

Organizational Implications of Systems of Systems

SoS Practice Team
Software Engineering Institute

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Our Goals for this Tutorial

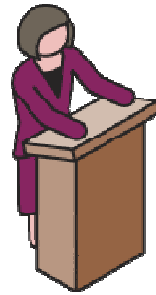
After attending the tutorial, participants should be able to:

1. Describe differences in system of systems (SoS) types that are relevant to making organizational and governance decisions
2. Describe the organizational implications of SoS participation
3. Describe the complexity and associated challenges organizations are faced with in an SoS context
4. Summarize methods that support organizations in the effective analysis of their SoS contexts

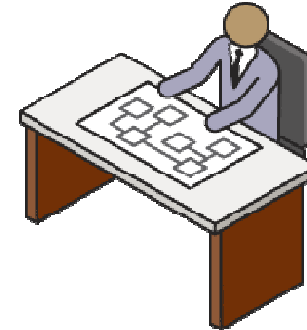


Who are you? What are your expectations?

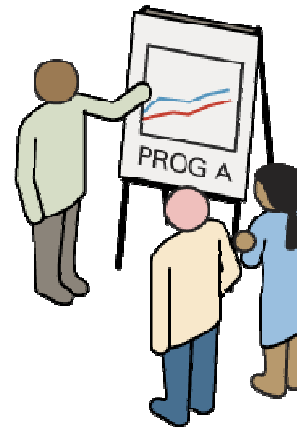
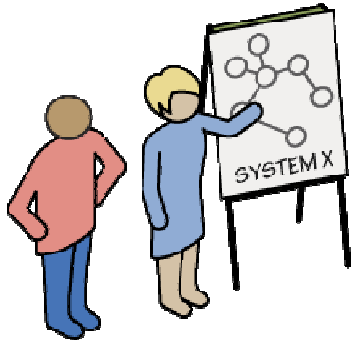
Policy Maker?



Portfolio Manager?



Chief Systems Engineer?



Program Manager?



Other???

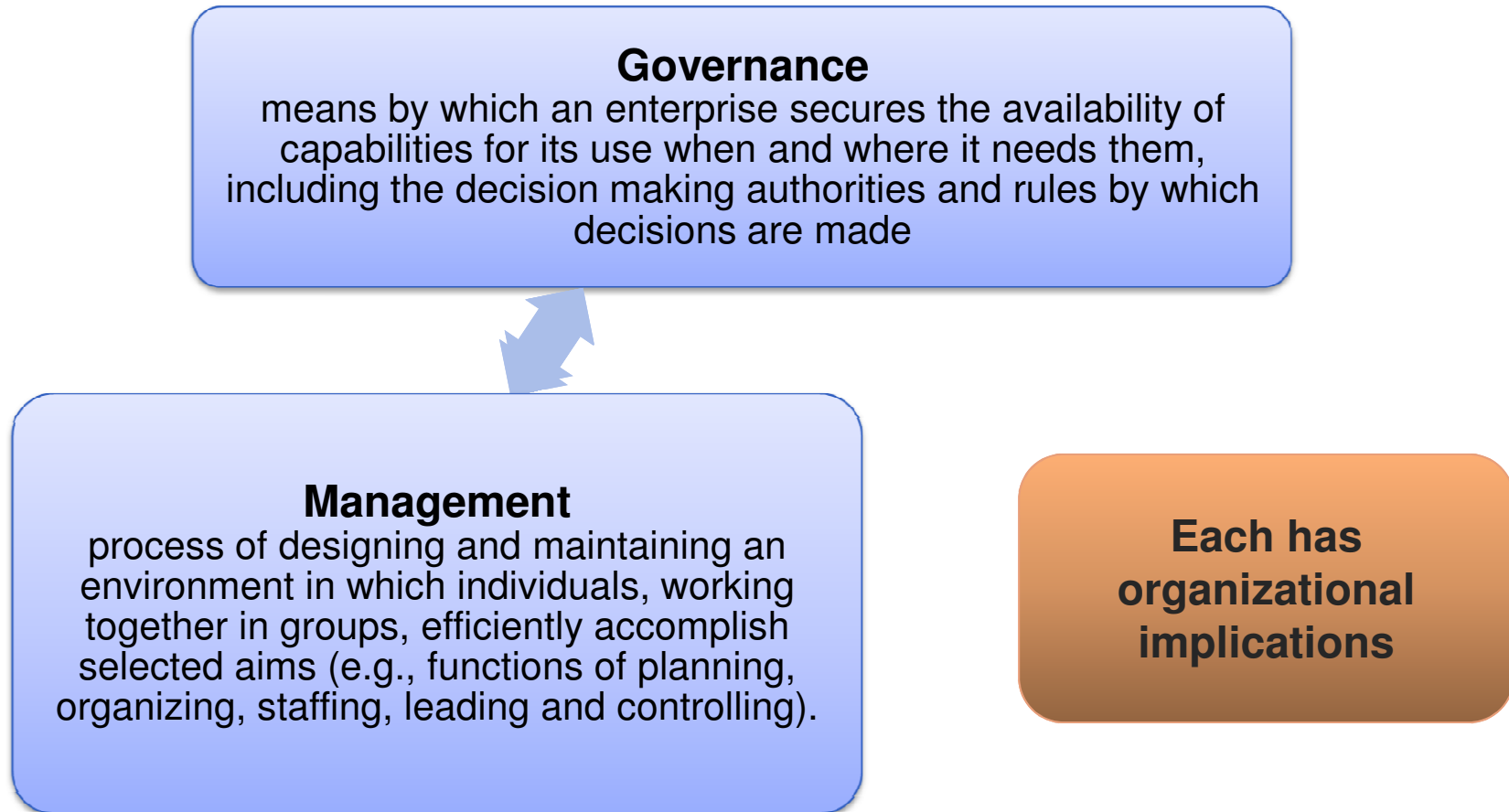


End User?

Engineering Technical Lead?



Terminology



Source for management and organization: Wehrich and Koontz, 2005



Galbraith STAR Model to Structure Discussions of Organizational Issues



We will come back to various aspects of this model as a framework for talking about organizational issues

Adapted from *Designing Complex Organizations*, Jay Galbraith, Addison-Wesley, 1973.



Agenda

Basics of Systems of Systems

- Perspectives of SoS Participants
- SoS Types and Characteristics

Organizational Implications of Systems of Systems

Responding to Organizational Implications in Systems of Systems

Summary



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Basics of Systems of Systems

- **Perspectives of SoS Participants**
- SoS Types and Characteristics

Organizational Implications of Systems of Systems

Responding to Organizational Implications in Systems of Systems

Summary

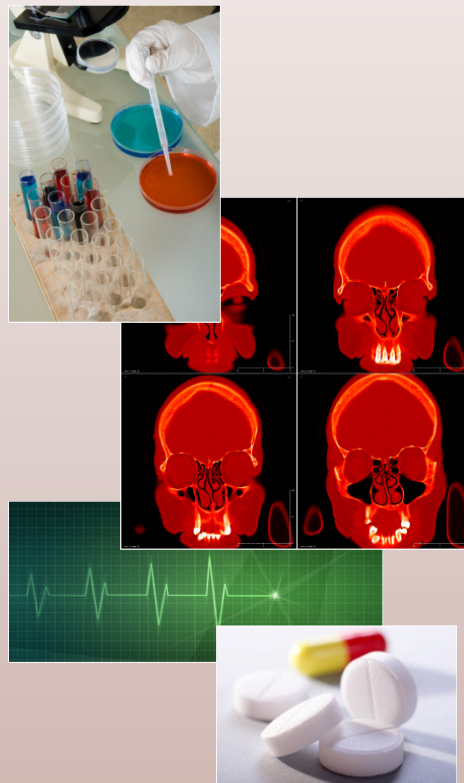


What are Systems of Systems? Health IT Systems Example

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



...in relation to some use



...within a changing, unpredictable context



What are Systems of Systems? Coalition Forces in Operational Context Example

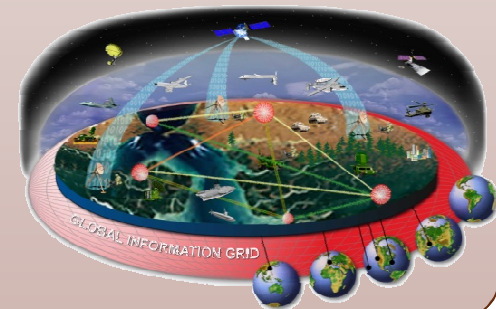
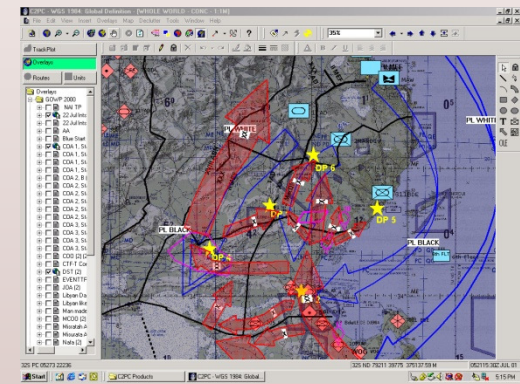
A collaboration among technical systems and organizational (people) systems...



...in relation to some use



...within a changing, unpredictable context



What are Systems of Systems? Wildland Fire Management Example

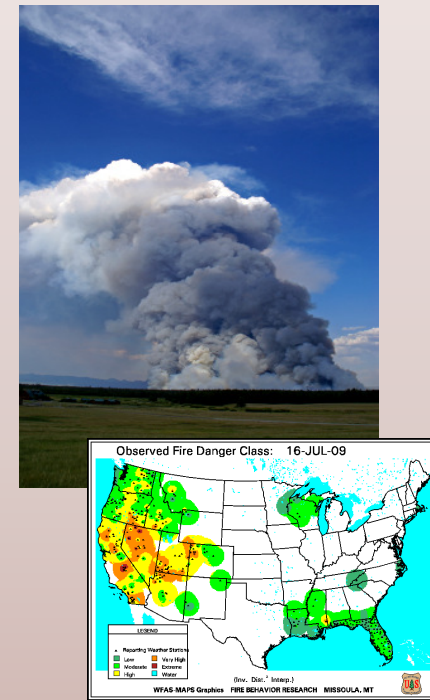
A collaboration among technical systems and organizational (people) systems...



...in relation to some use

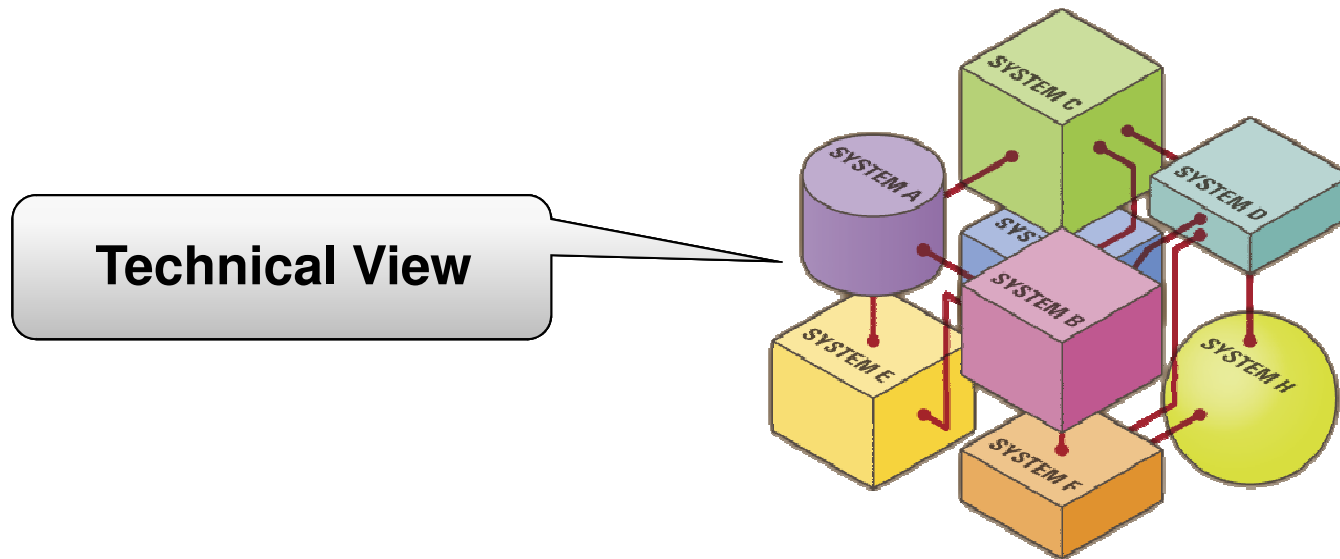


...within a changing, unpredictable context



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

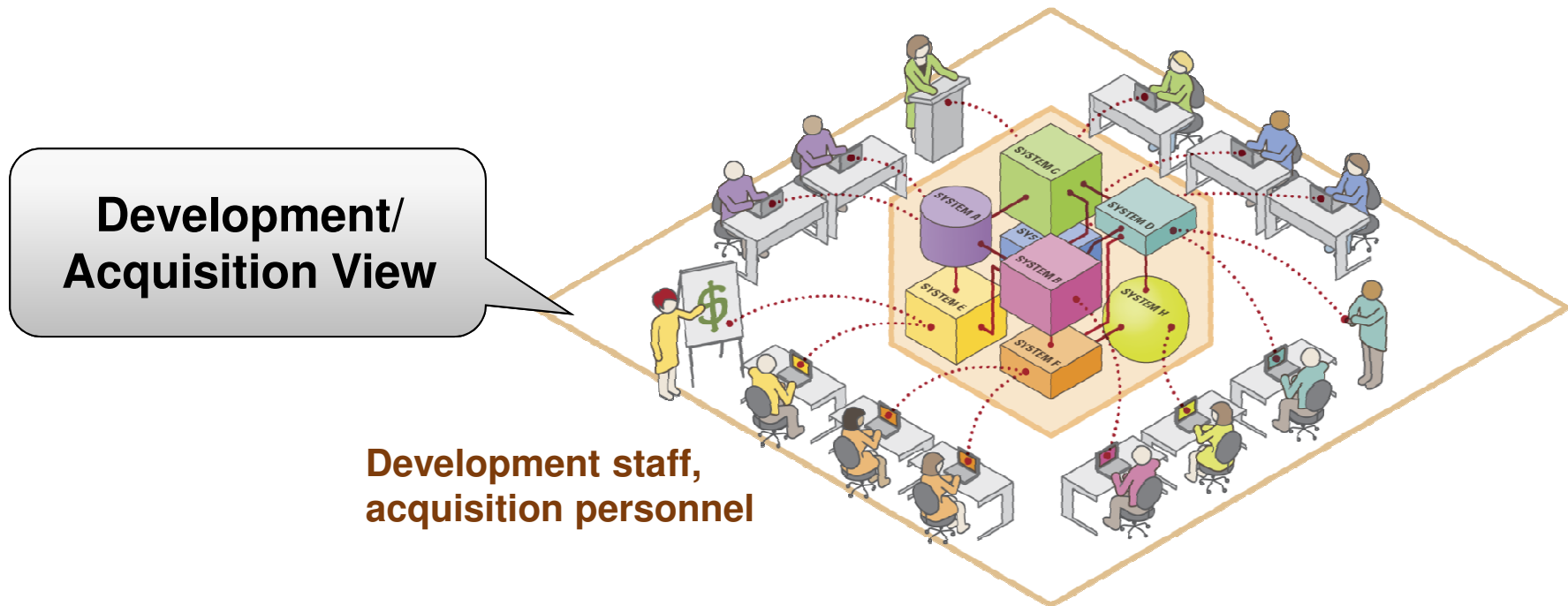


But...systems of systems are more than
interoperating hardware and software systems



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



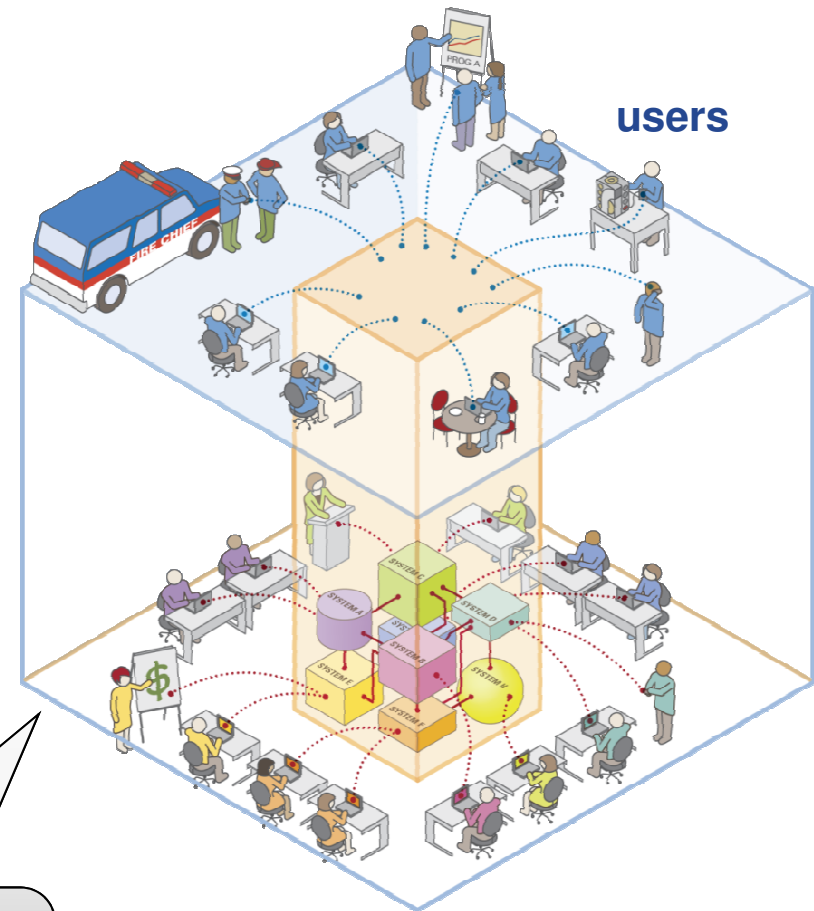
People systems are as important as technical systems



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

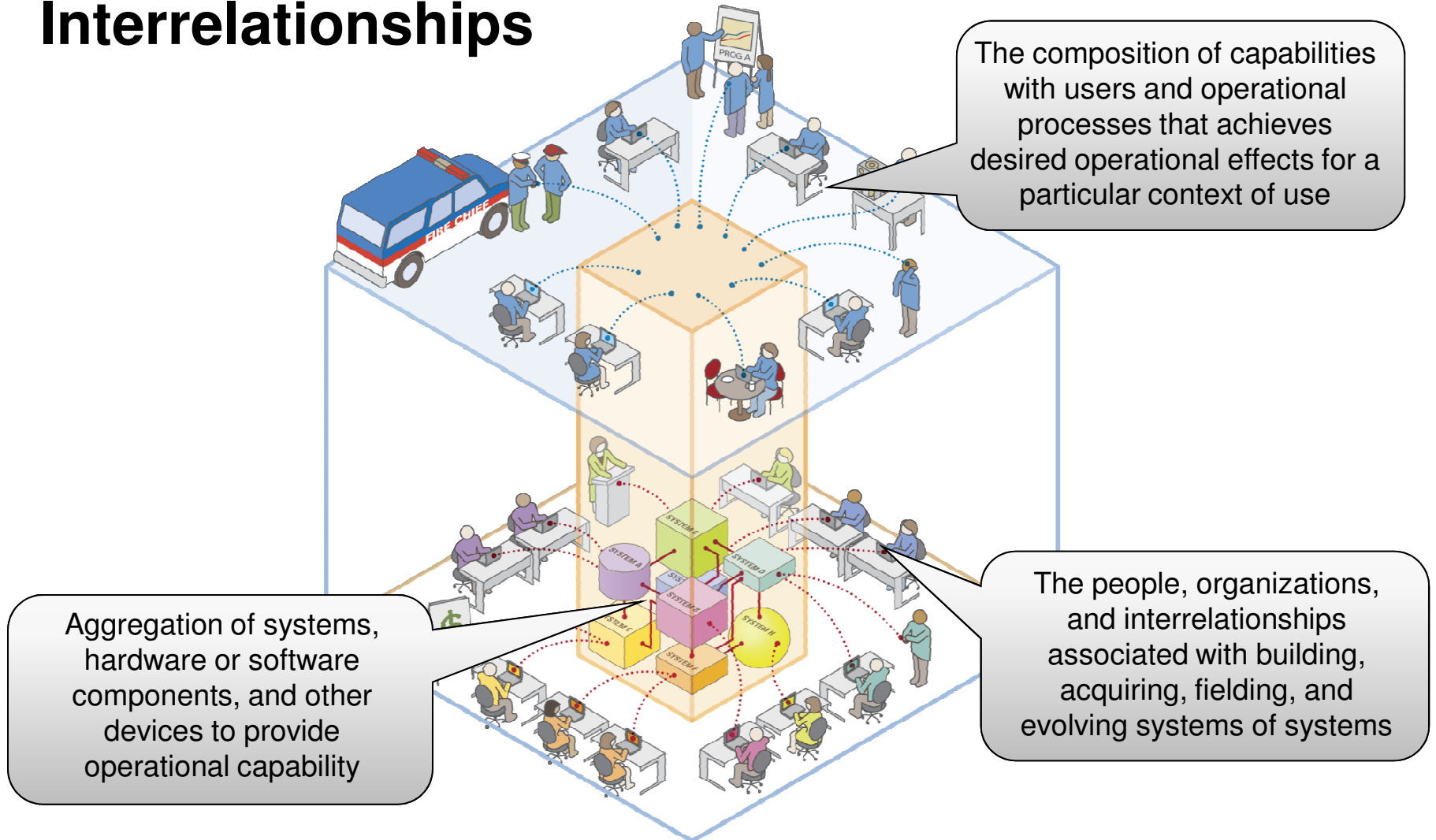
- Evolves to enable dynamically changing operational effects within the operational user's context of use
- Is likely to use technical and organizational assets outside of the original design context



**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



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Basics of Systems of Systems

- Perspectives of SoS Participants
- **SoS Types and Characteristics**

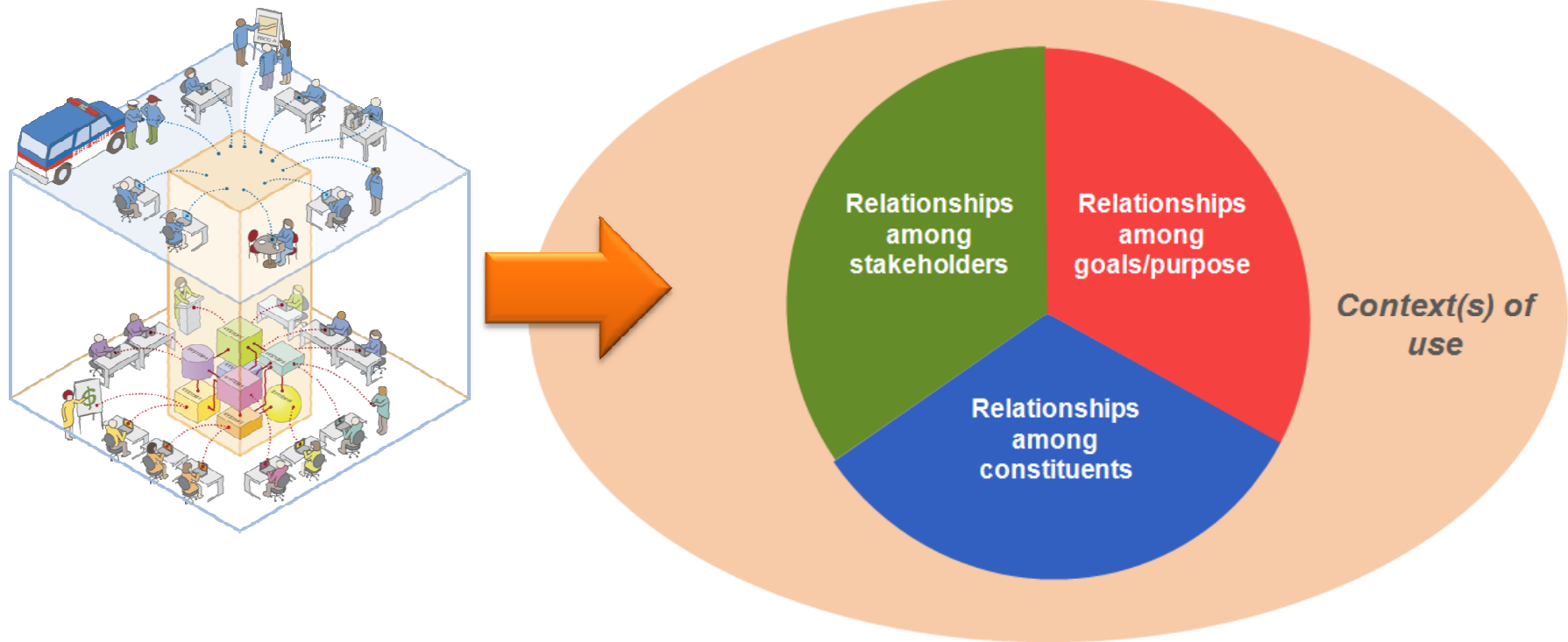
Organizational Implications of Systems of Systems

Responding to Organizational Implications in Systems of Systems

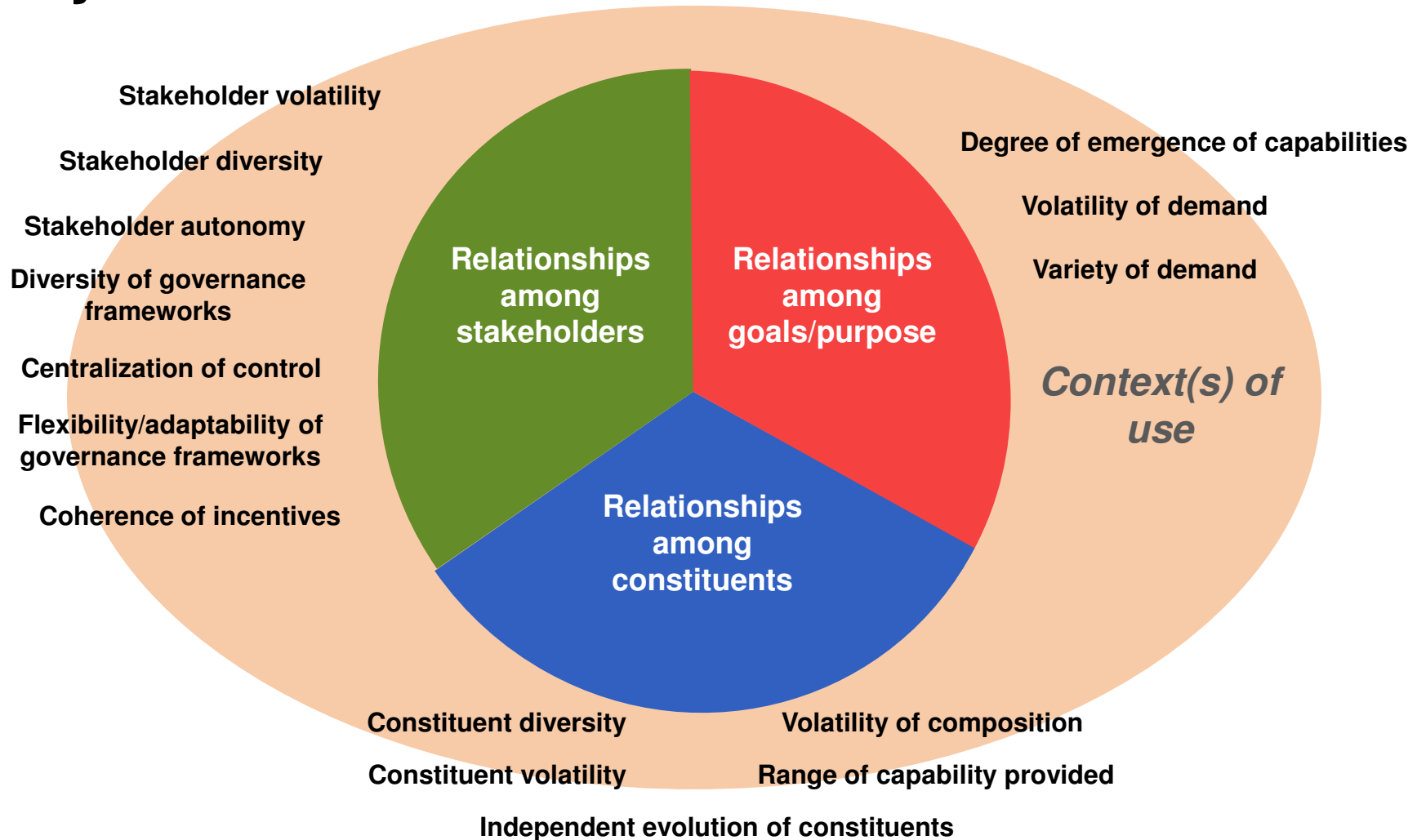
Summary



Understanding the Relationships Implied by the SoS Perspectives



Relationship Characteristics of Systems of Systems



Example Context: Wildland Fire Management (WFM)

To manage wildland fires, complex decisions need to be made quickly over the course of a wildland fire event

- Failure to make informed decisions can result in loss of life, homes, and habitat
- Decision makers rely on information from numerous existing systems grouped into a dozen application areas (e.g., fire behavior, weather, smoke, economic and risk analysis, fuels management)
 - Limited integration of existing systems and data sources, but users increasingly need them integrated
 - Systems independently developed by different groups using different software languages, platforms, architectures, and design assumptions

Interoperation of science models, systems, people, and governmental organizations is rapidly expanding the science of wildland fire management



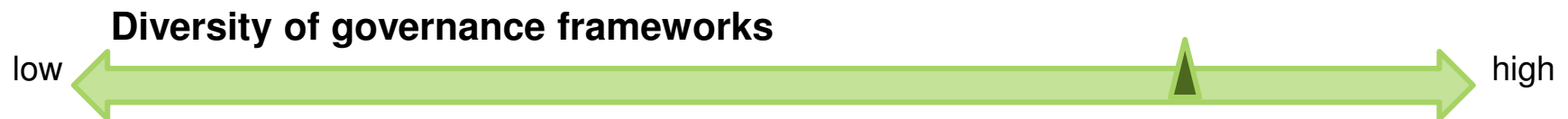
Characteristics: Stakeholder Relationships -1



WFM: dynamic relationships among stakeholders due to increased number, magnitude, and impact of fires. Each fire event has new set of players.



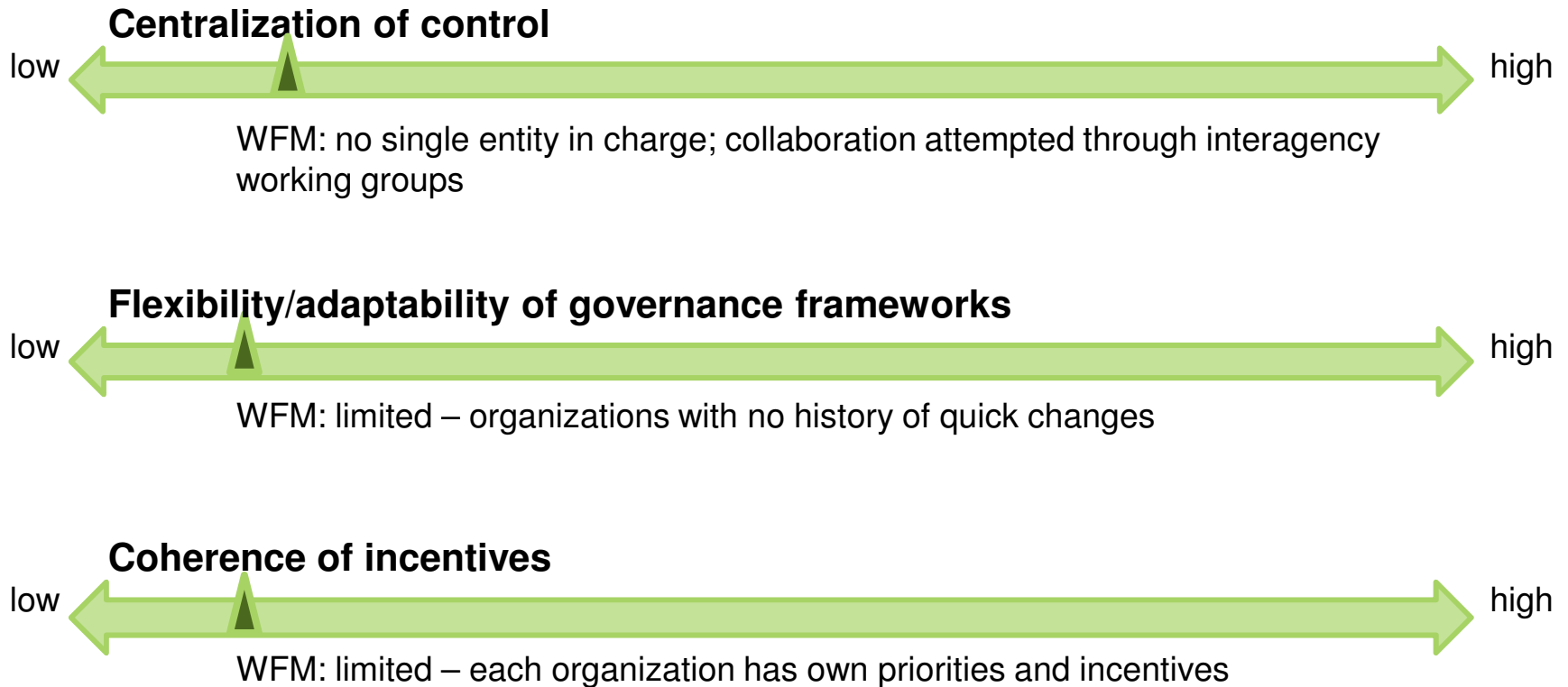
WFM: each agency and level of government has own priorities, stakeholders, and funding



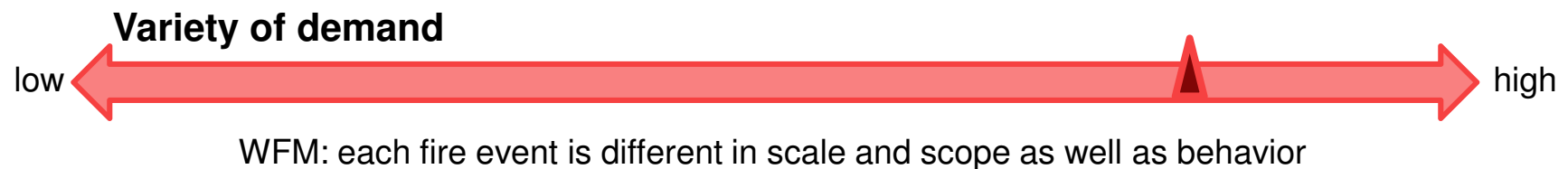
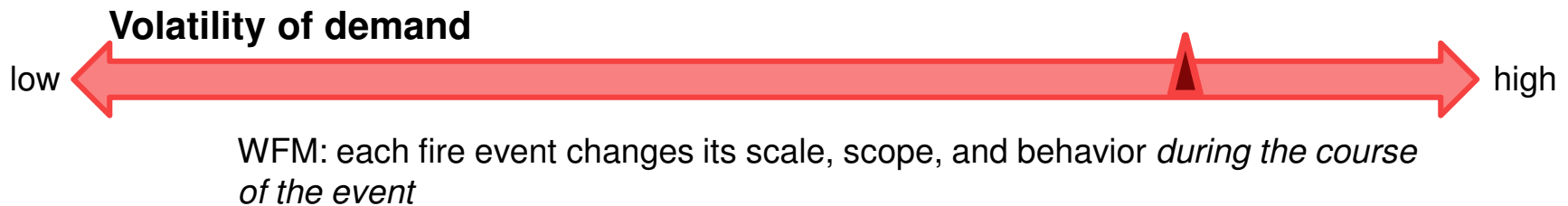
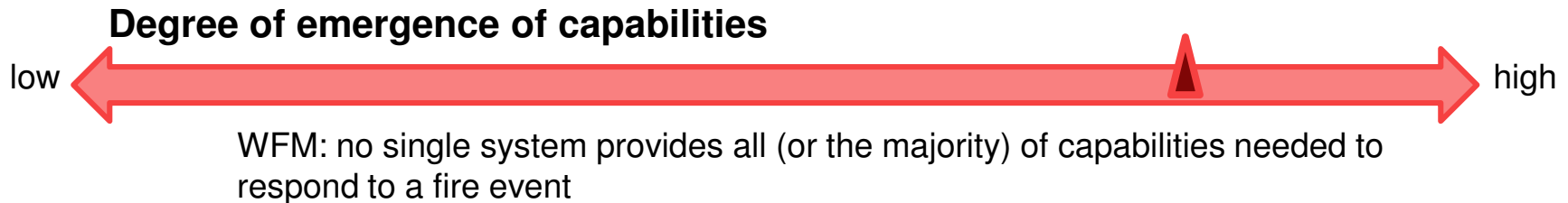
WFM: each agency and level of government has its own framework



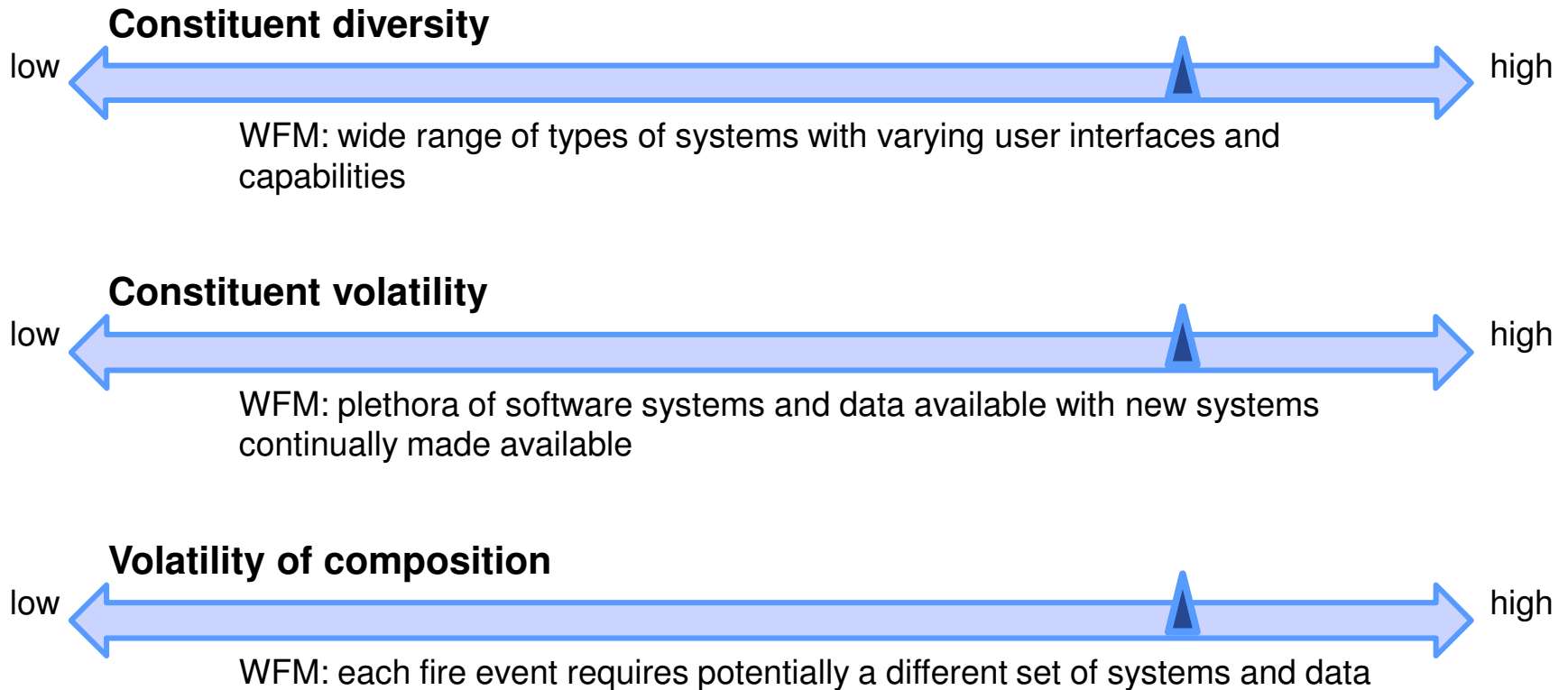
Characteristics: Stakeholder Relationships -2



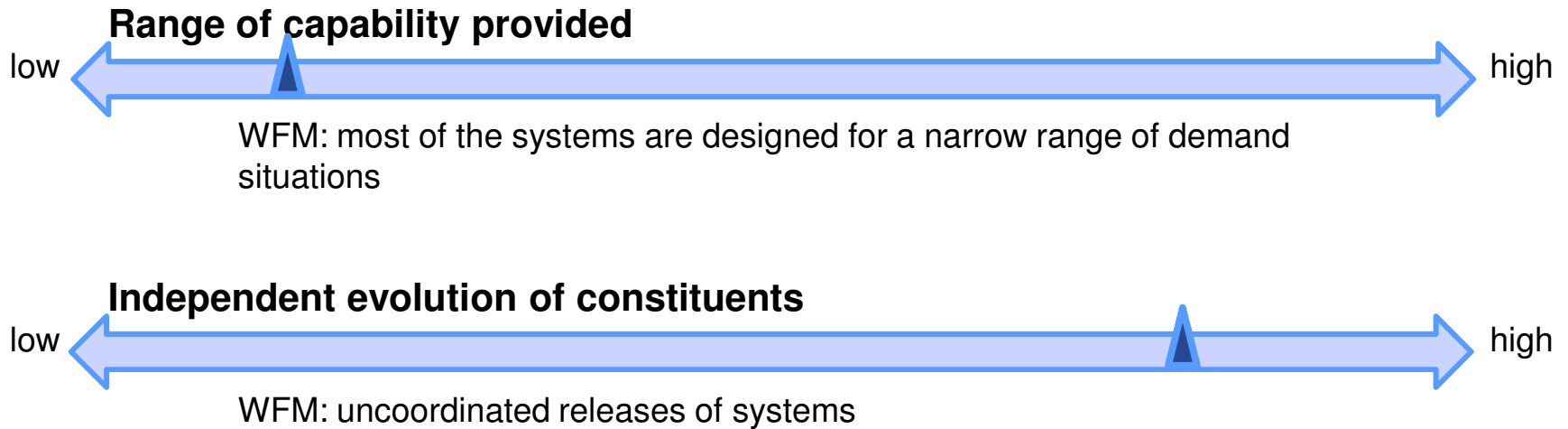
Characteristics: Goals/Purpose Relationships



Characteristics: Constituent Relationships -1

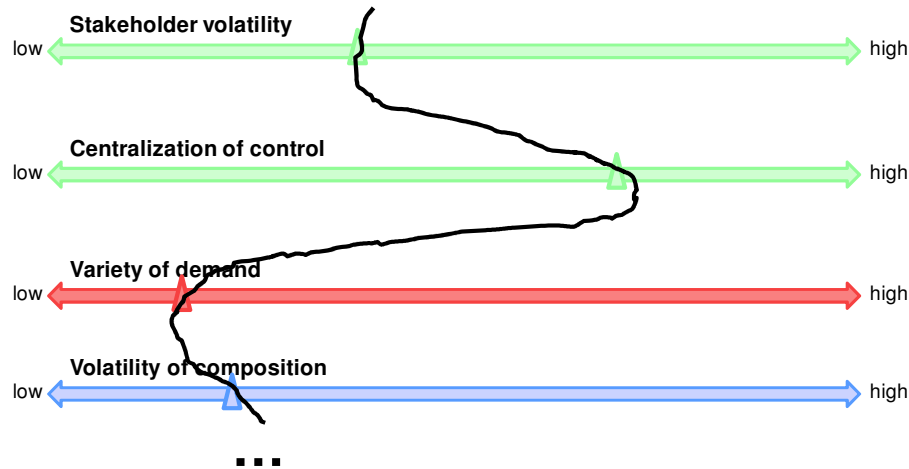


Characteristics: Constituent Relationships -2

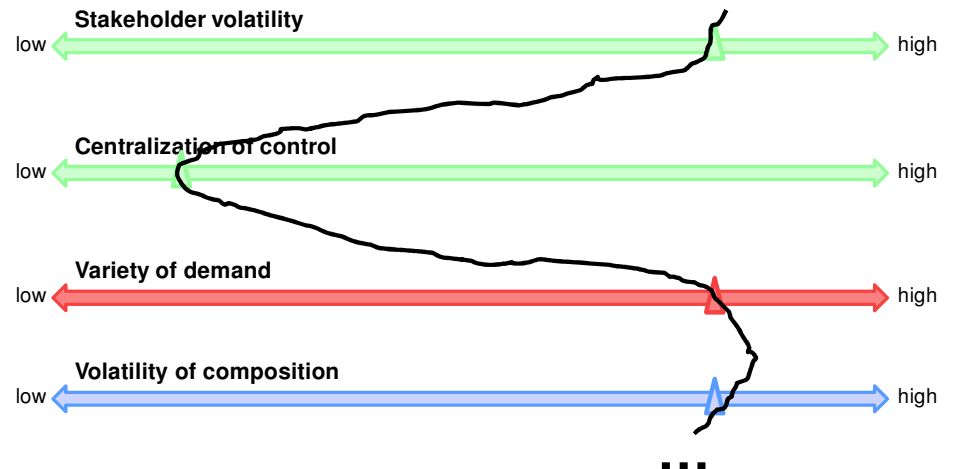


Different SoS will have Different Characteristics

System of Systems A



System of Systems B



Even though A and B are both systems of systems, given their characteristics, they would *not* be governed in the same way

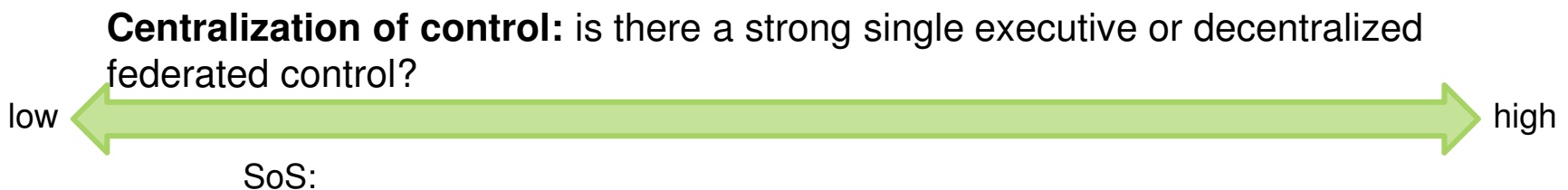
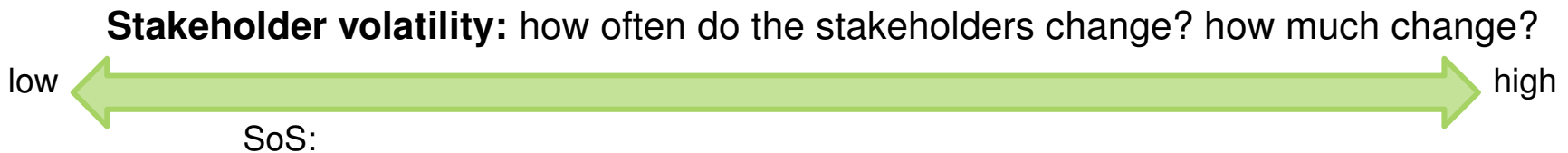


Discussion Exercise -1

Characterize a system of systems that you are aware of along the 5 dimensions listed below and on the next slide. For each dimension,

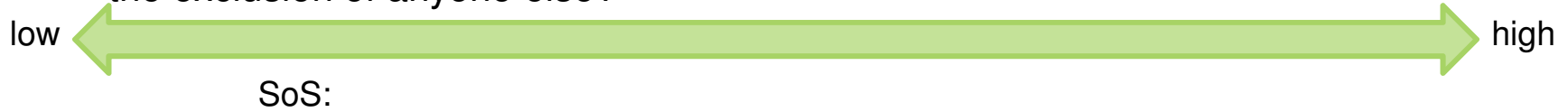
- Provide a brief description of the dimension as it applies to your SoS
- Mark where on the slider bar you would place your SoS

Pair up with someone involved in a different system of systems. Discuss how similar and different your situations are based on these 5 dimensions.

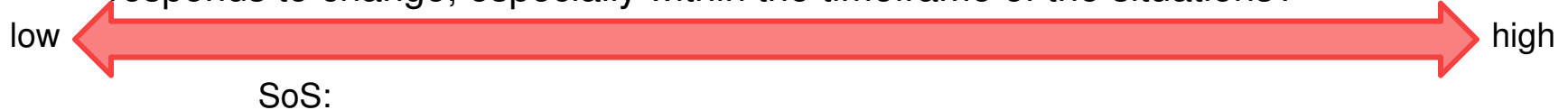


Discussion Exercise -2

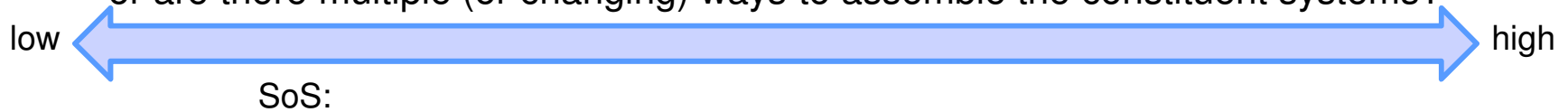
Coherence of incentives: are all stakeholders striving for the same collective good? or are some stakeholders incentivized to satisfy their requirements to the exclusion of anyone else?



Volatility of demand: how often and to what degree do the situations the SoS responds to change, especially within the timeframe of the situations?



Volatility of composition: is there a single way to build the desired capability, or are there multiple (or changing) ways to assemble the constituent systems?



Patterns of Relationship Characteristics

Patterns are emerging that allow summarizing different profiles of relationship and other characteristics

US DoD has proposed a set that provide a working framework of patterns



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)



Using Relationship Characteristics to Profile Different SoS Types

A more robust profiling of an SoS pattern would look at all relationship characteristics

For this tutorial, we will focus on this subset

- Stakeholder volatility
- Centralization of control
- Coherence of incentives
- Volatility of demand
- Volatility of composition

Profiles do not concentrate on what is possible; they concentrate on what is common

We do not expect that all SoS of a certain type will have all of their characteristics falling within the boundaries we have set



Notional Relationships Profile: Directed SoS

Stakeholder volatility: degree to which stakeholders are different, and frequency with which stakeholders change



Centralization of control: degree of centralization of decision and implementation authority



Coherence of incentives: degree to which stakeholders are incentivized toward the SoS goal vs. local goals



Volatility of demand: frequency of scope of changes in context across situations and within a single situation



Volatility of composition: degree and frequency of change in the way(s) that a desired capability is composed



Notional Relationships Profile: Acknowledged SoS

Stakeholder volatility: degree to which stakeholders are different, and frequency with which stakeholders change



Centralization of control: degree of centralization of decision and implementation authority



Coherence of incentives: degree to which stakeholders are incentivized toward the SoS goal vs. local goals



Volatility of demand: frequency of scope of changes in context across situations and within a single situation



Volatility of composition: degree and frequency of change in the way(s) that a desired capability is composed



Notional Relationships Profile: Collaborative SoS

Stakeholder volatility: degree to which stakeholders are different, and frequency with which stakeholders change



Centralization of control: degree of centralization of decision and implementation authority



Coherence of incentives: degree to which stakeholders are incentivized toward the SoS goal vs. local goals



Volatility of demand: frequency of scope of changes in context across situations and within a single situation



Volatility of composition: degree and frequency of change in the way(s) that a desired capability is composed



Relationships Profile: Wildland Fire Management

Stakeholder volatility: degree to which stakeholders are different, and frequency with which stakeholders change



Centralization of control: degree of centralization of decision and implementation authority



Coherence of incentives: degree to which stakeholders are incentivized toward the SoS goal vs. local goals



Volatility of demand: frequency of scope of changes in context across situations and within a single situation



Volatility of composition: degree and frequency of change in the way(s) that a desired capability is composed



Key Points -1

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

Different SoS types exhibit different relationship characteristics profiles

Understanding SoS characteristics profiles helps to understand the implications of the different types of SoS



Key Points -2

Directed SoS

Is most similar to traditional systems

Acknowledged SoS

Are more prevalent in SoS situations with less demand and compositional volatility

Still show centralization of authority, but weaker than a Directed SoS, due to independent ownership and evolution of the constituent systems

Have lower coherence of incentives and higher volatility/diversity of stakeholders than Directed SoS

Collaborative SoS

Are more prevalent in more volatile demand and compositional situations

Are decentralized in terms of authority, with situational authority granted to “leaders” of different elements

Are especially challenging because of the tendency toward low coherence of incentives

Have the fewest successful governance and management patterns



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- Perspectives of SoS Participants
- SoS Types and Characteristics

► **Organizational Implications of Systems of Systems**

Responding to Organizational Implications in Systems of Systems

Summary



Trends that are Affecting Today's Organizations

Industrial Age Emphasis	Post-Modern Emphasis
Value creation via heavy industry and physical products	Value creation via ideas, knowledge, intellect, innovation
Manufacturing	Services
Products consumed	Experiences consumed
Possession and ownership	Connections and relationships
Tangible value	Intangible value

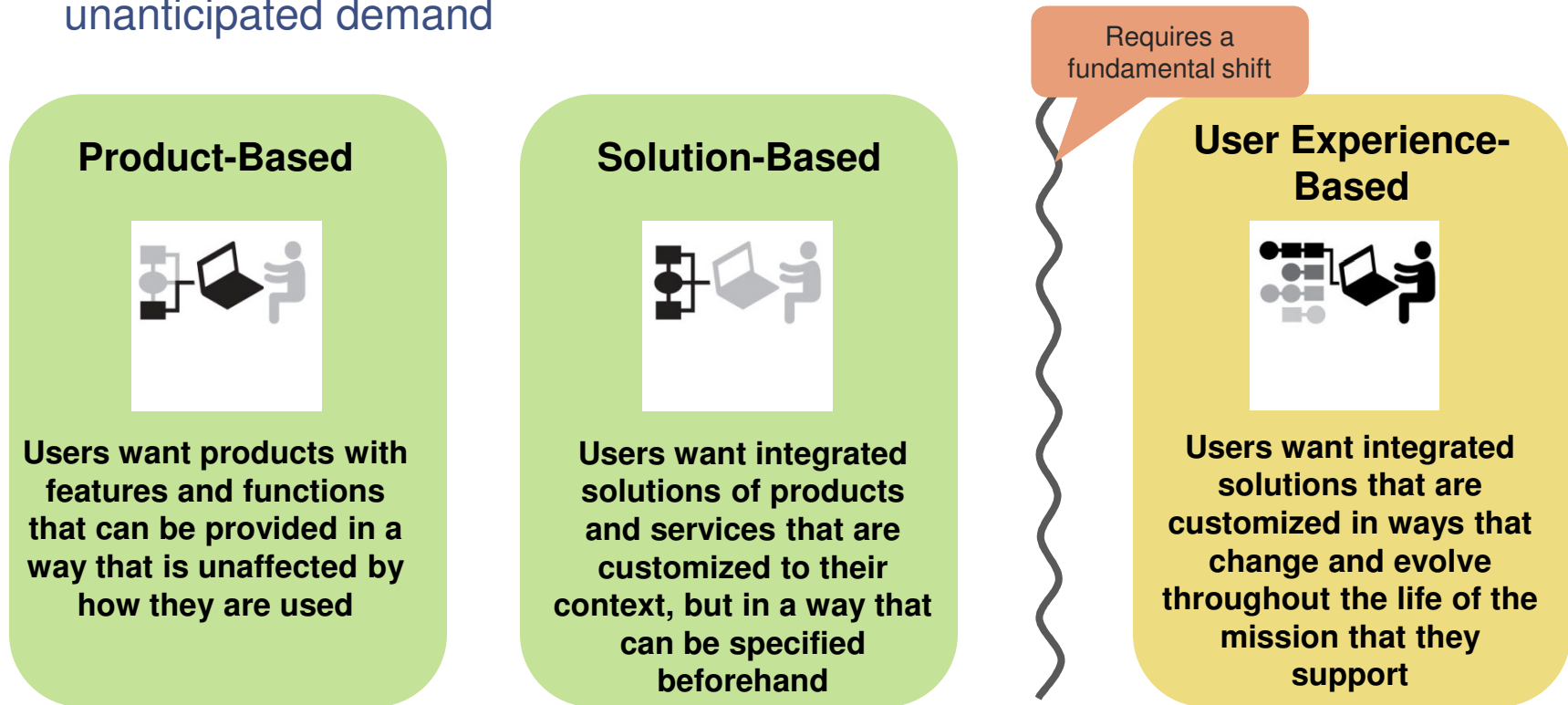
Implications

- Development of new business models—e.g., Google, eBay, online insurance sales and claims processing
- Appearance of new communities—e.g., blogs, online journals, open source community production
- Acceleration of competitive pressures—faster innovation cycles, lower half-life of products and services, and faster commoditization of intelligent products
- Relationship-based vs. ownership-based assets—requires more nimble business strategies



Responding to an Increasingly Turbulent, Post-Modern World

- Customers and users need more specialized solutions in ever-shorter time frames, continuously adapted to their changing and evolving situations
- Suppliers and capabilities have to become more flexible to respond to unanticipated demand



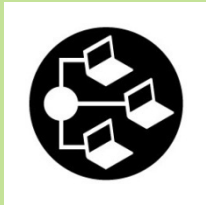
Sources: 'Turbulence' as per Emery (1965) Categories adapted from Prahalad (2003)



Governance and Management Must Accommodate Increasing Complexity

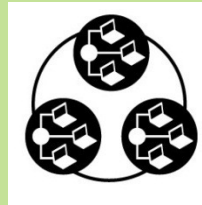
- Number, type, and roles of participants are increasingly diverse, reflecting differing vested interests and sovereign boundaries
- Scarce resources and the need for concurrent uses make a single decision authority increasingly ineffective

Single Task “System”



A single program directs composition
—little potential for conflict

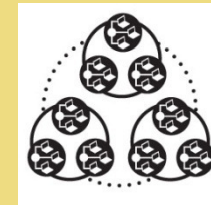
Single Enterprise



A real or virtual entity directs how multiple entities collaborate to compose multiple programs
—resolves potential conflicts by imposing constraints

Requires a fundamental shift

Multiple Enterprises



Multiple real or virtual directing entities making competing demands on SoS
—conflict resolution requires negotiating mutual constraints



Understanding Supply Complexity and Response to Demand

Increasing need for context/situation-dependent response

Response to Demand

Product Based

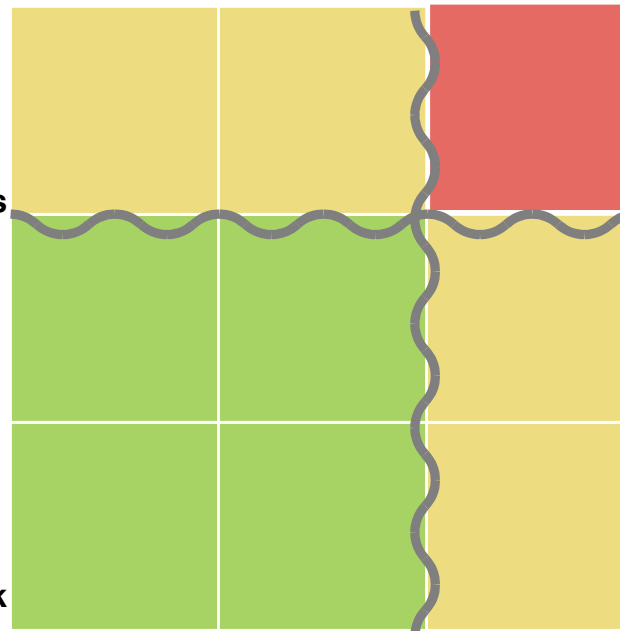
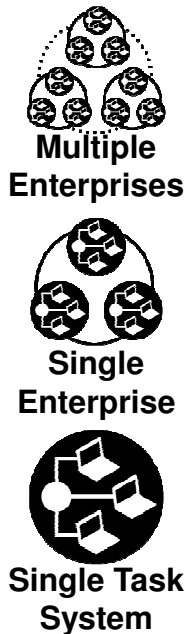
Solution Based

User Experience Based



Increasing diversity and independence of collaborators

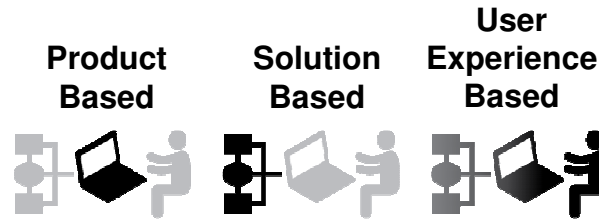
Supply Complexity



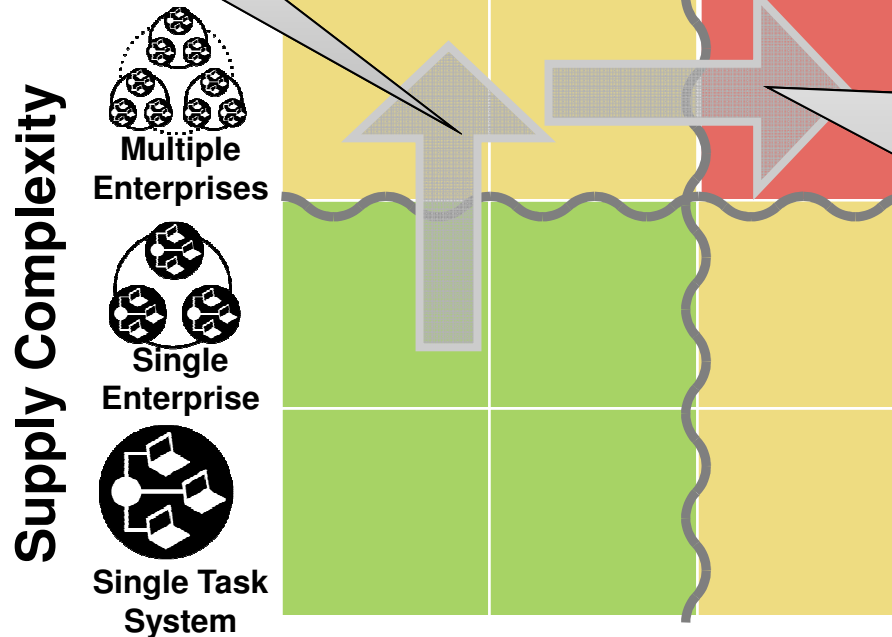
This Presents a Double Challenge

Challenge 1:
Collaborating effectively across boundaries

Response to Demand



Challenge 2:
Collaborating across boundaries to provide flexible responses to dynamic and unanticipated situations



Source: Boxer, Philip, Morris, Edwin, Smith, Dennis, & Anderson, Bill. "The Double Challenge in Engineering Complex Systems of Systems." *Eye on Integration*, news@sei 2007, 5.

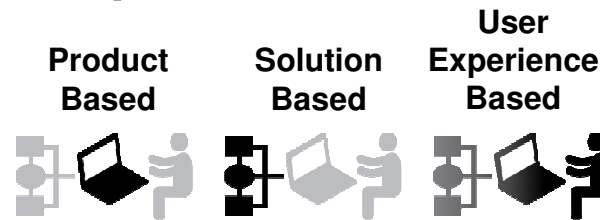


Wildland Fire Example and its Double Challenge

Challenge 1:

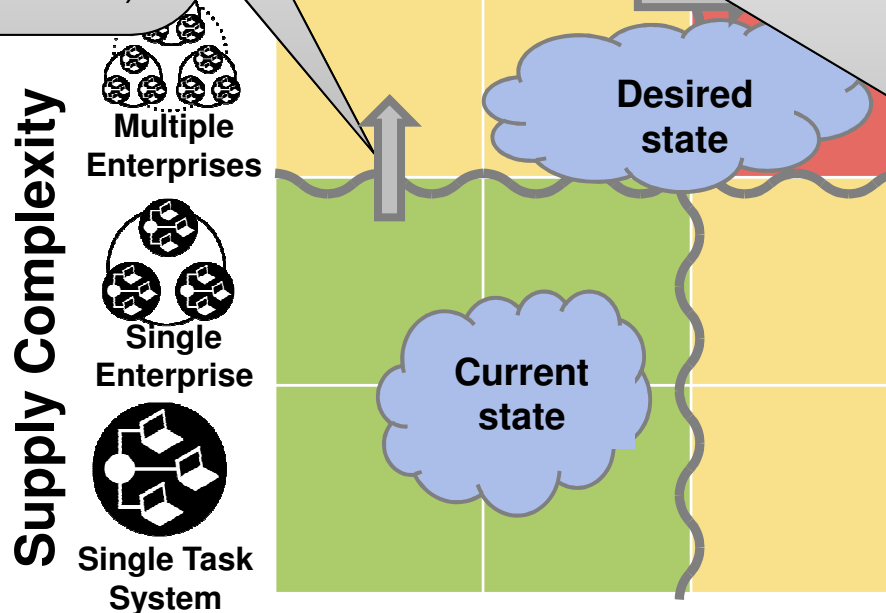
Responding to wildland fire situations requires using systems designed, built, and owned by different organizations (e.g. weather, land use, logistics, fire prediction)

Response to Demand

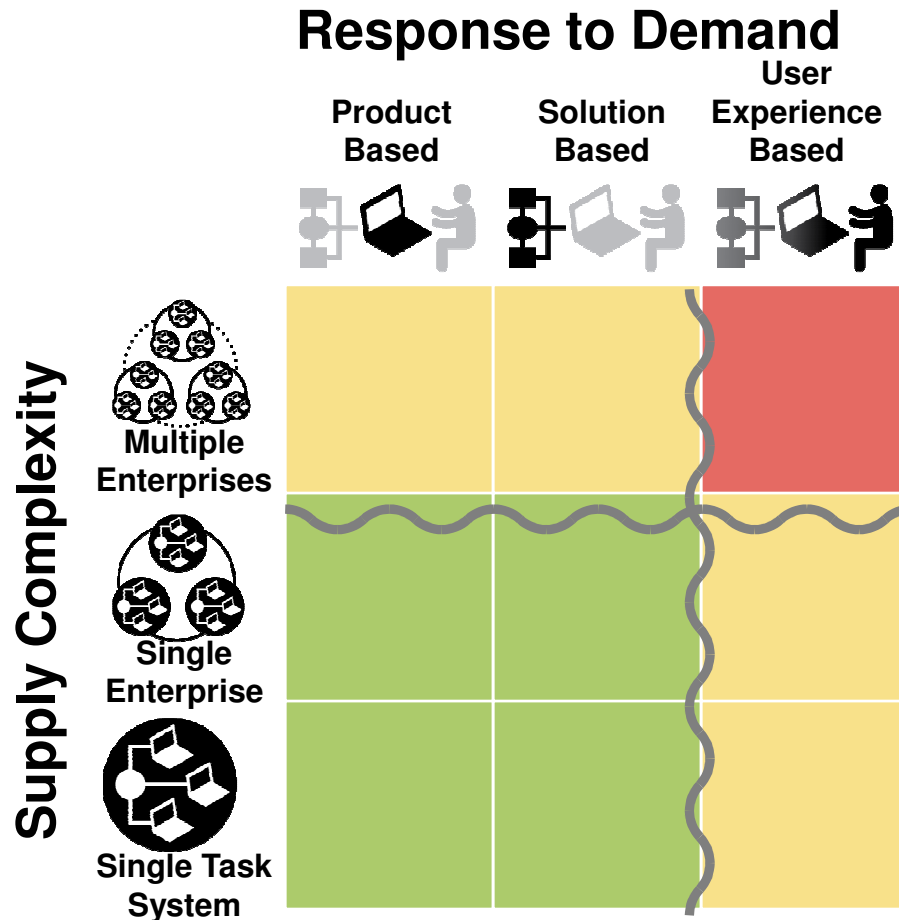


Challenge 2:

Wildland fires specialists (users of the systems) need the capability to combine different systems in varying ways depending on the particular characteristics of a given fire, through the changing life of that fire event



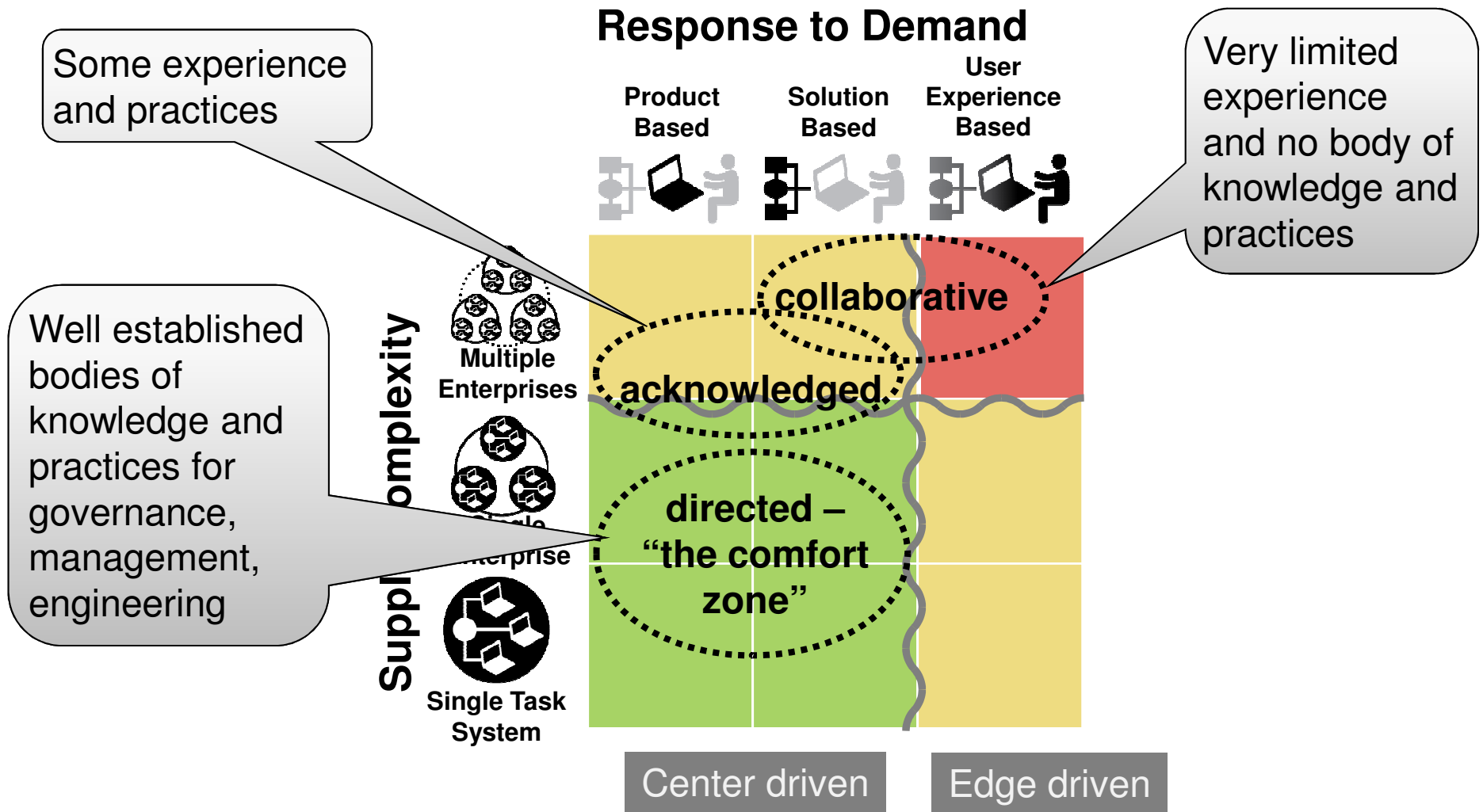
Discussion Exercise: Where is Your Organization in Relation to the Double Challenge?



Where does it need to be?



Governance Implications and SoS Types



Organizational Implications of the Double Challenge: Leveraging the Galbraith Star Model



Adapted from *Designing Complex Organizations*, Jay Galbraith, Addison-Wesley, 1973.



Selected Organizational Implications— Strategy



Directed

Positioning based on variety of products and services being offered to the collaboration under traditional terms and conditions

Acknowledged

Positioning based on predetermined sets of solutions for defined customer sets that fit the collaboration overall goals

Collaborative

Positioning based on providing deep customer-oriented services wherever needed throughout the collaboration



Selected Organizational Implications— Structure



Directed

Hierarchical organizational structures that mimic constituent internal structures are most common

Some staff will be uncomfortable if “their” organizational framework is not the one being followed

Acknowledged

Matrix structures are common at SoS (e.g., CCBs & IPTs)

More emphasis on the roles people play within the collaboration than on their job function within a single organization

Collaborative

Significant governance decisions occur in the customer context via distributed governance mechanisms

“Badgeless” environments where a person’s organizational affiliation is subsumed to the larger collaboration goal



Selected Organizational Implications— Processes



Directed

A subset of important SoS processes require cross-organizational interoperation (i.e. CM); central authority determines the SoS process framework and enforces adherence

Acknowledged

Bilateral agreements between constituents and the acknowledged SoS leader are facilitated by the leader, but they don't have traditional authority to enforce; alternate adherence incentives are needed

Collaborative

Combination of bilateral and multi-lateral process agreements for processes considered mutually important for collaboration interoperation are required among constituents; adherence cannot be enforced easily



Organizational Implications—Rewards, People

	Directed	Acknowledged	Collaborative
Rewards	Reward staff who sacrifice their traditional constituent practices to comply with the central authority's governance and management mechanisms	Similar reward structures to Directed, plus ensure that those building and delivering multi-system solutions are motivated to communicate effectively with external (to their organization) SoS constituents	Include significant rewards for furthering the goals of the collaboration, not just those of the individual SoS constituent; plus ensure that those interacting closely with the customers are motivated to communicate effectively with relevant external SoS constituents
People	Technical skills required across multiple systems; management skills focus on integration of multiple organizational units	Technical skills required for building solutions based on multiple products; management skills that are needed include operating across organizational boundaries	Ability to learn new systems quickly is paramount technical skill; consulting skills are prevalent: negotiation and influencing skills are critical to successful governance and management



Current State for Wildland Fire Management

Product-based orientation in response to demand; centrally driven from the entities in control of the research and development resources

Development skill base have experience in operational roles
Limited soft skills associated with cross-organizational negotiation and communications



Extensive use of IPTs to inform and make development decisions across organizational boundaries

Unaligned reward systems: some community based recognition for interoperation across systems; contributions to operational mission are recognized

Which SoS processes need to interoperate have not been determined
Manual integration across systems is required



Discussion Exercise: Wildland Fire Management As-Is and Should-Be

How do the descriptions of the wildland fire situation match with the descriptions of implications for Collaborative SoS?



A Few Ideas for Selected SoS Constituent Roles -1

Role	SoS Type		
	Directed	Acknowledged	Collaborative
CIO	<p>Be aware of changes in the demand/collaboration environment that could affect central authority (e.g., new government regulations)</p> <p>Ensure your understanding of the governance approaches put into place by the central authority (e.g., CCB)</p>	<p>Understand the limits of the decision making authority of the collaboration's acknowledged leader</p> <p>Ensure staff is assigned to stay close to the customer context</p>	<p>Understand which decision areas truly need to be under your control and help to ensure that appropriate SoS constituents are granted decision-making authority in other areas (help ensure situational authority)</p>
Portfolio Manager	<p>Try to ensure that the incentive structures for your individual programs don't conflict with the overall goals for your portfolio</p>	<p>Look for leverage points across your portfolio that improve flexibility of the overall collaboration solution</p>	<p>Recognize that many of your portfolio elements participate in SoS collaborations that have little to do with your portfolio and minimize governance approaches (i.e., mandatory reports with only one audience) that interfere in those relationships</p>



A Few Ideas for Selected SoS Constituent Roles -2

Role	SoS Type		
	Directed	Acknowledged	Collaborative
Program or Project Manager	Include all stakeholders, including those in operational environments, in design-time decision making	Allocate sufficient time and resource for participating in interoperating governance approaches among collaborators (e.g., architecture CCB)	Spend sufficient time with your staff who are working directly in operational environments to understand and be able to support their infrastructure/governance needs
Technical Manager	Be prepared to make changes to your constituent system that may be suboptimal but are needed for the SoS as a whole	Recognize that people working with customer communities are your best source of information about engineering solutions from your products and services	Look for technical solutions that enable staff on the edge to more easily respond to the dynamic customer environments in which they operate
Operations Manager	Ensure that you are participating as actively as possible in the design-time decisions that will affect your operation downstream	Participate as actively as possible in the spectrum of change control mechanisms offered by the central authorities of the collaborations you're involved with	Encourage and support the SoS participants who are seriously trying to operate "from the edge"



Key Points -1

Suppliers and enterprises are being driven out of the comfort zone of traditional systems engineering by

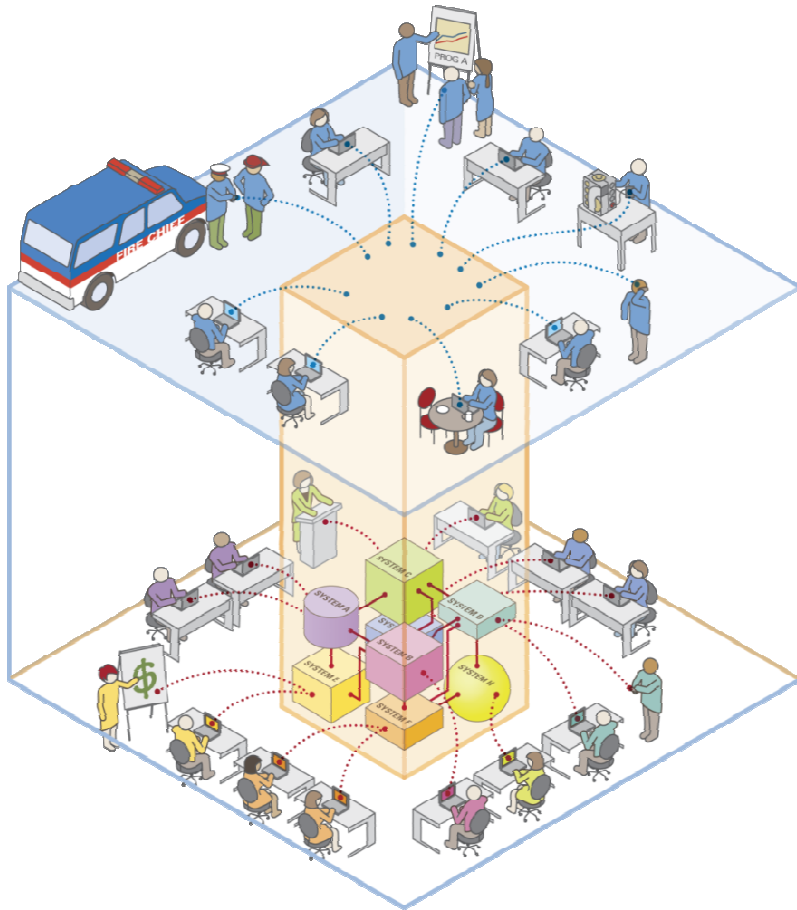
- Multi-enterprises systems of systems with limited centralized authority
- Suppliers who are taking greater responsibility to provide solution- or experience-based value for users
- Suppliers who are dealing with greater complexity associated with providing experience-based value to users

How governance changes are implemented in complex systems of systems depends on the type of SoS and the culture of the organizations involved

Organizational implications range across multiple dimensions—People, Strategy, Processes, Reward Systems, and Structures—governance frameworks and management practices need to accommodate



Key Points -2



Era of the end user/operations group as second class citizens in terms of involvement in engineering and design is over!

- In SoS, the operational situation is increasingly key to composing/recomposing systems of systems to achieve mission or market objectives
- Increasing volatility in operations means that traditional requirements elicitation processes won't work—the operational community is a primary connection to the evolving situational demands
- Hierarchical governance approaches do not give enough authority to staff working “at the edge” so they can be effective in working in customer/operational situations



Agenda

Basics of Systems of Systems

- Perspectives of SoS Participants
- SoS Types and Characteristics

Organizational Implications of Systems of Systems

▶ **Responding to Organizational Implications in Systems of Systems**

Summary



To Respond to SoS Organizational Implications

UNDERSTAND how key aspects of our situation reflect SoS realities

DETERMINE CHANGES that are needed to our governance practices

PREPARE TO ADOPT those new practices effectively

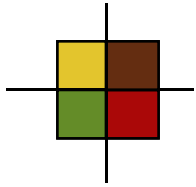
MAKE AND MONITOR CHANGES to ensure that they are effective

- Leverage traditional organizational change approaches

SEI SoS Practice Governance and Acquisition (SoSP GA) team supports some of these activities

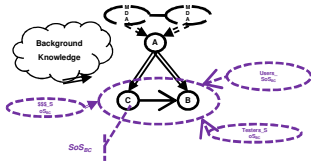


UNDERSTAND How Key Aspects of Situation Reflect SoS Realities



Critical Context Analysis (CCA)

- Identifies stakeholders outside known spheres of influence and exposes critical hidden relationships between organizations that could have impacts on governance approaches



Influence Mapping Analysis (IMA)

- Makes stakeholder and constituent expectations, constraints, and boundaries explicit
- Exposes the real nature and the actual implications of existing agreements among SoS constituents



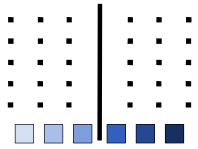
Strategic Alternatives Analysis (SAA)

- Reveals the impact of candidate governance and acquisition approaches as a response to potential changes in external environment



DETERMINE CHANGES that are Needed to Governance Practices

SoS Focus Analysis (SFA)

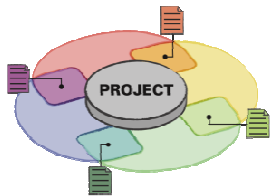


- Indicates governance choices to achieve appropriate balance between technical and operational elements of a SoS (e.g., resource allocation, incentive policies, success criteria)



Governance Alignment Analysis (GAA)

- Identifies gaps between current and needed governance mechanisms and structures along eight critical dimensions (e.g., policy, collaboration)

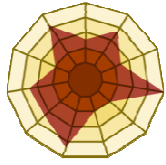


Distributed Governance Analysis (DGA)

- Operationalizes agreements and extends them by specifying appropriate individuals, actions to be taken, and additional data (e.g., completion date, notifications on failure)



PREPARE TO ADOPT Those New Practices Effectively



Readiness & Fit Analysis (RFA)

- Uncovers risks and creates mitigation strategies that account for social realities of the organization when adopting new governance practices



SoSP Methods for Governance & Acquisition

Optimize for One or More SoS Types

Method	Directed	Acknowledged	Collaborative
Critical Context Analysis		X	X
Influence Mapping Analysis		X	X
Strategic Alternatives Analysis	X	X	X
SoS Focus Analysis		X	X
Governance Alignment Analysis		X	X
Distributed Governance Analysis	X	X	
Readiness & Fit Analysis	X	X	X

Most methods can also be used outside their primary area



Example Use of Selected Governance & Acquisition Methods: Wildland Fire

UNDERSTAND: characterize who is involved in the broad SoS context and critical stakeholders

Critical Context Analysis

UNDERSTAND: identify possible future demands and trends

Strategic Alternatives Analysis

*Context(s)
of use*

Supplier
Community

Existing Systems
& Methods

**Systems of
Systems
Challenges**

Possible Future
Demands

Operational
Decision-Making
to Meet Current
Demands

Operational User
Community

DETERMINE CHANGES: establish use of existing systems and their alignment to their context of use

SoS Focus Analysis

DETERMINE CHANGES: determine needed balance of resources to operationalize SoS capabilities

Governance Alignment Analysis



Future Directions of SoSP Work in Governance & Acquisition

Develop governance and acquisition guidance for an SoS Practice Framework

- Analyze results from pilot uses for potential recommended practices

Refine the methods for specific problems of different SoS types

- Identify standard profiles to predict governance gaps common to different SoS situations

Pilot SoSP methods (e.g., Critical Context Analysis) in situations with different characteristics than previous pilots

- Expand our understanding of the applicable scope and scale for the methods



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Key Takeaways

The shift in how systems are built, deployed, and used has implications for organizations

- Systems are rarely standalone; rather they are networks of socio-technical systems (of systems)

New bases for making organizational decisions are needed

- An SoS can be characterized by relationships of constituent systems, stakeholders, and goals and purpose—all within a particular context of use
- Understanding the type of SoS context you are in can help frame decisions

New governance structures and approaches are needed as capabilities of systems of systems cross sovereign enterprise boundaries

- Collaboration of constituent systems and stakeholders is required where a central authority *realistically* does not exist

SEI is adapting and packaging methods to facilitate the analysis of essential relationships across SoS types, particularly for Directed, Acknowledged, and Collaborative



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