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Introduction to Systems Thinking & System Dynamics

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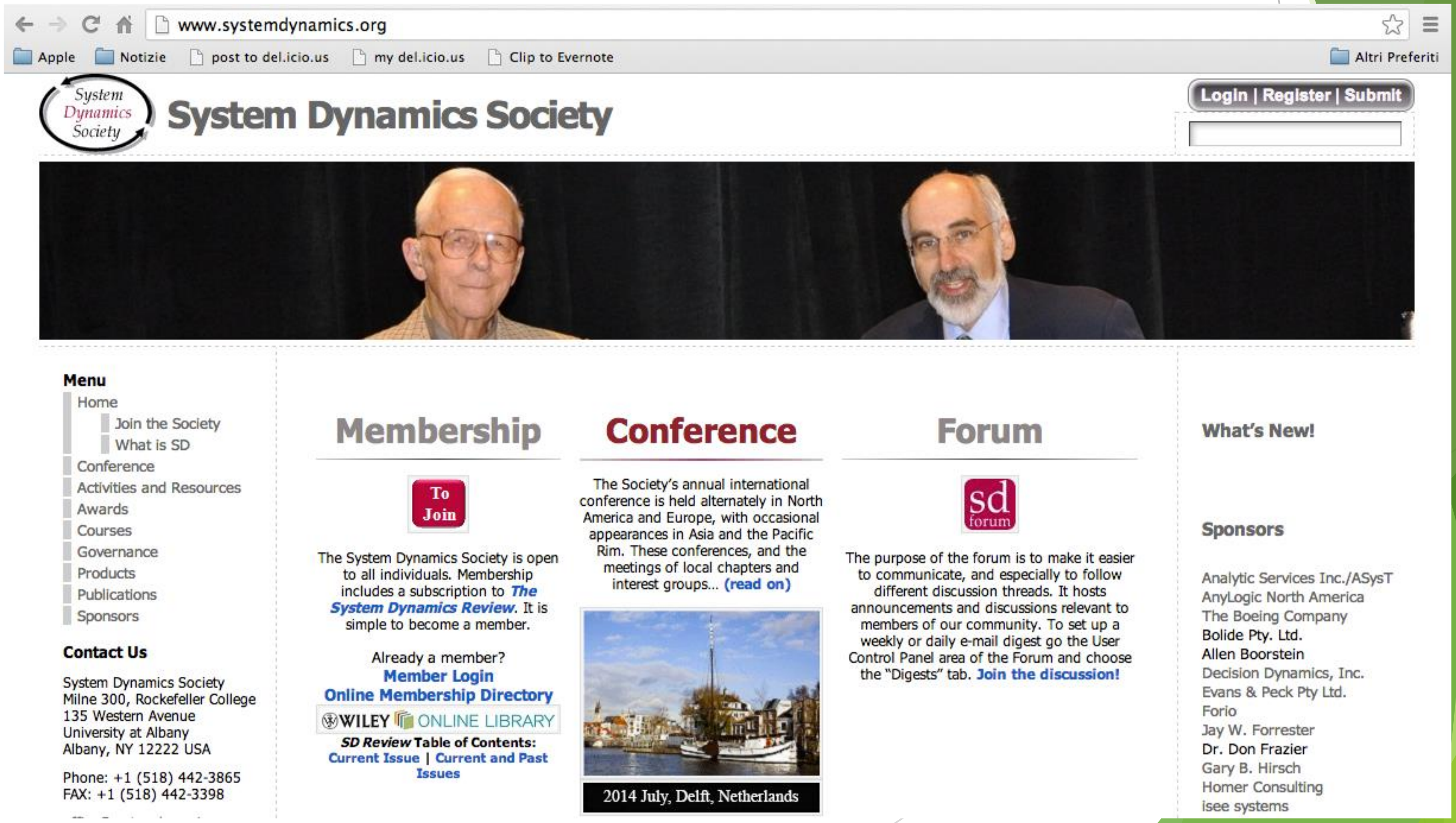
System Dynamics Society

- SDS: www.systemdynamics.org



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SYDIC SYstem Dynamics Italian Chapter

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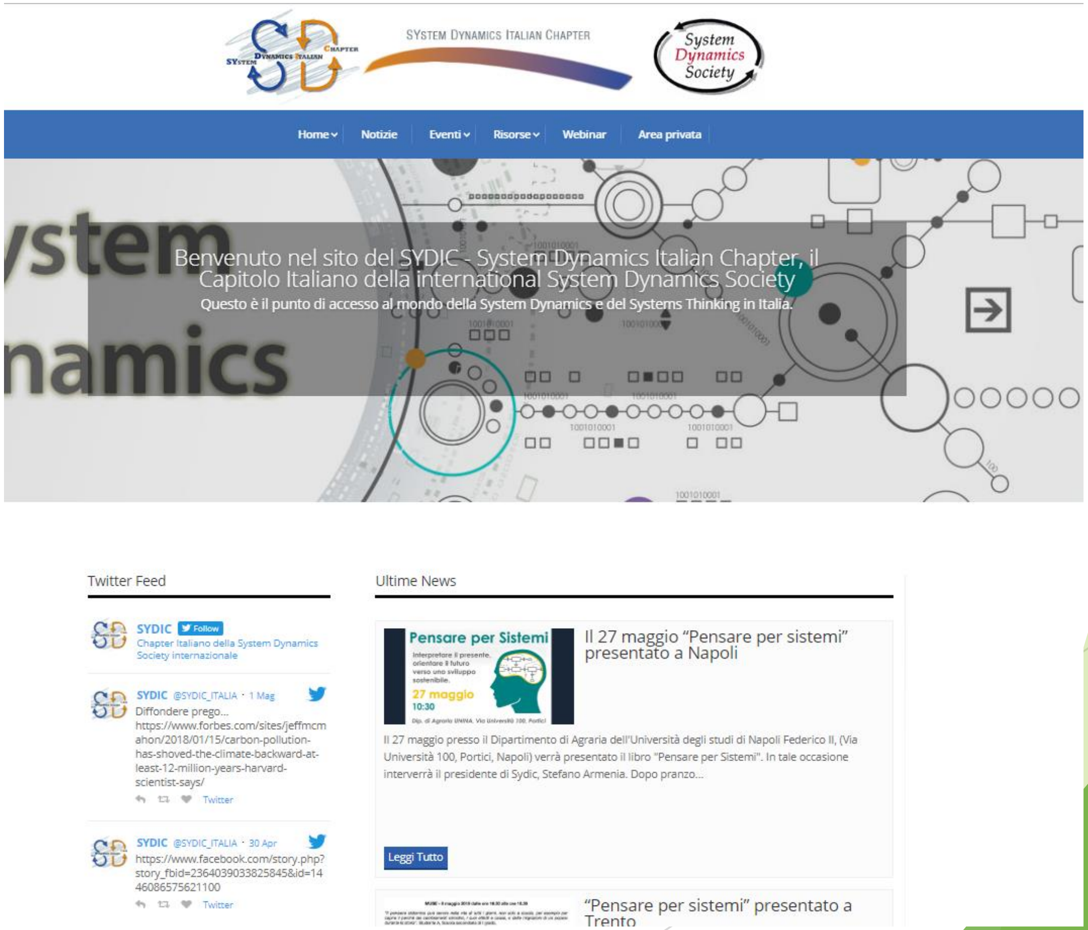


Thinking in Systems

"The problems we have created in the world today will not be solved by the level of thinking that created them."

--Albert Einstein

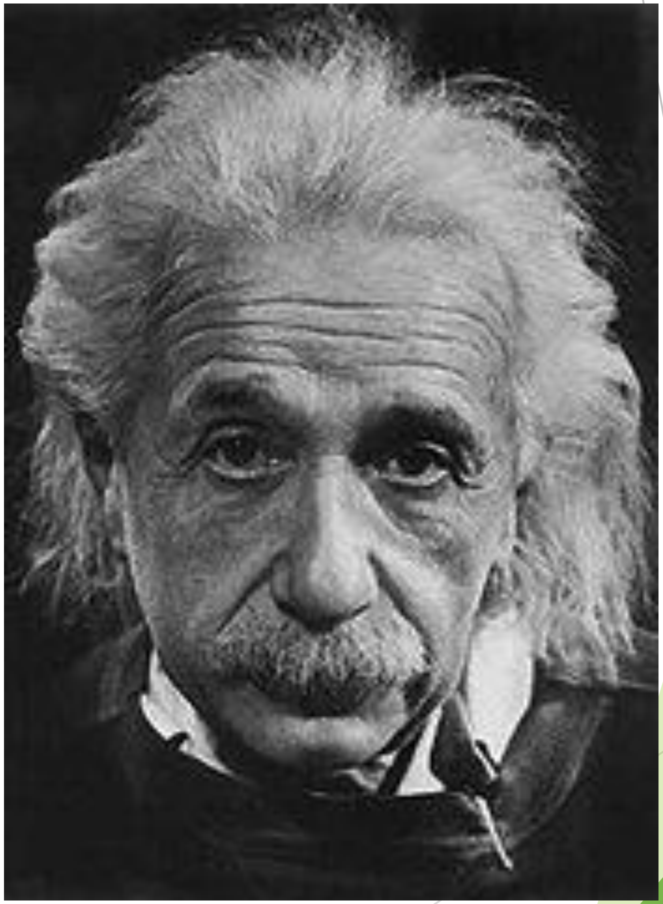


Image Source: Flickr Creative Commons, by mansionwb

The World’s Biggest Problems

- Armed Conflict
- Spread of Infectious Disease
- Growing Population
- Availability of Energy
- International Terrorism
- The Economy
- Climate Change
- Poverty, Hunger, Lack of Water

Date Source: Eurobarometer survey of the EU, 2011
Image Source: 123RF

Why Do These Problems Persist?

Schools Have Not Prepared Students to Solve Them

Learning to solve this…

A car averages 27 miles per gallon. If gas costs $4.04 per gallon, which of the following is closest to how much the gas would cost for this car to travel 2,727 typical miles?

A. $44.44
B. $109.08
C. $118.80
D. $408.04
E. $444.40

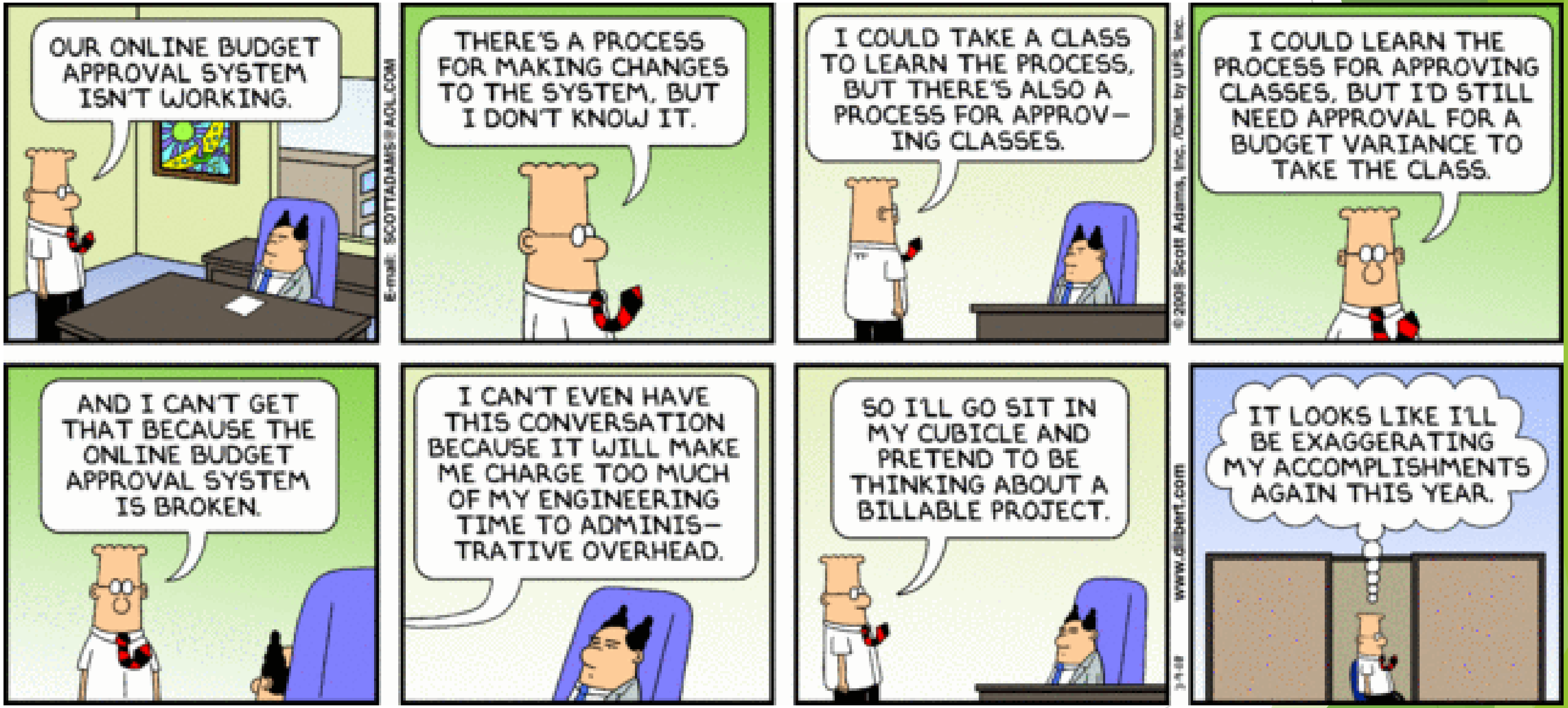
Question Source: ACT Prep
Image Source: MarketMixup

won’t teach you to solve this.

The United States consume more than 20% (7 billion barrels) of the world’s oil supply annually, yet only have 2% of the world’s proven oil reserves. What factors will determine when we reach “peak oil”—the point in time when the maximum rate of petroleum extraction is reached, after which the rate of oil production is expected to enter terminal decline?

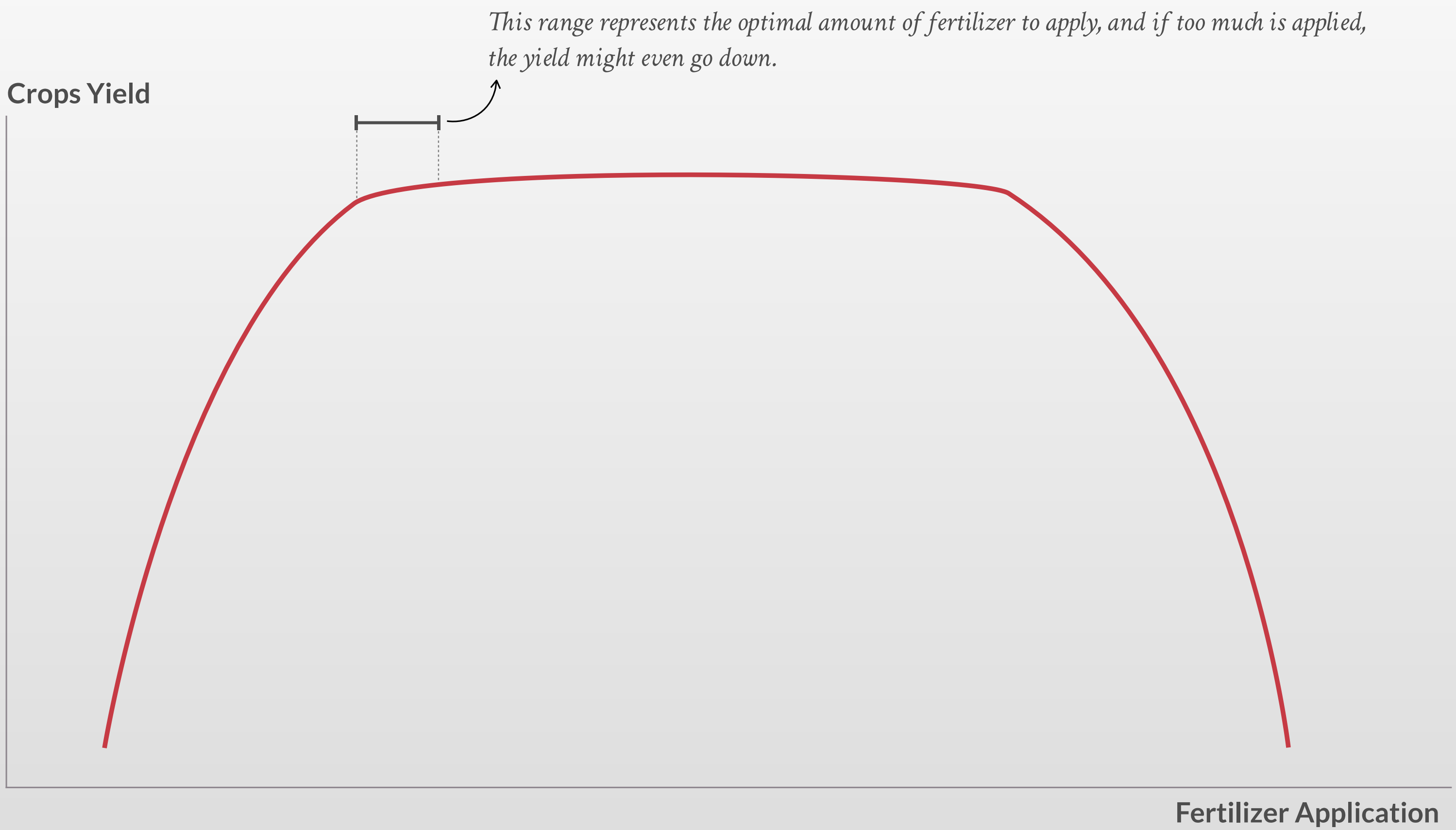
Image Source: [OnlineBikeMania]()

The Dilbert System



We are linear thinkers in a non-linear world.

In a nonlinear relationship, the cause does not produce a proportional effect.



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Reality is made up of circles, but we see straight lines. Herein lies the beginnings of our limitation as systems thinkers.

—

Peter Senge

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BOUNDED RATIONALITY

In decision making, rationality of individuals is limited by the information they have.

Fishermen are not aware of the total number of fish in the ocean or how many fish others harvest. This is a typical example of a dilemma referred to as "The Tragedy of the Commons" - a situation in which a group of individuals act rationally in their own self-interest and deplete a shared limited resource.

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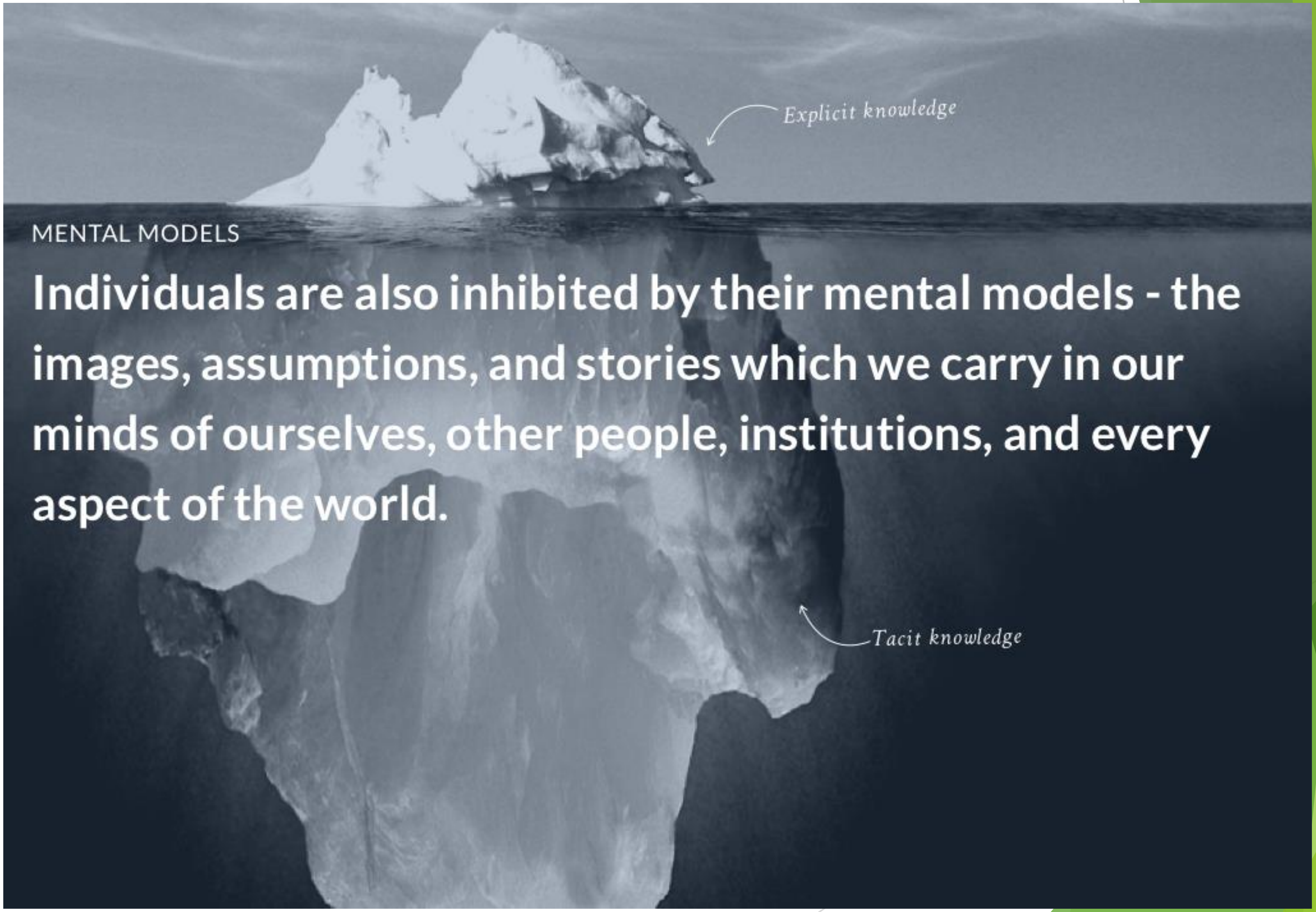

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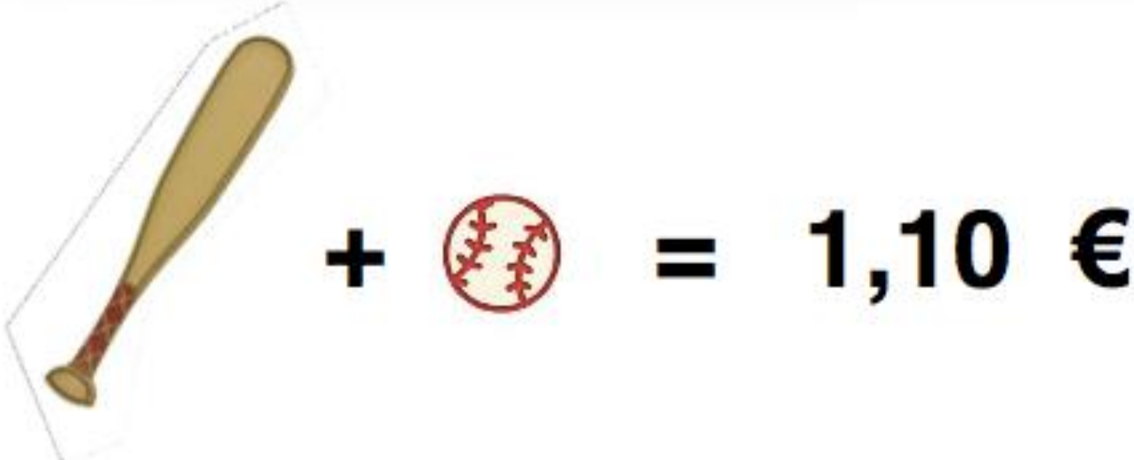
Bounded rationality

DECIDE Cognitive self-monitoring (Frederick, 2003)



The bat costs 1 euro more than the ball

How much does the ball costs ?

Bounded Rationality /2

WRONG !!!!

= 0,10 €

= 1,10 €

Total = 1,20 €

(Correct answer = 0,05 €)

All of these things are systems.

Ping pong is a system.

IT HAS IDENTIFIABLE INDIVIDUAL PARTS.

PART 2

PART 1

PART 3

PART 4

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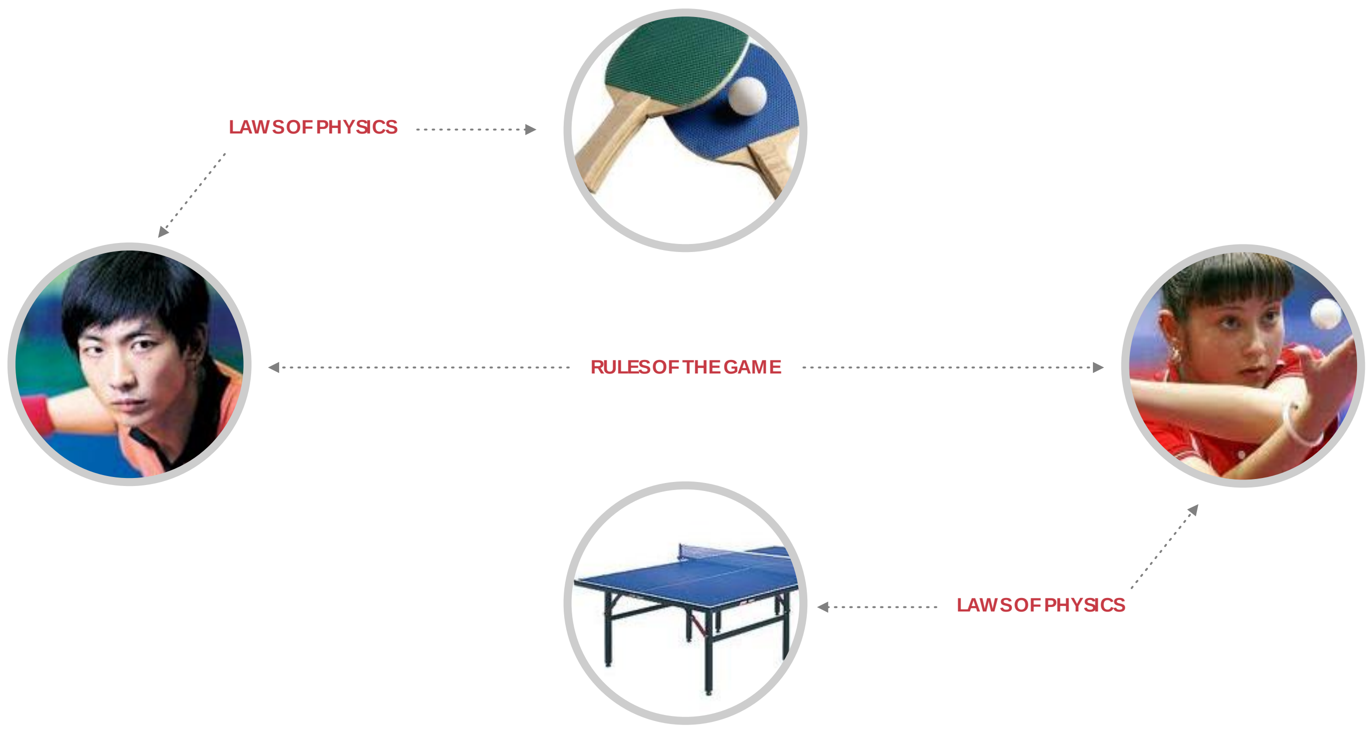
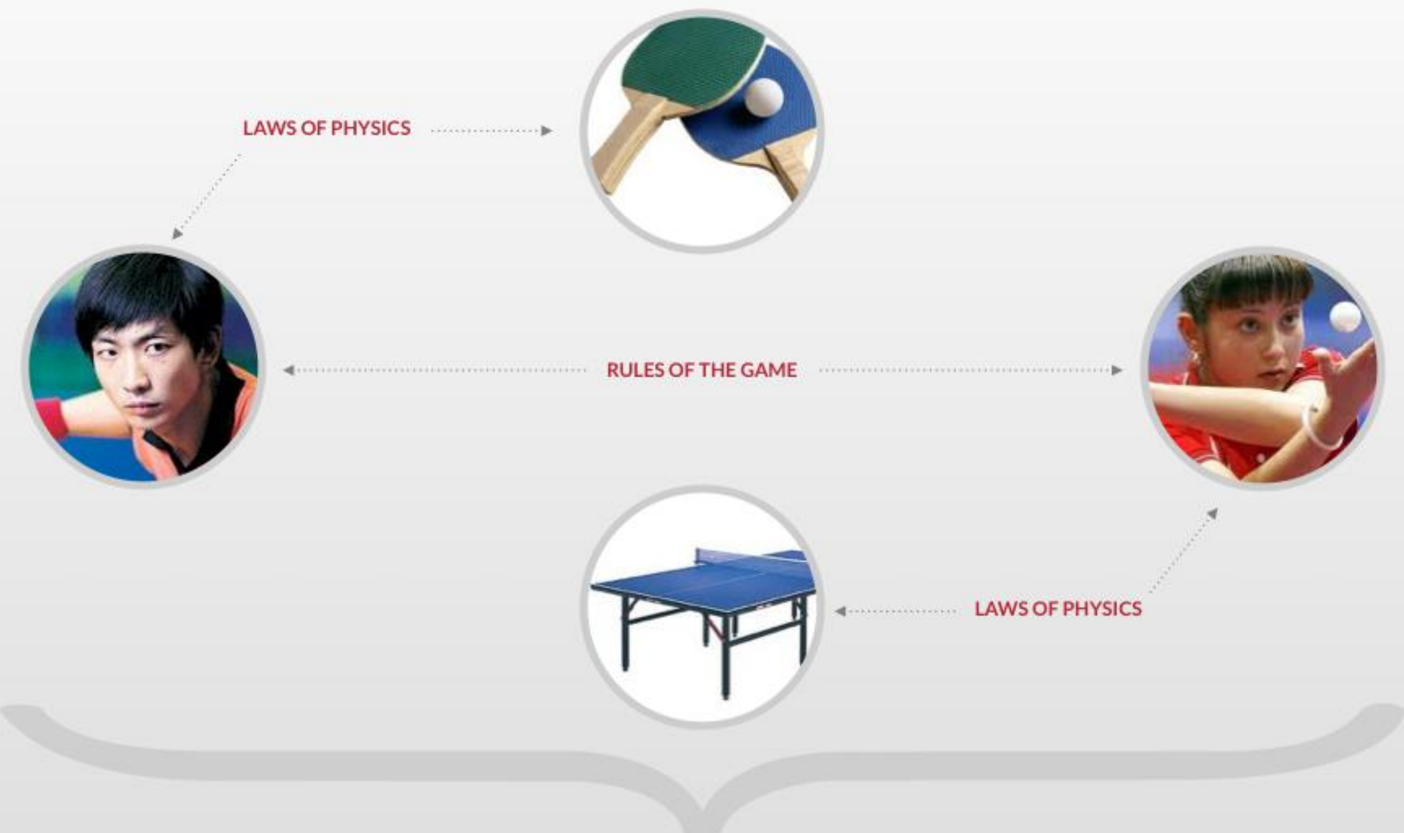
Ping pong is a system.

THE PARTS AFFECT EACH OTHER.



Ping pong is a system.

TOGETHER, THESE PARTS CREATE A UNIQUE EFFECT.



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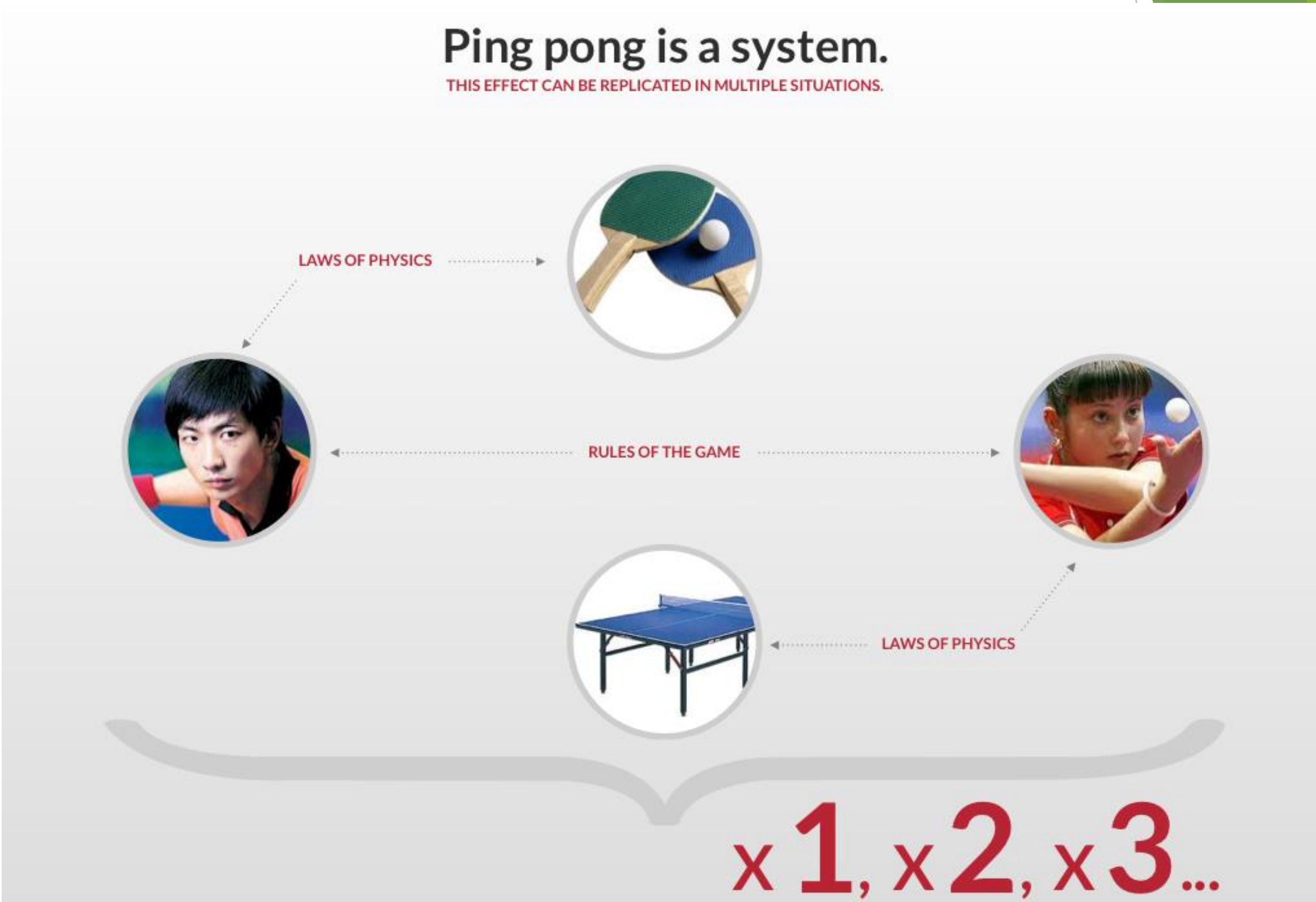
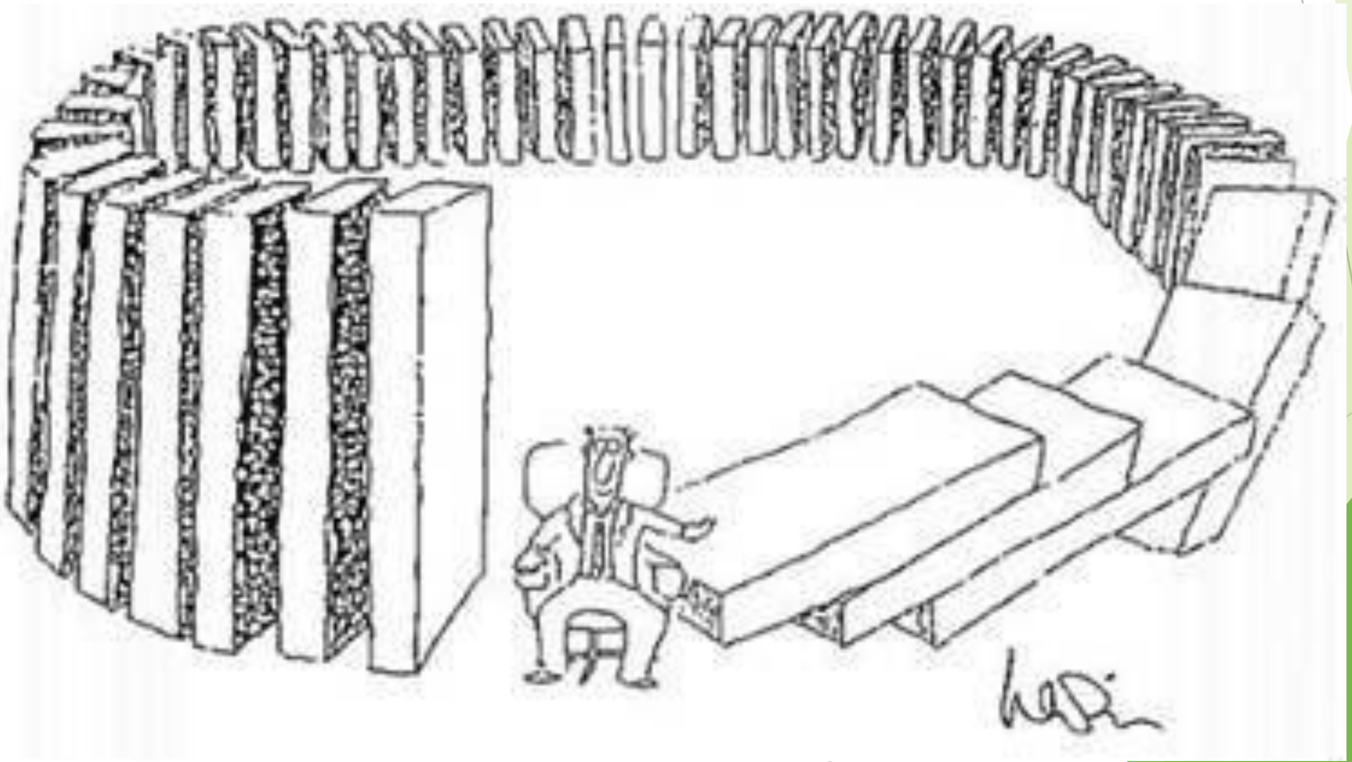


What you see is “not” what you get…

Counter-intuitive Behaviours: Misperceptions of Delays



Counter-intuitive Behaviours: Misperceptions of Feedbacks

Counter-intuitive Behaviours: policy resistance

Systems Thinking

Traditional analysis focuses on the individual pieces of what is being studied. **Systems thinking** focuses on how the things being studied interact with the other constituents of the system.

Instead of isolating smaller and smaller parts of the system being studied, systems thinking works by expanding its view to consider larger and larger numbers of interactions as an issue is being studied.

Image Source: Flickr Creative Commons, by erwlas

What is Thinking?

"Thinking consists of two activities: constructing mental models and then simulating them in order to draw conclusions and make decisions." – Barry Richmond

Understanding the concept of a tree requires more information than is available through sensory experience alone. It's built on past experiences and knowledge.

Source: Jeremy Merritt

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Systems Thinking

- The approach of systems thinking is fundamentally different from that of traditional forms of analysis.

- Traditional analysis focuses on separating the individual pieces of what is being studied; in fact, the word "analysis" actually comes from the root meaning "to break into constituent parts.‟

- Systems thinking, in contrast, focuses on how the thing being studied interacts with the other constituents of the system — a set of elements that interact to produce behavior — of which it is a part.

- This means that instead of isolating smaller and smaller parts of the system being studied, systems thinking works by expanding its view to take into account larger and larger numbers of interactions as an issue is being studied.

This results in sometimes strikingly different conclusions than those generated by traditional forms of analysis, especially when what is being studied is dynamically complex or has a great deal of feedback from other sources, internal or external.

Endogeneity: the requisite Systems Principle

"We have met the enemy and He is Us."

(Walt Kelly's *Pogo*, originally on an *Earth Day* poster, 1970)

The Endogenous Point of View

"The fault, dear Brutus, is not in our stars, but in ourselves …"

Cassius, in Shakespeare's *Julius Caesar* (1599)

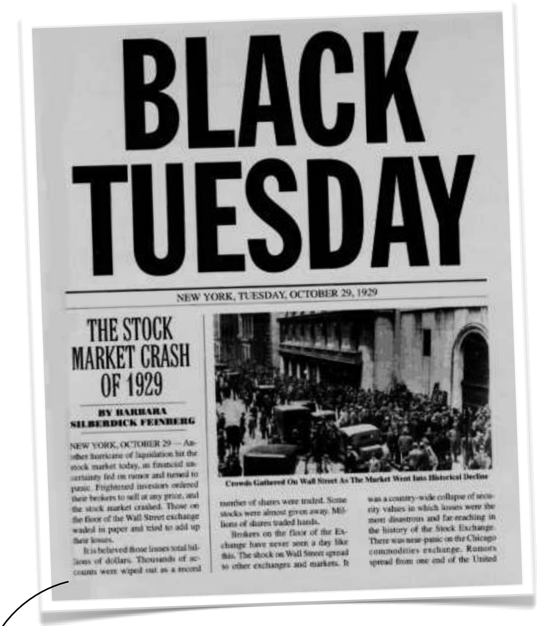
An Example

- Exogenous point of view
  - Sam is always mean to Pam.
  - It's all his fault.
  - If he would be nicer, Pam's life would be better.

- Endogenous point of view
  - Maybe there is something Pam is doing …

Endogeneity – essential for systems thinking

Systems fool us by presenting themselves as a single event.


BLACK TUESDAY

NEW YORK, TUESDAY, OCTOBER 29, 1929

THE STOCK MARKET CRASH OF 1929

BY BARBARA SILBERDICK FEINBERG

NEW YORK, OCTOBER 29 — Another hurricane of liquidation hit the stock market today, as financial uncertainty fed on rumor and turned to panic. Frightened investors ordered their brokers to sell at any price, and the stock market crashed. Those on the floor of the Wall Street exchange waded in paper and tried to add up their losses.

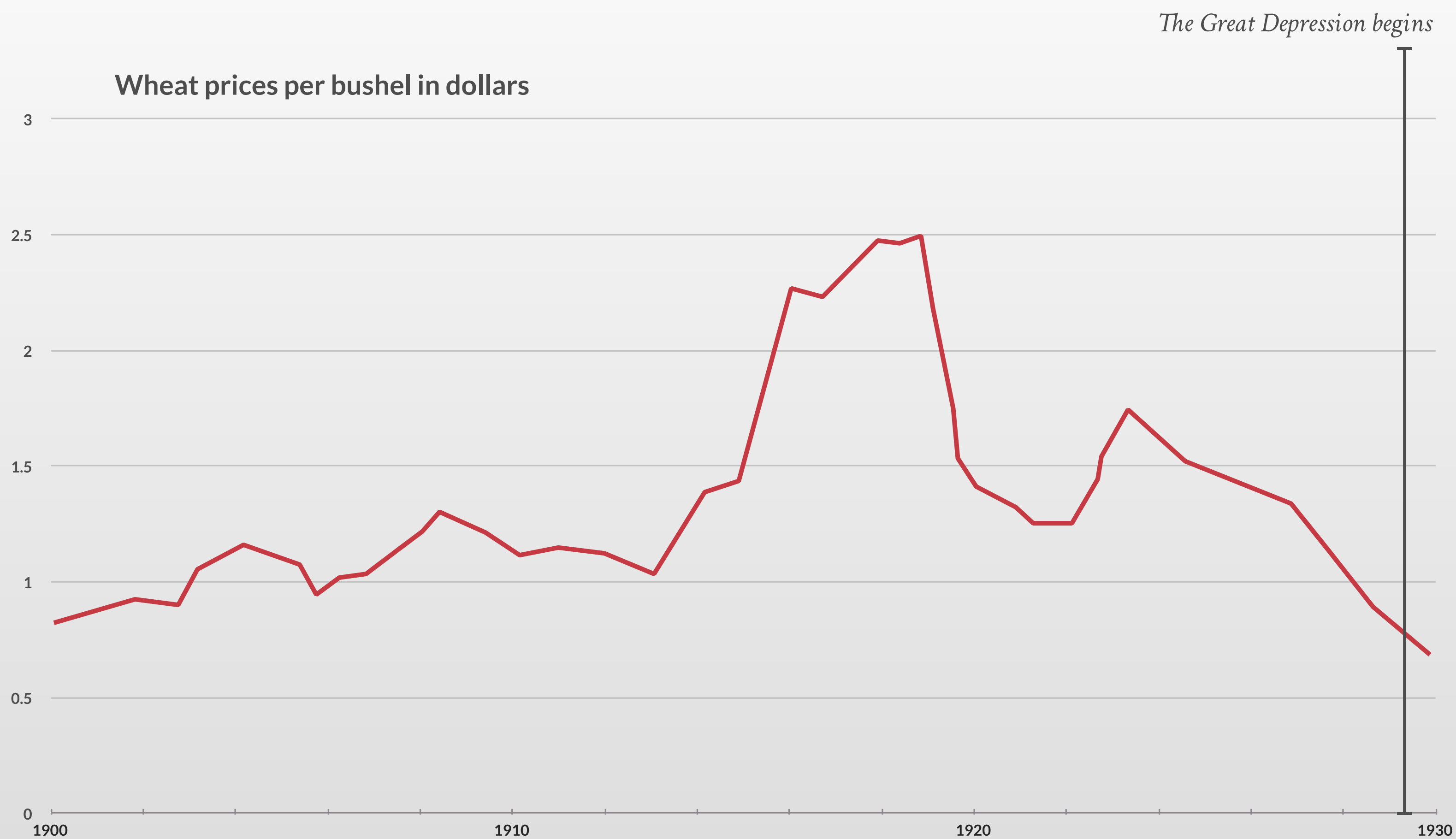
It is believed those losses total billions of dollars. Thousands of accounts were wiped out as a record number of shares were traded. Some stocks were almost given away. Millions of shares traded hands.

Brokers on the floor of the Exchange have never seen a day like this. The shock on Wall Street spread to other exchanges and markets. It was a country-wide collapse of security values in which losses were the most disastrous and far-reaching in the history of the Stock Exchange. There was near-panic on the Chicago commodities exchange. Rumors spread from one end of the United

Crowds Gathered On Wall Street As The Market Went Into Historical Decline

The stock market crashed in 1929, making headlines. This single event was overemphasized, and other, more important, events influencing the Great Depression were less salient, like the 200,000 factory workers being replaced by machines and farmland value falling by 40%.

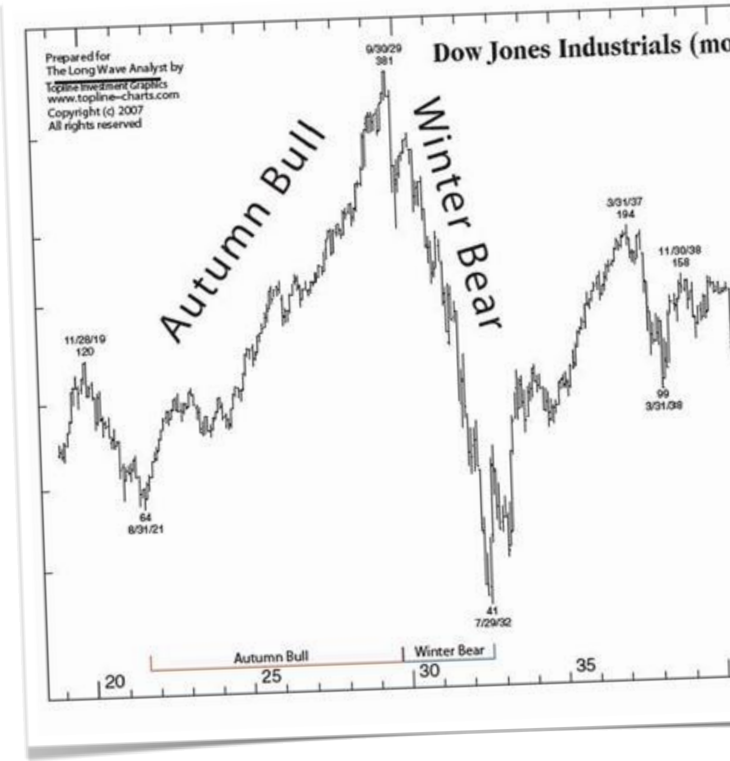
Events accumulate into dynamic patterns of behavior.



Long-term behavior provides clues to the underlying system structure.

System structures are created by the choices people make consciously or unconsciously over time.

In systems thinking, structure is the pattern of interrelationships among the key components of the system. That might include hierarchy and process, but it also includes attitudes and perceptions, the quality of products, the ways in which decisions are made, etc.



The winter of 1929 was a so called "long wave" winter. Long wave theory, a subset of systems thinking, says that economic crisis come and go in cycles.

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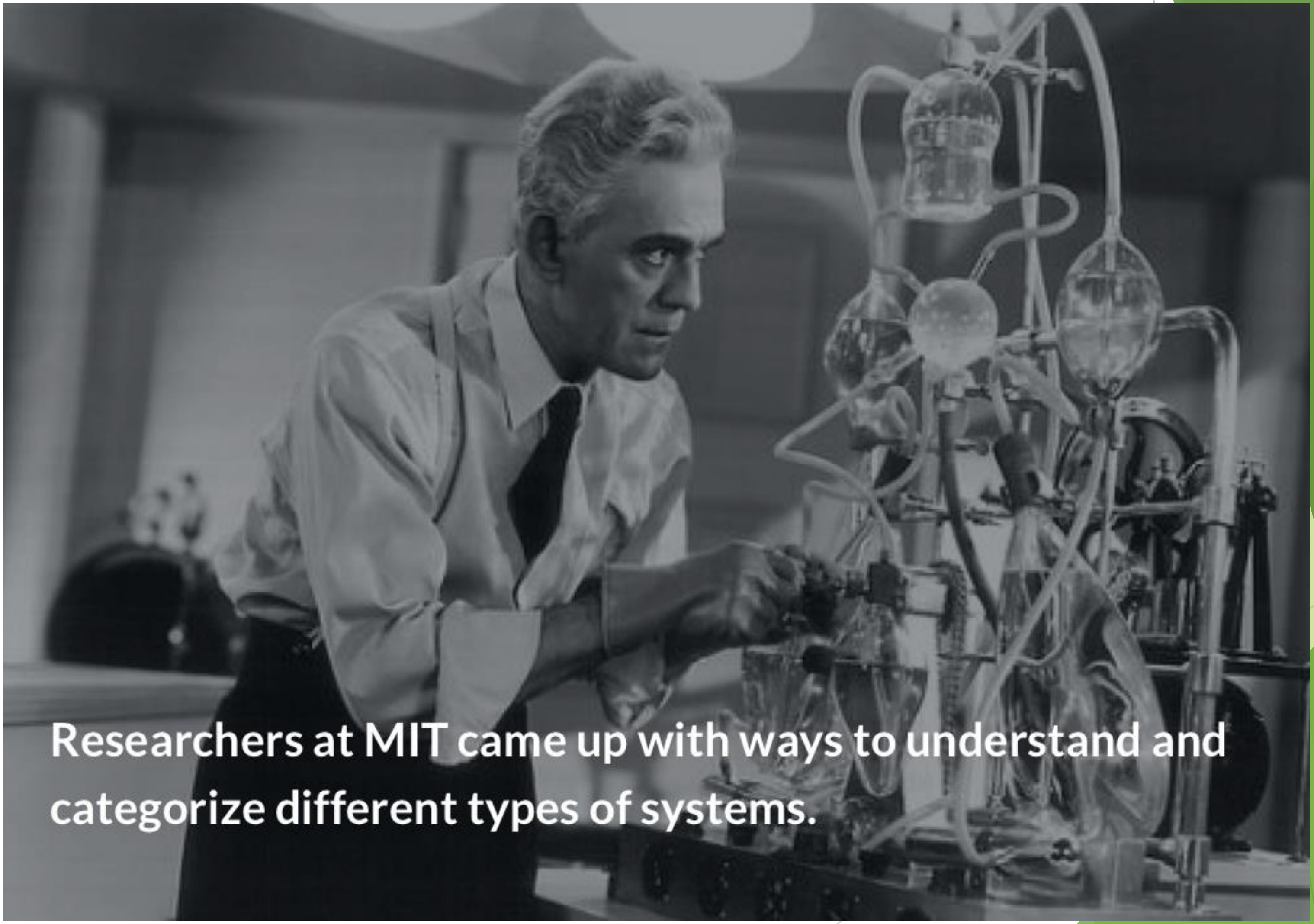
Talking about complex Systems

If we only have a hammer, we will tend to consider all types of problems as just nails…!


Researchers at MIT came up with ways to understand and categorize different types of systems.


With practice, these tools can help you unpack complex problems in a flash.
Think of these tools as your diagnostic repertoire.
HOW-TO-BE A DETECTIVE

Links and Loops

THE FOUNDATION OF SYSTEMS MODELING

Links are arrows that represent influence between elements in a system.

Loops are combinations of links that that reveal interdependencies; In a loop, every element is both the cause and the effect.

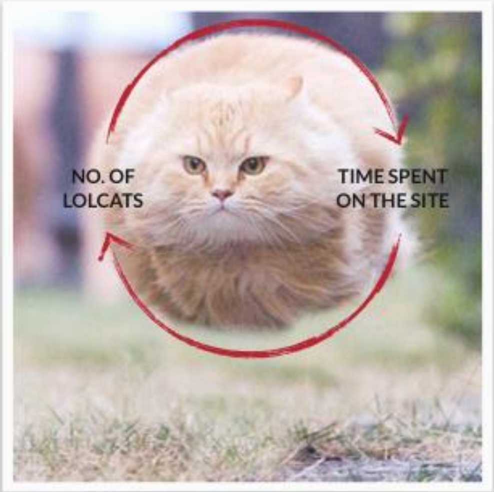
Example: The more lolcat pictures on icanhazcheeseburger.com, the more time people spend there, commenting on lolcat pictures, and becoming inspired to create more. (Because we all know lolcats are awesomely hilarious!)

A LINK:

NUMBER OF LOLCATS → TIME SPENT ON THE SITE

Cause *Effect*

A LOOP:



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Balancing and Reinforcing Loops

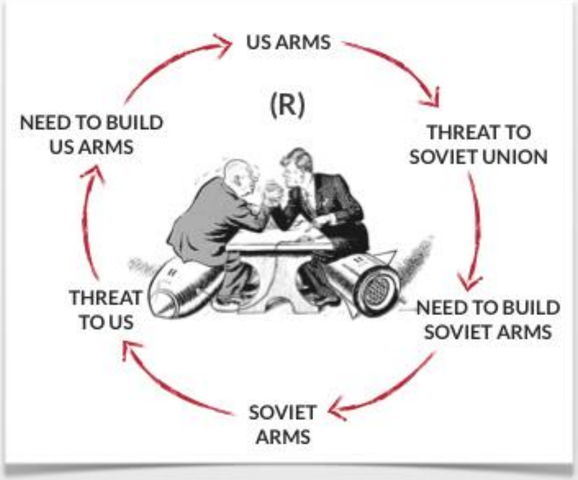
TWO TYPES OF LOOPS THAT OCCUR FREQUENTLY

Balancing loops occur in systems that are self-regulating. The system has an inherent goal, and when that goal isn't met, intense pressure is applied to reach it.

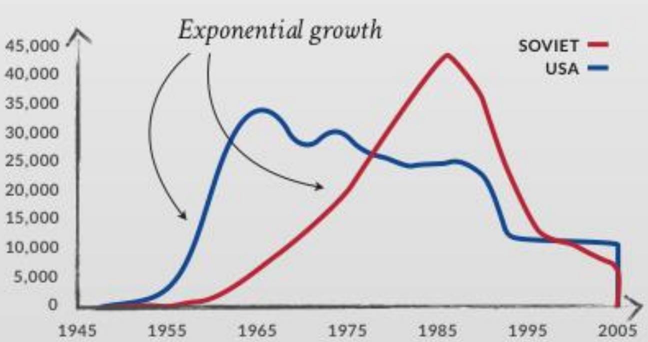
Example: Your refrigerator's goal is to keep food at a chilly 35 degrees. When a half-eaten pizza enters, the refrigerator decreases the temperature to cool the warm pizza, bringing the refrigerator back to equilibrium.

Reinforcing loops occur in systems that steadily grow and/or collapse over time.

Example: The Nuclear Arms Race between the US and the Soviet Union during the cold war is a typical example of a reinforcing loop. The US created the first atomic bomb in 1945. The Soviet Union followed in 1949. By the 1950s both sides had enough nuclear power to obliterate each other. The system then declined when both stockpiles decreased in the 1990s.



NUCLEAR STOCKPILES 1945 - 2005



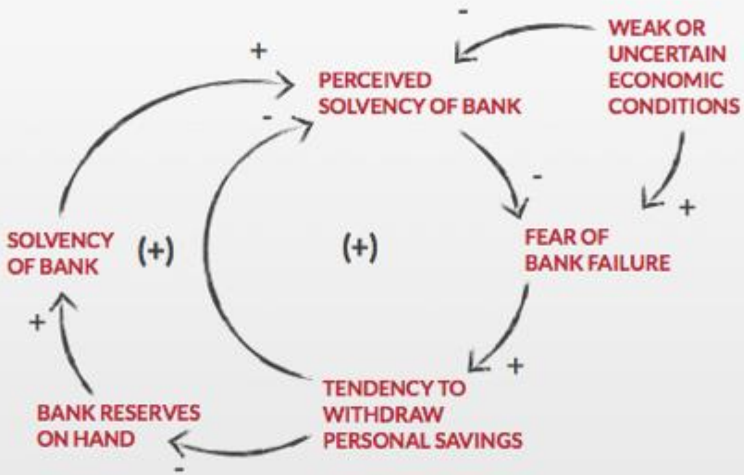
Sources: Natural Resources Defense Council (1946-2002 data), Bulletin of the Atomic Scientists (2003-2006 data)

Causal Loop Diagrams

HELPING YOU TELL A MORE ROBUST STORY

Causal loop diagrams combine multiple loops and reveal more detail about the system. A "plus" indicates that the elements change in the same direction while a "minus" indicates that the elements change in opposite directions.

Example: The bank panic during the Great Depression was caused by a public fear of bank failure. This caused people to withdraw their personal savings, reducing bank solvency, which in turn drove private withdrawals of funds further in a spiraling, reinforcing, loop.



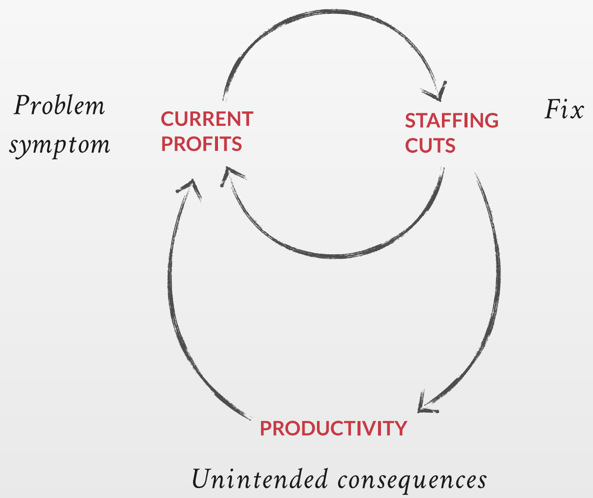
Casual loop diagram describing the bank panic during the Great Depression (adapted from Beyond Training Wheels by John Sterman).

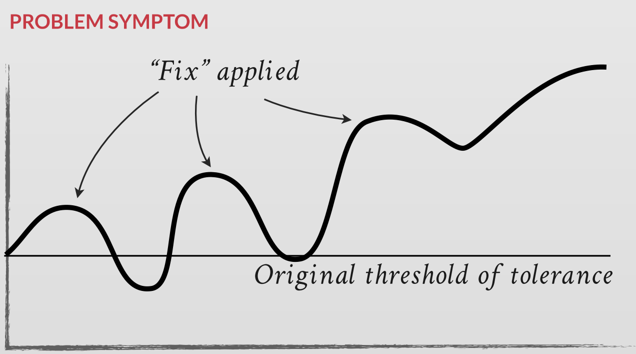
System Archetypes

A PERIODIC TABLE OF THE MOST COMMON SYSTEM BEHAVIORS

If we think of each system as a story, system archetypes are the classic stories that we keep seeing over and over again. By measuring our systems against these classics, we can quickly identify the dominating behavioral patterns.

For example, "Fixes That Backfire": A company is struggling with profitability (the problem symptom) and decides to let some people go to reduce costs (the fix). Profitability initially improves, but the loss of experienced employees as well as a drop in morale impact productivity negatively (the unintended consequence).





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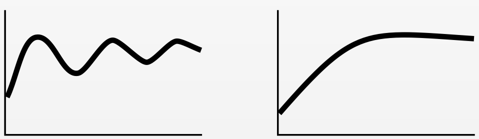
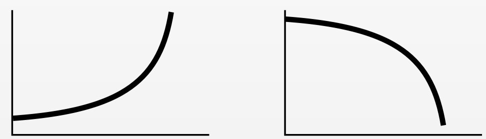
Archetypes: Comparison Chart

ADAPTED FROM THE FIFTH DISCIPLINE BY PETER M. SENGE



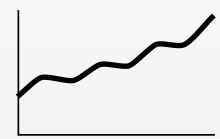
BALANCING LOOP

There is a movement toward a target (without delay), or else oscillation, hovering around a single target (with delay).



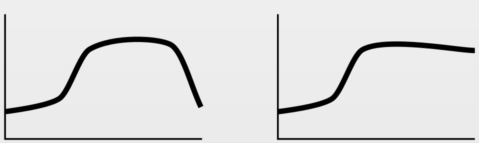
REINFORCING LOOP

An important variable accelerates up (or down), with exponential growth or collapse.



"FIXES THAT BACKFIRE"

A problem symptom alternately improves (the problem variable goes down) and deteriorates (the problem goes up, worse than before).



"LIMITS TO GROWTH"

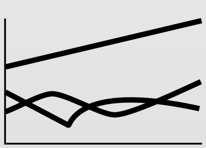
There is a growth (sometimes dramatic growth), leveling off or falling into decline.

"SHIFTING THE BURDEN"

The reliance of the short-term fix grows stronger, while efforts to fundamentally correct the real problem grow weaker. The problem symptom alternately improves and deteriorates.

"TRAGEDY OF THE COMMONS"

Total activity grows, but the gains from individual activities are dropping.



"ACCIDENTAL ADVERSARIES"

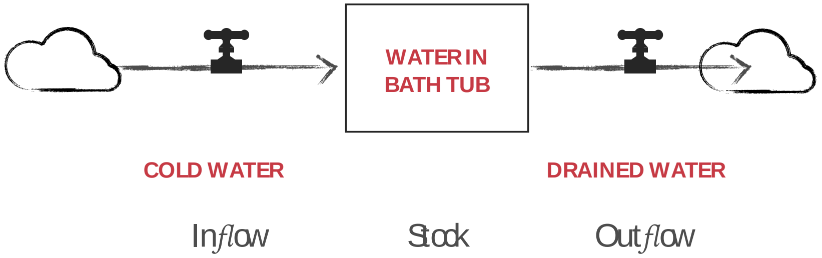
Each side's performance either declines or stays level and low, while enmity or competitiveness increases over time.

Stocks And Flows

ADAPTED FROM THINKING IN SYSTEMS BY DONELLA MEADOWS

Stock and flow diagrams are another way to analyze systems. Stocks are tangible and measurable, and they change over time through the actions of flows. Stocks act as buffers, delays or shock absorbers in systems.

Example: Imagine you've decided to take a bath. You begin to fill your bathtub with hot water and go read while you're waiting for the tub to fill. When you come back, the water is a bit too hot for your liking. To get the temperature down quickly, you open up the drain and turn the cold water faucet on. Your bathtub is now a simple system with one stock (the water in the tub), one inflow (the cold water) and one outflow (the water that is leaving through the drain).



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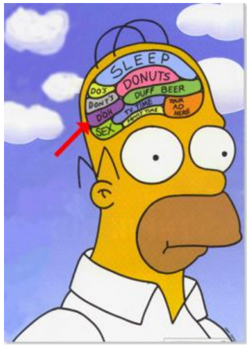
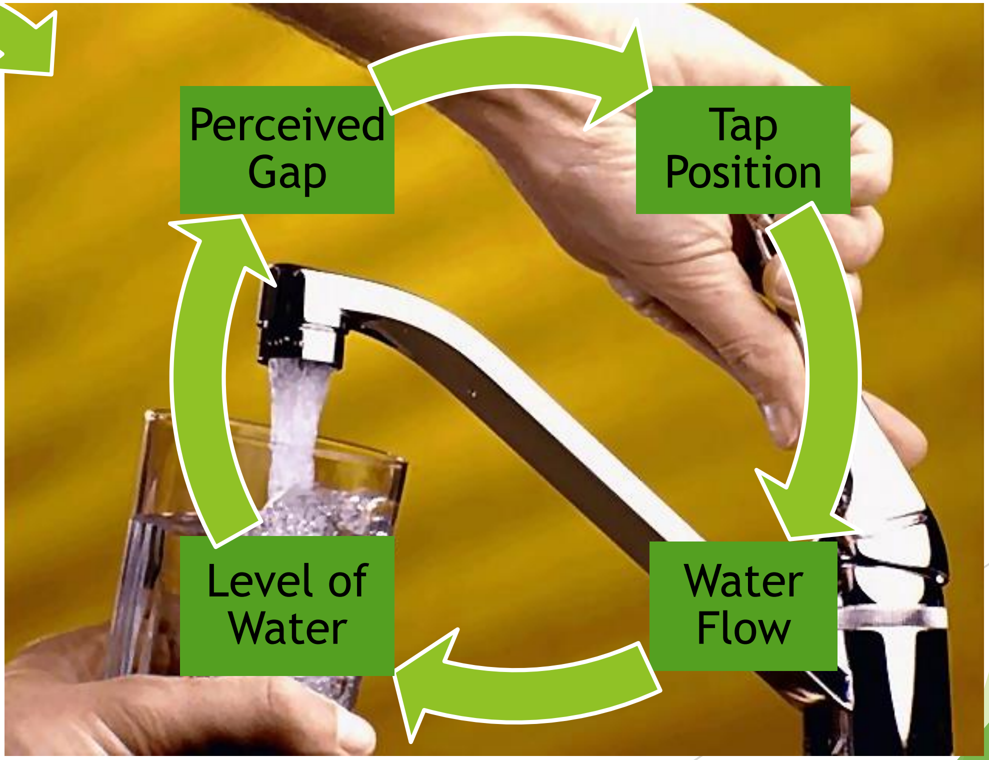
Beyond Linear Thinking

Easy just as filling up a glass of water…

Are we sure…???

Desired Level

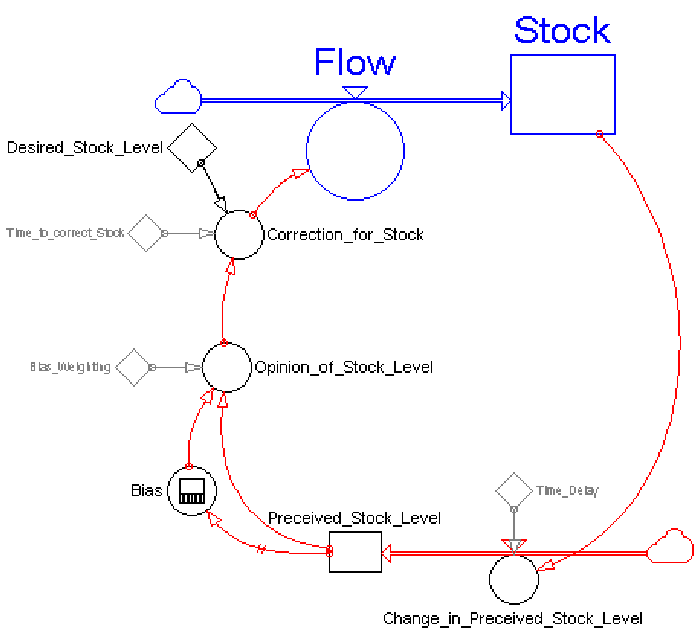




Stocks & Flows Properties

Stocks:
- Have memory, flow accumulation (deficit Vs Debt, emissions Vs extinction)
- Change the time shape of flows
- Decouple flows
- Create delays

However stocks and flows dynamics acquire particular meaning when information regarding their values is fed back to other variable which rely on their value to trigger other behaviours (feedback)



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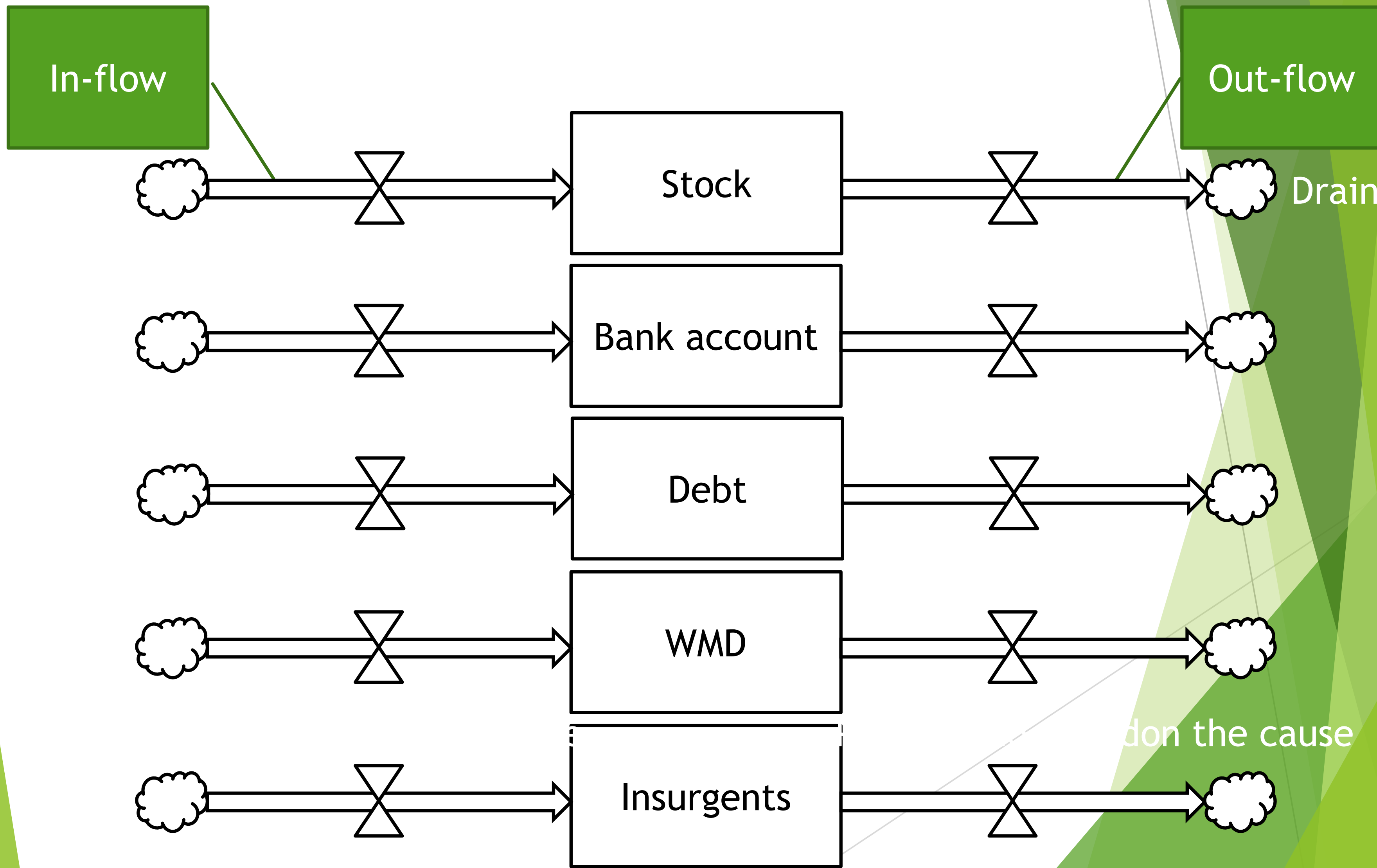
Stocks and flows



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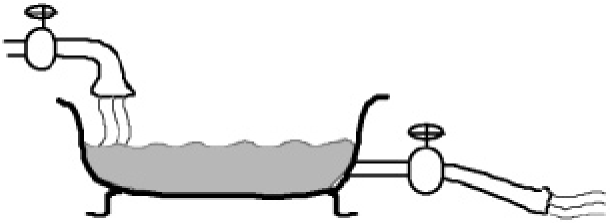
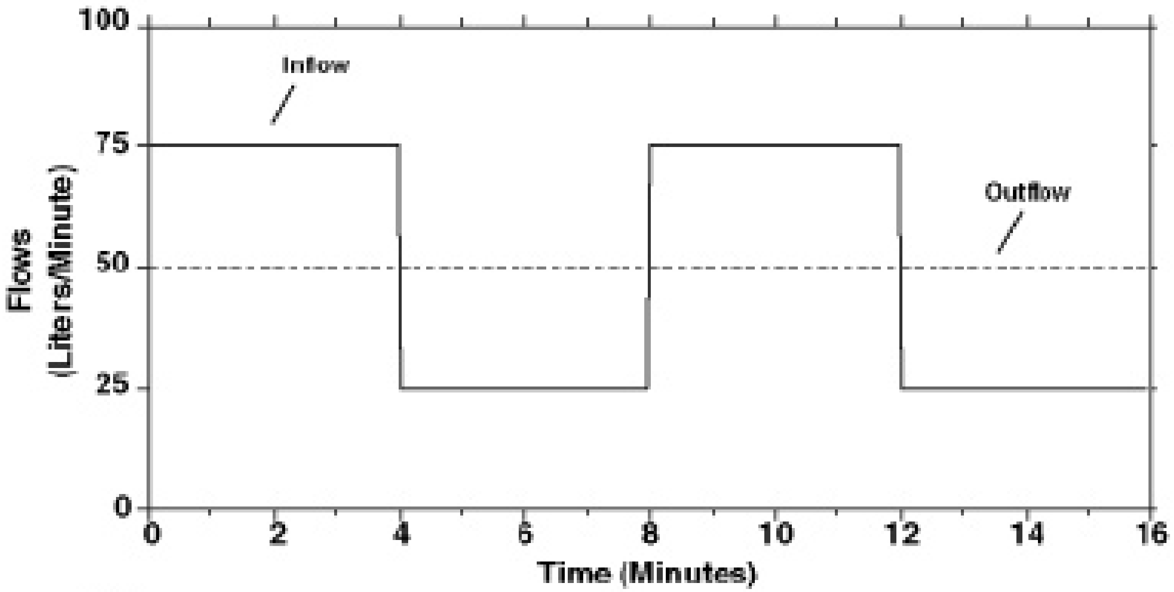
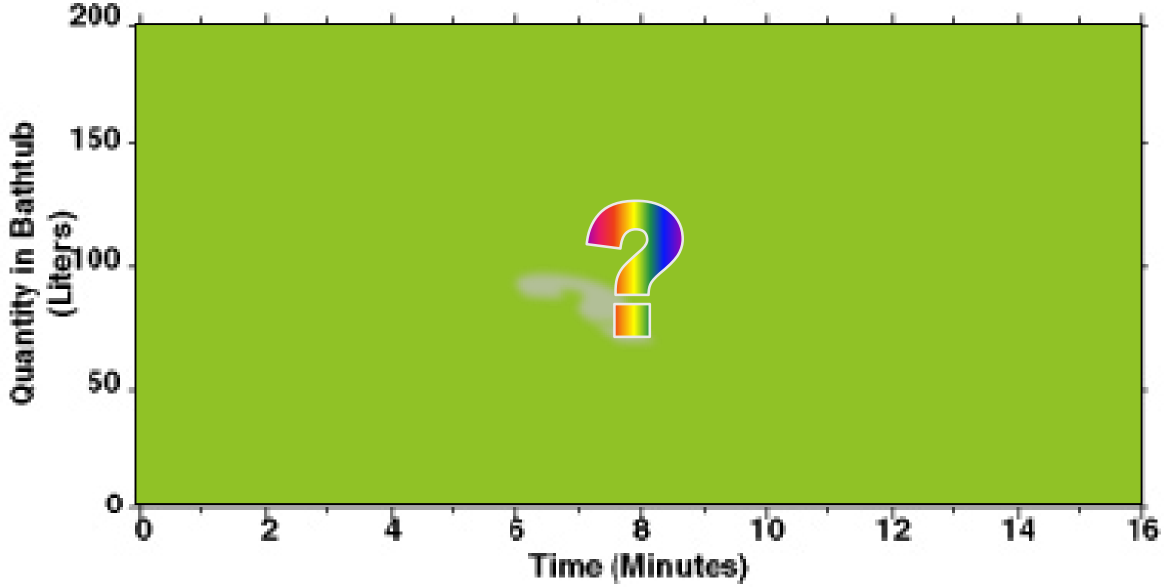
Exercise 1







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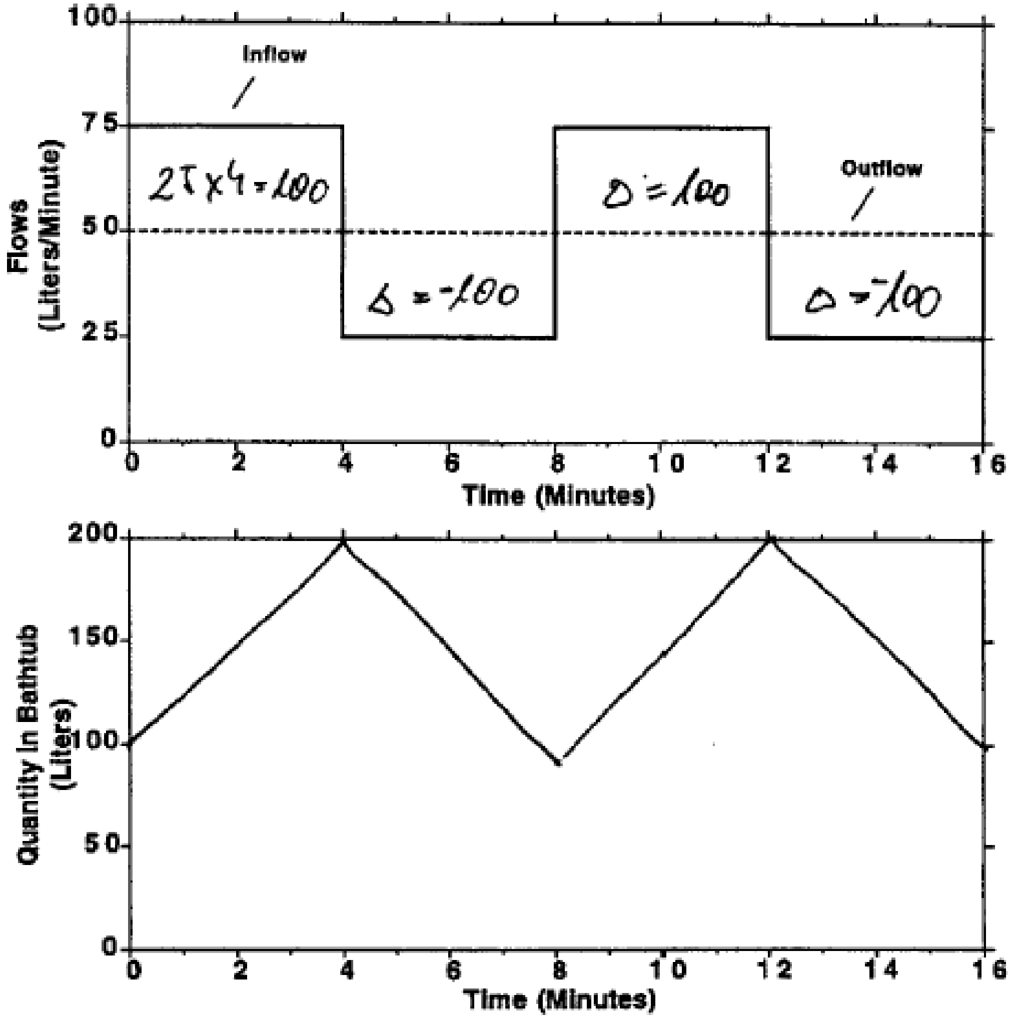
Exercise 1: solution



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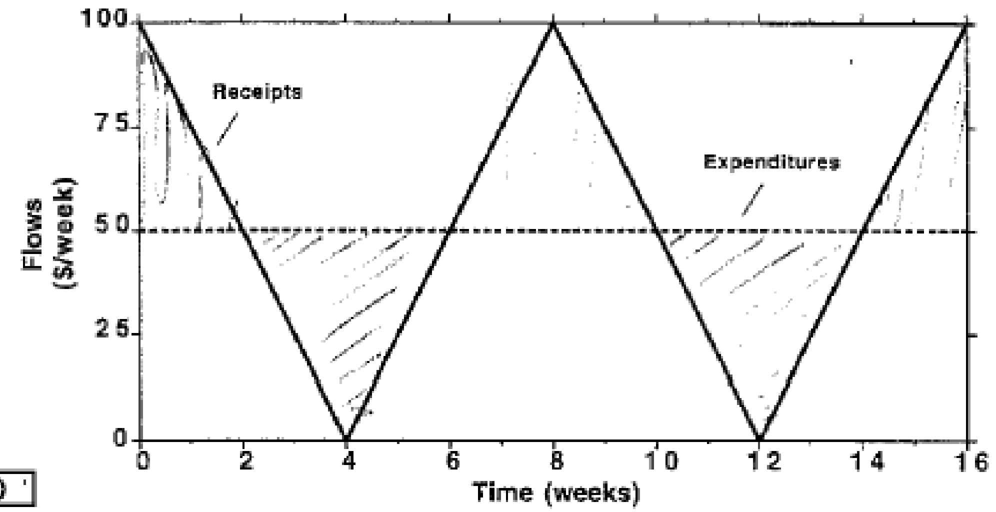
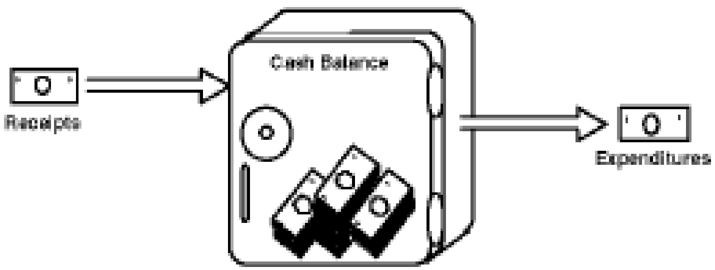
Exercise 2





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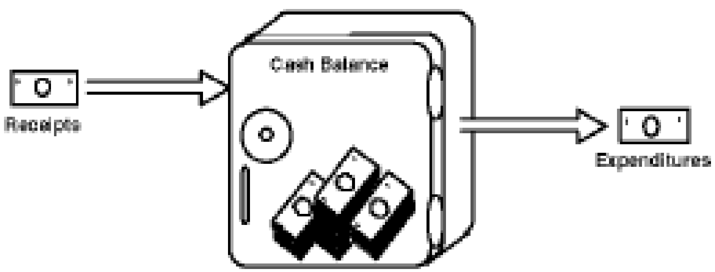
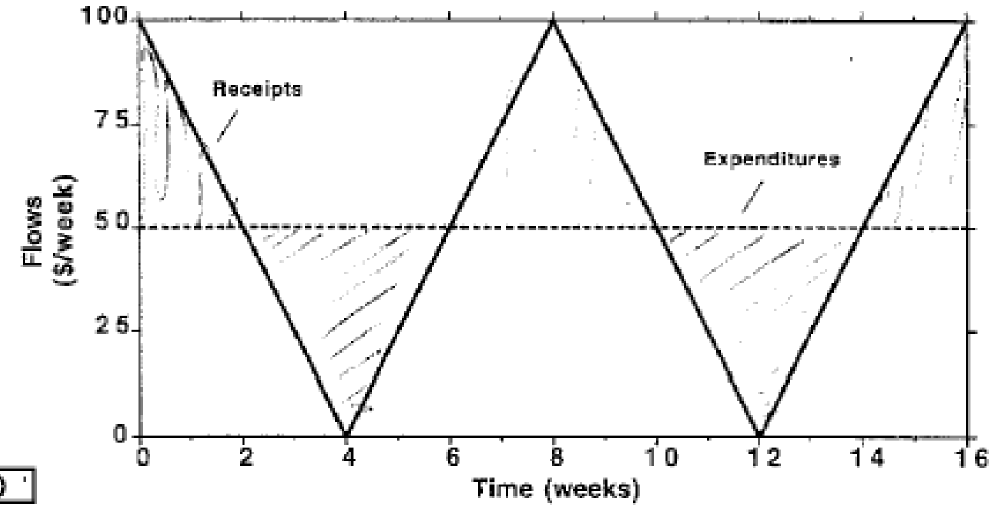
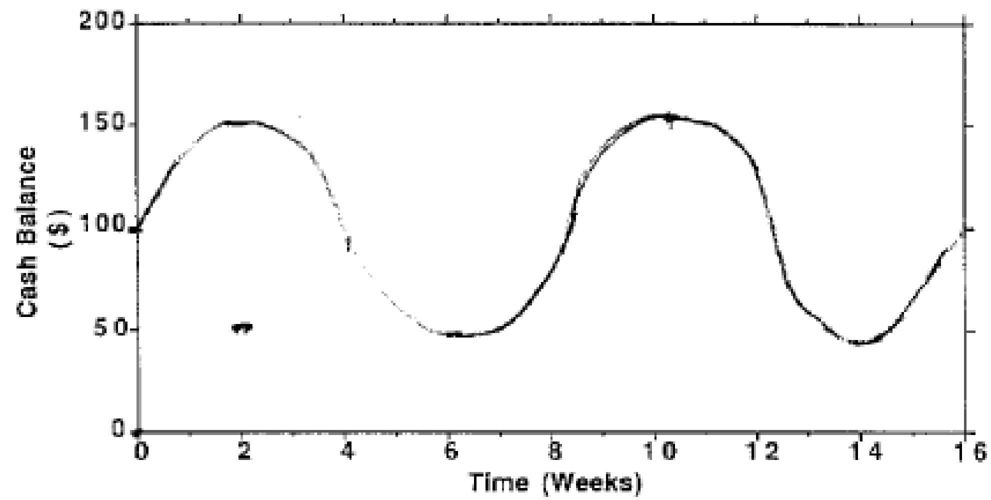
Exercise 2: solution







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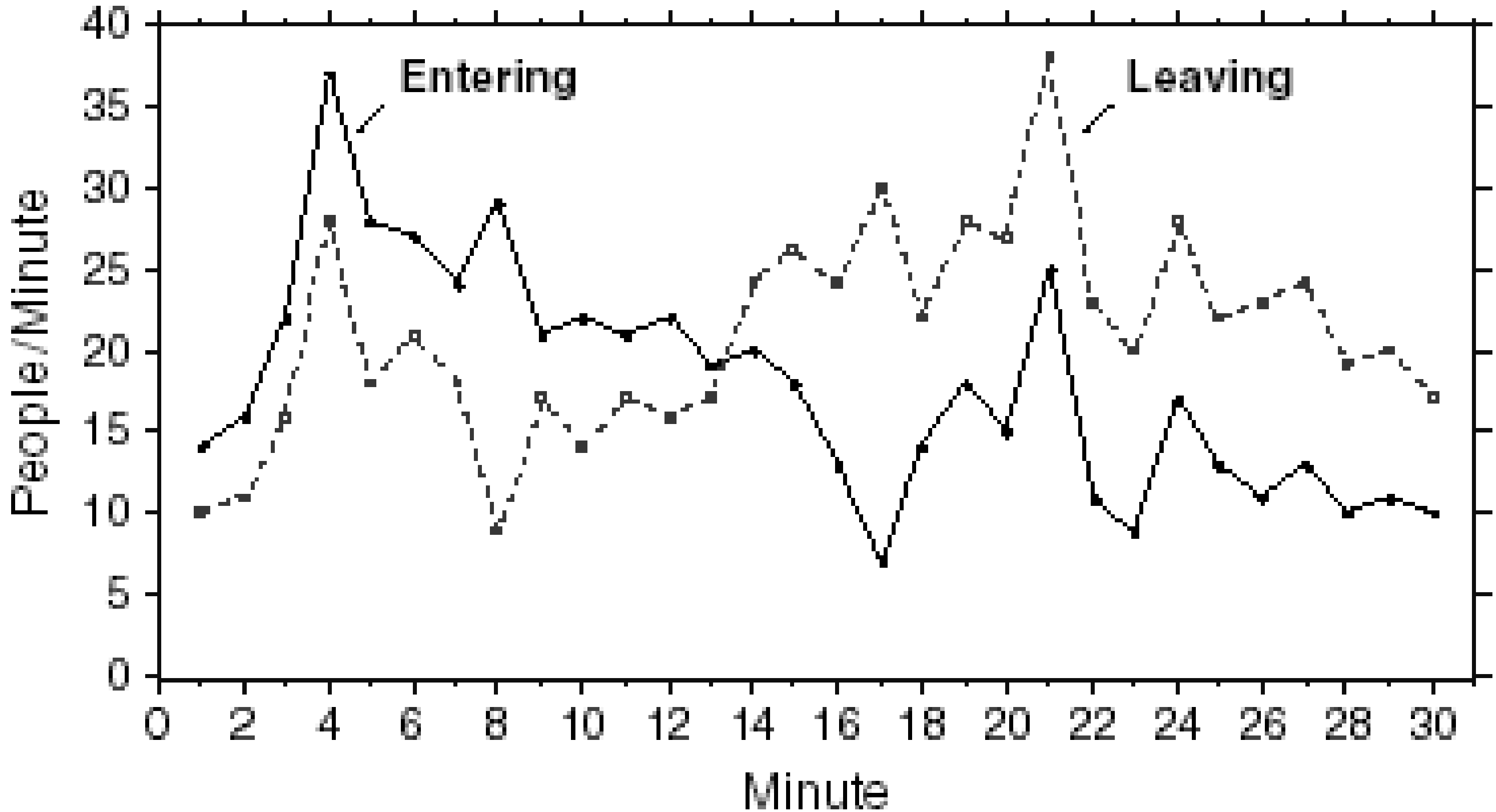
Exercise 3


Entering
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People / Minute
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35
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14
16
18
20
22
24
26
28
30

Exercise 3: questions

1. At which minute were the most people *”going in"* the Dept. Store?

   ☐ Minute: ______ ☐ Cannot be determined

2. At which minute were the most people *”going out"* the Dept. Store?

   ☐ Minute: _______ ☐ Cannot be determined

3. At which minute does the graph show the **maximum** number of people *”inside”* the Dept. Store?

   ☐ Minute: _______ ☐ Cannot be determined

4. At which minute does the graph show the **minimum** number of people *”inside”* the Dept. Store?

   ☐ Minute: _______ ☐ Cannot be determined

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Exercise 3: Solutions

1. At which minute were the most people *"going in"* the Dept. Store?

   ☐ Minute: _4_ ☐ Cannot be determined

2. At which minute were the most people *"going out"* the Dept. Store?

   ☐ Minute: __21__ ☐ Cannot be determined

3. At which minute does the graph show the **maximum** number of people *"inside"* the Dept. Store?

   ☐ Minute: __13__ ☐ Cannot be determined

4. At which minute does the graph show the **minimum** number of people *"inside"* the Dept. Store?

   ☐ Minute: __30__ ☐ Cannot be determined

Systems Analysis Guidelines

THE SYSTEMS TOOLKIT IN ACTION

All models are simplifications of the real world. It's up to you to decide how much detail to illustrate.

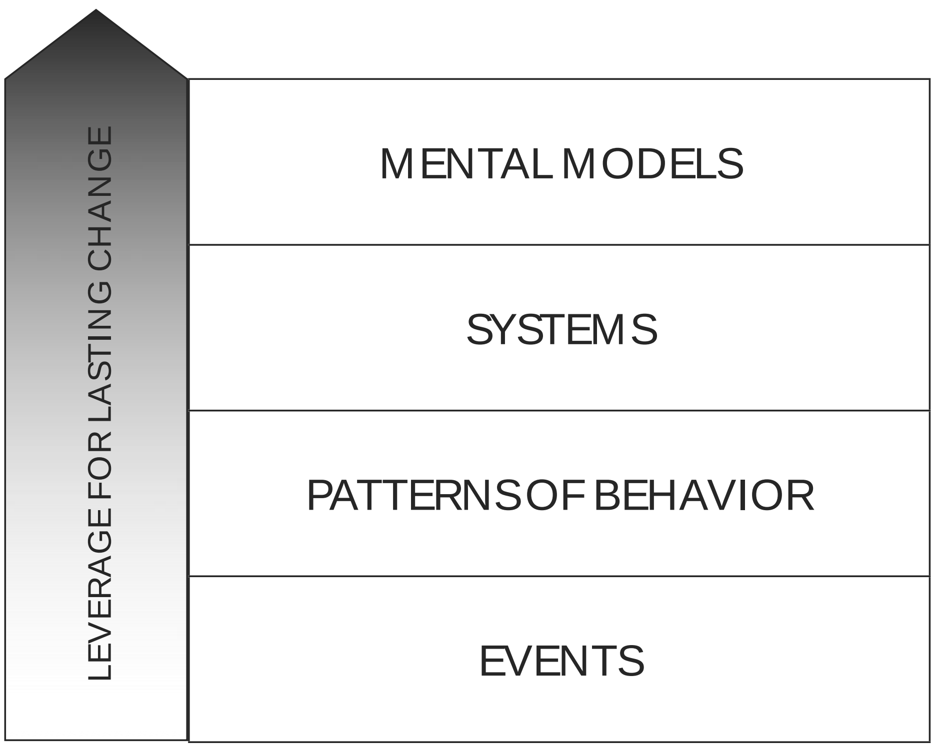
There are no right answers. Mapping out a system will reveal a set of potential actions you may take. As you become more a more proficient systems thinker, you'll begin to recognize the consequences of different interventions.

Cause and effect will not be closely related in time and space. Don't look for leverage near the symptoms of your problem.

Good results in a complex system depend on bringing in as many perspectives as possible. Consider who else you can bring in to make your system model more informed.

Use your intuition when you work with archetypes. It's not critical that you pick the right archetype - as long as it rings true with your story, it's good enough as a starting point.

A good systems thinker avoids traps by looking for multiple levels operating simultaneously.



ADAPTED FROM <u>THE FIFTH DISCIPLINE FIELDBOOK</u> BY PETER M. SENGE

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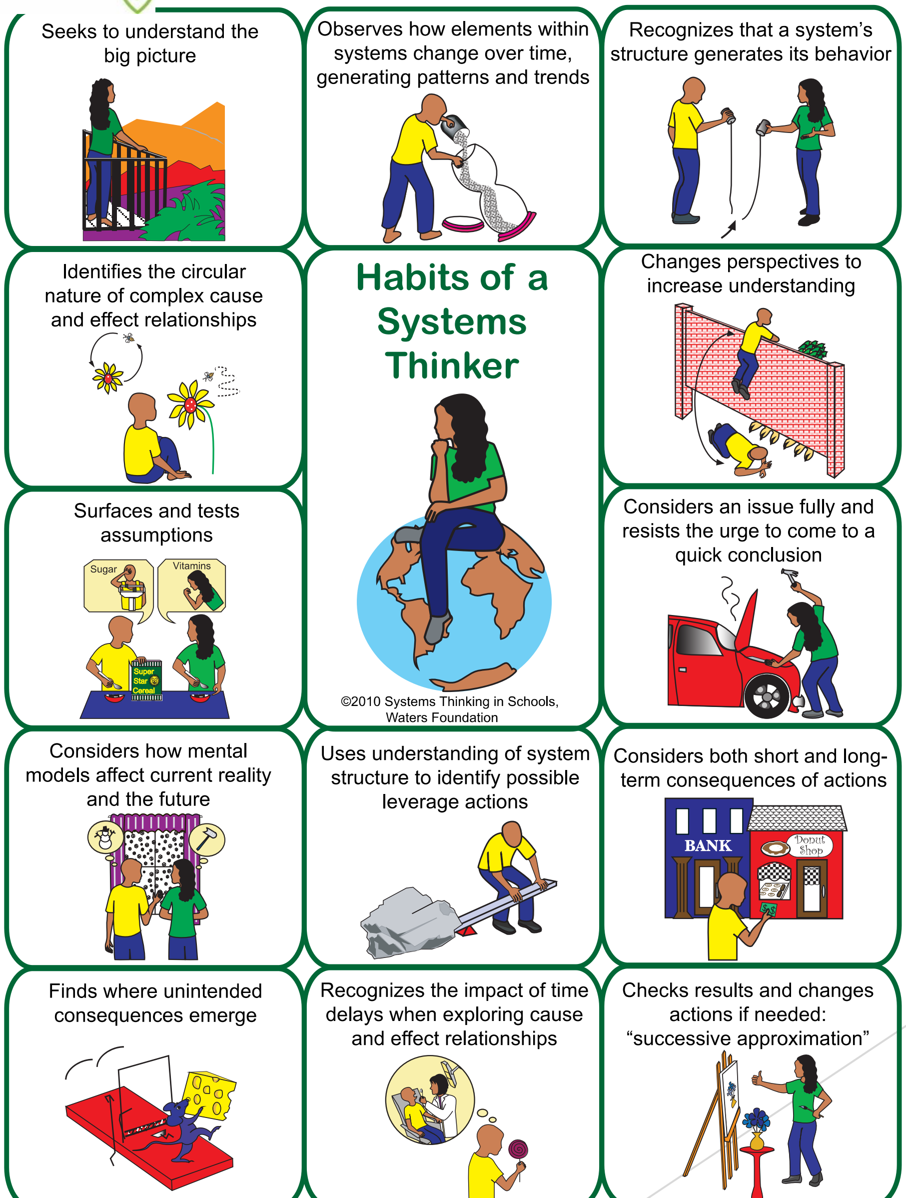


Understanding a System's Structure

Good Systems Thinkers Make Good Strategists

A STORY OF HOW STRATEGY DEFEATED 1:25 ODDS

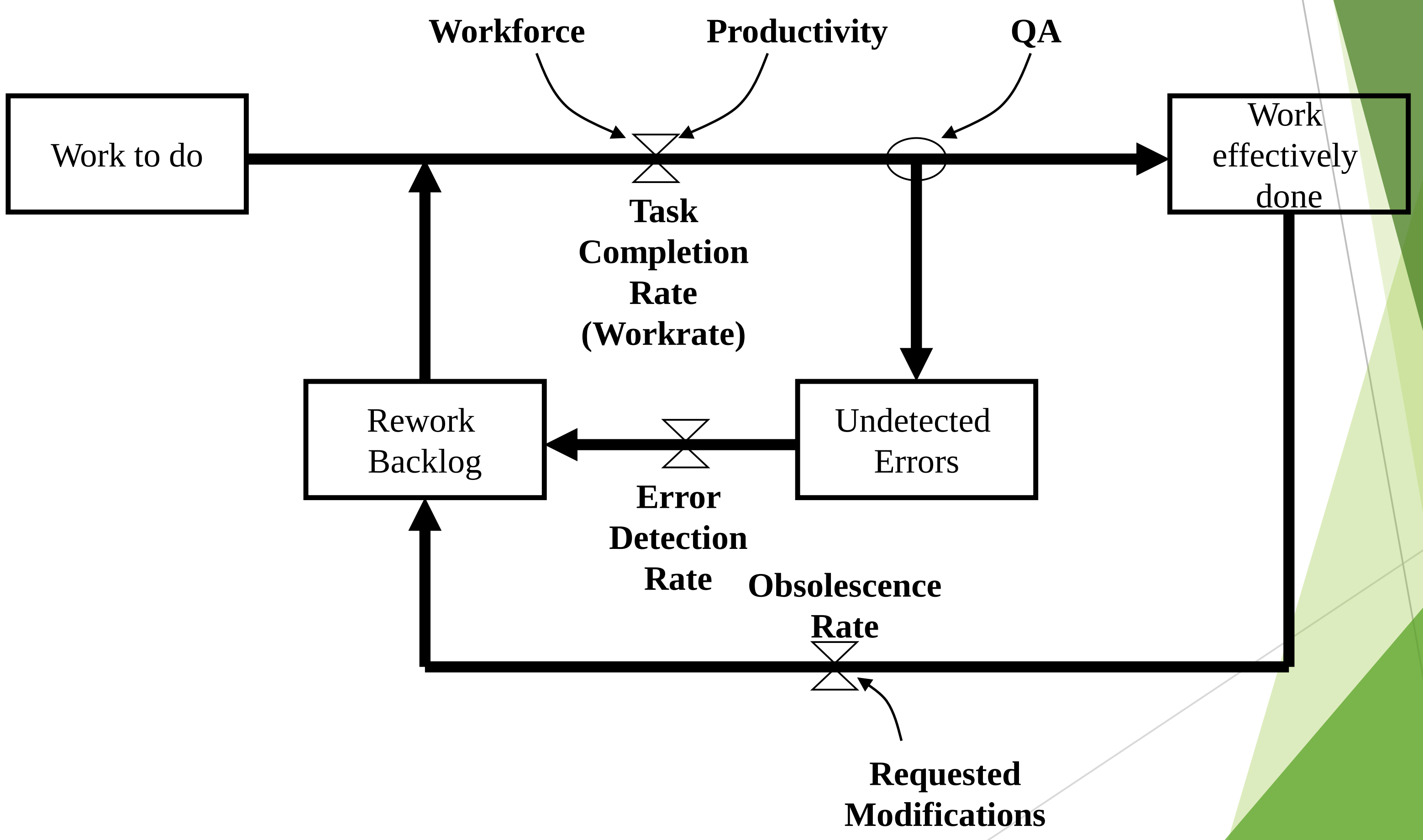
On October 26, 1597, the Korean admiral Yi Sun-sin famously defeated the Japanese fleet of 333 units with only 13 ships at his disposal.

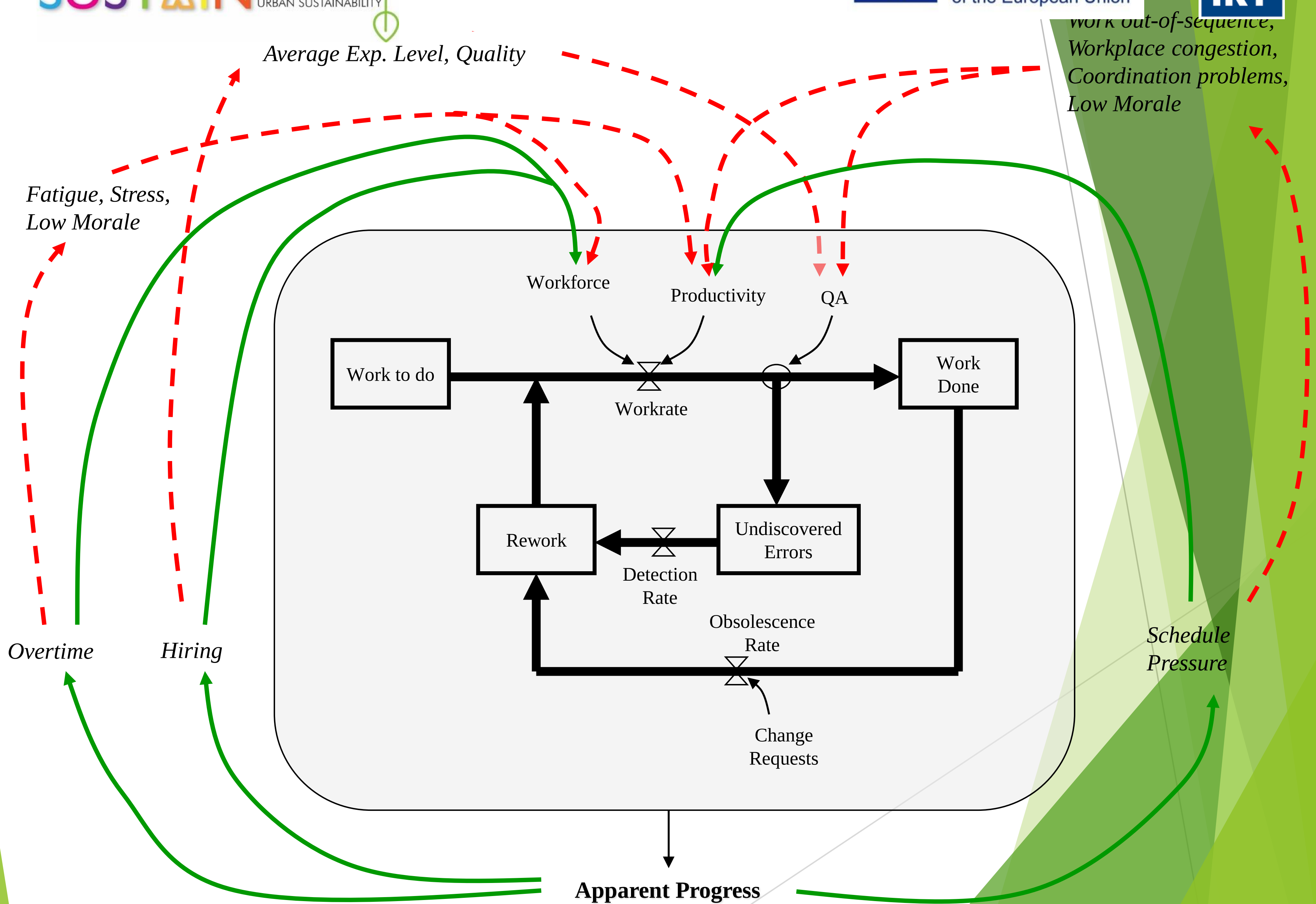
Yi strategically chose the Myeongnyang Strait as the arena for his last stand with the Japanese based on its strong currents, narrowness, rough tides and surrounding shadowy hillsides. By reading the environment as a system, admiral Yi used it to his advantage.

No other naval battle involving fleets of this size, has resulted in a victory for such a proportionately small force, also **making it one of the greatest military achievements in world history.**

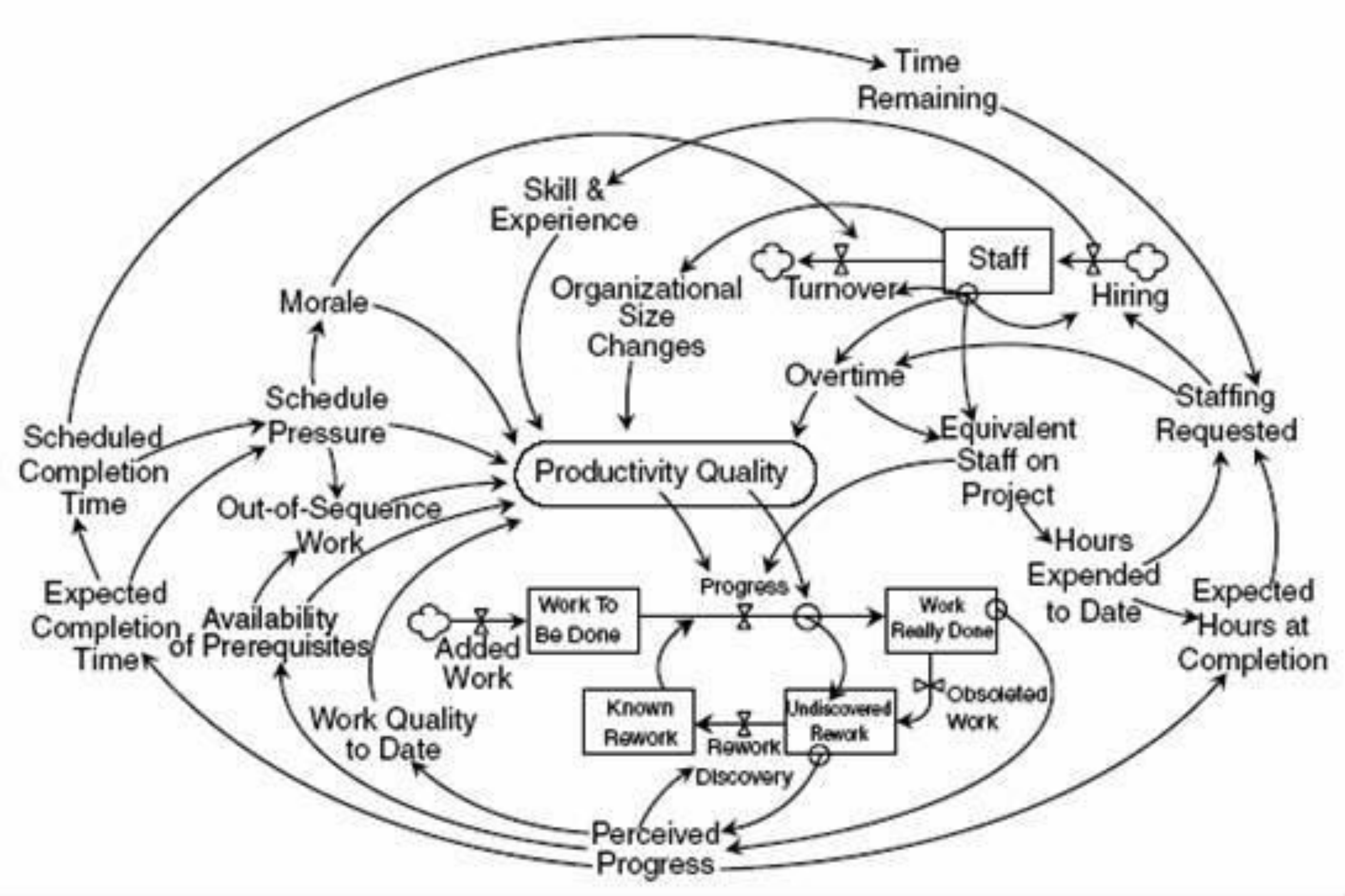
Admiral Yi: a badass systems thinker.

Work / Rework Cycle in Projects




Average Exp. Level, Quality
Work out-of-sequence,
Workplace congestion,
Coordination problems,
Low Morale
Fatigue, Stress,
Low Morale
Workforce
Productivity
QA
Work to do
Workrate
Work
Done
Rework
Detection
Rate
Undiscovered
Errors
Obsolescence
Rate
Change
Requests
Overtime
Hiring
Schedule
Pressure
Apparent Progress

An overall Project Causal Model (Lyneis, 2001)



System Dynamics Simulation

"A unique feature of dynamic project models not offered by networking planning methodologies is the ability to calculate the ripple (secondary) effects on project costs and schedule due to changing requirements and complex unpredictable interactions between parts of the systems. Such changes might include changing government regulations… (or) workforce availability. Ripple effects occur in labour productivity, unanticipated schedule slack and float time...These processes can only be modelled by using dynamic modelling with explicitly represented feedback mechanisms. In these respects, dynamic project models complement the static ones by providing the capability to readily perform sensitivity analysis of likely perturbations and their consequential ripple effects"

(*Ondash et al., 1988*)

System Dynamics is the application of *feedback control systems* principles and techniques to managerial, organizational and socioeconomic problems.

By modelling the integration of both engineering and managerial aspects with system dynamics and by the use of simulation tools, thus an **integrative approach**, one will be able to examine the effectiveness of an intended management decision on overall project performance.

Dynamic Models Simulation

"***All models are wrong***" (Sterman, 2001)

…but valuable to the extent that they provide useful insights, predictions and answers to the questions they are used to address…

- A simulation model is a computerized model which possesses the characteristics described above and that represents some dynamic system or phenomenon.
- It is an inexpensive way to gain important insights when the costs, risks or logistics of manipulating the real system of interest are prohibitive.
- Simulations are generally employed when the complexity of the system being modelled is beyond what static models or other techniques can usefully represent (stochasticity, dynamic behaviours, feedback mechanisms).

Scenario, planning, control, training/learning, understanding, consensus building

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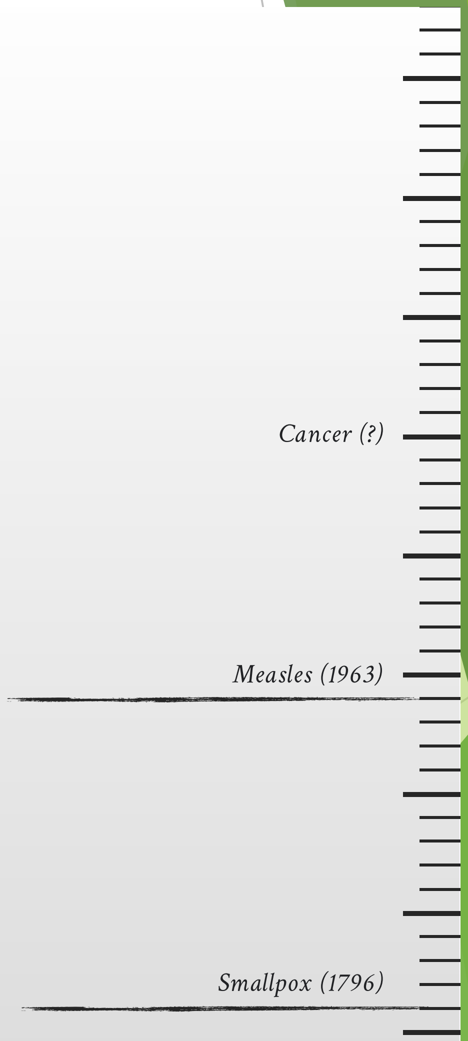
The challenges society faces are growing.



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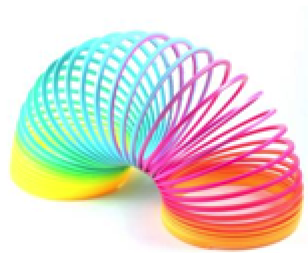
Knowledge and Experience

0 — 5 — 10

I Recognize Dilbert

I Have Heard of Systems Thinking



Jay Forrester Sends Me Flowers On My Birthday

System Dynamics Society

In order to meet those challenges, we need to explore new ways of thinking. Systems thinking is the cornerstone of how adaptive organizations think about their world.

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CAUSAL MAPS AND SYSTEM ARCHETYPES

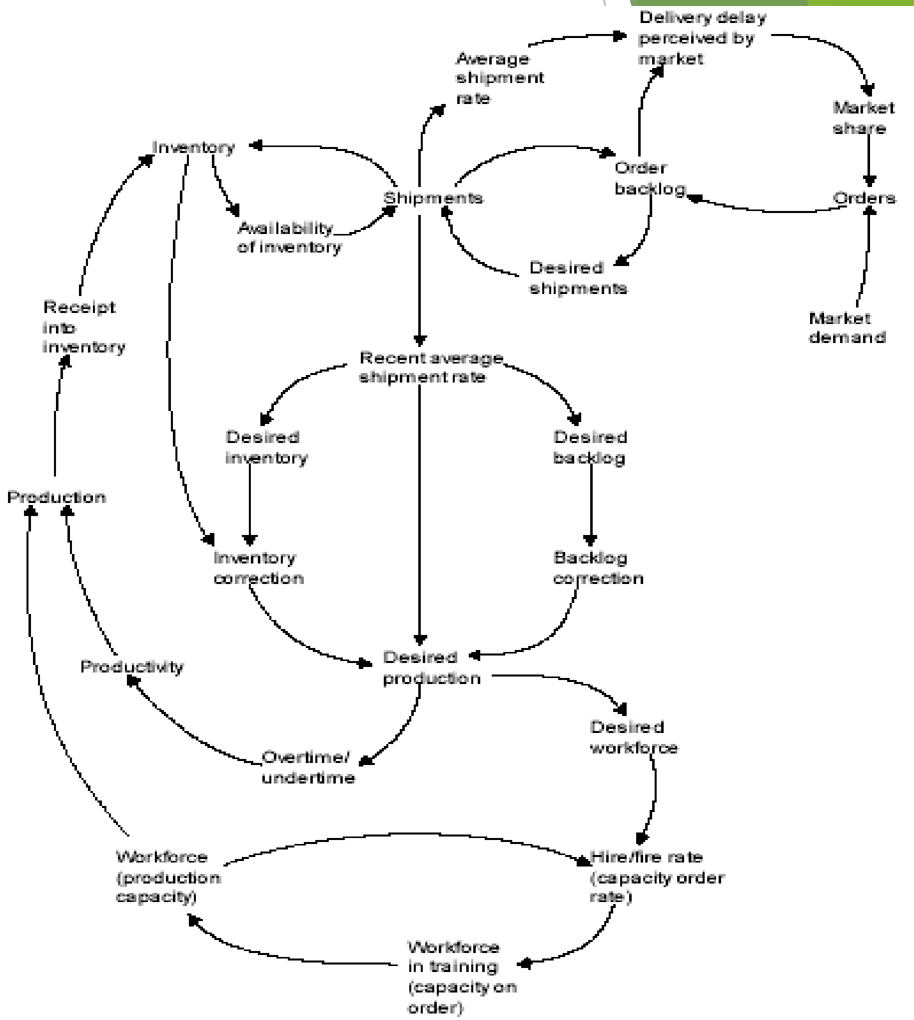
Part 2

Feedback Loops and Causal Loop Diagrams

- Notations for the representation of systems' structures

  Elements of the system are described verbally and are connected by arrows indicating an influence of one element to another.

  When an element indirectly influences itself, through its influence on other elements that in turn influence it, we speak of a feedback circuit or a **feedback loop**.



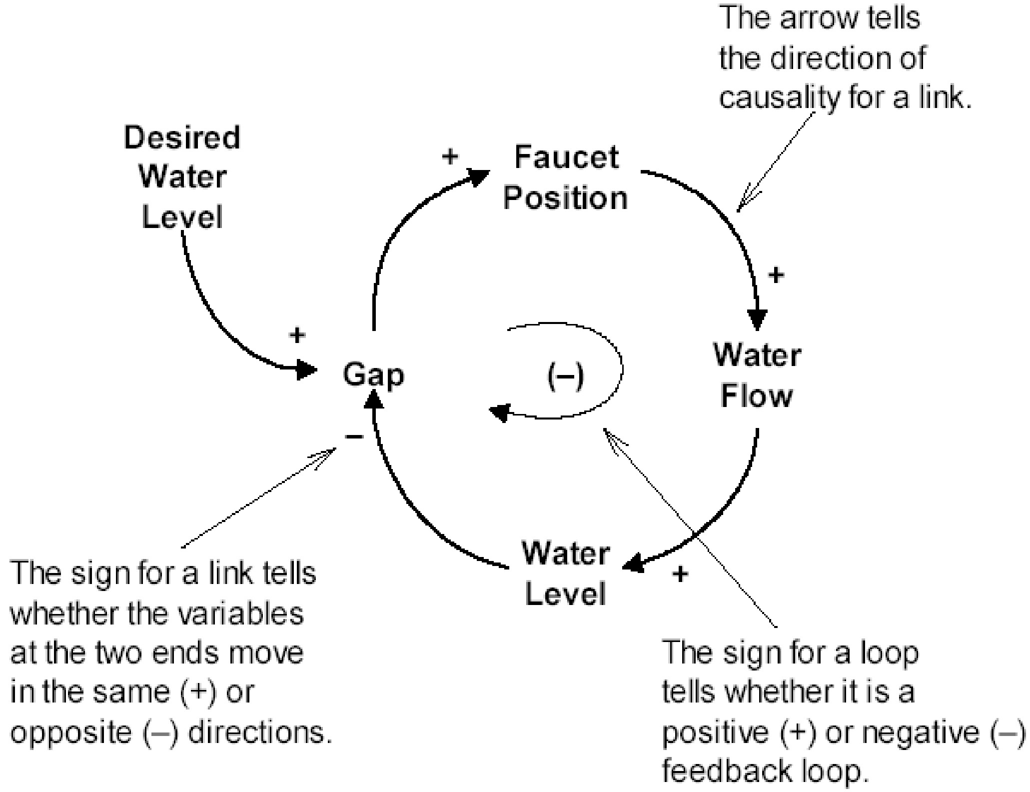
Feedback Loops

- Definition:

  A "closed" sequence of causes and effects or a closed path on itself composed of action and information (Richardson & Pugh, 1981)

- In the field of management, it is absolutely necessary to consider the effects caused by various feedback loops present within a system, as they can contribute to generating the behavior patterns described above.

Notation on Causal Loop Diagrams: How to fill a glass of water!



Causal Loops

- Positive (+) (R):

  If the feedback loop contains an even (or zero) number of negative signs (-)

- Also referred to as "self-reinforcing cycle"

- Negativo (-) (B):

  If the feedback loop contains an odd number of negative signs

- Also referred to as the "self-balancing cycle"

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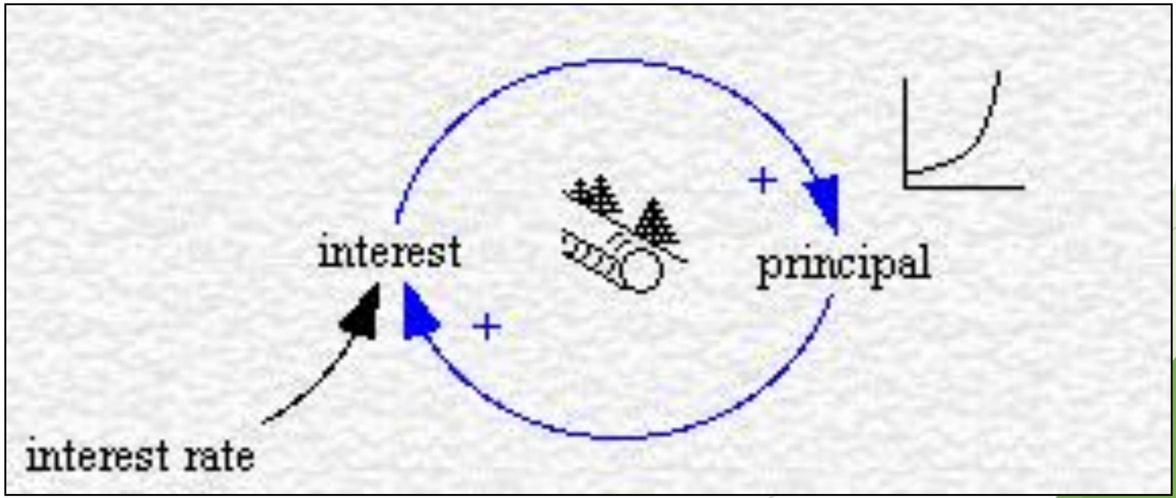
Positive Self-Reinforcing Cycle

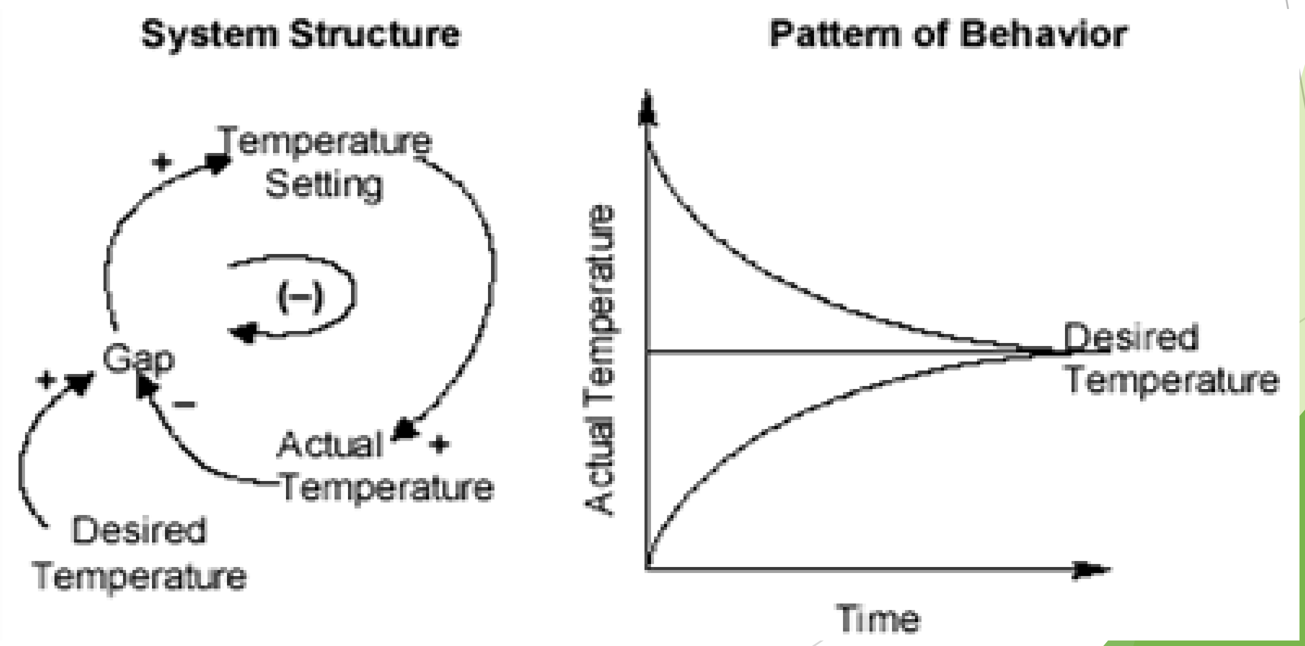
- Example: Current Bank Account Balance

The principal amount, deposited in the bank, is periodically increased by the interest amount given by an interest rate. Thanks to these, the next time, the amount will be greater, the interest amount larger and so on ...



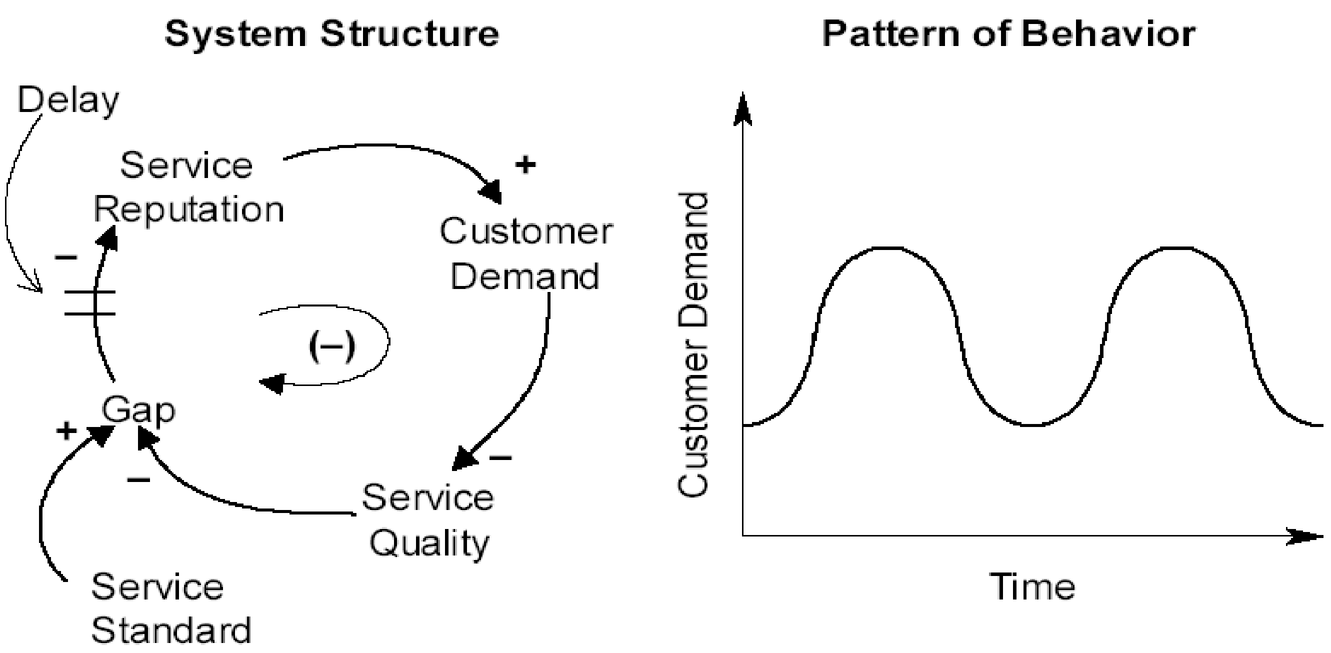
Negative self-balancing cycle

- Example: Thermostat for temperature regulation in a typical heating / air conditioning system
- The user sets the desired temperature on the thermostat and the system tends to regulate the room temperature based on the difference found

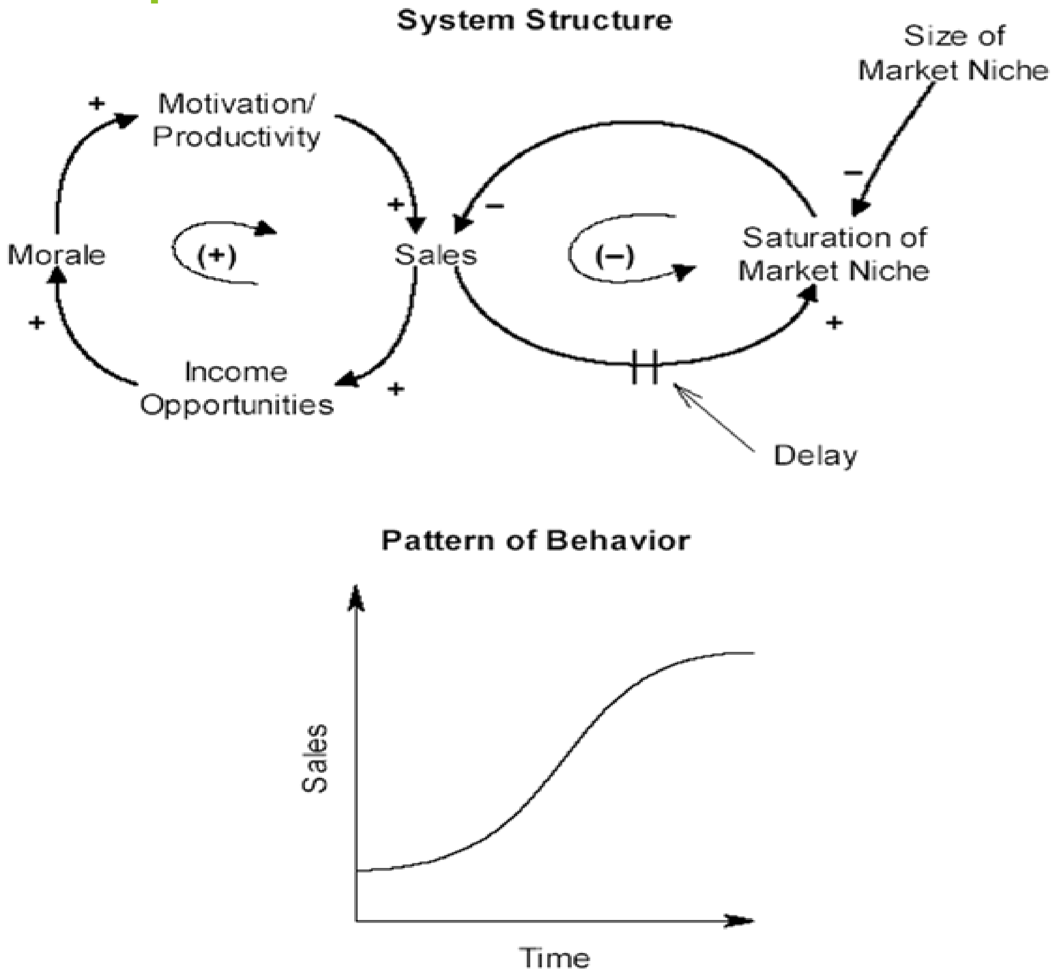


Negative loop with a delay

- Example: Delay present in the context of Quality control in a Service System (hypothesis of fixed resources assigned to the service)



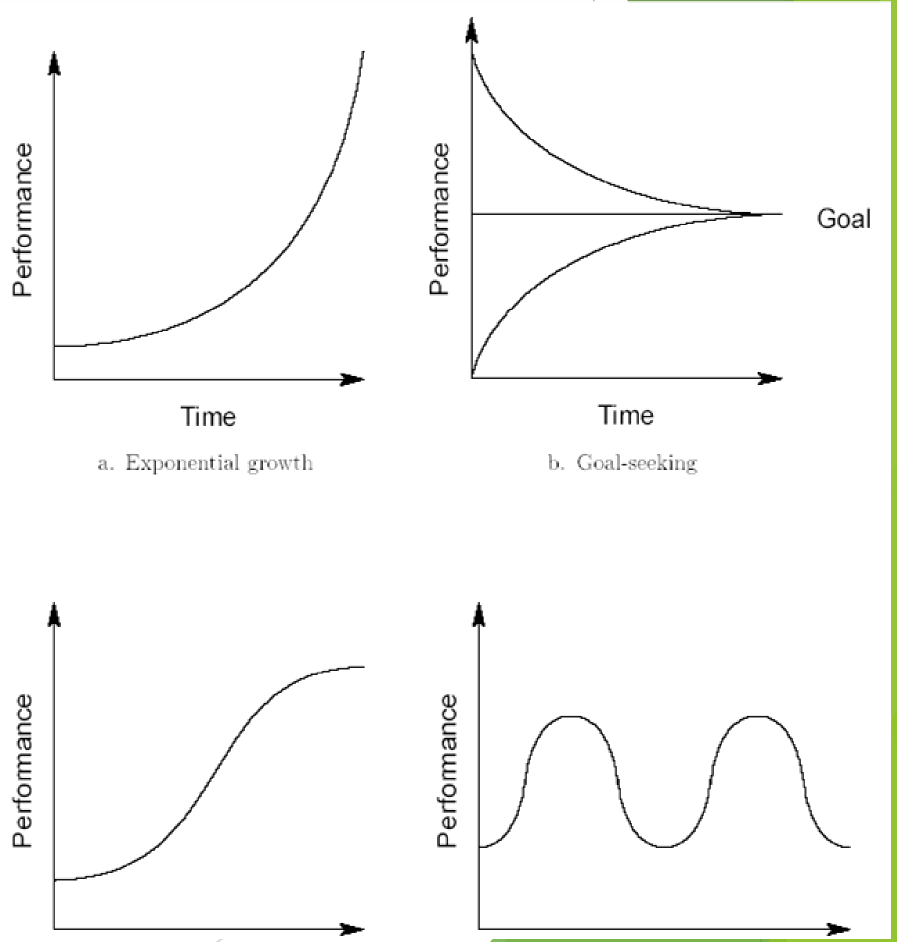
Combination of a positive and negative loop



Behavior Pattern

- Exponential growth
- Goal-Seeking
- Limits to growth
- Oscillatory

- There are obviously different combinations of these patterns (ex: Oscillatory exponential, Goal-seeking with oscillations, Limits to growth with oscillations)



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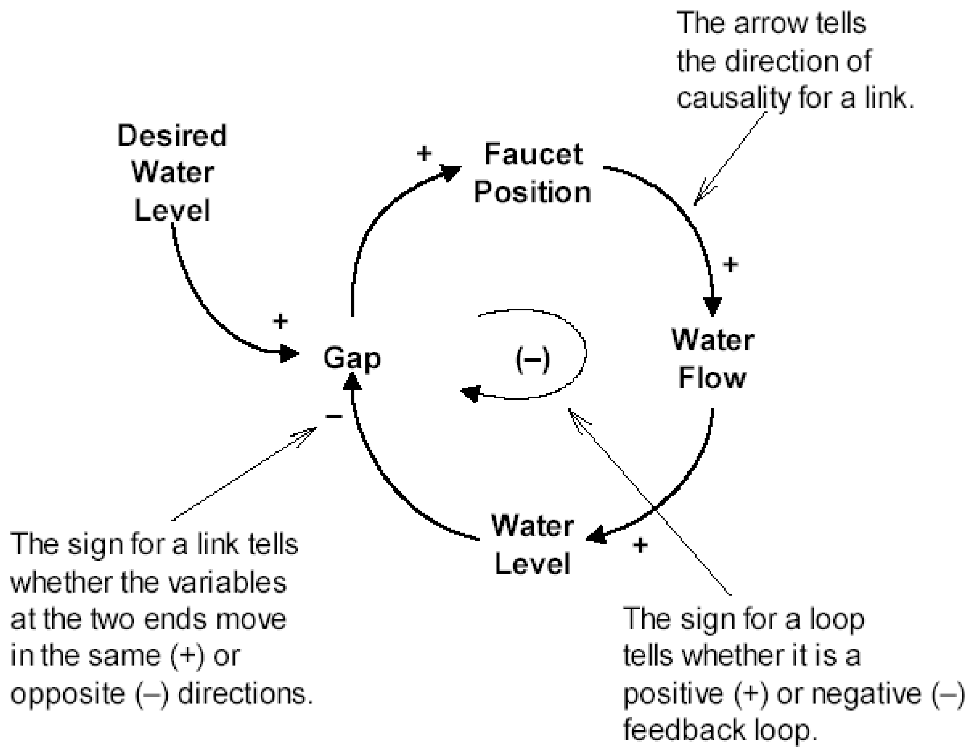
Systemic Archetypes

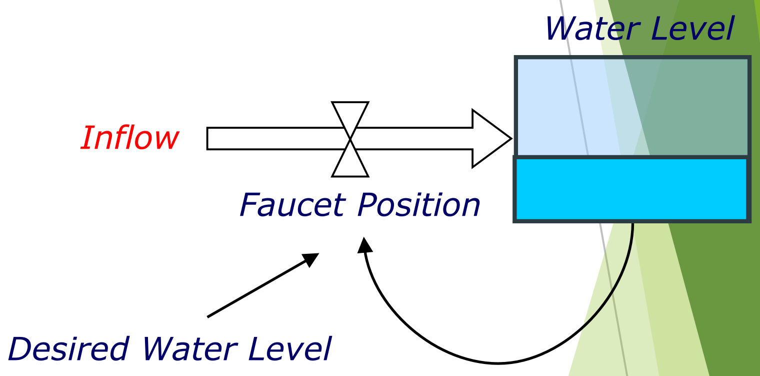
- The schemes described so far are part of a well-known set formed by a few "modular" structures (that is, to be used as if they were basic structural blocks). These structures each show a particular behavioral pattern and, due to their particularity, are defined as Systemic Archetypes.
- In practice, these micro-structures can be used, individually or in conjunction with others, to explain a whole series of behaviors that can be found in the trends of the observable variables of a system, and therefore, ultimately, to determine the basic system structure
- Ref. Web: www.outsights.com\systems\arch\arch.htm

Systemic Archetypes

- Balance between process and delay
- Limitations on Growth
- The transfer
- Transfer to those who intervene
- Erosion of objectives
- Success to the successful
- The tragedy of the commons
- Solutions that fail
- Growth and insufficient investment
- Ref. “The Fifth Discipline”, Peter Senge - Appendice 2

Modeling in System Dynamics

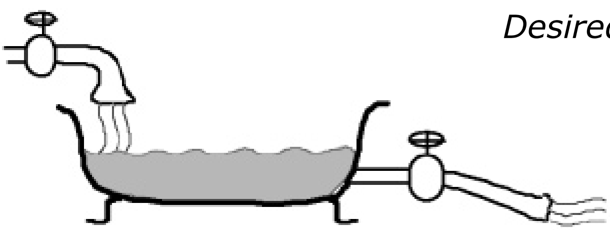


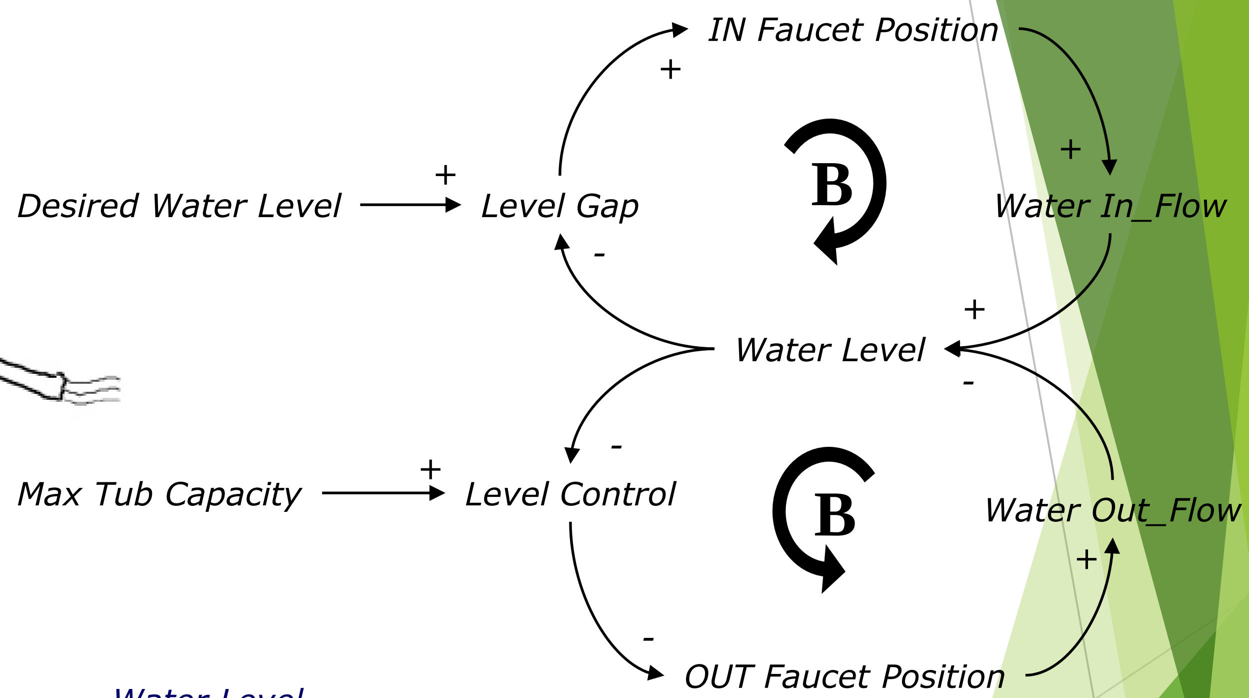


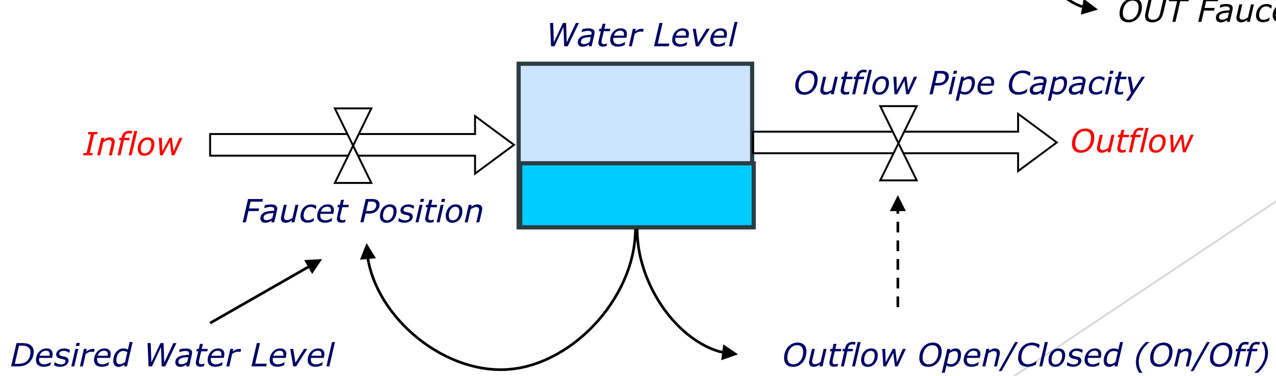
The problem is first analyzed through a qualitative description of both the components of the system and the causal relationships between the various parts, trying to establish feedback cycles and to recognize any systemic archetypes

Subsequently, we move on to describe it quantitatively, and with levels and flows model the relations identified through causal maps

Model generalization





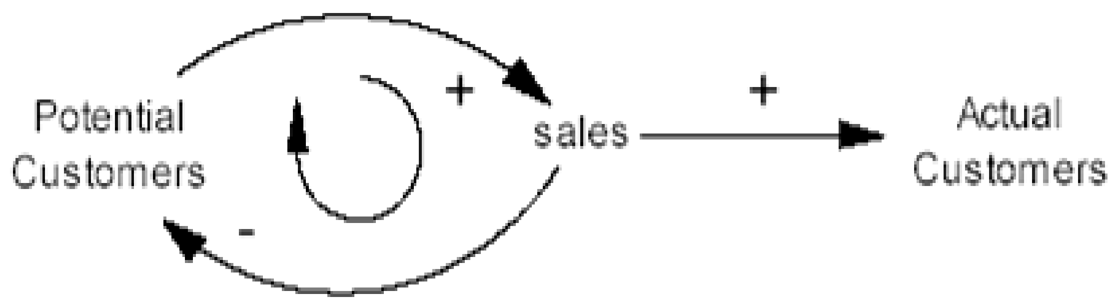


STOCK AND FLOWS

PART 2

From Causal Map to Model System

- Considering the causal map in the figure, we can initially draw very general, qualitative and non-detailed observations:
- Sales tend to zero when potential customers are gone (or zero). For managerial purposes, this observation is not very useful, because it does not provide us with information on the speed (the RATE) with which sales decrease.
- There is in general a nice difference between the average of filling a petrol in an hour instead of a week !!!
- For a simple case like this, you could use spreadsheet-based tools, but often situations turn out to be much more complex than the one in the picture.



Stock and Flow Diagram (SFD)

- The new diagram has the same variables as the previous one, but in a different form: it is composed of 3 of the 7 fundamental elements of System Dynamics:
- LEVELS (Stocks): they indicate an accumulation of a certain thing
- FLOWS (Flows): indicate the flow of an entity from / to one or more levels
- INFORMATION LINKS: they carry, at any moment of time, information on the values assumed by the other system variables

Stocks - Levels

- they can initially be imagined as a point of accumulation and movement of physical entities (but also non-physical ones, eg stress).
- They are the "nouns" of the system.
- They maintain the value of the state of the system (they do not disappear)
- They send signals related to their status, to the rest of the system
- It is the integral, over time, of the associated flows

Flows - Streams

- they can be initially imagined as flows of physical entities (but also non-physical ones, eg stress).
- They are the "Verbs" of the system
- They are the derivative of the Level
- They are "continuous" flows - problem of the divisibility of quantities
- They are deterministic variables: the randomness is added later

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Information Links

- The creation, control and distribution of information is central to any managerial activity and in any business !!!
- In the reorganization of a company, the process of managing information and knowledge, or its re-engineering, can be the real plus point for developing a competitive advantage
- It may be difficult to model this passage of information, but experience shows that by changing the ways in which information is passed in a process (ie changing Info Links into an SFD) it can have a significant impact (whether positive or negative, attention !!!) on its performance.

Feedback

- Although the mere presence of flows and levels (open systems) allows to have a dynamic behavior of the system (derivatives and integrals of temporal functions), what contributes in creating the non-linearities in a system (and therefore the difficulties ...) is the feedback loop
- Counterintuitive behavior due to feedback loops (example of the cascade)
- Feedback loops create closed systems. In an SFD, it is constructed using informational links in a timely manner.
- RULE: a feedback loop must contain at least one level in its path

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Modeling Phases

- Description of the problem (not necessarily with a negative meaning)
- Analysis and understanding of the system
- Model construction (CLD, SFD)
- Model test
- Use of the model
- In each of these phases it is possible to envisage a return to one of the previous ones in order to redefine the analysis carried out in that phase and then retrace all the steps.

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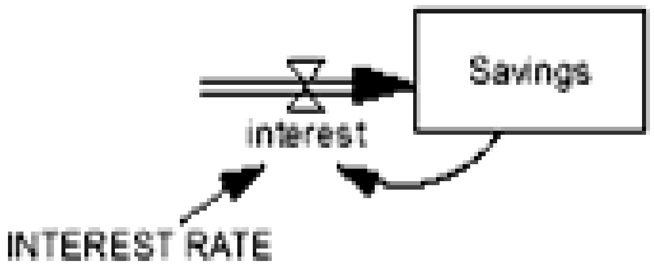
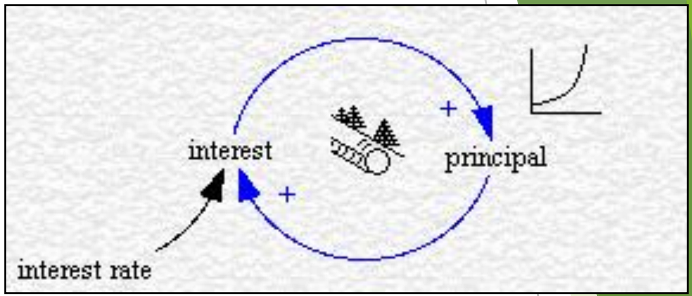
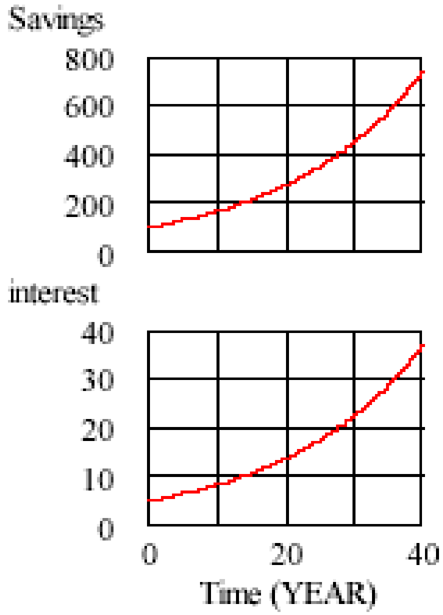
Basic feedback structures

Examples

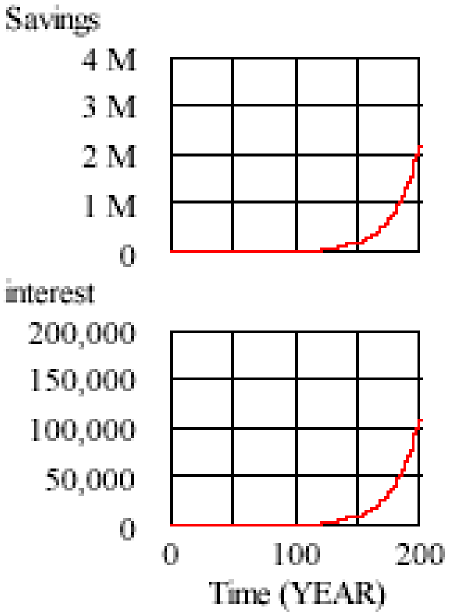
Exponential Growth





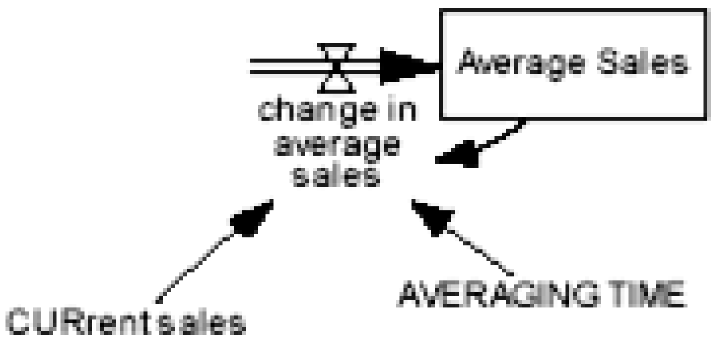


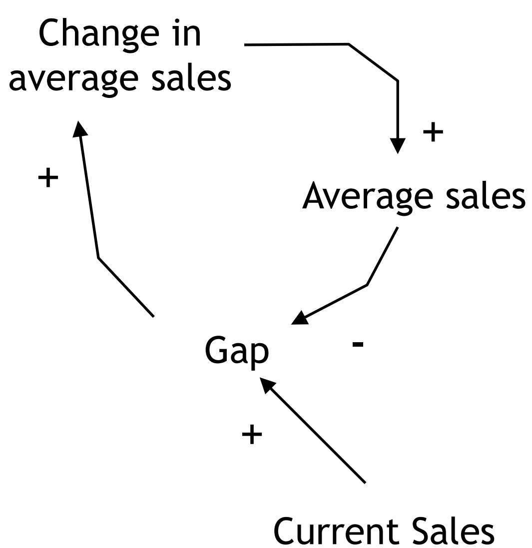
c. Forty year horizon

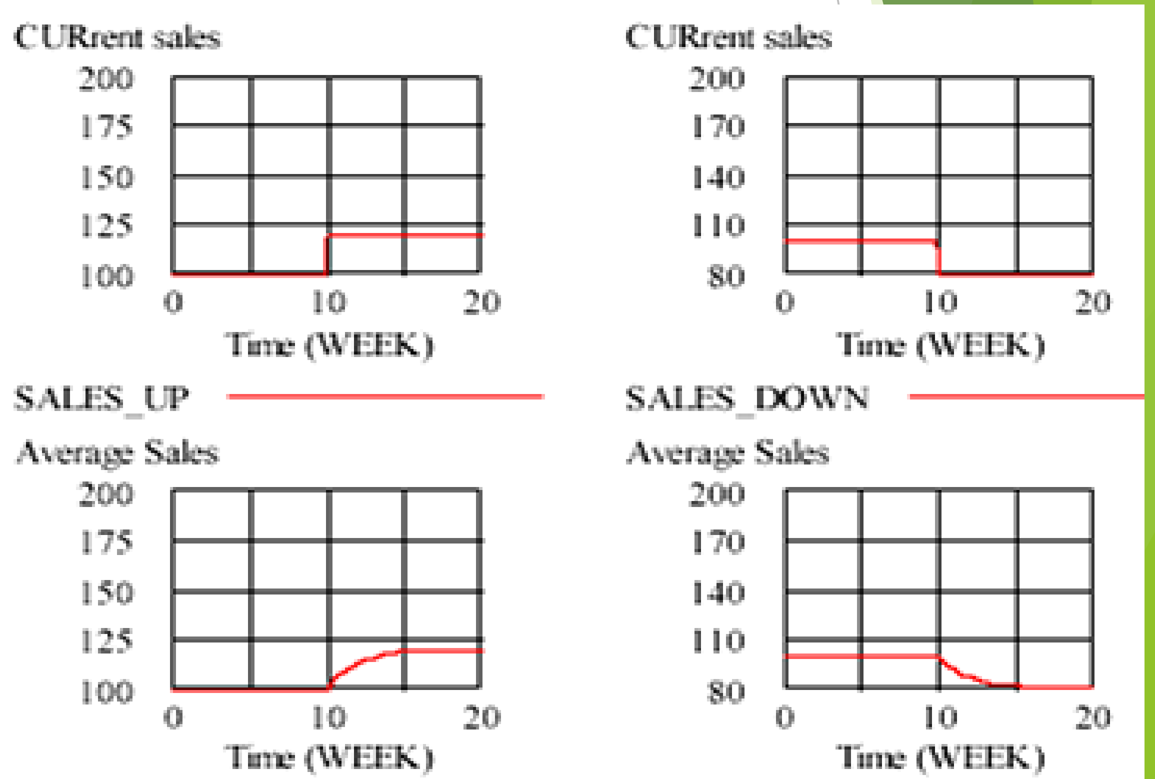


d. Two hundred year horizon

Goal Seeking



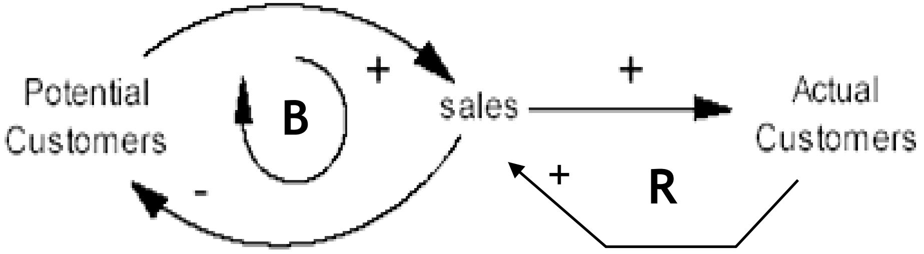


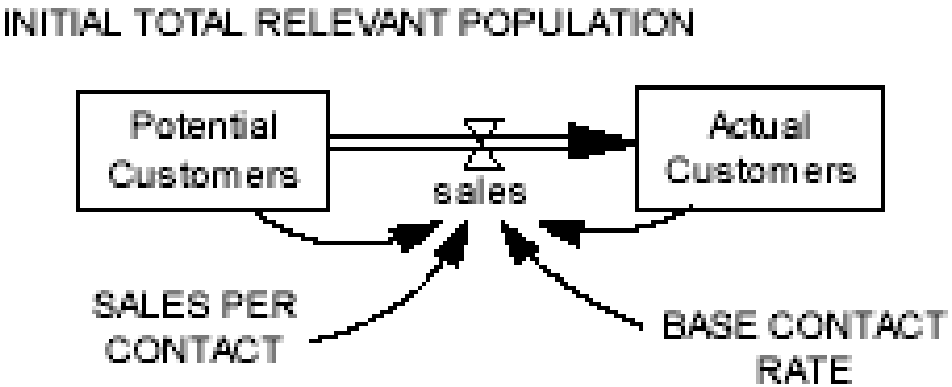


c. Sales move up

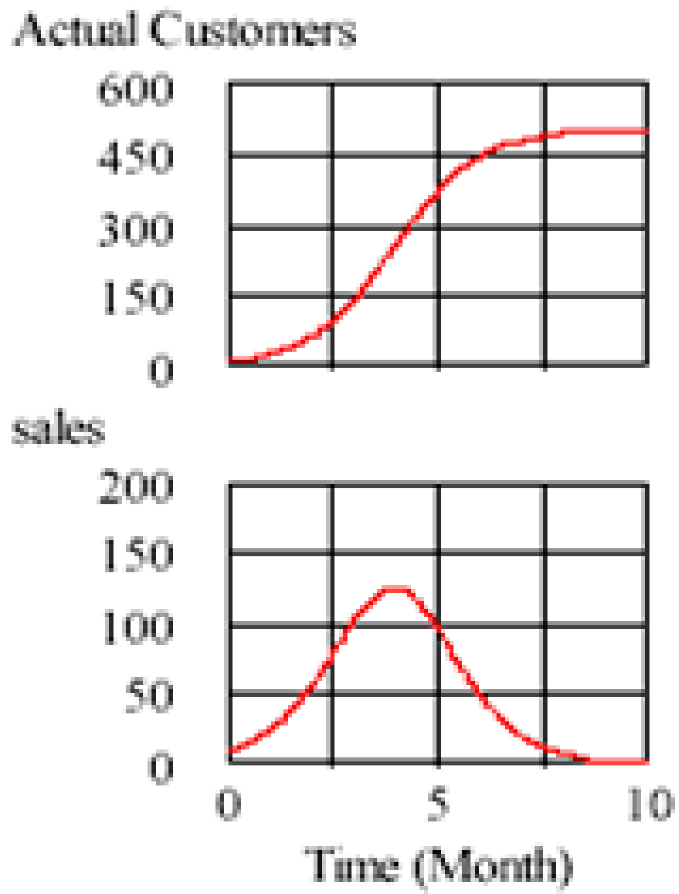
d. Sales move down

S-shaped Growth





a. Stock and flow diagram



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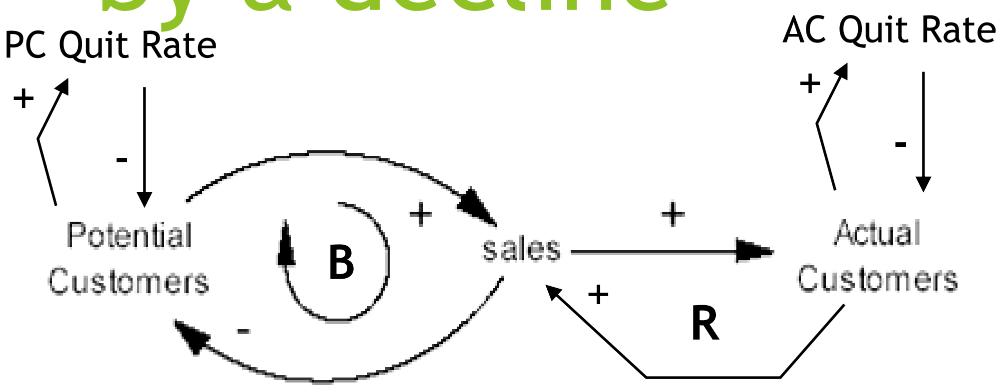
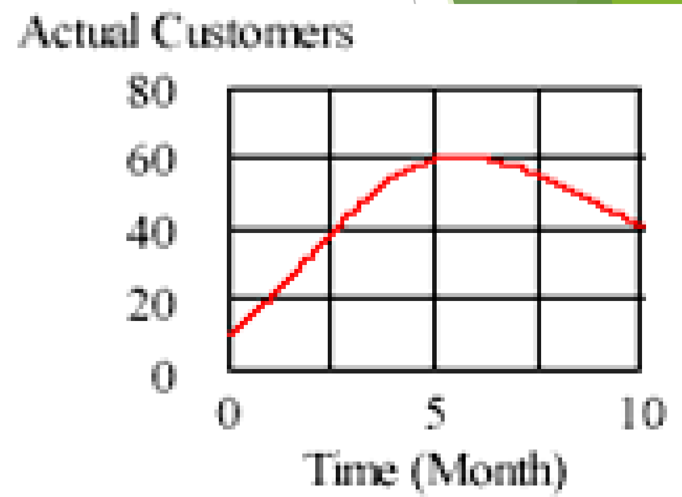
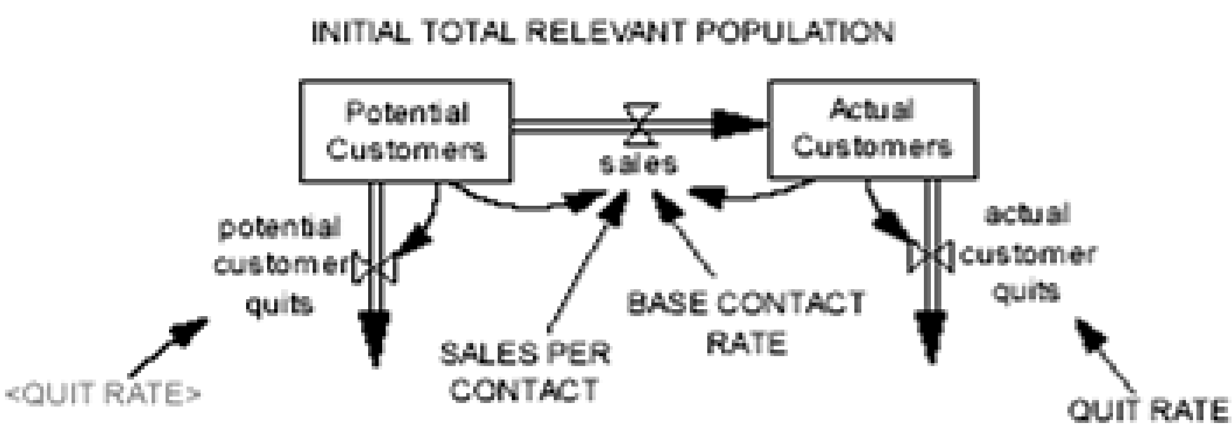
“S-shaped growth” followed by a decline



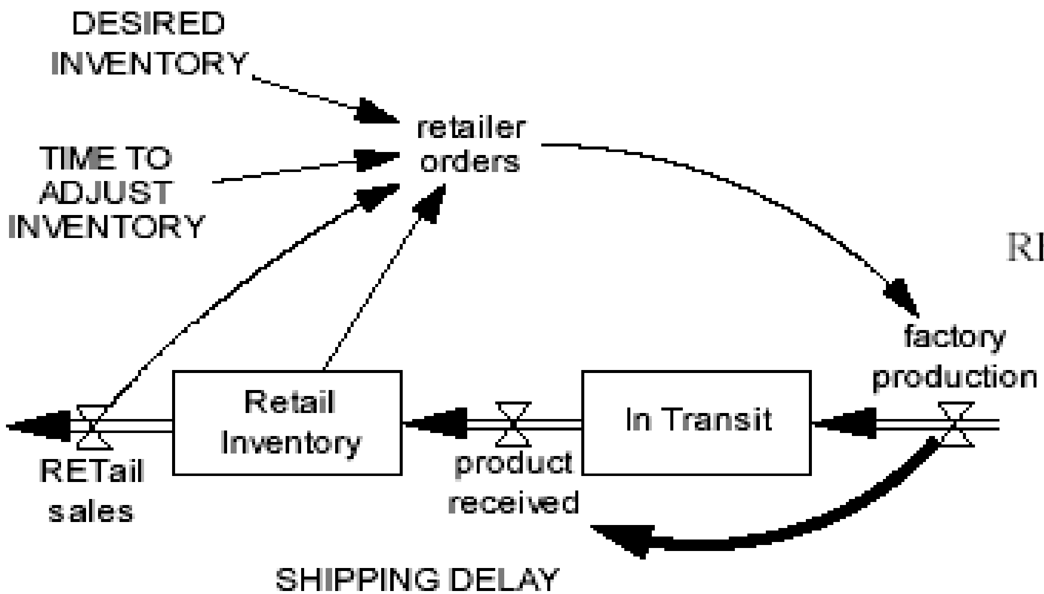


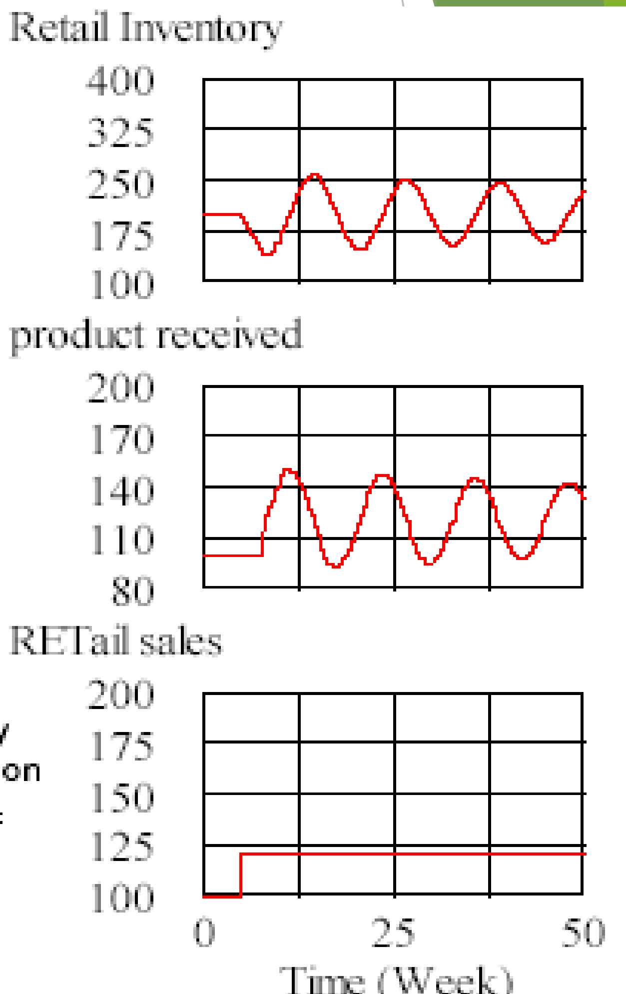
c. Customer performance



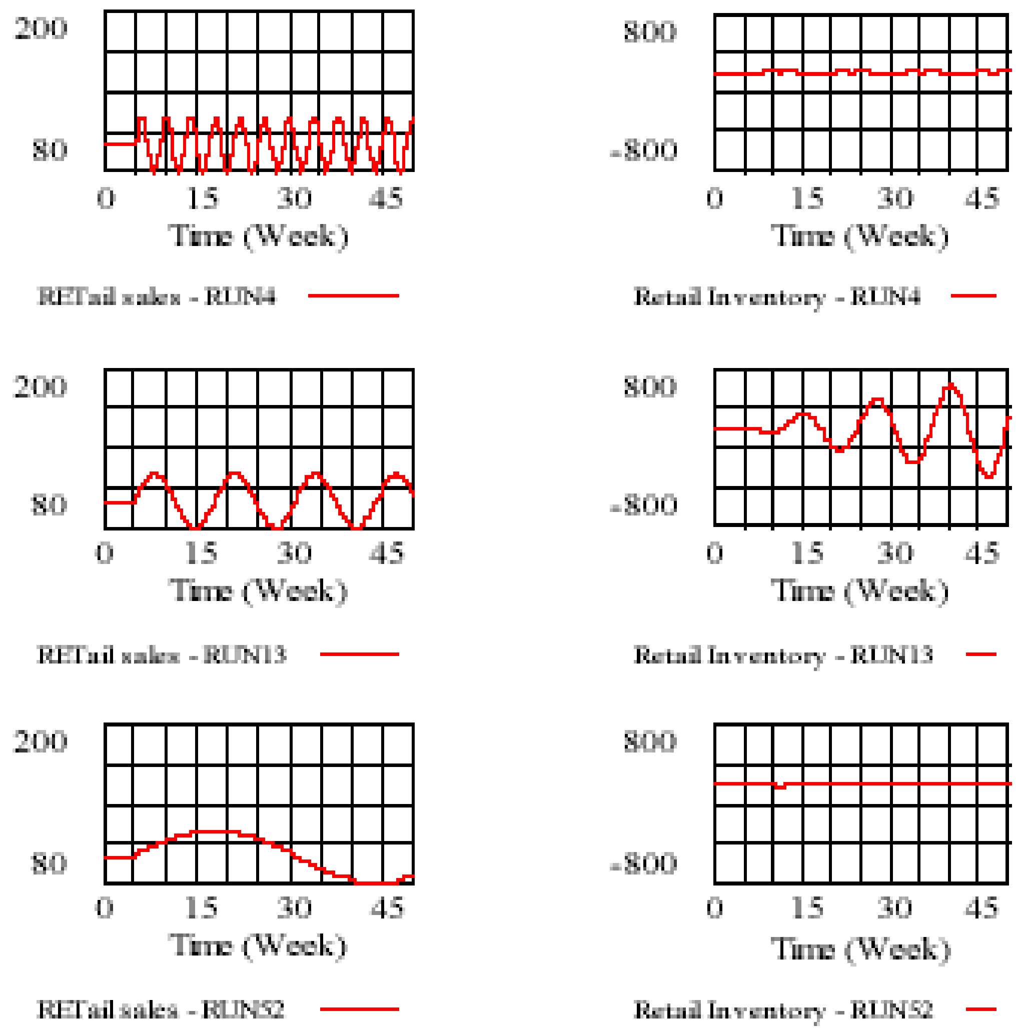
Oscillatory process /1

EXERCISE: try to build the CLD knowing that the behavior is generated by a negative cycle with delay ...





Oscillatory process/2



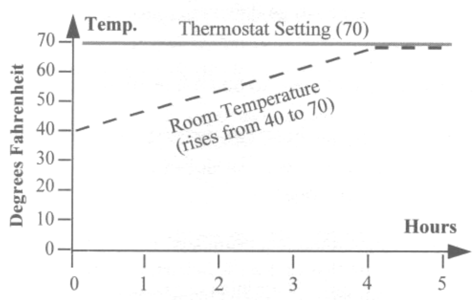
Some examples

Rif. SW - Powersim

Heating system (simple)

- Description of the problem: analyze how a thermostat in a heating system regulates the temperature of a room
- The description of the problem in the figure can then be used as a Reference Behavior to test the behavior of our model later

Time graph for problem description

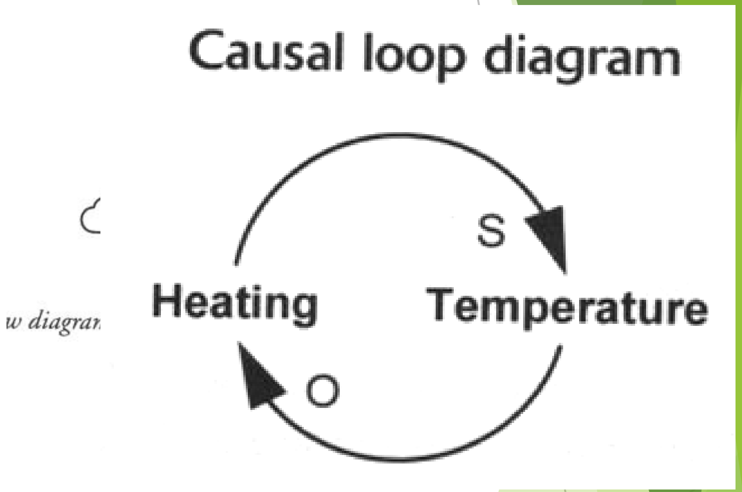


Reminder Notes

- Remember that while a flow is defined during a whole interval of time, a level is defined in an instant of time.
- When Bush proclaims: "We will reduce gas emissions in the atmosphere", is he really doing anything against the greenhouse effect?
- So is the room temperature a flow or a level? And the heating?

Model Construction

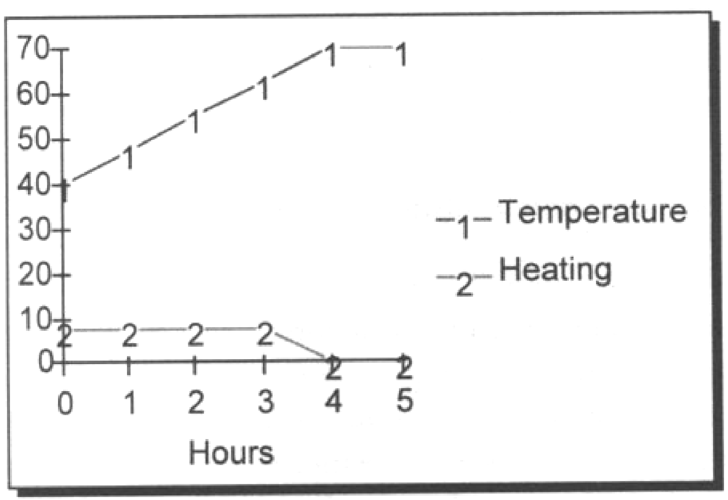
- Very simple CLD based on a self-balancing cycle (B), or negative (-)
- The construction of the SFD is trivial in this case: there is no need to resort to the Burns method, which is more useful instead in more complex situations where the entities present in the CLD exceed the ten.
- A level, a flow and an Information Link: Temp: INIT(40°F)
  - Heating: IF(TEMP<70°F, 7,5, 0)



Testing the model

- Set the interval and the simulation step (dT = 1)
- Analyze the differences between the simulated and the reference behavior (expected)
- Since they correspond (they are practically the same), it can be assumed that the model is realistic. Can it be made MORE realistic? Is it correct to say that the temperature remains constant when the thermostat is off? It depends on the outside temperature ...!

Simulation result in a time graph

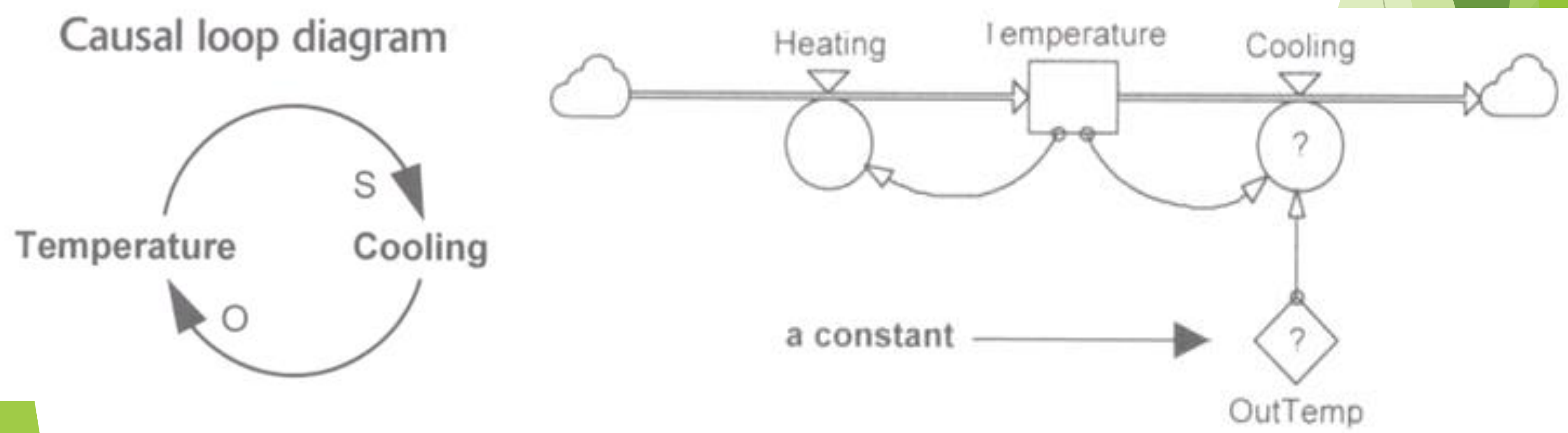


Simulation result in a time table

Hours	Temperature	Heating
0	40.00	7.50
1	47.50	7.50
2	55.00	7.50
3	62.50	7.50
4	70.00	0.00
5	70.00	0.00

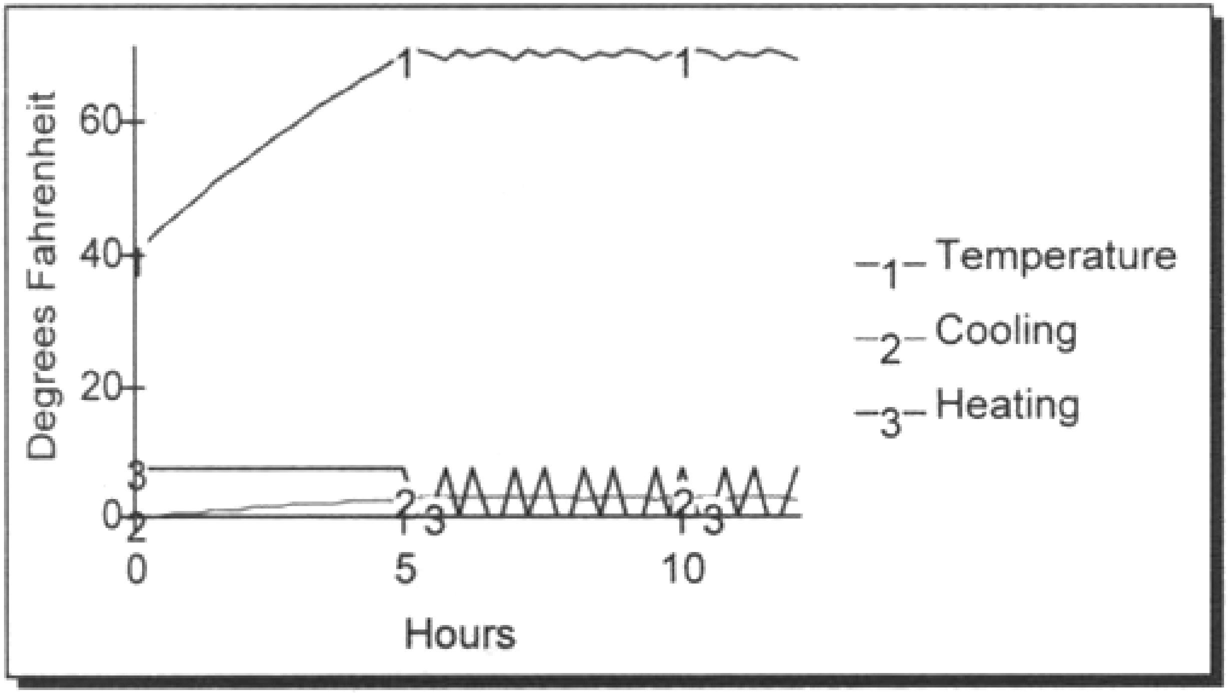
Extension of the problem and the model

- Assuming that the temperature outside the room is lower (eg 40 ° F), due to the laws of heat transmission, once the thermostat “goes off", the temperature starts to drop (more slowly than it has obviously risen, and depending on the insulation of the room): there is a delay.
- Reverse example: when it's warmer outside, it takes time before the house heats up!



Testing of the model

- Cooling = (Temperature – OutTemp) * 10%
- OutTemp = 40°F (costante)
- Time_Step (dT) = 0,25 hours
- Some aspects of the system that were not initially detected are captured



Further extension of the model

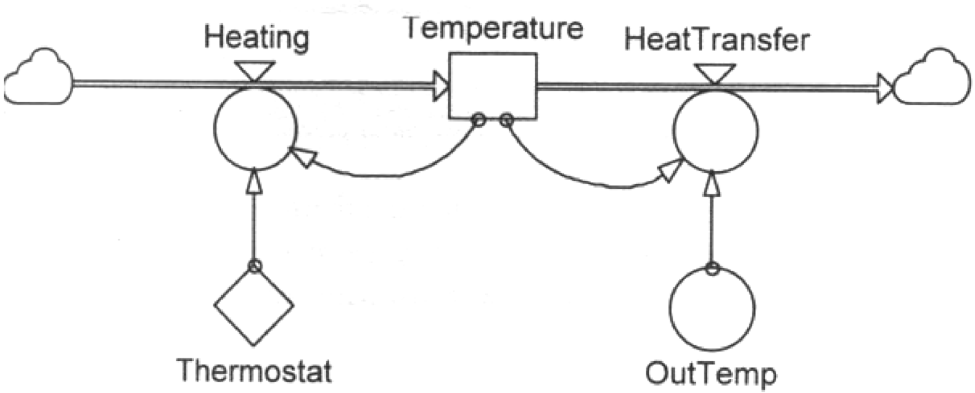
- What happens if the outside temperature is higher?
- The most appropriate definition for the "Cooling" variable becomes "Heat Transfer", which in this case becomes a positive flow (ie heat accumulation)
- If the simulation interval is extended to 24h, the method of changing the external temperature must also be taken into account
- It is also possible to add a simulation "lever" relative to the temperature set on the thermostat, which can therefore be changed during the simulation: if I feel cold, I raise the temperature on the thermostat!

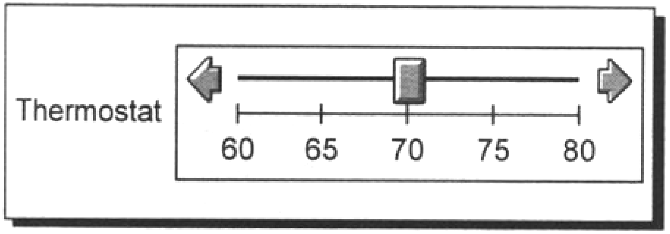
SUSTAIN GAME-BASED LEARNING ON URBAN SUSTAINABILITY

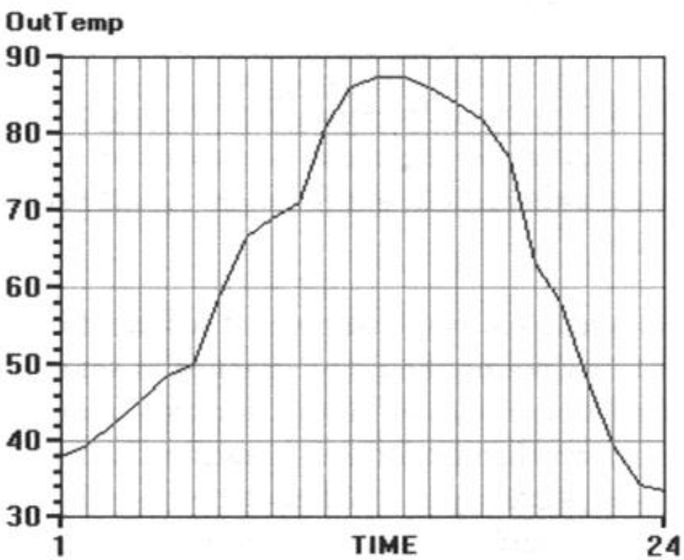
Co-funded by the Erasmus+ Programme of the European Union

ΙΔΡΥΜΑ ΚΡΑΤΙΚΩΝ ΥΠΟΤΡΟΦΙΩΝ IKY

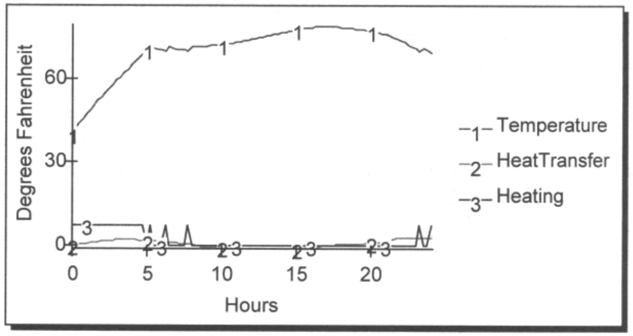
Final Model







Simulation results in time graph



Simulating with day and night variations in temperature. Notice that the

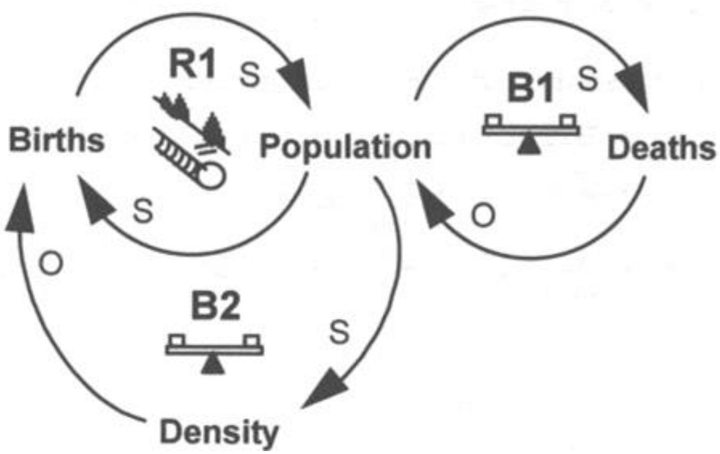
Population Dynamics

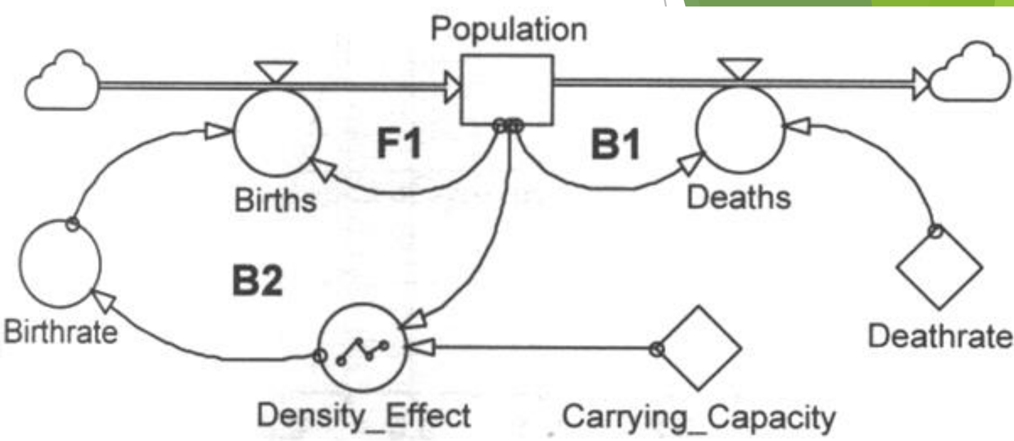
- Focus on a generic population (for example of animals) on a certain territory
- Limit hypothesis on the number of animals that can survive in the ecosystem in analysis (due to food scarcity)
- Maximum Capacity = 10,000
- Initial level POP = 1,000
- Initial analysis of the cycles of birth (R) and death (B, with implicit limit to zero)
- Analysis of the model with the two integrated cycles (Birthrate = 3% - Deathrate = 2%)
- Net entry in POP = + 1%

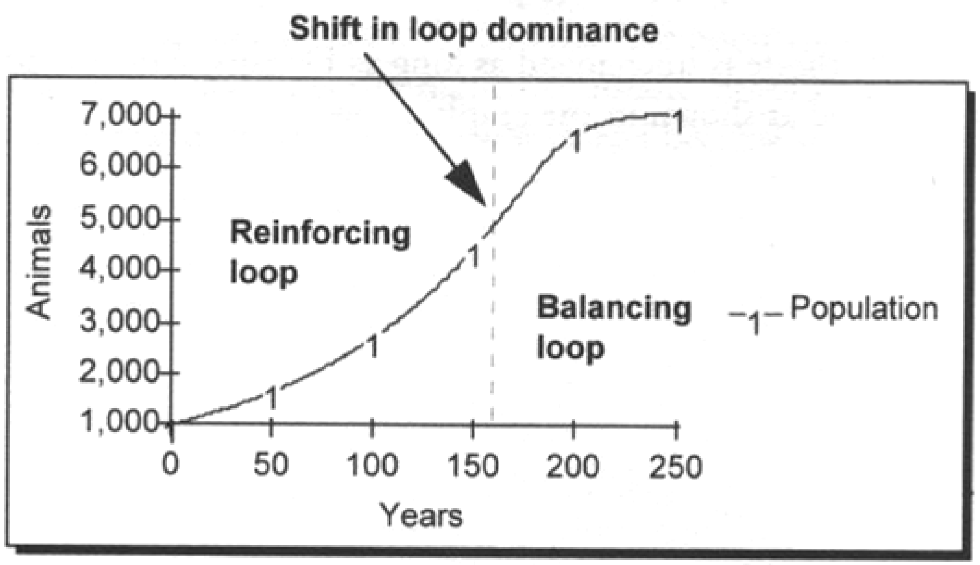
Model adaptation

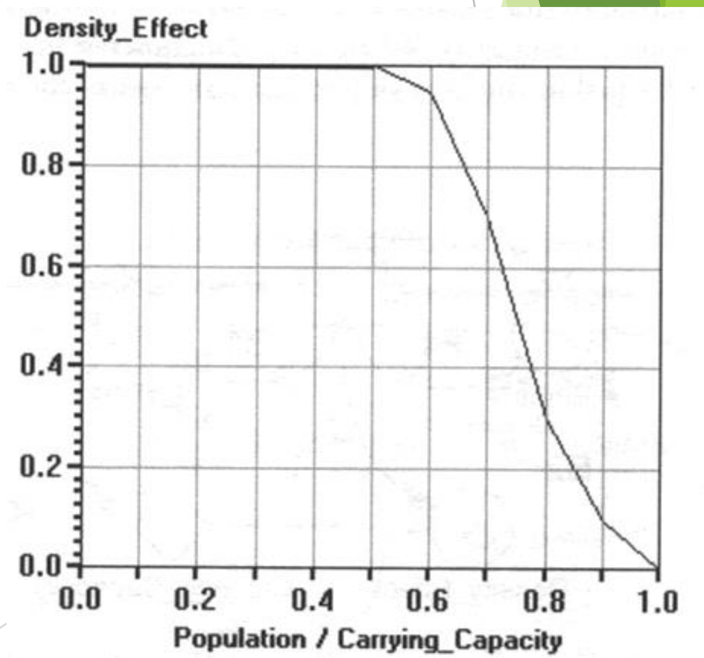
- What happens when the POP exceeds the Maximum Capacity of the Ecosystem?
- You must go back to the CLD and the system analysis. It will be noted that it is necessary to take into account the effect of the density of POP on births (another mechanism according to biological laws that integrates within itself, for example, the increased infant mortality due to lack of food)
- We therefore consider the new equation:
- Birthrate = 3% * Density_Effect

Growth-reducing loop added

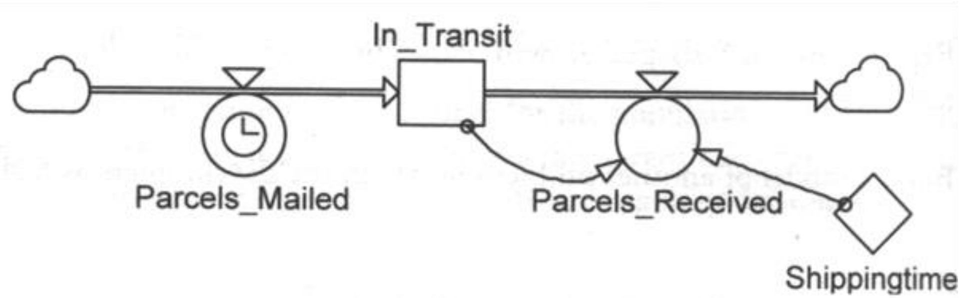


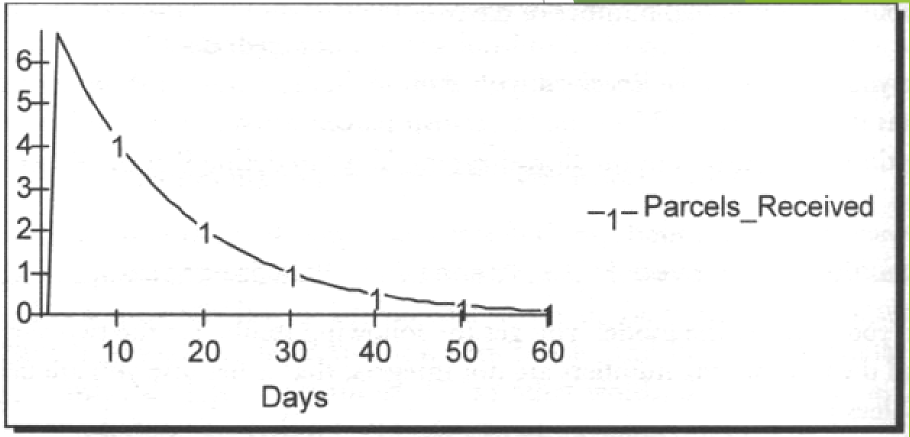




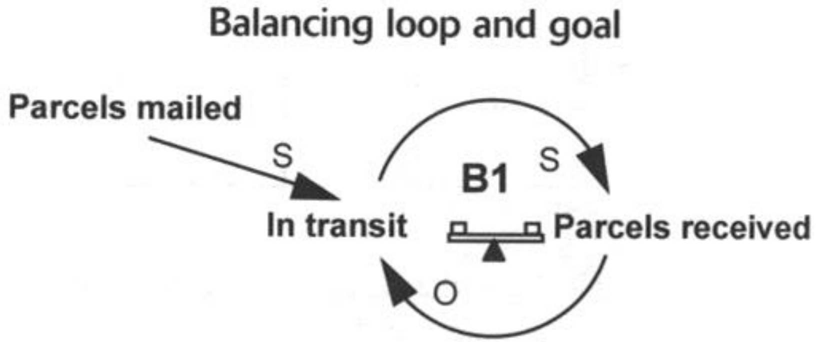


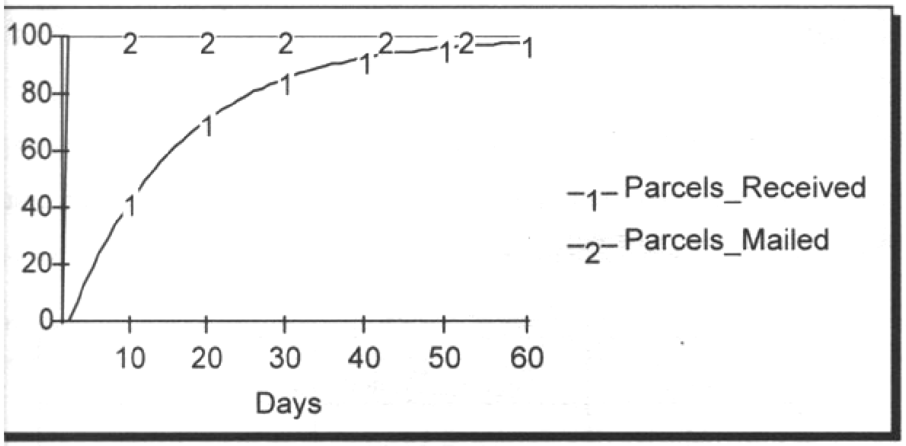
Delays



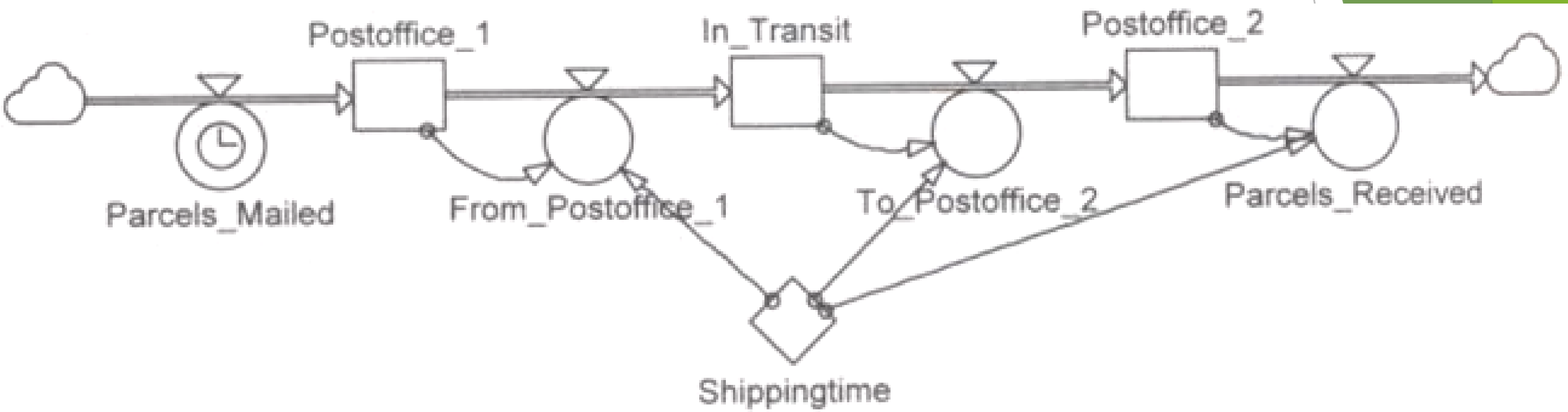


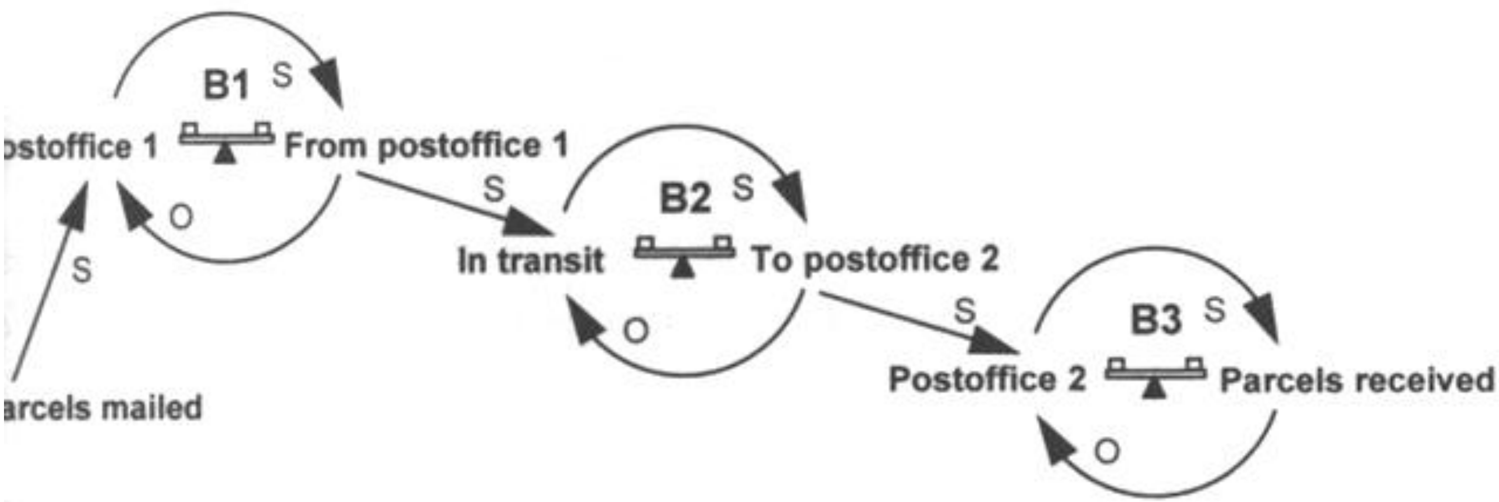
- Parcels_Received = In_Transit/Shippingtime
- Shippingtime = 15
- Parcels_Mailed (a) = IF(TIME = 2, 100, 0)
- Parcels_Mailed (b) = IF(TIME >= 2, 100, 0)





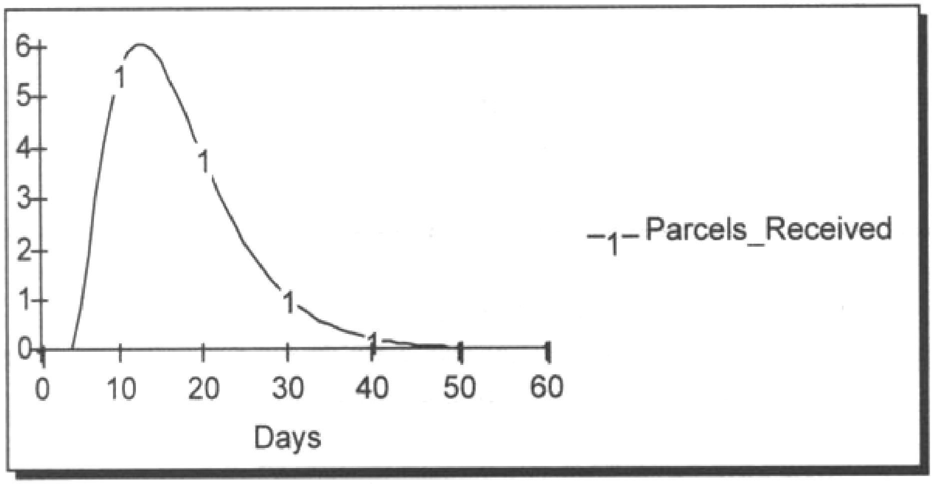
Delays through more levels

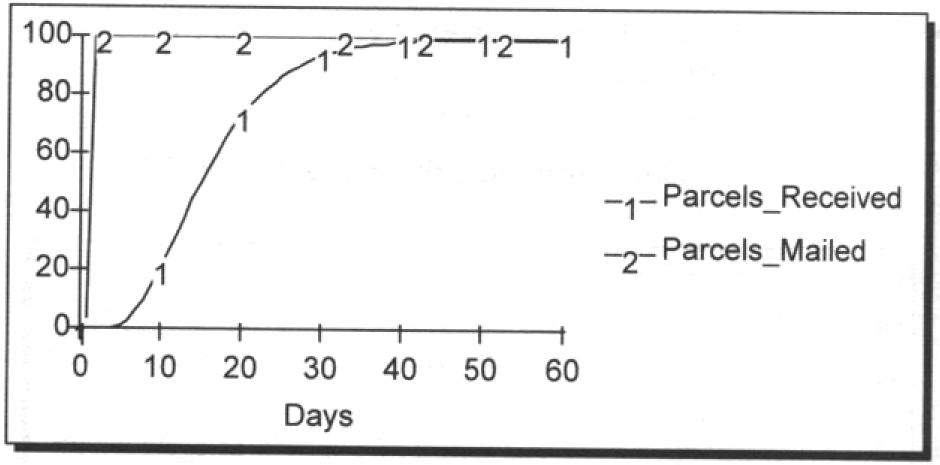




Effect of more delays

- This highlights that a stimulus to the system that is delayed by passing through a series of self-balancing cycles, each of which has only one level, causes an S-shaped (or growing or decreasing) trend towards a point of equilibrium.





- Are we in the presence of another Archetype? NO.

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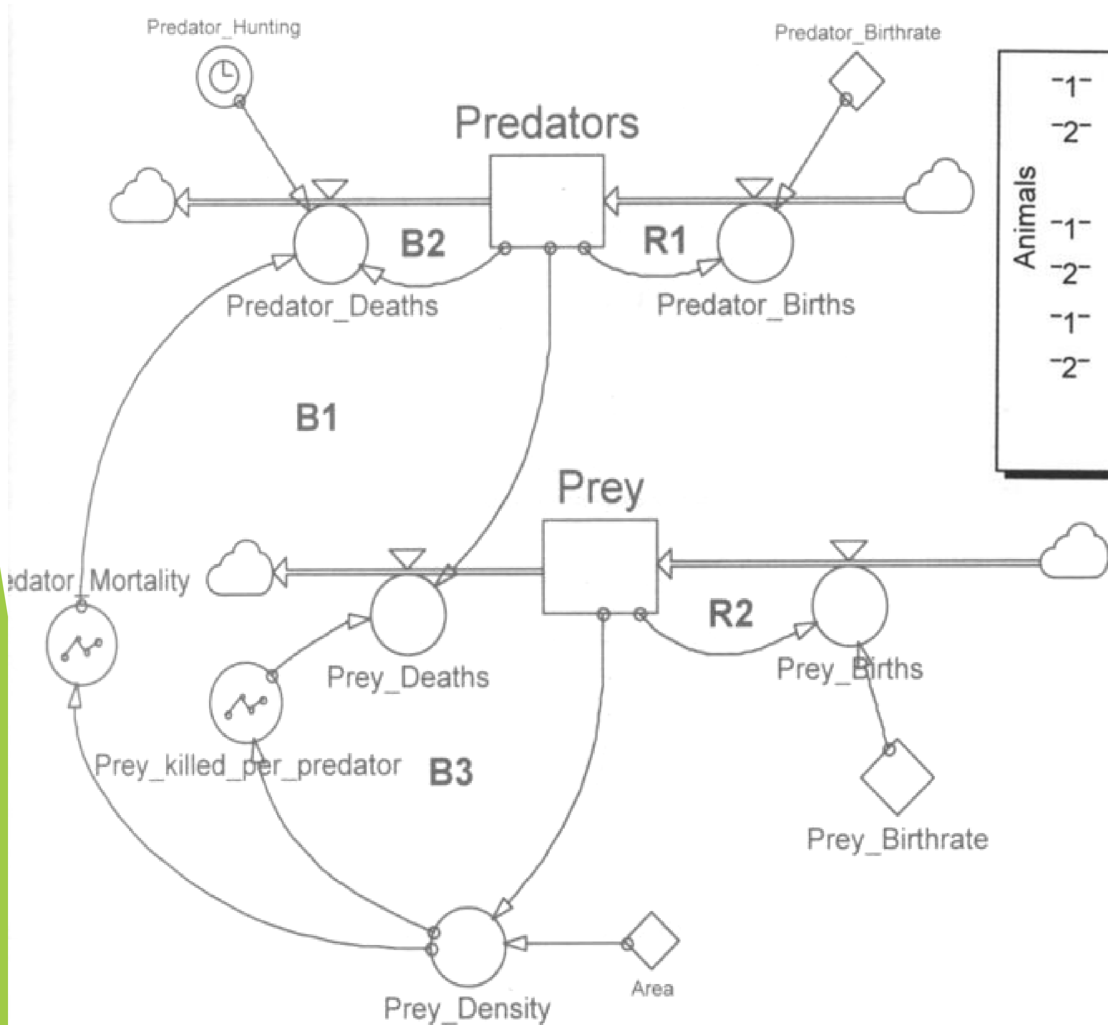
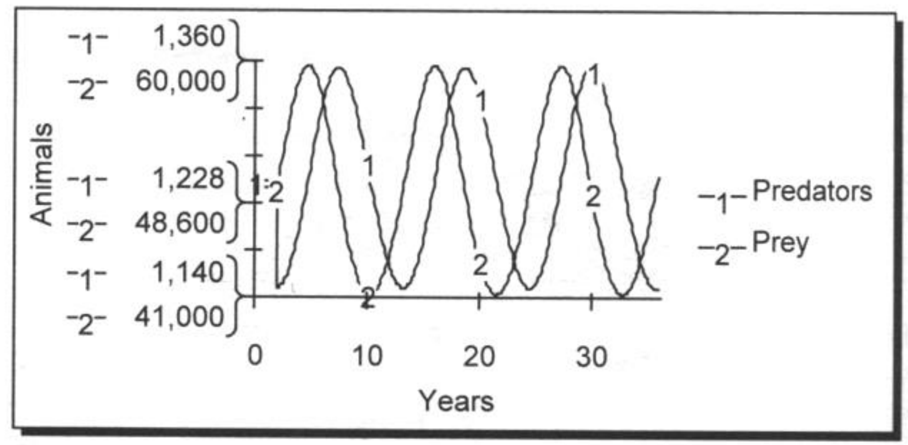
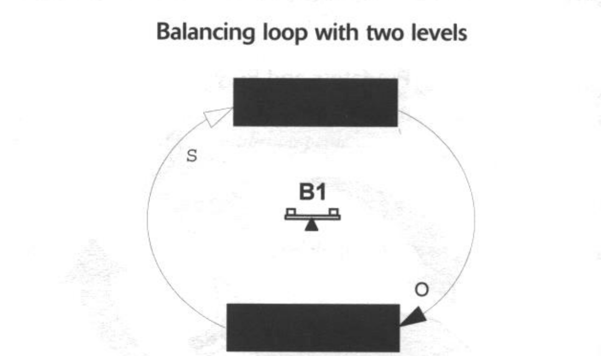
The rise of oscillations







crease in the prey population leads to a delayed increase in the predator population.
eased predator population will, after some time, lead to a decrease in prey. The mai