Systems Concepts

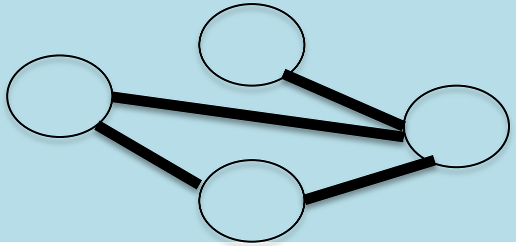
Presented by Dr. David Gould

Contents

Systems Basics

Systems Basics

- A **network** is a set of agents (nodes) and links (relationships).
- A **system** is a set of interrelated elements (agents) exhibiting behavior according to Meadows (2008). Thus, three things are present: elements (agents), relationships between elements (agents), and some sort of behavior(s).
- **Structure** includes both tangible and intangible parts of a system
- The **structure** of a system basically determines its behavior
- Basic **behavior dynamics** of a **system**
  - Growth / contraction / cycle
  - Split / merge
  - Birth / death



Meadows, D. H. (2008). *Thinking in systems: A primer*. Chelsea Green.
Pryut, E. (2013). *Small systems dynamics models for big issues*. The Netherlands.

What is a System

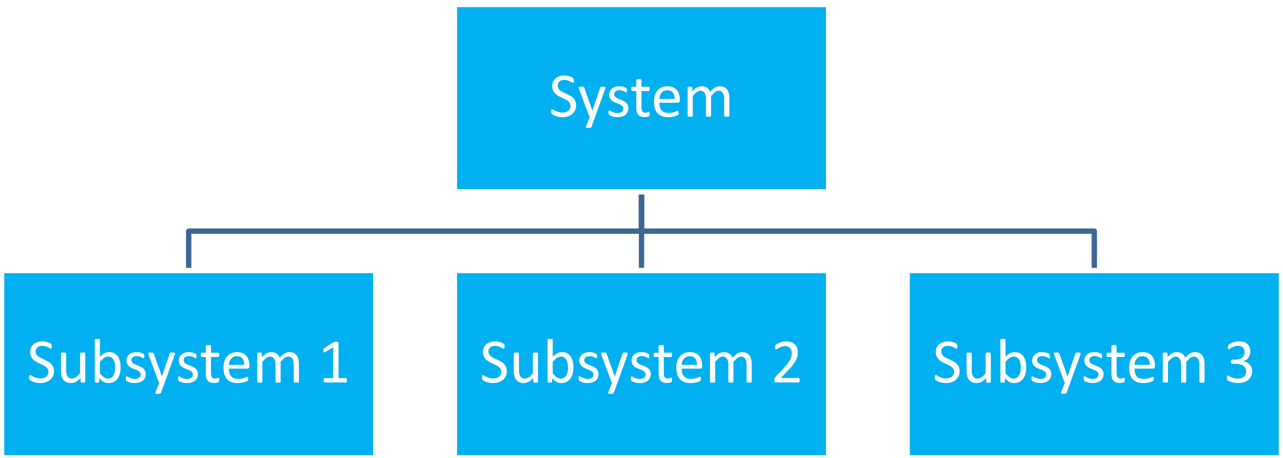
- A *system* **S** is a 7-tuple: $S_{i,\,l} = \{C,N,G,B,T,H,\Delta t\}_{i,\,l}$
- Where:
  - The index i is a subsystem index and l is an index related to the level of complexity. Level 0 is the top for the system of interest.
  - C is a multiset of component subsystems
  - N is a flow network description in graph theoretical terms
  - G is a graph in which some of the nodes are not inside the system, but either sources or sinks, which are outside the system
  - B is the boundary
  - T is the set of transformation rules for the subsystems in S
  - H is a super complex object that records the history of the system or a record of state transitions.
  - Δt is the relevant time element to the system

Mobus, G. E., & Kalton, M. K. (2015). *Principles of systems science*. Springer.
Mobus, G. E. (2022). *Systems science: Theory, analysis, modeling, and design*. Springer.

System with two Levels

Environment (Level -1) – External to the System

System (of Interest)
(Level 0)

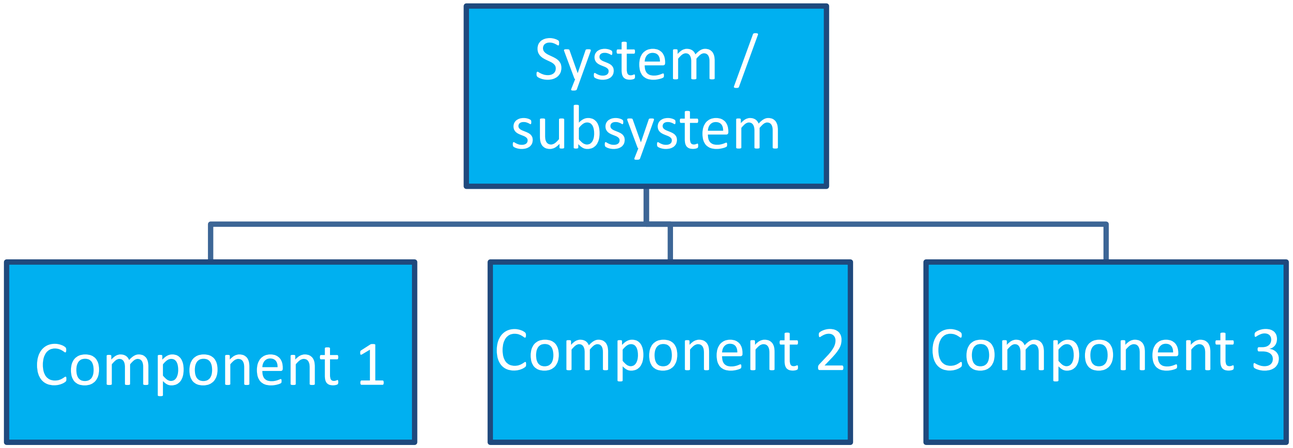


Subsystems
(Level 1)

Systems may be functionally decomposed as practical.

System Boundary: Boundaries may be fixed, permeable, semipermeable, porous …

Systems Components



System components may be multisets, atomic components, or subsystems. This image is an example of a system with 3 components.

Principles of Complex Systems

- Systems may be composed of subsystems
- Systems exhibit behavior; that is they are nonstationary
- Systems have a history
- Systems are bounded
- Systems are dynamic
- Systems interact with other systems
- Systems process information (some may process material or energy)
- Systems are composed of networks
- Systems regulate themselves through negative feedback
- Systems develop; systems evolve
- Systems have a life cycle (origin or startup, growth, mature, decline)
- Systems will collapse at some point and die

Source: Mobus, G. E., & Kalton, M. K. (2015). *Principles of systems science*. Springer.

Principles of Complex Systems (cont)

- Interactions with External Systems
  - Systems react to threats and opportunities in their external environment.
- Systems contain strengths and weaknesses.
- Systems have constraints.

Principles of Complex Systems (cont)

- Another good list of systems principles is found at this link to the Systems Engineering Body of Knowledge.
- These sets of principles are good approaches to thinking about systems.
  - https://www.sebokwiki.org/wiki/Principles_of_Systems_Thinking

Additional Principles

- Abstraction
- Multifinality
- Equifinality

Abstraction

- A focus on essential characteristics is important in problem solving because it allows problem solvers to ignore the nonessential, thus simplifying the problem
  - Sci-Tech Encyclopedia 2009; SearchCIO 2012; Pearce 2012.
- Examples from mathematics
  - The symbol *n* can represent any integer from 1 to infinity
  - a + b = b + a for any two integers
  - ab = ba for any two integers

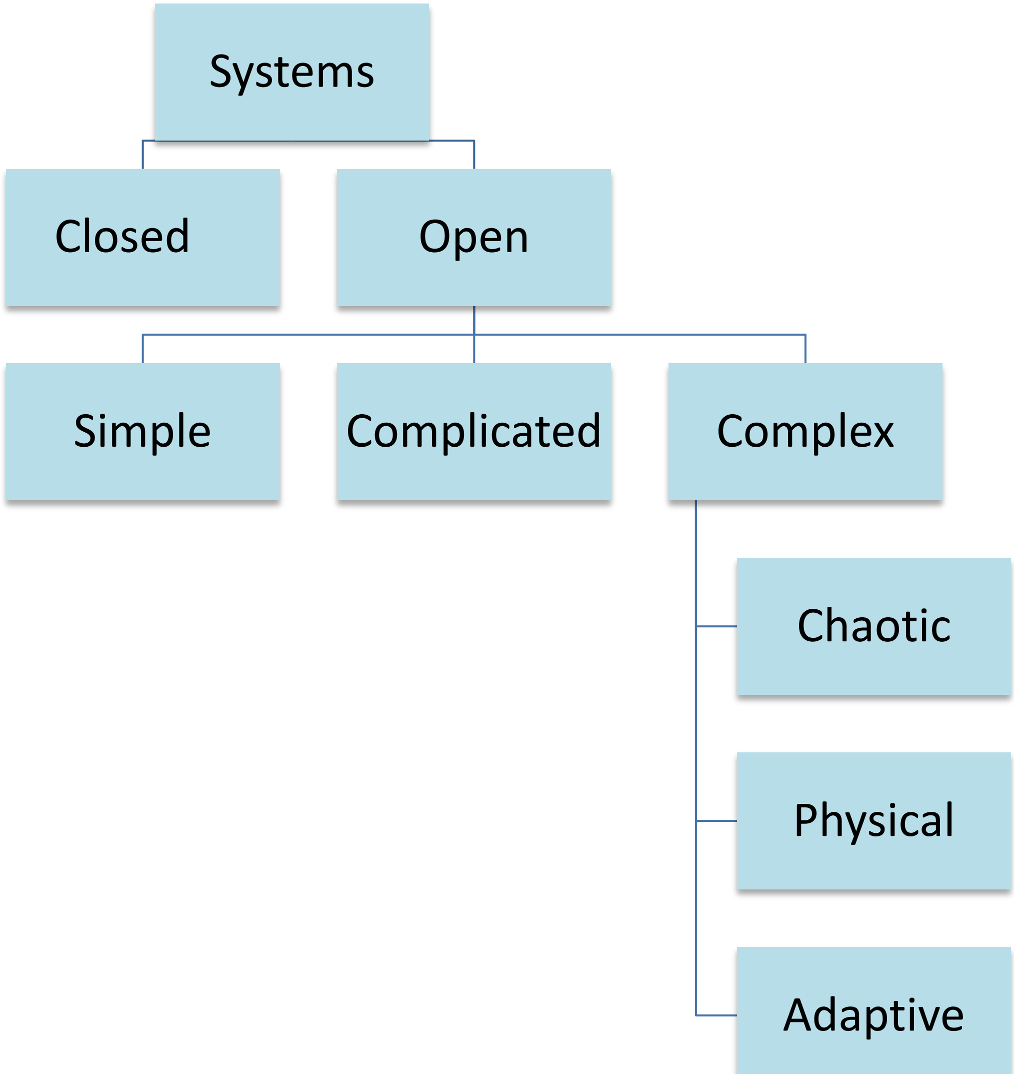
Multifinality

- Multifinality - attaining alternative objectives from the same inputs (divergence).
  - See http://environment-ecology.com/general-systems-theory/379-systems-thinking.html
- An example:
- Using the concept of "Multifinality", a coffee shop could be considered to be:
  - a "profit making system" from the perspective of management and owners
  - a "distribution system" from the perspective of the suppliers
  - an "employment system" from the perspective of employees
  - a "materials supply system" from the perspective of customers
  - an "entertainment system" from the perspective of loiterers
  - a "social system" from the perspective of local residents
  - a "dating system" from the perspective of single customers
- As a systems scientist, think about the concept of multifinality and today's world and mix in some of the governance concepts noted by Straw and Ray. See https://oecd-opsi.org/systemic-governing-applied-systems-thinking-in-practice/
- How could concept of multifinality be applied to addressing our social problems? For example, how could we apply the concept of multifinality to capitalism to achieve more than the primary goal of shareholder value? Could we derive other goals from capitalism?

Convergence / Divergence

- Equifinality is convergence from multiple points or approaches to one final state.
- Multifinality is divergence from a single state to multiple states.

Systems Taxonomy



Systems Taxonomy

- Closed systems
  - No exchange of material, information, or energy (MIE) with its environment
- Open systems
  - Exchange of MIE with its environment
- Simple systems
  - Few parts, few linear interactions
- Complicated systems
  - Many parts, few interactions
  - Examples: Cars, airplanes, trains ..

Systems Taxonomy (cont)

- Complex systems
  - Few to many parts, few to many nonlinear interactions
  - Examples: a jazz band, a business organization, a city, an ant colony, society, a school of fish, …..
- Chaotic Systems
  - Dynamical systems exhibiting sensitive dependence on initial conditions (SDIC)
  - Example: a pendulum, the weather
- Physical systems
  - Examples: a forest, a desert, an ecosystem
- Adaptive systems
  - Examples: people, families, organizations, ecosystems, industries, the economy, language, religion….

Boulding's Hierarchy Of Systems Complexity

• Transcendental	Unknowable
• Social Organizations	Social Organizations
• Human	Human Individuals
• Animal	Animal Level
• Genetic-Societal	Plant Level
• Open Systems	Input-Throughput-Output
• Cybernetic	Control Mechanisms
• Clockwork	Predetermined Motion
• Framework	Static Structures

Boulding's Hierarchy

- Properties within a given level of the hierarchy are inherited or exhibited in the next and higher levels.
  - For example, the first level or frameworks level is about static structure and it is observable that each higher level includes at least some static structures, the static structure of a molecule being level one
  - Thus properties contained within frameworks are found in clockworks, properties found within clockworks are found within cybernetic systems, and so on.

Open Systems

- A system open to its environment such that material, information, or energy is exchanged.
- An organization is a example of an open system, wherein materials, information, and energy are obtained from the external environment, processed into goods or services, and are sold in the marketplace.
- Systems that are open to their environment (contrasted with closed systems).
- Organizations are open systems for example as they exchange MIE with systems outside of it – for example customers, suppliers, …

Complex Systems

Complex Systems

A complex system is a group of “agents” existing far from equilibrium, interacting through positive and negative feedbacks, forming interdependent, dynamic, evolutionary networks, that are sensitive dependent, fractionally organized, and exhibit avalanche behavior (abrupt changes) that follow power-law distributions.

Fichter, L.S., Pyle, E.J., & Whitmeyer, S.J. (2010). Strategies and Rubrics for Teaching Chaos and Complex Systems as Elaborating, Self-Organizing, and Fractionating Evolutionary Systems. *Journal of Geoscience Education*. *58*(2)

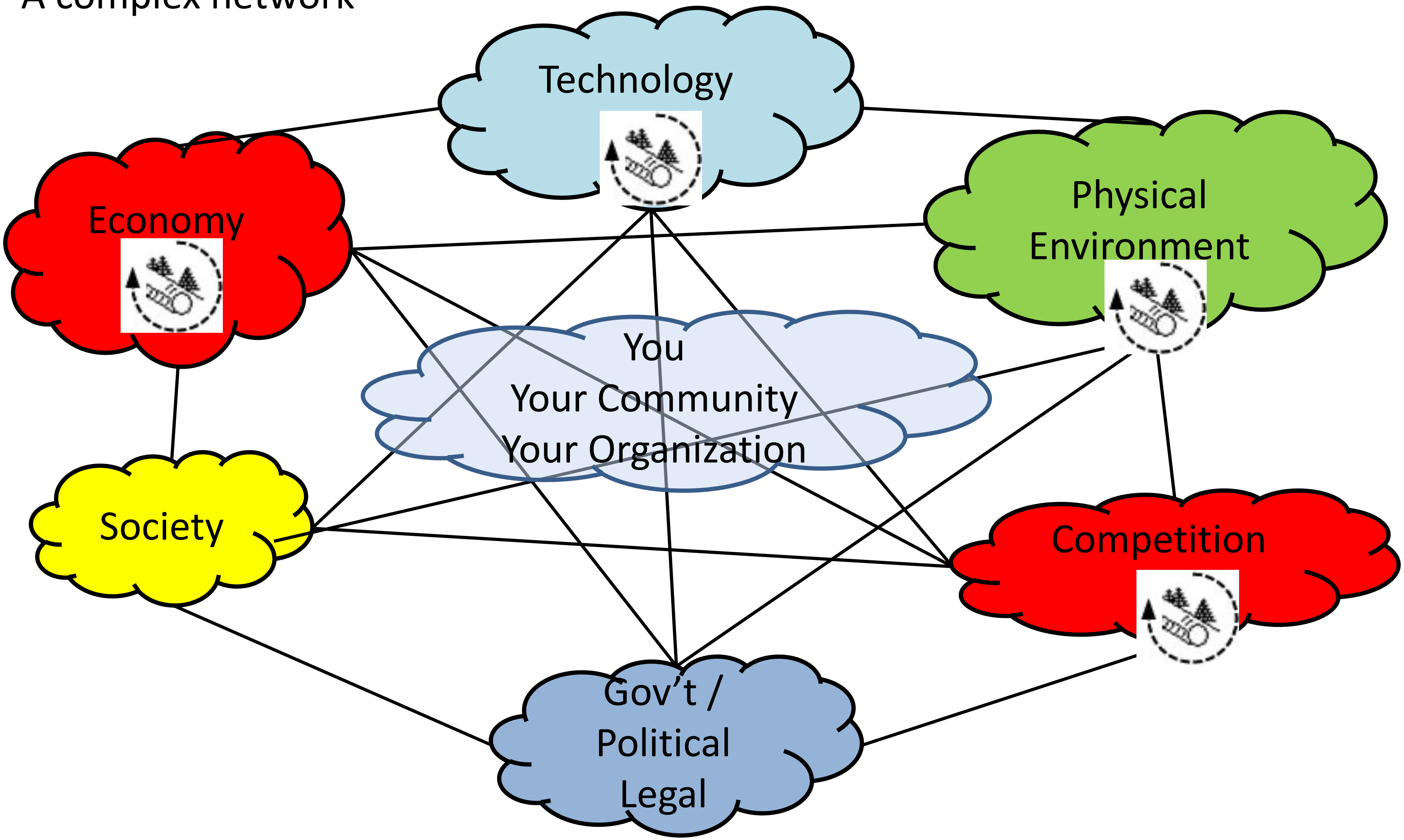
Complex Adaptive Systems

- Complex adaptive systems (CAS) are "composed of elements or agents that learn or adapt in response to interactions with other agents" according to Holland (2014, Chapter 3).

Holland, J. H. (2014). *Complexity: A very short introduction*. Oxford University

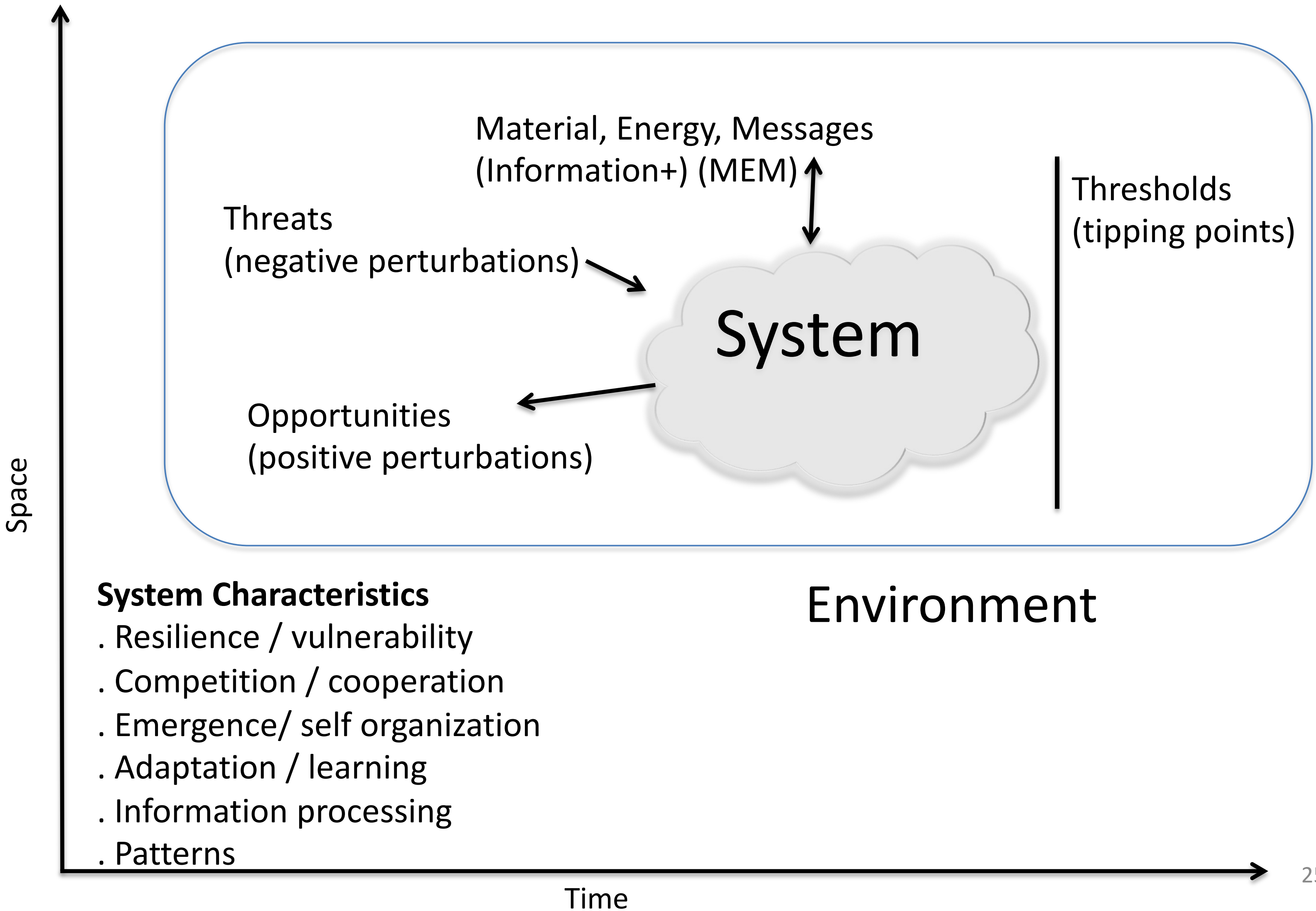
The Environment (for Social Systems)

A complex network

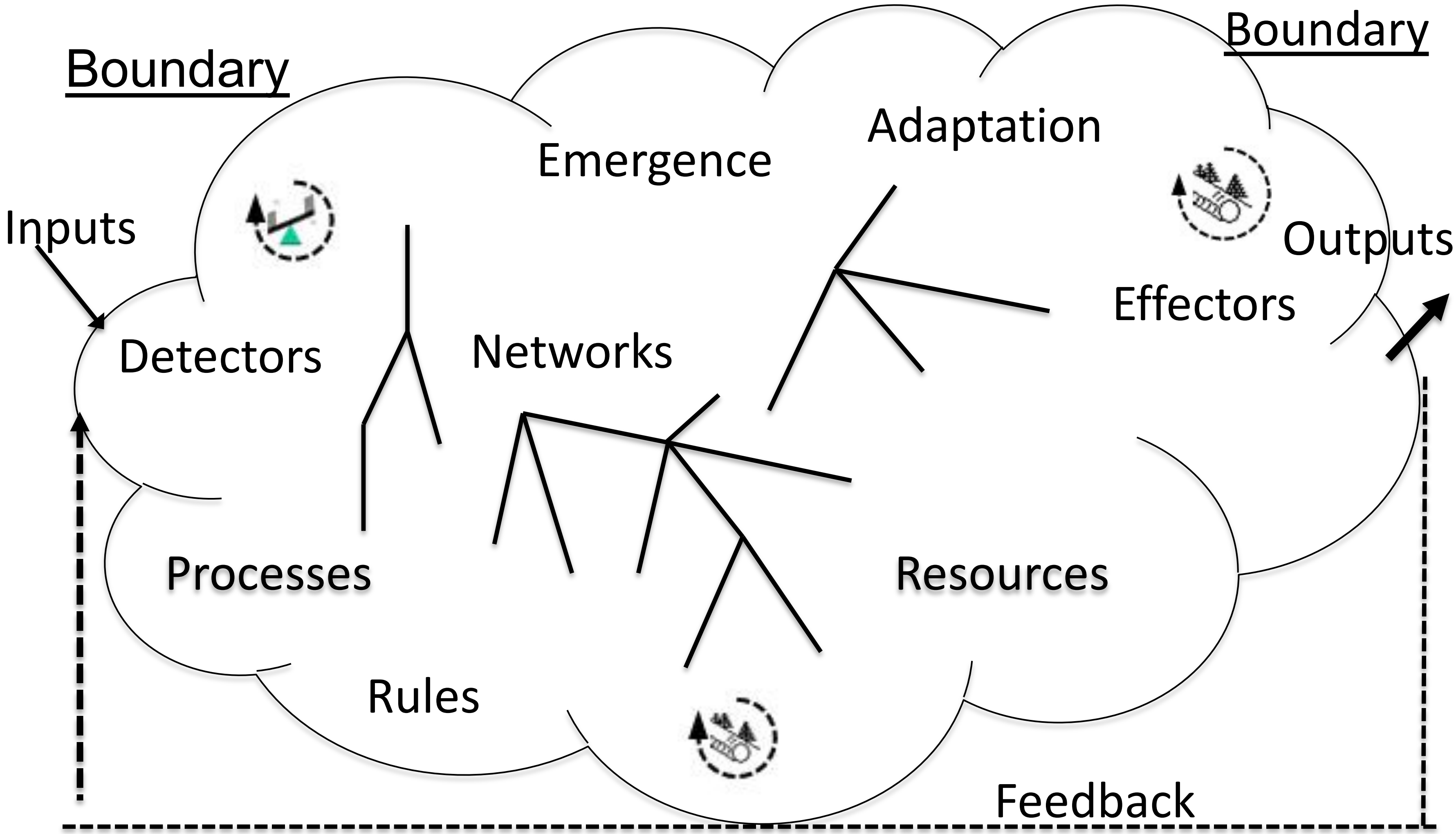


Note: Each of these systems is a complex adaptive system.

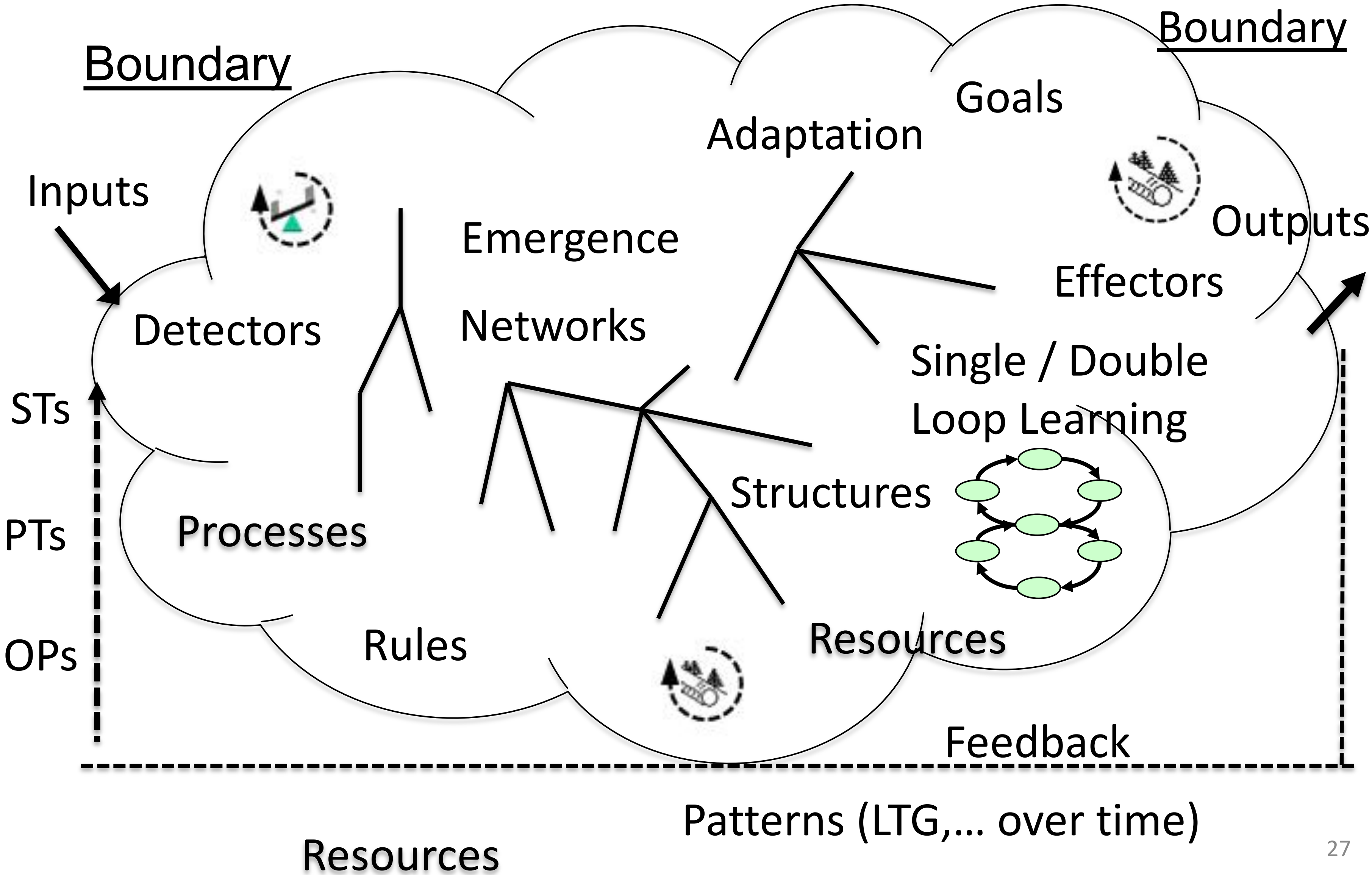
A Complex Systems Model



Complex Systems Model



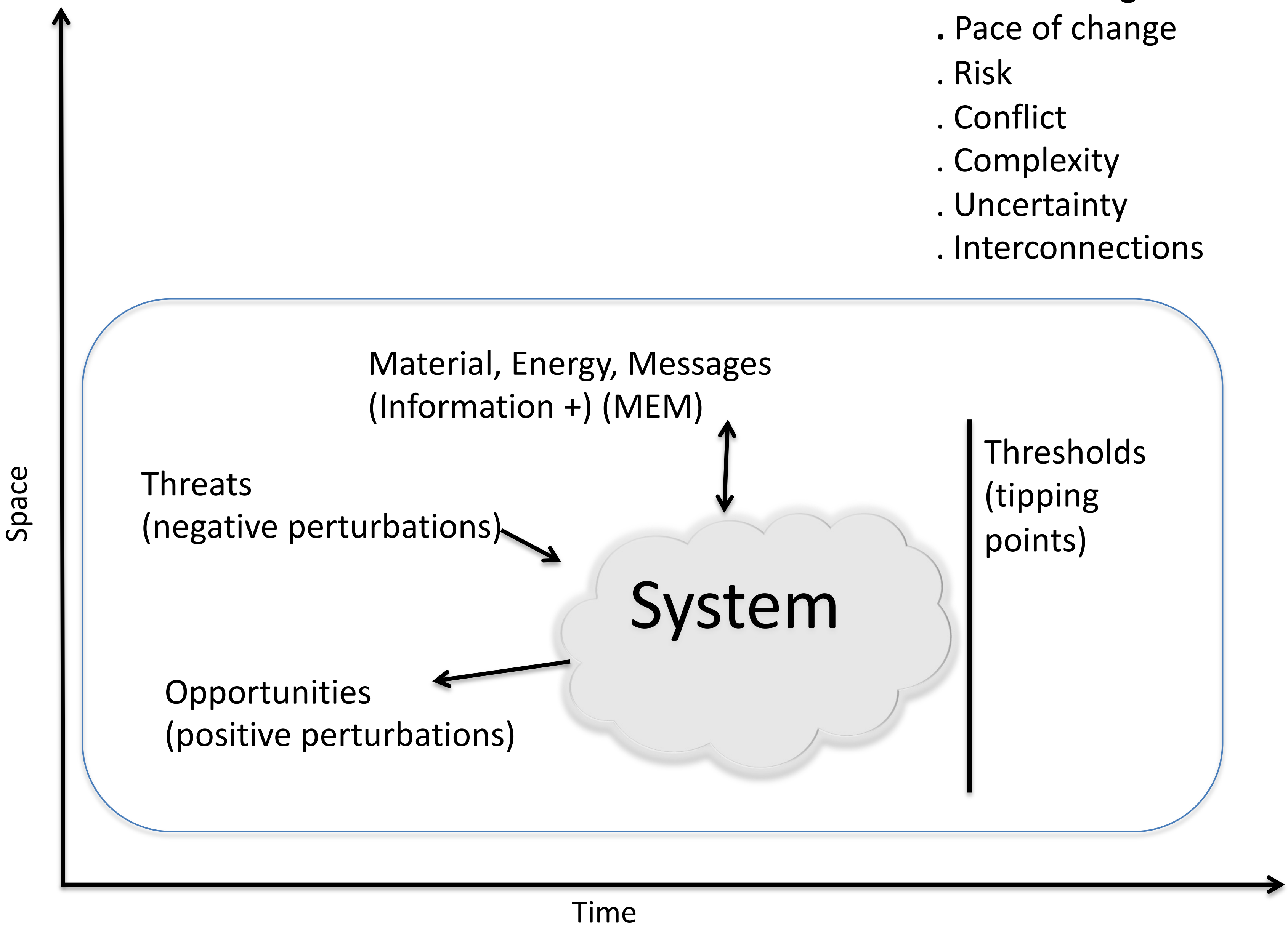
Complex Social Systems Model



A Complex Systems Model

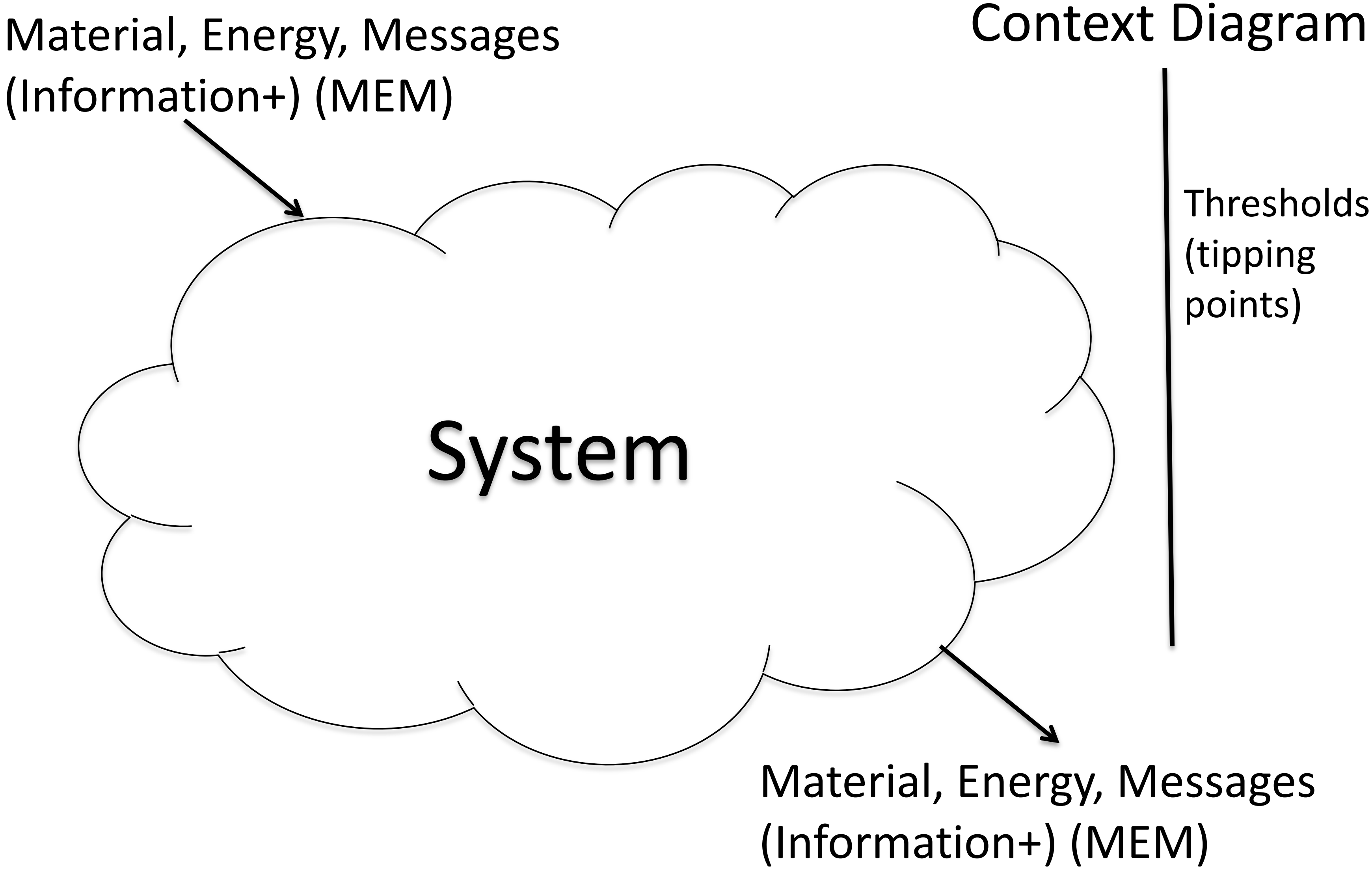
Future Changes– Increasing:

. Pace of change
. Risk
. Conflict
. Complexity
. Uncertainty
. Interconnections



Systems Model

Context Diagram



Systems Model

- Applying the reporters questions to material, information, and energy leads to …
  - Who: Vendor, provider, supplier …
  - What: Product, service
  - Where: source and sink
  - When: Frequency, time, date
  - Why: Rationale
  - How Much: Cost

Systems Model

Material
Energy
Messages

{

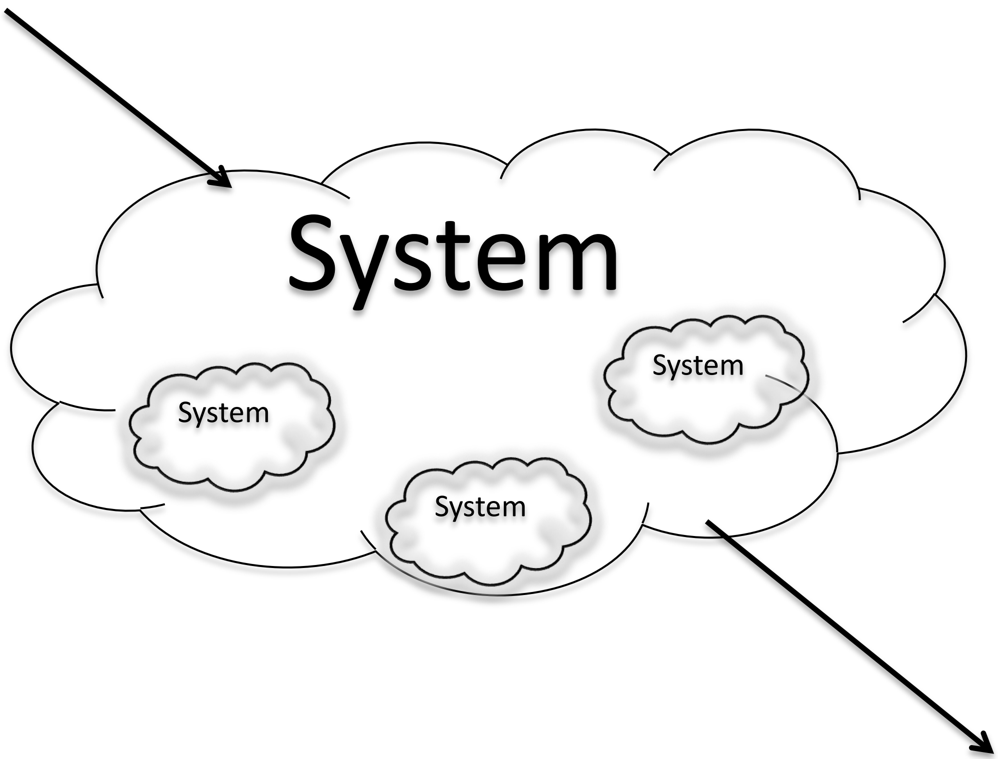
Supplier
Product, service
Quantity, quality
Source, sink
Frequency, time, date
Rationale
Cost

For each MEM, there are several factors

Systems Model

Context Diagram

Material, Energy, Messages (Information +) (MEM)
(types, volumes, frequency, time, costs, sources, rules, regulations, policies, plans, mandates …)



Thresholds (tipping points)

Material, Energy, Messages (Information +) (MEM)
(types, volumes, frequency, costs, time, sinks, rules, regulations, policies, plans, mandates …)

Systems Model

Context Diagram

Material, Energy, Messages (Information +) (MEM) (types, volumes, frequency, costs, time, sources, rules, regulations, policies, plans, mandates …)

Thresholds (tipping points)
- Merger
- Acquisition
- Bankruptcy

Material
- Milk
- 10 gallons
- Daily
- $2 / liter
- Wholesaler

Material
- Waste Milk
- 1 gallon
- Daily
- $2 / liter
- Metro waste

Simple Example. Easy to expand to include more material, energy, and messages.

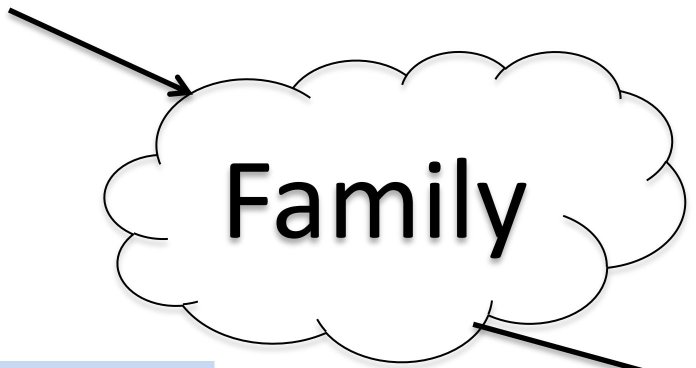
Material, Energy, Messages (Information +) (MEM) (types, volumes, frequency, costs, time, sinks, rules, regulations, policies, plans, mandates …)

Systems Model

Context Diagram

Messages (Information)

- Income
    - Weekly
    - $1000



Messages (Information)

- Options

Thresholds (tipping points)

- Bankruptcy
- Divorce
- Death

Simple Example. Easy to expand / analyze. What if: income goes up or down? How does that affect the family?

The more income, relative to the cost of living means more options. The less income means fewer options.

Throughput

- The amount of material, energy, messages (information +) (MEM) processed for output in a period of time.
- For example:
  - A university may graduate 1,000 students per year
  - A bakery may sell 200 pastries per day

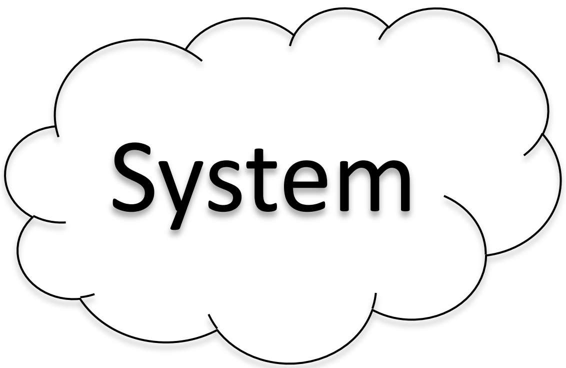
Theory of Constraints

- All systems have constraints or limits.
- A constraint is something that prevents a system from achieving goal.
- Systems have at least one constraint and possibly more but a limited number.
- Constraints may be internal or external.
- An internal constraint exists when demand is more than a system can produce.
- An external constraint exists when a system can produce more than the demand.
- Types of (internal) constraints are categorized by materials, energy, messages (information +) (MEM).
  - Examples: Lack of skilled agents, limited resources, outdated equipment, outdated policies, and so on
- Reducing constraints may improve systems performance.
- Think about a chain being as strong as its weakest link.

Systems Flow

- MEM flows within a system generally take one of four possibilities:
  - One-to-many or divergent or one type of MIE may flow to multiple processes. For example, sugar may be used in creating multiple pastries.
  - Many-to-one or convergent or many types of MEM may flow to one process. A bakery for example may take flour, sugar, salt, chocolate chips among other food products to make chocolate chip cookies.
  - Many-to-many or multiple types of MEM flow to multiple processes. For example, flour, sugar, salt, and so on are used in multiple pastries.
  - One-to-one or linear flow of a type of MEM to one process after another (think assembly line).
  - Some flows cycle within a system or between systems, such as recycling of materials.

Coffee Shop System
(with applied principles)



Systems may be composed of subsystems

- Coffee shop is functionally decomposed into sales, marketing, and operations subsystems.

Systems exhibit behavior; that is they are nonstationary

- Coffee shop is in an expansionary phase

Systems have a history

- Coffee shop was founded 10 years ago and is still in the same location.

Systems are bounded

- Coffee shop has only one location in a mid-sized city.

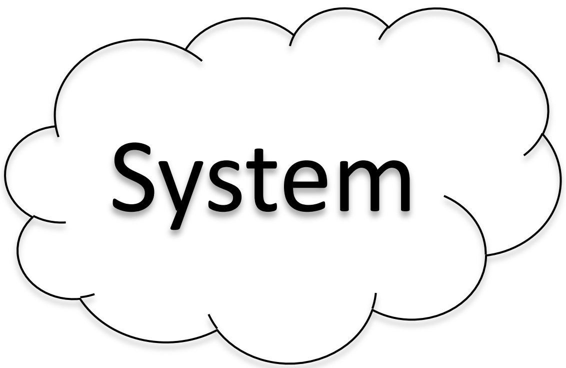
Systems are dynamic

- At times, the coffee shop is stable, other times, growing, and sometimes shrinking

Systems interact with other systems

- Coffee shop interacts with suppliers and customers, government agencies

Coffee Shop System
(with applied principles)



Systems process information (some may process material or energy)

- Processes required MEM for operations

Systems are composed of networks

- Internal networks among operational agents as well as external networks among suppliers, customers, …

Systems regulate themselves through negative feedback

- Coffee shop requires maintenance in terms of the number of agents, types of products sold, …

Systems develop; systems evolve

- Development / evolution in response to environmental conditions

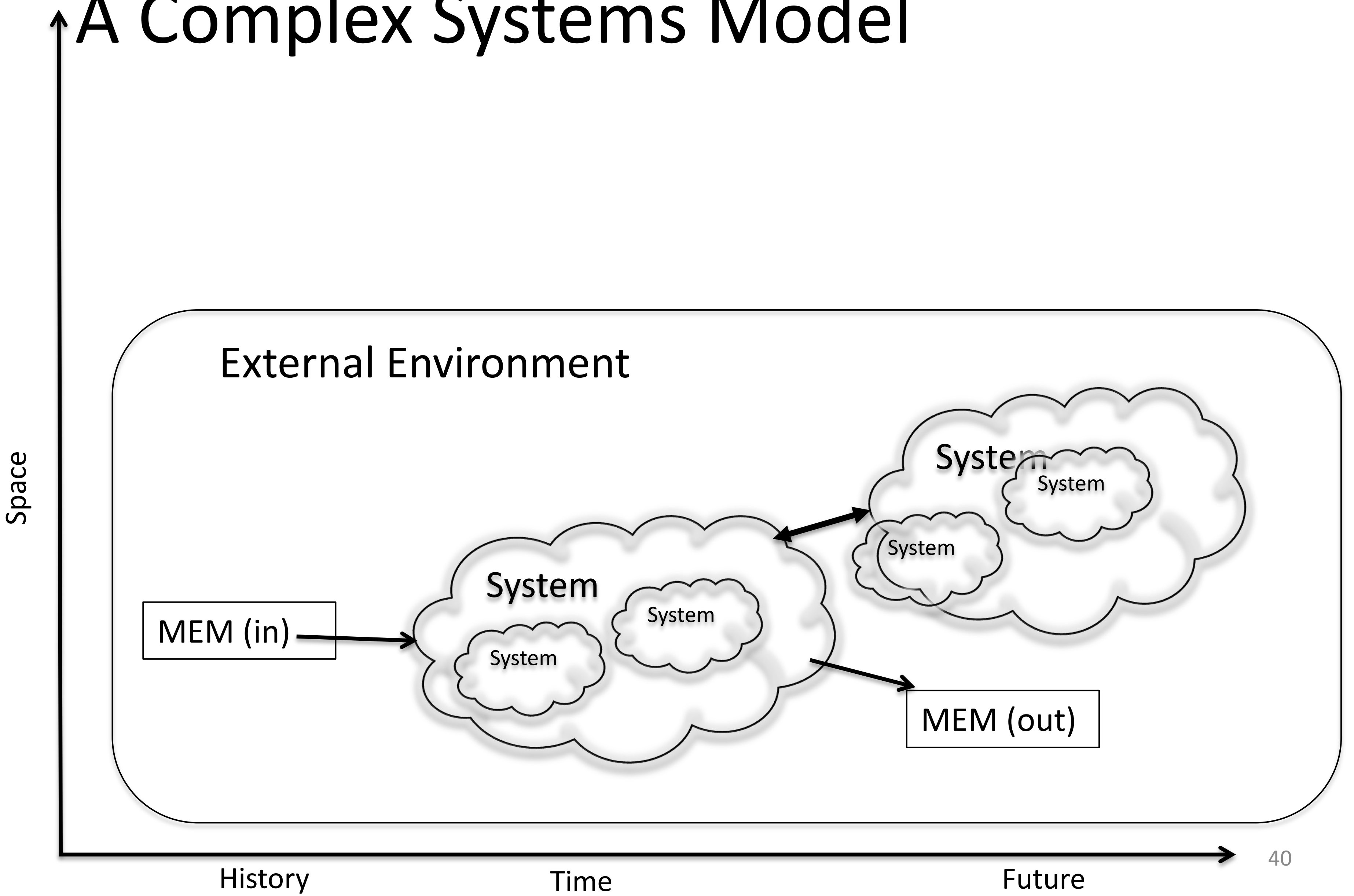
Systems have a life cycle (origin or startup, growth, mature, decline)

- Founded 10 years ago and in the growth stage

Systems will collapse at some point and die

- Not there yet

A Complex Systems Model



MEM Discussion

- MEM or material, energy, messages (information +), are inputs (inflows) to a system, through a system, and outputs (outflows) from a system. Inflows may be stored within a system as a stock. Note: MEMs are resources.
- Inflows and output flows can be measured in flow units per units of time.
  - Examples: Income or inflow of $4,000 per month or $48,000 per year. Mortgage payment of $1,500 per month.
  - Number of student accepted and the number graduated
- Systems process or transform inputs into outputs, which is essentially throughput.
  - Throughputs or outputs can be measured in flow units of time. For example, 30 Boeing 737 airplanes per month

Complexity Theories

- One of the early theories of complexity is that complex phenomena arise from simple rules.
- Consider the rules for the flocking behavior of birds: Fly to the center of the flock, match speed, and avoid collision.
- This simple-rule theory was applied to industrial modeling and production early on, and it promised much; but it did not deliver in isolation.
- More recently, some thinkers and practitioners have started to argue that human complex systems are very different from those in nature and cannot be modeled in the same ways because of human unpredictability and intellect.

Source: Snowden & Boone

Complexity Theories (cont)

- Consider the following ways in which humans are distinct from other animals:
  - They have multiple identities and can fluidly switch between them without conscious thought. (For example, a person can be a respected member of the community as well as a terrorist.)
  - They make decisions based on past patterns of success and failure, rather than on logical, definable rules.
  - They can, in certain circumstances, purposefully change the systems in which they operate to equilibrium states (think of a Six Sigma project) in order to create predictable outcomes.

Source: Snowden & Boone

Complex Systems

Characteristics

- CAS involves large numbers of interacting elements
- Minor nonlinear interactions can produce disproportionately major consequences.
- The system is dynamic, the whole is greater than the sum of its parts, and solutions can not be imposed; rather, they arise from the circumstances. This is frequently referred to as *emergence*
- The system has a history, and the past is integrated with the present; the elements evolve with one another and with the environment; and evolution is irreversible.

Source: Snowden & Boone

Complex Systems (cont)

Characteristics

- Though a complex system may, in retrospect, appear to be ordered and predictable, hindsight does not lead to foresight because the external conditions and systems constantly change.
- Unlike in ordered systems (where the system constrains the agents), or chaotic systems (where there are no constraints), in a complex system the agents and the system constrain one another, especially over time. This means that we cannot forecast or predict what will happen.

Source: Snowden & Boone

Complex Adaptive Systems

- Diversity
  - Complex, nonlinear behavior is possible without component diversity, for instance in a turbulent but otherwise homogeneous fluid, adaptation relies on variations and differences between system components.
  - Diversity means more than simply having a range of different individuals, strategies, or populations. From the perspective of the entire system, diversity means having a greater range of options for responding to environmental change and a corresponding higher likelihood that a solution to a particular problem will be found.

Source: Norberg & Cumming

Complex Adaptive Systems

- Diversity
  - Diversity in complex adaptive systems arises by chance and imperfection, recombination, and in social sciences by innovation and foresight.
  - Diversity is maintained by successful innovation that replaces those that are lost from the system through selection.
    - Diversity is maintained via innovation
    - Diversity is lost by selection

Source: Norberg & Cumming,

Complex Adaptive Systems

Examples

- Central Nervous System
- Cities
- Economy
- Ecosystems
- Immune System
- **Organizations**
- Technology

Types of Systems

- Systems may be natural, social, or artificial
- Examples:
  - Natural: The universe, solar systems, planets, atmosphere, hydrosphere, lithosphere, ecosystems, floral, fauna, …
  - Social: Society, organizations, communities, families, …
  - Artificial: Artificial life, artificial societies …

Notes

Open systems, including *complex systems*, are open to the environment and exchange information, energy, or material to survive

A threshold is a breakpoint between two regimes of a system. (aka, tipping point)
Source: Walker and Meyers

Opportunities are favorable changes in the environment

Threats are unfavorable changes in the environment

Notes

An environment for a social system includes the economy, technology, society, the physical environment, government / legal / military, and competition

These six elements comprise the framework used by many strategic planners and futurists.

While a framework perspective is appropriate; it is more complete to note that each of these elements is not just an environment but a complex adaptive system as well

Notes

The boundary of a system delineates it from its environment

Detectors sense environmental stimuli

Processes transform inputs to outputs

Effectors express outputs to the environment

Notes

Physical Technologies or PTs are methods and designs for transforming matter, energy, and information from one state to another

Examples: blueprints, diagrams, models, …

Social Technologies or STs are methods and designs for organizing people

Examples: rule of law, job descriptions, cultural norms

Organization Plans or OPs are schema that code for the design of an organization

Example: A business plan

Beinhocker, E. D. (2010). *Evolution as computation: Implications for economic theory and ontology*. Retrieved from http://www.santafe.edu

Notes

Complex systems contain structures and algorithms and exhibit patterns and behaviors

Evolution is an algorithm

The general evolutionary algorithm (GEA) is replication or reproduction with variation / differentiation, selection, amplification, and repeat.

Beinhocker, E. D. (2010). *Evolution as computation: Implications for economic theory and ontology*. Retrieved from http://www.santafe.edu

Evolution

- Evolutionary change is any process that leads to increases in complexity, diversity, order, and / or interconnections.
- Three distinct mechanisms or theories of evolution exist
  - Elaboration (biological evolution is an instantiation)
  - Self-organization
  - Fractionation

Fichter, L.S., Pyle, E.J., & Whitmeyer, S.J. (2010). Strategies and Rubrics for Teaching Chaos and Complex Systems as Elaborating, Self-Organizing, and Fractionating Evolutionary Systems. *Journal of Geoscience Education*. 58(2)

Examples of Evolutionary Systems

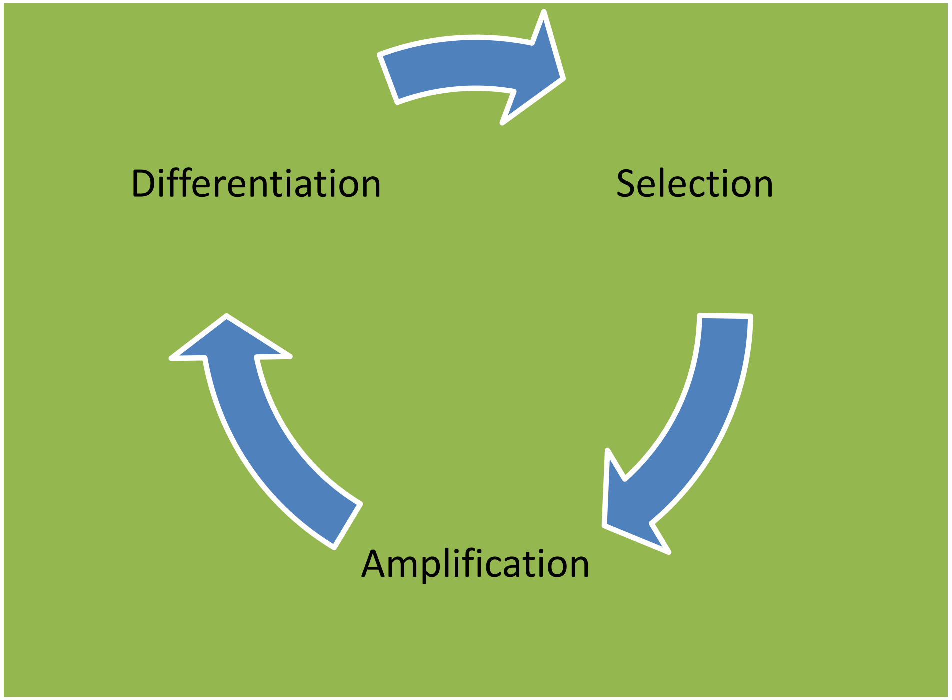
- Biology
- Common Law
- Culture
- Economy
- Industries
- Language
- Morality
- Religion
- Technology

Examples of Evolutionary Systems

- Self-organizing evolution examples
  - Cities (settlements to large cities)
  - Human development (embryo to adulthood)
- Fractionation evolution examples
  - Crude oil to refined gasoline
  - Raw sugar to refined sugar

Evolutionary Systems

- Elaboration evolutionary systems are complex adaptive systems with additional processes

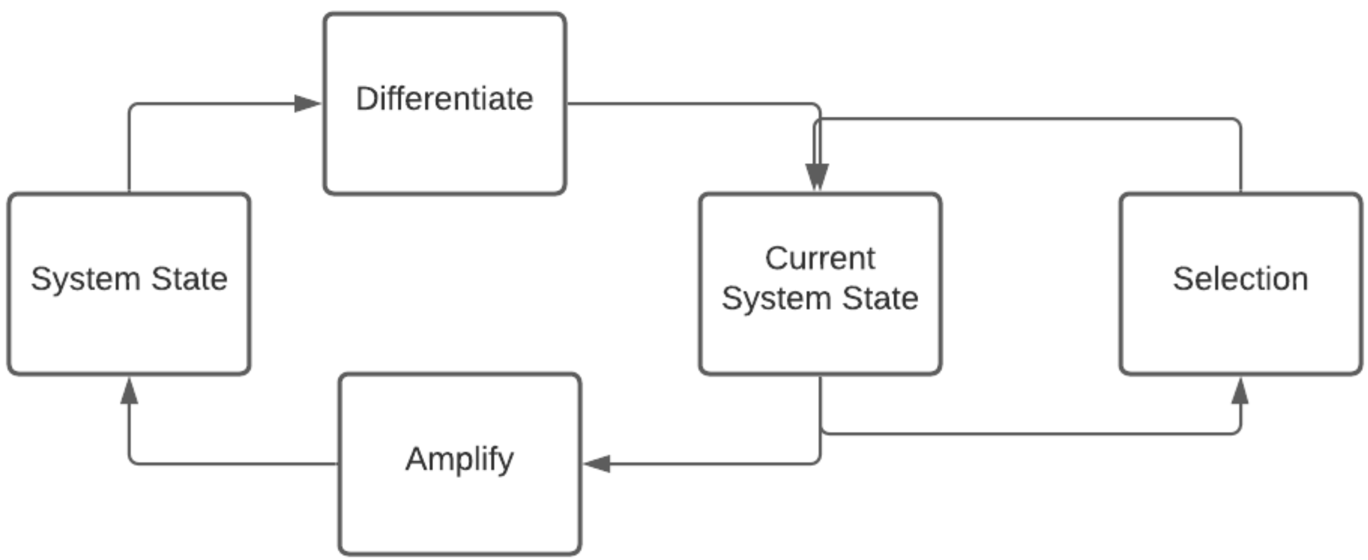


Beinhocker, E.D. (2006). *The origin of wealth*. Boston, MA: Harvard Business School.

Evolutionary Systems

Positive Feedback

Negative Feedback



Limits to Growth / Success

Differentiation Approaches

System

- Elaborate (grow) an existing system
- Reduce (shrink) the size of a system
- Birth a new system
- Spinoff or split into two or more systems
- Merger or combine two or more systems

Note: A system may be an organization, a technology, a culture, a religion, a language, a form of government, ….

Agent

- System elements are referred to by different names such as component, element, entity, object, part, unit, or agent.
- Agents detect, process, and effect material, energy, messages (information +) (MEM)
- An agent's behavior is determined by a set of rules
- Agents may be aggregated into meta-agents

Relationships

- Agents are connected to other agents via one or more links or relationships.
- Relationships may be
  - Strong / weak
  - Attract / repel
  - Competitive / cooperative
  - Necessary
  - Synergistic
  - Redundant

Relationships (Examples)

- Is the parent of
- Is the child of
- Is the sibling of
- Is a
- Is part of
- Is contained in
- Is consumed by
- Is transformed by

Relationships

Classification in Social Relations

- Interactions
  - Helped
  - Hindered
  - Consulted with
  - Talked to
  - Had sex with
- Flows
  - Information (data, beliefs, …)
  - Energy (electricity, …)
  - Material

Caldarelli, G., & Catanzaro, M. (2012). *Networks*. Oxford University Press.

Relationships

Classification in Social Relations

- Similarities
  - – Location (same spatial or temporal space)
  - – Membership (same clubs, events, activities …)
  - – Attributes (same gender, attitude, …)
- Social Relations
  - – Kinship (mother of, father of, sibling of, ….)
  - – Other role (friend of, student of, professor of, …)
  - – Affective (likes, dislikes, neutral, …)
  - – Cognitive (knows, knows about, …)

Caldarelli, G., & Catanzaro, M. (2012). *Networks*. Oxford University Press..

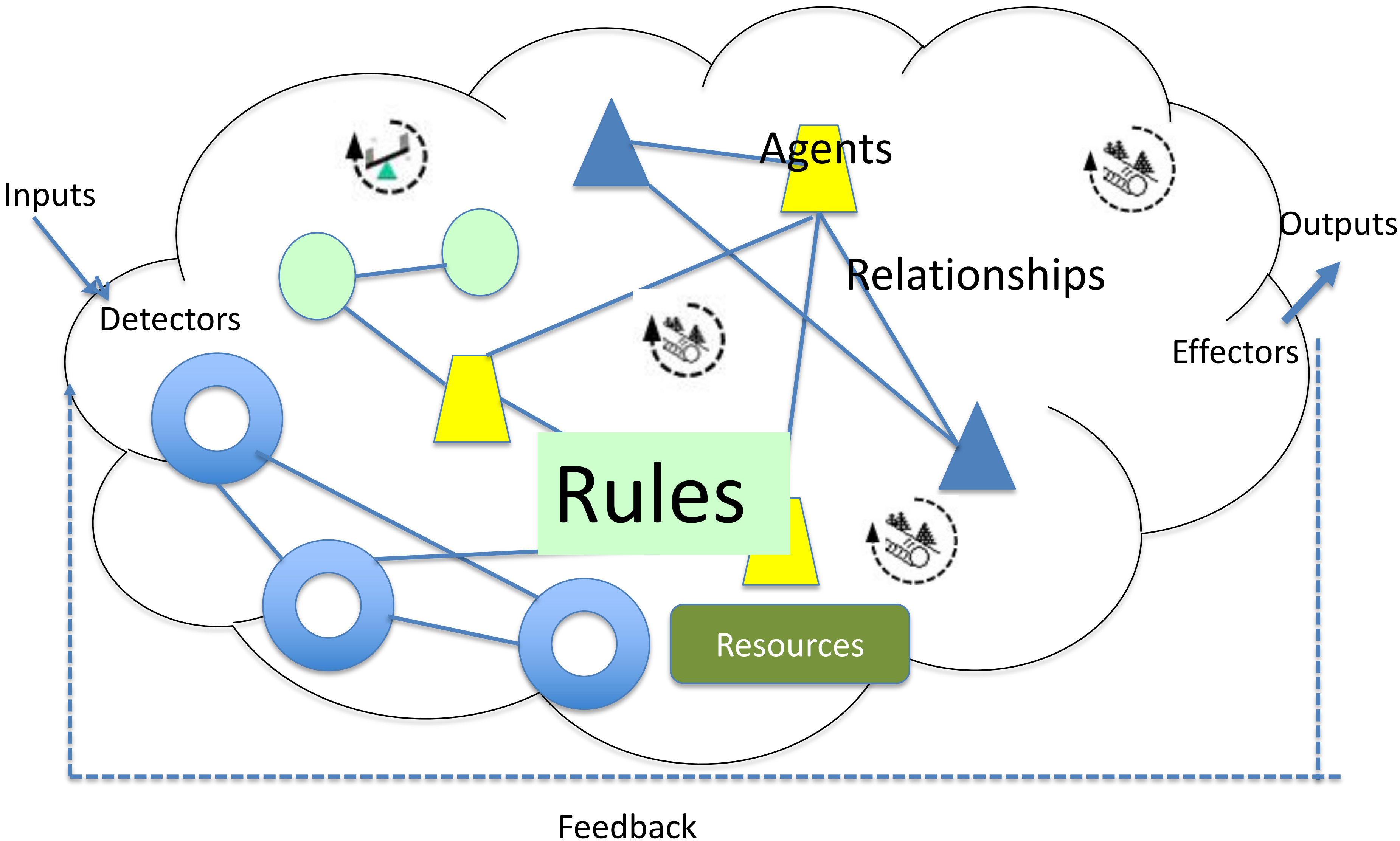
Relationships

- Symbiosis
  - Competition
  - Predation
  - Parasitism

Interdependencies

- Agents are interdependent with other agents …
- Examples
  - Agents may trade with other agents
  - Agents may cooperate with other agents to achieve something
  - Agents may consult with other agents
  - Agents may provide inputs to other agents

System Model



Rules

- May be in the form of If Then Else
- For example,
  - If x is true, then do y, else do z
- Rules exist for the use or consumption of resources, where use means use with changing the resource and consumption means use and changing the resource
  - Resources such as cooking utensils are USED in cooking and can be reused.
  - Resources such as ingredients are CONSUMED in the cooking and cannot be reused.
- Rules may exist for signal detection and effecting, for signal processing

Rules (Information)

- A formal means of defining agents
- Stimulus response or if then else rules
  - Basic format: If Then Else
  - Examples:
    - If (income > 40%) then (distribute bonuses + merit) else (distribute merit only)
    - If (customer walks in the door) then (greet), else (continue working on current projects)
    - If (student does not complete assignment), then (student fails)
    - If (our products lose money) then (….)

Holland, J. H. (1995). *Hidden Order*

Rules (Information)

- Examples within human social systems
  - Code of conduct
  - Job descriptions
  - Processes (steps by which inputs are transformed into outputs. *Note*: processes are executed by agents)
  - Team charters
  - An agenda

Resources

- Resources are Material, Energy, Messages (Information +) (MEM)
  - Examples in human social systems
    - Computers
    - Data
    - Raw materials
    - Processes
    - Software
    - Tools

Feedback

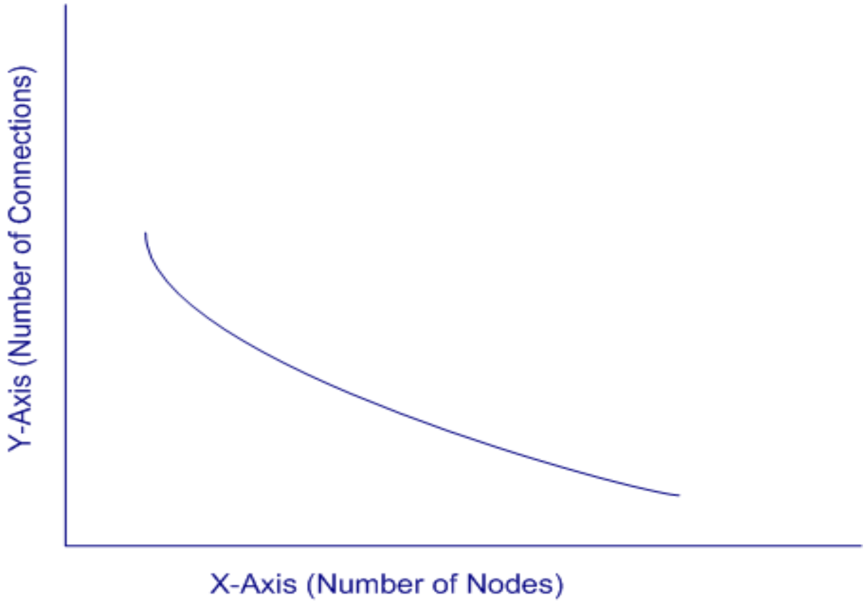
- Complex systems exhibit positive and negative feedback loops
- Positive feedback is an amplifying feedback
- Negative feedback is regulating, balancing, goal seeking feedback, or maintaining feedback

Scale Free Networks

Scale free networks are characterized by a few nodes having large numbers of connections while most nodes have considerably fewer connections. This distribution follows a power law.

Examples of scale free networks include social networks, the Internet, and ecological networks.

Scale free networks are robust against accidental or random failure; however, they are vulnerable to targeted destruction.

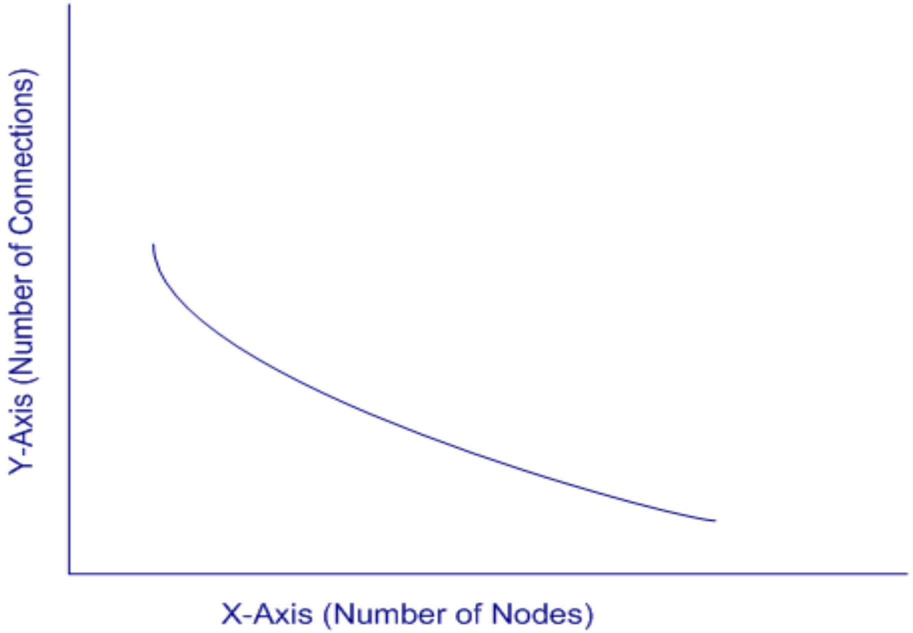


Buchanan, M. (2002). *Nexus: Small worlds and the groundbreaking science of networks*. New York: W.W. Norton & Company

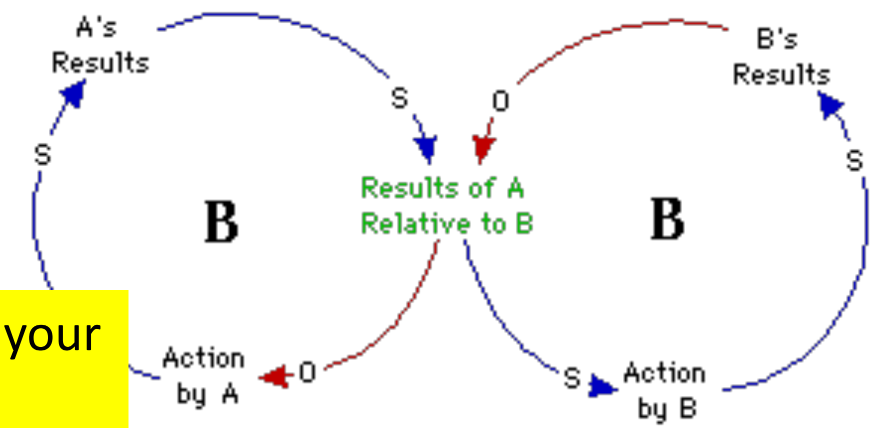
Scale Free

This graph represents the power law or a scale free network distribution.

In terms of human populations, non-behavioral attributes such as height or weight typically follow a bell shaped curve, while behavioral attributes such as wealth accumulation, popularity, and such follow the power law.



Success to the successful Archetype



Thought experiment: How might this affect your organization, your community, or you?

Buchanan, M. (2002). *Nexus: Small worlds and the groundbreaking science of networks*. New York: W.W. Norton & Company

Regime Shift

- A regime is a characteristic pattern or rule of management
- Sudden shifts in ecosystems, whereby a threshold is passed and the core functions, structure, and processes of the new regime are fundamentally different from the previous regime.

Scheffer, M., and S. R. Carpenter. 2003. Catastrophic regime shifts in ecosystems: linking theory to observation. Trends in Ecology and Evolution 18(12): 648–656.

Resilience

- The capacity of a system to absorb disturbance and re-organize so as to retain essentially the same function, structure, and feedbacks—to have the same identity.
  - Source: David Salt
- The opposite of resiliency is vulnerability
  - Brian Walker
- Resilience is the capacity of a system to continually change and adapt yet remain within critical thresholds
  - Stockholm Resilience Centre
- Components
  - Robustness, redundancy, resourcefulness, response, recovery
  - Source: World Economic Forum (2013). Global Risks Report

Resilience Examples

- An ecosystem is resilient to change if it can withstand storms, fire, or other perturbations
- A society is resilient if it can manage political instability, natural disasters, population growth, economic disasters, viral pandemics, or other perturbations.
- A company is resilient if it can manage financial swings, increasing / decreasing numbers of customers, increasing competition, lawsuits, ….

Tipping Points / Thresholds

- That point beyond which something becomes something different and becomes difficult to reverse
- Example:
  - Heating water up to 99.9999 degrees Celsius is hot, but still water. The tipping point is the boiling temperature at which point, water changes from a liquid to a gas
  - A company continues to lose money, but remains in business. If the company declares bankruptcy or is acquired, it tips. If not, it doesn't tip.
  - A married couple fights and makes up until they don't. A divorce is a tipping point.

Adaptation

Adaptation is successful change to either external forces or internal capabilities

What happens to societies, organizations, communities, or families that cannot adapt?

Mitigation

The effort to reduce the effects of a problem or situation

CAS Properties

Tags

Internal Models

Nonlinearity

Flows

Diversity

Building Blocks

Aggregation

Source: Holland*, J. H. (1995). Hidden Order.* Basic Books.

Mechanism

- A means of mediating interactions

Property

- A characteristic of an object

Mechanisms and Properties of Complex Adaptive Systems

- Aggregation
- Tags
- Nonlinearity
- Flows
- Diversity
- Internal Models
- Building Blocks

Holland, J. H. (1995). *Hidden order: How adaptation builds complexity*. Basic Books.

Aggregation (Property)

- An approach to simplifying complex systems
- For example, we aggregate similar things into categories—schools, buildings, food—and then we treat them as a single abstract unit.
- Aggregation is an approach to constructing models
- For example, we can aggregate sales of companies into GDP
- How might we classify and aggregate communities?

Holland, J. H. (1995). *Hidden order: How adaptation builds complexity*. Basic Books.

Tags (Mechanism)

- Tags are a mechanism that facilitates the formation of aggregates
- Examples: flags, political parties, …
- Provide a basis for filtering, specialization, cooperation, selection, …
- The mechanism behind hierarchical organization

Holland, J. H. (1995). *Hidden order: How adaptation builds complexity*. New York, NY: Basic Books.

Nonlinearity (property)

- A nonlinear function of one or more variables
- Not a simple weighted sum of variables such as $z = ax + by$
- Exponential growth and decline are good examples of nonlinearity
- A community example would be a YouTube video going viral

Holland, J. H. (1995). *Hidden order: How adaptation builds complexity*. New York, NY: Basic Books.

Flows (property)

- A transfer of information, money, resources, or energy across a network of agents within a system
- For example, electronic mail flows across a set of computers, from source to target via connections
- Money flows across a set of agents from a source (company, agency, …) to employees to retailers …..
- Information flows through a community; for example by a telephone or email tree

Holland, J. H. (1995). *Hidden order: How adaptation builds complexity*. Basic Books.

Diversity (property)

- The variety of agents within a system
- A city may contain hundreds to thousands of distinct kinds of businesses
- A country may contain several regions
- A city may contain a variety of communities
- A community may contain a variety of individuals

Holland, J. H. (1995). *Hidden order: How adaptation builds complexity*. Basic Books.

Internal Models or Schema (mechanism)

- Structures within agents enabling the prediction and anticipation of consequences
- Internal models develop from interactions with the environment
- An example of a community internal model would be a set of response rules (if then else) for processing environmental signals

Holland, J. H. (1995). *Hidden order: How adaptation builds complexity*. Basic Books.

Building Blocks (mechanism)

- Reusable objects that can be combined and recombined in new ways, which determine a systems appearance
- Examples of community building blocks include organization charts, document templates, contracts, meeting sites, …

Holland, J. H. (1995). *Hidden order: How adaptation builds complexity*. Basic Books.

Fiske's Relational-Models Theory

- Models corresponding to Holland's internal models
- Four relational models, that in various combinations, govern all social interactions, which operate when resources are transferred

Fiske's Relational-Models Theory

- Communal sharing
  - A relationship among a bounded group of people in which members are considered equivalent
- Authority ranking
  - A linear, hierarchical relationship in which one person is above or below another person
- Equality matching
  - A relationship in which there is a one-to-one correspondence in the transfer of resources (tit for tat)
- Market pricing
  - An exchange of resources based on proportionality, such as exchanging goods or services

Approaches to Quantification

- Number of types of agents
- Number of agents of each type
- Number of unique relationships
- Number of relationships for each agent
  - Source: George Mobus: Always Question

Subsystems of a Country

- Economy
- Environment
- Governance
  - Federal
  - State
  - Local
  - City
- Infrastructure
- Society (a human society is a complex dynamical system)

CAS Structures

- Networks may be the only structure, aside from the boundary, which may not actually be physical, in a CAS.
- A simple, abstract CAS, then, may only include a network structure of agents, while other structures emerge and be present in more complex CAS.
  - Think of the abstract concept Airplane. Few structures actually contained in the concept; most structures and details emerge in specific instantiations of airplanes

CAS Structures (cont)

- Many structures have associated algorithms, such as a FIFO structure has an associated queuing algorithm
- The idea of these few notes is that we can model cas in terms of objects
- Class *cas (contains methods and data* or *variables)*

CAS

- Abstract CAS
  - Structures / properties
    - Boundary
    - Agents
    - Networks
    - Feedback loops

Social (cas)

- Inherits structures / properties / from abstract cas
- Adds new structures / properties

Organizations (cas)

- Inherits structures / properties / from social (cas)
- Adds new structures / properties

Information Organization Patterns Aggregation Possibilities

- Alphanumeric
- Chronological
- Color
- Geography
- Network
- Size
- Type

Agents can be aggregated in a few possibilities.

Examples of types: clusters of managers, technical staff, …

Organization charts are organized by hierarchy

May organize by the size of cities, countries, ..

Patterns in Systems

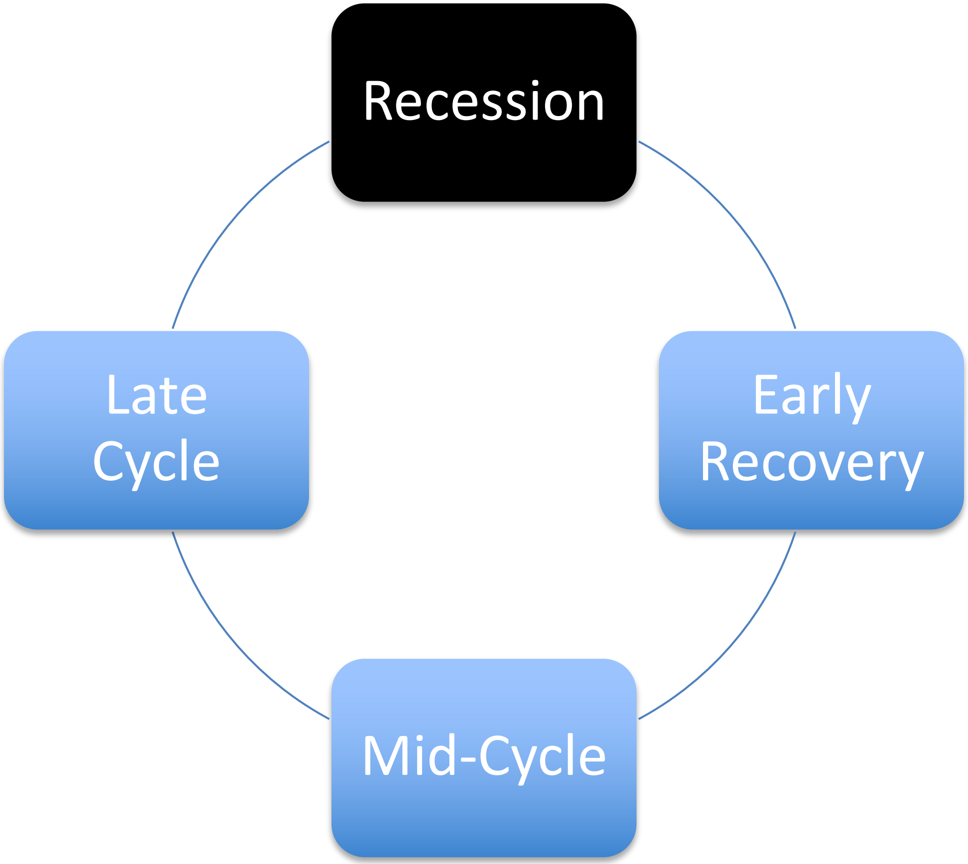
Systems Archetypes

- Limits to Success
- Shifting the Burden
- Tragedy of the Commons
- Growth and Underinvestment
- Attractiveness
- Escalation
- Positive Feedback
- Negative Feedback
- Birth / Death
- Success to the Successful

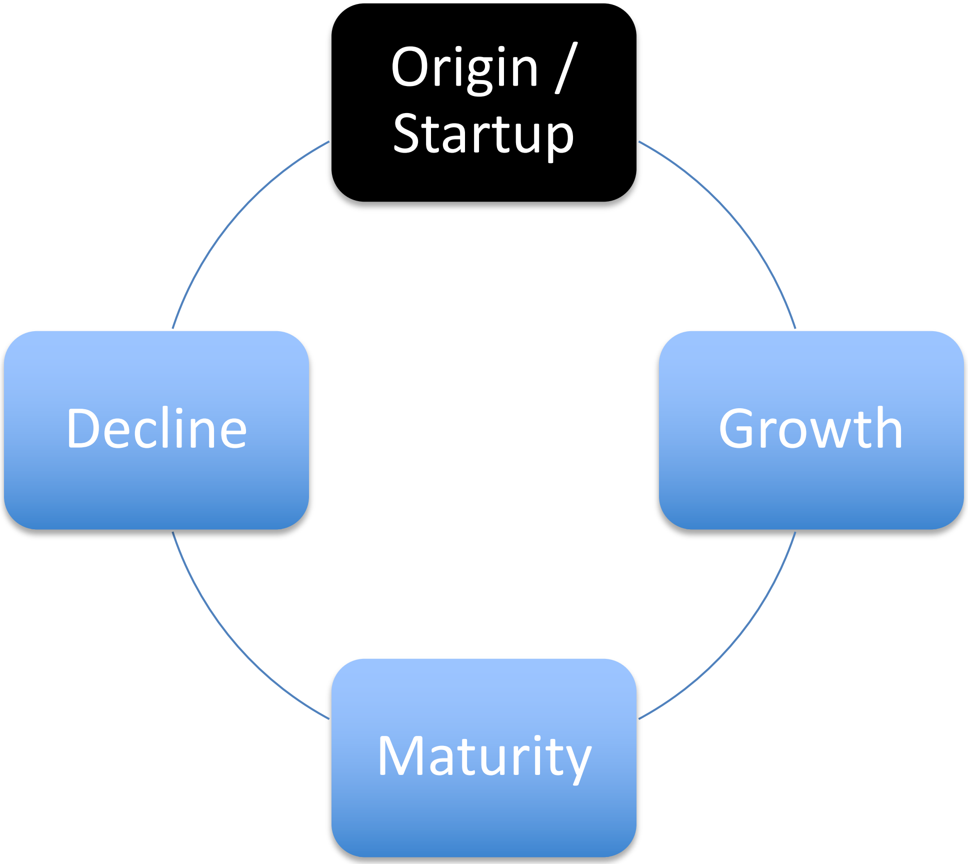
Cycles in Human Social Systems

- Adaptive Cycle (conservation, release, reorganization, exploitation)
- Agricultural Cycles
- Economic Cycles
- Innovation Cycles
- Life Cycles
- Reproductive Cycles
- Secular Cycles (growth, stagflation, crisis, collapse)
- Temporal Cycles (hourly, daily, weekly, …)
- Plus ……

Economic Cycles



Life Cycles



Collapse

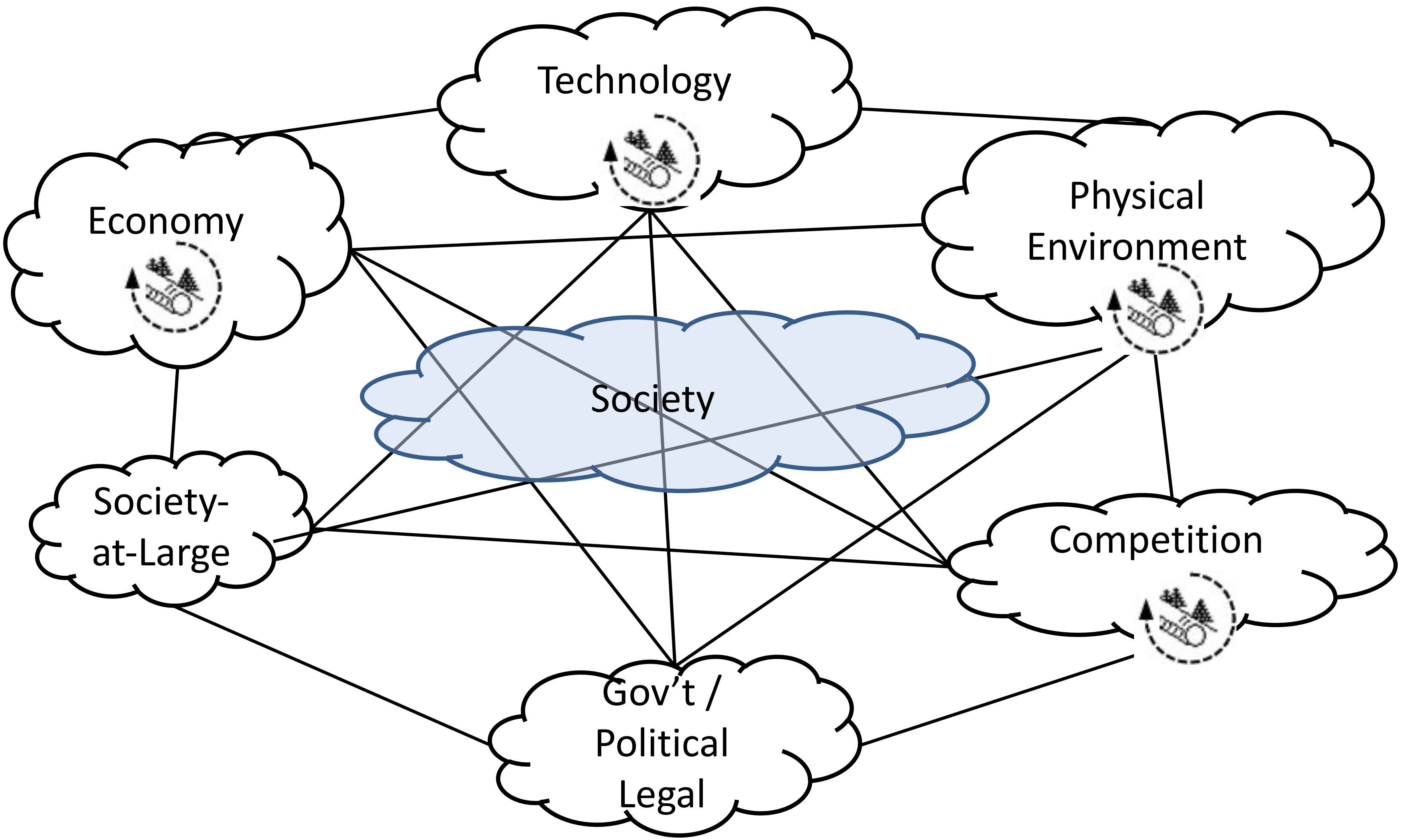
Some say the world will end in fire. Some say in ice.

- Robert Frost

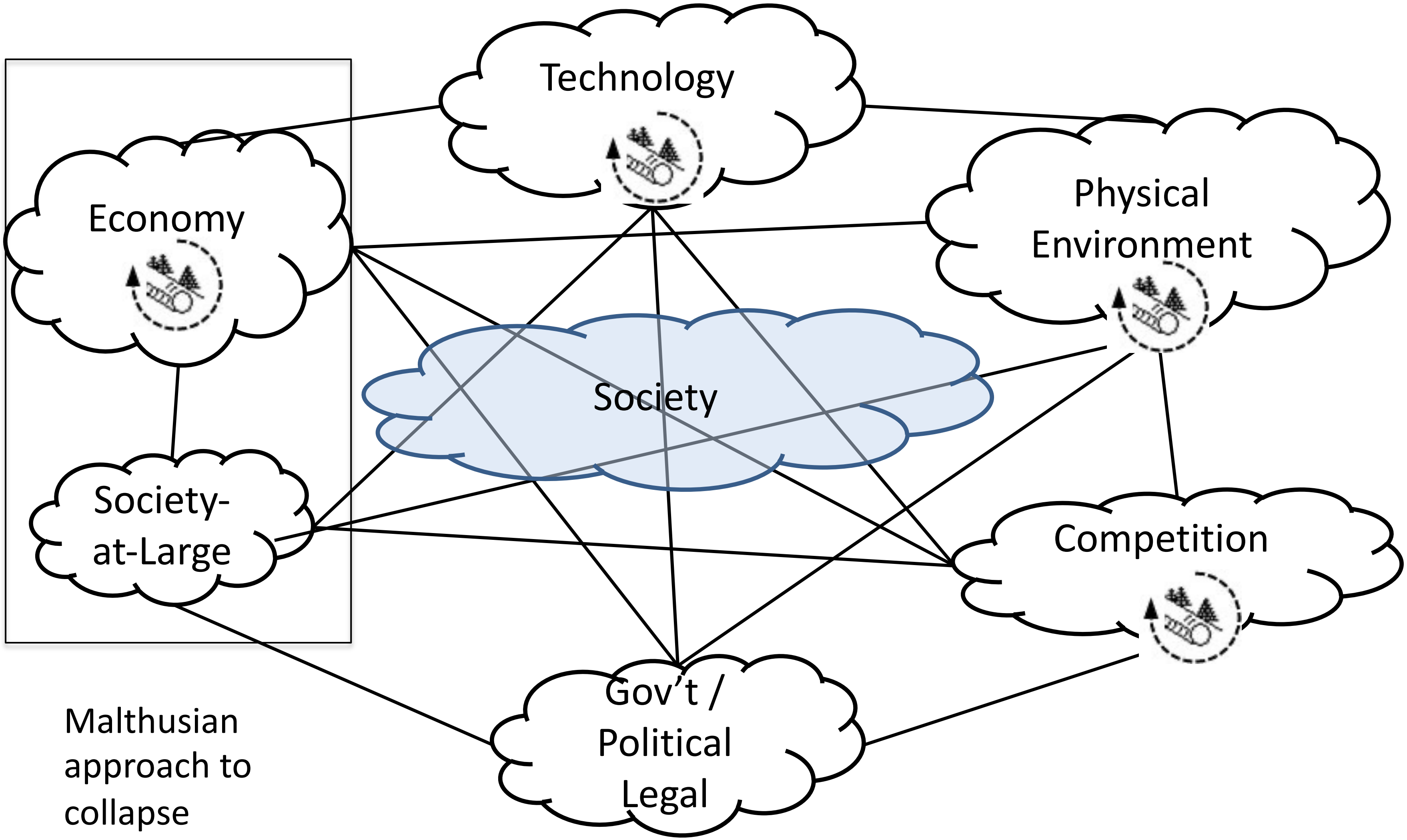
Collapse

- Systems, including societies, collapse for a variety of reasons.
- Threats from the external environment may overwhelm a system
- Weaknesses within a system may cause it to collapse

System Collapse or Failure



System Collapse or Failure



Malthusian
approach to
collapse

Collapse (cont)

- From the systems model (previous page).
  - Human social systems are dependent on their environment (independent variables).
  - Human social systems are dependent on supplies (within a range) of MEM.
  - Changes (perturbations) to MEM flowing into a system may result in threats or opportunities
  - Changes (perturbations) to MEM flowing out of a system may result in threats or opportunities

Collapse (cont)

- Exogenous perturbations to a social system may cause it to fail and collapse
  - Physical environment (climate change, pests / bugs / disease; viral pandemics such as Coronavirus …)
  - Economics (The law of diminishing returns, economic conflict, disruption of MEM from suppliers or the environment, …)
  - Competition (conflict, war, disruption of MEM …)
  - Technology (unable to keep up with advanced technology)
  - Political (war, conflict, terrorism …)
  - Society-at-large (disruption of MEM flows)

Collapse (cont)

- Exogenous perturbations to a social system may cause weaknesses in it to fail and possibly collapse
  - Weaknesses include a lack of resources, resiliency, talent, leadership, interest, finances, energy to survive, apathy,, racism, inequality, polarization, among many others.
  - Example: A rapidly spreading viral pandemic could create panic leading to economic shutdowns (with a loss of jobs, income, status, opportunity, …); constraints on personal freedoms (including social mobility, social interactions, …); resource shortages (food, water, electricity, clothing, …); and so on.

Essentially systems fail or collapse when a system-threatening situation cannot be solved.

Collapse (cont)

- Exogenous perturbations to a social system may cause it to fail and possibly collapse
  - Questions:
    - What challenges might climate change bring?
    - What challenges might a major cybersecurity war bring?
    - What challenges might another world war bring?

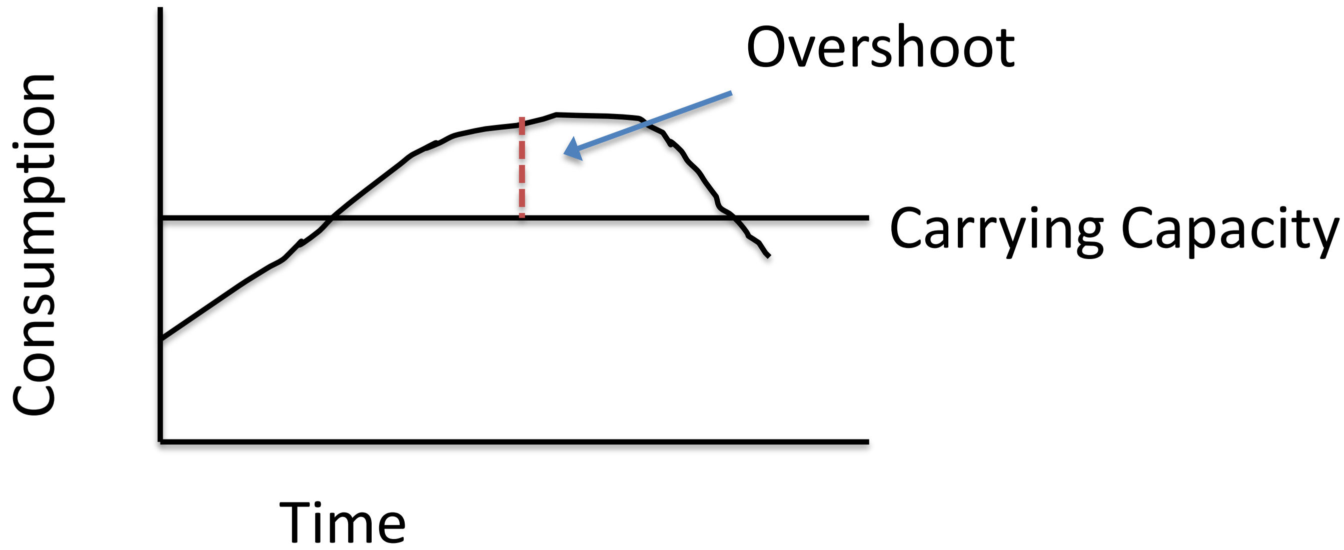
Essentially systems fail or collapse when a system-threatening situation cannot be solved.

Collapse (cont)

- Endogenous weaknesses in a social system may cause it to fail and possibly collapse
  - Questions:
    - What challenges might a decline in food / water supplies bring?
    - What challenges might increasing political, social, economic, educational, technological fragmentation and polarization bring?
    - What challenges might a political leadership crisis bring?
    - What challenges might over population bring?
    - What challenges might another civil war bring?

Essentially systems fail or collapse when a system-threatening situation cannot be solved.

Collapse (overshoot)



Overshoot occurs when a population exceeds the carrying capacity of its environment. Note: The carrying capacity varies depending on factors in the environment such as the availability of food and water, climate change, ….

Collapse

- A collapse is the rapid rearrangement of a large number of links, including their breakdown and disappearance.
- The things that collapse (everyday objects, towers, planes, ecosystems, companies, empires, or what have you) are always networks.
- Sometimes the nodes are atoms and the links are chemical bonds; that’s the case with solid materials.
- Sometimes the nodes are physical links between elements of artificial structures.

Bardi, U. (2017). *The Seneca Effect* (The Frontiers Collection). Springer International Publishing. Kindle Edition.

Collapse

- And sometimes the nodes are human beings or social groups and the links are to be found on the Web or in person-to-person communication, or maybe in terms of monetary.

Bardi, U. (2017). *The Seneca Effect* (The Frontiers Collection). Springer International Publishing. Kindle Edition.

Collapse

- One way to look at the tendency of complex systems to collapse is in terms of "tipping points."
- This concept indicates that collapse is not a smooth transition; it is a drastic change that takes the system from one state to another.

Bardi, U. (2017). *The Seneca Effect* (The Frontiers Collection). Springer International Publishing. Kindle Edition.

Force Field Analysis
Example

System (Society)

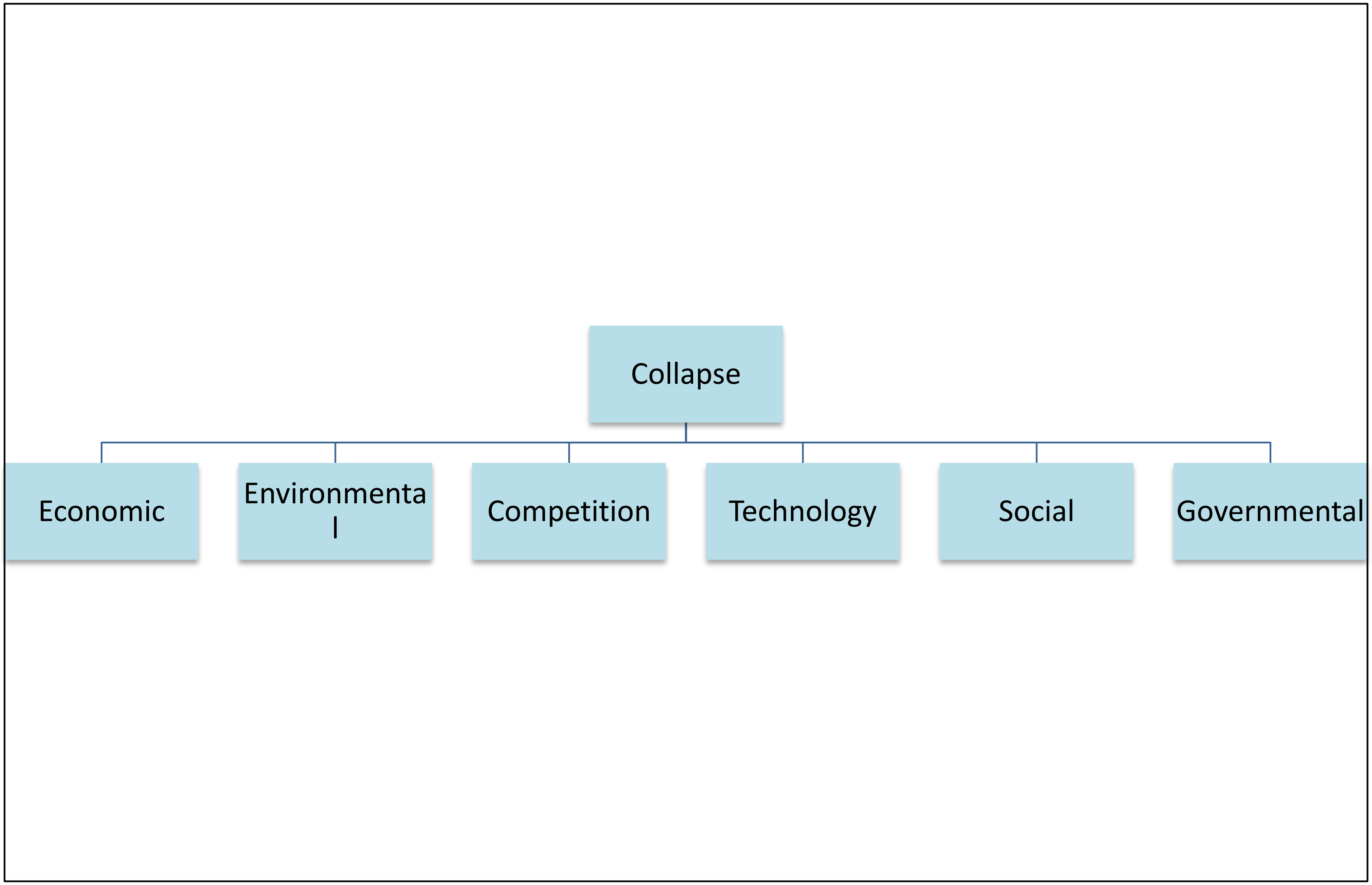
Forces for Change

- Climate Change
- Resource Depletion
- Technology Advances
- Economic Changes
- Inequality
- Competition
- Racism
- Conflict
- Pandemics

Forces Against Change

- Resilience
- Robustness
- Problem Solving Capability
- Capacity to Act
- Mitigation
- Adaptation

Taxonomy of Collapse

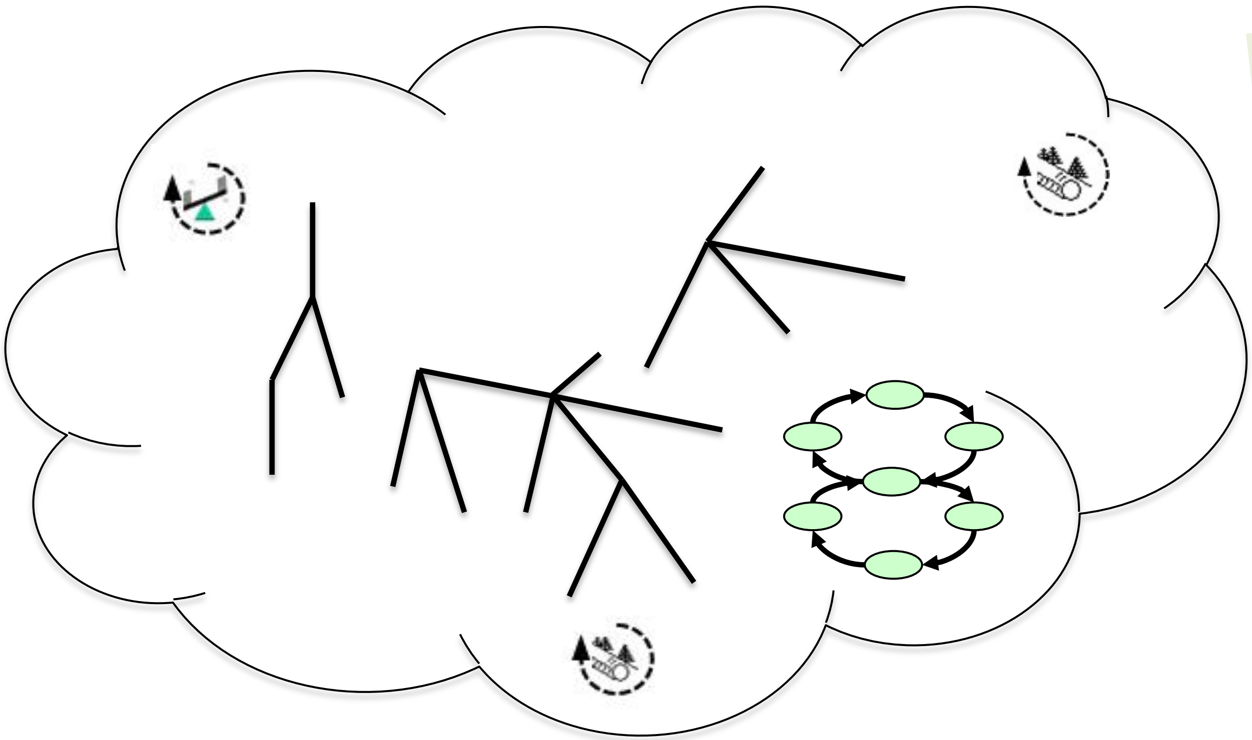


Some Trends / Forecasts

- U.S. Top 1%
  - 25 years ago, 12% of income, 33% of wealth; today 25% of income and 40% of wealth.
- U.S. population projected to increase from 308 million to 440 million by 2050, and 1 billion by 2100.
- Political gridlock (divergent world views or philosophical civil war?)
- Human consumption is now 5X larger than nature's capacity to regenerate or to absorb our "ecological footprint."

Complex Social Systems

Behavior Patterns Over Time



Equilibrium

Periodic

Random / Chaotic

Complex

Perturbing a system results in one of four possible system outcomes: equilibrium, periodic, chaotic, or complex. Note: equilibrium means stable, possibly because of systems failure / collapse

Understanding complex adaptive and evolutionary systems provides insights into change that affect ourselves, our families, communities, organizations, and society.

Complex systems are composed of structures and algorithms or processes.

We understand some structures such as boundaries and networks, while quantitative algorithmic understanding is very limited

Systems Thinking

Systems Thinking

- Five Key Processes
  – Personal Mastery
  – Mental Models
  – Team Learning
  – Shared Vision
  – Systems Thinking

Personal Mastery

- A process of developing a personal vision and purpose of life along with continual learning to achieve personal and professional goals.
- Personal mastery or learning changes a person's behavior, which in turn, if applied, can change or shape the system.
  - Source: Flack, J. and Mitchell, M.
- The ability to learn faster than your competitors may be the only sustainable competitive advantage.
  - Source: Arei P. De Geu

Mental Models

- The values, beliefs, ideas, principles, and so on that help us make sense of the world. Mental models shape our identity.
- Examples:
  - Pro-choice or pro-life
  - Republican or Democrat
  - Professional role (doctor, engineer, …)
  - Religious or secular
- Strongly held mental models are rarely changeable except through a significant emotional event. Even then …

Team Learning

- The process of team building, team learning, and team performance.
- How well does your team learn and apply what it has learned?
- Does your team learning help your organization to become a learning organization?

Shared Vision

- A process of sharing an organizational vision throughout the organization to help focus and drive **collective** energies and talents.
- What is your families *shared vision*?
- What is your *vision*? Do you have one?

Systems Thinking

- The process of how things (parts) influences the whole.
- Recall, the elements or parts or components of a system are connected (a network) and work collectively to achieve goals of the system.

Systems Archetypes

Systems Archetypes

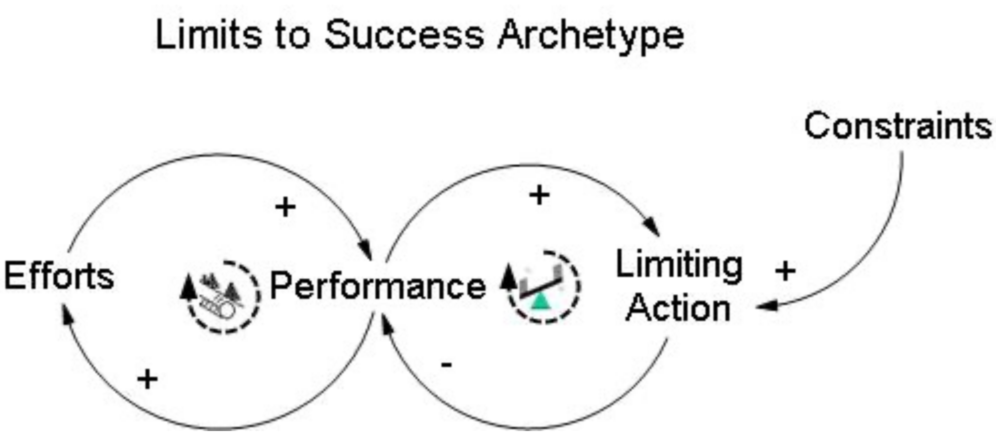
- Archetypes describe commonly observed patterns in natural, social, or artificial systems
- Examples
  - Limits to success (growth)
  - Tragedy of the commons
  - Escalation
  - Shifting the burden
  - Success to the successful
  - Growth and underinvestment
  - Eroding goals

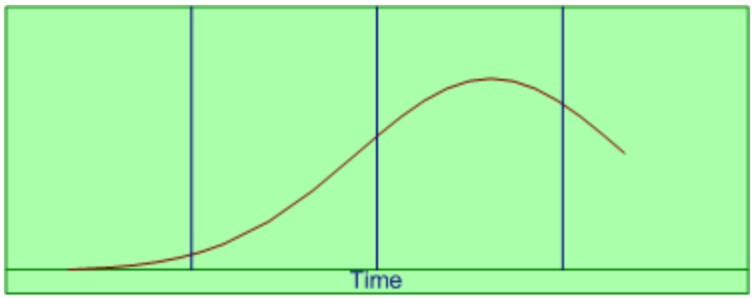
Limits to Success (Growth)

- At some point, growth slows due to limiting factors and depending on circumstances overshoots and flattens, collapses, or oscillates around some equilibrium.
- Examples of limiting factors of a population include the average lifespan and the carrying capacity of the environment such as the availability of food or water

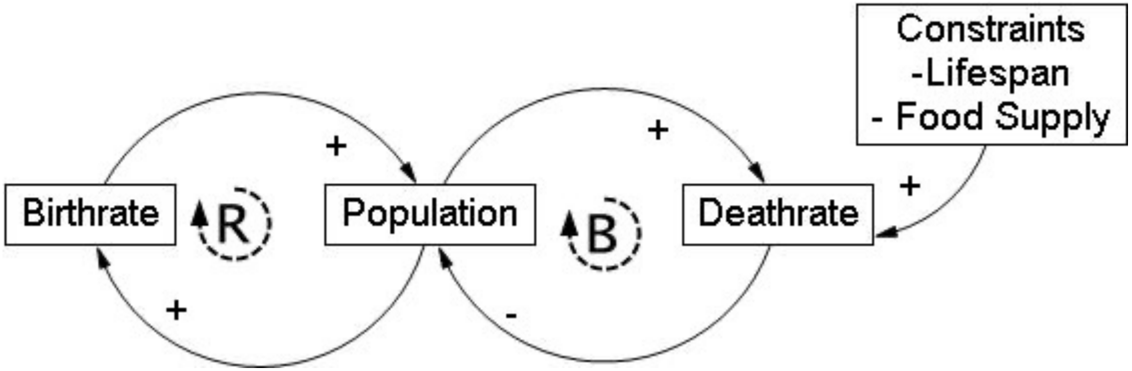
Limits to Success (Growth)

Generic Structure

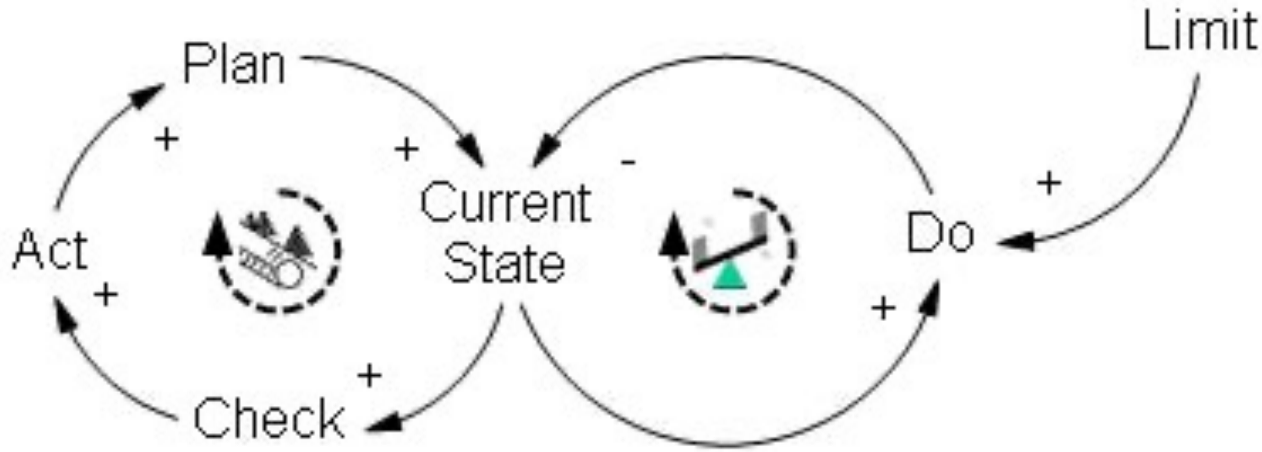




Example

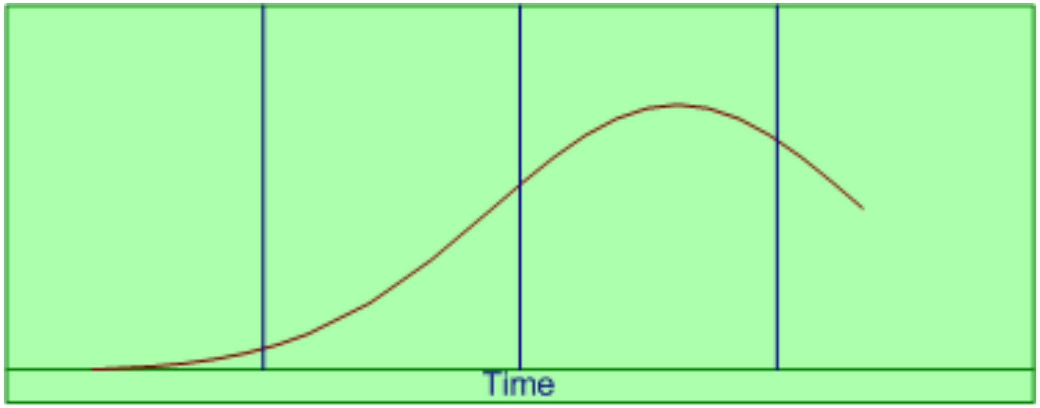


PDCA – Limits To Success Model



There are limits to improvement such as the laws of physics, investment capital, time, mental models, interest ….

PDCA Behavior Over Time

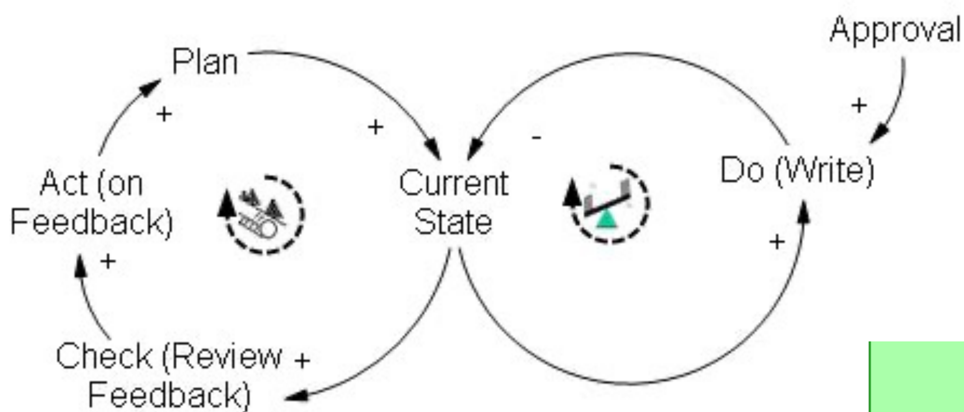


Improvements may start slow, speed up, slow to stop, oscillate about a line, or even decline as limits to improvements are reached

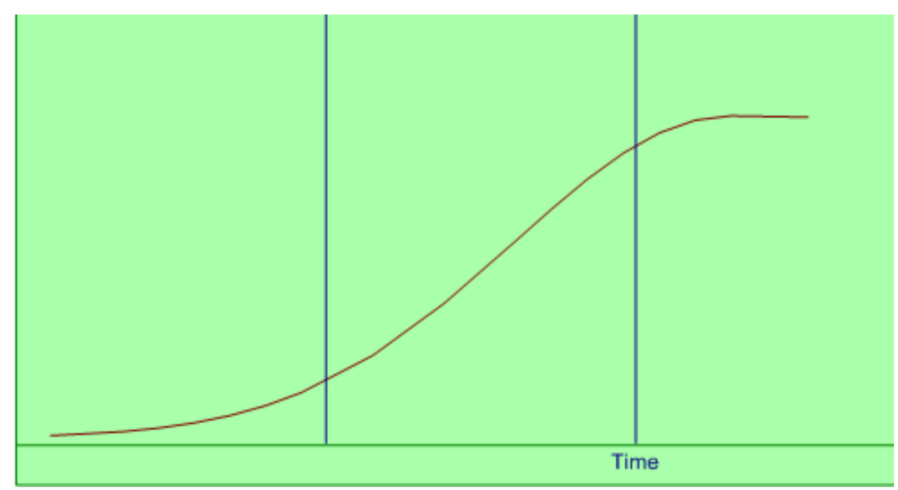
Any thoughts here?

PDCA with Applications

PDCA - Limits Model
Dissertation / Doctoral Study / Book / Article

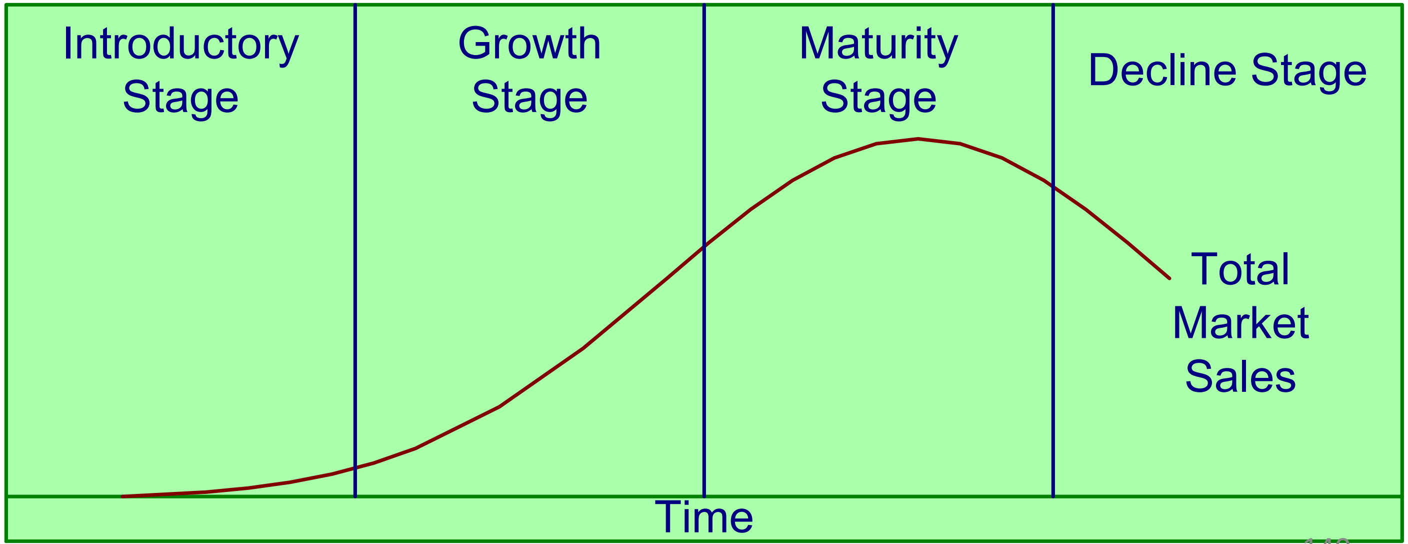


Behavior of Writing Progress



Product Life Cycle Model or Pattern

- The product life cycle model is a special case of the more general limits to growth pattern or archetype. See below for the behavior over time.



Limits

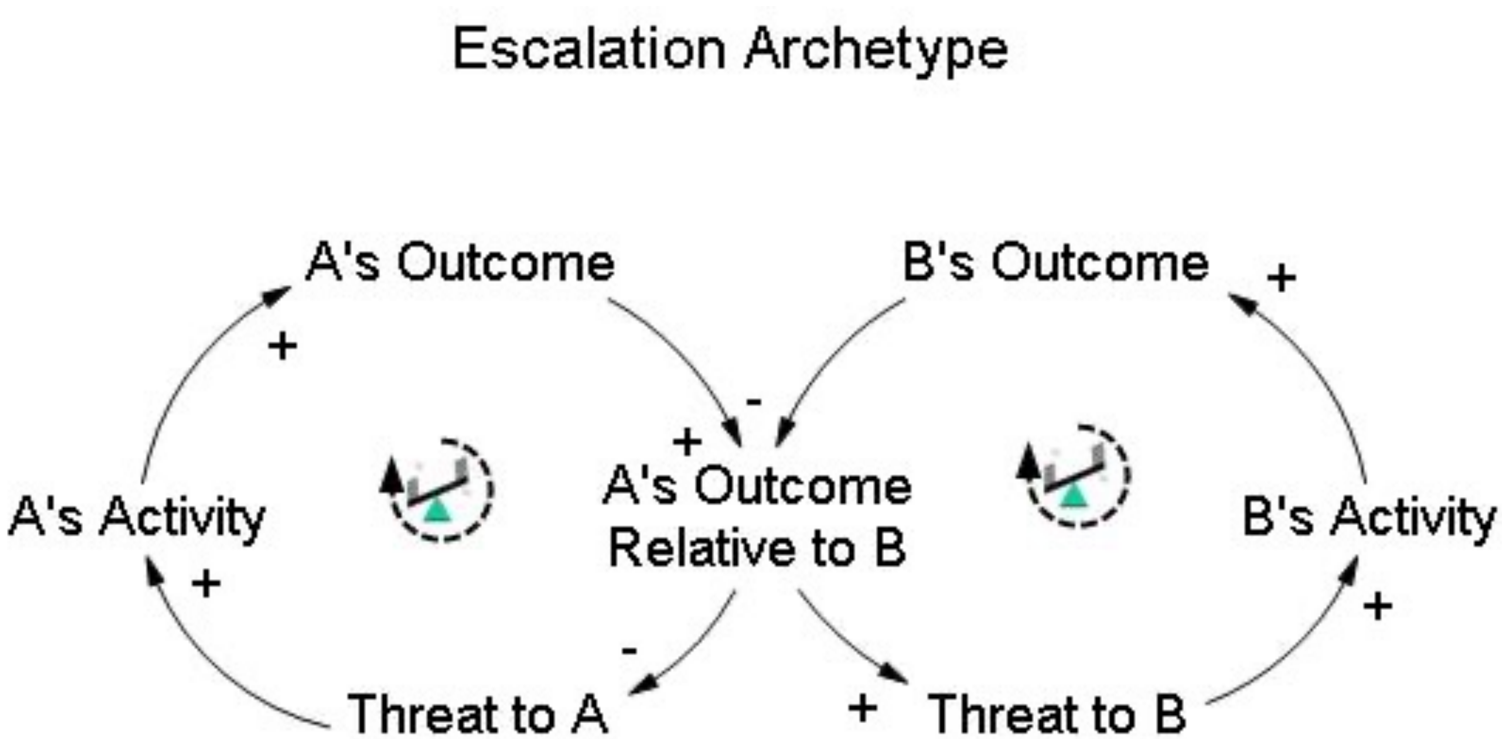
- Limits may constraint growth or progress
- Limits may be reduced or increased; if not static or fixed

Approaches to Raising the Limit

- These approaches are based on a sales model for specificity
  - Increase sales to same type of customer by varying the price
  - Sell the same products to new customers
  - Develop and sell new products / services
  - Change the delivery system or approach
  - Expand into new territories or geographies
  - Change the industry structure (M&A)
  - Look outside the industry for opportunities

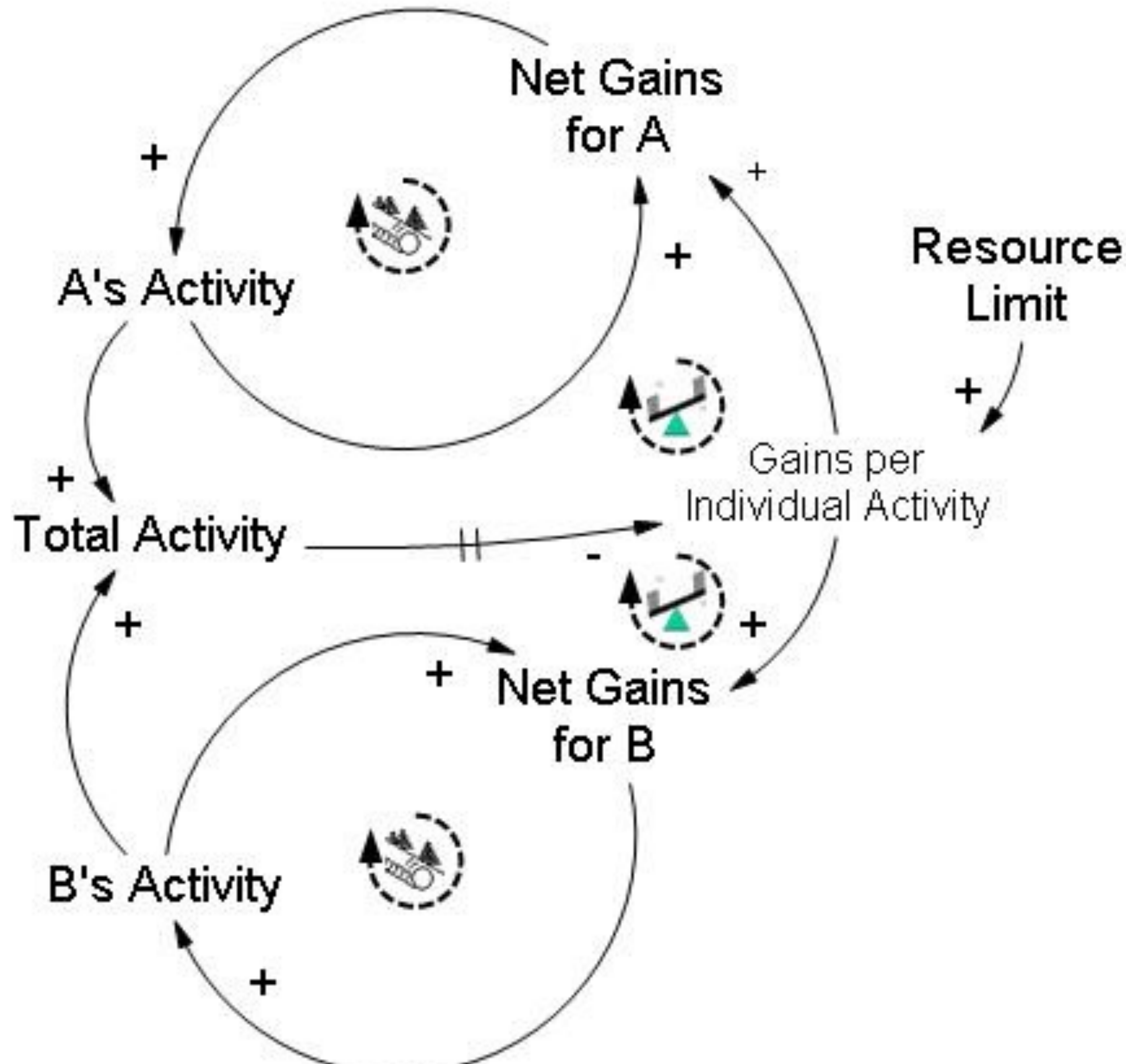
Baghai, M., Coley, S., & White, D. (1999). *The alchemy of growth*. Reading, MA: Perseus.

Escalation Archetype



This archetype is about competition between parties. Examples: Two countries, companies, people (spouses, employees, children, …), ….

Tragedy of the Commons Archetype
Developed in MapSys
Source: Peter Senge's Fifth Discipline



Systems Dynamics

Definitions

- Stock
  - Stocks are the foundation of any system (including organizations).
  - Stocks are the elements of the system (organization) that you can see feel, count, or measure at any given time.
    - Source: Meadows (2008)
  - Stocks are resources: material, energy, messages (information +) (MEM)
  - Stocks are nouns and accumulate over time based on inflows or outflows (verbs)
  - Think of stocks as **resources**

Definitions

- Inflow
  - An inflow is a flow of material, energy, messages (information +) (MEM) into a stock
  - Inflows can be measured (e.g., dollars / week, tons of CO2 / year, calories consumed / day, ..
  - Inflows may be linear or nonlinear
- Outflow
  - An outflow is a flow of MEM from a stock
  - Outflows can be measured (e.g., calories burned / day, gallons of gasoline burned / week, packets processed, instructions processed ….
  - Outflows may be linear or nonlinear

Notes

- MEM is material, energy, messages (information +)
- One or more MEM is input to a system (e.g., organization), through a system (e.g., organization) along system’s (e g., organizational) networks from stock to stock; agent to agent, agent to stock; stock to agent and output from a system (e.g., organization)

Throughput

- The amount of material, energy, and messages (information +) processed or manufactured for output delivered in a period of time.
- Sometimes referred to as the flow rate
- For example:
  - A company may process or manufacture 100 units per month.
  - Boeing may manufacture 1000 airplanes per year.
  - A university may graduate 250 PhDs per year
  - A software company may sell 50 apps per month
  - A router may process 1 million packets per second

Throughput

- Throughput is the number of manufactured units per period of time.
- Throughput may vary from time period to time period.
- May want to calculate the average rate over a longer period of time.
- Capacity is the maximum sustainable flow rate. In periods of heavy congestion, throughput is equal to capacity.

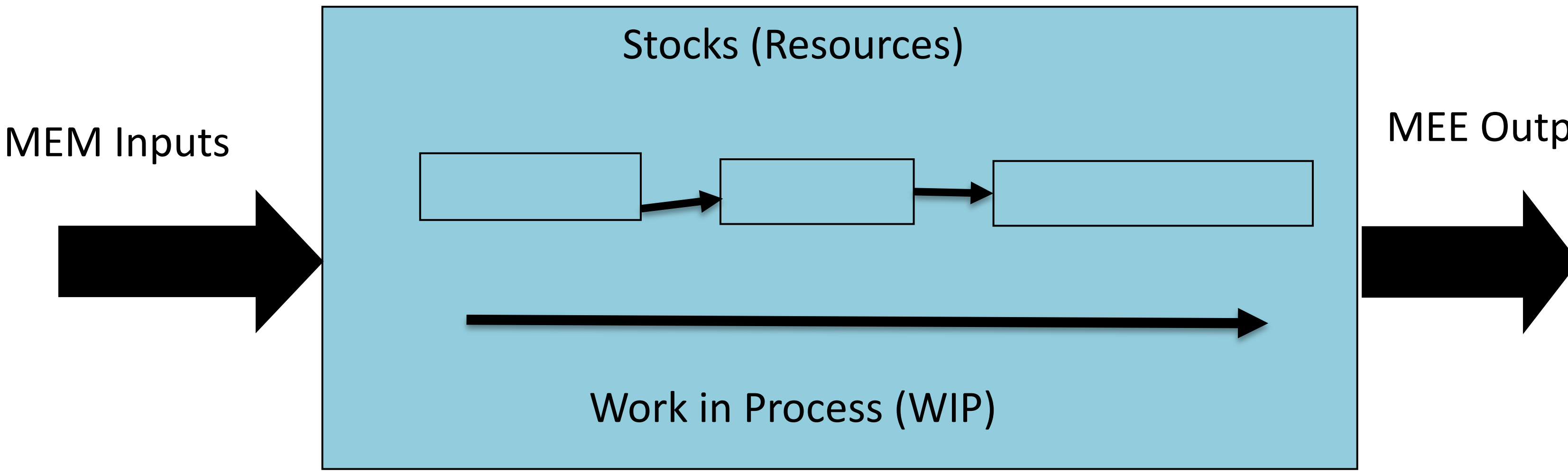
Cycle Time

- Cycle Time is defined in terms of Capacity.
- Examples:
  – Cycle time = 1/Capacity
  – If Capacity = 10 units /hour, then Cycle Time = 1/10 hour or 6 minutes.
- Throughput is typically less than Capacity given a maximum rate is not sustainable.

Input / Output Model

A generic input / output or birth / death model.
Easy to enhance and expand.

Any Production System
(Processing MEM)



Input = Output [– defects] (1st Law of Factory Physics)

Idle time - % of time a resource is not working

Throughput – the average number of manufactured or processed MEM units per unit of time

Lead time –time needed to process a component of MEM

Little's Law

Little's Law:
WIP = (Throughput) x (Lead Time)

- Little's Law is a fundamental law of system dynamics
- Gives good results for a variety of scenarios
- *Throughput* (Units/time).

Example: A facility can produce 250 units / month, and the average lead time is 3 months. According to Little's law the average WIP = 250 x 3 = 750 units.

Examples of Stocks

- Savings account / credit card account
- National debt
- Inventory
- Stock / bonds owned
- CO_2, water vapor, methane, … in the atmosphere
- People in an aircraft, hotel, cruise ship
- Population (people, ants, fish, cows, elephants, ..)
- Ice in a glacier
- Marine life in Glacier Bay
- Trees in a forest
- Apples in an orchard
- Employees in an organization
- Students in class
- Laptops in an organization

Stocks are resources of MEM

Definitions

- Feedback loops
  - A feedback loop is a closed chain of causal connections from a **stock**, through a set of decisions or rules or physical laws or action that are **dependent** on the *level* of the **stock**, and back again through a flow to change the **stock**.
    - Source: Meadows (2008)

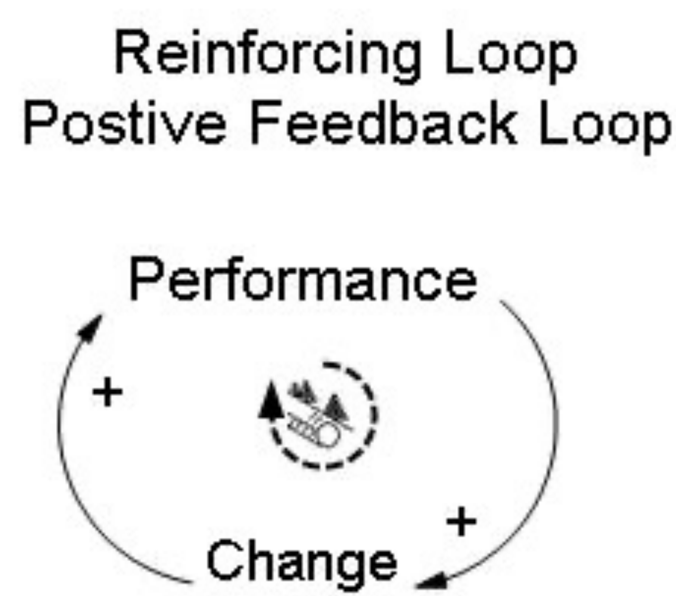
Definitions

- Positive feedback loop
  - A positive feedback loop is an amplifying, reinforcing, or self-multiplying snowballing loop that may cause either growth (**virtuous**) or destruction (**vicious**) of the **stock**.
    - Source: Meadows (2008)
- Negative feedback loop
  - A negative feedback loop is a balancing, stabilizing, regulating, or goal-seeking feedback loop of the **stock**.
    - Source: Meadows (2008)

Positive Feedback Loop
Causal Loop Diagram

A positive feedback loop is also called a reinforcing or amplifying loop and is designated with an R or a growing snowball

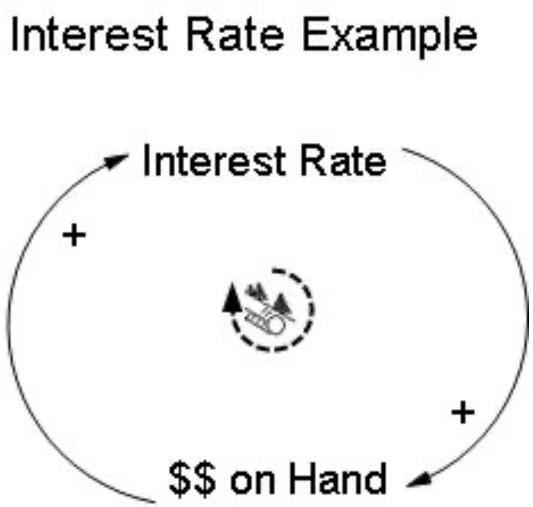
The behavior of a positive feedback loop is the growth / decline of the systems state.



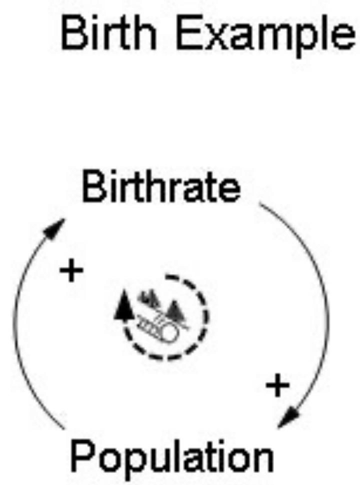
Positive Feedback Loop

Causal Loop Diagrams

Example of a positive feedback loop in economics

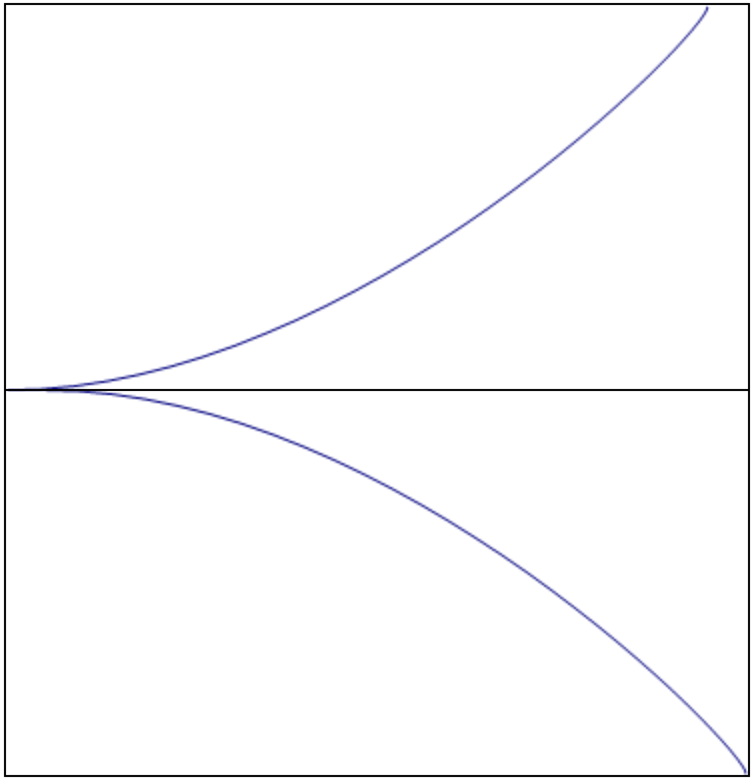


Example of a positive feedback loop in populations



Note: The state of the system will continue to grow or decline unless some intervention occurs.

Positive Feedback – Behavior Over Time



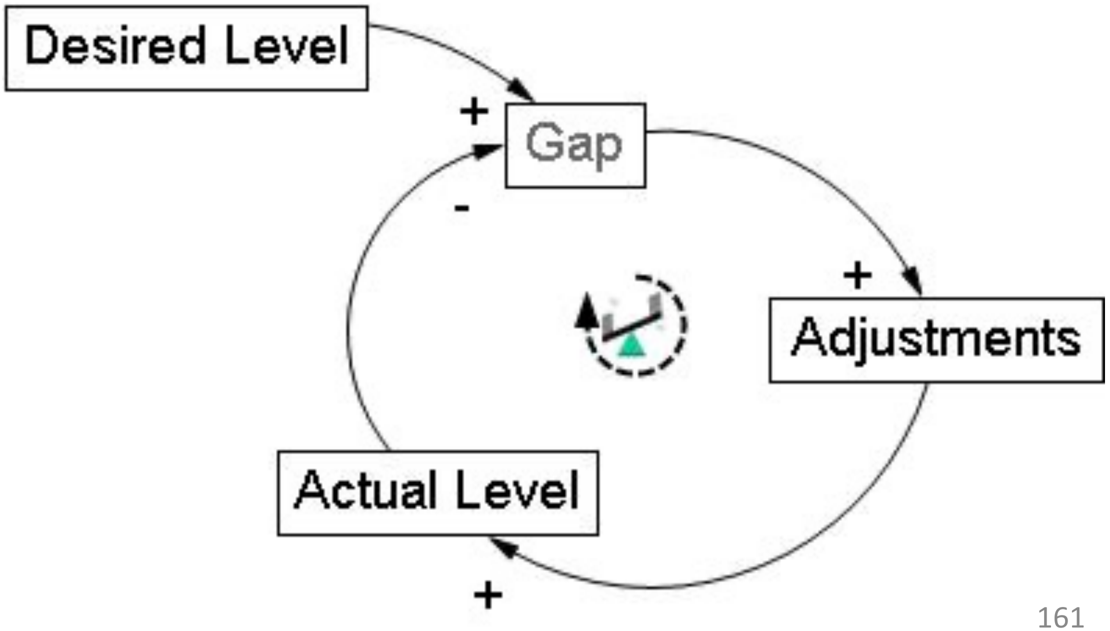
Virtuous Cycle (Exponential Growth)

Vicious Cycle (Destruction)

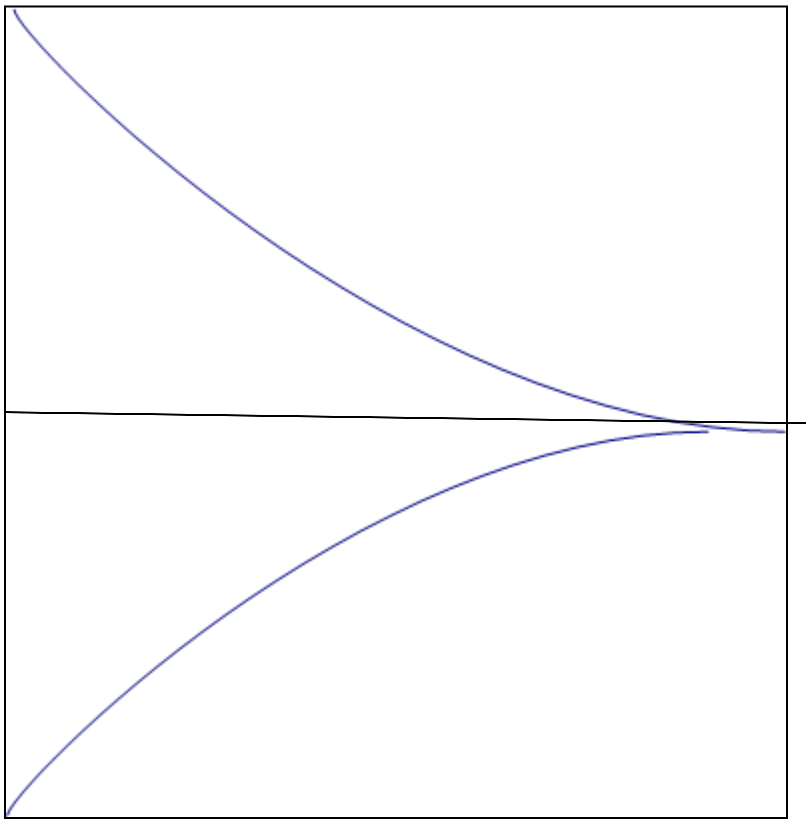
Negative Feedback Loop
Causal Loop Diagram

Negative feedback or a balancing loop is a goal seeking behavior or systems regulation behavior. A generic model is provided below.

Think in terms of the desired level of some MIE stock: parts, staffing, money, energy, …



Negative Feedback – Behavior Over Time



Goal Seeking—from any direction. Behavior may oscillate around the goal until settling down

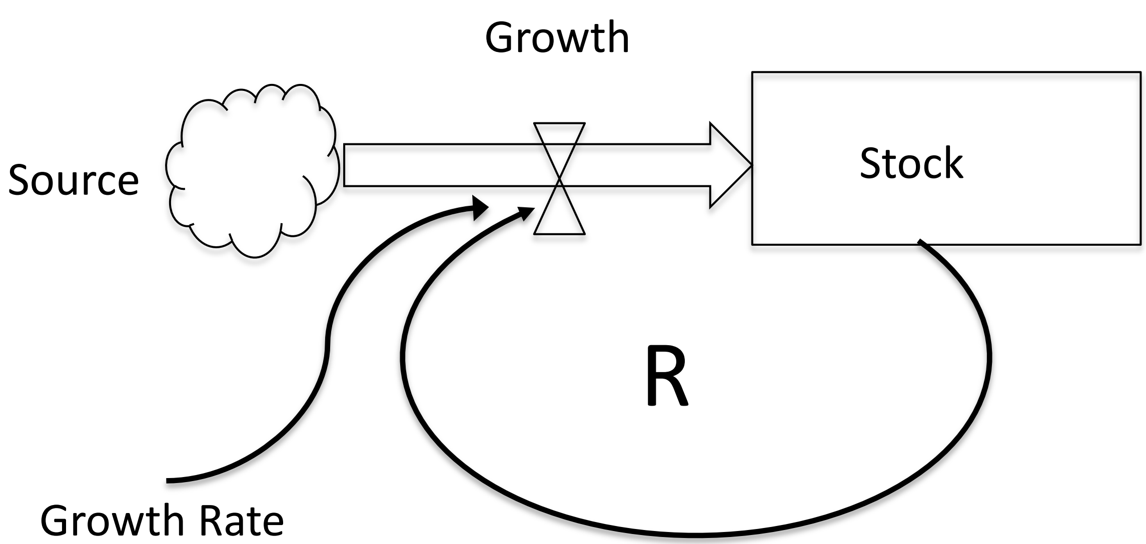
Examples

Positive Feedback Loop

- Banking
  - Stock as a Savings Account $$$$$
  - Inflows as (a) monthly deposit, and (b) earned interest.
  - Outflow as a withdrawal as needed
  - A positive feedback loop (virtuous) exists as part of the **stock** (earned interest) inflows monthly into the **stock**. The larger the **stock**, the more earned interest.

Positive Feedback Loop

Generic Stock and Flow Diagram



This example of a positive loop illustrates several elements. First, a source illustrated by the cloud, second a stock or accumulator, and third a rate of two inflows—governed by the growth rate and size of the stock. Even if the growth rate stays constant, the size of the stock can alter the amount of growth.

Examples

Negative Feedback Loop

- Inventory (MEM could be people, products, money, energy ..)
  - Inventory (some desired level)
  - Inflow as new inventory elements
  - Outflow as a withdrawal as needed
  - A negative feedback loop exists if there is a desire to maintain a **stock** (inventory, in this case). If inventory becomes greater than the desired level, new input is stopped until the inventory drops to the desired level. If inventory becomes less than the desired level, new input is requested to build inventory

Negative Feedback Loop Examples

- Taking the inventory model, we can replace inventory with more specific examples
- Inventory as …
  - Parts
  - People levels (engineers, faculty, students, …)
  - Seats (airplanes, cruise ships, trains, …)
  - Money (a stable amount)
  - Energy (maintain at least a 50% change of laptop batteries)

- In each case, there is a defined goal for the stock

Negative Feedback Loop Examples

- A thermostat system
  - Stock: The amount of heat in the room
  - Set the desired temperature (a goal)
  - The loop: heating / cooling starts until the desired temperature is reached and then stops. If the temperature changes, heating or cooling is activated again!
- Budgeting
  - Allocate a certain amount of MEM for something and stay within it over time (a goal)

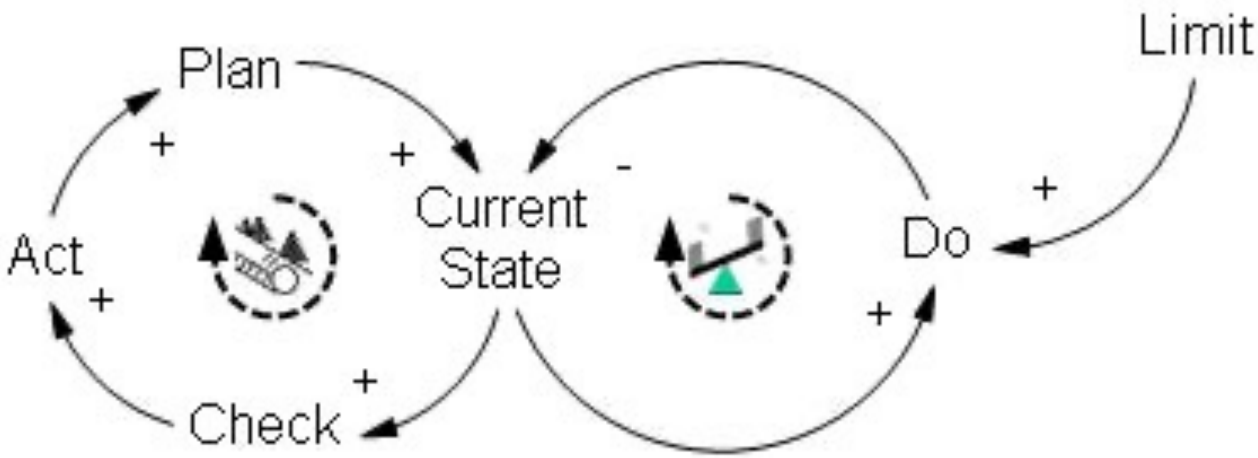
Negative Feedback Example

- Employment
  - Stock: employees
  - Goal: 10,000 employees
  - Inflows: new hires
  - Outflows: retirements, deaths, transfers, other attritions
  - Negative feedback loop: When the number of employees drops below a certain desirable point, say 9,500, the organization decides to hire more employees to maintain the 10,000 needed to do the work.

Notes

- Not all inflows or outflows make up feedback loops; that is, some inflows or outflows are not dependent on the size of the **STOCK**. For example, filling a bathtub is only dependent on the rate of inflow and any outflow if present. Adding more CO_2 to the atmosphere is independent of the size of the **stock** of CO_2 already in the atmosphere. This is an example of linear inflow and outflow.
- Not all positive feedbacks are good forever, may need to be tempered with a negative feedback loop at some point.

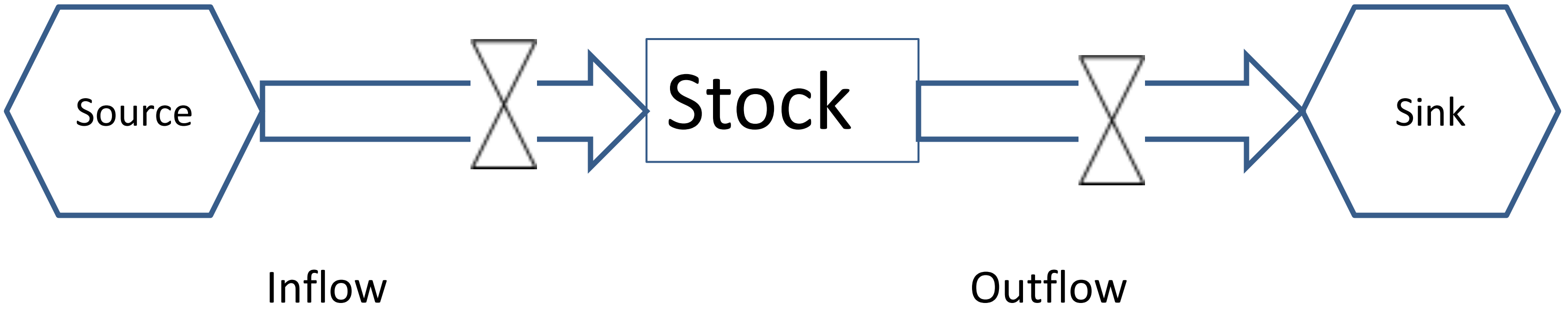
PCDA – Limits To Success Model



There are limits to improvement such as the laws of physics, investment capital, time, mental models, interest ….

Stock and Flow Diagram

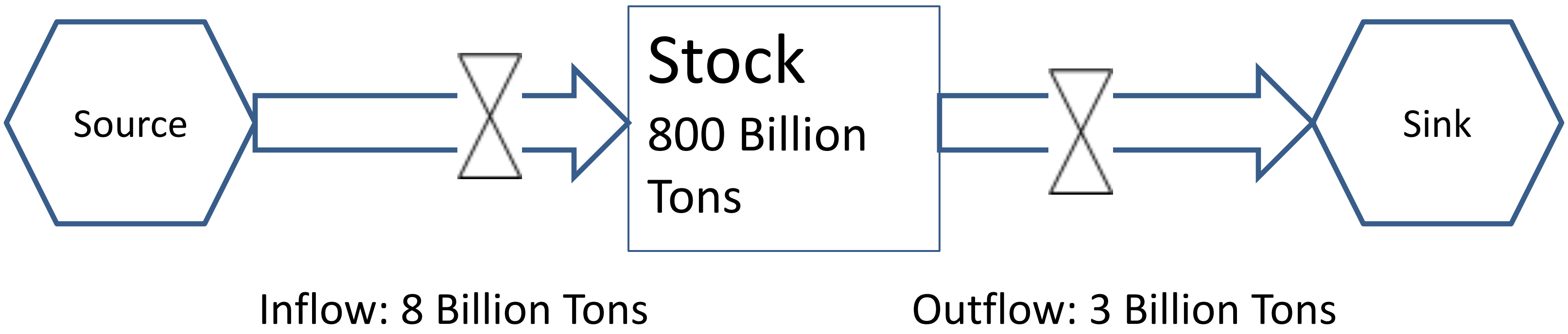
Birth Death Template



Source: John Sterman, *Business Dynamics.*

Stock and Flow Diagram

Atmospheric CO_2



Currently the level of CO2 is 35% higher than anytime in the past half million years.

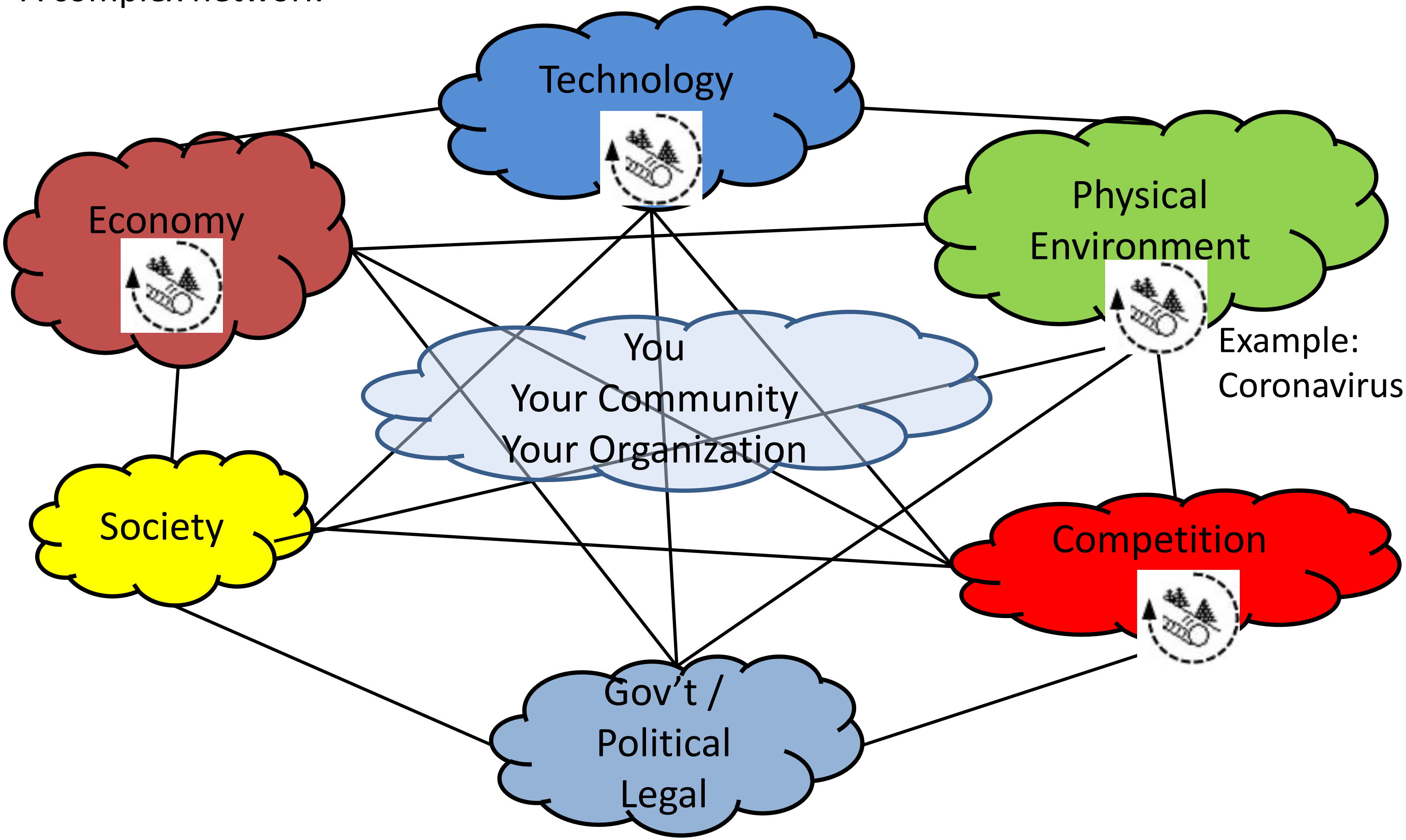
The increase of CO2 has been exponential during the industrial age

Source: Peter Senge, The Next Industrial Imperative, *Strategy+Business*

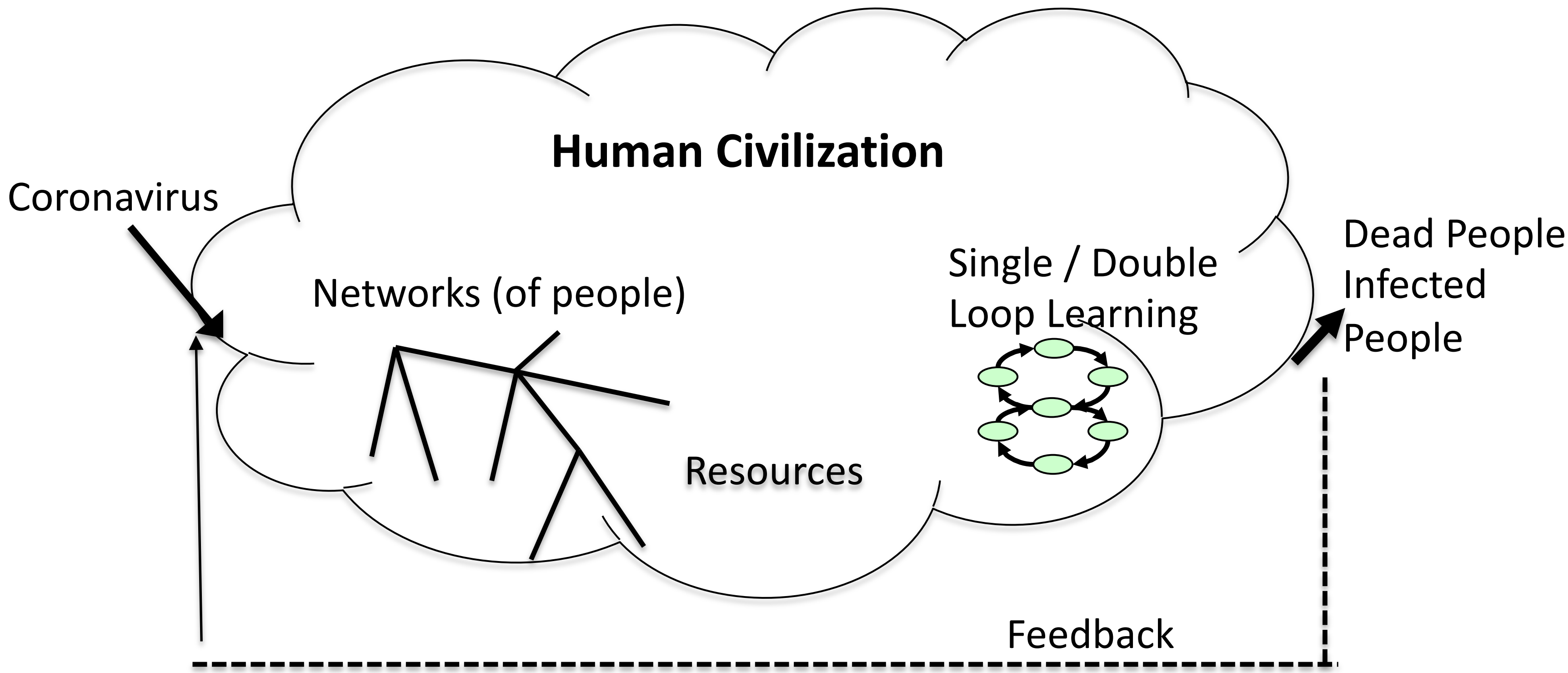
Organizations

The Environment (for Social Systems)

A complex network



Viral Pandemic Systems Model



Things to look for: Patterns such as limits to growth (spread), fixes that fail, and success to the successful; tipping points or thresholds; resources to fight back (history, current knowledge; distributed intelligence; research methods); learning approaches (single / double loop learning); complex systems theory; physical and social technologies; approaches to adaptation and mitigation; and so on. Easy to expand or simplify this model.

Coronavirus is a Complex Adaptive System

- Covid-19 is **not only a health crisis**, it is **also an organizational and systemic crisis.**
- It shows the **weaknesses** that we “afford” ourselves too often regarding how we manage our society and organizations.
  - Source: Jessica Flack and Melanie Mitchell

myCoffeeShop

- myCoffeeShop is a small organization with three people, a barista, an order taker, and an order server.
- The barista has various administrative duties in addition to making tasty coffee drinks

myCoffeeShop Systems Model

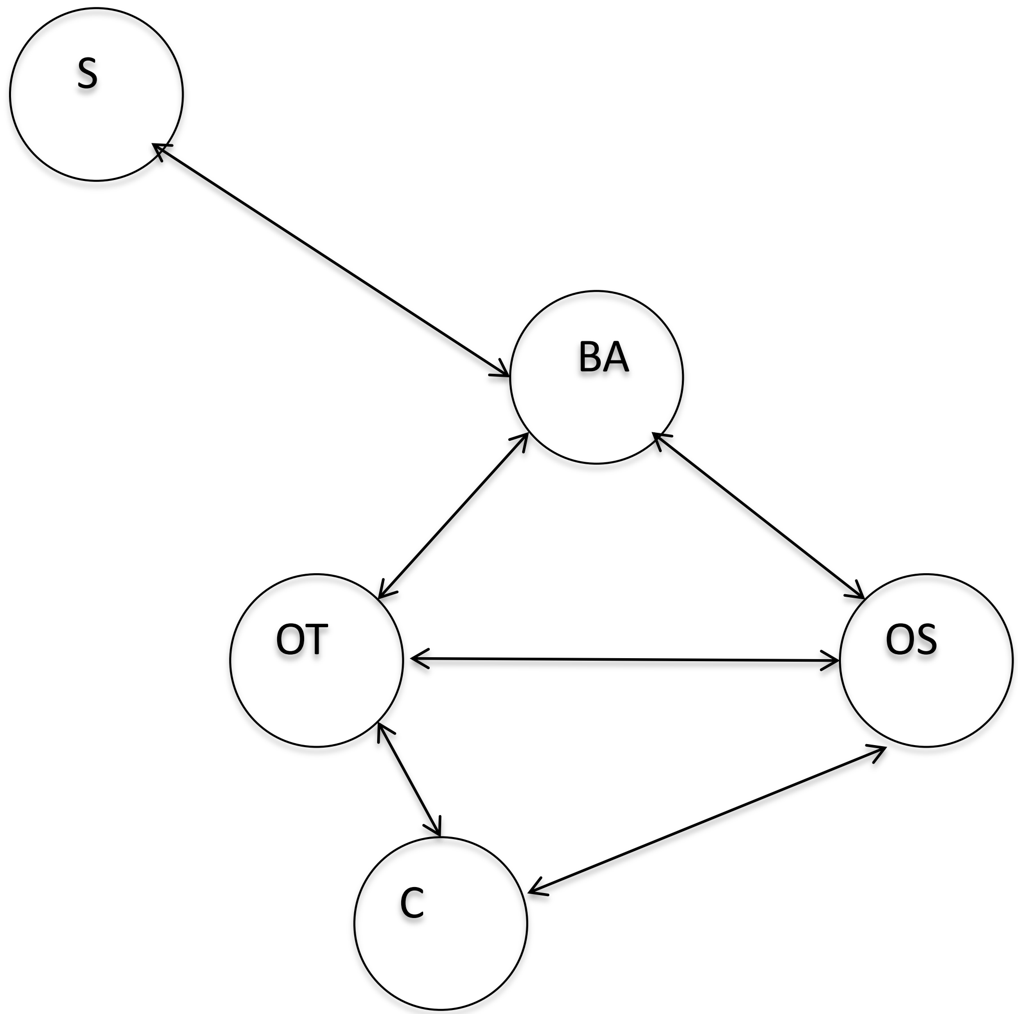
Messages (money, customer preferences, recipes, …)
Material (coffee beans, milk, flavorings, cups, spoons, water, paper, …)
Energy (electricity, natural gas, …..)

Thresholds (bankruptcy, acquisition, …)

Messages (income, expenses, …)
Material (coffee, pastries, napkins, trash, ..)
Energy (waste heat, …..)

myCoffeeShop Network

Network Structure



myCoffeeShop Network

- Notation:
  - The double arrow indicates a bidirectional relationship.
  - S indicates a supplier
  - BA indicates a barista
  - OT indicates an order taker
  - OS indicates an order server
  - C indicates a customer
- Numbers
  - There may be more than one of each Supplier or Customer agent

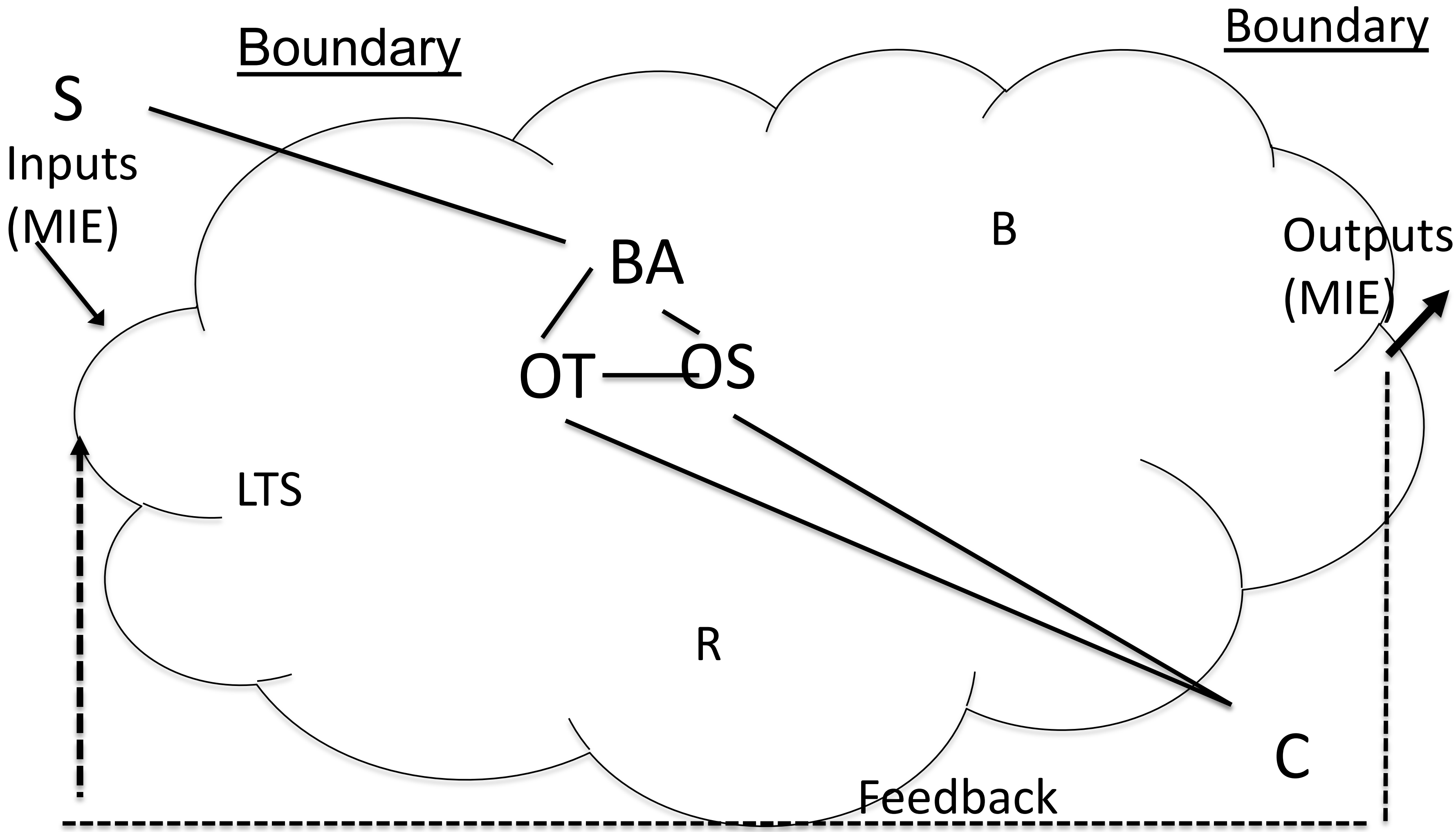
myCoffeeShop Network

- Relationships (examples)
  - S to BA: supplier(s) provide materials, energy, or information to the barista, who responds with information (acceptance, money), materials (returns, ….)
  - C to OT: customers order materials (beverages) from the OT, who in turn takes information (money) and provides information (acknowledgement).
  - OT to OS: exchange information for clarity … as needed
  - OT to C: order servers deliver materials (beverages) and information (thank you) to customers, who in turn provide information (acknowledgement)

myCoffeeShop

- System archetypes
  - Patterns of structures found in systems
  - For example, the limits to success (LTS) or limits to growth archetype can describe a typical lifecycle of an organization, an organization's product lifecycle, or a performance curve among others.
  - Modeling or drawing archetypes without specialized software is difficult, but for the purposes of this course, abbreviations inserted into the systems model such as LTS with text based descriptions elsewhere are acceptable.

myCoffeeShop



myCoffeeShop

- Where networked agents are:
  - C (customer)
  - S (supplier_
  - BA (Barista)
  - OT (order taker)
  - OS (order server)
- Where LTS, B, and R are archetypes or patterns
  - LTS (limits to success)
  - B (balancing loop or negative feedback loop, such as the thermostat)
  - R (reinforcing loop or positive feedback loop, such as word of mouth messaging drives sales growth)
- Where MEM are matter, energy, and messages (information +)

myCoffeeShop Notes

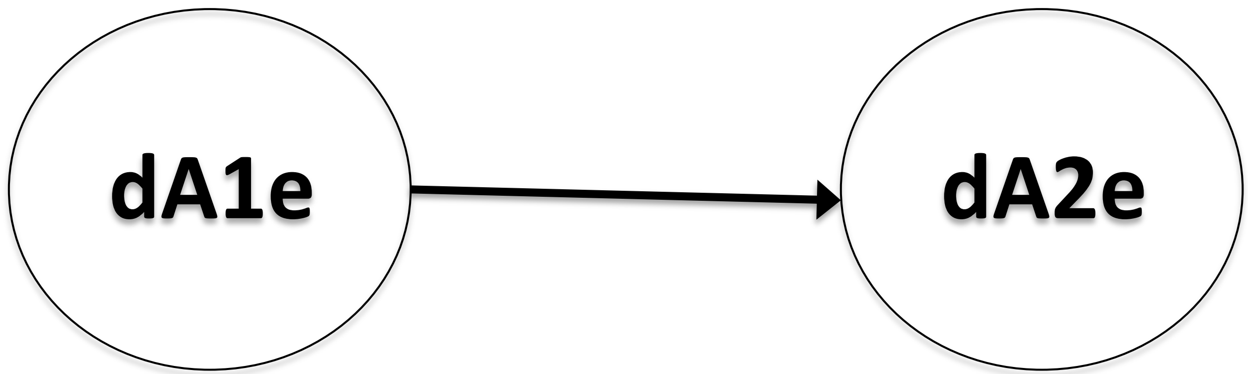
- Agents may have four roles: detection, assessment, processing, and effecting
- Detectors sense environmental stimuli
- Processes transform inputs to outputs (think recipe)
- Effectors express outputs
- Detectors and effectors are capabilities of agents

myCoffeeShop Notes

An agent (A) and a system (S) view are noted above.
The d represents detector and e represents effector.

Detectors sense environmental inputs or stimuli and effectors express outputs to the environment

myCoffeeShop Notes

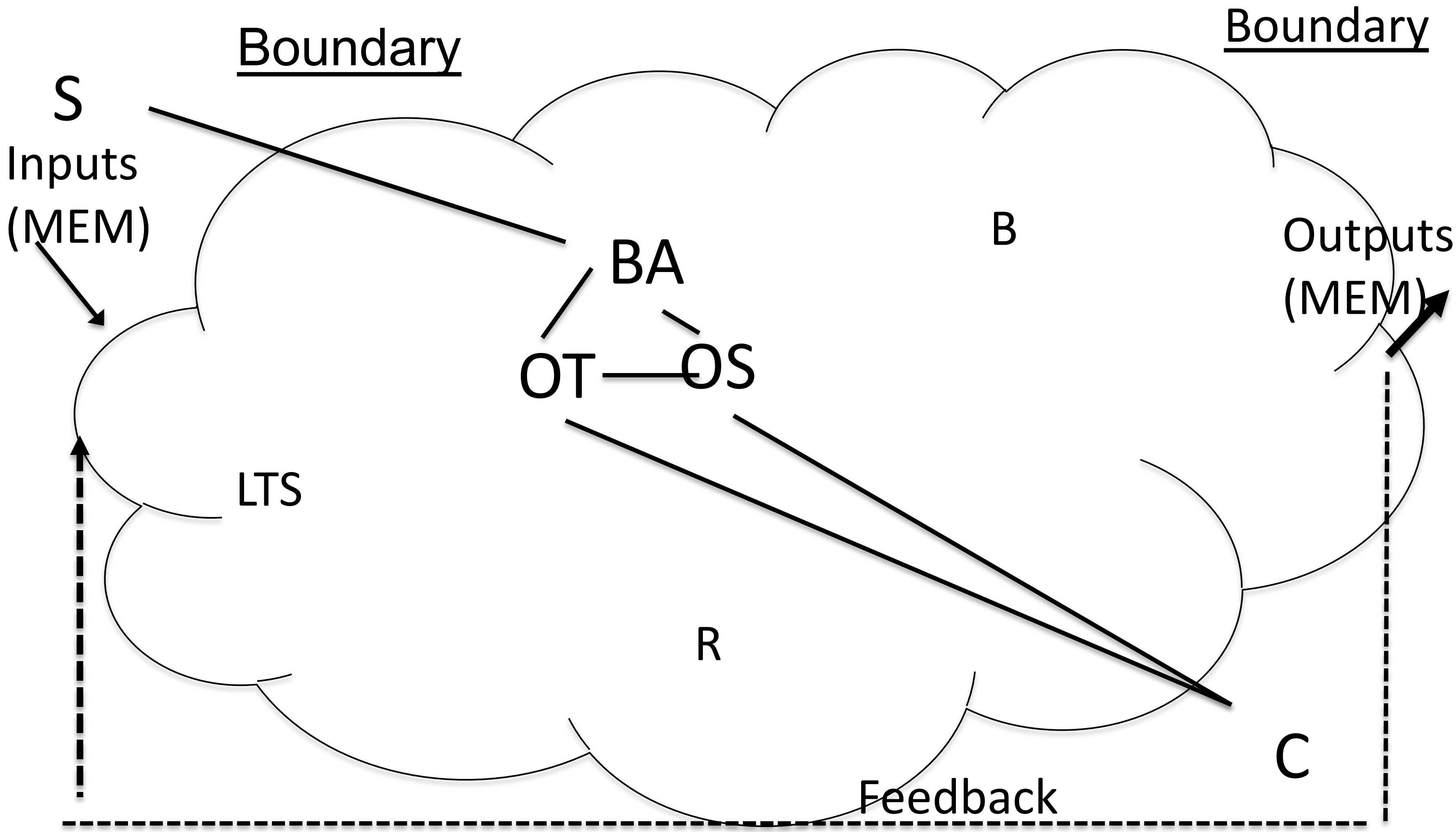


This simple network contains two agents (or systems) A1 and A2. Agent A1 expresses an output across the link or relationship to Agent A2, which detects the output or now, the input or stimulus.

Agent A2 can process the input according to a set of rules the Agent can follow and express an output or outputs across another link.

Each agent is capable of detecting and effecting

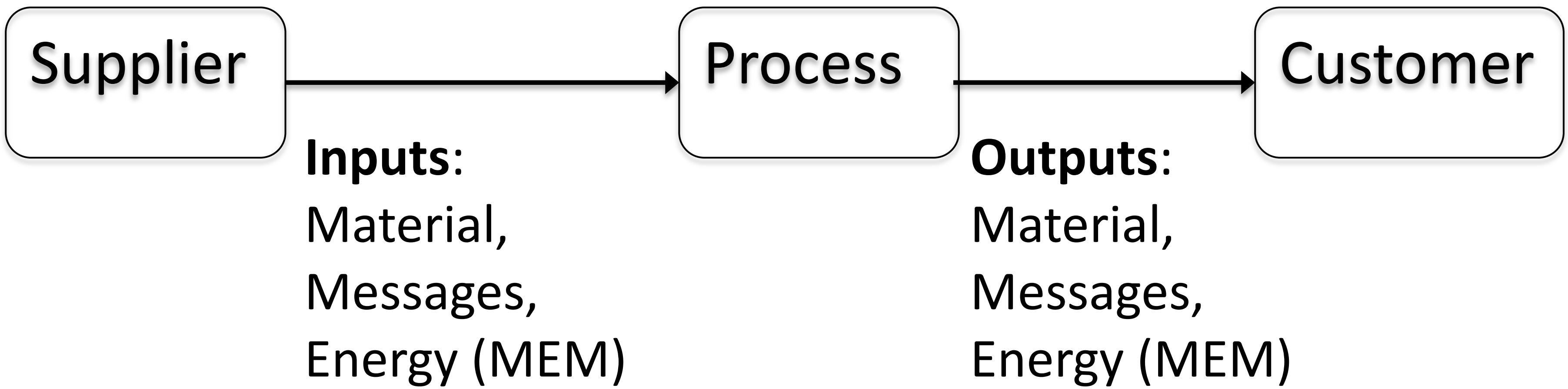
myCoffeeShop



myCoffeeShop

- Where the primary detectors are the barista and the order taker at the system level
- Where the primary effectors are the barista and the order server at the system level
- Where processes (subprocesses) include taking delivery of supplies, payment processing, taking coffee orders, making coffee drinks, serving customers, among many others

Supplier Input Process Output Customer (SIPOC) Model



This model can be used at any level of an organization. The entire organization, division, department, team, or person.

Thoughts on the Future

The ability to learn faster than your competitors may be the only sustainable competitive advantage.

Source: Arei P. De Geus

Thoughts on the Future

Alice - Would you tell me please, which way I ought to go from here?

Cat – That depends a good deal on where you want to get to.

Alice I don't much care where

Cat – Then it doesn't matter which way you go!

-- Lewis Carroll

Thoughts on the Future

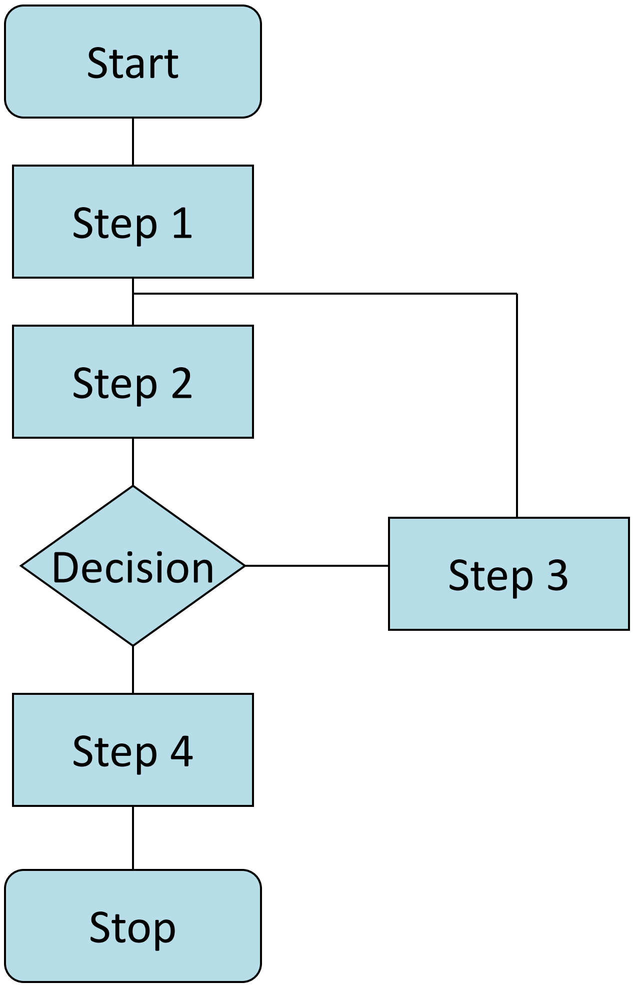
"There is nothing more difficult to take in hand, more perilous to conduct or more uncertain in its success than to take the lead in the introduction of a new order of things."

Niccolo Machiavelli

Business Process

- A process is a means of transforming a set of inputs to a set of outputs.
- A process is a set of steps, from beginning to an end.
- There may be multiple paths through the process
- A process use resources and consumes resources
- A process should have an owner
- A process takes some finite amount of time
- A process has a cost associated with it
- A good process is repeatable
- A process has an executing agent (people, computers, or other automation)
- Processes may be efficient or not, but can be improved
- Processes may be functionally composed of subsystems

Business Process



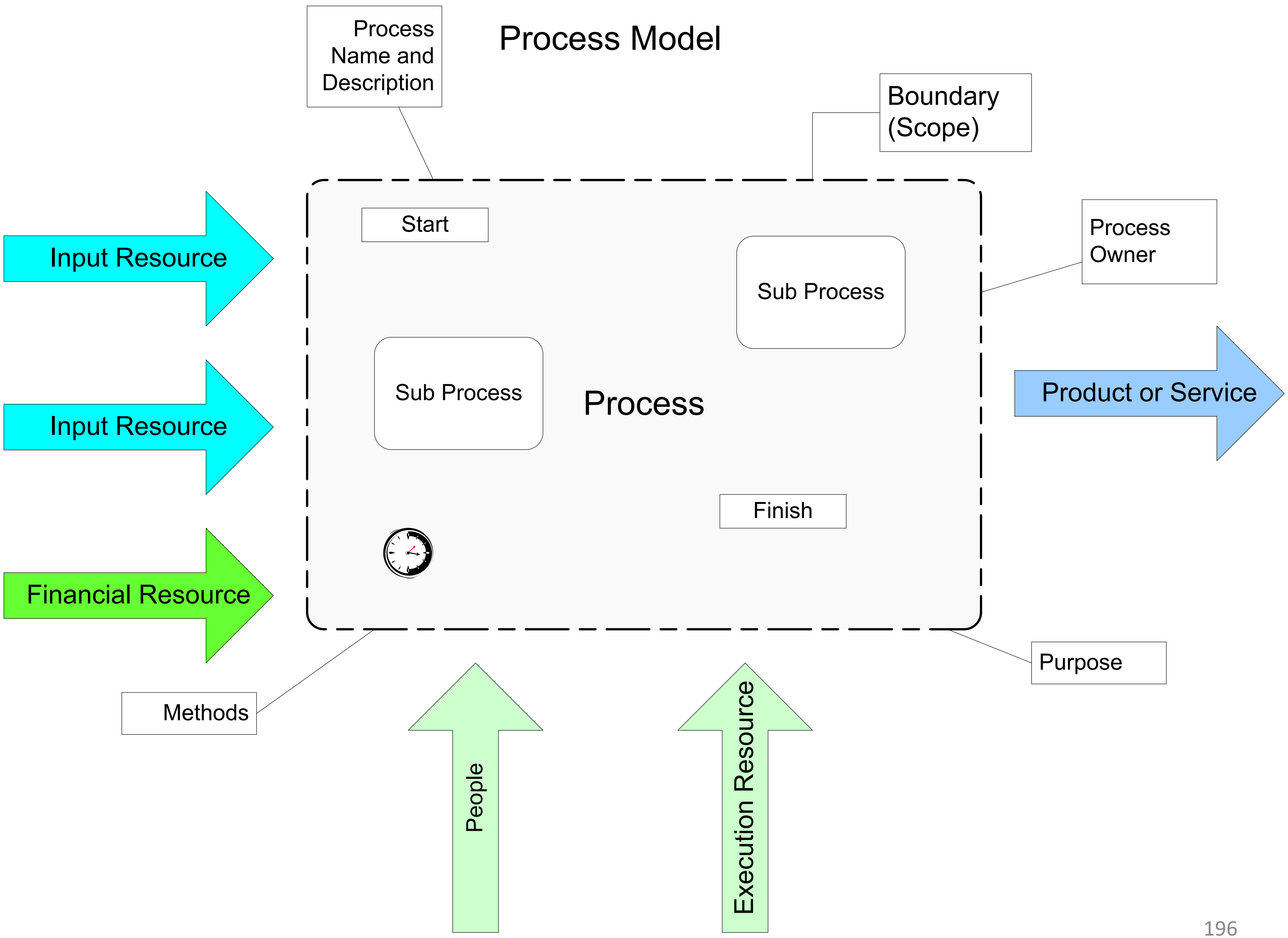
Note: an activity is like a process

Basic logic

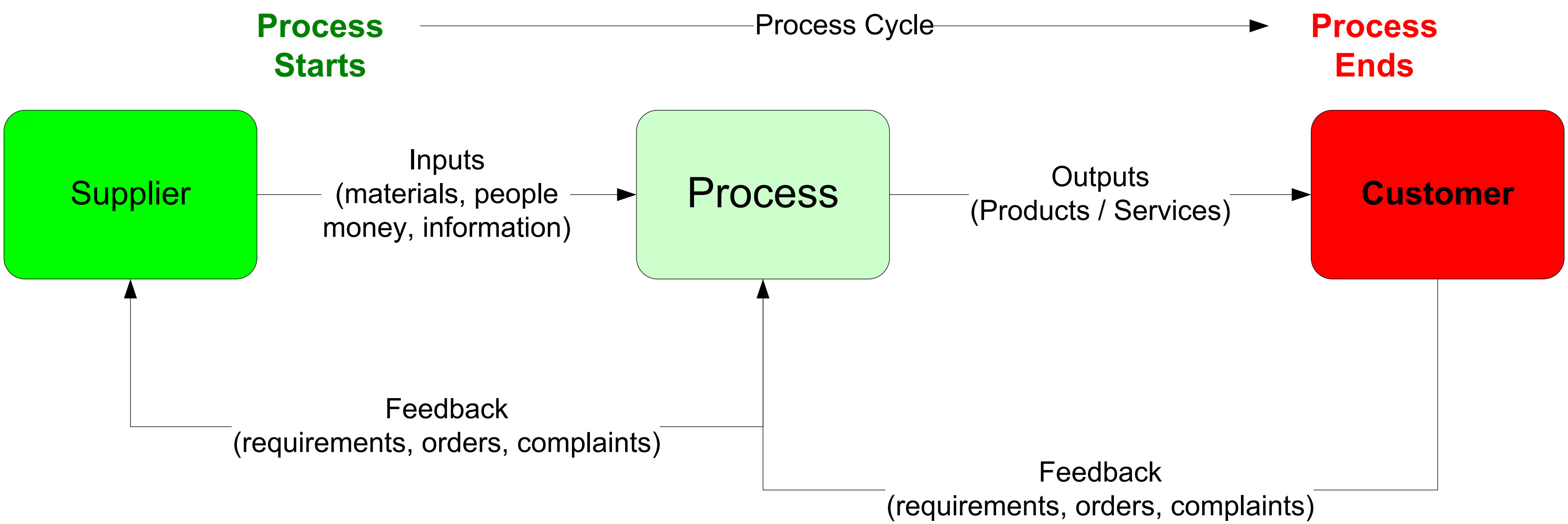
-Transaction

-If Then Else

-Iteration


Process Name and Description
Process Model
Boundary (Scope)
Input Resource
Start
Sub Process
Process Owner
Input Resource
Sub Process
Process
Product or Service
Finish
Financial Resource
Purpose
Methods
People
Execution Resource

SIPOC Model



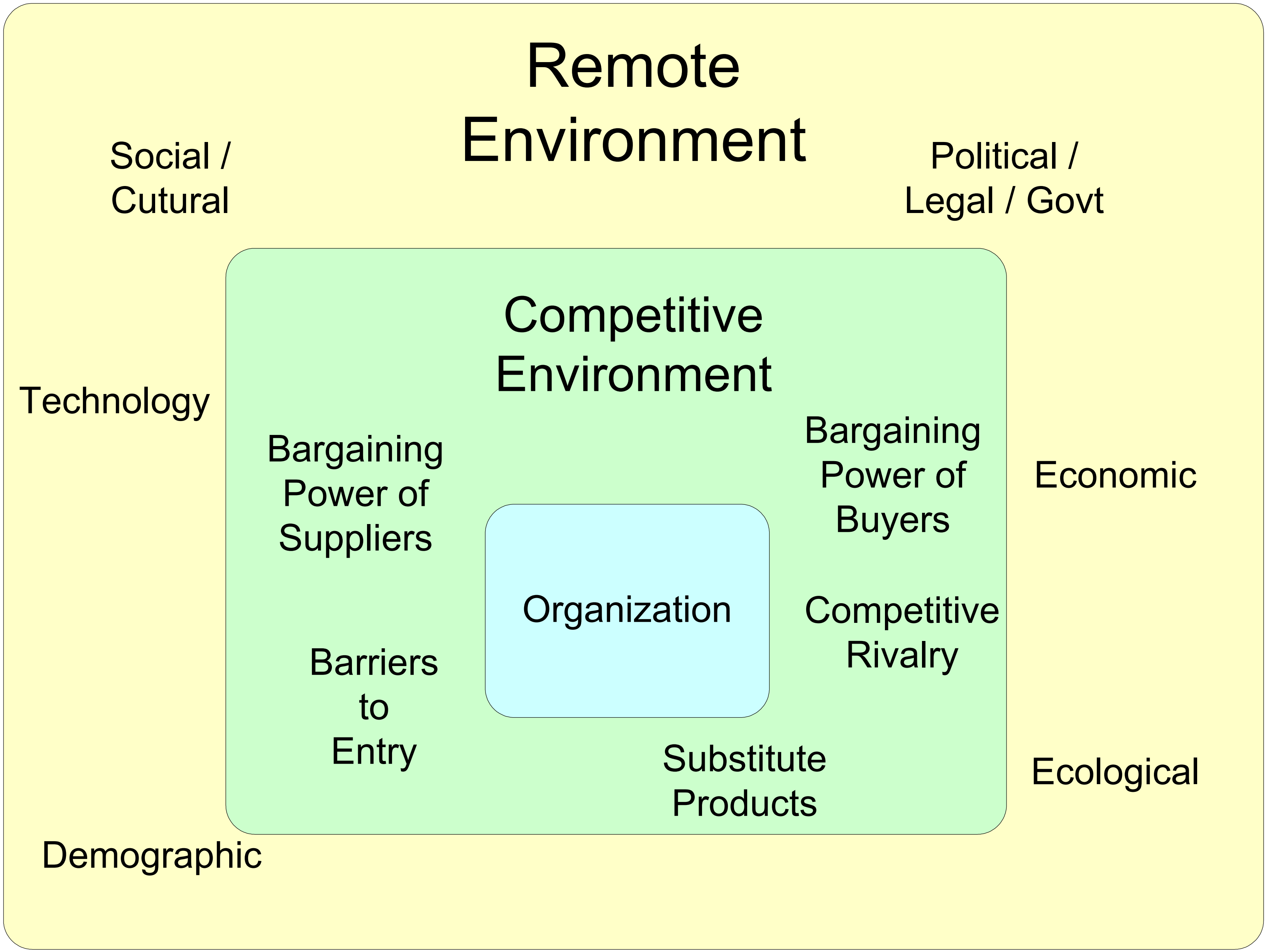
Notes:
Determine measures for improvements- cycle time, customer satisfaction, product quality, waste, service levels, timeliness, accuracy, and so on.

SIPOC Espresso Example

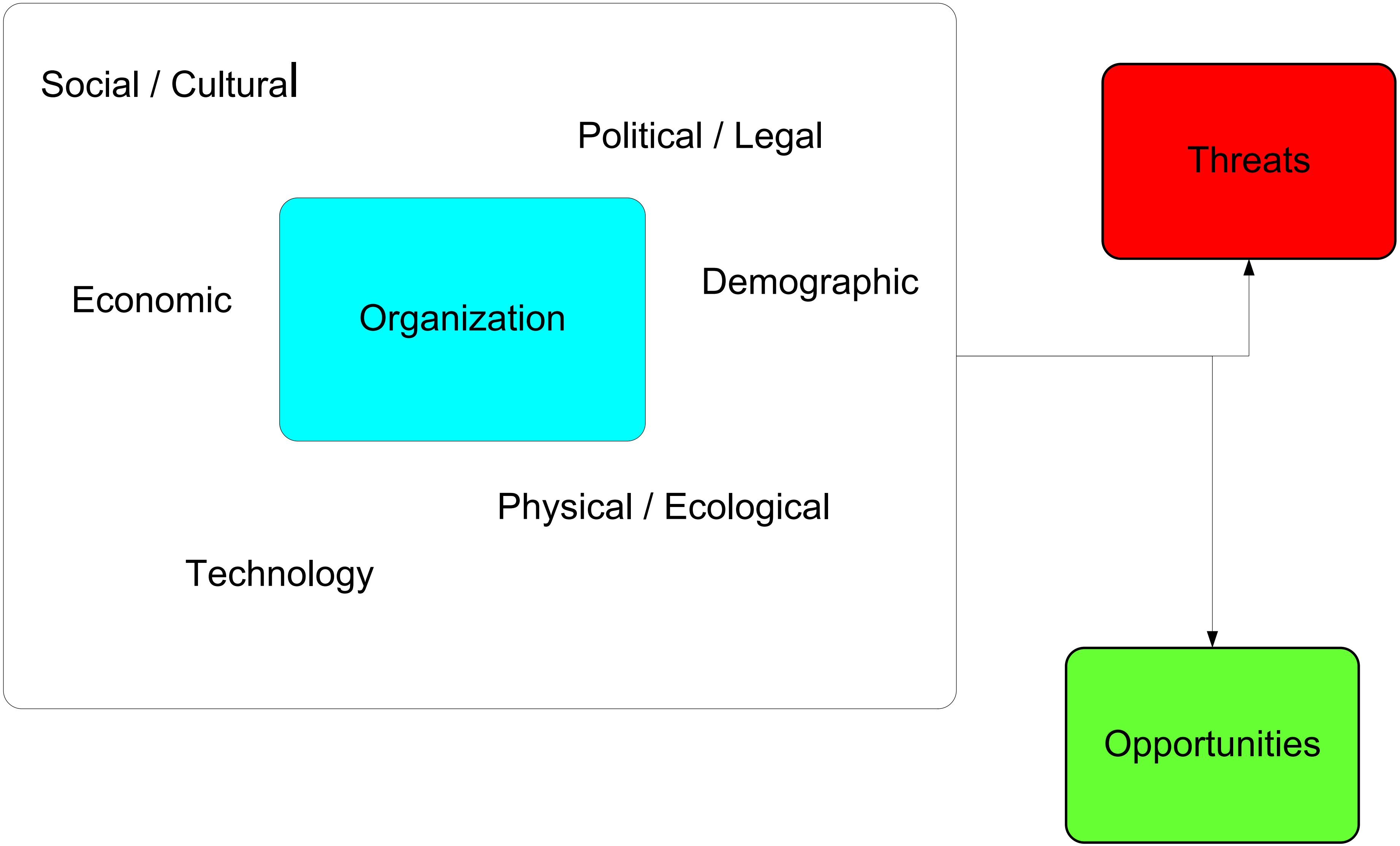
Supplier	Input	Process	Output	Customer
Carnation Paper Cup Supply Coffee Beans Inc	Milk Paper Cups Coffee Beans	Make Espresso	Espresso	Espresso Drinker

Notes: Start with key suppliers, inputs, one process, primary output, and key customers. Sometimes it's easier to work right to left. Then functionally decompose the one process into multiple second level processes and add other suppliers, inputs, outputs, and customers as necessary. Be sure to be able to link supplier, input, process, output, and customer threads. Then continue functionally decomposing processes as needed to construct the model.

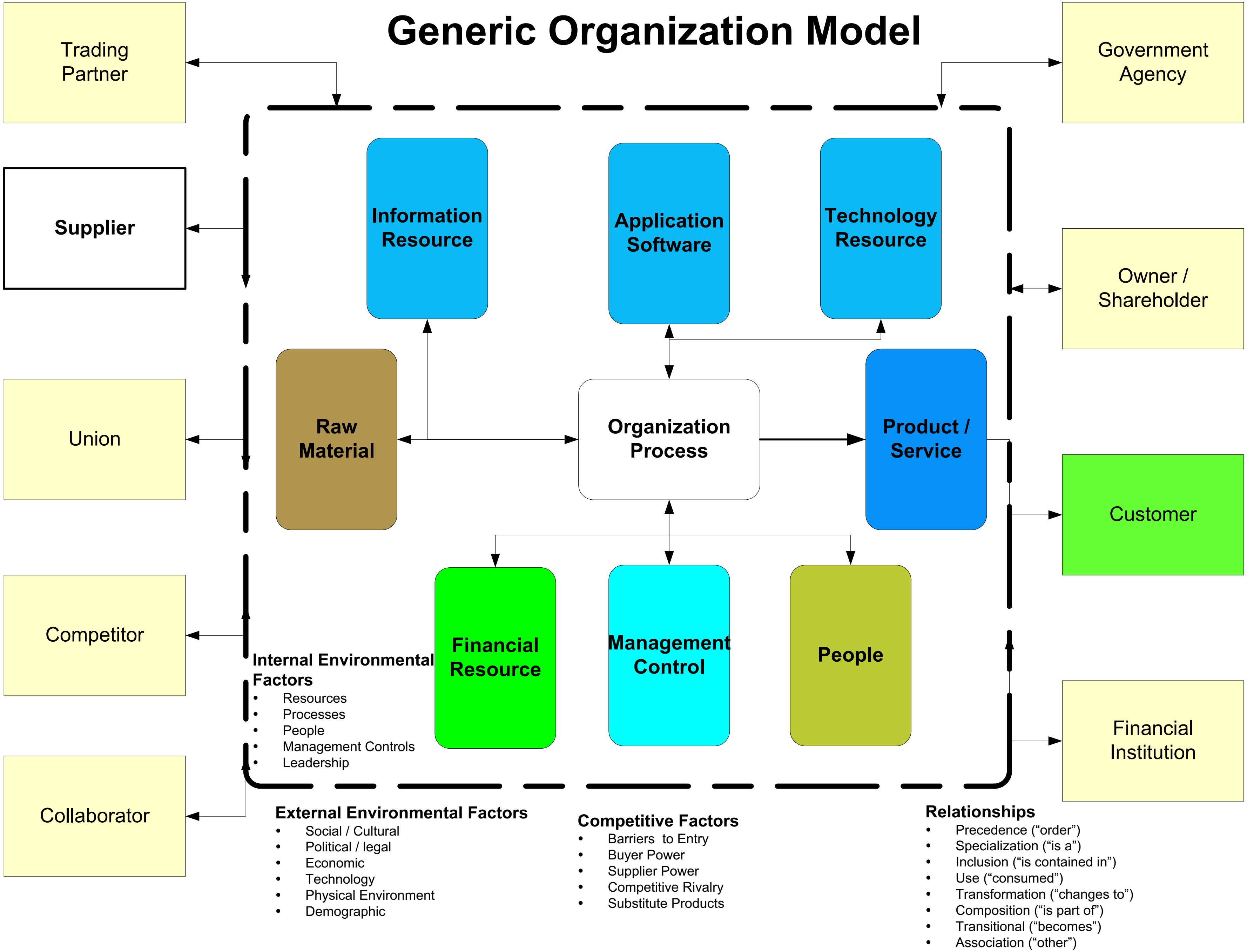
Organizational Environment



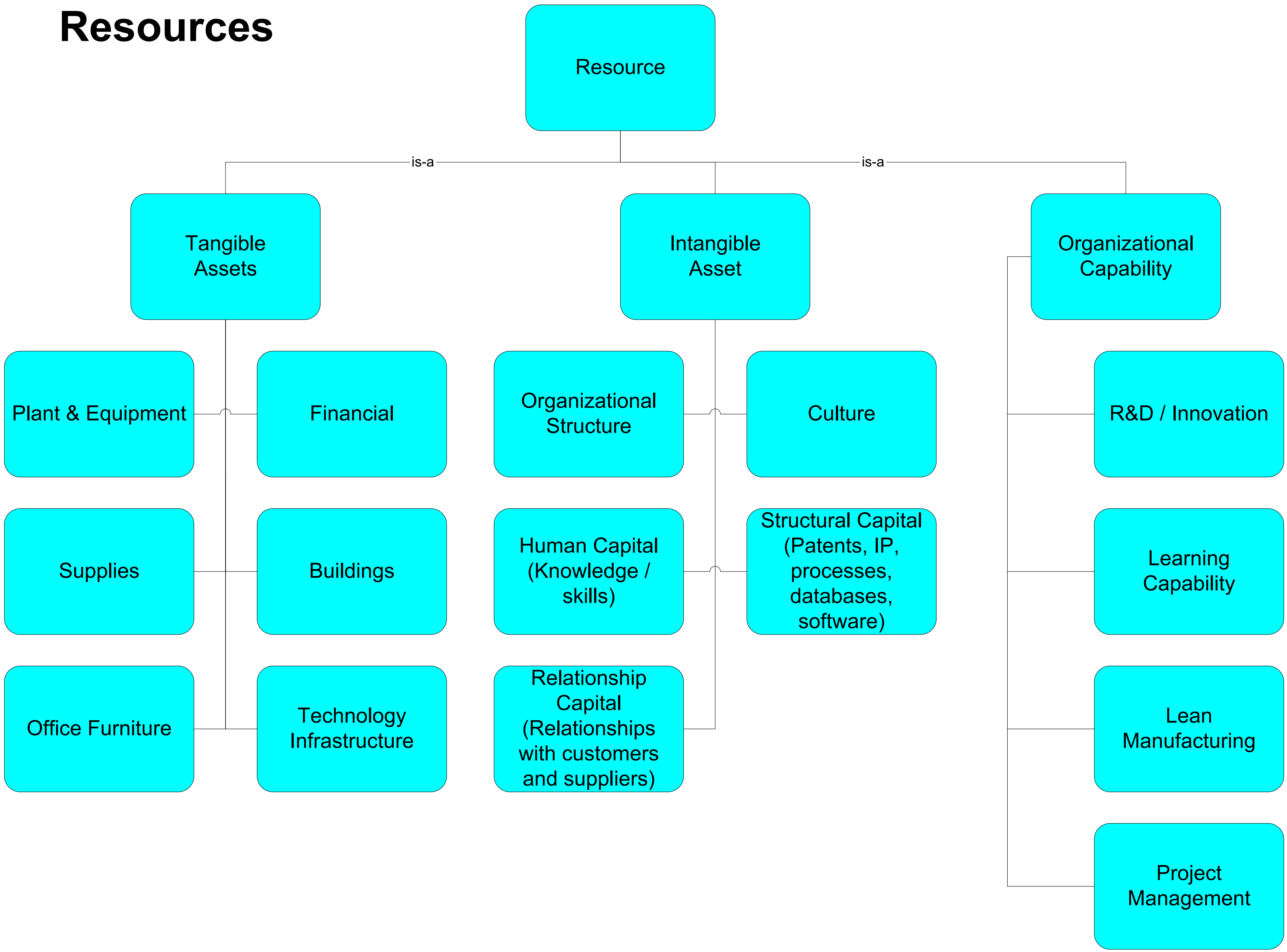
Remote Environment



Generic Organization Model



Resources



Resource
is-a
is-a
Tangible Assets
Intangible Asset
Organizational Capability
Plant & Equipment
Financial
Supplies
Buildings
Office Furniture
Technology Infrastructure
Organizational Structure
Culture
Human Capital (Knowledge / skills)
Structural Capital (Patents, IP, processes, databases, software)
Relationship Capital (Relationships with customers and suppliers)
R&D / Innovation
Learning Capability
Lean Manufacturing
Project Management

SWOT Analysis

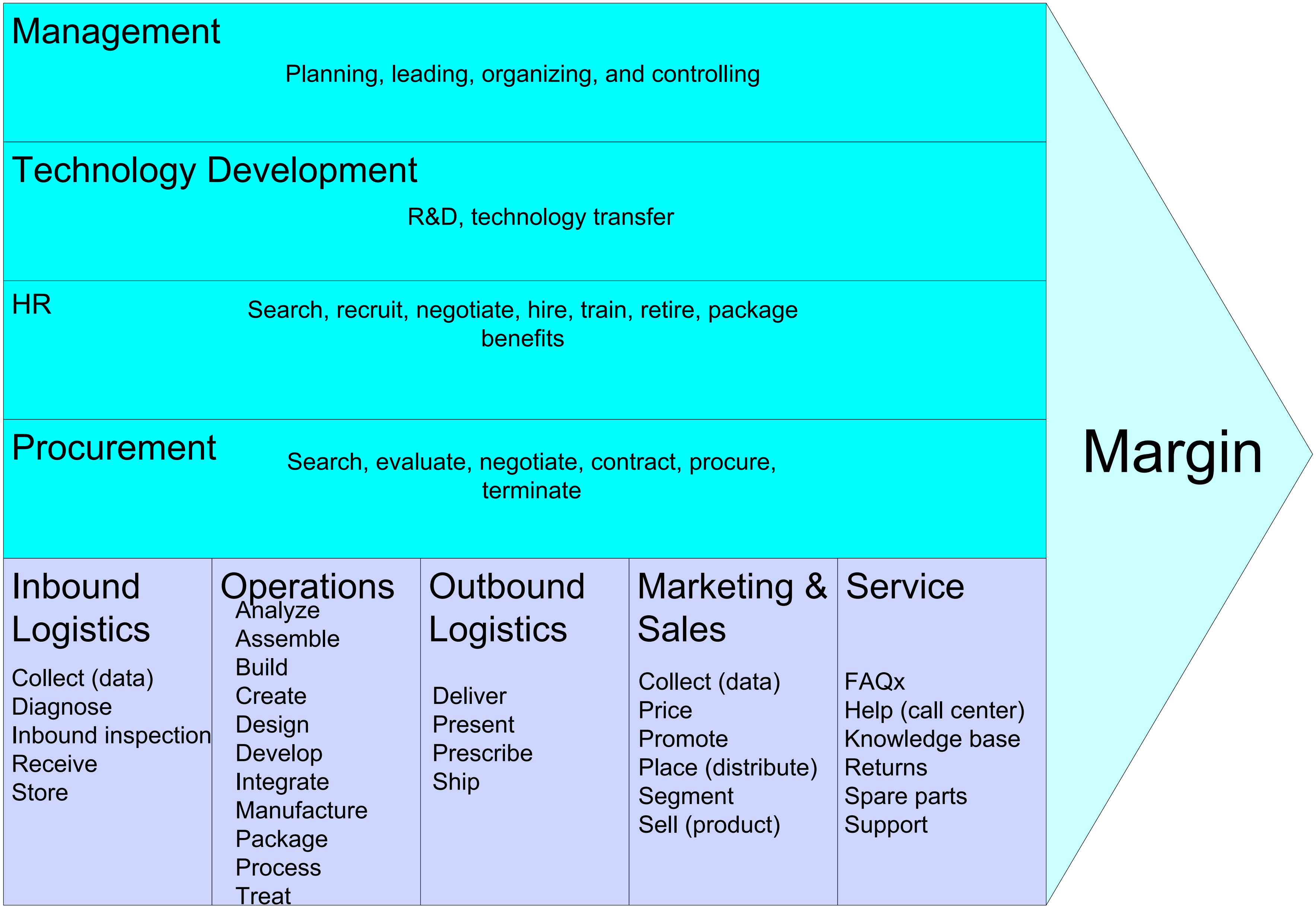
	Strengths 1. 2. 3. 4. 5.	Weaknesses 1. 2. 3. 4. 5.
Opportunities 1. 2. 3. 4. 5.	<u>SO Strategies *</u> Use strengths to leverage opportunities	<u>WO Strategies</u> Use opportunities to overcome weaknesses
Threats 1. 2. 3. 4. 5.	<u>ST Strategies</u> Use strengths to avoid or overcome threats	<u>WT Strategies</u> Manage weaknesses and avoid threats

SWOT Analysis

Blank	List of Strengths	List of Weaknesses
List of Opportunities	Use strengths to take advantage of Opportunities*	Overcome weaknesses by taking advantage of opportunities
List of Threats	Use strengths to avoid threats	Minimize weaknesses and avoid threats

Source: Fred David, “Strategic Management Concepts”

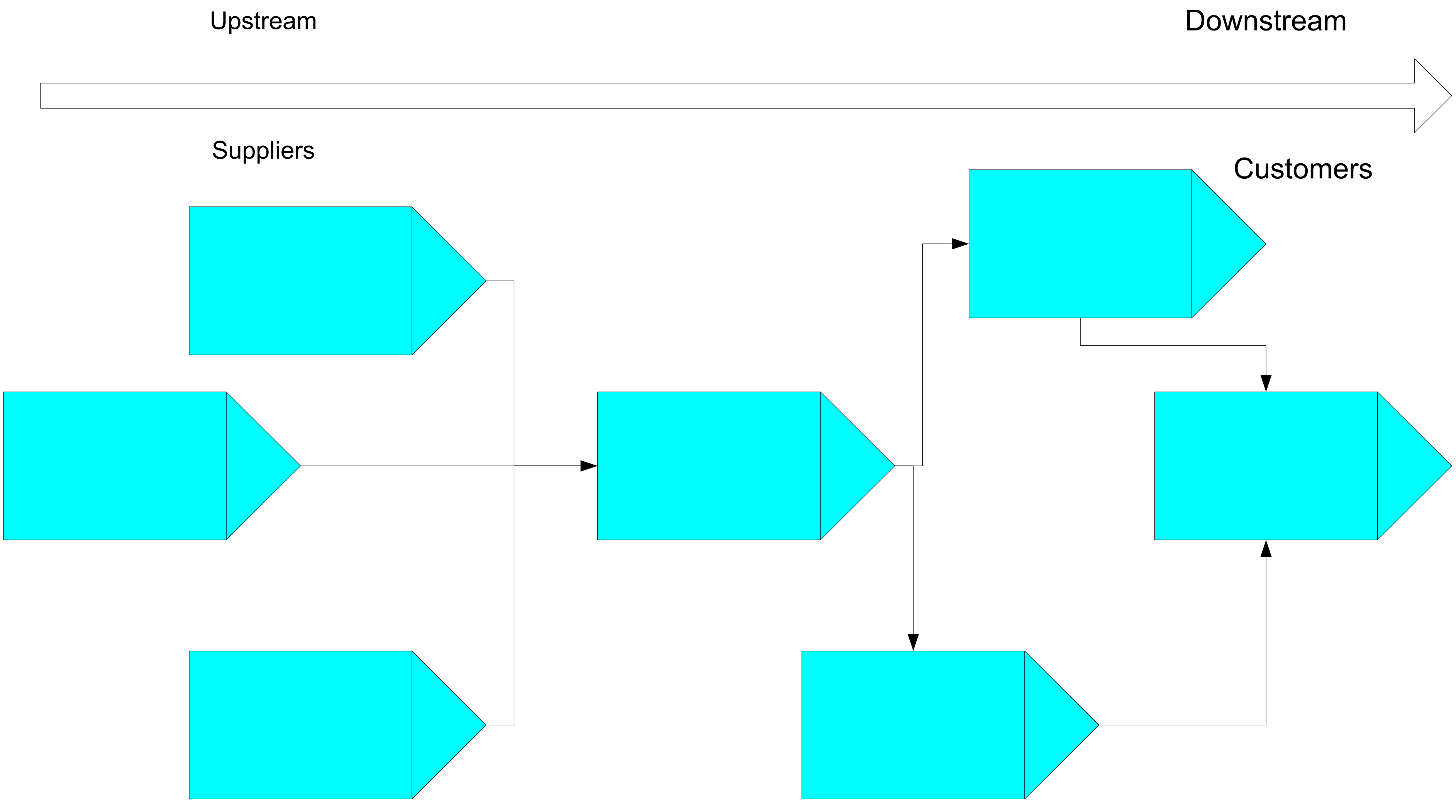
Generic Value Chain



Technologies in a Value Chain (Representative)

Source: Burgeman et al, Strategic Management of Technology and Innovation. McGraw-Hill, 2004

Supply Chain



Forecasting Tools and Techniques

- Delphi Method
- Focus Groups
- Simulation
- Nominal Group Technique / Brainstorming
- Benchmarking
- Future Studies
- Experience Curves
- SWOT Analysis
- Scenarios
- Environmental Scanning, Forecasting, and Trend Analysis

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  - http://www.iseesystems.com/
- Santa Fe Insitute
  - http://www.santafe.edu
- Seminars about Long Term Thinking
  - http://www.longnow.org/projects/seminars/
- Systems Engineering Body of Knowledge
  - https://www.sebokwiki.org/wiki/Principles_of_Systems_Thinking