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Flexibility in Complex Enterprises:

Case Studies from Military Operations and Acquisition

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Background and Motivation

- **Professional Experience**

- **DoD challenge: Developing *<u>flexibility</u>* in operations and acquisition to cope with uncertainty and technical change**
  - Much attention on automation and improvement of existing processes
  - Major focus: minimizing risk, uncertainty; maximizing local efficiency
- **Observations:**
  - Detailed study of commercial and military innovation in military has not helped
  - Little appreciation for hierarchical aspects of *<u>formal and informal structures</u>* and their impact on system level properties

We lack a framework that can help create and manage flexible enterprise architectures and identify design principles for them

Core Issues

Today's environment creates an operational imperative for flexibility in enterprises.

We lack theoretical and practical tools to address this challenge

"How does enterprise architecture enable or inhibit flexibility?"

"How do we design flexible enterprises?"

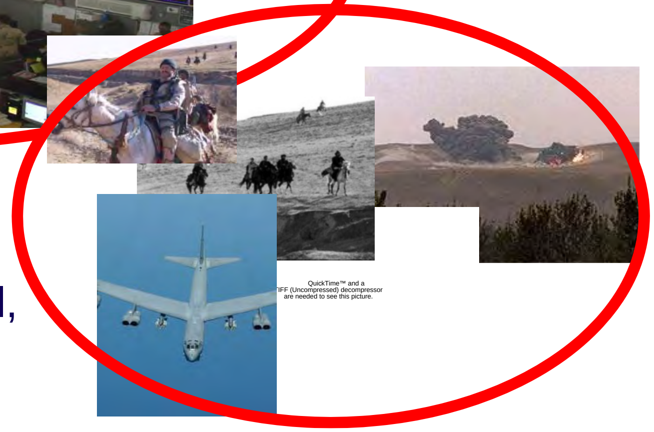
Knowledge Gaps

- **Hierarchy as a concept is narrowly framed**
  - Usually as control and power; focus on efficiency and minimizing error
    - Ref: Sah-Stiglitz; Radner; Ioannides; Ranson, et al.; Volberda
  - Not as abstraction and complexity management
- **Flexibility is not addressed systemically**
  - Usually narrow, problem-specific, with either known or bounded uncertainties
    - Ref: Stigler; Suarez, Cusumano, Fine; Fine and Freund; Khoste and Malhotra
- **Information processing views of organization are not well informed by concepts from computer science and information system design**
  - Mainly analogies and metaphor
    - Ref: Galbraith; Mandeles; Nadler and Tushman
  - Multiple levels of abstraction and a total system view are not used*
  - Intersection of abstraction with traditional concept of hierarchy is missing
- **Underlying _assumptions_ about structure are rarely challenged**
  - Impact of structure on behavior or properties in enterprises is poorly understood
  - Often treated as hierarchy vs. network (tree vs. flat)--little thought about either a middle ground or a spectrum of possible structures
    - Ref: Owen-Smith and Powell; Powell; Nadler and Tushman

***Except to distinguish levels of analysis**

Combat Air Operations

A foundation for developing a model of enterprise flexibility



- **Kometer (ESD Ph.D., 2005)**
  - Impact of information on *practice* of Air Force command and control doctrine: “centralized control, decentralized execution”
  - How to balance accountability with empowerment: *when* to move decisions down the tree
  - Emphasized *process* and *interactions* with an underlying tree-like architecture

AF-Army Tension

- **Air Force emphasizes strategic level action over direct support of ground forces**
- **The Army derives direct combat value from air power**
  - Ground combat situations usually change quickly
  - Challenges centralized approaches to command and control
  - History shows that ground forces and pilots can collaborate on appropriate responses on relevant timelines
- **Information technology enhances air power's combat value to ground forces (and vice-versa)**
- **We find that air-ground collaboration is successful if a similar collaboration also occurs at upper (strategic) and middle (operational) levels of hierarchy**

Research Overview

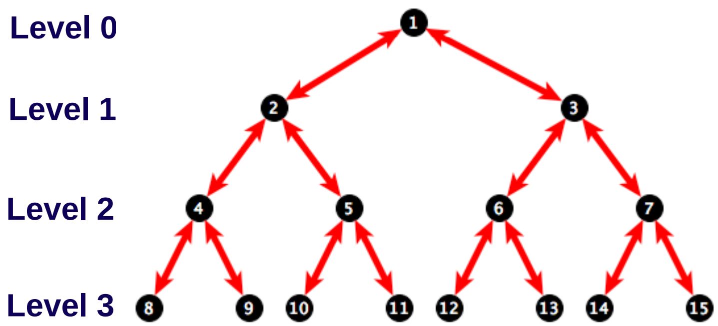
- **Kometer (ESD PhD 2005) analyzed 4 US air campaigns**
  - Iraq-I (1991)
  - Kosovo (1999)
  - Afghanistan (2001-2)
  - Iraq-II (2003)
- **Major combat operations in Iraq-II achieved victory with 1/3 the ground force used in Iraq-I**
  - Many felt that this was due to Net-Centric Warfare, where all levels of the US military had access to current battlefield information
- **We show that in Iraq-II, *in addition to* the value of increased information access and sharing, there was a change in enterprise architecture (esp. between AF and Army)**
  - Architecture created *collaboration at multiple levels* which enabled increased flexibility
- **This resulted in greater operational effectiveness using fewer forces at lower risk**
- **Early indications from an defense acquisition case study shows a similar pattern**

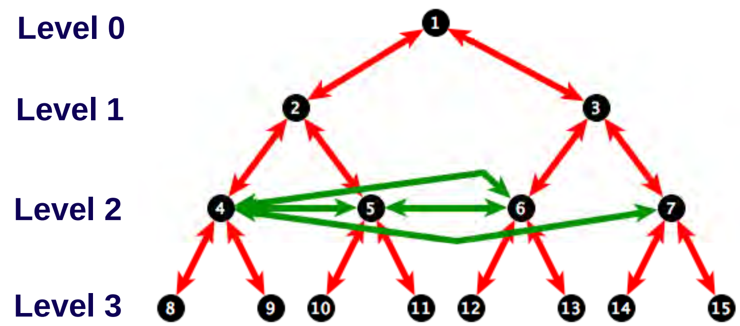
Basic Constructs

- **Enterprise**
  - Organizations as information processors: input-process-output
    - Ref: Galbraith; Tushman and Nadler; Bolton and Dewatripont; Arrow; Radner; Ioannides; Sah and Stiglitz
  - Multi-organizational systems**:** fully functioning separate organizations that are also part of a larger whole
    - Ref: Murman, et al.; Agranoff-McGuire; Mandeles; Nightingale and Rhodes
- **Flexibility in *operation*:**
  - Alternative combinations of capabilities and information--alternative paths through the structure of the enterprise
    - Ref: Moses; Leveson; Shannon-Moore; von Neumann
  - “Programmed” interactions: relationships or sequences that can be called on as necessary
    - Ref: Kometer; March and Simon
  - A well chosen architecture can create a large set of alternatives
    - Ref: Galbraith; Joyce, et al.; Moses; Brooks; Ulrich; Clark; de Weck and Silver
- **Multiple layers of abstraction (computer science)**
  - Each level can access/direct/delegate to next lower level to solve problems
  - Each level operates with distinct models, terminology, information needs
    - Ref: Moses; Abelson et.al; Liskov; Bar-Yam; Mandeles

Architectural Framework

- **Hierarchy and lateral interactions:**

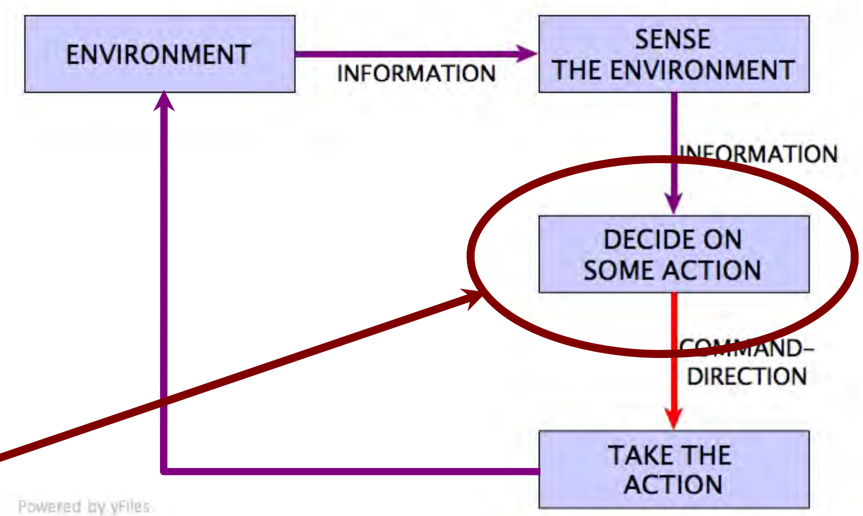




- **Examine enterprise architecture hierarchically**
- **Analyze how the structure of multi-layered interactions effects the ability to balance:**
  - Unified action (coherence)
  - Innovation, change (flexibility)

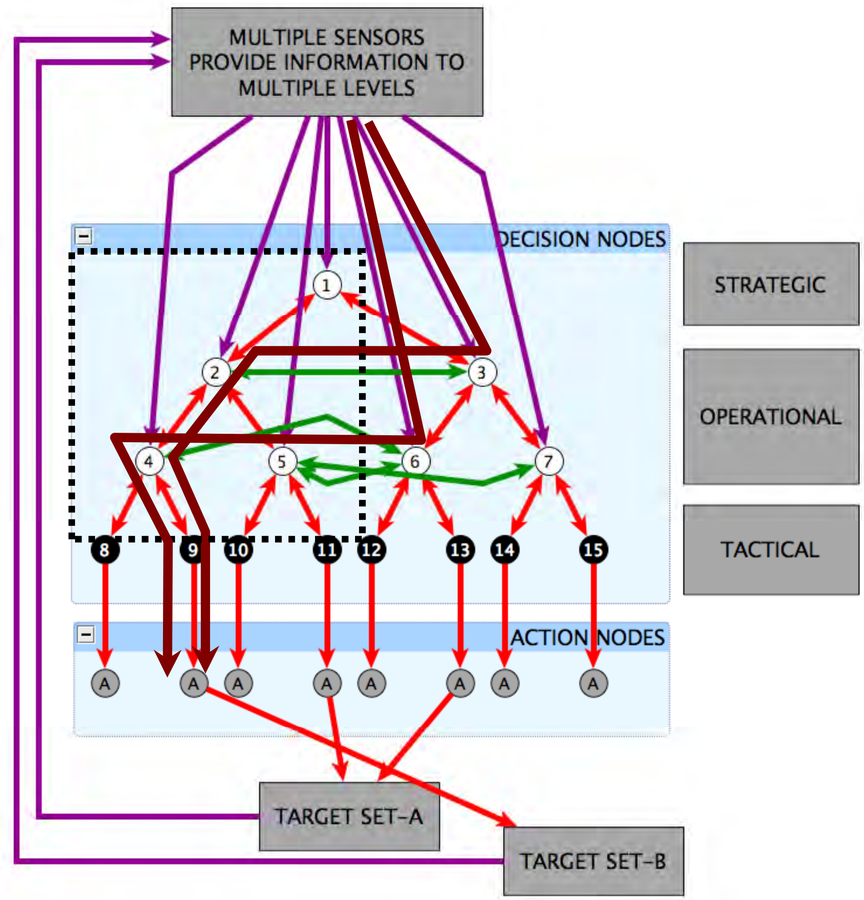
Operational Model:
Open System, Information Processing

- **Three functions: sense, decide, act**
  - *Sensing gathers information from the environment* and makes it available for processing and decision
    - Sensing information is increasingly ubiquitous and nearly uniformly available throughout the enterprise
  - *Decision* structure is a multi-level control hierarchy that *gathers and processes information, collaborates and coordinates to make decisions and direct action*
  - *Act* functions *manipulate the environment* in some way; they are single action outputs to the environment (e.g.: shooting a weapon)
- **Flexibility: number of possible alternatives from sensing to action**
- **Our focus:**
  - Decision architecture
  - Impact of lateral interactions and hierarchy on the number of alternatives available in the system



Operational Model:
Open System, Information Processing

- **Strict tree hierarchy, with sensor information coming into the top**
  - Limited number of operational options
- **Technical capability is making information access ubiquitous**
  - Enables moving decisions lower in the hierarchy, increasing the number of options
- **Adding lateral interactions increases the number of options even more**
  - Node 2 can collaborate with node 3, enabling retargeting of assets that belong to node 2's subordinate nodes
- **More paths from sensing to action on the environment**

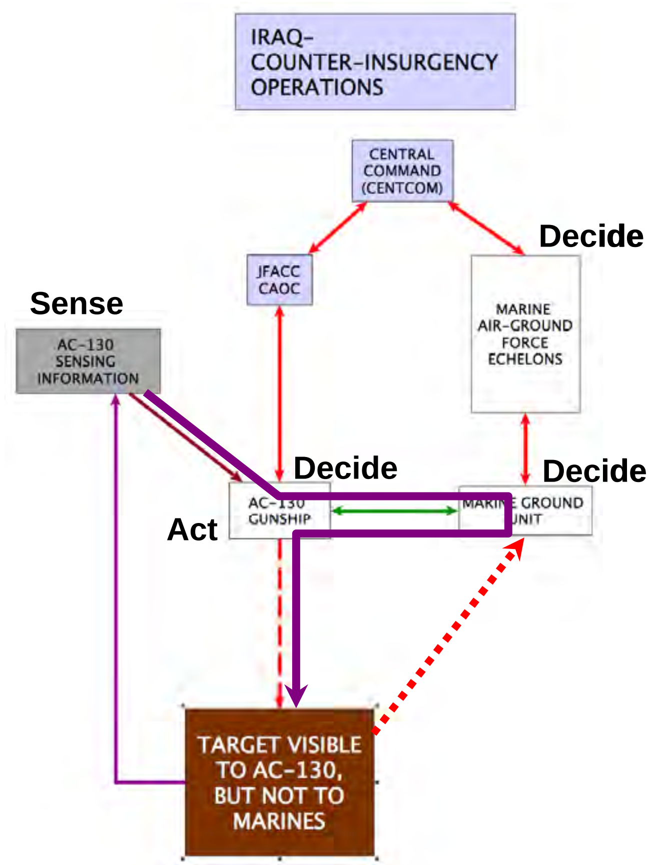


= Most analysis focuses only on this box

Example:

Air-ground operations in Iraq with AC-130 gunships *

- **Battle of Fallujah, April 2004**
- **Marines in control of AC-130 providing support to the operation**
  - AC-130 has better situational awareness than Marines
- **AC-130 detects insurgent activity threatening the Marines and requests to engage**
  - Marines request higher authority permission
  - Insurgents attack before permission is granted
- **Vertical architecture: slow response, low collaboration**
- **Alternative architecture: Allow tactical level units to shift control as necessary**
- **Lateral architecture enables faster response based on collaboration**

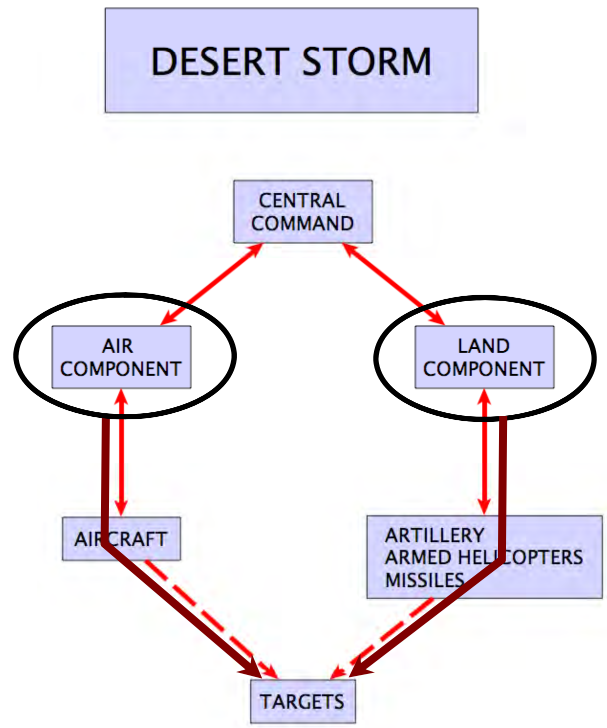


*Based on Kometer and Siefert

Selected Examples From Air Campaign Cases

Desert Storm (1991)

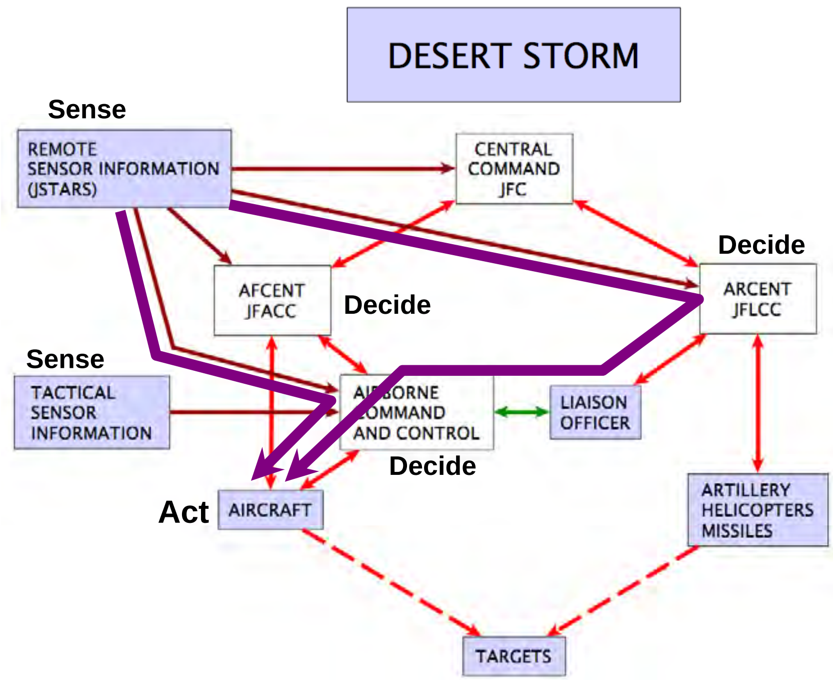
- **Overall architecture: tree***
  - Separate service plans
  - Integrated and managed from the top
  - Little collaboration
- **Flexibility:**
  - Ad-hoc collaborative interactions at lower levels developed over time
  - Responsive lateral interactions to enable flexibility
- **Overall:**
  - Difficult to leverage complementary service capabilities
  - Hard to adjust priorities to changing battle conditions
- **Laterality: 0**



***Ref: Gulf War Air Power Survey; Mandeles, Hone, Terry; Atkinson**

Desert Storm-Evolved

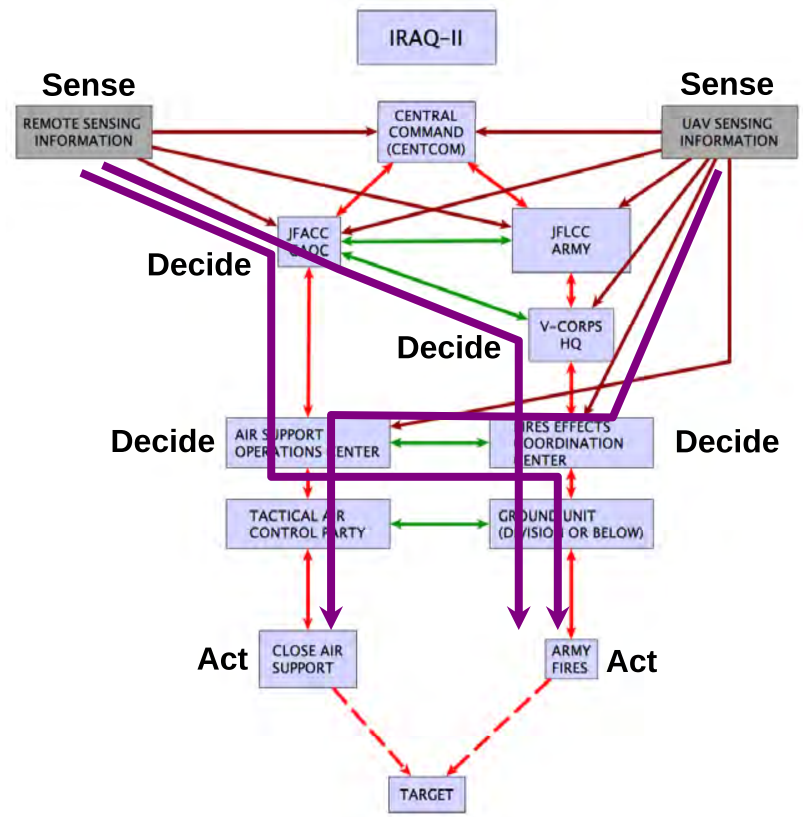
- **As Desert Storm evolved, lateral connections developed**
  - Liaison officers on board airborne command-control aircraft
- **Sensor information passed directly to airborne command enables faster response**
- **Issue:**
  - Target modifications were generated from Liaison Officer → Airborne Command and Control interactions
  - These might not have been in accord with JFC priorities
- **Laterality: L2 (Operational level)**



Iraq-II

(Major Combat Operations, Mar-May 2003)

- **Overall architecture: lateral hierarchy**
  - ACCE to connect JFACC to major ground commanders*
  - Air-ground interface close and strong at multiple levels between V Corps/4th ASOC
- **Close collaboration**
  - planning and
  - collaborative operational relationships, esp at Corps level and below
- **Resources and diplomatic constraints**
  - U.S. ground force ~1/3 size of Desert Storm
  - Turkey's denial of over flight
  - Desire to maximize diplomacy
- **Real time battlefield sensor information available in more locations**
  - Predator video to aircraft
  - 2-way air-ground video transmission
- **Laterality: L1/L2/L3 (multi-level laterality)**



*Air Component Coordinating Element

Summary: Laterality-Flexibility

Conflict	Levels where lateral connections existed	Assessed Flexibility
Desert Storm	0	Low (basic architecture)
Desert Storm	L2	Medium (evolved, interdiction)
Kosovo	0	Low
Kosovo	L1/L2	High (fixed targets)
Kosovo	L3	Medium (moving targets)
Afghanistan	L2/L3	Medium (SOF-air)
Afghanistan	0	Low (sensitive targets)
Afghanistan	L2/L3	Medium (overall)
Iraq-II (Major Combat Ops)	L1/L2/L3	High (air-ground ops)

Military Operations 1990-2003

- **Trend: laterality increases from beginning to end**
  - Highly contingent on multiple factors such as senior leader personalities, political issues, technology (information access) and specific missions
- **In *every case except Iraq-II:***
  - Lack of laterality at higher layers inhibited flexibility
  - The need for flexible air-ground coordination required creating lateral connections at lower layers of hierarchy *after the start of the conflict*
- **Flexibility helps increase operational effectiveness and efficiency while helping to maintain safety margins**
  - Tensions arise over efficiency vs. effectiveness *judgments*
  - Boils down to arguments over objective functions
- **DoD's operational forces are flexible: the enterprise "learns"**
  - Different architecture from start to end of each conflict
  - Each conflict had a different architecture, tailored to the operational problem and political/policy constraints
  - Double-loop learning (Argyris): ***but we can do better***

Trade-offs

- **In military operations, flexibility is necessary to maintain overall force effectiveness**
  - Must always be balanced with efficiency considerations*
- **Flexibility-efficiency trade-off is complex**
  - Different metrics and different value depending on layer of hierarchy
  - Flexibility at one level can often be characterized as inefficiency at another
- **Flexibility can be used differently depending on strategic choice**
  - Increase complexity for the enemy
  - Maintain effectiveness if resources are constrained
- **Lateral interactions within a layered architecture can help balance flexibility and efficiency**

***Economy of force is an enduring principle of war**

Summary Findings

- **Hierarchical architectures with lateral interactions at multiple layers are more flexible than traditional tree-structured hierarchies**
  - Ad hoc laterality in tactical layer enables flexibility but can lead to loss of coherence
  - Layer violations can result in unintended outcomes but can also yield benefits
- **Lateral interactions at higher layers are important to maintaining strategic coherence**
- **Lateral interactions at lower levels are required to gain flexibility in uncertain and fast-moving operations**
- **Enterprise architecture entails the acceptance of suboptimization in some parts of the enterprise**
  - Global optimality is difficult, possibly impossible, to attain
  - Layered architectures and lateral interactions can mitigate this effect
- **Our architectural framework enables system level comparative analysis of flexibility among different possible enterprise architectures**
  - enriches current conceptual models
  - adds analytical dimension missing in modern models of military operations

Limitations of Laterality

- **People will still make errors**
  – Lateral interactions can cause confusion, even if they are designed into the architecture and processes
- **Operationally, political constraints will always determine the ability to leverage the flexibility designed into an architecture**
- **There are significant contingent factors in *<u>implementing</u>* laterality and then *<u>using it</u>* to enable flexibility:**
  – Culture may inhibit ability to design lateral architectures
  – Personality and preferences of senior leadership may also limit the degree to which laterality may be designed into an enterprise
  – There are cases where laterality may not be an optimal architecture, such as high risk and/or tightly constrained resource situations

Recommendations

- **Design of enterprise architectures should be conducted as a *strategic* activity**
  - Deserves dedicated, possibly primary, attention of senior leadership
  - "Just do it", evolutionary or "emergence" approaches are insufficient
- **Examine warfighting doctrine in context of lateral architecture**
  - Identify areas where traditional doctrinal perspectives inhibit laterality (i.e., where tree-structures are written into doctrine when more flexible operations may be necessary)
- **Examine enterprise architecture of DoD for areas where lateral architectures may be beneficial**
- **Explore wider implications of lateral architectures for DoD**
  - Command structures, relationships
  - Career paths
  - Budget structure
- **Develop a more complete set of enterprise architecture design principles (next slide)**

Initial Enterprise Design Principles

- **Design of enterprise architectures requires dedicated attention of senior management**
  - It is an ongoing and pro-active design activity
- **The impact of technical system architecture on future operational enterprise architecture should be a specific design consideration**
  - Sensor inputs (of all types) may define where collaboration is (and is not) possible
    - Where should new sensing system information be made available?
    - Where should options for future sensing information access be designed?
    - What are the implicit or explicit assumptions regarding interoperability and data exchange in new and existing information systems?
- **When designing flexible enterprises, consider how hierarchical structure enables and inhibits:**
  - information flows,
  - the number of force engagement alternatives (paths) and
  - the time responsiveness (path lengths) of those alternatives
- **System-level properties and their value must be considered together with individual subsystem and organization performance metrics**

Future Work

- **More operational case studies using the framework and model:**
  - Military operations: Operation Anaconda (Afghanistan); Iraqi Freedom Surge and Counter Insurgency (COIN) Operations
  - Disaster Relief operations: Hurricane Katrina
- **Acquisition and system development applications:**
  - Information-based military systems (radar, sonar, radio)
  - Large-scale commercial or public projects (787, public infrastructures)
- **Use case analysis to develop more detailed principles for enterprise design; some initial principles are visible**
- **More detailed exploration of the applicability of information and computer science theory to a theory of enterprise architecture**
  - Shannon Information Theory
  - Computer science architecture practices

Research Strategy

- **Literature-based conceptual framework**
  - Grounded in concepts from computer science and mathematics
  - Hierarchical layers are significant, possibly enduring, features of complex organizational structures
- **Main idea:**
  - Layered architectures, with an emphasis on lateral interactions within layers, enable increased enterprise flexibility to be balanced with overall system level strategic coherence
- **Research design:**
  - Historical case study analysis of military operations, emphasizing inter-organizational interactions at multiple levels of hierarchy
  - Examined an unrelated case (New England Patriots) as an initial check on case study insights

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Navy Acquisition Case

- **Post-Cold War defense cuts**
  - A legacy Navy system was hampering operational performance of a critical platform (national mission)
  - Upgrading legacy system was not viable: too expensive, too much time
- **Senior Flag Officers convened expert panel to examine problem and offer solutions**
  - Lacked flexibility; could not leverage benefits of Moore's Law
- **Decision: move to COTS-based hardware and middleware-enabled open architecture**
  - Dropped cost by 3 orders of magnitude and time to upgrade by factor of 10
- **Shifted acquisition to an open business model**
  - Key to flexibility in acquisition are lateral interactions at multiple levels of organizational hierarchy within the acquisition program