Applying systems thinking to Systems Engineering

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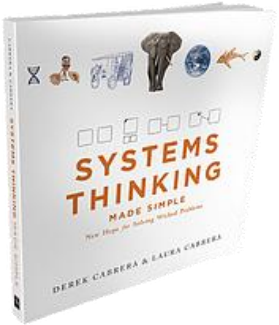
MODERN SYSTEMS 2025 Tutorial

Your Instructor: Paul B. Martin

- B.S. 1979 Widener University, General Engineering
- M.S. 1994 George Mason University, Systems Engineering
- Worked as an Engineer for several decades
  - GE → NAVSEA → NIMA → Army → DoD → Retired
- UMBC Adjunct Professor since 2006
  - Teaching Graduate Level Systems Engineering Classes
  - My Systems Engineering Principles class is for Academic Equivalency for INCOSE SEP Exam
- Involved INCOSE & local Chesapeake Chapter since 2000
  - Director of Programs (once) and Communications (twice)
- Certified as INCOSE ESEP & CompTIA CTT+

Objective

- At the end of this tutorial, the student will be able to apply different **System Thinking Perspectives** to various situations and problems so they can be framed and reframed in different ways, thus allowing for new kinds of solutions to emerge.



Primary Reference Text:

- Cabrera, Derek & Cabrera, Laura. (2015). *Systems Thinking Made Simple: New Hope for Solving Wicked Problems.*

Agenda

- Why Systems Thinking
- Considering Systems
- Considering Thinking

Applying systems thinking to Systems Engineering

SECTION 1: WHY SYSTEMS THINKING?

“Systems Thinking” is . . .

- A **strong competitive advantage** as we face a more complex, challenging, and ever-changing environment
- A **mindset** that requires us to consider
  - every aspect of a problem,
  - its impact across all disciplines, and
  - our individual contribution to the mission.

But why Systems Thinking?

SCHOLAR
Systems Engineering *Understood*!

systhink

The Human struggle
. . . to understand the universe

"What is real? How do you define real? If you're talking about what you can hear, what you can smell, taste and feel then real is simply electrical signals interpreted by your brain"

~ Morpheus, *Matrix* (1999)

The Triumph of Reductionism

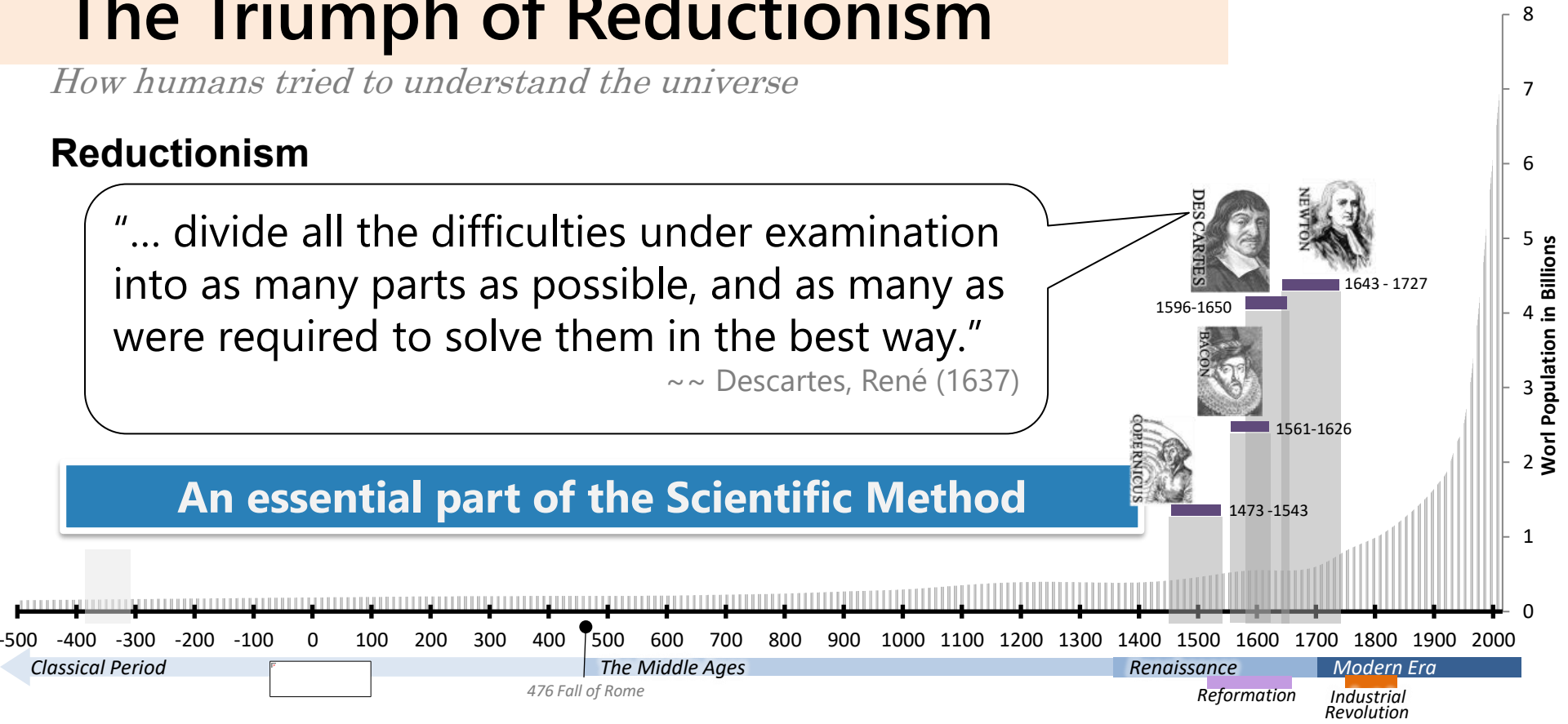
How humans tried to understand the universe

Reductionism

"… divide all the difficulties under examination into as many parts as possible, and as many as were required to solve them in the best way."

~~ Descartes, René (1637)

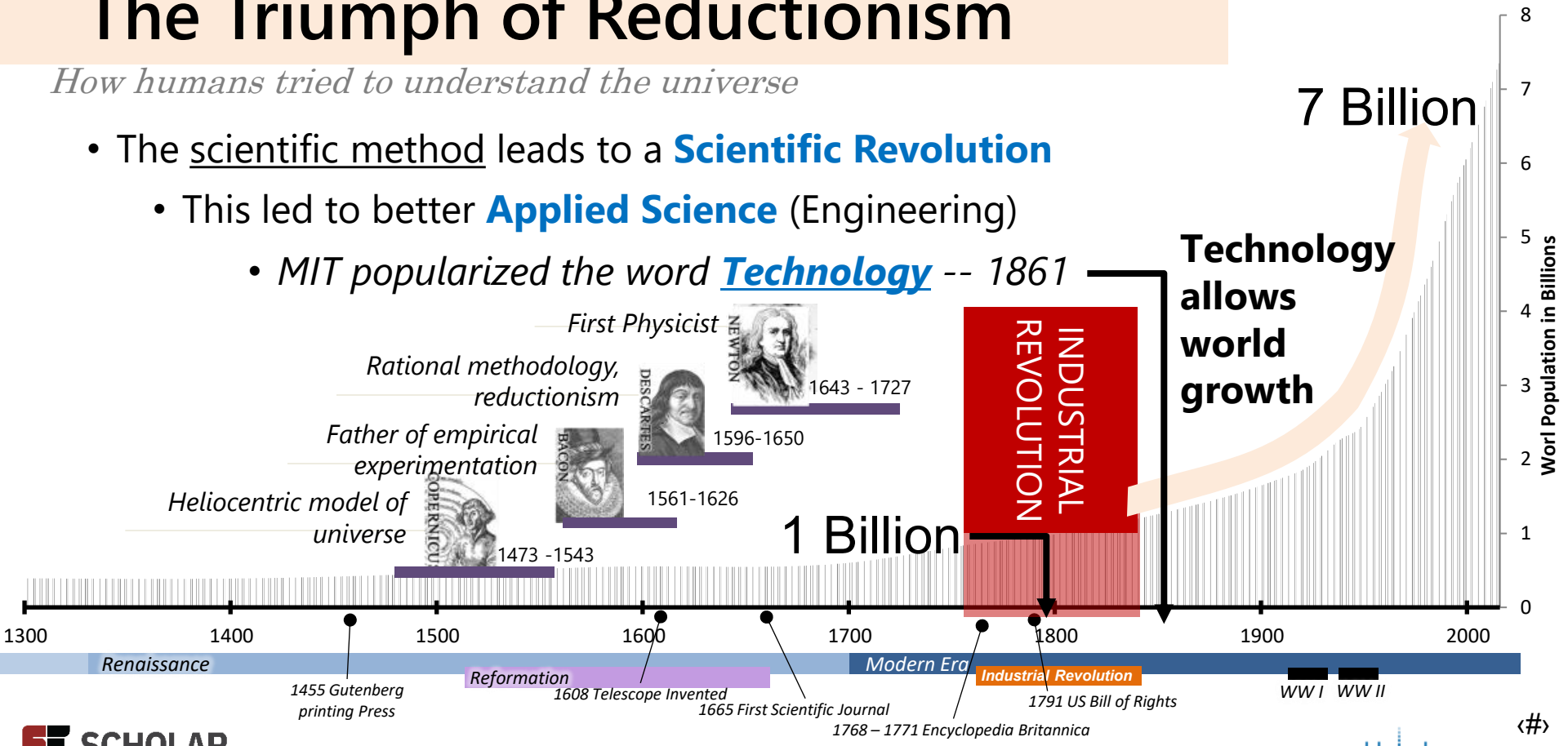
An essential part of the Scientific Method



The Triumph of Reductionism

How humans tried to understand the universe

- The scientific method leads to a **Scientific Revolution**
  - This led to better **Applied Science** (Engineering)
    - *MIT popularized the word **Technology** -- 1861*



SCHOLAR
Systems Engineering *Understood*!

systhink

Limitations in Reductionism

How humans misunderstand the universe

- "From a very early age we are taught to break apart problems, to fragment the world. This apparently makes complex tasks and subjects more manageable, but we pay a hidden, enormous price. We no longer see the consequences of our actions; we lose our intrinsic sense of connection to a larger whole. When we then try to "see the big picture," we try to reassemble the fragments in our minds, to list and organize all the pieces …. after a while we give up trying to see the whole altogether."

~ Senge, P.M. (1990). *The Fifth Discipline*

The price of reductionism is NOT seeing the overall system!

Limitations in Reductionism

How humans misunderstand the universe

- **It basically ignores Complexity**
  - The whole idea of Reductionism is to reduce complexity – but this doesn't mean complexity isn't still there.

    "Our inability to fathom complexity leads to a belief that any worthwhile solution to a situation must be simple."

    ~ David Green, blog post "Simple thinking in a complex world is a recipe for disaster."

- **We can't study Emergence with Reductionism**
  - The concept of emergence is based on characteristics that the whole demonstrates and cannot be attributed to the components.

    "An appeal to emergence is thus a way to describe the need to go to the macro level and its unique dynamics, laws, and properties in order to explain more adequately what is going on."

    ~ Jeffrey Goldstein

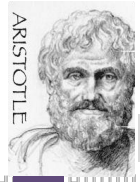
The need for Systems understanding

How humans tried to understand the universe better

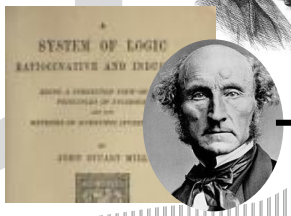
- Aristotle observed the fact that **system properties will manifest only when components interact** with one another. These system level properties are different than the individual component level properties.

"the whole is greater than the sum of the parts"

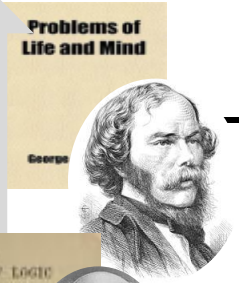
~ Metaphysics Book H 1045a 8-10



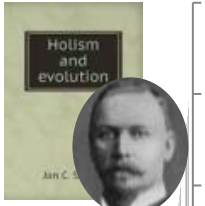
1843 - John Stuart Mill *System of Logic*
"... no mere summing up of the separate actions of those elements will ever amount to the action of the living body itself."



1875 - George Henry Lewes *Problems of Life and Mind.* "the emergent ... cannot be reduced either to their sum or their difference."



1926 – Jan Smuts *Holism and Evolution*



Concept of Emergence

World Population in Billions

0 1 2 3 4 5 6 7 8

-500 -400 -300 -200 -100 0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000

Classical Period | *The Middle Ages* | *Renaissance* | *Modern Era*

476 Fall of Rome

Reformation

Industrial Revolution

The need for Systems understanding

How humans tried to understand the universe better

1926 – Jan Smuts
Holism and Evolution

1948 - Wiener N.. *Cybernetics or Control and Communication in the Animal and the Machine.*

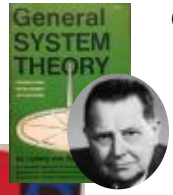
Cybernetics

1950 - Churchman, Ackoff, and Arnoff, *Introduction to Operations Research.*

Operational Research

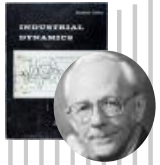
1951 - Ludwig Von Bertalanffy, *General System Theory: A New Approach to Unity of Science.*

General System Theory



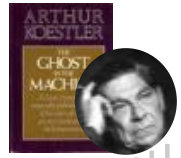
1961 - Jay W. Forrester, *Industrial Dynamics.*

System Dynamics

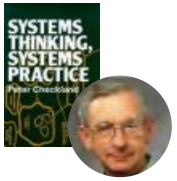


1967 - Arthur Koestler. *The Ghost in the Machine*

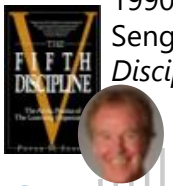
Holons



1981 – Peter Checkland, *Systems Thinking, Systems Practice.*



1990 - Peter M. Senge, *The Fifth Discipline*



Systems Thinking

Modern Era

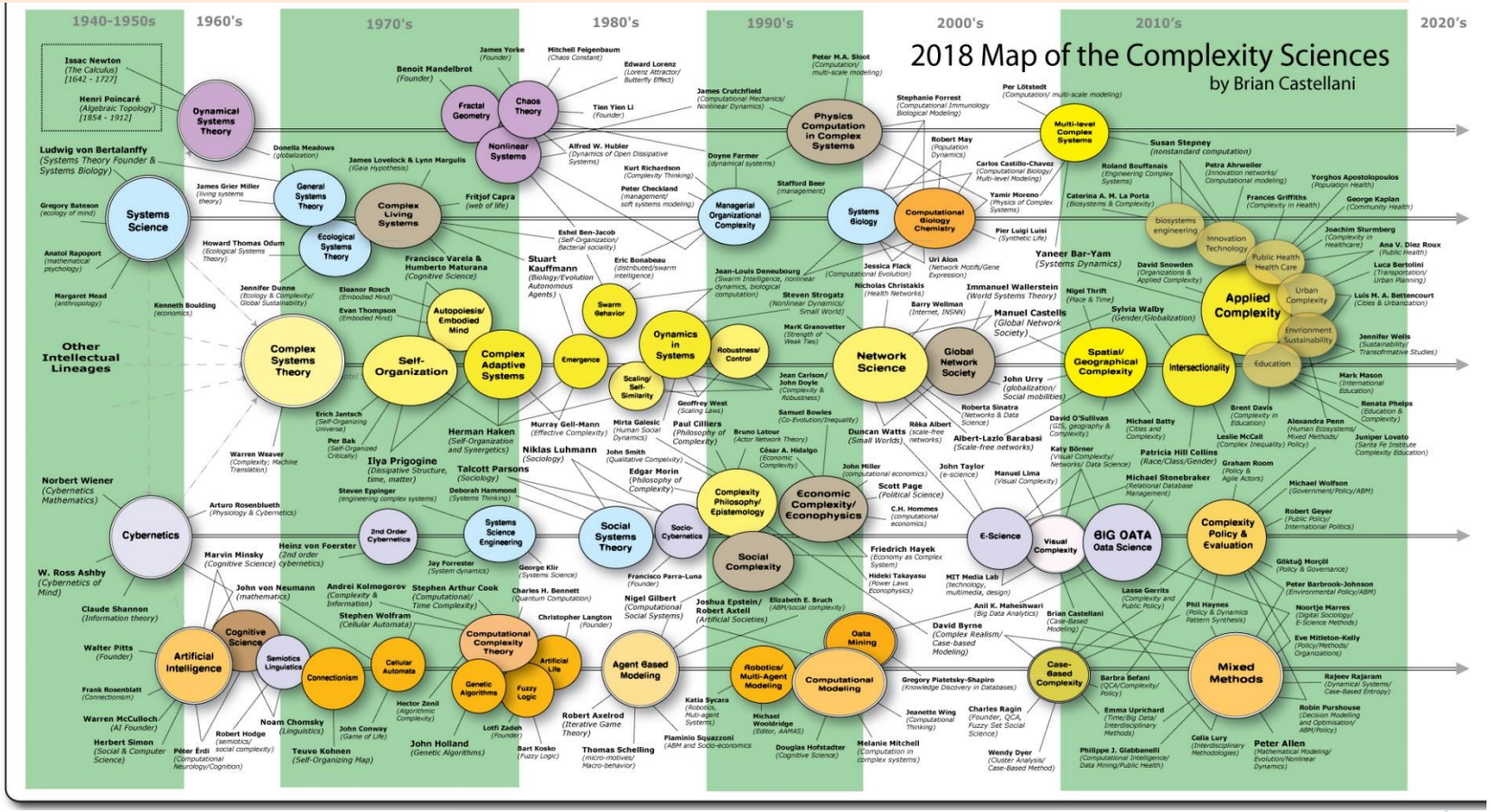
1900 1905 1910 1915 1920 1925 1930 1935 1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010 2015

WW I *WW II*

Worl Population in Billions

0 1 2 3 4 5 6 7 8

Many and various systems theories



Systems Science

The Oxymoron

Systems – holistic view to comprehend phenomena

- *Synthesis* – refers to a combination of two or more entities that together form something new

Science – reductionist view to comprehend phenomena

- *Analysis* – the process of breaking a complex topic or substance into smaller parts in order to gain a better understanding of it.

A new paradigm - that changes the framework of analysis to an approach of one of synthesis

It's not one or the other!

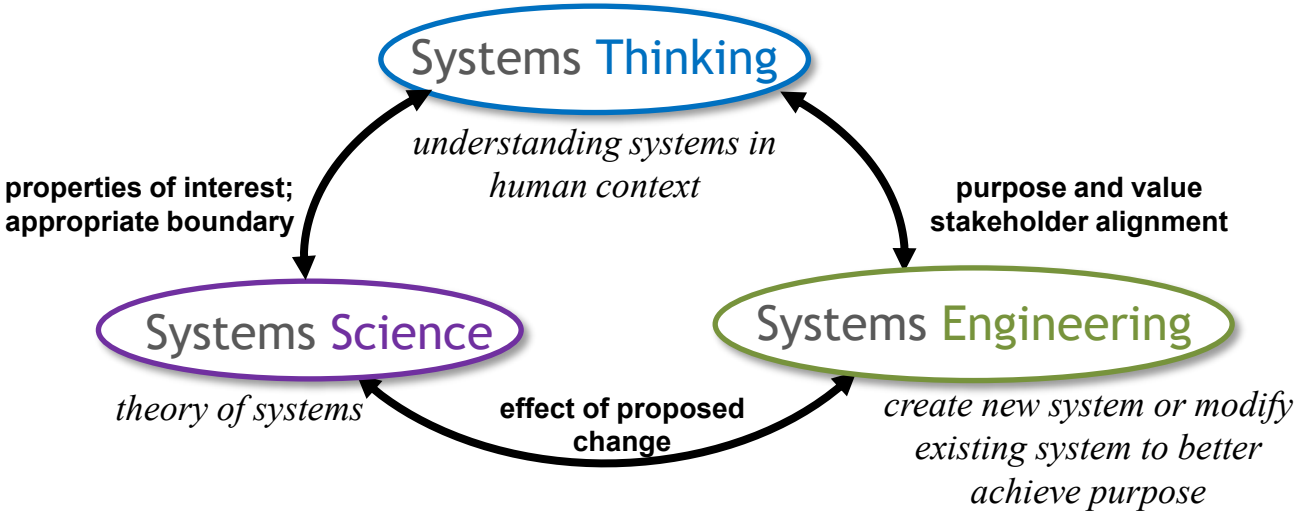
- "**The good systems scientist or philosopher is both reductionist and holist.** Consider the care with which he considers the detailed structure of a system: the meticulous attention he gives to establishing the proper relations between the objects; the methodical way in which he builds his whole model from these parts, having, of course, first defined the boundaries of the whole system; the agonies he goes through as he tries to establish the validity of the model. **This is good hypothetical-deductionist science, and it is good reductionism and holism.**"

~ M'pherson, P. K. "A Perspective on Systems Science and Systems Philosophy." *Futures* 6.3 (1974): 219-39.

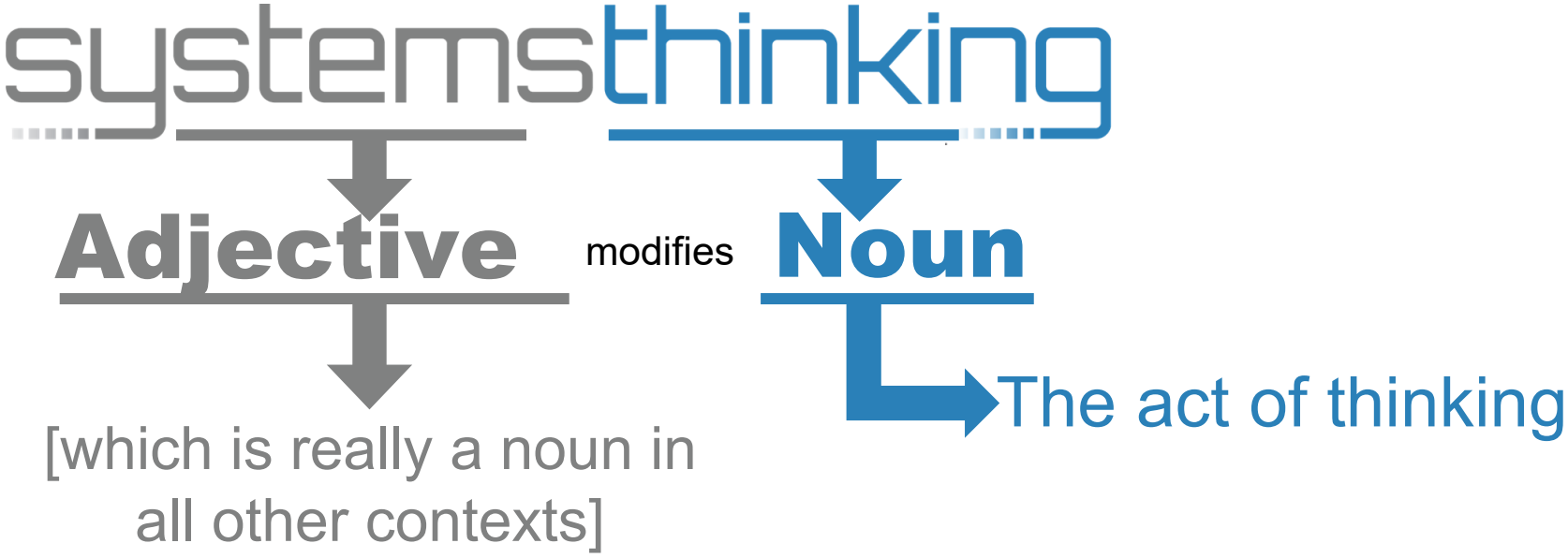
A good Systems Thinker will use both!

A good Engineer needs both

… Science and Systems Thinking!



Sillitto, H. (2012), 4.3.2 Integrating Systems Science, Systems Thinking, and Systems Engineering: understanding the differences and exploiting the synergies. *INCOSE International Symposium*, 22: 532–547



"Systems thinking is not a science; it is **a conceptual ability, an orientation, and a framework**. However, systems thinking is informed by ***knowledge-about-systems***."

~ Cabrera, D., & Cabrera, L. (2015). *Systems thinking made simple: New hope for solving wicked problems*.

Four Rules of Systems Thinking

D

- **DISTINCTIONS RULE:** Any idea or thing can be **distinguished from the other** ideas or things it is with

S

- **SYSTEMS RULE:** Any idea or thing can be **split into parts or lumped into a whole**

R

- **RELATIONSHIP RULE**: Any idea or thing **can relate to other** things or ideas

P

- **PERSPECTIVES RULE**: Any idea or thing **can be the point or the view of a perspective**

Applying systems thinking to Systems Engineering

SECTION 2: CONSIDERING SYSTEMS

Four Rules of Systems Thinking

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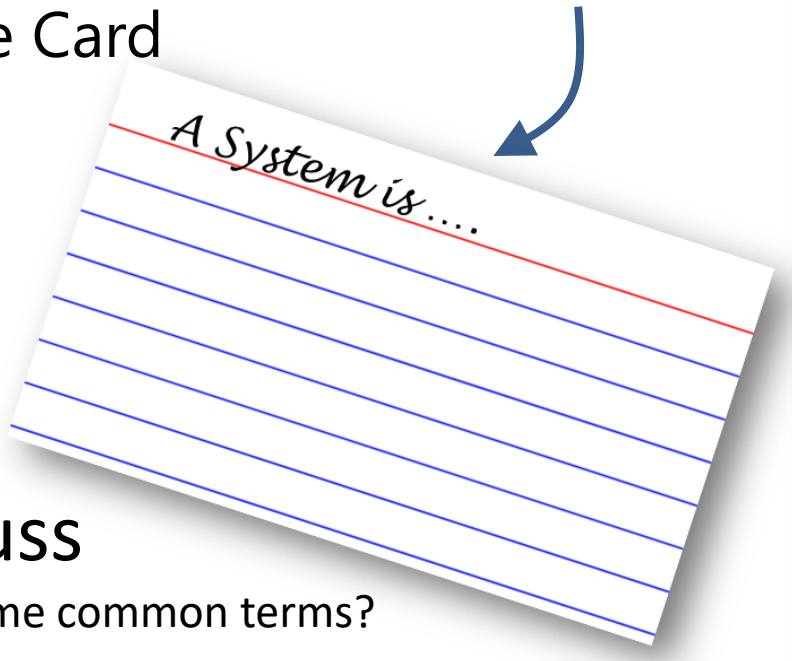
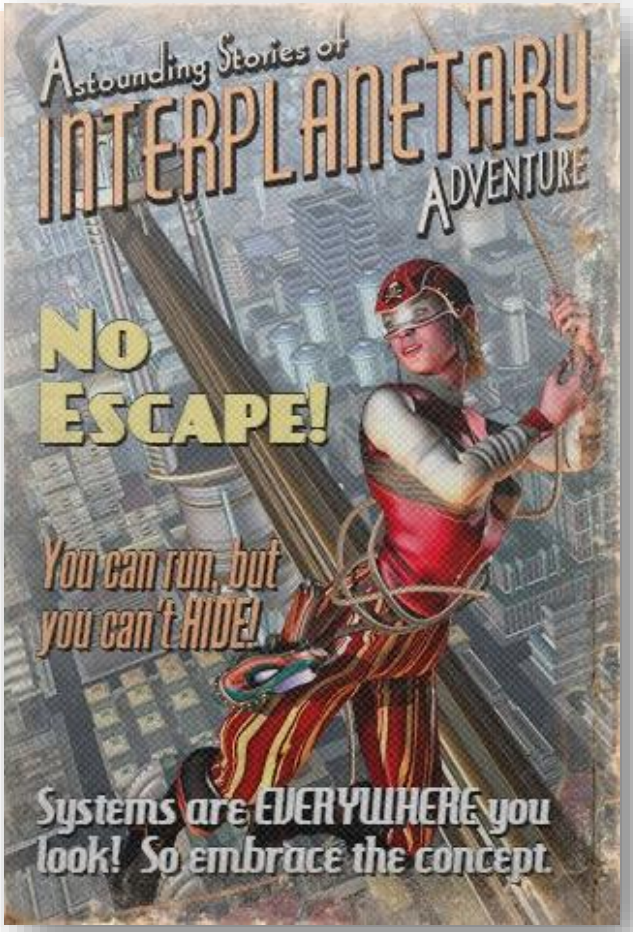
What is a System?

- Write your definition of “System” onto Note Card





Let’s Discuss

- What are some common terms?

Knowledge-about-Systems

General System Theory:

- A "whole" consisting of interacting "parts."

~ von Bertalanffy, L. (1968). *General System Theory: Foundations, Development, Applications.*

ISO/IEC/IEEE 15288:

- A combination of interacting elements organized to achieve one or more stated purposes

~ ISO/IEC/IEEE 15288:2015 *Systems and software engineering -- System life cycle processes*

INCOSE POV:

- A system is an arrangement of parts or elements that together exhibit behavior or meaning that the individual constituents do not.

~ Systems Engineering and System Definitions | INCOSE-TP-| 22 July 2019

Knowledge-about-Systems

Wikipedia:

- Every system is
  - *delineated* by its spatial and temporal boundaries
  - *surrounded and influenced* by its environment
  - *described* by its structure and purpose
  - *expressed* in its functioning

Let’s play a game:

Is it System? or
Is it a Collection of Parts?

System or Collection of Parts?

- Football Team

System or Collection of Parts?

- Toaster

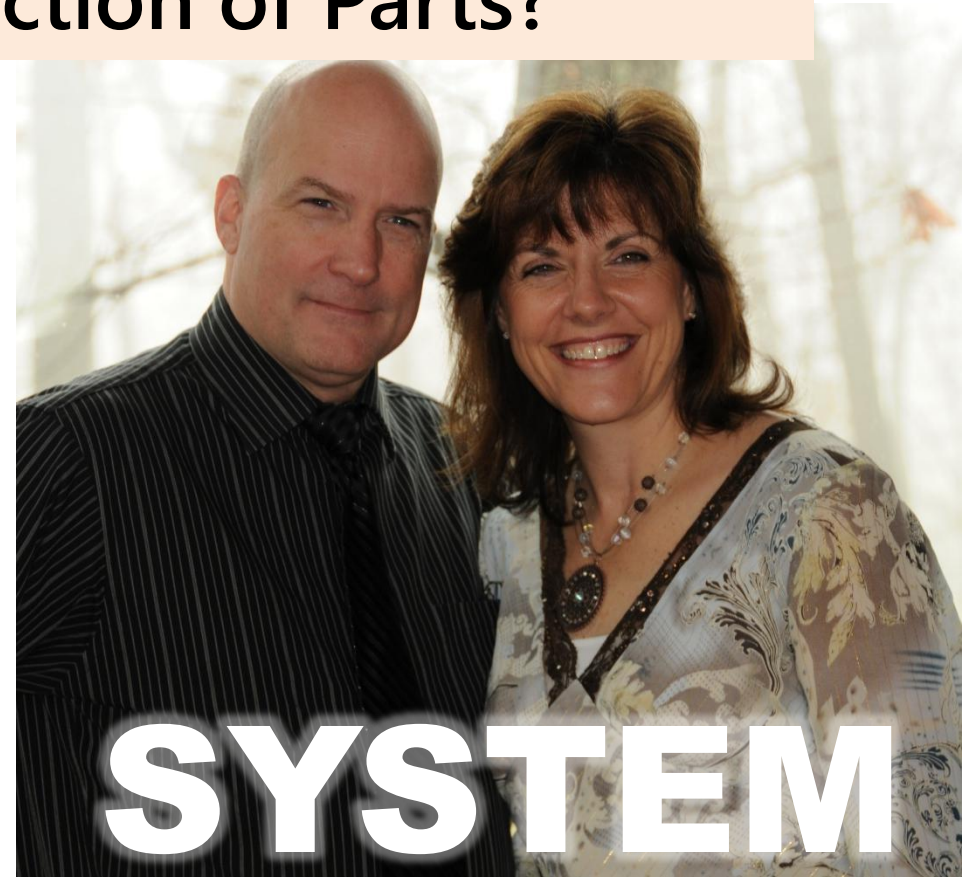
System or Collection of Parts?

- Kitchen

- What additional element would make it a system?

System or Collection of Parts?

- Marriage



System or Collection of Parts?

- Tools in a Toolbox

- What additional element would make it a system?

Collection

Boundaries of a System

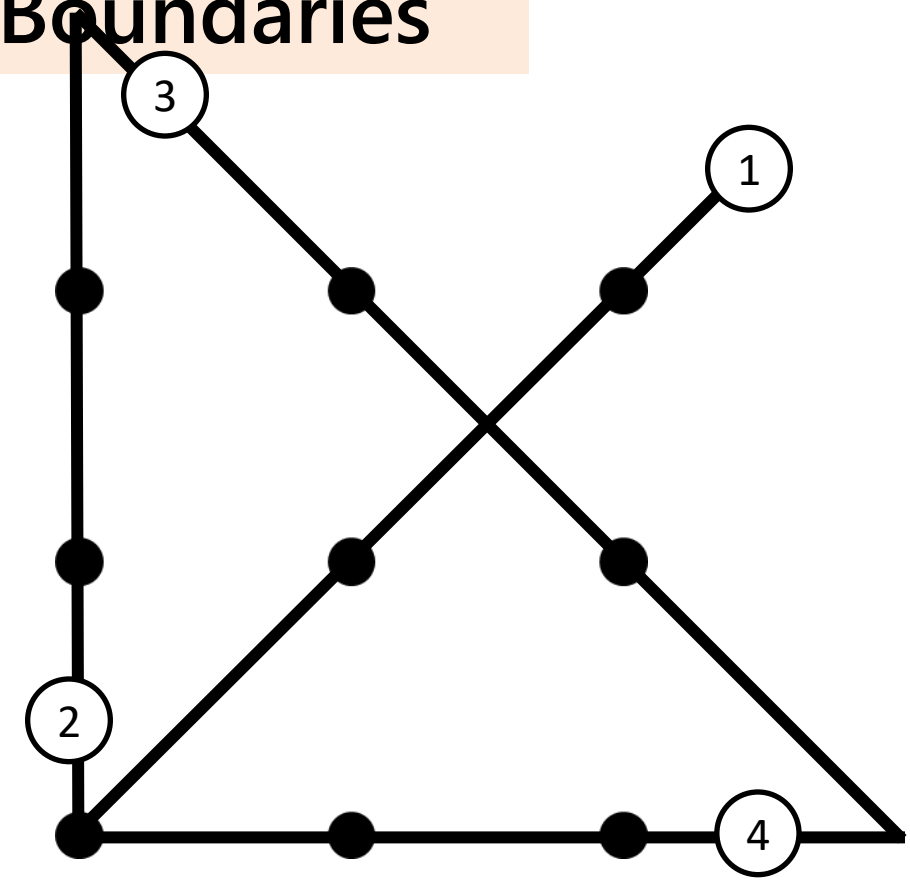
System Boundary: *A distinction made by an observer which marks the difference between an entity he takes to be a system and its environment.*

Source: Checkland, P. 1999. *Systems Thinking, Systems Practice.*

Where do you set the boundaries? At what level?

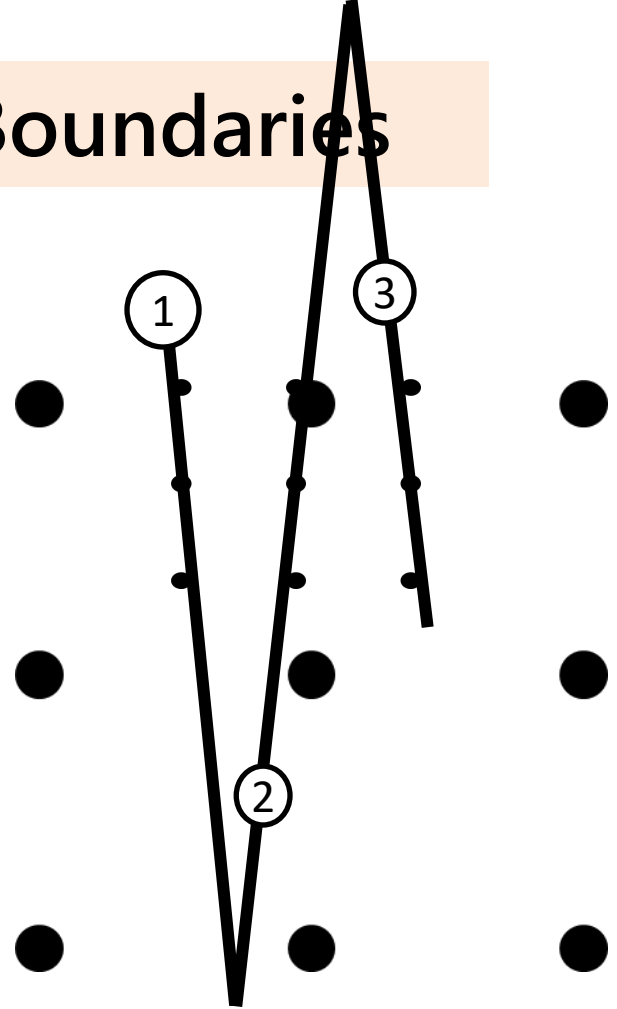
The challenge: Setting Boundaries

- 9 Dots
- One Rule: Connect the dots by drawing **four** straight lines through the nine dots without retracing and without lifting your pen.



The challenge: Setting Boundaries

- 9 Dots
- One Rule:
  Interconnect the dots by drawing ~~**four**~~ three straight lines through the nine dots without retracing and without lifting your pen.



The challenge: Setting Boundaries

- 9 Dots

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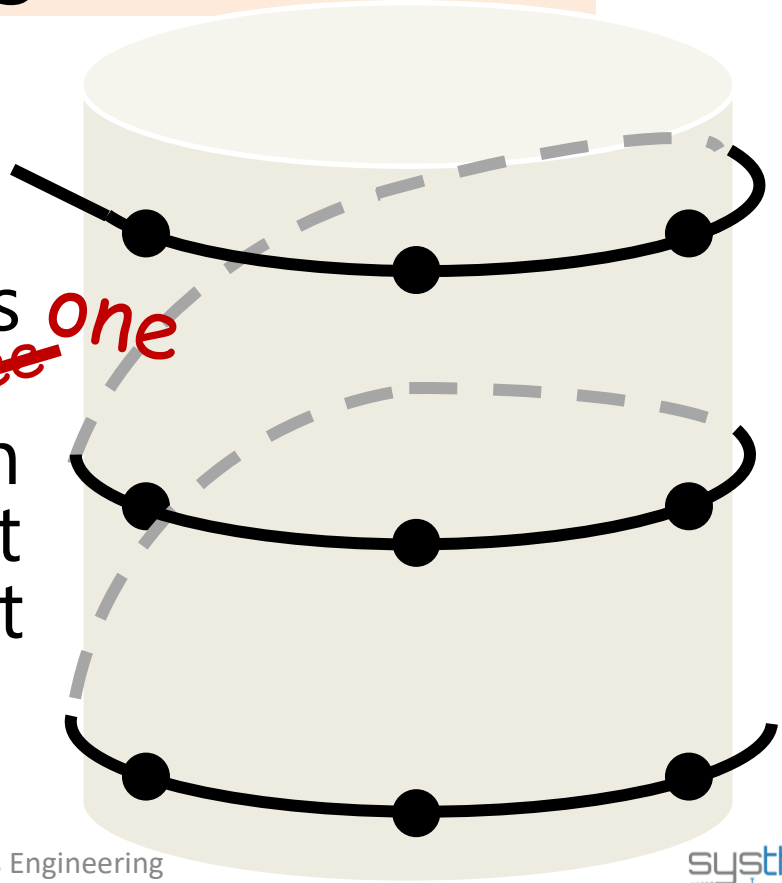

Boundaries at the Micro Level

The moment one gives close attention to anything, even a blade of grass, it becomes a mysterious, awesome, indescribably magnificent world in itself.

~ Henry Miller

Boundaries at the Micro Level

"The Brute ... That Shouted Love... At the Heart of the Atom."

Incredible Hulk Vol 1 #140 (June 1971), Marvel Comics.

Boundaries at the Macro

Impact of the fourth dimension

System or Collection of Parts?

- Bowl of Fruit

Impact of the fourth dimension

System or Collection of Parts?

- A piece of Art in NY Park
  - 36 foot high structure of aluminum and magnesium slab bolted together

New York City's prominent 1974 outdoor sculpture, 3000 A.D. by Terry Fugate-Wilcox where the piece's various aluminum and magnesium slabs will join themselves into one continuous alloy block around the year 3000. With time all boundaries disappear.

System or Collection of Parts?

- Tools in a Toolbox

What is the Impact of the fourth dimension?

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From Boundaries to Interfaces

- Every system is delineated by its spatial and temporal boundaries, **surrounded and influenced by its environment,** described by its structure and purpose and expressed in its functioning.

~ Wikipedia

From Boundaries to Interfaces

- This way of observing systems wherein the **complex system relationships** are focused around a particular system boundary … Systems thinking requires an ongoing process of attention and adaptation to ensure that one has appropriately identified **boundaries, dependencies, and relationships**

~ SEBOK Article: What is Systems Thinking?

From Boundaries to Interfaces

A system is a set of **related components** that **work together** in a **particular environment** to perform whatever functions are required to achieve the system's objective.

~ Donella Meadows

~ From Disruptive Design blog

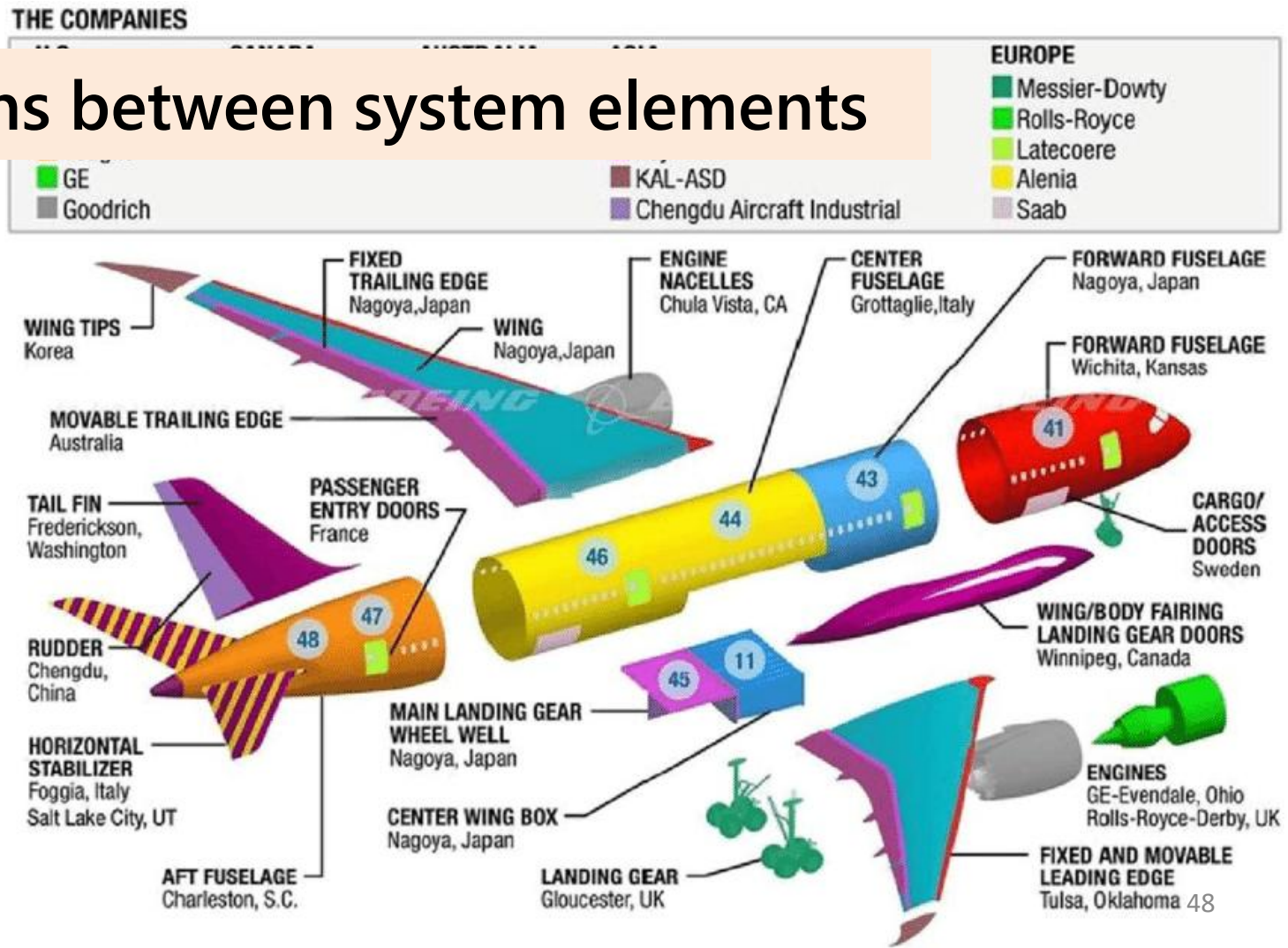
From Boundaries to Interfaces

- The focus on interactions and holism is a push-back against the perceived reductionist focus on parts and provides recognition that in complex systems, **the interactions among parts is at least as important as the parts themselves.**
- An open system is defined by
  - the **interactions between system elements within a system boundary**
  - and by the **interaction between system elements and other systems within an environment**.

~ SEBOK Article: Concepts of Systems Thinking

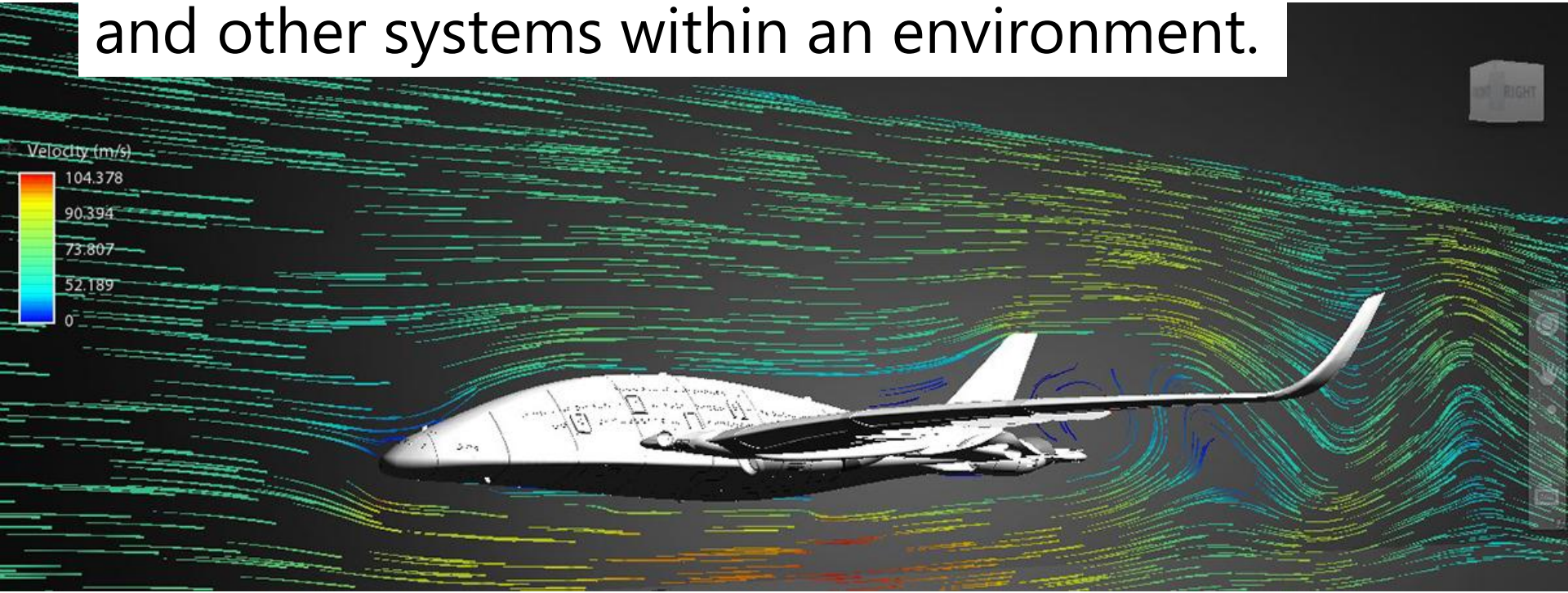
Interactions between system elements

within a system boundary



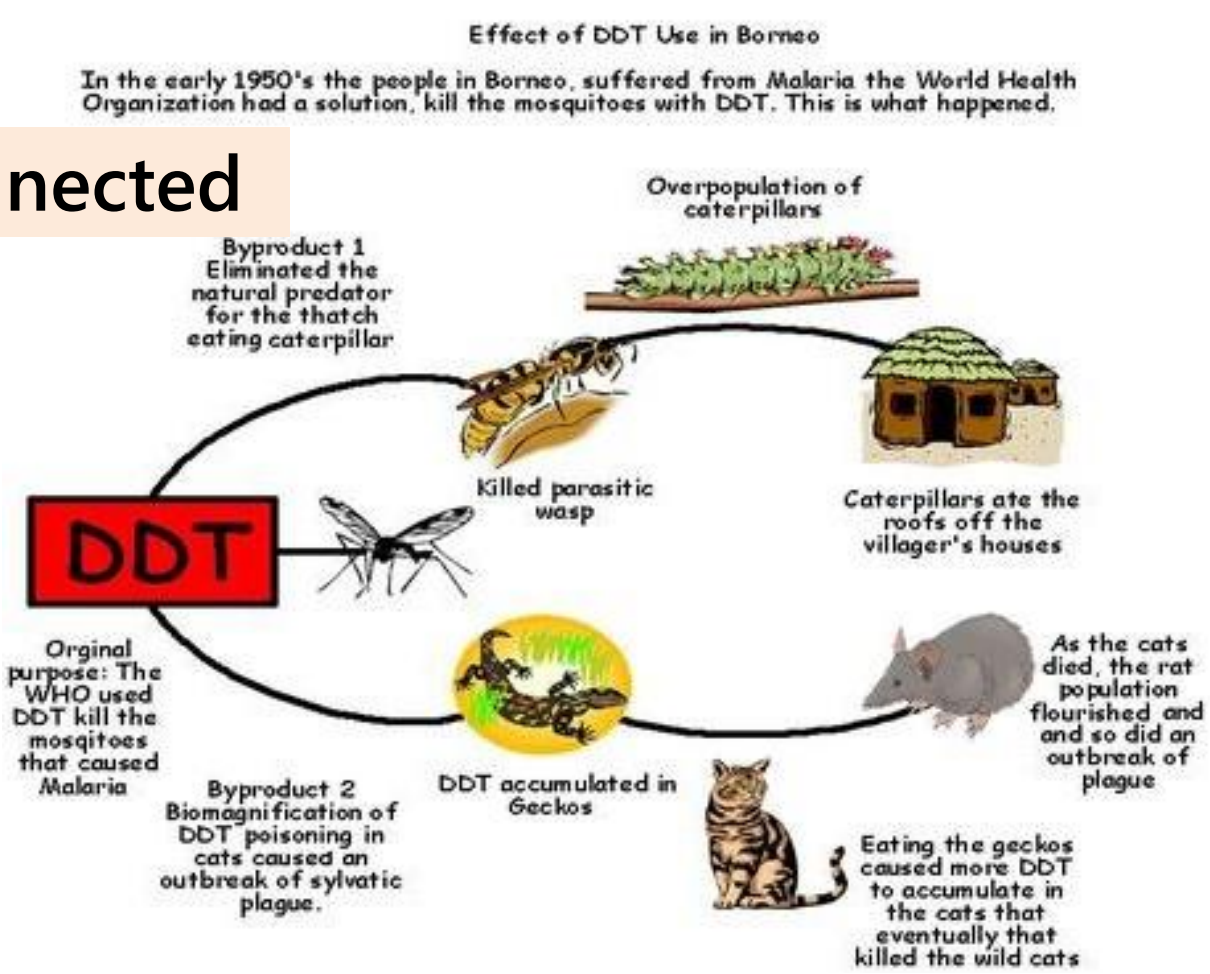
Interaction between system elements

and other systems within an environment.



Everything is connected

If you don't understand the interrelatedness of things, solutions often cause more problems



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SECTION 3: CONSIDERING THINKING

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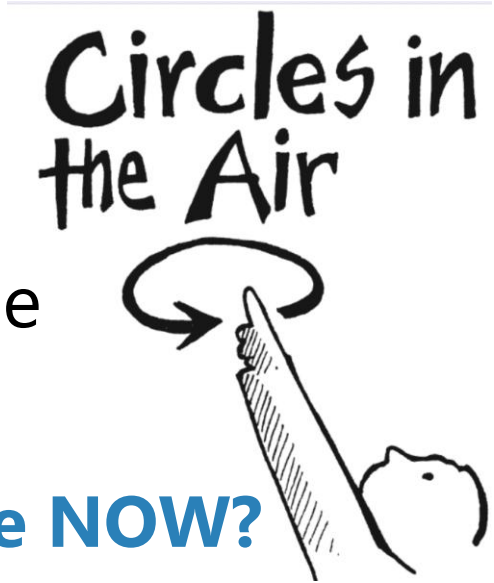
Perspective is important

- …**a lens, a point of view, frame, mindset or worldview**, all are synonymous with or forms of perspective-taking.
- Perspective-taking is **essential to systems thinking** because understanding systems is in large part understanding how those systems look from various perspectives.

~ Cabrera, D., & Cabrera, L. (2015). *Systems thinking made simple: New hope for solving wicked problems*. .

Perspectives can change

- Hold pen in air
- Draw circle clockwise
- Continue to draw the circle as you lower it so you can look at the circle from the top.



What is the direction of the circle NOW?

- Why did this happen?

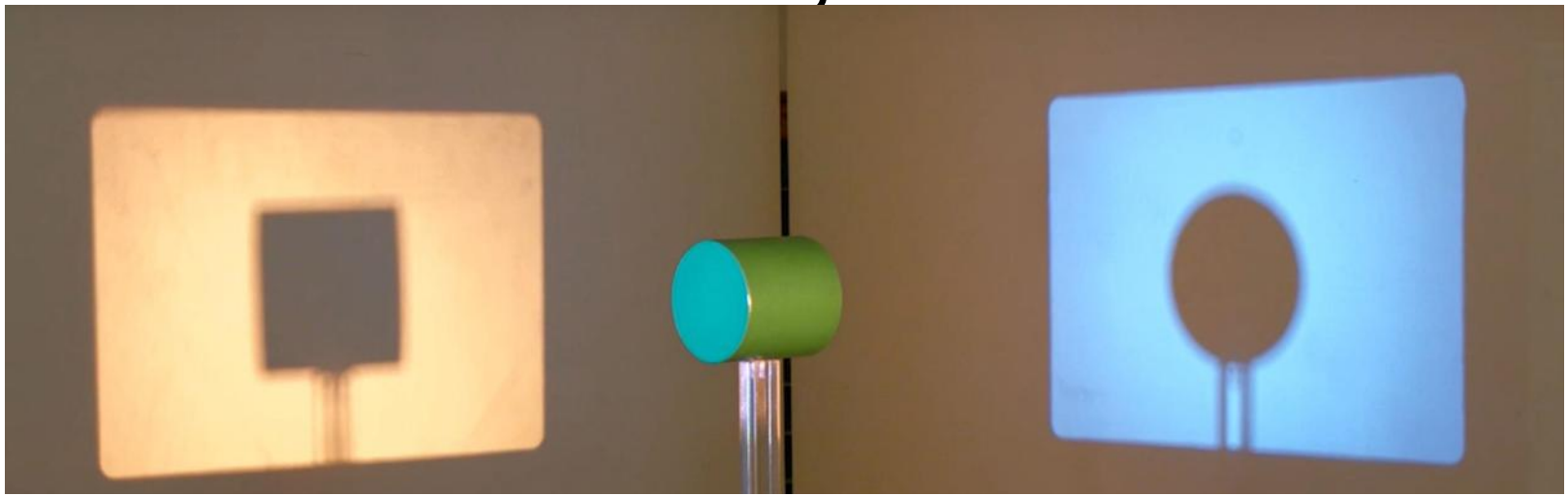
Perspective Matters

- What is this man's perspective?

"Everything we hear is an opinion, not a fact. **Everything we see is perspective**, not the truth." *~Marcus Aurelis*

Two Points can Yield Different …

Views of the Same Object



"When you **change the way you look at things**, the things you look at change."

What do you see?

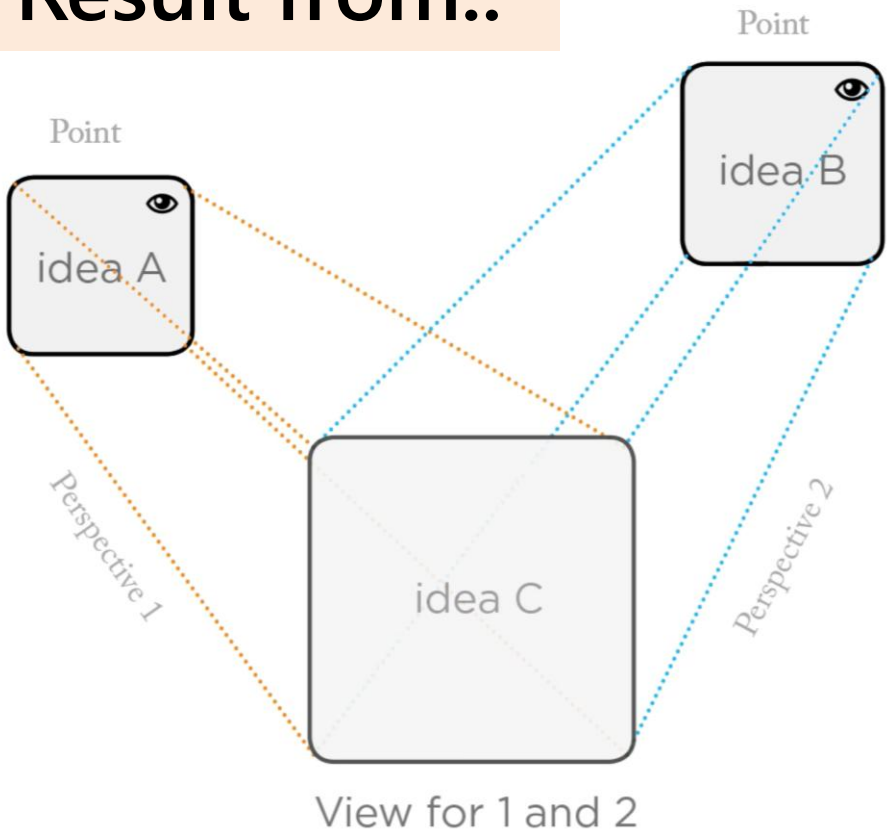
- Is one Point of View less valid than the other?

"I've learned that two people can look at the exact same thing and see something totally different."

Check out https://youtu.be/qQCHWBKrkew

Different Perspectives Result from..

- Changing the point, the view, or both.



Perspective's enemy

- **Categorization** is the process in which ideas and objects are recognized, differentiated, and understood
  - **The Scientific disciplines** (e.g., physics, chemistry, biology, psychology, sociology, economics)
  - **Biological Classifications** (Life, Domain, Kindom, Phylum, Order, Family, Genus, Species)
  - **Bloom's Taxonomy** (Knowledge, Comprehension, Application, Analysis, Synthesis, Evaluation)
  - **Internet, Computer desktop, filing systems, Libraries**

We can’t help but Name and Classify everything

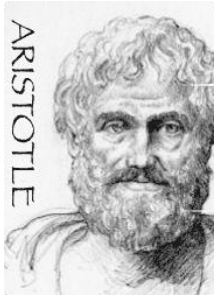
“Now out of the ground the Lord God had formed every beast of the field and every bird of the heavens and brought them to the man to see what he would call them. And whatever the man called every living creature, that was its name.”

~ 1445 B.C [Genesis 2:19-20]

Once the whole is divided, the parts need names.
There are already enough names.
One must know when to stop.
Knowing when to stop averts trouble.

~ 500BC [The Tao Te Ching]

Aristotle loved this insidious device



~ 350BC

Aristotle began this hierarchical tendency when he

- Classified animals into different types based on physical characteristics;
- Reduced the Rhetoric technique into a rational system
  - particular proofs and topics
  - common proofs.

"Aristotle was tremendously satisfied with this neat little stunt of **naming and classifying everything**. His world began and ended with this stunt."

~ Pirsig, R. M. (1974)

Categories have a dark side

- …they are a cognitive cul de sac or dead end in the road. Categories make us feel like we're getting somewhere, speeding down the highway of understanding and knowledge until *Wham!*, dead end. We're stuck. And, it usually takes a long time to get unstuck.

  ~ Cabrera, D., & Cabrera, L. (2015). *Systems thinking made simple: New hope for solving wicked problems*. .

- 'We must stop acting as though nature were organized into disciplines in the same way that universities are'

  ~ Ackoff RL. 1960. Systems, organizations and interdisciplinary research. General Systems Yearbook 5: 1–8. p. 6

Why are Categories “insidious”

- They proceed in a gradual, subtle way – but with **harmful effects**.
- When we teach this concept it leads to
  - **Less robust,**
  - **More black & white**
  - **Less adaptive**

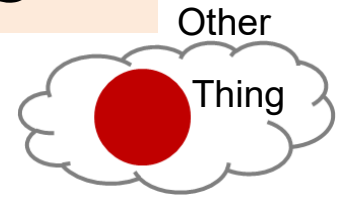
THINKERS

Four Rules of Systems Thinking

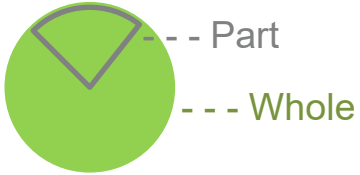
- **DISTINCTIONS RULE:** Any idea or thing can be **distinguished from the other ideas or things** it is with
- **SYSTEMS RULE:** Any idea or thing can be **split into parts or lumped into a whole**
- **RELATIONSHIP RULE**: Any idea or thing **can relate to other** things or ideas
- **PERSPECTIVES RULE**: Any idea or thing **can be the point or the view of a perspective**

Each Rule has Co-implying elements

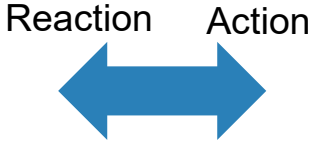
D
- **DISTINCTION:** A thing implies an other



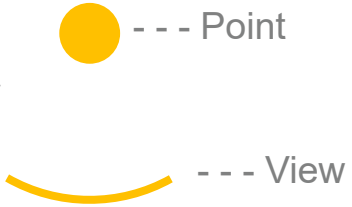
S
- **SYSTEM:** A part implies a whole



R
- **RELATIONSHIP**: An action implies a reaction



P
- **PERSPECTIVE**: A point implies a view.



Questions?

Applying Systems Thinking to SE

"Shift of Mind [is going] from seeing parts to **seeing wholes**, from **seeing people** as helpless reactors to seeing them as active participants in shaping their reality, from reacting to the present to **creating the future**."

Senge, P.M. 1990, 2006. *The Fifth Discipline: The Art and Practice of the Learning Organization*. New York, Doubleday/Currency (p. 69)

Conclusion

- Why Systems Thinking?
  - Attacking problems from a Systems Perspective is a reaction to the ineffectiveness of Scientific Reductionism.
- Use both frameworks
  - Use all the tools from System Science and Traditional Science
  - Systems Science is new and young – give it time!
- Beware of Cognitive Biases

Applying systems thinking to Systems Engineering

THANK YOU!!!