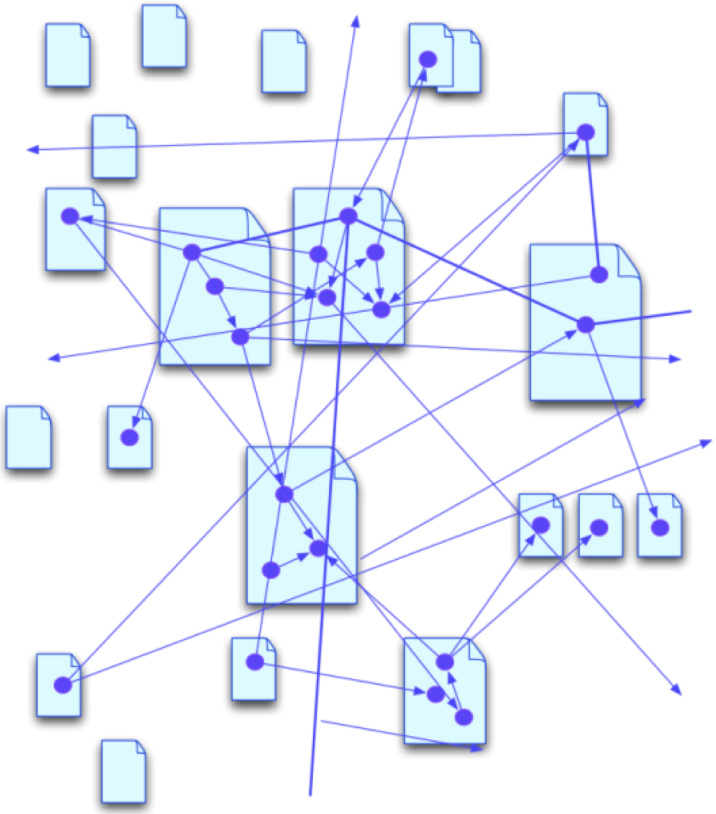
Systems Theory, Systems Thinking



Tim Berners Lee, The Semantic Web

Stephanie M. White, Ph.D.
Senior Professor
Long Island University
(LIU-Post)

IEEE Systems Council
DL Talk at UBC
Nov. 15, 2018

Outline

- What is systems thinking?
- A few important concepts
- Brief discussion of 3 methods based on system thinking

Benefits:
- Improve your ability to analyze & solve problems
- Use these concepts & methods with your current analysis methods

What is a system?

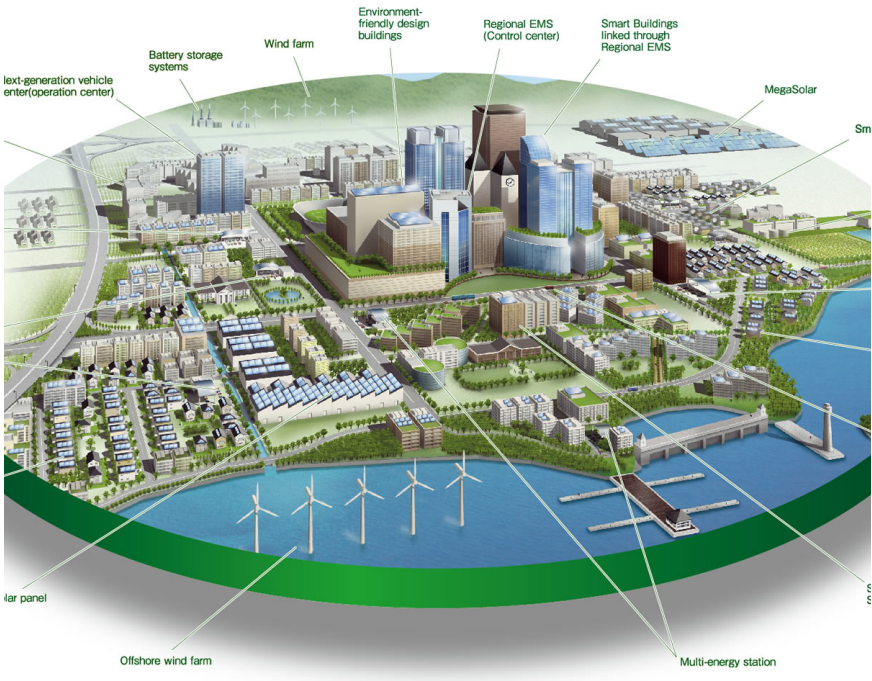
- Simple definition: A group of interacting, interrelated, or interdependent elements forming a unified whole

  $S = (T,R)$, T: *set of things; R is a relation defined on T*

- We are interested in systems that perform a function, are purposeful
- Designed systems (engineered, set of ideas, procedure, human activity system)
- Natural systems

Developing & Managing Complex Systems

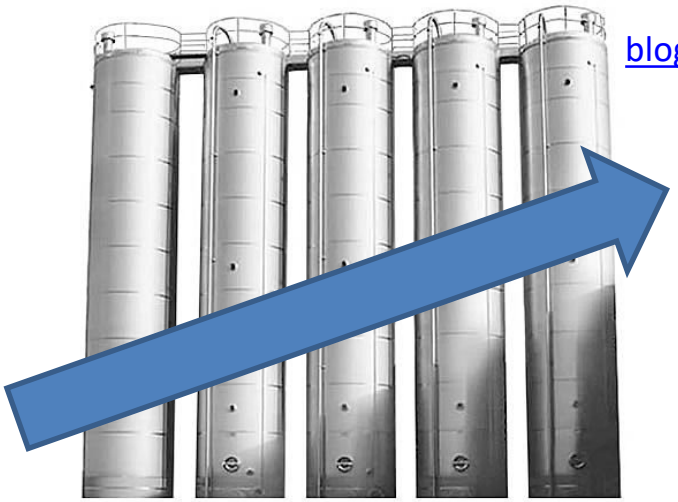
- Exciting interdisciplinary field
- Cuts across all traditional disciplines of science, as well as engineering, medicine & management
- Until recently we believed that if we understood the parts, we would understand the whole
- But many of the problems in our world concern the relationship between the parts



Smart Cities, an IEEE Future Direction

Systems thinking means understanding connections & inter-dependencies

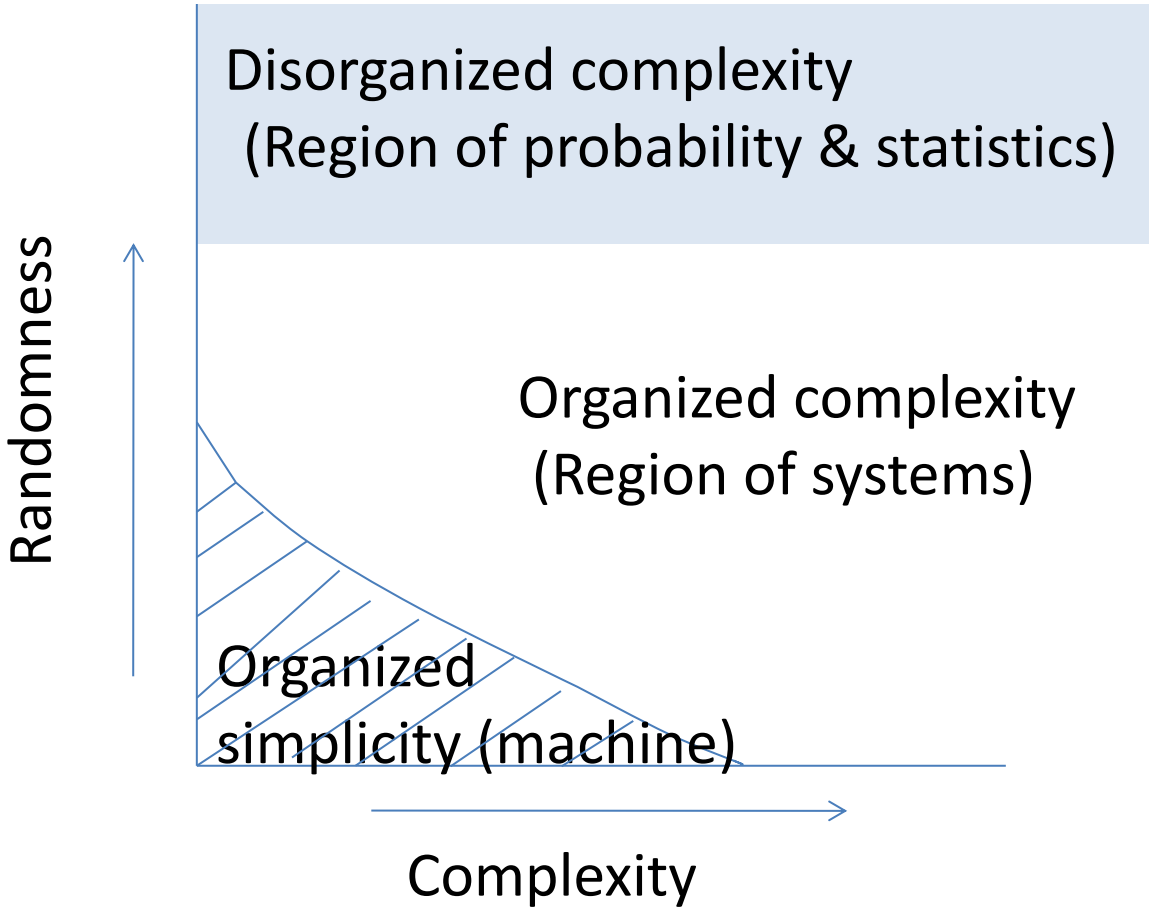
- Many people see the world as “silos” or “*content bins*”
- Few have skills in seeing *horizontal connections*



blog.dlvr.it/

“The spread of specialized deafness means that someone who ought to know something that someone else knows isn't able to find it out for lack of generalized ears.”(Boulding)

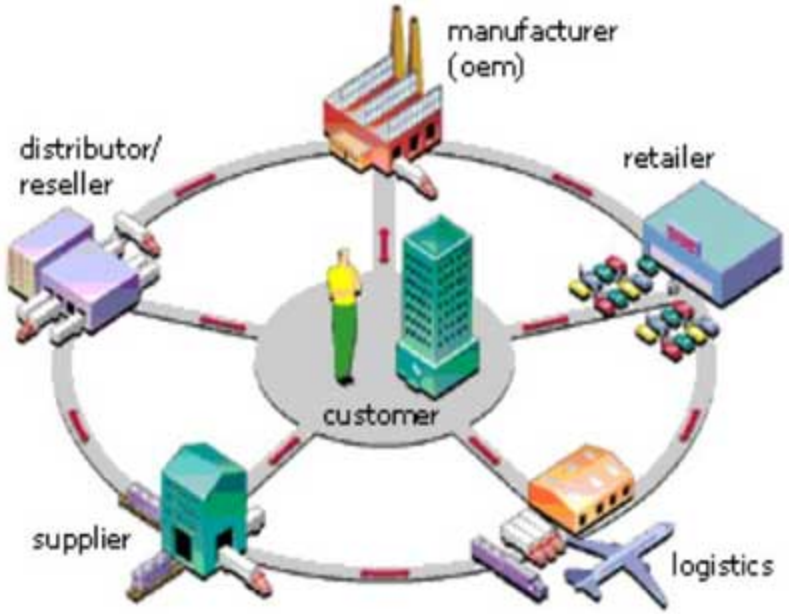
Types of systems with respect to methods of thinking



Based on Warren Weaver's work

(from G.M. Weinberg, *An Introduction to General Systems Thinking)*

Supply Chain – example of a system of organized complexity



From http://www.axtin.com/solutions/supply_chain.html

When one part of the supply chain is disrupted, it can affect the entire process

Systems Thinking Concepts

- A few concepts of interest to system science & cybernetics
  1. Transformation
  2. Negative feedback
  3. Positive feedback
  4. Control (uses negative feedback)

  There are underlying laws of control that apply to the nervous system, an ecosystem, an organization

Transformation (A→ B)

- State description
- Process description

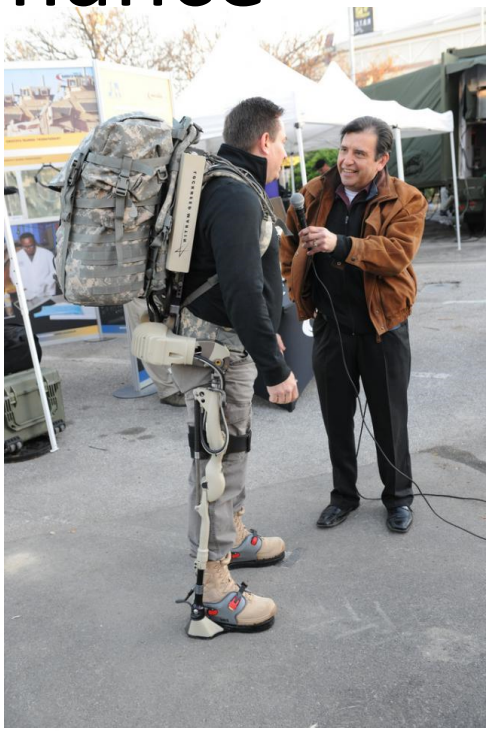
mathsteacher.com.au

EXAMPLE

State description:
Existing state: No circle
Desired state: set of all points equidistant from one point called the center of the circle
Process description: procedure for drawing circle with compass

Existing & desired states define the basis for survival of organisms & organizations

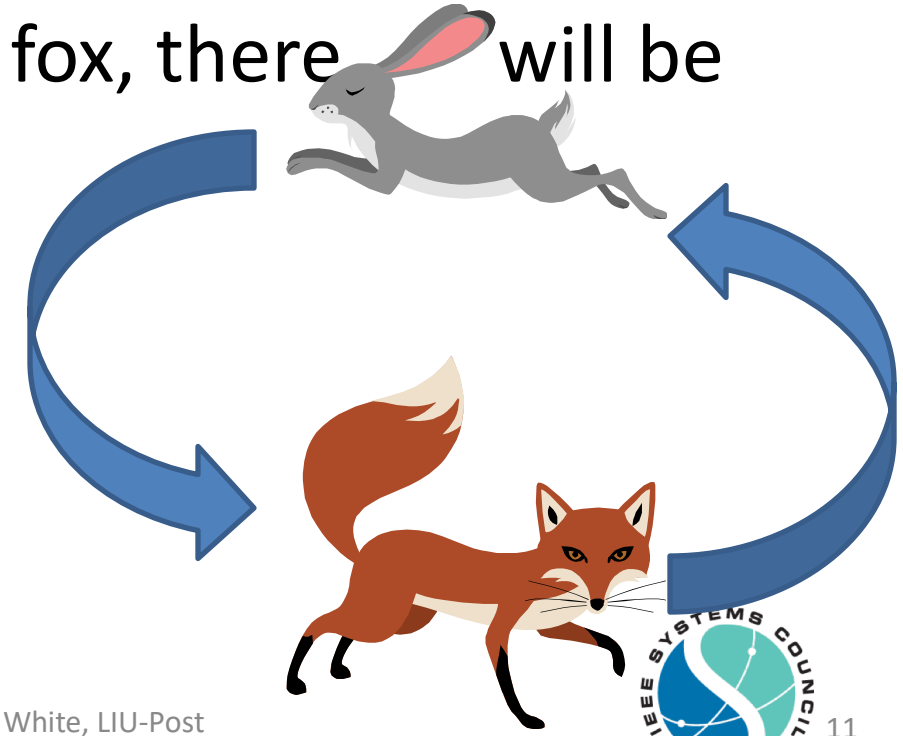
Transformation: Exoskeleton augments human performance



https://www.army-technology.com/projects/raytheon-xos-2-exoskeleton-us/
https://www.army.mil/article/50144/exoskeleton_enhances_warfighter_strength_reduces_injury

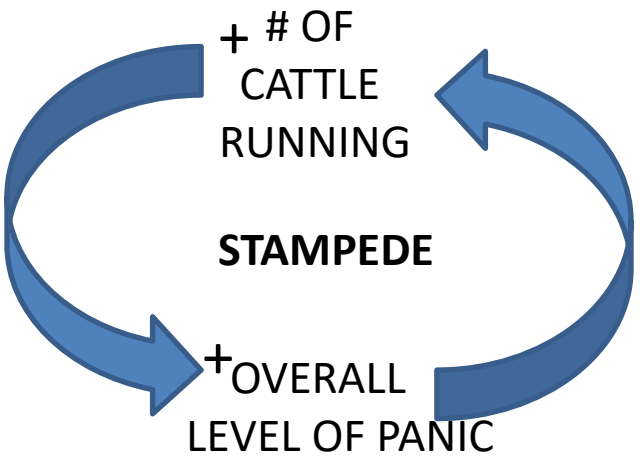
Negative Feedback

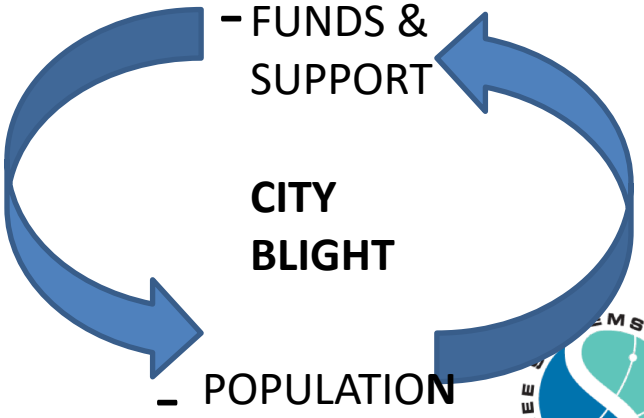
- Negative feedback helps maintain stability in a system. Fox eat rabbits. More fox mean fewer rabbits. Fewer rabbits provide less food, so fewer fox. With fewer fox, there will be more rabbits, …



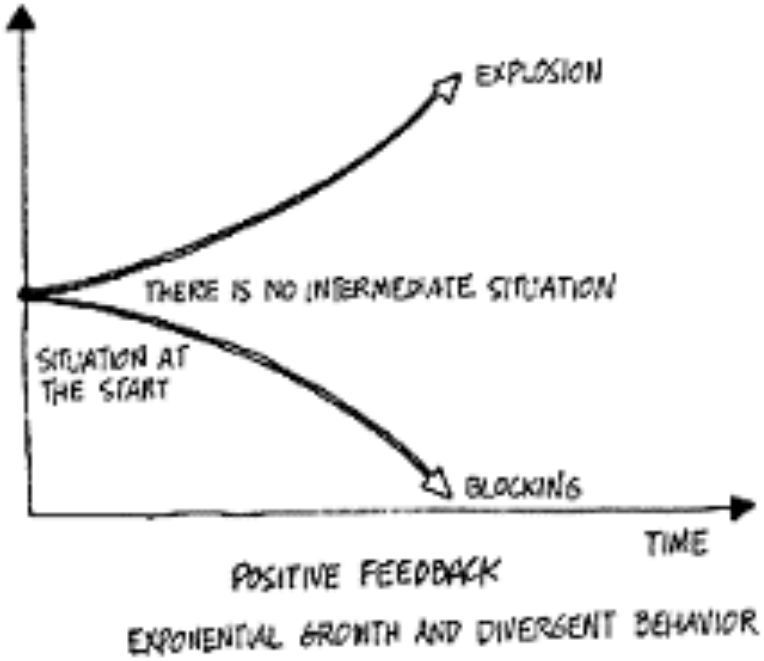
Positive feedback

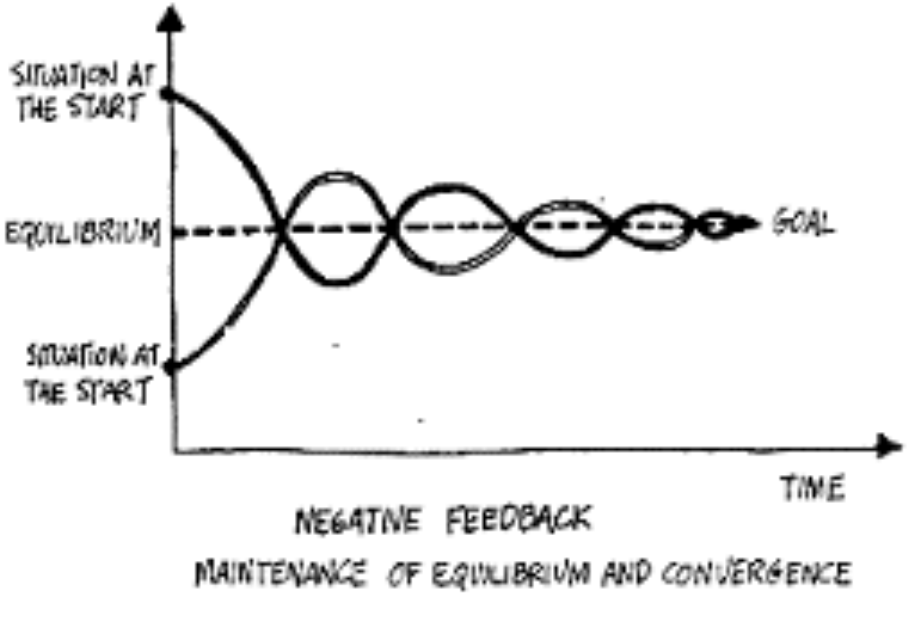
- Leads to indefinite expansion or explosion
  - Chain reaction
  - Population explosion
  - Industrial expansion
  - Capital invested at compound interest
  - Inflation
  - Spread of cancer cells
- Or total blocking
  - Bankruptcy
  - Economic depression
  - City blight





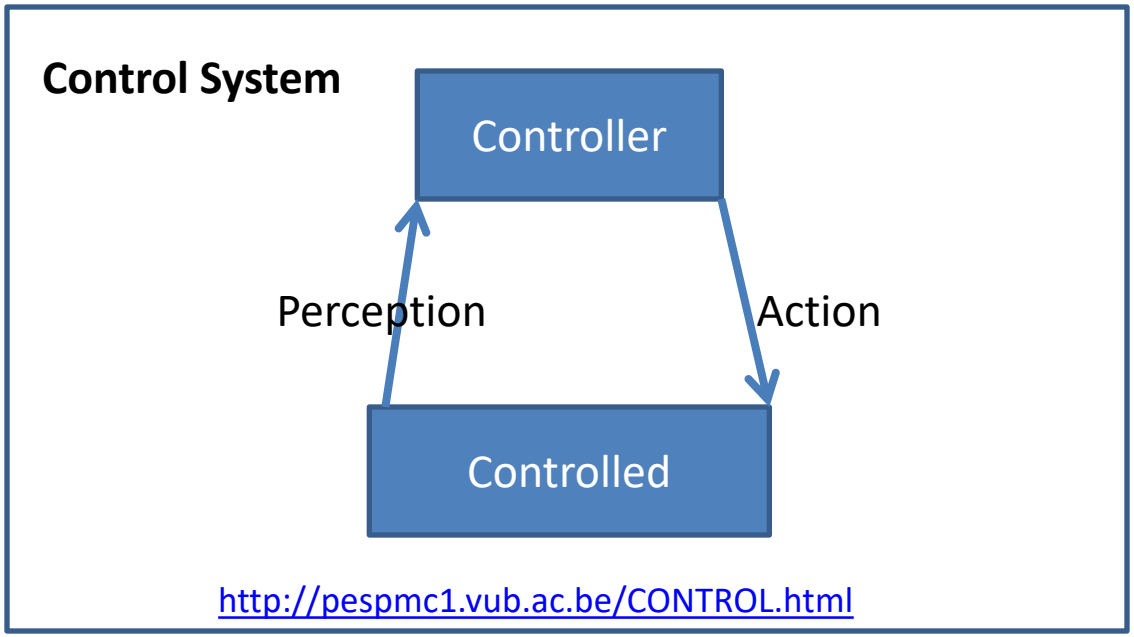
Feedback





From Principia Cybernetica Web, http://pespmc1.vub.ac.be/FEEDBACK.html

Control



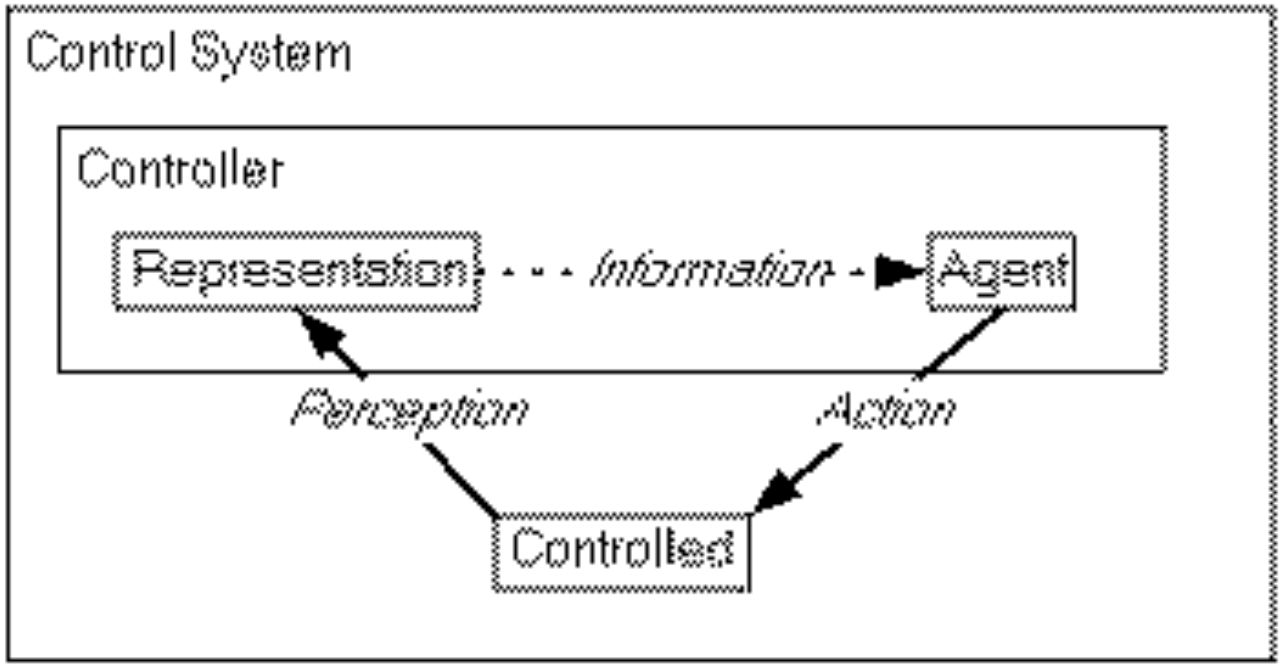
Ashby's Law of Requisite Variety: For appropriate regulation, the variety of actions in the regulator must be equal or greater than the variety of actions in the system being regulated.

(consider a home heating system furnace)

Furnace Subsystem Control (an example)

- Furnace
  - Motor provides air for combustion & is turned on/off
  - Valve provides fuel & must be opened/closed
  - Ignition must ignite fuel
  - To shut down delays are necessary so fuel is fully consumed
- Controller
  - Needs model of furnace or must “know” procedure

Model of system in controller

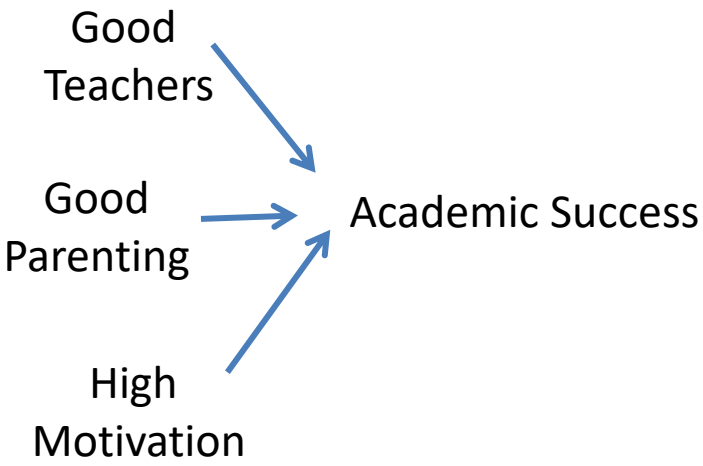


http://pespmc1.vub.ac.be/CONTROL.html

Methods based on holistic thinking & cybernetics

- Causal Loops & System Dynamics (Jay Forrester)
  - For analyzing dynamic problems arising in complex social, managerial, economic, or ecological systems
- Soft Systems Methodology (SSM) (Peter Checkland)
  - For problem understanding
  - Focus on making process of inquiry into real-world complexity a system for learning
- Viable System Model (VSM) (Stafford Beer)
  - For diagnosing & re-engineering organizations
  - Organization structure, recursive sub-organizations, uses "variety" reduction & amplification in component interaction

Laundry List Thinking versus Causal Loops

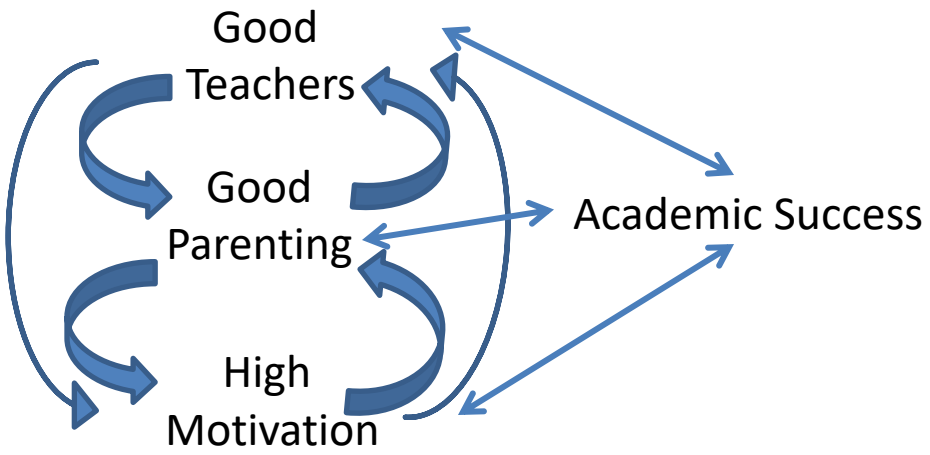


Laundry List Thinking

Each factor, or independent variable, is assumed to exert its impact *independently on* Academic Success, the *dependent variable.*

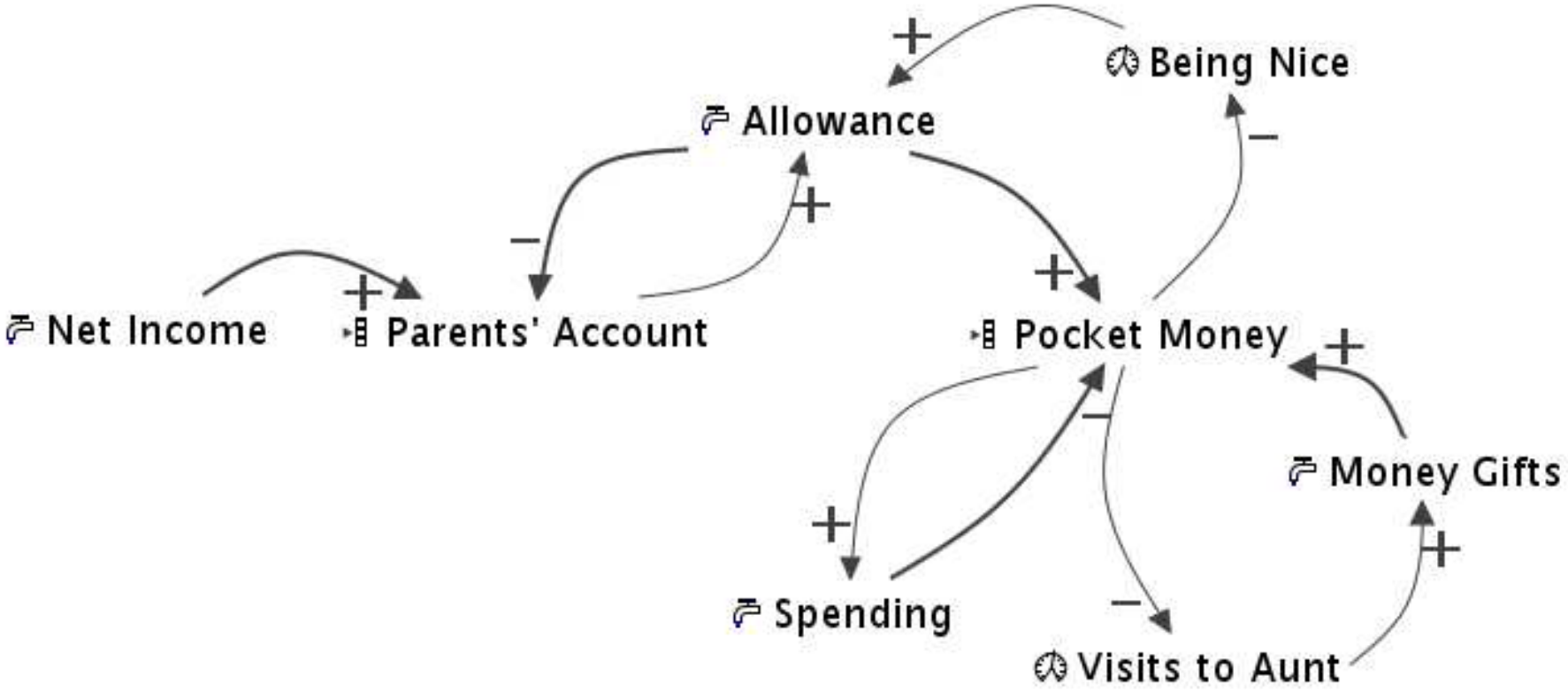
Dynamic View (Causal Loops)

Effect is also cause



High Performance Systems, "An Introduction to Systems Thinking", iseesystems.com/resources/Articles/STELLA_IST.pdf

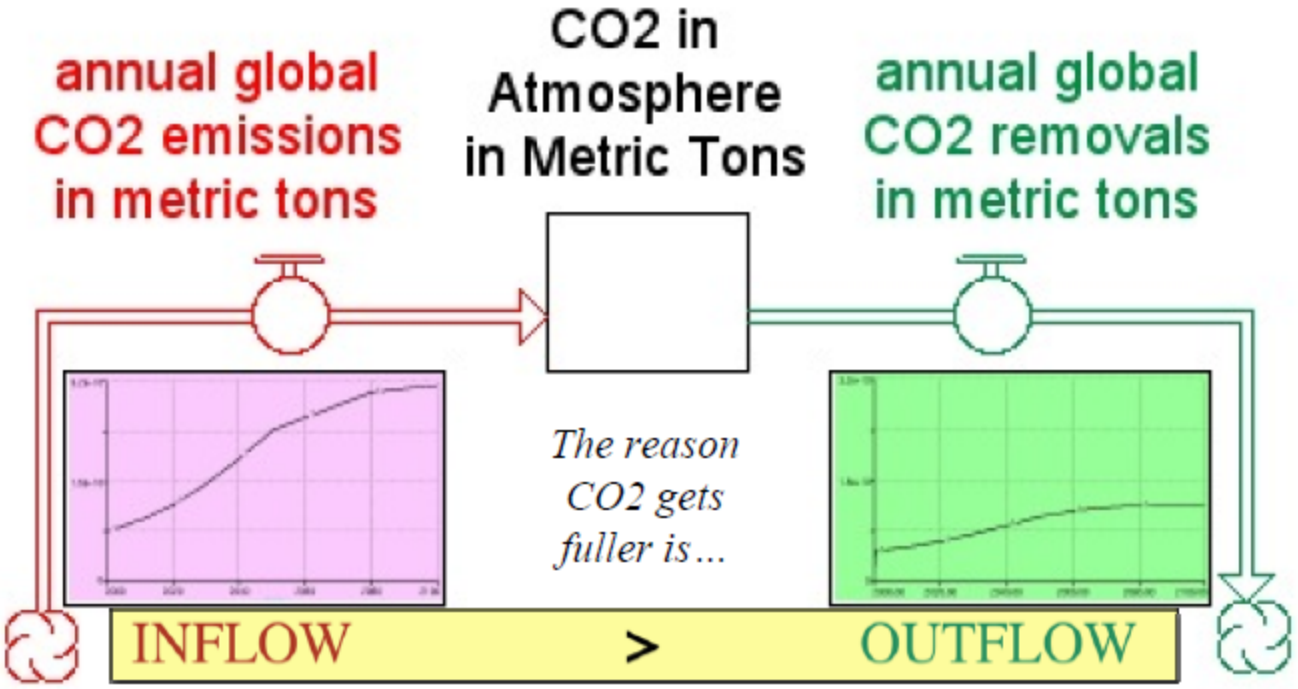
System Dynamics: Causal Loop Diagram (example)



Binder et al, "Developing System Dynamics Models from Causal Loop Diagrams", citeseerx.ist.psu.edu

System Dynamics 101: Core Concept

CO_2 in the Atmosphere Behaves Like a Bathtub



System Dynamics Model

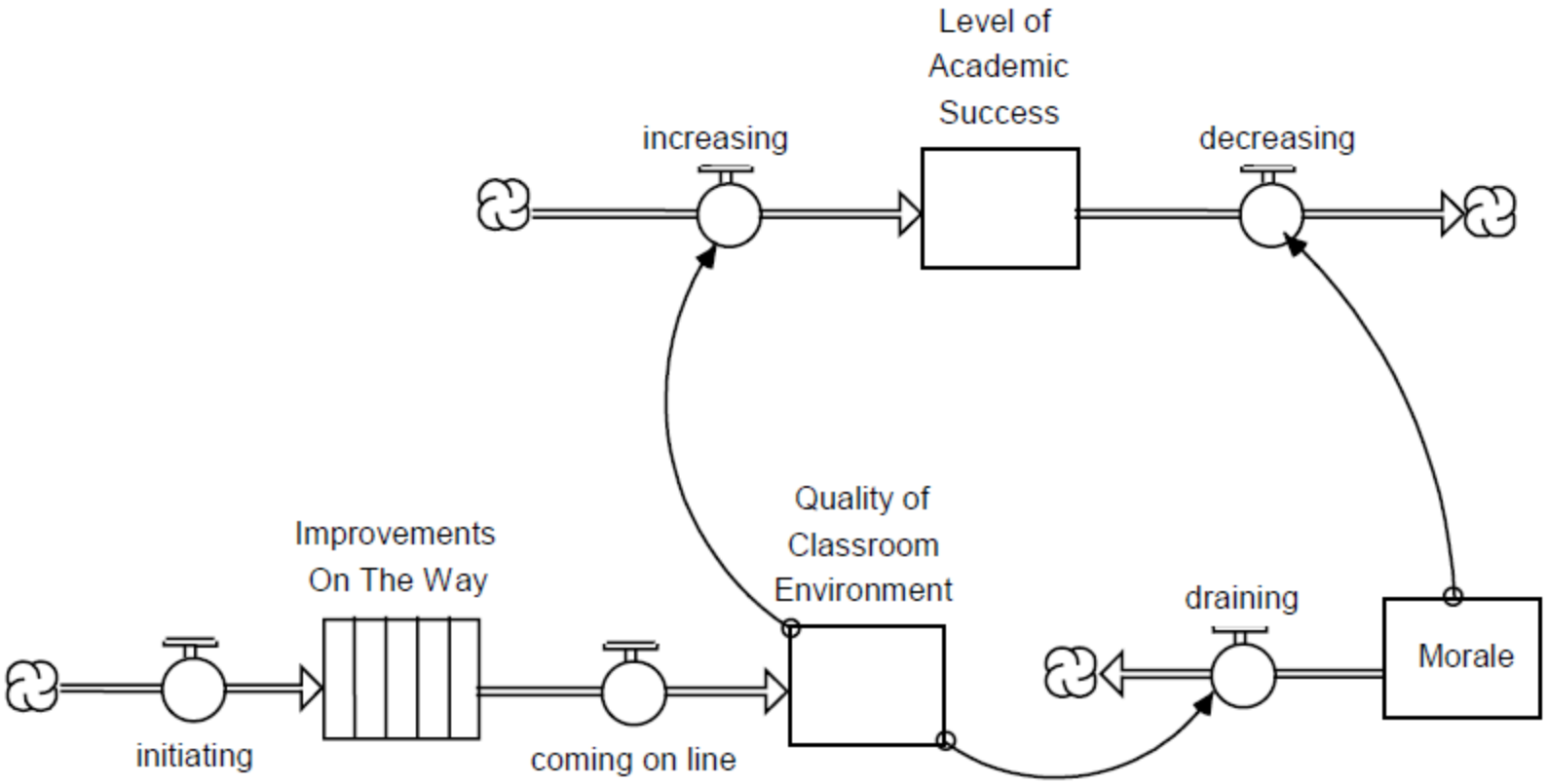


Figure 1-12.
A "Non-instantaneous" View.

High Performance Systems, "An Introduction to Systems Thinking", iseesystems.com/resources/Articles/STELLA_IST.pdf

System Dynamics Model Component– Factors Affecting Tropical Cyclones

TCIP : Tropical Cyclone Intensification Potential
TCIF: Tropical Cyclone Intensification Factor
H: Humidity
LAWS: Low-Altitude Wind Strength
TCO: Tropical Cyclone Occurrence
VWSP: Vertical Wind Shear Probability
VWSF: Vertical Wind Shear Factor
F: Frontal Systems Nearby
AP: Air Pressure

Vensim Model

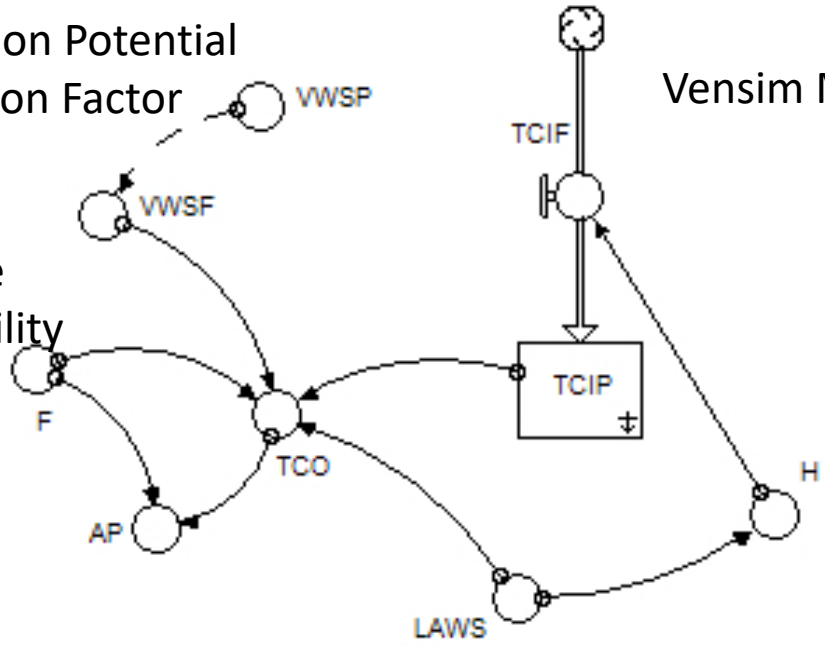
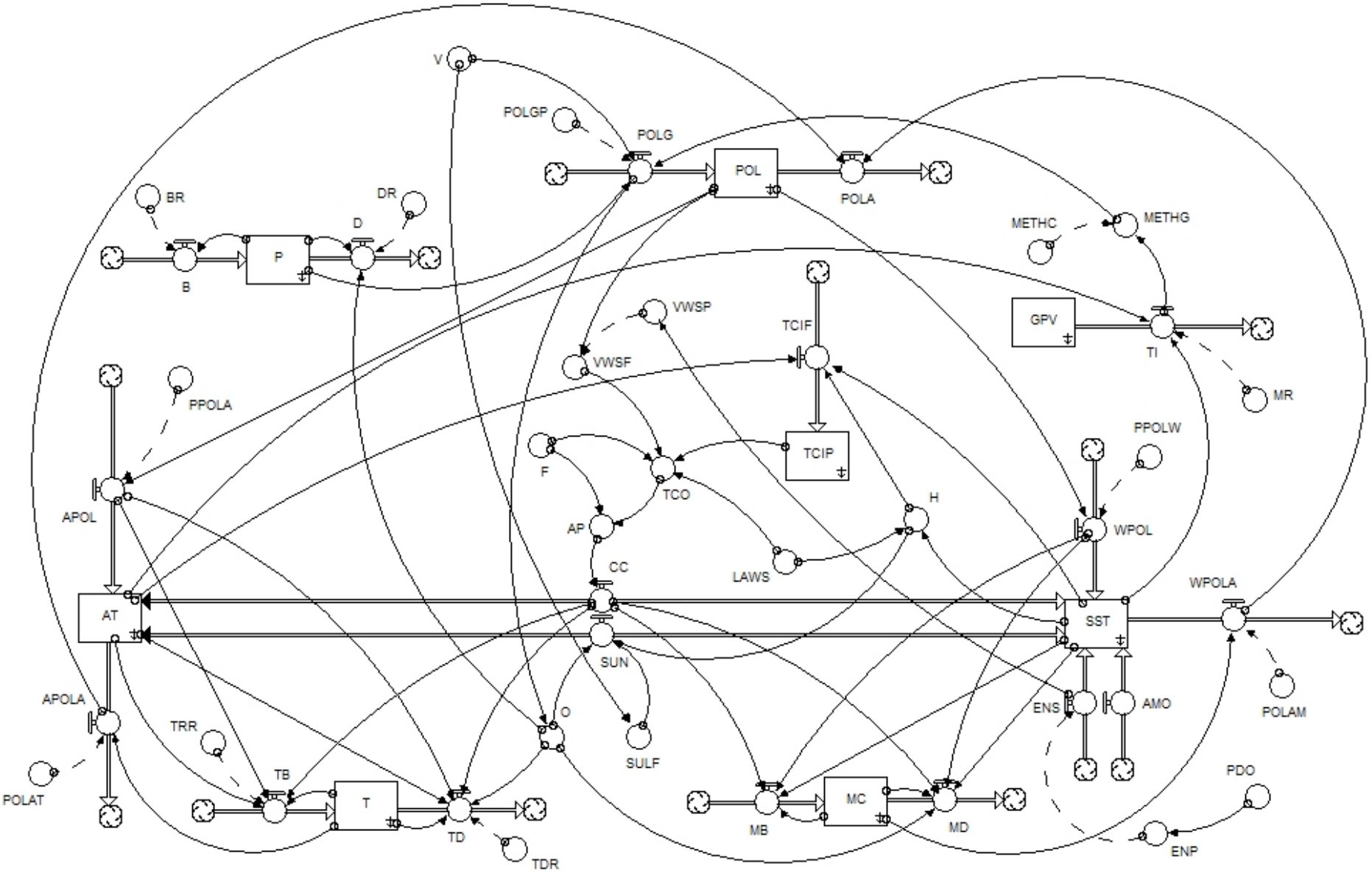


Figure 5-17 The Tropical Cyclone Subsystem

- TCIP is a stock variable that tracks the accumulation of changing climate conditions as time progresses
- TCO monitors factors & records TC occurrence & dissipation

[Kris Frick, Undergraduate Honors Student, 2010



APPENDIX B - THE TROPICAL CYCLONE MODEL

Kris Frick, Honors Thesis

Name	Description
AMO	Atlantic Multi-decadal Oscillation
AP	Air Pressure
APOL	Total Air Pollution
APOLA	Air Pollution Absorption
AT	Air Temperature
B	Births
BR	Birth Rate
CC	Daily Cloud Cover
D	Deaths
DR	Death Rate
ENP	El Niño/ El Niña Pattern
ENS	El Niño/ El Niña Strength
F	Frontal Systems Nearby
GPV	World Glacier & Permafrost Volume
H	Humidity
LAWS	Low-Altitude Wind Strength
MB	Microorganism Births
MC	Microorganism Concentration
MD	Microorganism Deaths
METHC	Methane Concentration
METHG	Methane Gas Released
MR	Melting Rate
O	Ozone Layer Intactness
P	World Population
PDO	Pacific Decadal Oscillation

Name	Description
POL	Total World Pollution
POLA	Total Pollution Absorption
POLAM	Pollution Absorption per Microorganism
POLAT	Pollution Absorption per Tree
POLG	Total Pollution Generation
POLGP	Pollution Generation per Person
PPOLA	Percent of POL in the Air
PPOLW	Percent of POL in the Water
SST	Sea Surface Temperature
SULF	Atmospheric Sulfate
SUN	Yearly Solar Strength
T	World Trees
TB	Tree Births
TCIF	Tropical Cyclone Intensification Factor
TCIP	Tropical Cyclone Intensification Potential
TCO	Tropical Cyclone Occurrence
TD	Tree Deaths
TDR	Tree Deforestation Rate
TI	Thawing Ice
TRR	Tree Replanting Rate
V	Volcanic Activity
VWSF	Vertical Wind Shear Factor
VWSP	Vertical Wind Shear Probability
WPOL	Total Water Pollution
WPOLA	Water Pollution Absorption

Kris Frick, Elements of the Cyclone Model

Soft Systems Methodology (SSM)

Rich Picture

An attempt to assemble *everything* that might be relevant to a complex situation

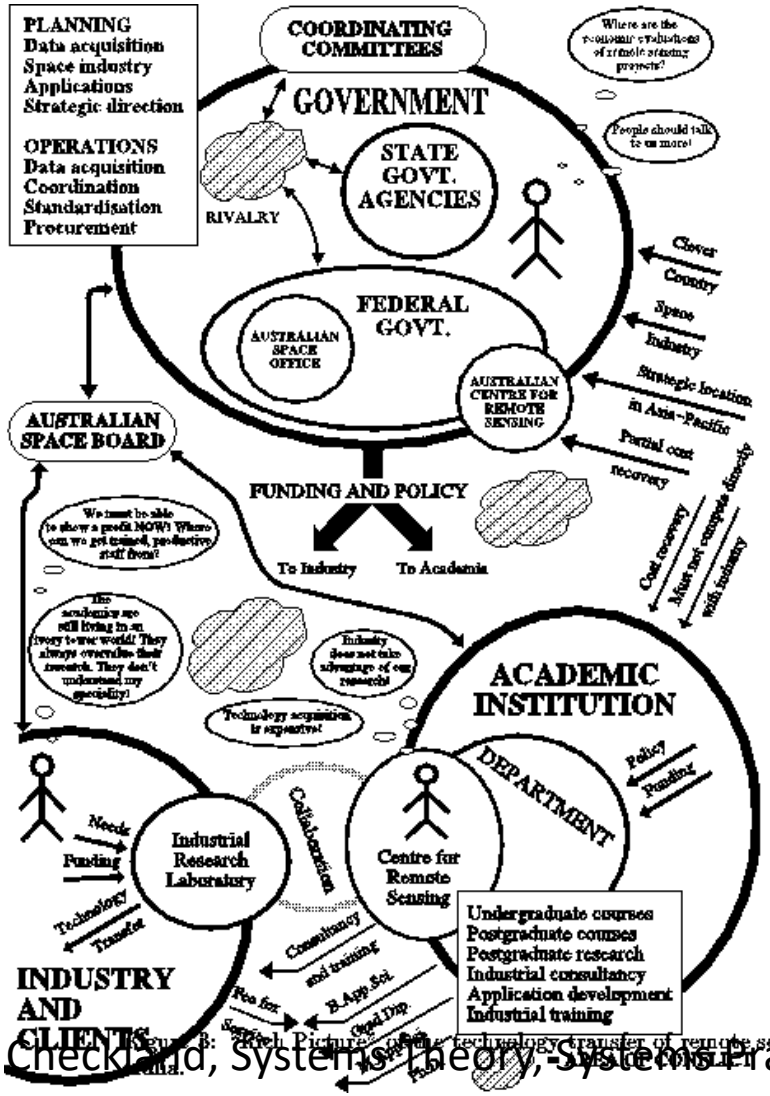
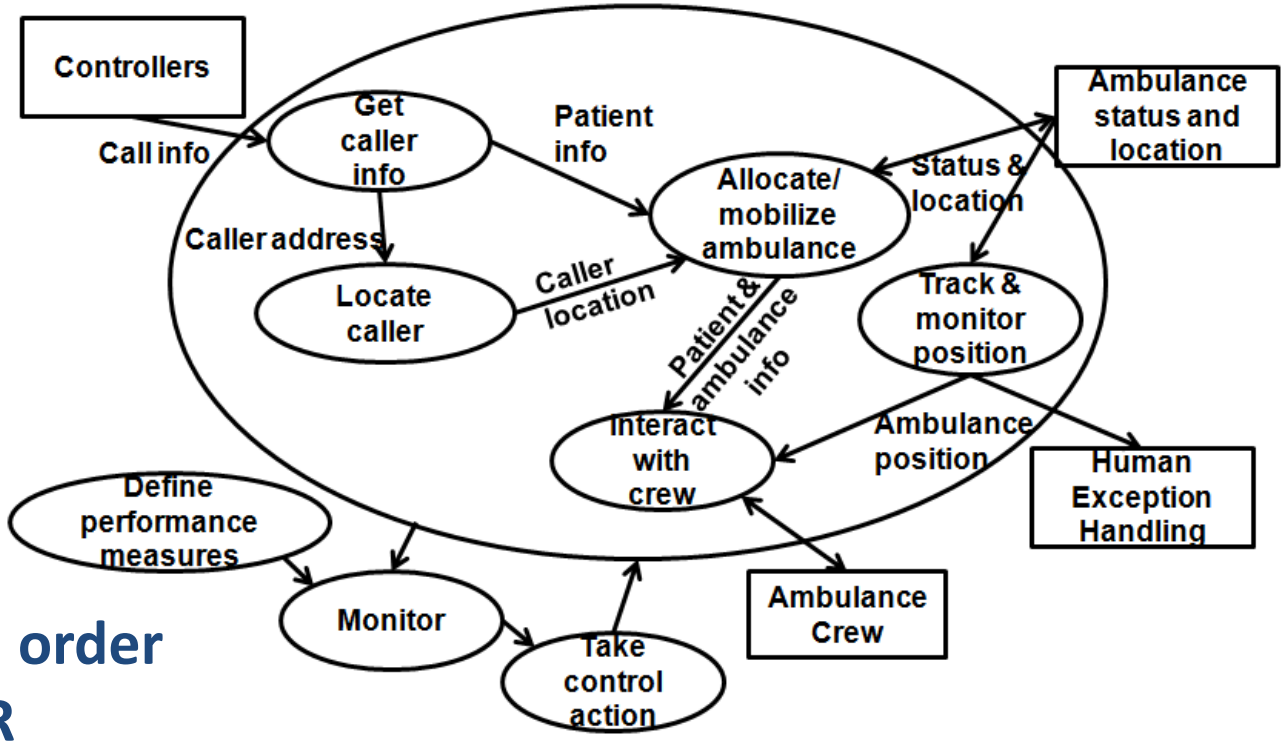


Figure 3: 'Rich Picture' of the technology transfer of remote sensing in Aus-

P. Checkland, Systems Theory, Systems Practice

Soft Systems Methodology (SSM)

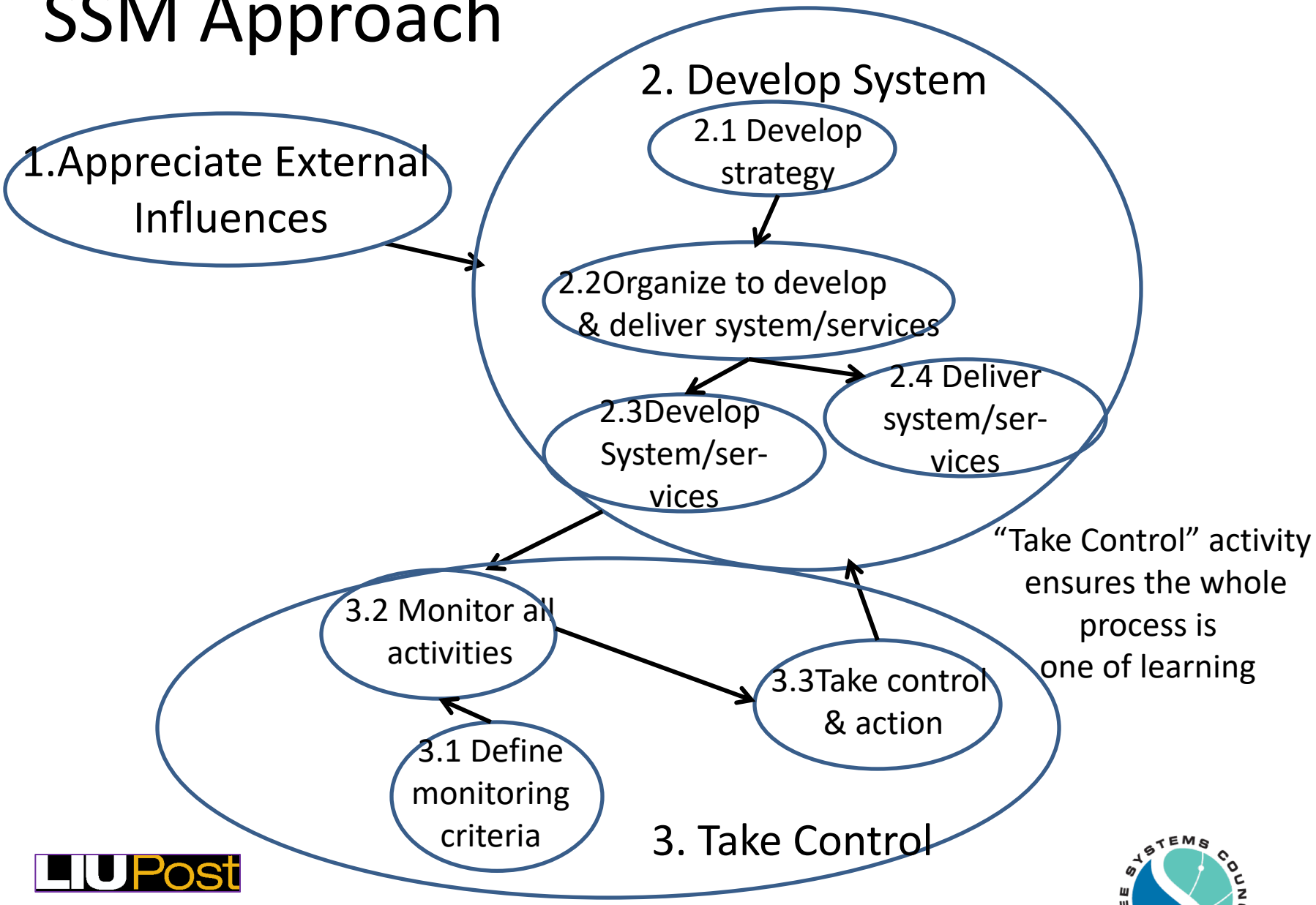
Customers
Actors
Transf. Process
Worldview
Owners
Environment-constraints



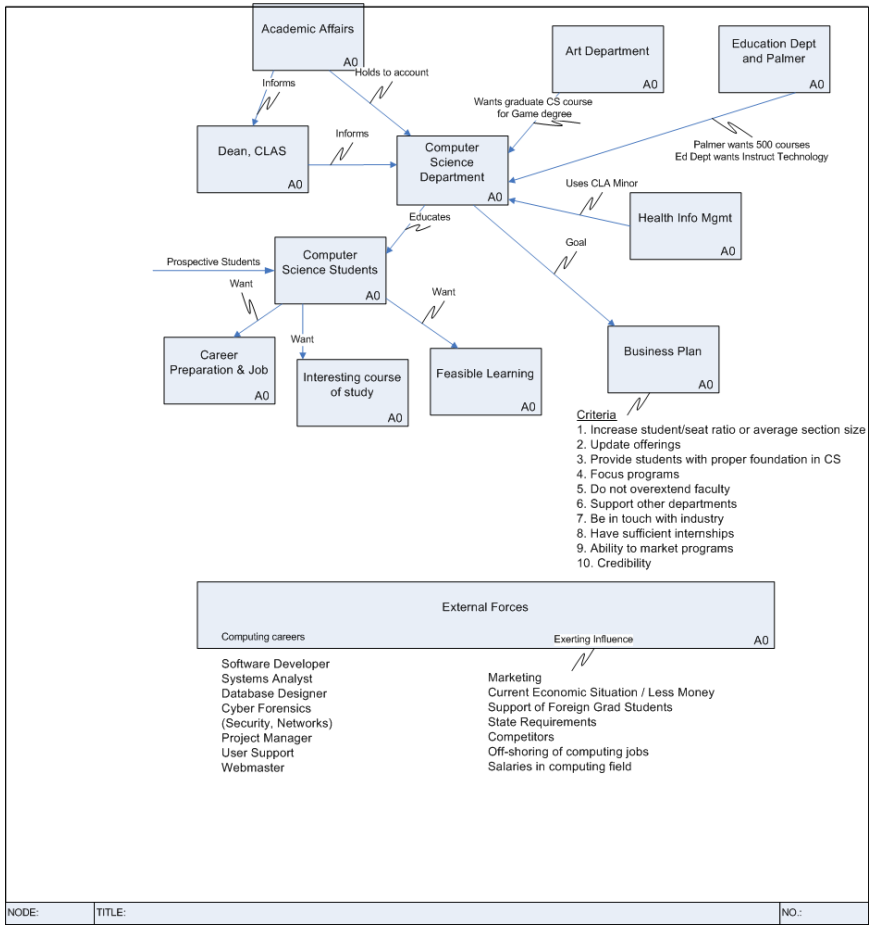
RD: Do P, by Q in order to help achieve R

RD 1. (Government Worldview) Create an efficient streamlined ambulance system by using automation to enable appropriate resources to be dispatched & arrive with minimum delay

SSM Approach



Creating the CSC Dept. Business Plan (Rich Picture)



Entities/Things

Our & Other Departments

Student Course of Study

Business Plan, …

Relationships

Criteria for Success

External Forces

Career Options

Economics

Marketing

Competitors

Off-Shoring

Viable System Model (S. Beer)

"Cybernetics is the science of effective organizations"

- Organization is viable if it can maintain a separate existence (corp. division)
- System One: set of embedded viable systems in organization
- System Two: anti-oscillatory device for System One ("almost totally misunderstood")
- Management is a subsystem of the viable system, not an overlord

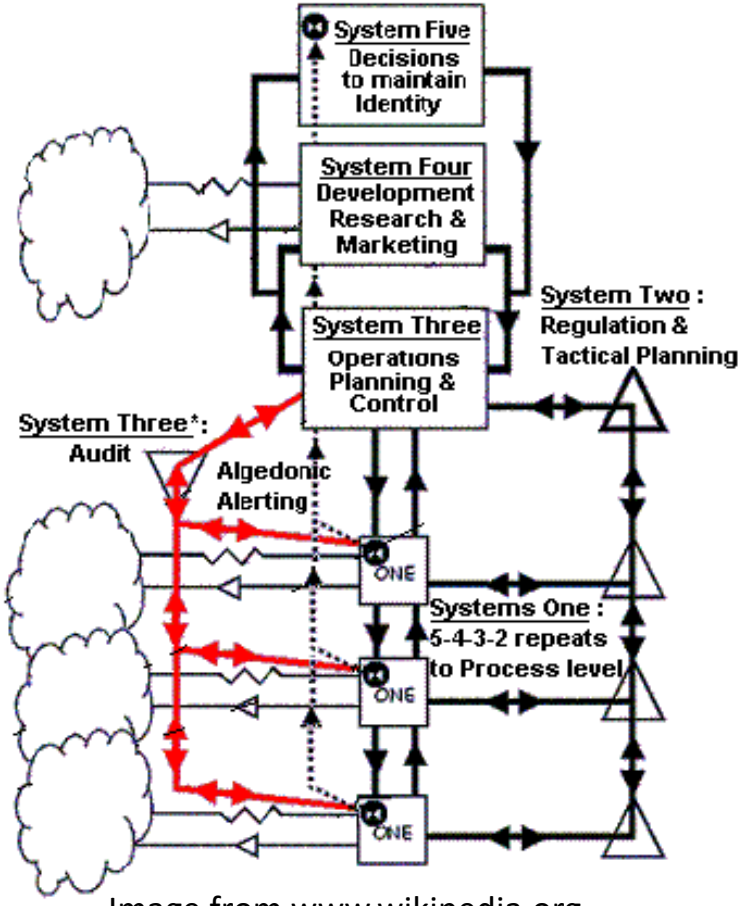
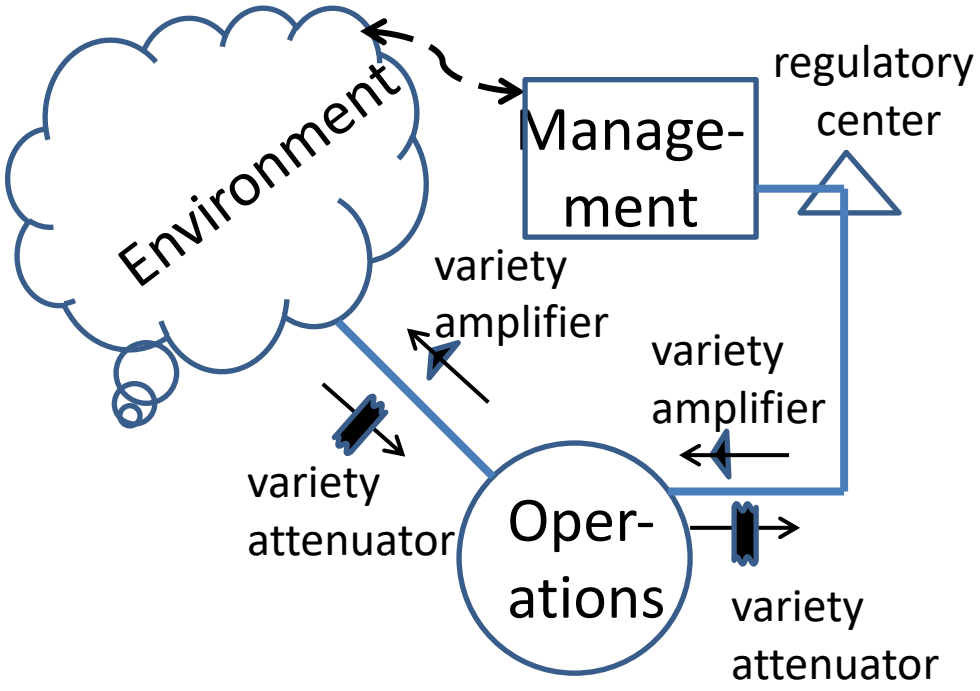


Image from www.wikipedia.org

Stafford Beer, DIAGNOSING THE SYSTEM for organizations, 1985.

Addressing variety

- Variety is a measure of complexity, because it counts the number of possible states of the system.
- Because a situation has high variety, an agreed low variety model of the situation will be addressed, e.g. at meeting.



S. Beer, DIAGNOSING THE SYSTEM for organizations, 1985

Value of models for communicating

- Models built during *Systems Thinking* provides raw material for *Communicating*
- Others can compare results to information they possess & provide *feedback*
- Drives *interdisciplinary* learning
- *Improves understanding* of problem

Each method provides an abstraction

- Using Causal Loops & System Dynamics
  - We model & simulate interactions among system elements & avoid emergent problems when the system, service or plan becomes operational
- Using Soft Systems Methodology(SSM)
  - We learn about the whole problem under study, the criteria for success, and all the influences and constraints
- Using Viable System Model (VSM)
  - We diagnose & control the organization & work towards improving it

Recommended reading

1. Gerald M. Weinberg, *An Introduction to General Systems Thinking*, Dorset House, 2001
2. Jamshid Gharajedaghi, *Systems Thinking, Managing Chaos & Complexity*, Morgan Kaufman, 2011
3. George Klir, *Facets of Systems Science*, IFSR International Series on Systems Science and Engineering, Vol. 7, Plenum Press, New York, 1991
4. John Sterman, Business Dynamics, Systems Thinking and Modeling for a Complex World
5. Stafford Beer (VSM), Peter Checkland (SSM), W. Ross Ashby (Cybernetics)

Recommended reading

6. Donella H. Meadows, Thinking in Systems, A Primer, Chelsea Green Publishing, 2008
7. Herbert A. Simon, The Sciences of the Artificial, 3rd edition, MIT Press, 1996
8. Melanie Mitchell, Complexity, A Guided Tour, Oxford University Press, 2009.
9. John H. Holland, Complexity, A Very Short Introduction, Oxford University Press, 2014.

A few of many system & cybernetics societies

- IEEE Systems Council
  - Integrate IEEE activities regarding aspects of multiple disciplines and specialty areas associated with the engineering of systems
- INCOSE
  - Share, promote and advance the best of systems engineering from across the globe for the benefit of humanity and the planet
- IEEE Systems, Man, & Cybernetics
  - Field of Interest (abridged): Integration of the theories of communication, control, cybernetics, systems, and human-factors engineering.

A few of many system & cybernetics societies, p.2

- International Society for the System Sciences (formerly GSR)
  - The ISSS is a society of professionals from diverse endeavors, drawn together by a common interest: understanding & interacting systemically with reality. Scope includes practical application of systems methodologies to problem solving.
- American Society for Cybernetics
  - The advancement of cybernetics as a science, a discipline, a meta-discipline, and a practice
- International Federation for Systems Research
  - Advance cybernetic and systems research and systems applications and to serve the international systems community
- System Dynamics Society
  - An international organization devoted to encouraging the development and use of systems thinking and system dynamics around the world
- World Organization of Systems & Cybernetics
  - A federation of national associations and institutions devoted to systems or cybernetics; 34 societies in 22 nations, but 37 nations involved

Questions, Comments, & Discussion