

Systems of systems: Answering the organizational implications

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Abstract

Last year you heard the problems and this year you can hear the solutions, and working together in this session tailor the answer to your particular organizations, customers, and what you are trying to optimize. Less of death by PowerPoint and more interactive problem-solving using a library of long-standing tools and methods. Most of the organizational-related problems of SoS have been solved in other settings, so this tutorial seeks to marry the well-known solutions to your specific issues. The format will be question and (long) answer; participants should be prepared to describe their environments and concerns, and then the guide will expose the whole group to what successful organizations have done to address those very subjects. Most of the material will be new to the participants because it comes from sources outside of our usual engineering, science, and technology backgrounds. One objective of the tutorial will be to equip participants with a lens with which to best see organizational dynamics and leverage points. Remember: some problems that look technical, such as requirements allocation, are usually results of how engineers are organized. Participants will leave not only with the answers to their own questions and the others' in the room, but also a deeper understanding of approaches that are off of our usual radars, outside of our normal experience-base – along with advice about where to look in the future as new organizational challenges arise.

There is nothing to sell here.

Acknowledgments

- Lisa Brownsword, Software Engineering Institute, for presenting “Organizational Implications of Systems of Systems” at last year’s conference.
- Drs. Jo Ann Lane & Barry Boehm, Center for Systems & Software Engineering, University of Southern California, for addressing the hard problems of SoS.
- NDIA Systems Engineering Division for providing this forum for listening & learning.

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Who are you? What are your expectations?

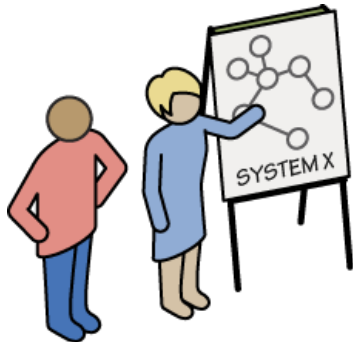
Policy Maker?



Portfolio Manager?



Chief Systems Engineer?



Program Manager?



Engineering Technical Lead?

Other???



End User?

What are Systems of Systems?

Coalition Forces in Operational Context Example

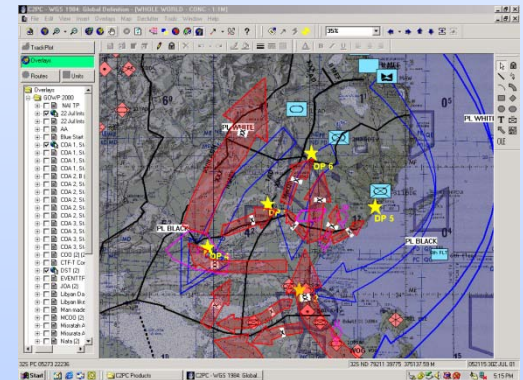
A collaboration among technical systems and organizational (people) systems...



...in relation to some use

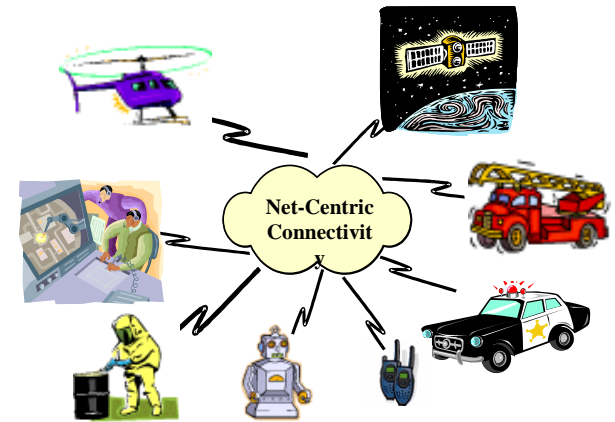


...within a changing, unpredictable context



What is a “System of Systems”?

- Very large systems using a framework or architecture to integrate constituent systems (CSs)
- Exhibits emergent behavior not otherwise achievable by CSs
- SoS CSs
 - Independently developed and managed
 - New or existing systems in various stages of development/evolution
 - May include a significant number of COTS products
 - Have their own purpose
 - Can dynamically come and go from SoS
- Typical domains
 - *Military/Crisis Response*: Dynamic communications infrastructure



Types of System of Systems

Focus for this tutorial



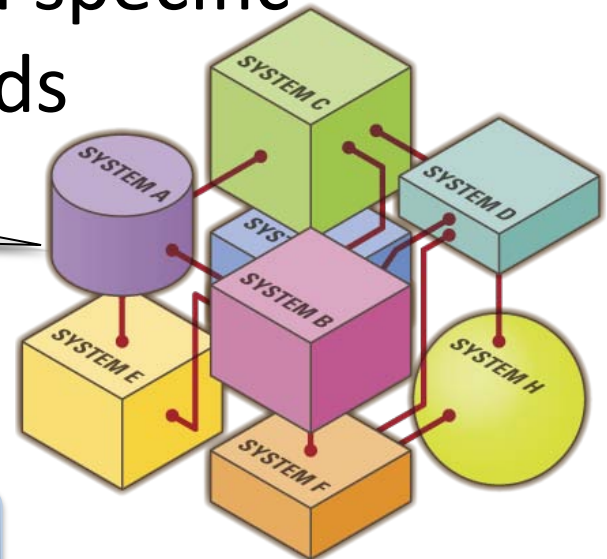
	Directed	Acknowledged	Collaborative	Virtual
Management authority	Centrally managed One stakeholder has dominance	A designated manager and resources One stakeholder given dominance	Central stakeholders collectively decide how to provide or deny service Relatively few dominant stakeholders	No central authority Many stakeholders, none dominant
SoS purpose	Systems are integrated and built to fulfill specific purposes	Recognized objectives Changes negotiated between the SoS and the constituent systems	System constituents voluntarily agree to fulfill central purposes	No centrally agreed purpose; large-scale behavior emerges from constituent systems able to integrate
Independence of constituent systems	None	Retain independent ownership	Retain independent ownership	Retain independent ownership

Source of SoS types: DoD System Engineering Guide for System of Systems Engineering (Version 1, August 2008)

Multiple Perspectives on System of Systems -1

- An SoS is a collection of integrated and interoperable hardware and software entities providing capabilities that fulfill specific functional and operational needs

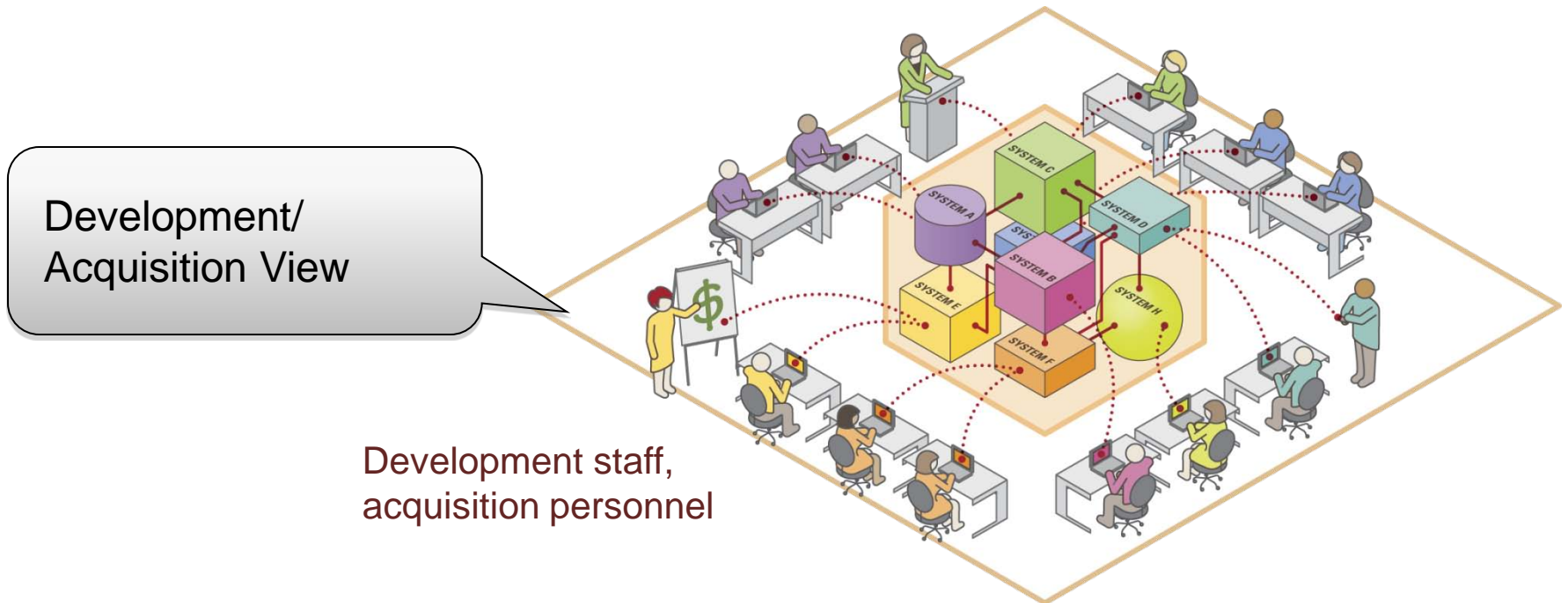
Technical View



But ... systems of systems are more than interoperating hardware and software systems

Multiple Perspectives on System of Systems -2

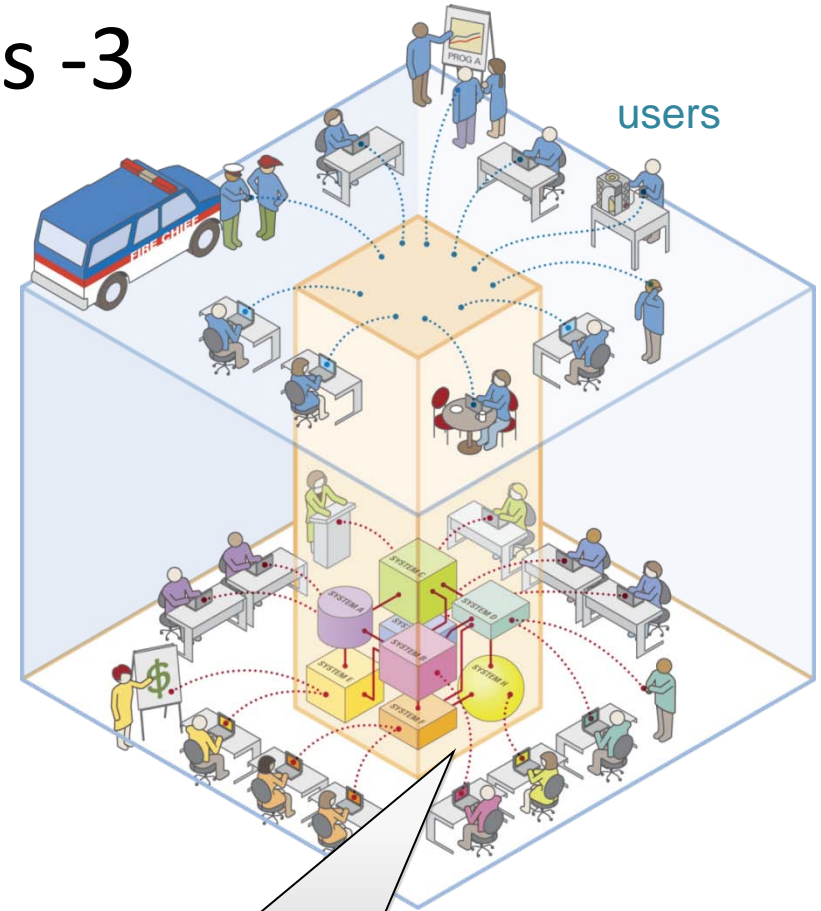
- An SoS is a collection of people and organizational entities involved in acquiring and composing “systems of systems” that provide capabilities to fulfill specified functional and operational needs



People systems are as important as technical systems

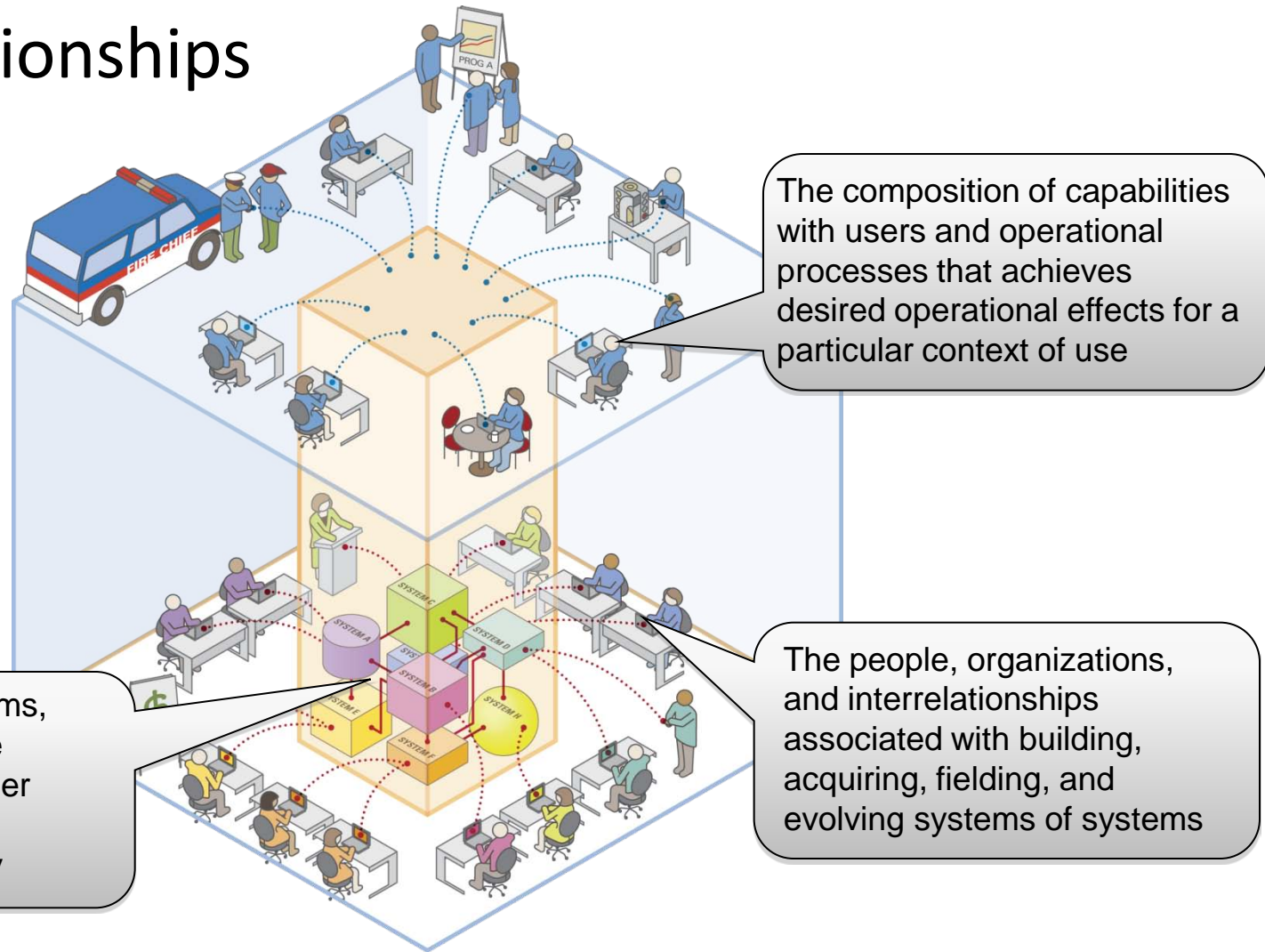
Multiple Perspectives on System of Systems -3

- An SoS provides capabilities that enable a collection of operational users to achieve the effects they need to meet their business/mission goals
 - Evolves to enable dynamically changing operational effects within the operational user's context of use
 - Is likely to use technical and organizational assets outside of the original design context



Operational Effects/
Users View

Key Point: Systems of Systems Result from Interrelationships



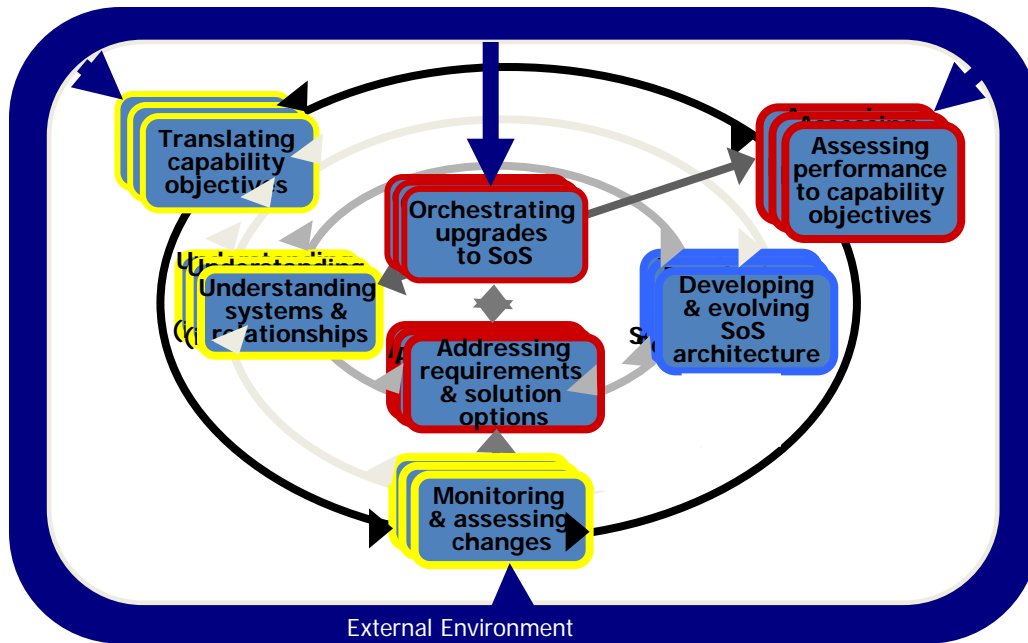
Key Point: Systems of Systems Involve Social AND Technical Networks

- Systems of systems involve understanding the networks of social and technical systems
 - Paying insufficient attention to the social systems in which technical systems operate is a common failure pattern
 - Social systems are open and non-deterministic in nature and require different approaches than many technical systems

Key Points

- There are four major types of SoS patterns identified by the US DoD that are useful for profiling SoS types
 - Directed
 - Acknowledged
 - Collaborative
 - Virtual
- Relationship characteristics are useful for creating these profiles of SoS
 - Relationships among stakeholders
 - Relationships among goals and purpose
 - Relationships among constituent systems
- [...]

SoS Engineering Activities for “Acknowledged” SoS



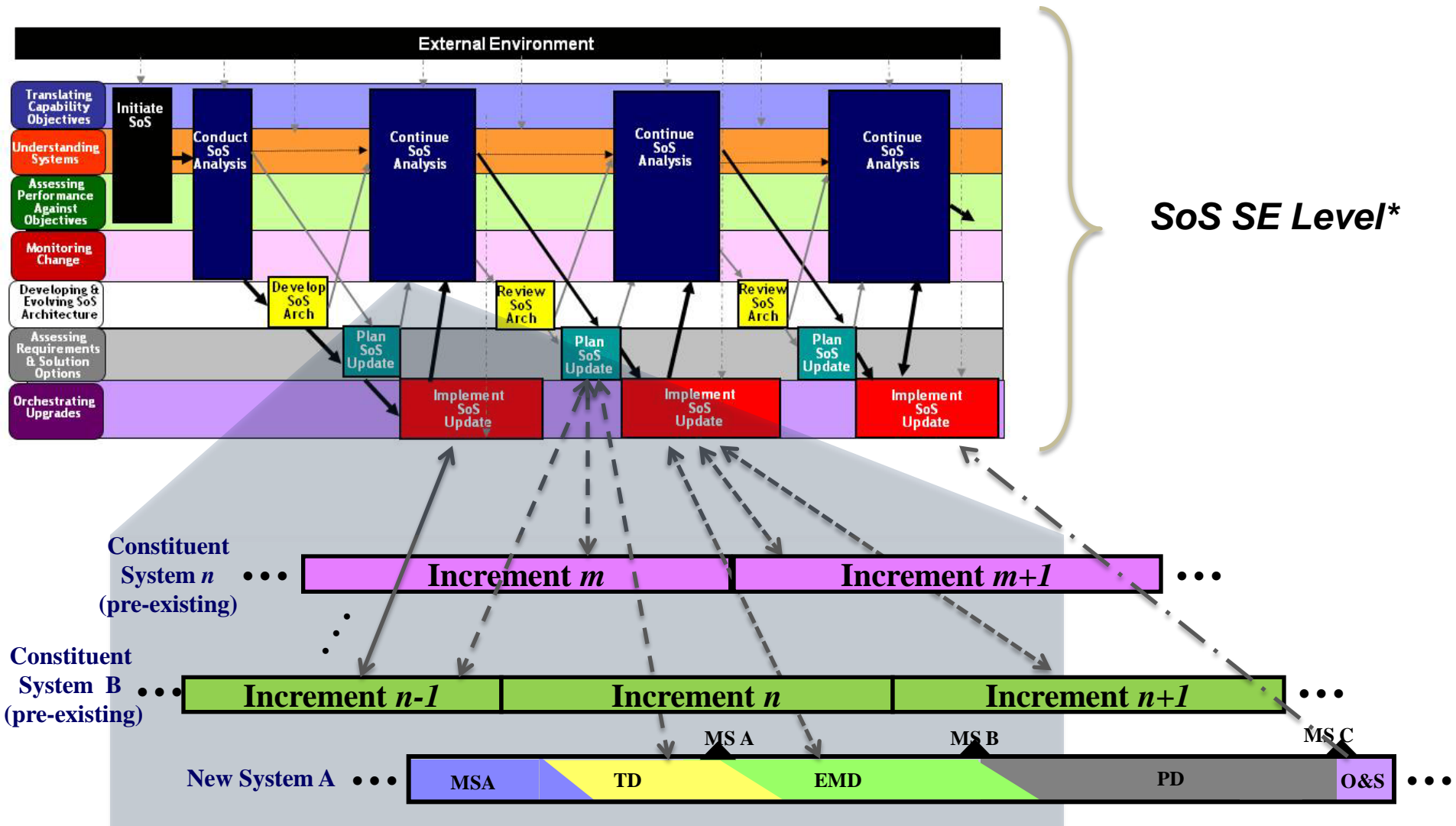
SoSE

(SoS Systems Engineering Guidebook View Based on Interviews and Analysis of 18 DoD SoSs in Various Stages)

•Key challenges

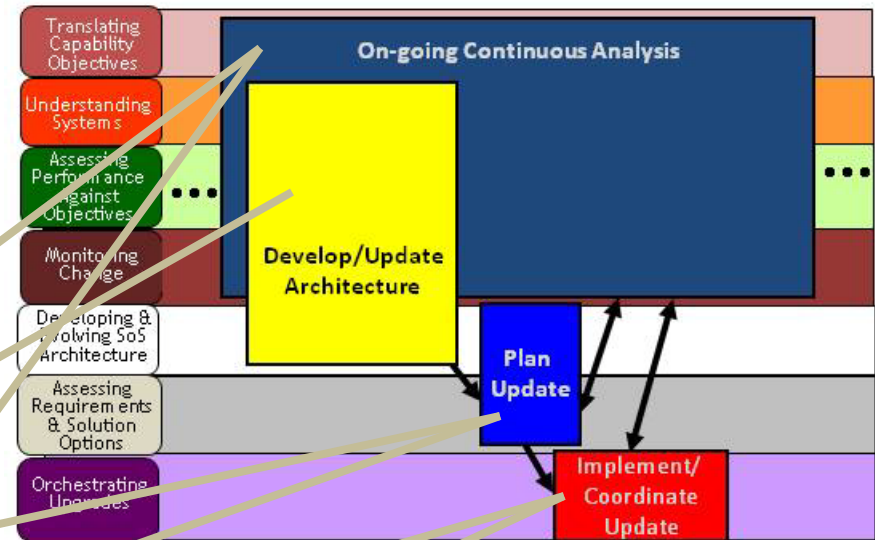
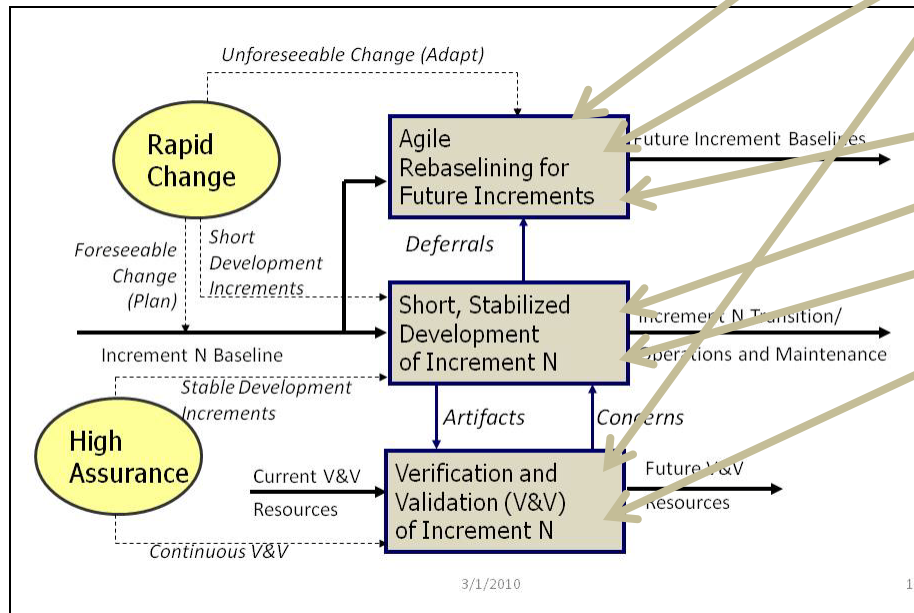
- Focusing CSs on SoS needs and capabilities
- Coordinating development of new capabilities across CSs
- Creating SoS roadmap to guide CS activities
- Testing SoS capabilities in an asynchronous development environment

SoSE Synchronization Challenges

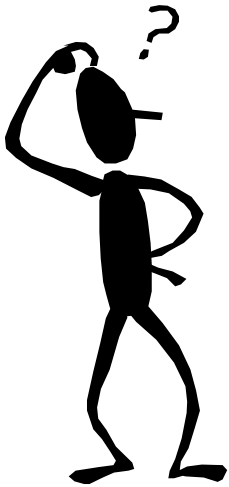


SoSE Process Strategies: Incremental Commitment Model for SoS

Clear “battle rhythm” for SoS incremental upgrades, driven by prioritized backlog of needed capabilities....



Constituent systems use their own lifecycle upgrade processes to integrate SoS requirements into their own incremental upgrade....



Complex vs. complicated

		Knowable?	
		Yes	No
Predictable?	Yes	Simple/Complicated	Complex
	No		Chaos

Simple – Easy to understand the parts.

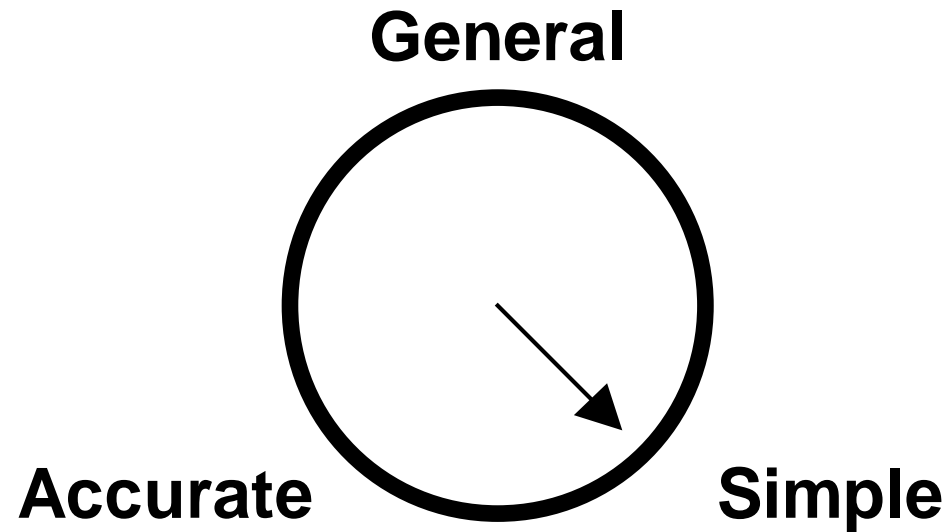
Complicated – Can understand the system by taking it apart, identifying its parts. The parts predict the behavior of the whole.
(Reductionism)

Complex – Can understand the parts, but they do not predict the behavior of the whole.

Chaos – Cannot identify the parts and cannot predict the behavior of the whole.

Why so much theory?

“There is nothing as practical as a good theory.” Kurt Lewin



Thorngate's one-armed clock

Problem of levels

- Cellular -- biology
- Individual -- psychology
- Collective: teams, groups, organizations, joint, “systems” -- sociology
- Religious, regional, national – anthropology

Take away: Often, we can make an inference at one level and it CANNOT be transferred to another.

Why?

They have different values for what is considered knowledge, research methods & basic assumptions.

Source: Burrell & Morgan

Mapping alternative world views

	"Normal Science"				"Pure Subjectivism"	
Core Ontological Assumption	reality as a concrete structure	reality as a concrete process	reality as contextual field of information	reality as realm of symbolic disclosure	reality as social construct	reality as projection of human imagination
Metaphors	machine	organism	hologram, brain	theater, drama	sense-making	transcendental
Human Nature Assumption	people are responders	people are adaptors	people are information processors	people are actors, symbol users	people are symbol creators	people are spirit, being
Epistemological Stance	construct a rational objective science, emphasizing networks of causal laws and rule-governed relations	study systems, process and change	map contexts to understand how actions and contexts mutually evolve over time	understand patterns of symbolic discourse; symbolic actions used to shape and make meaningful social reality	understand processes by which social reality is created and sustained	obtain phenomenological insights; get/receive revelations
Knowledge Generated	systematic laws to explain and predict	understanding the impact of context on organization	understanding mutual causality; causal loops	identification of typologies of symbolic actions	understanding of processes used to create org. reality	understanding of the contents of consciousness
Research Approaches	lab experiments, surveys	historical analysis	contextual analysis	symbolic interactions	semiotics, ethno-methodology	explore pure subjectivity

Adapted from: Hunt, James G. (1991). *Leadership: A new synthesis*. Sage.

How to think about organizing

- Around the problems in the environment?
- Around our solutions?
- How to be adaptable as those both change?



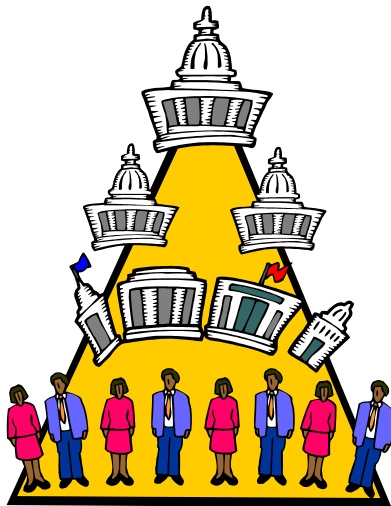
Is there an optimal way to organize?

- Yes:
 - In the contingency sense that you are taking into account all that is important, critical, makes a difference in the outcome.
 - Can be viewed as an optimization problem
(linear programming, per Burton & Obel, 1984):
 - Optimize this objective function, conditional on
 - These constraints
- No reason to think this is static.

Requisite variety – a way to organize due to Ashby (1956)

“The larger the variety of actions available to a control system,
the larger the variety of perturbations it is able to compensate.”

<http://pcp.lanl.gov/reqvar.html>



Environment



Organization

Only chaos can kill chaos.

Contingency approach

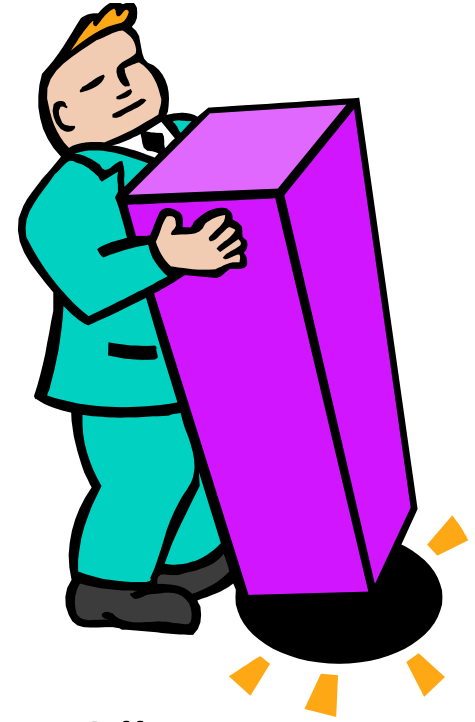
“What’s the best way to do x ?”

“Well, that depends!”

“Depends? Depends on what?”

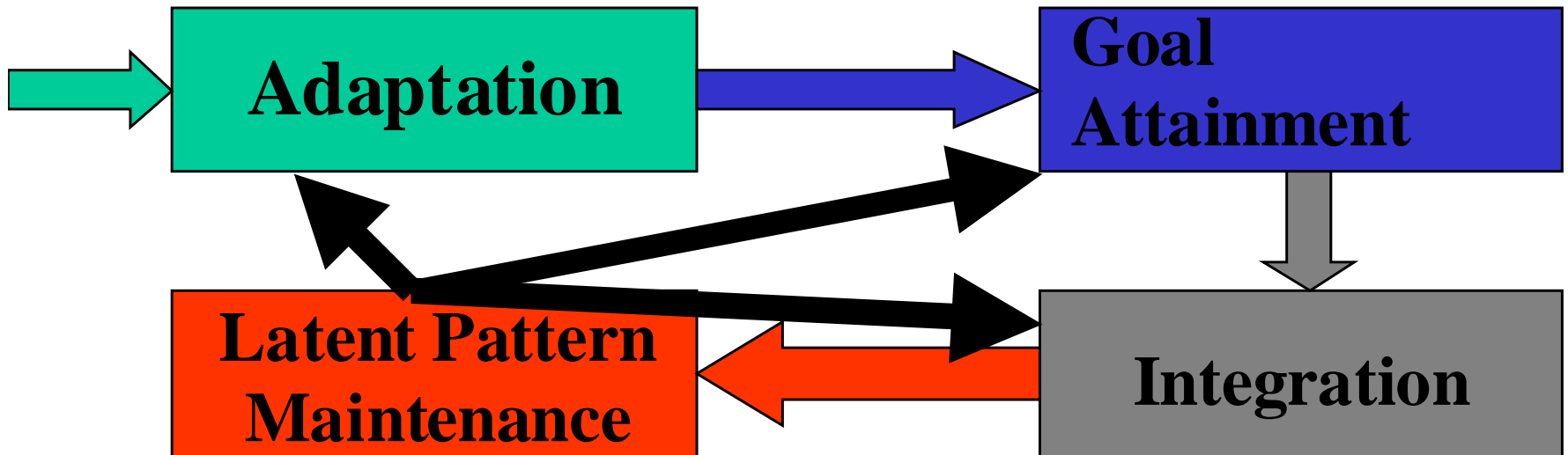
⇒ “One size does not fit all.”

⇒ “OK, then how many sizes are there?”



- Encyclopedia of contingency: Burton & Obel, 2003.

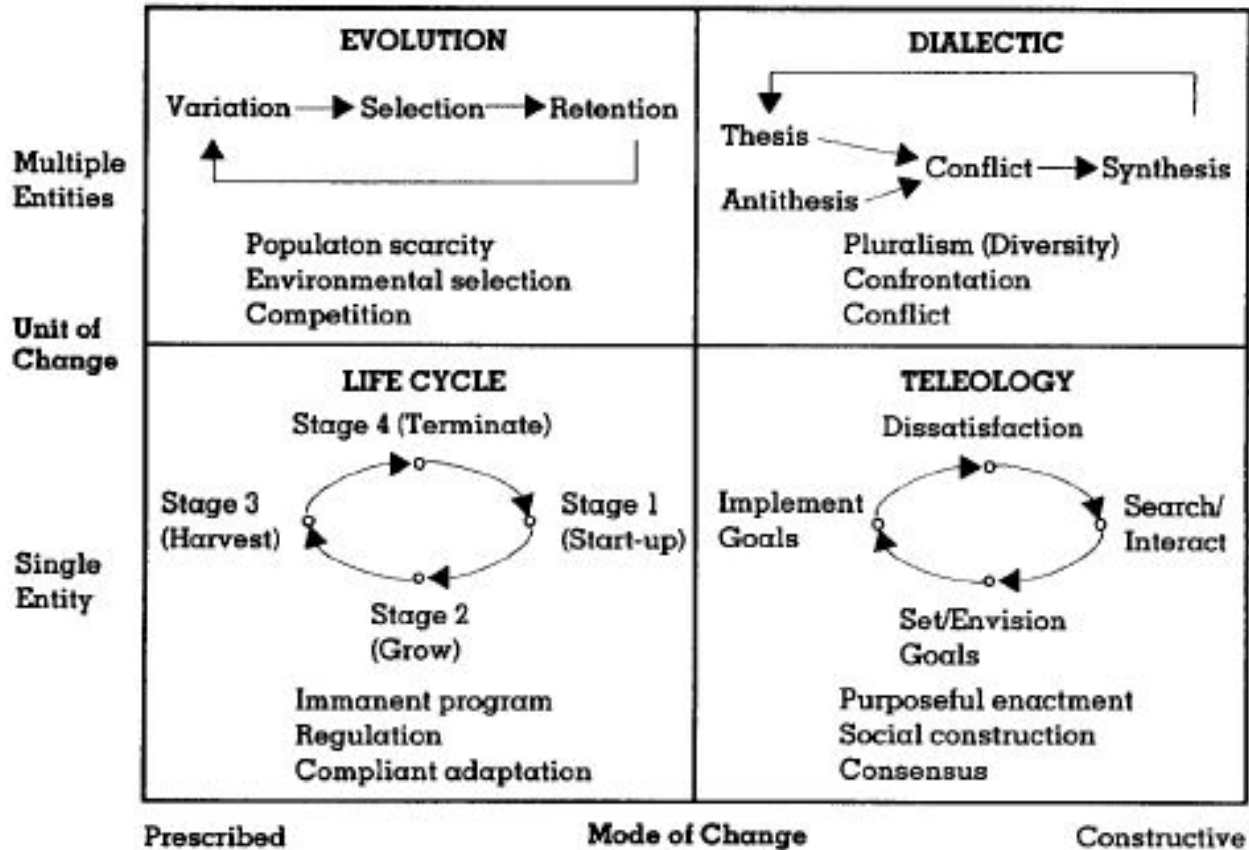
Understanding orgs: Energy flow among the functional prerequisites



Source: Parsons et al.

Understanding orgs & change

Process Theories of Organizational Development and Change^a



^a Arrows on lines represent likely sequences among events, not causation between events.

Loose vs. tight coupling

“although organizational forms are designed to deal with inherent contradictions, the language of organizational scholars does not allow them to capture this reality. Organizations appear to be both determinate, closed systems searching for certainty and indeterminate, open systems expecting uncertainty. ... People simplify their analyses either by ignoring uncertainty to see rationality or by ignoring rational action to see spontaneous processes.”

p. 204, Weick & Orton, 1990

	Distinctive	Responsive
Not a system (uncoupled)	No	No
Tightly coupled	No	Yes
Decoupled	Yes	No
Loosely coupled	Yes	Yes

Source: Weick, 1982, and Orton & Weick, 1990 (looked at 300 works on loose coupling).

Loose vs. tight coupling (cont.)

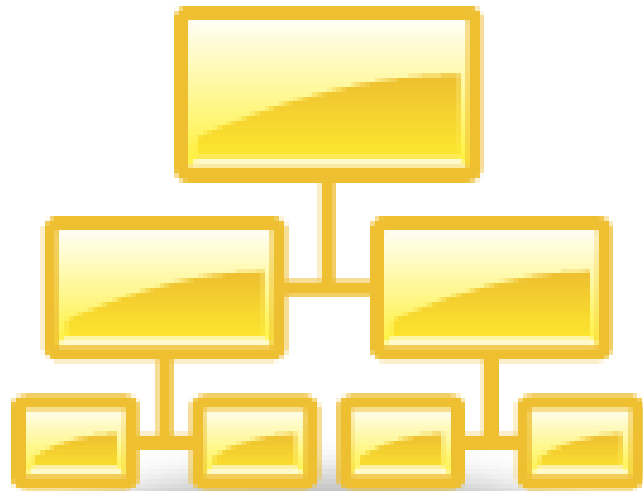
- Causation – indeterminacy, fragmentation internally & externally
- Typology – Among individuals, subunits, orgs, hierarchical levels, org & environment, ideas, activities, intentions vs. actions.
- Compensations -- Enhanced leadership, focused attention, shared values
- Outcomes – Persistence (stability), buffering, adaptability

Take away: The idea is NOT to settle on a particular hard & fast setting, but rather to let the dialectic continue to evolve, to continue to have the conversation.

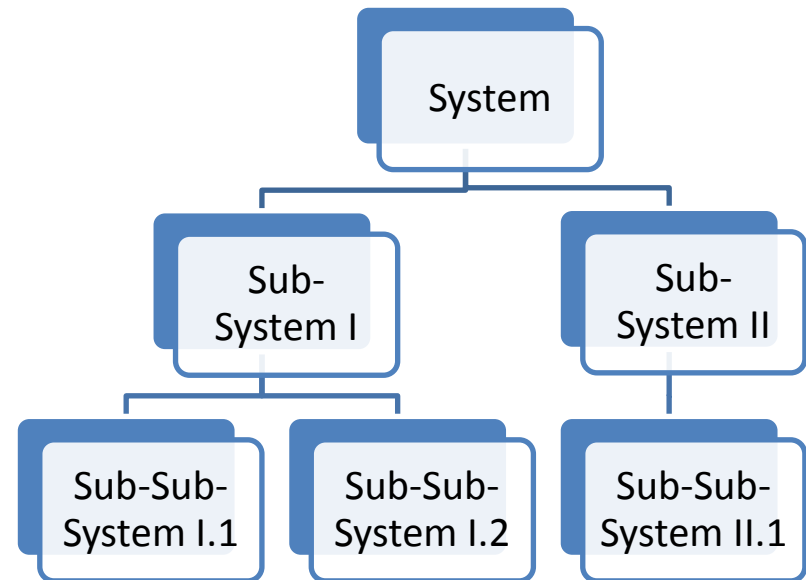
Conway's "Law"

(really "conjecture," 1968)

"...organizations which design systems ... are constrained to produce designs which are copies of the communication structures of these organizations."



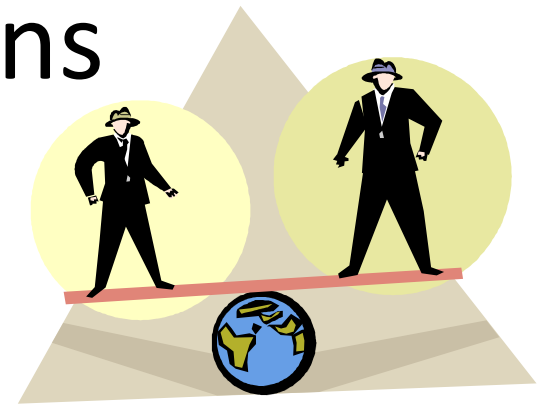
Organization
(communication)
chart



Product breakdown
chart

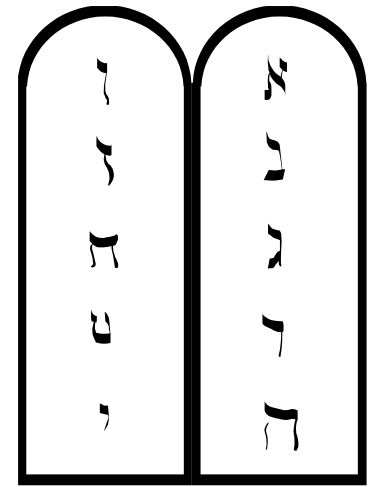
Best way to organize technology- centric organizations

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- What's the difference between those that succeed widely & those that don't?
- Experts (differentiators)
- Integrators – what does their business card say?
- How do integrators get their work done?

Ends vs. means



- Often there is confusion.
- What is the best way to get a team to perform its work? Align around the goal?
 - But means-alignment is sufficient!
- Means-alignment is at the heart of the process improvement movement – without being spoken!
- = Agree on the rules.

Should we have a meeting?

- What is the purpose of organizations?
- Reduce equivocality (Weick)?
 - Uncertainty: absence of facts
 - Ambiguity: absence of sense
- Lever/driver: Media richness.



Source: Russ, Daft & Lengel. Note that there is a line of counter examples due to Ann Majchrzak, University of Southern California, who rather than media richness uses a variant of structuration theory.

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