Stock and Flow Diagram

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References:

1. Sterman, John D. (2000). *Business Dynamics: Systems Thinking and Modeling for a Complex World.* McGraw-Hills. Chapter 3: The Modeling Processes.

Preview of Previous Topic

- What is System Dynamics
- Causal Loop Diagram
- Augmenting Causal CLD
- Loop dominance
  - Labeling link polarity
  - Determining loop polarity
- Exogenous items and delays

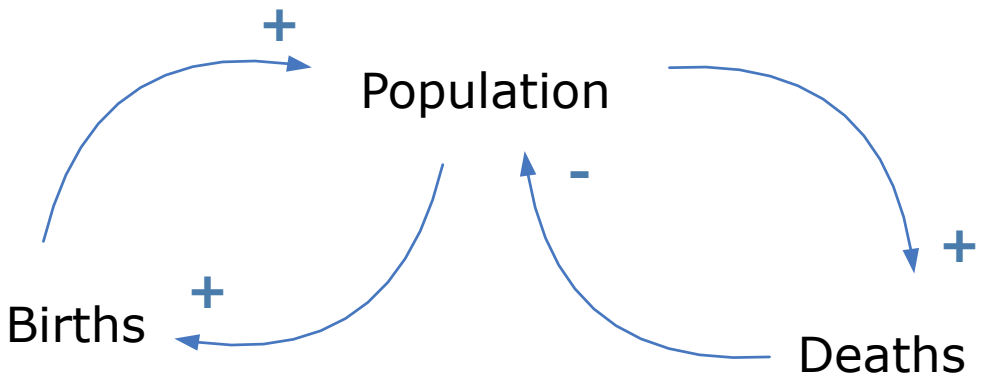
Stock and Flow Diagram (SFD)

Why Stock and Flow Diagram? (1)

- Want to bring causal loop diagram to life by **turning them into computer simulations**

- Simulation equations are more orderly when one has defined stocks and flows

Why Stock and Flow Diagram? (2)



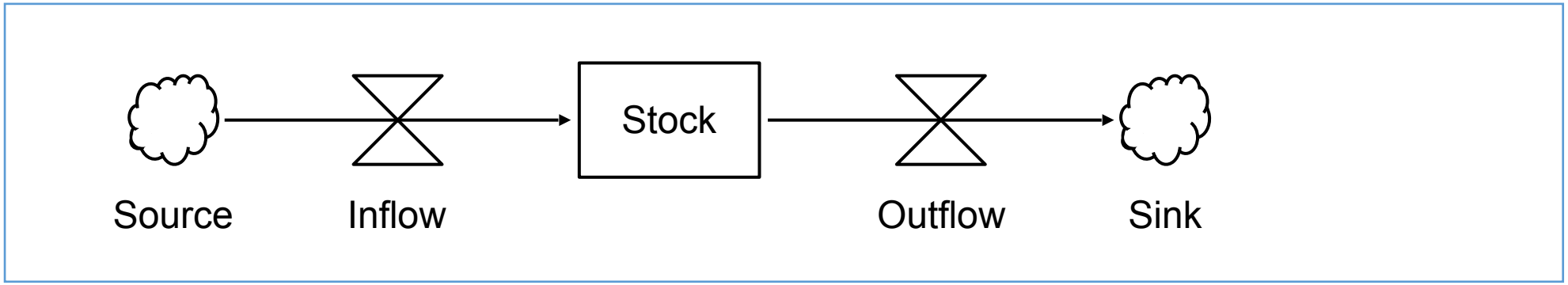
- CLD: Make no categorical distinction between concept of births, deaths, and population
- SFD:
  - See that population is durable
  - One is being born, dying for only seconds
    - Birth is inflow rate
    - Death is outflow rate

Why Stock and Flow Diagram? (3)

- CLD provide insight into a system's structure
- CLD often difficult to infer the behaviour of a system from its casual-loop representation
- CLD unable to capture the stock and flow structure of systems.
- Need to use computer simulation
- Simulation model: flow diagrams, equations, simulation language

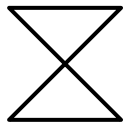
Diagramming Notation for Stocks and Flows (1 of 2)

- General Structure



Stock

Flow



Valve/Rate (Flow Regulator)

Source or Sink
(Stocks outside model boundary)

Diagramming Notation for Stocks and Flows (2 of 2)

Type of Variable	Definition
Stocks	Quantities which can accumulate, represented by rectangles
Inflows	are represented by a pipe (arrow) pointing into (adding to) the stock
Outflows	are represented by pipes pointing out of (substracting from) the stock
Valves / Rates	Changes in quantity over time, control the flows
Sources / Sinks	**A source** represents the stock from which a flow originating outside the boundary of the model arises, **Sinks** represent the stocks into which flows leaving the model boundary drain. Sources and sinks are assumed to have infinite capacity and can never constrain the flows they support

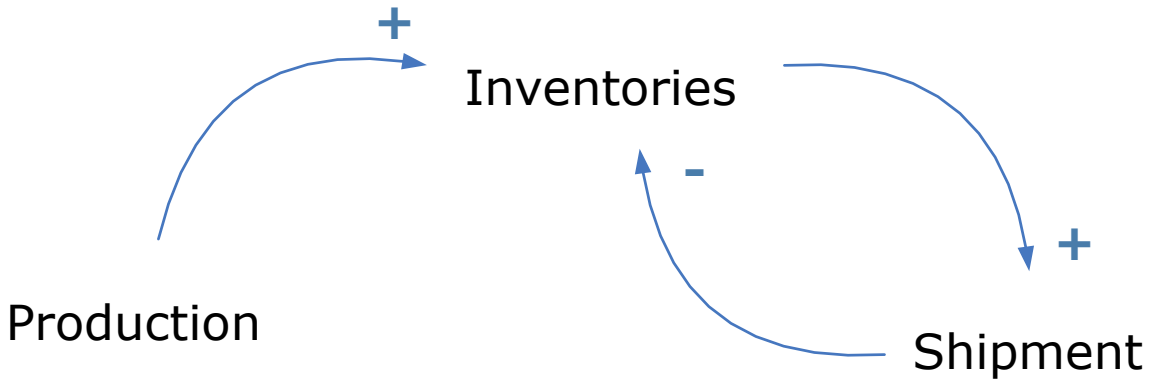
Stock

- Stock:
  - level, accumulation, or state variable
  - A quantity that accumulates over time
- Stock characterise the state of the system, and generate the information upon which decisions and actions are based.
- Stocks are altered by flows (inflows and outflows).
- Stocks create delays by accumulating the difference between inflow to a process and its outflow.
- By decoupling rates of flow, stocks are the source of disequilibrium dynamics in systems.

Flow

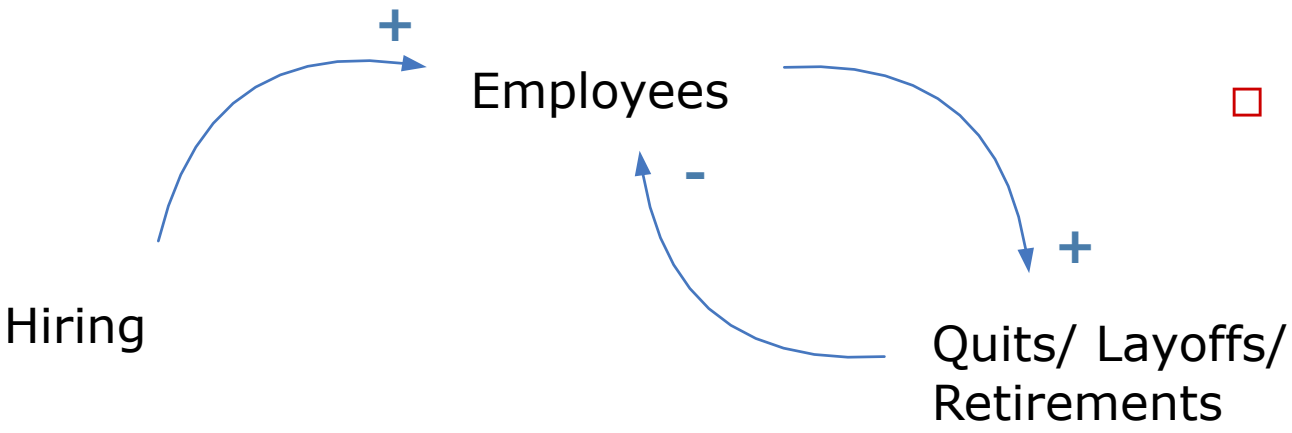
- Flow: rate, activity, movement
- Change the values of stocks
- The value of a flow is
  - Not dependent on previous values of that flow
  - But dependent on the stocks in a system along with exogenous influences

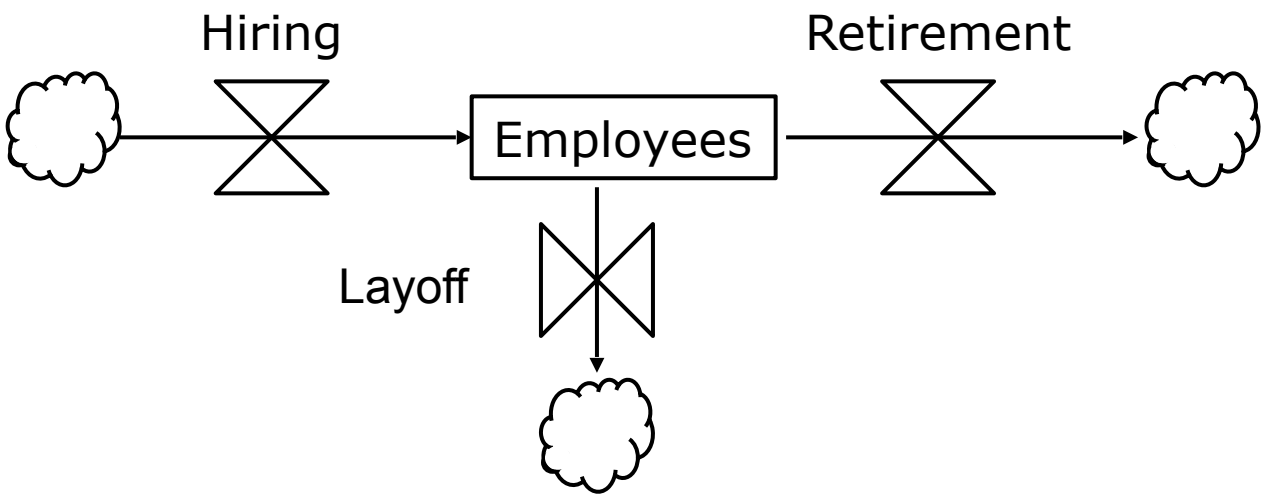
Examples #1:
The Inventory of a Manufacturing Firm



- A firm's inventory is increased by the flow of production and decreased by the flow of shipments (and possibly other outflows due to spoilage or shrinkage)

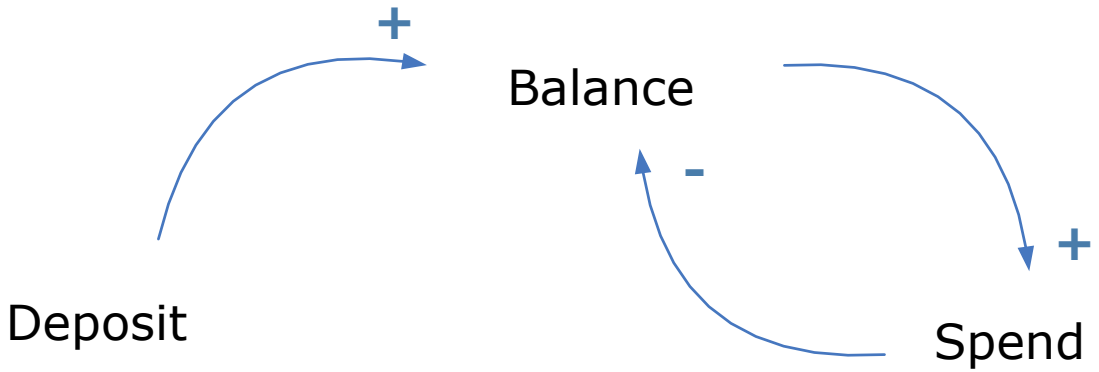
Examples #2:
The Number of People Employed by a Business



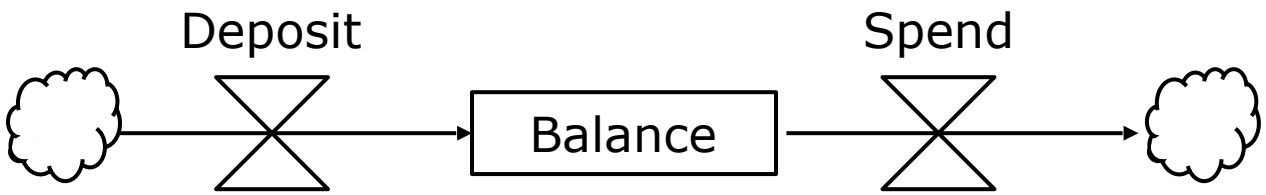


- The workforce increases via the hiring rate and decreases via the rate of quits, layoffs, and retirements.

Examples #3:
The Balance in your Checking Account



- Your bank balance increases with deposits and decreases as you spend.



- **Failure to understand the difference between stocks and flows often leads to underestimation of time delays, a short-term focus, and policy resistance.**

Mathematical Representation of Stocks and Flows (1 of 2)

- The stock and flow diagramming conventions (originated by Forrester 1961) were based on a hydraulic metaphor - the flow of water into and out of reservoirs.
- The quantity of material in any stock is the accumulation of the flows of material in less the flows of material out.
- Stocks accumulate or *integrate* their flows; the net flow into the stock is the rate of change of the stock. Hence the structure represented in Figure 6-1 above corresponds exactly to the following integral equation
- Where Inflow(s) represents the value of the inflow at any time s between the initial time t_0 and the current time t.

$$\text{Stock}(t) = \int_{t_0}^{t} [\text{inflow}(s) - \text{outflow}(s)]\, ds + \text{Stock}(t_0)$$

Mathematical Representation of Stocks and Flows (2 of 2)

- Equivalently, the net rate of change of any stock, its derivative, is the inflow less the outflow, defining the differential equation

$$d(Stock)/dt = Inflow\ (t) - Outflow(t)$$

The Contribution of Stocks to Dynamics (1 of 2)

Stocks are critical in generating the dynamics of systems for the following reasons (Mass 1980):

1. Stocks characterise the **state** of the system and provide the basis for actions
   - A pilot must know the state of the aircraft including position, heading, altitude, and fuel level. Without knowledge of these states, the pilot is flying blind and won't survive long.
2. Stocks provide systems with inertia and memory
   - Stocks accumulate past events.
   - Stocks don't have to be tangible.

The Contribution of Stocks to Dynamics (2 of 2)

3. Stocks are the source of delays
   - A delay is a process whose output lags behind its input.
4. Stocks decouple rates of flow and create disequilibrium dynamics
   - In equilibrium, the total inflow to a stock equals its total outflow so the level of the stock is unchanging.
   - However, inflows and outflows usually differ because they are often governed by different decision processes.

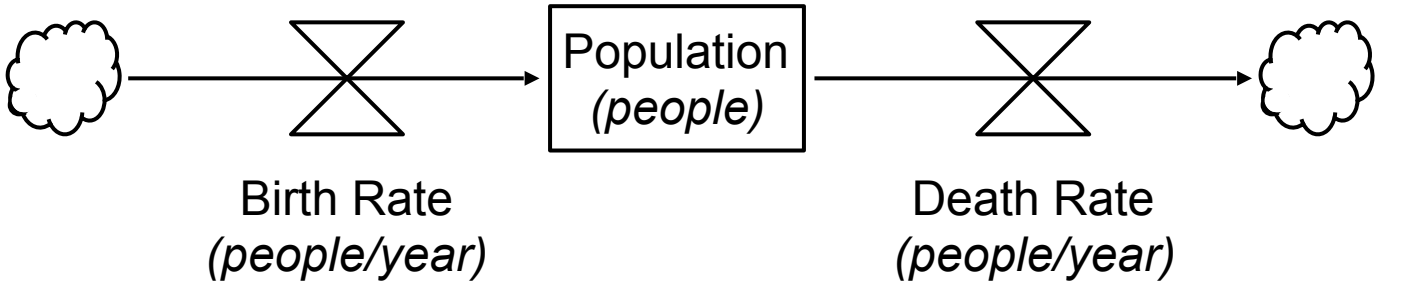
Identifying Stock and Flow

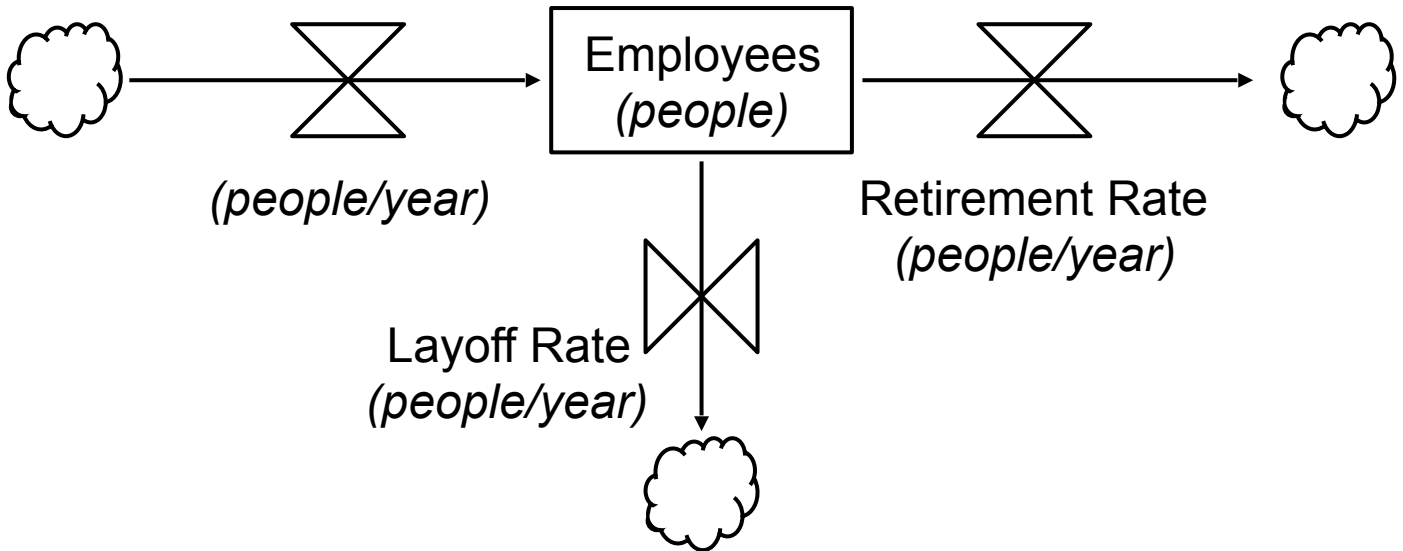
FIELD	STOCKS	FLOWS
Mathematics, Physics	Integral, states, state variables	Derivatives, rates of change, flows
Engineering Chemistry	Reactans and reaction products	Reaction rates
Manufacturing	Buffer, inventories	Throughput
Economics	Levels	Rates
Accounting	Stocks, balance sheet items	Flows, cash flow or income statement items
Biology, physiology	Compartments	Diffusion rates, flows
Medicine, epidemiology	Prevalence, reservoirs	Incidence, infection, morbidity, and mortality rates

Identifying Stock and Flow:
1. Units of Measure in Stock and Flow Networks

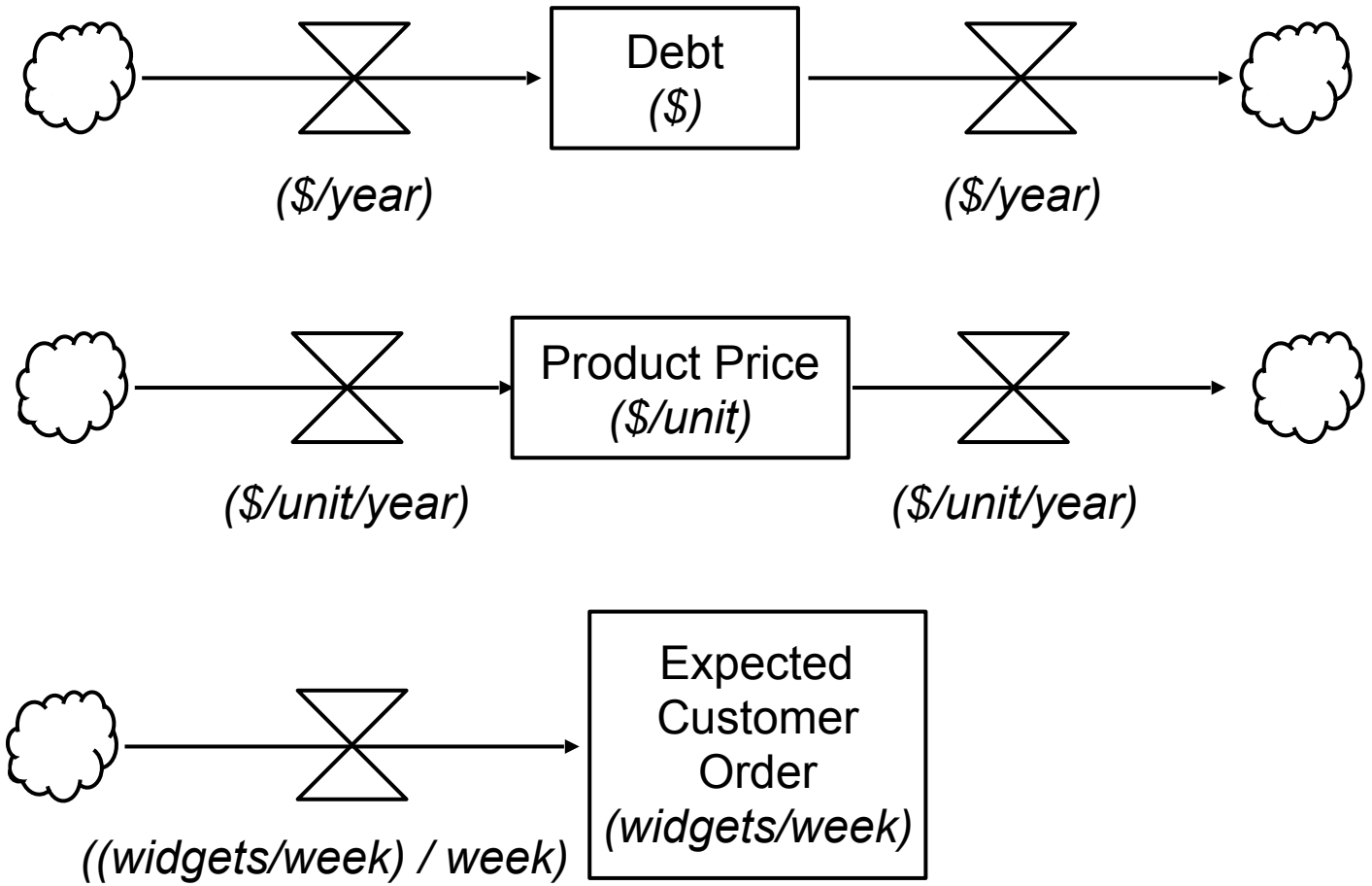
- Stocks are usually a quantity
- Flows must be measured in ***the same units per time period***
- You are free to select any measurement system you like as long as you remain consistent. Example:
  - "The current rate of production is 1200 widgets per day" is equivalent to "Production is proceeding at a rate of"
    - 8400 widgets per week
    - 50 widgets per hour

Example of Stocks and Flows with their units of measure (1 of 2)





Example of Stocks and Flows with their units of measure (2 of 2)



Identifying Stock and Flow:
2. The Snapshot Test

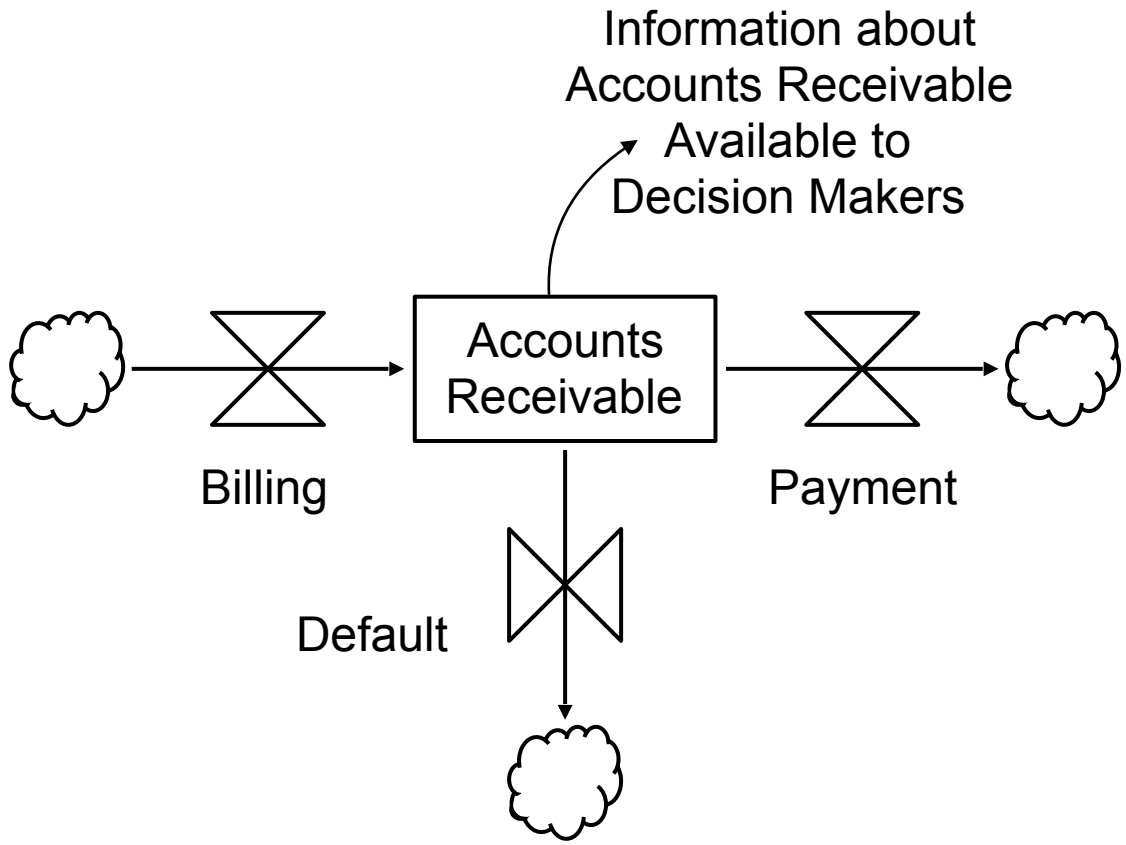
- To identify key stocks in a system, imagine freezing the scene with a snapshot: stock will be those things you could count or measure in the picture.
- If time stopped, it would be possible to determine how much inventory a company has or the price of materials but not the net rate of change in inventory or the rate of inflation in materials prices.
- This snapshot test applies also to less tangible stocks.

Identifying Stock and Flow:
3. Conservation of Material in Stock and Flow Networks (1 of 2)

- A major strength of the stock and flow representation is the clear distinction between **the physical flows** through the stock and flow network and **the information feedbacks** that couple the stocks to the flows and close the loops in the system.
- The contents of the stock and flow networks are ***conserved*** in the sense that items entering a stock remain there until they flow out.
- Stocks can represent information as well as more tangible quantities such as people, money, and materials.
- Stocks can also represent intangible variables including psychological states, perceptions, and expectations such as employee morale, the expected rate of inflation, or perceived inventory.

Identifying Stock and Flow:
3. Conservation of Material in Stock and Flow Networks (2 of 2)

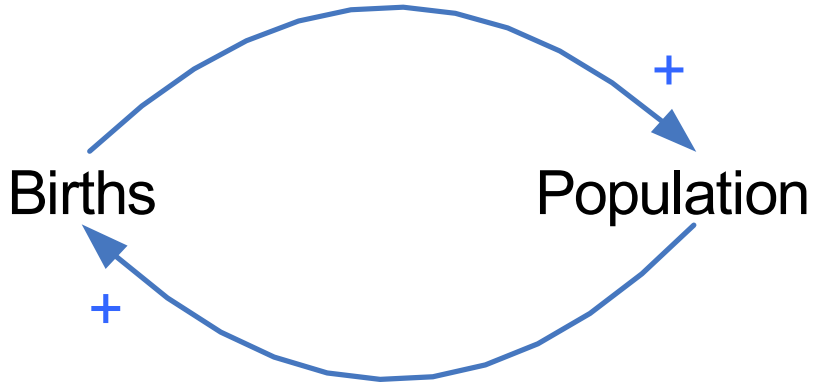
- Example: Stock and flow structure of Accounts Receivable
  - The material flowing through the network is actually information about customers and the amounts they owe. This information is conserved- the only way a receivable, once billed, is removed from the stock is if the customer pays or defaults.
  - Information about the stock of receivable is not conserved. It can be made available throughout the system and is not depleted by usage.

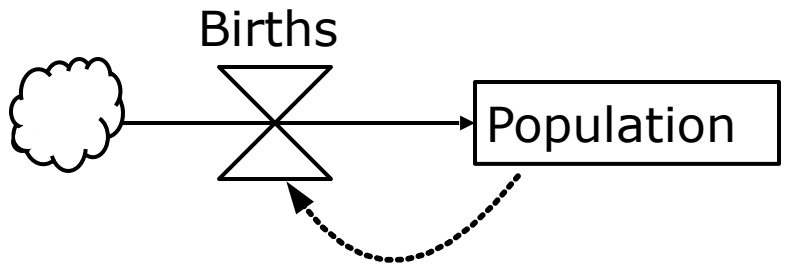


Identifying Stock and Flow: State-Determined Systems

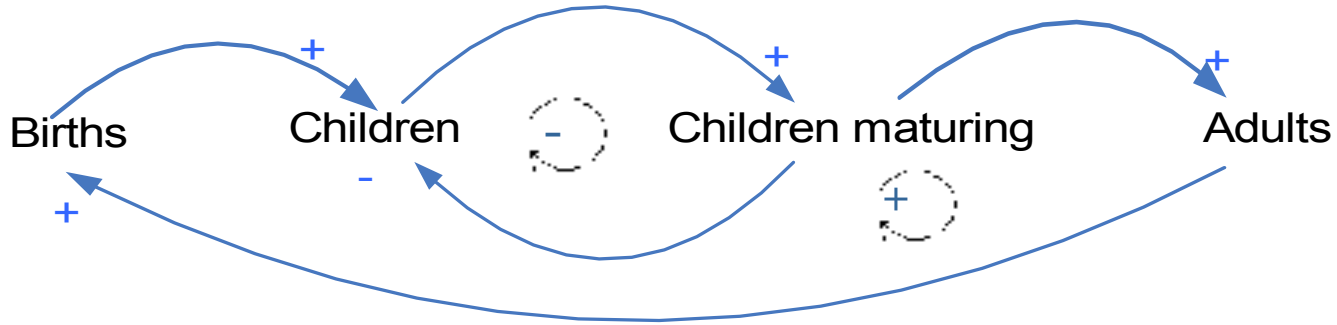
- The theory of dynamic systems takes a state-determined system or state variable approach.
- The only way a stock can change is via its inflows and outflows. There can be **no** causal link directly into a stock.
- In turn, **the stocks determine the flows**. Systems therefore consist of networks of stocks and flows linked by **information feedbacks** from the stocks to the rates

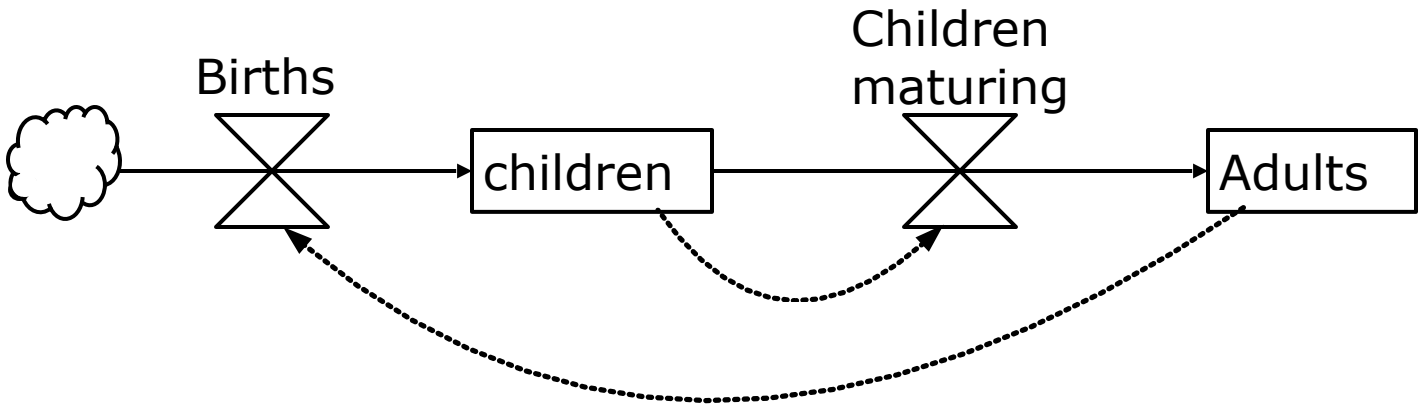
Example 1
(Population and Birth)





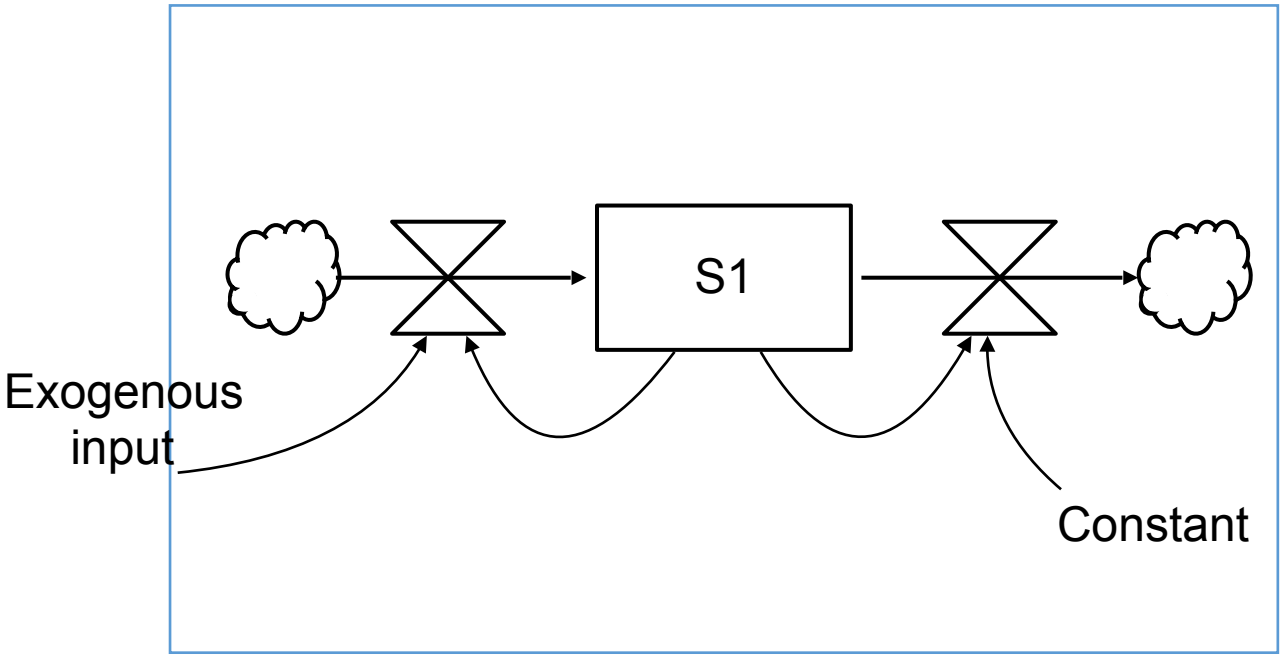
Example 2
(Children and Adults)





Identifying Stock and Flow: State-Determined Systems

- The determinants of rates include any constants and exogenous variables (these too are stocks).
  - **Constants**: state variables that change so slowly they are considered to be constant over the time horizon of interest in the model.
  - **Exogenous variables**: stocks you have chosen not to model explicitly and are therefore outside the model boundary.



Auxiliary Variables: ◯

- Auxiliary consist of functions of stocks (and constants or exogenous input).
- Auxiliary variables arise when the formulation of a level's influence on a rate involves one or more intermediate calculations
- Often useful in formulating complex rate equations
- Used for ease of communication and clarity
- Value changes immediately in response to changes in levels or exogenous influences

Example: A Model for Customer Service

- Customers arrive at some rate and accumulate in a queue of Customers Awaiting Service. The queue could be
  - a line at a fast food restaurant
  - cars awaiting repair at a body shop, or
  - people on hold calling for airline reservations.
- When the service is completed customers depart from the queue, decreasing the stock of customers waiting for service.
- The rate at which customers can be processed depends on
  - the number of service personnel,
  - their productivity (in customers processed per hour per person), and
  - the number of hours they work (the workweek).
- If the number of people waiting for service increases, employees increase their workweek as they stay an extra shift, skip lunch, or cut down on breaks.

Example: A Model for Customer Service