

Thinking About "Systems of Systems"

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My Objectives Today

- Challenge your thinking
- Admire the problem
- Suggest some definitions
- Foster dialog



On Systems Thinking

Systems thinking is a discipline for seeing wholes. It is a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static “snapshots.” ... And systems thinking is a sensibility — for the subtle interconnectedness that gives living systems their unique character.

Peter Senge

Basic Questions

- How does a Systems of Systems differ from a System?
 - Is this a new class of systems?
- Do we have to address a Systems of Systems in a different way?
 - Does traditional "top-down" Systems Engineering scale-up?
- Are there "new" techniques that help us deal with SoS challenges?

***There are more things in heaven and earth, Horatio,
Than are dreamt of in your philosophy.***

-- William Shakespeare, *Hamlet* (I, v, 166-167)

SoS Engineering: DoD Definition

System of systems engineering deals with planning, analyzing, organizing, and integrating the capabilities of a mix of existing and new systems into a system of systems capability greater than the sum of the capabilities of the constituent parts.

DoD Acquisition Deskbook on line, November 2004

What's new about SoS?

- A problem that nobody "owns"
- Systemic properties are primary
- System level properties easily altered
- Component systems are self-sustaining and purposeful *without* the SoS
- Realization via evolution through "stable" states
- People, business, and other enabling systems are as important as technical systems

Results from NDIA

- Top five issues in systems engineering include:
 - Lack of awareness of the importance, value, timing, accountability, and organizational structure of systems engineering on programs - *Systems engineering has not adequately demonstrated the ability to operate beyond the technical level of enterprise problems.*
 - Adequate, qualified resources are generally not available within government and industry for allocation on major programs - *A new type of systems engineer, skilled in understanding and resolving complex systems problems must be developed and made accessible.*
 - Insufficient systems engineering tools and environments to effectively execute systems engineering on programs - *Tacit recognition that the environment, as well as the supporting tools, must be developed to address emerging systems engineering problems.*
 - Requirements definition, development and management is not applied consistently and effectively - *Requirements are a necessary function of effective systems engineering; however, requirements must be developed from a holistic systems perspective. They must consider the wide array of organizational, managerial, and contextual constraints influencing complex system development - not simply technological constraints.*
 - Poor initial program formulation practices put successful execution at risk - *For complex systems engineering problems, effectiveness in the systems engineering contribution is most important in initial formulation, but required throughout the initiative.*

System(s) of Systems Examples

- The U.S. Intelligence Community
- DoD's "Persistent Surveillance" C4ISR System
- The transportation system in the tri-state metropolitan area

- What else?
 - A gas turbine engine?
 - An aircraft carrier?
 - The USA?

Suggested SoS Attributes

- An assemblage of systems, each capable of and often practicing a separate, independent existence (*autonomy*);
- The prospective component systems are self-sustaining and purposeful *without* the SoS, and that pursuit of purpose should not necessarily be attenuated (*belongingness*);
- The systems comprising the SoS can be connected and reconnected to produce different, and often unanticipated, effects making the SoS adaptive (*connectedness*);
- The systems comprising the SoS invariably exhibit enormous diversity, in essence and in utility and this can be both an advantage and a limitation (*diversity*);
- The SoS exhibits the property of "emergence," which means that there are properties characteristic of the SoS that are irreducible and not evident in the component systems (*emergence*).

Traditional Systems Engineering versus SoS Engineering

| <u>Traditional Systems Engineering</u> | <u>SoS Engineering</u> |
|---|---|
| <ul style="list-style-type: none">• Based on principle of well-defined authority and control<ul style="list-style-type: none">• <i>Requirements allocated by a Systems Engineer</i>• <i>Requirements controlled through a Configuration Control process</i> | <ul style="list-style-type: none">• Based on emergent properties of multiple independent solutions (control paradox)<ul style="list-style-type: none">• <i>No single Chief Systems Engineer</i>• <i>No single Configuration Control process</i>• <i>Multiple "owners"</i> |
| <ul style="list-style-type: none">• Designed to address a bounded, constrained problem<ul style="list-style-type: none">• <i>Stable requirements are essential</i> | <ul style="list-style-type: none">• Designed to address broadly scoped problems and evolving needs<ul style="list-style-type: none">• <i>Component systems contribute to SoS capabilities (intelligence paradox)</i>• <i>Interoperability is a major consideration (collective paradox)</i> |
| <ul style="list-style-type: none">• Success is determined by how well the designed <u>system</u> meets the <u>requirements</u> | <ul style="list-style-type: none">• Success is determined by how well the <u>solution</u> delivers <u>capability</u> to the customer |

Paradox

"A paradox is an apparent contradiction; however, things are not always as they seem. A Paradox can be explained, but only by seeking wisdom from above.

For the systems guy this is to look up and out, not just down and in. Paradoxical thinking is systems thinking at its best."

Dr. John Boardman

"Control" Paradox

You have to have command and control in order to ensure orderliness and conformity to strategic direction.

BUT, you have must also NOT have command and control to foster innovation, tactical opportunism and preservation of self-awareness.

Answer: creative disobedience, reciprocal loyalty, and ordered liberty enables both systems to operate not in conflict but in intelligent use of each.

Centralization breeds confusion, hesitation, and inactivity among subordinates denied initiative in expectation of a command.

Admiral Horatio Nelson

"Collective" Paradox

A system is a collection of entities assembled in such a way that the whole is greater than the sum of the parts. The parts belong so as to serve the purpose of the whole.

BUT, this purpose is not well served if the parts belong for that reason alone, since heterogeneity enhances the purpose of the whole beyond the sum of the parts. Yet, diversity among parts must never jeopardize belongingness to the whole. Thus a tension is set up between autonomy and dependence.

Answer: in order for a whole to be fulfilled, parts must belong, and yet they must maintain diversity for true fulfilment of the whole's purpose.

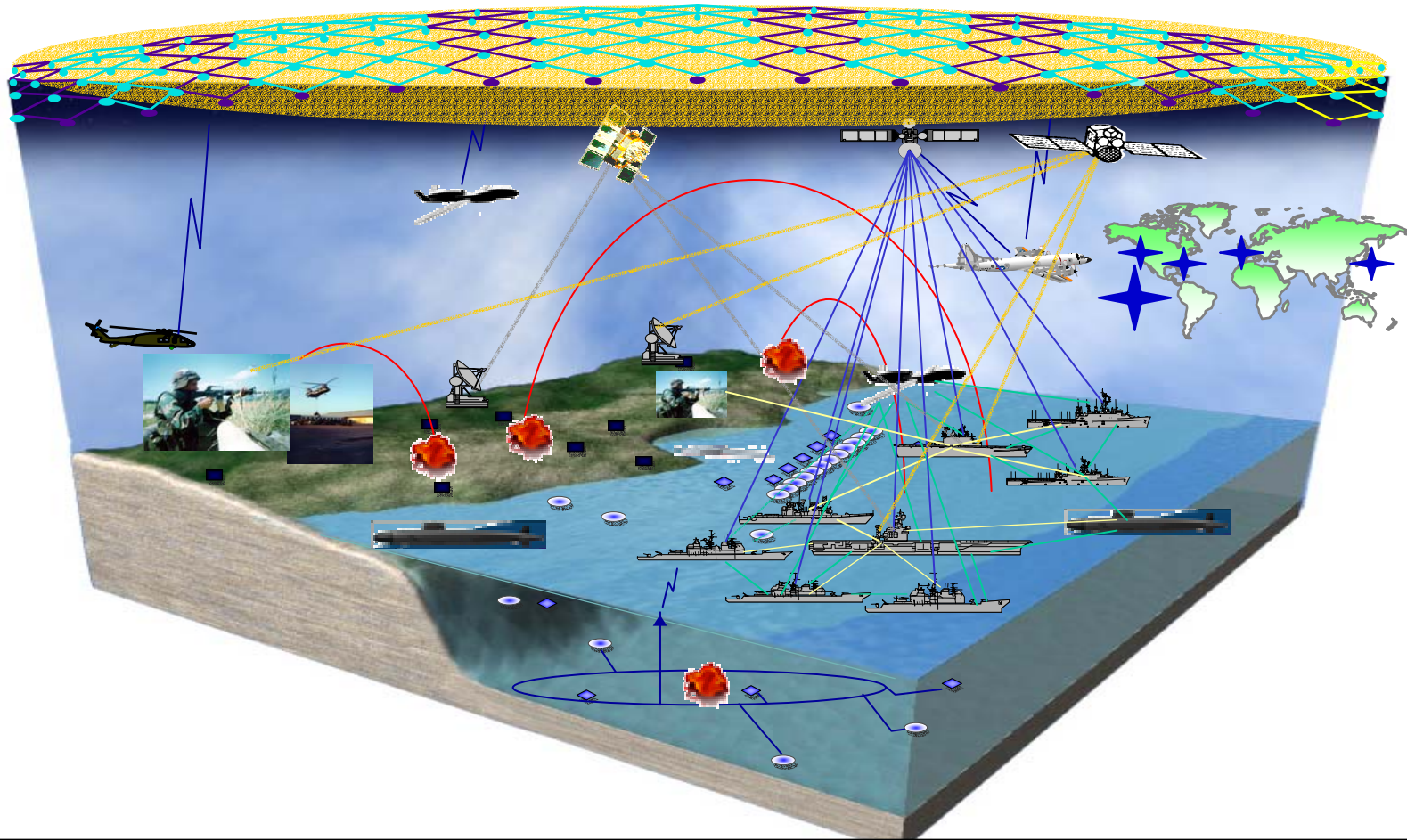
"Intelligence" Paradox

You have to have prescience in order to make sound preparations, execute orderly planning, consider risk mitigation, and ensure effective communication of the agenda.

BUT, you must also allow for emergence, which is a feature of self-organization, self-sustainment, collective intelligence, and subordination of self to whole.

Answer: recognize that prescience is not omniscience.

A Specific Example



“FORCENet is the operational construct and architectural framework for Naval Warfare in the Information Age which integrates Warriors, sensors, networks, command and control, platforms and weapons into a networked, distributed combat force, scalable across the spectrum of conflict from seabed to space and sea to land.”*

**CNO's Strategic Study Group - XXI definition from 22 July 02 CNO Briefing*

Why is this hard?

- Emergence
 - How does functional decomposition deal with properties that are only apparent at the SoS level?
- Abstractness
 - How do you have a conversation about a SoS that does not exist in the physical domain?
- Lack of "ownership" at the SoS level
 - Who controls the Intelligence Community at the SoS level?

When a system is taken apart, it loses its essential properties.

Russell Ackoff



On Optimization

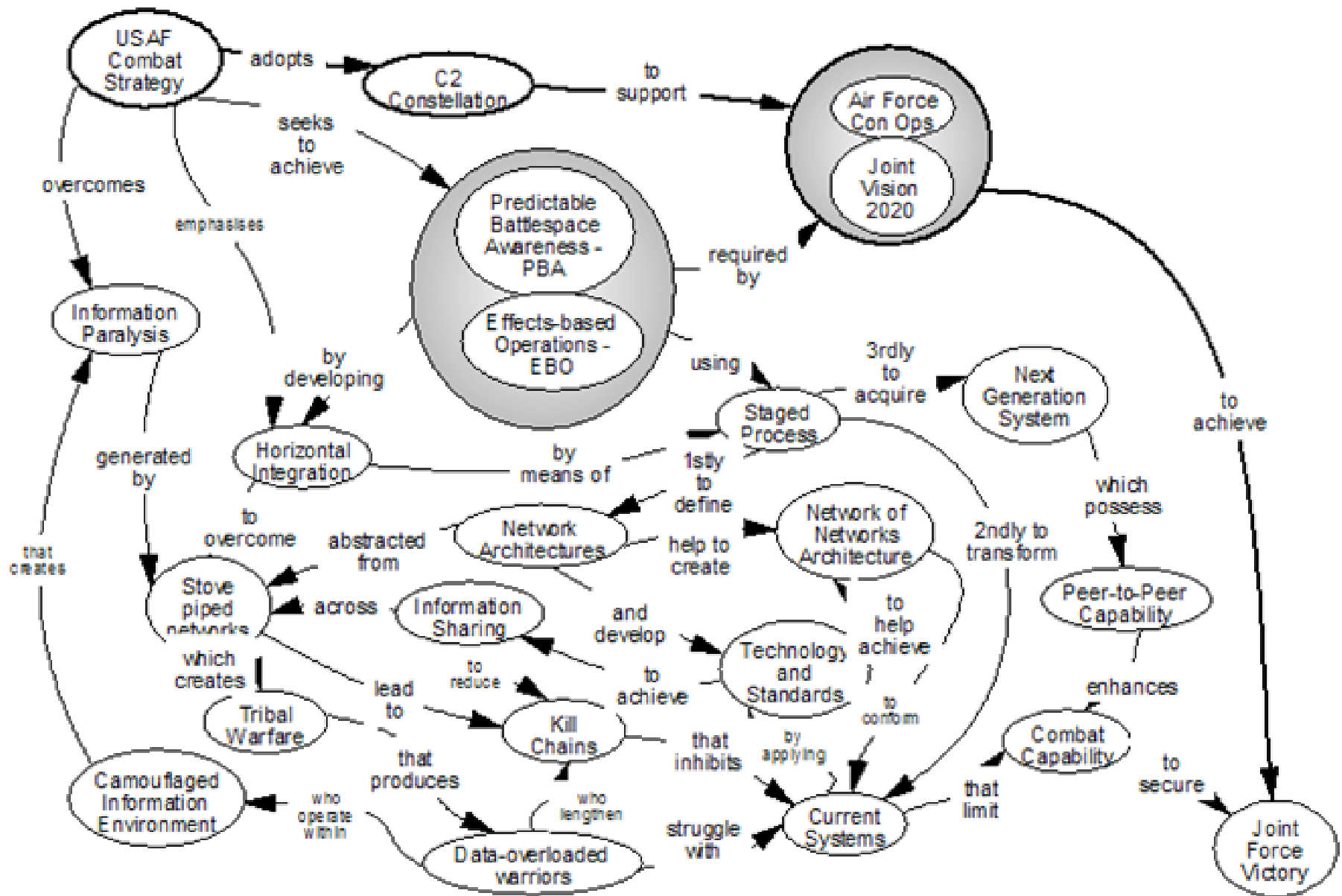
"To optimize the whole, we must sub-optimize the parts."

W. Edwards Deming, Statistician, (1900-1993)

Can Basic Systems Concepts Help?

- Boundary, Interior, Exterior
- Wholes, Parts, Relationships
- Inputs, Outputs, Transformations
- Structure, Function, Process
- Emergence, Hierarchy, Openness
- Requisite variety, Parsimony, Harmony

Are there better ways of thinking about a SoS?



Conclusions

- You have to think differently about SoS
- SE 101 methods are insufficient to grapple with SoS challenges
 - You must address the SoS at a conceptual level
 - SoS “ownership” issues can’t be ignored



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