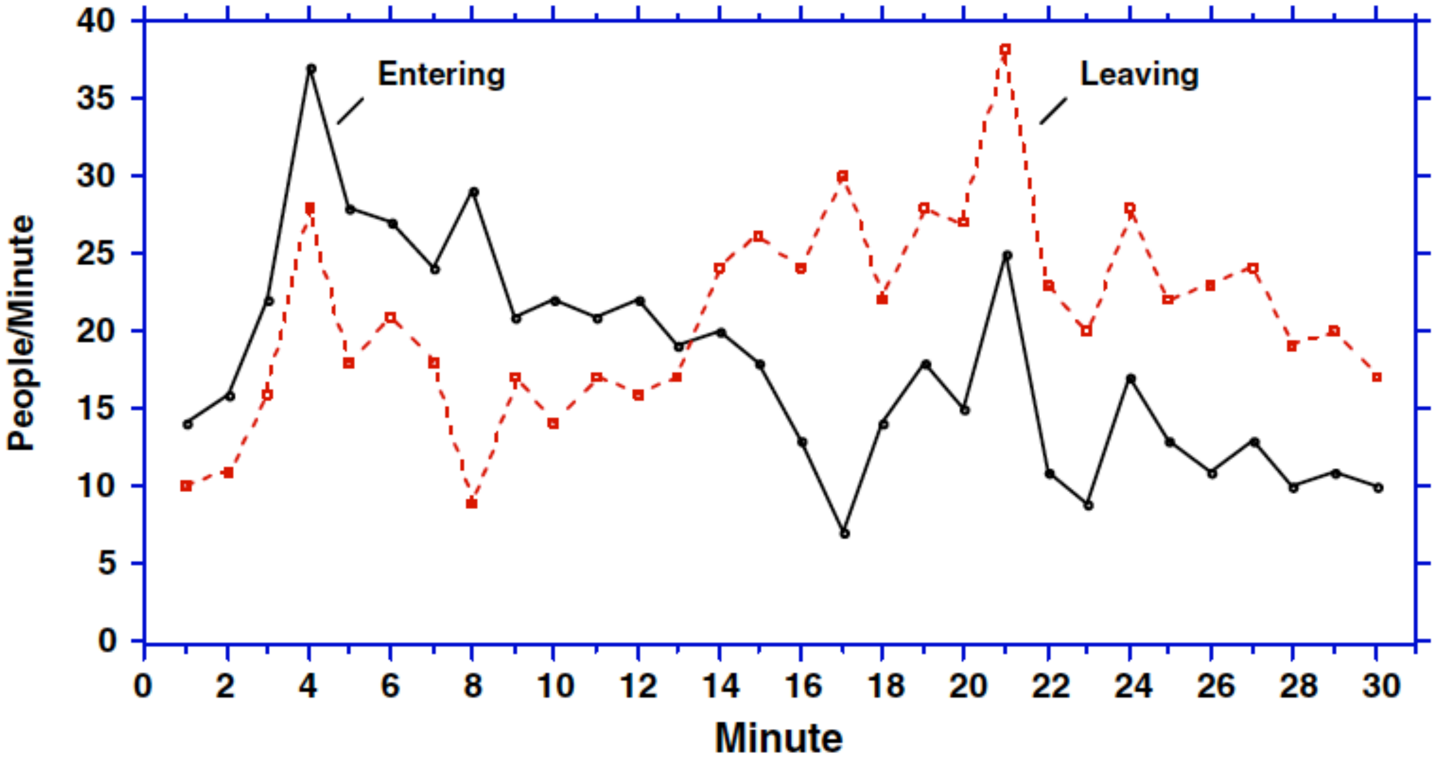
Question 2



2. During which minute did the most people leave the store?

Minute _________ ❑ Can't be determined

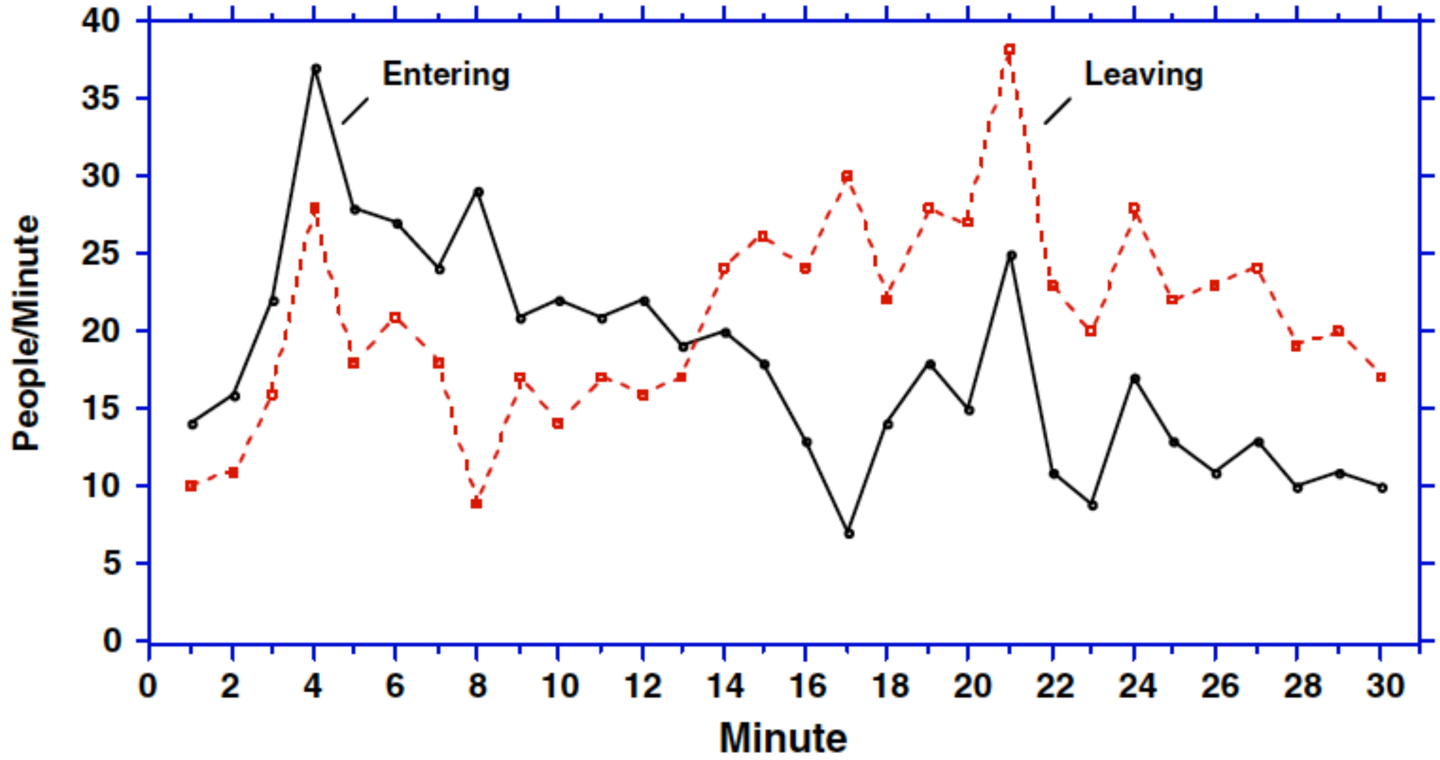
Question 3



3. During which minute were the most people in the store?

Minute ________ ❑ Can't be determined

Question 4



4. During which minute were the fewest people in the store?

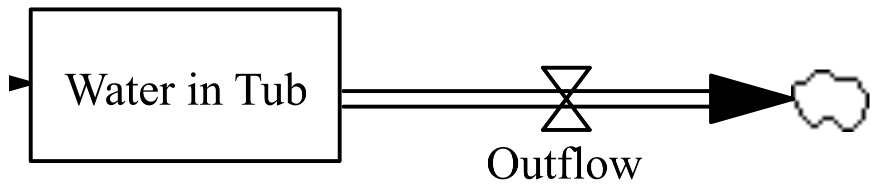
Minute ________ ❑ Can't be determined

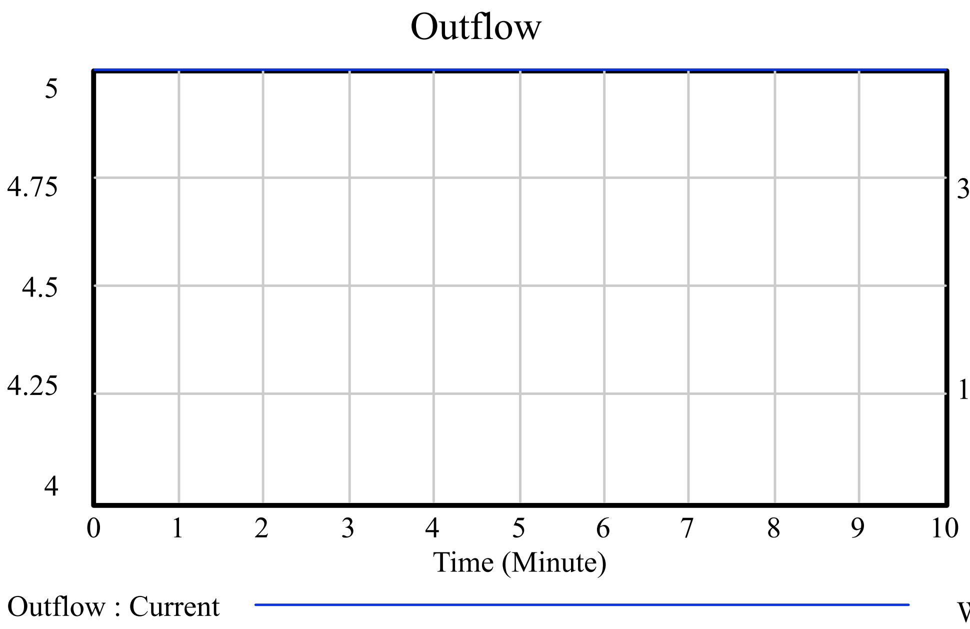
General Principle of Stock/Flow Systems

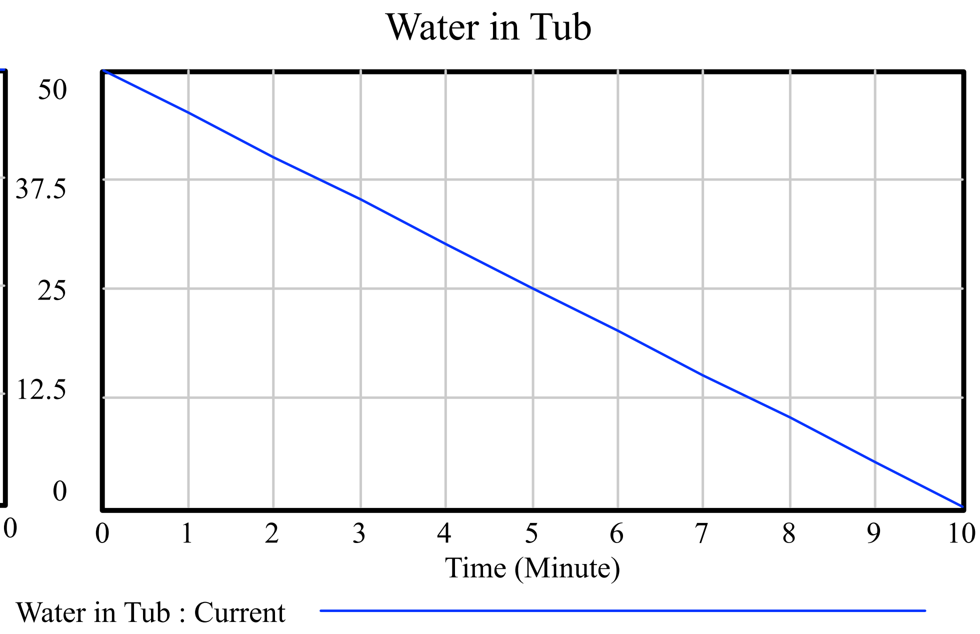
- From this simple bathtub model you can deduce **several important principles** that extend to more complicated systems:
  - As long as the sum of all inflows exceeds the sum of all outflows, the level of the stock will **rise**.
  - As long as the sum of all outflows exceeds the sum of all inflows, 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.

Stock and Flow Model

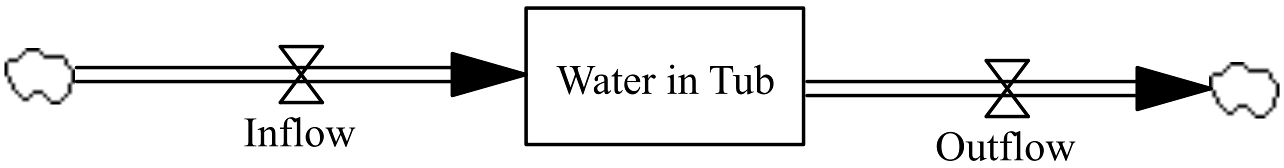






What happens next?

- Now imagine starting again with a full tub, and again open the drain, but this time, when the tub is about half empty, turn on the inflow faucet so the rate of water flowing in is <u>just equal</u> to that flowing out.



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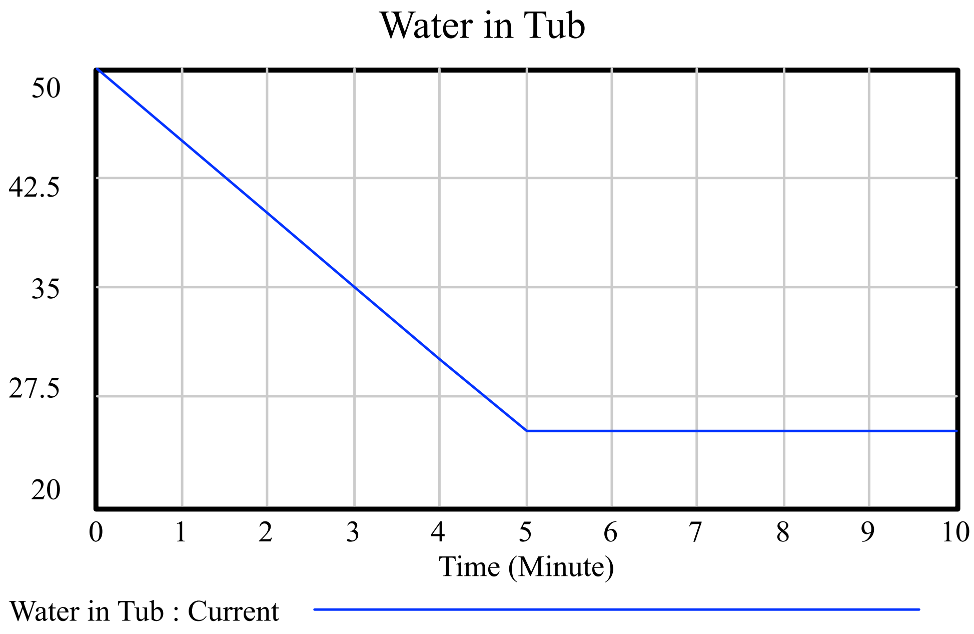
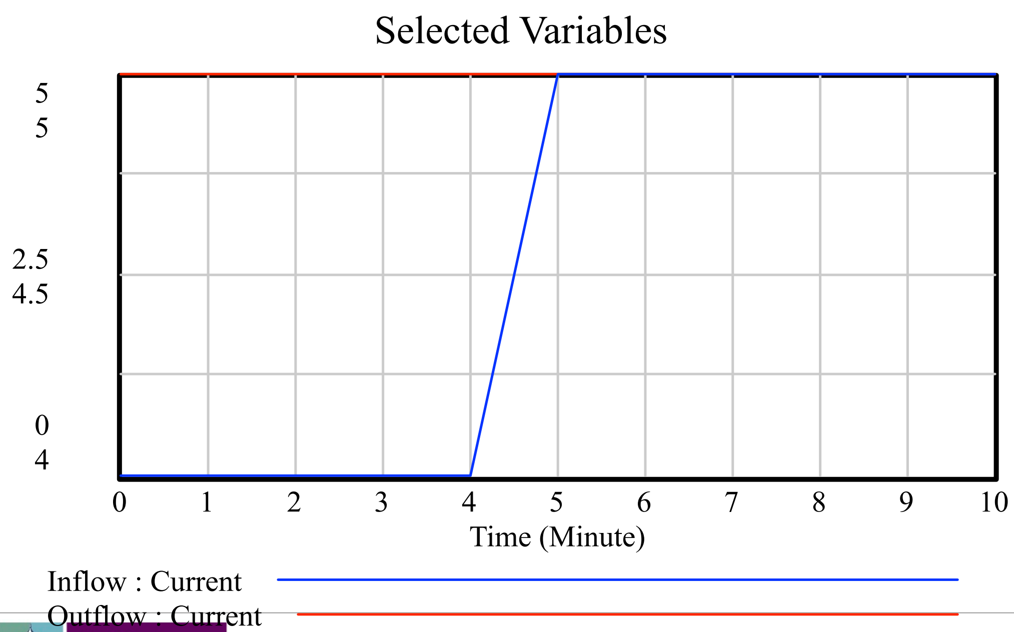


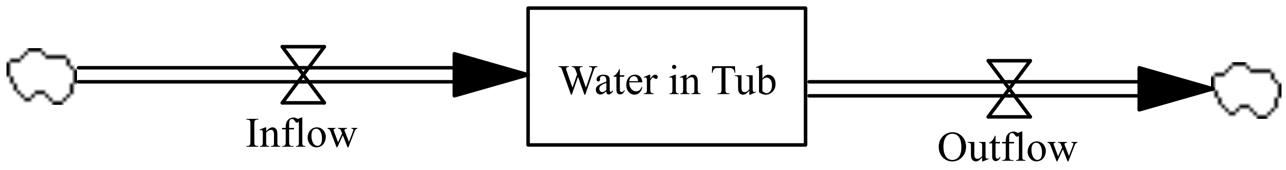


- The amount of water in the tub stays constant at whatever level it had reached when the inflow became equal to the outflow.
- It is in a state of **dynamic equilibrium**—its level does not change, although water is continuously flowing through it.

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

What happens next?

- Now imagine starting again with a full tub, and again open the drain, but this time, when the tub is about half empty, turn on the inflow faucet so the rate of water flowing in is <u>greater than</u> that flowing out.



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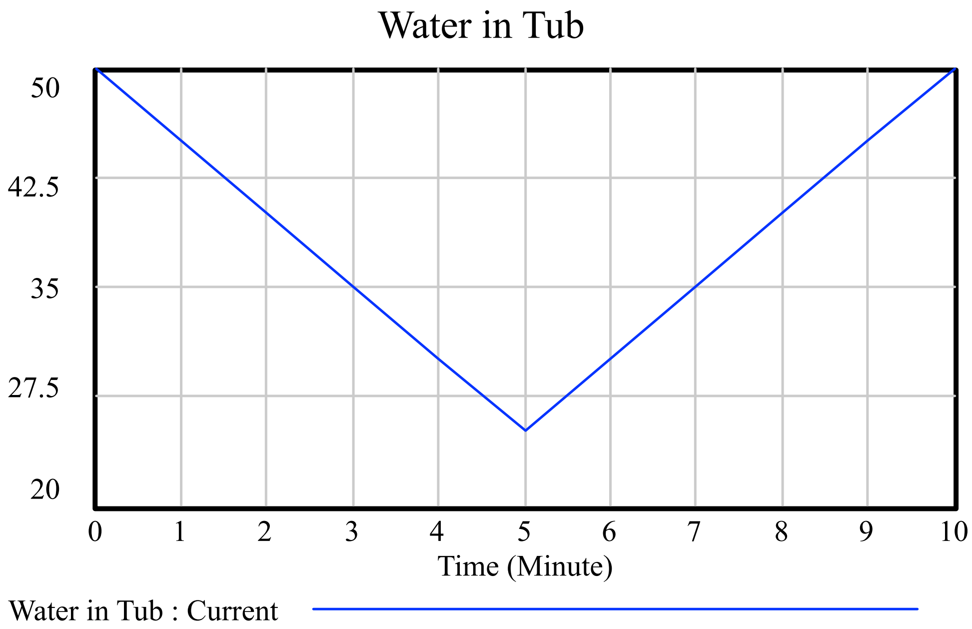

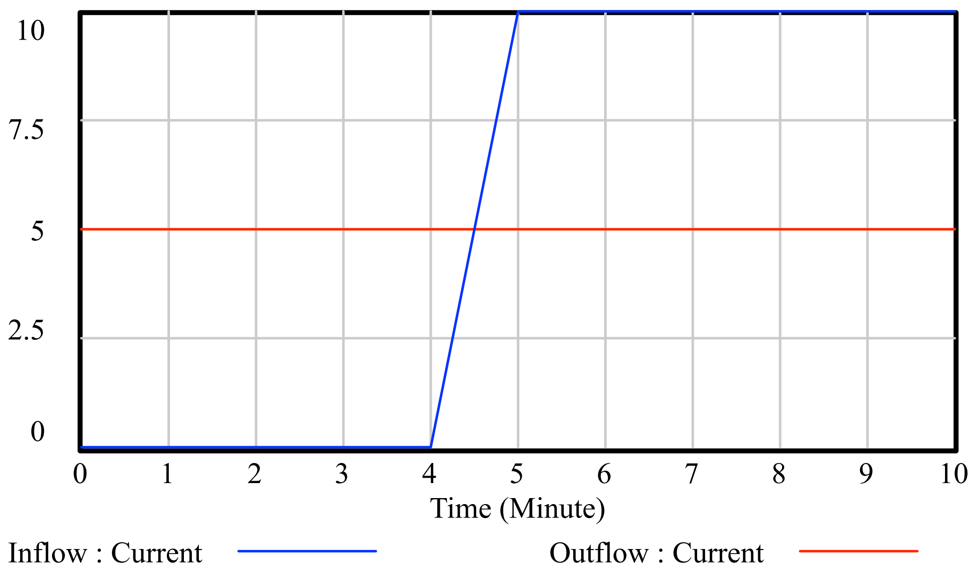

- The level of water in the tub slowly rises.
- This model of a bathtub is a very simple system with just one stock, one inflow, and one outflow.

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

Regulating Stocks

- Most individual and institutional decisions are designed to regulate the levels in stocks.
  - *If the stock of food in your kitchen gets low, you go to the store.*

- People monitor stocks constantly and make decisions and take actions designed to **raise** or **lower** stocks or to keep them within **acceptable ranges**.

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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.**

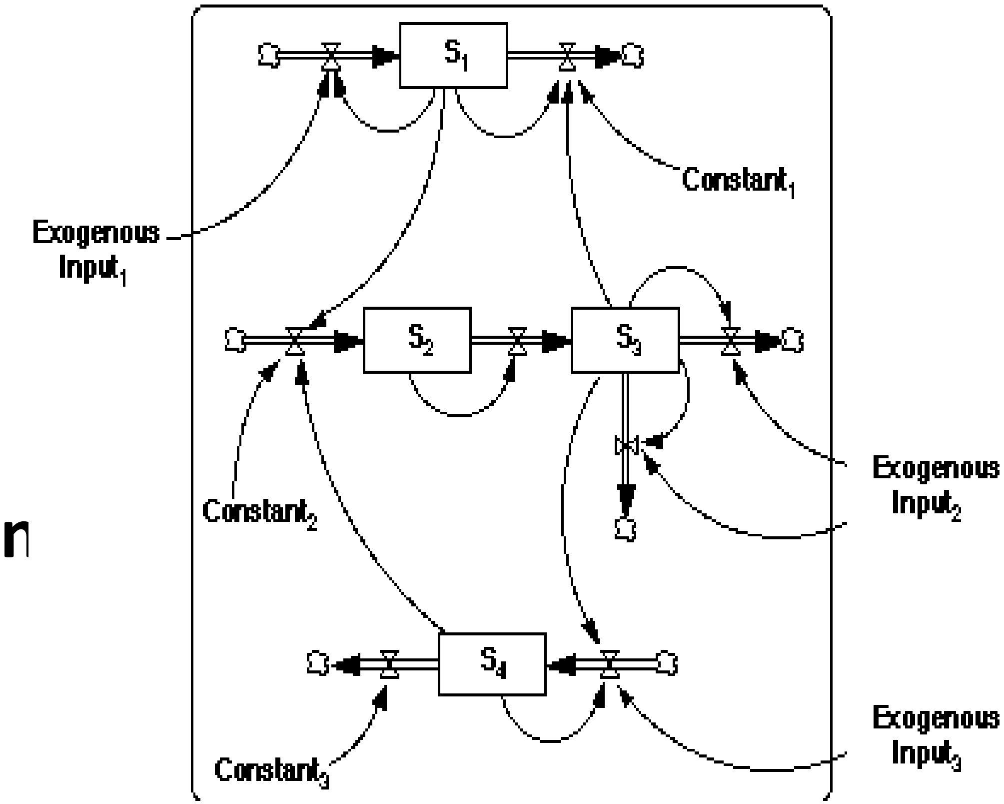

Diagram source: J.D. Sterman,Business Dynamics: Copyright © 2001 by the McGraw-Hill Companies

Challenge 1.5

- Where are the stocks in a University System?
- For each stock
  - What is the inflow
  - What is the outflow