“What if our beliefs about a system are not wholly accurate? What if?”

Gary Langford
Systems Engineering Program
Department of Engineering & Technology Management
Do we really know what a system is?

Systems Science is the field of scientific inquiry whose objects of study are systems. In order to understand what this means it is necessary to explain what a system is.


Why does that definition matter?
Would You think that bringing all definitions into balance would be correct? How Correct?

• James G. Miller “Living Systems” 1978
  • “A set of interacting units with relationships among them.” A concrete system is a nonrandom accumulation of matter-energy, in a region in physical space-time, which is organized into interacting interrelated subsystems or components – Integrated hierarchy.

• Flood & Carson 1993
  • “A system is a set of related elements in an organised whole.”

• Ackoff 1981
  • “A system is a whole that cannot be divided into independent parts.”

• Flood & Carson 1993
  • Emergence – something that happens when the whole is greater than the sum of its parts.

• Ludwig von Bertalanffy “General Systems Theory” 1940s – 1970s
  • Systems are hierarchical
A System Is An Intuition – To Some Sensical; To Others – Illogical

• **A System Is Not an Intuition and IT IS LOGICAL**

• To Some Sensical – inconsistencies are ignored or rationalized

• To Some Illogical – inconsistencies limit the use of word system

• The consequence of ignoring or rationalizing inconsistencies is to misinterpret an action, e.g., to state that systems are integrated wholes implies horizontal integration within vertical limitations, as used by systems engineers. Various forms of hierarchy, e.g., level-based and value-based (parent-child), are used to organize, partition, granularize, separate, and synthesize – then iterate till your boss insists you stop or the project is over. The hierarchical model is used to construct design, and architect according to priority needs and resources, and then build, test, verify, and validate. Do it early & often. But hierarchical thinking is fraught with error.
• Vadim Sadovsky wrote, “It is interesting that we all seem to know what a system is, yet no generally accepted definition exists”. Sadovsky, Foundations of General Systems Theory. Moscow, Nauka Publishers 1974, 279pp.

• Herbert Simon wrote, “However, the goal in defining a system, whether the system is natural or artificial, is to examine the phenomena to identify what is “commonplace” or to simplify complexity—to find pattern hidden in apparent chaos”. The Sciences of the Artificial, MIT Press 1996, 248pp.

**Do We Know Enough to:**

• Build a system? – therefore, what is a system...

• Make a system work, and work well or poorly? – therefore, how do I improve it...

• Know why a system fails? – therefore, how can it be destroyed...

It is as if we have given up; the systems wars are ended.

- Engineering Systems Integration – Theory, Metrics, and Methods

- Stanisław Leśniewski (1916-1939) Formal Methods and Mereology of Objects and Processes
- Marcel Proust (1871 – 1922) “The voyage of discovery is not in seeking new landscapes but in having new eyes”
- Herbert Spencer (1820 – 1903) “There is a soul of truth in things erroneous”
- Paul Feyerabend (1924 – 1994) “I’m against method until I invent”
- Parmenides (500 B.C.E.) It exists, it does not exist, it cannot exist
Stanisław Leśniewski – logic of parts and wholes

• Key difference between set theory and Leśniewski’s Mereology (the name coming from Greek μέρος (meros), meaning part)
  • Set theory uses sets and elementhood, Mereology used wholes and parthood.
  • Sets are supposed to be abstract objects, mereological wholes are meant to be nominalistically (physical objects, or abstract concepts are mere names without corresponding reality (labeled by same term but have nothing in common but their name) – meaning physical objects exist and properties, traits, attributes, and numbers are not further things in the world but merely features of the way of considering the things that do exist.
  • The set of these stones is supposed to be an abstract object, while the mereological whole composed of these stones is just a heap of stones.

Parts and Wholes are Not hierarchical, Not a decomposition
BEWARE - Set Theory Disregards Emergence

Decomposition
To Break Down

Recomposition
To Restore

Must Incorporate Emergence

Objects Interact to Create Emergence – regardless of system or notasystem

- Some Emergence Is Useful; We Call Useful Emergence *function*
- Useful Emergence can be measured and quantified
- Set Theory Ignores Non-useful Emergence

https://www.colourbox.com
Systems Theory is Hierarchical, So is Systems Engineering.

OOPS …. PROBLEMS

• What is the hierarchical structure of a human? What is the most abstract part of a human? Then? And then?

Bone is parts and whole with:
• Brain
• Nerves
• Ligaments
• Skeletal muscles
• Blood vessels
• White blood cells
• Red blood cells
• Calcium and phosphate ions
• More (if I knew more)
Definitions of Systems Proliferate and Homogenize (equilibrate by mixing) With Other Definitions

- James G. Miller “Living Systems” 1978
  - “A system is a set of interacting units with relationships among them.”

- Flood & Carson 1993
  - “A system is a set of related elements in an organised whole.”

- Ackoff 1981
  - “A system is a whole that cannot be divided into independent parts.” (emergence)

- Flood & Carson 1993
  - Emergence – something that happens when the whole is greater than the sum of its parts.

- von Bertalanffy 1940s – 1970s
  - Homologies (quality of being similar) exist between disciplines

  Is the Solar System random, unorganized? How about an electron, a complex molecule, a galaxy?

  Is a crystal unorganized? How about a rock, a neatly stacked pile of wood?

  Is a metal bookcase a whole that cannot be divided into independent parts? Bookcase = System?

  Is a whole never not greater than the sum of its parts? YES A WHOLE IS ALWAYS GREATER!

  BUT YES! ALL SYSTEMS ARE HOMOLOGOUS.
Langfordian Research Paradigm to Find the Soul of Systemness

* Energy, Matter, Material wealth, Information
A system is a coalesced neighborhood of objects bounding behaviors that are metastable, have internal agility, external adaptiveness, and irreversible/nonreciprocal emergence.

**ASSUMPTIONS**
- Quarks to galaxies are comprised of atoms and molecules
- Order and Disruption co-exist at all scales

**HYPOTHESES**
- Same core systemic behaviors occur from quantum to galaxies
- These same core mechanisms always result in systems

**FINDINGS**
- Object/Process Ontologies Predict Systems
- Interaction of EMMI creates emergence and builds systems
- Self-preservation implies synchronization and self-adaption
- Systemic behavior is controlling and irreversible
- Systems exist throughout the spectrum of scale
- ALL Systems satisfy the exact same four conditions
- Systems - 3 boundary types (physical, functional, behavioral)
- Notasystem behavior not controlling or adaptive (only physical)

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<table>
<thead>
<tr>
<th>Prefix</th>
<th>Sci. Not. (m)</th>
<th>Object</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yotta-</td>
<td>$10^{24}$</td>
<td>Universe radius</td>
</tr>
<tr>
<td>Zetta-</td>
<td>$10^{21}$</td>
<td>Magellanic Clouds</td>
</tr>
<tr>
<td>Exa-</td>
<td>$10^{18}$</td>
<td>Near stars</td>
</tr>
<tr>
<td>Peta-</td>
<td>$10^{15}$</td>
<td>Planetary Debris</td>
</tr>
<tr>
<td>Terra-</td>
<td>$10^{12}$</td>
<td>Saturn to Sun</td>
</tr>
<tr>
<td>Giga-</td>
<td>$10^9$</td>
<td>Sun diameter</td>
</tr>
<tr>
<td>Mega-</td>
<td>$10^6$</td>
<td>Lunar diameter</td>
</tr>
<tr>
<td>Kilo-</td>
<td>$10^3$</td>
<td>Mt. Everest</td>
</tr>
<tr>
<td>Deka-</td>
<td>$10^2$</td>
<td>Eiffel Tower</td>
</tr>
<tr>
<td>BASE</td>
<td>$10^1$</td>
<td>Statue of Liberty</td>
</tr>
<tr>
<td>Deci-</td>
<td>$10^{-1}$</td>
<td>Compact disk dia.</td>
</tr>
<tr>
<td>Centi-</td>
<td>$10^{-2}$</td>
<td>Credit Card dim.</td>
</tr>
<tr>
<td>Milli-</td>
<td>$10^{-3}$</td>
<td>Finger width</td>
</tr>
<tr>
<td>Micro-</td>
<td>$10^{-6}$</td>
<td>Bacterium length</td>
</tr>
<tr>
<td>Nano-</td>
<td>$10^{-9}$</td>
<td>DNA length</td>
</tr>
<tr>
<td>Pico-</td>
<td>$10^{-12}$</td>
<td>Water molecule</td>
</tr>
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<td>Femto-</td>
<td>$10^{-15}$</td>
<td>Electron radius</td>
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<td>Atto-</td>
<td>$10^{-18}$</td>
<td>Quarks</td>
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<tr>
<td>Zepto-</td>
<td>$10^{-21}$</td>
<td></td>
</tr>
<tr>
<td>Yocto-</td>
<td>$10^{-24}$</td>
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</tr>
</tbody>
</table>

Define a System by Conditions

http://www.cyclingweekly.com
http://www.daytonairshow.com
http://www.theengineeringworld.weebly.com
http://www.mbmahiquesarch.wordpress.com
http://www.southbaytraps.com
http://www.bestbuy.com
http://www.cnet.com
http://www.amazon.com
http://www.walmart.com
http://www.evergreenartsupply.com
http://www.physics.appstate.edu
http://www.cyclingweekly.com
http://www.daytonairshow.com
http://www.theengineeringworld.weebly.com
http://www.mbmahiquesarch.wordpress.com
http://www.southbaytraps.com
http://www.bestbuy.com
http://www.cnet.com
http://www.amazon.com
http://www.walmart.com
http://www.evergreenartsupply.com
http://www.physics.appstate.edu
Four Patterns of Object Behaviors Form *The Conditions for Systemsness*

- **EMMI**
- **Metastability**
- **Internal Agility**
- **External Adaptability**
- **Nonreciprocal Or Irreversible Emergence**

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I am an acquired flavor. Not everybody has to like me. I can’t force you to have good taste.

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Gary Langford
### Conditions for Systemic Operations

<table>
<thead>
<tr>
<th>Objects</th>
<th>Dynamic stability</th>
<th>Internal Agility</th>
<th>External Adaptability</th>
<th>Irreversibility $^+$</th>
<th>Nonreciprocility $^@$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rock, Paper, Scissors</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Building-old</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Bicycle (no control)</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Pendulum – simple</td>
<td>Yes, w/displacement</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Light Emitting Diode/μP</td>
<td>Yes-w/power on</td>
<td>Yes-w/power on</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Galactic Nebulae</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Bicycle (moving)</td>
<td>Yes-w/power-control</td>
<td>Yes-w/power-control</td>
<td>Yes-w/power-control</td>
<td>Yes-w/power on</td>
<td></td>
</tr>
<tr>
<td>Building-“green”</td>
<td>Yes-w/power-control</td>
<td>Yes-w/power-control</td>
<td>Yes-w/power-control</td>
<td>Yes-w/power on</td>
<td></td>
</tr>
<tr>
<td>Computer-powered</td>
<td>Yes-w/power-control</td>
<td>Yes-w/power-control</td>
<td>Yes-w/power-control</td>
<td>Yes-w/power on</td>
<td></td>
</tr>
<tr>
<td>Airplane / Ship</td>
<td>Yes-w/power-control</td>
<td>Yes-w/power-control</td>
<td>Yes-w/power-control</td>
<td>Yes-w/power on</td>
<td></td>
</tr>
<tr>
<td>Automobile-computered</td>
<td>Yes-w/power-control</td>
<td>Yes-w/power-control</td>
<td>Yes-w/power-control</td>
<td>Yes-w/power on</td>
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<tr>
<td>Atom</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Living Tree</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Living Animal</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Today’s Earth</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Solar Orbiting Objects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>

* $^+$ Natural
  $^@$ Artifactual
Living Systems Behaviors

• All living systems tend to maintain steady states of many variables, keeping orderly balance among subsystems

• Systems also ordinarily maintain steady states with their environments and suprasystems, which have outputs to the systems and inputs from them

• Boundary – at the perimeter of a system that holds together the components which make up the system, protects them from environmental stresses, and excludes or permits entry to various sorts of matter-energy and information
Matter – Energy Transduction Functions

Ingestor → Distributor → Converter → Producer → Supporter

Converter → Reproducer → Storer → Extruder

Motor

Input Transducer → Internal Transducer → Channel And Net → Timer

Channel And Net → Decoder

Encoder → Decider → Memory

James Miller
17 Aug 1987
The World of Systems is Quite Different Than Most Believe, but…

• Models might be good enough depending on boundary conditions to pass disruptive Energy, Matter, Material Wealth, and Information

• Representations might be strong enough if the value ensconced is neither very large nor important

• Watch for emergence that causes catastrophic failures (evaluate all interactions)

• Be wary of potential black swan events (design for limits that govern acceptable performances and behaviors)

• Manage constraints by continually monitoring the losses of EMMI throughout the system or system of systems
Hiccup Charts – a minor difficulty or problem
Key difference between set theory and Leśniewski’s Mereology (parts and wholes)

- Languages of formal systems are abstract sets of formulas, for Leśniewski only written instructions existed as to how new inscriptions should be constructed to count as formulas of the language and those inscriptions.
- Normally, proofs and theorems of formal systems are taken to exist, no matter whether they have been discovered or written down, for Leśniewski only those proofs and theorems exist, which have been written down.
- Thus, for Leśniewski the context of a concrete object changes with time as additional formulas are written down.
- If we think about mereological wholes rather than abstract sets, we must find a correlate of the parthood relation.
Stanisław Leśniewski – logic of parts and wholes

• Key difference between set theory and Leśniewski’s Mereology (parts and wholes)
  • For Leśniewski, the essence of parts and wholes is being an ingredient, where each object is its own ingredient and each part of an object is among its ingredients.
    • If being an ‘element of’ is being a ‘part of’ and each object is by definition its own part, each object is its own element. This logic has two consequences:
      • There is no empty class. For a class to be empty, it would have to have no elements. But we know it is impossible, because it is its own element,
      • There are no things that are not their own elements.
  • An object \( a \) is a group of \( bs \) (things that belong together and are so used) if and only if every one of \( a \)’s parts has a part that is a part of an object that is \( b \). [Leśniewskian Definition]
    Meaning the mereological whole constituted by all people in Portland is a group of people, because every one of its ingredients has an ingredient which is an ingredient of a person in Portland.
Why is the definition a rather complicated formulation of parthood?

Consider what would happen if the Leśniewskian definition required only that every ingredient of $a$ be an ingredient of an object which is $b$. Then, the mereological whole constituted by all people in Portland would not be a group of people, because Portland would have ingredients, like the mereological fusion of one person’s leg and another person’s right hand, which would not be ingredients of any particular person.

Note, that the indefinite article in ‘is a group’ is there not without a purpose. That purpose is to indicate that each part has an integral relation without which the whole would be a different whole.

Also according to the Leśniewskian definition, one countable object may generate many different groups. Every mereological whole constituted by some objects $b$ (i.e., by some objects denoted by the countable noun phrase ‘$b$’) is a group of $b$, although choosing different representatives (or groups of representatives) of $b$ we get different mereological wholes.
Stanisław Leśniewski – logic of parts and wholes

• Any heap of stones is a group of stones in the sense of the Leśniewskian Definition – An object \( a \) is a group of \( bs \) (things that belong and are so used together) if and only if every one of \( a \)'s ingredients has an ingredient that is an ingredient of an object that is \( b \).

• Therefore, if \( a \) names more than one object, the name \( \text{group}(a) \) also names more than one object. It names any mereological whole built from some objects that fall under \( a \).

• Leśniewski defined the maximal group of objects \( a \), that is the group of all \( as \), i.e., the notion of class.
  • Class is described through the properties and traits of their elements.

\[
\begin{align*}
(a) & \quad \text{The class } [z \mid z \text{ is a } \varphi\text{-er}] \text{ exists only if there is at least one } \varphi\text{-er.} \\
(b) & \quad \text{One and the same object can be identical with classes of different objects. For example, with reference to Figure 1, we have both } AD = [AB, BD] \text{ and } AD = [AB, BC, CD] \text{ (hence } [AB, BD] = [AB, BC, CD]). \\
(c) & \quad \text{If } x \text{ is the only } \varphi\text{-er, then } x = [z \mid z \text{ is a } \varphi\text{-er}] = [x]. \\
(d) & \quad \text{If } y \text{ is a class, then } x \sqsubseteq y \text{ iff, for some } \varphi, x \text{ is a } \varphi\text{-er and } y = [z \mid z \text{ is a } \varphi\text{-er}].
\end{align*}
\]

origin of the notion of mereological “sum”
References


Critical Subsystems of Living Systems-1

• Ingestor – brings matter-energy across system boundary from the environment
• Distributor – carries inputs from outside the system or outputs from its subsystems around the system to each component
• Convertor – changes certain inputs to the system into forms more useful for the special process of that system
• Producer – forms stable associations that endure for significant periods among matter-energy inputs to the system or outputs from its converter, provides energy for moving and other functions
• Matter-energy storage – retains in the system, for different periods of time, deposits of various sorts of matter-energy
• Extruder – transmits matter-energy out of the system in the forms of products or wastes.
• Timer – provides a clock reference
Critical Subsystems of Living Systems-2

- **Motor** – moves the system or parts of it in relation to part or all of its environment or moves components of its environment in relation to each other

- **Supporter** – maintains the proper spatial relationships among components of the system, so that they can interact without weighting each other down or crowding each other

- **Input transducer** – brings observable bundles of matter-energy bearing information into the system, changing them to other matter-energy forms suitable for transmission within it

- **Internal transducer** – receives, from subsystems or components within the system, markers bearing information about significant alterations in those subsystems or components, changing them to other matter-energy forms of a sort which can be transmitted within it

- **Channel and net** – composed of a single route in physical space, or multiple interconnected routes, by which markers bearing information are transmitted to all parts of the system
Critical Subsystems of Living Systems-3

• Decoder – alters the code of information input to it through the input transducer or internal transducer into a “private” code that can be used internally by the system

• Associator – carries out the first stage of the learning process, forming enduring associates among items of information in the system

• Memory - carries out the second stage of the learning process, storing various sorts of information in the system for different periods of time

• Decider – receives information inputs from all other subsystems and transmits to them information outputs that control the entire system

• Encoder – alters the code of information input to it from other information processing subsystems, from a “private” code used internally by the system into a “public’ code which can be interpreted by other systems in its environment
Critical Subsystems of Living Systems-4

• Output transducer – puts out markers bearing information from the system, changing markers within the system into other matter-energy forms which can be transmitted over channels in the system’s environment.

• Reproducer – capable of giving rise to other systems similar to the one it is in.

• Boundary – at the perimeter of a system that holds together the components which make up the system, protects them from environmental stresses, and excludes or permits entry to various sorts of matter-energy and information.
Relationships Among Subsystems

• Structural relationships
  • Containment in boundaries

• Temporal relationships
  • Containment in time
  • Simultaneously operating subsystems

• Spatial-temporal relationships
  • Action - a subsystem by transmission of matter-energy brings about an action on the part of another subsystem
  • Communication – transmission of information from one subsystem to another
Metastability in

How does 2-ff synchronizer ensure proper synchronization?

Using 2-ff synchronizers has been a standard for a signal to cross clock boundaries. And there are lots of paper/figures illustrating the mechanism, such as this one.

It seems \texttt{bclk} can only sample the pulse of \texttt{adat} once (at the second rising edge of \texttt{bclk}), which causes output metastability on \texttt{bq1_dat}. How can \texttt{bq1_dat} be sampled "high" on the next active clock edge?
