A New Methodology for Design and Evaluation of Heterarchical Structures

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Track 1: ***C2 Modeling and Simulation***

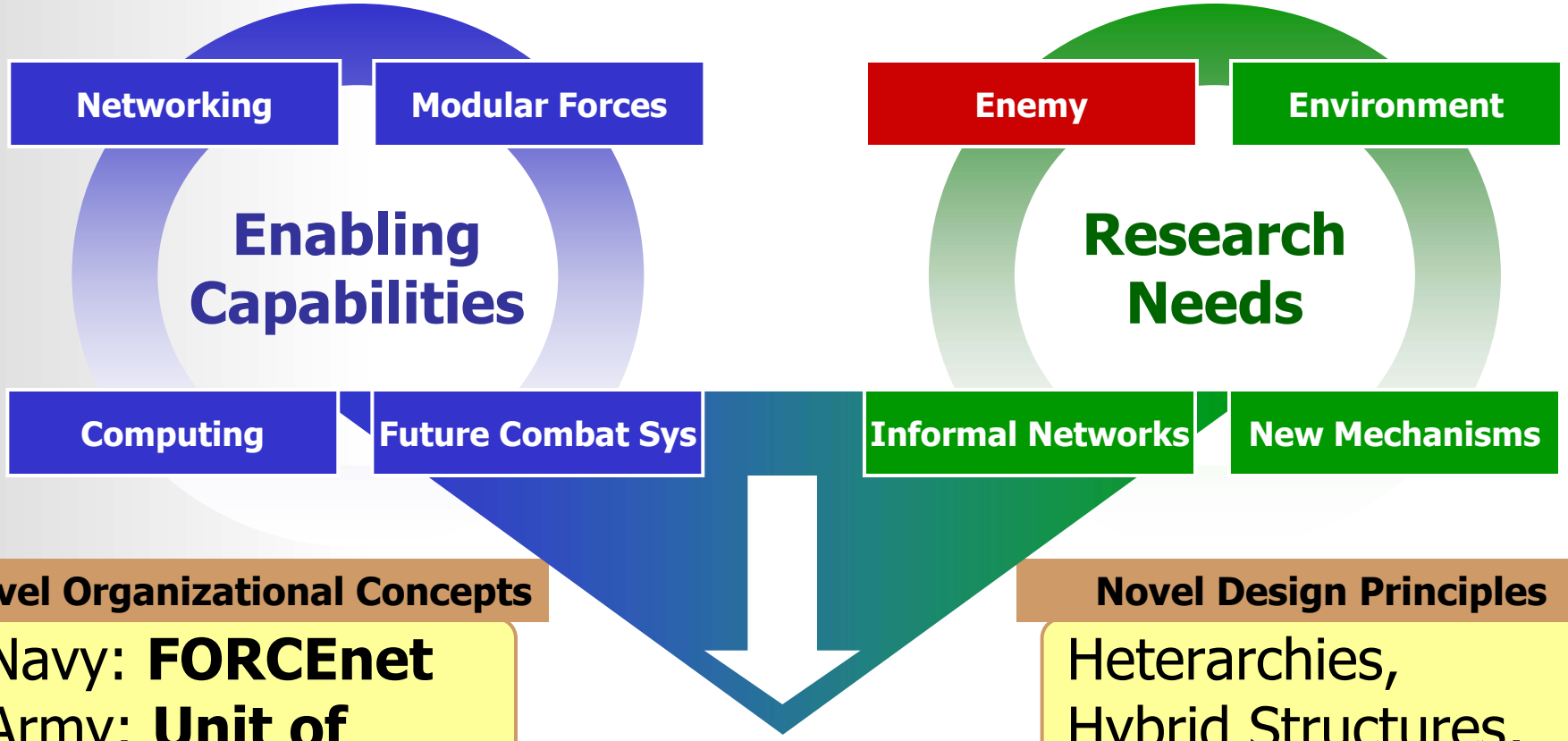
What is Heterarchy?

- A **Heterarchy*** is a form of organization resembling a network, where authority is determined by knowledge and function

- A **decision heterarchy** is made up of a group of humans with **common purpose**. The group is organized horizontally with all individuals sharing equal authority and equal responsibility.

*The term **heterarchy** was introduced into science more than half a century ago by the neurophysiologist and cybernetician Warren St. McCulloch in his study "A Heterarchy of Values Determined by the Topology of Nervous Nets"

Why Study Heterarchies?



Novel Organizational Concepts

Navy: **FORCEnet**
Army: **Unit of Employment**

Novel Design Principles

Heterarchies, Hybrid Structures, Swarms

- **Imbed** modeling principles into design of *friendly* organizations to ***enhance performance***
- Determine how to ***influence*** adversary organizations

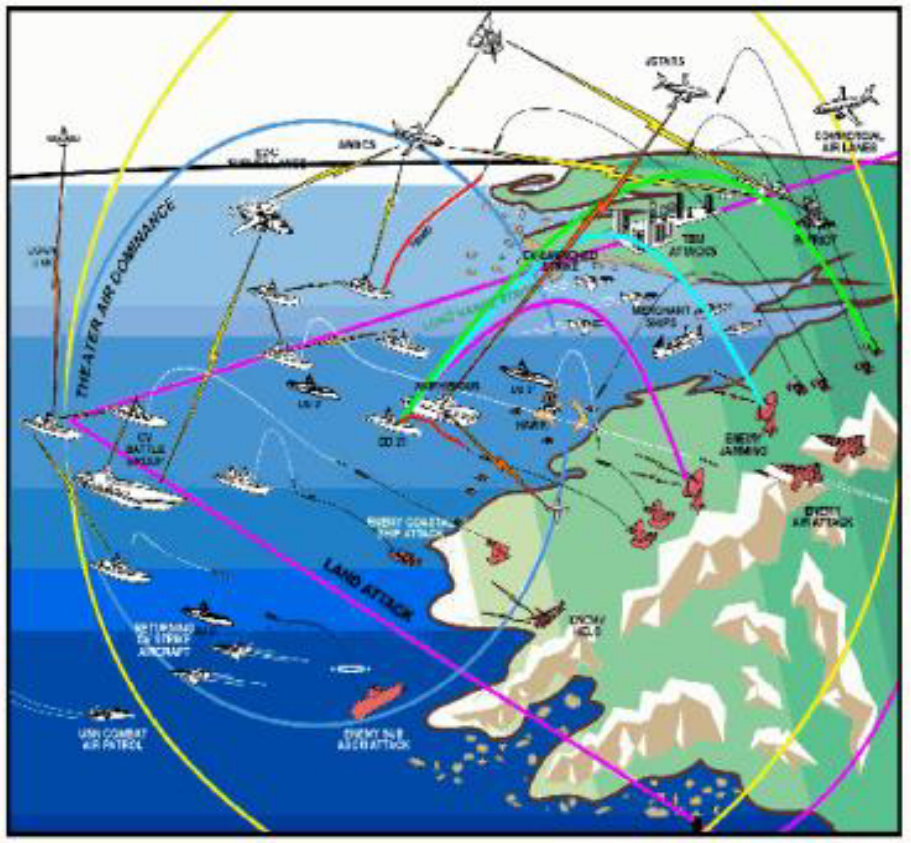
Overview of Presentation

- The Problem
- Types Of Organizational Structures
- Operational Example: Call For Fire
- Problem Identification & Modeling Formalism
- Solution Approach
- Simulation Example
- Potential Implications

Designing C2 Organizations in the Age of Network-Centric Operations

The General Problem:

→ How would you design a C2 organization for this mission?



→ How would you derive human requirements for the organization?

→ How would you evaluate its performance for this mission?

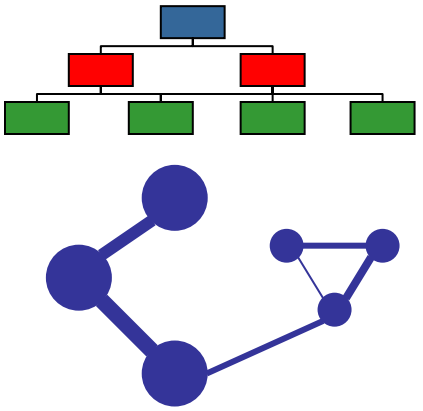
→ How would you structure this organization?

Modeling Focus

- What problem are we addressing?
  - Design of organizational **structures/networks** and **strategies/processes**

structure/network

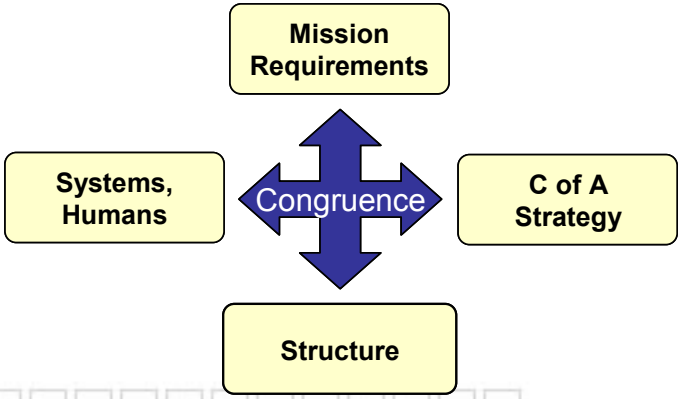
Collection of items (nodes) and rules/constraints (links) of their interactions
- Command
- Control
- Communication
- Information/knowledge



strategy/processes

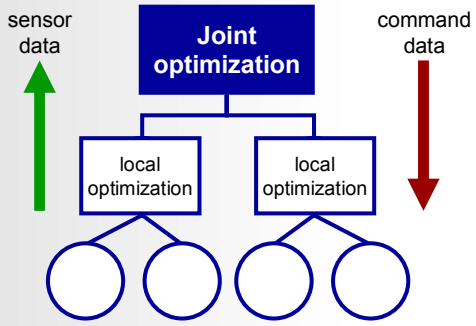
Policy/procedures/rules/guidance to execute a mission
Processes, interactions, courses of action methods

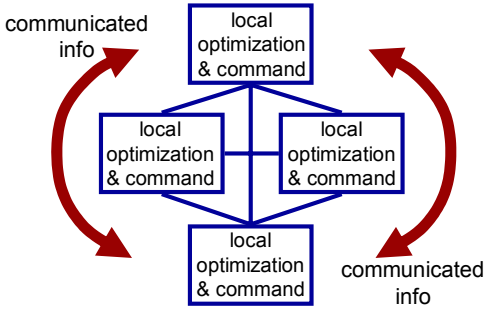
- What is our focus?
  - **Interactions** between mission, structure, strategy, and humans
  - We model "**organizational processes**" – system & interactions design

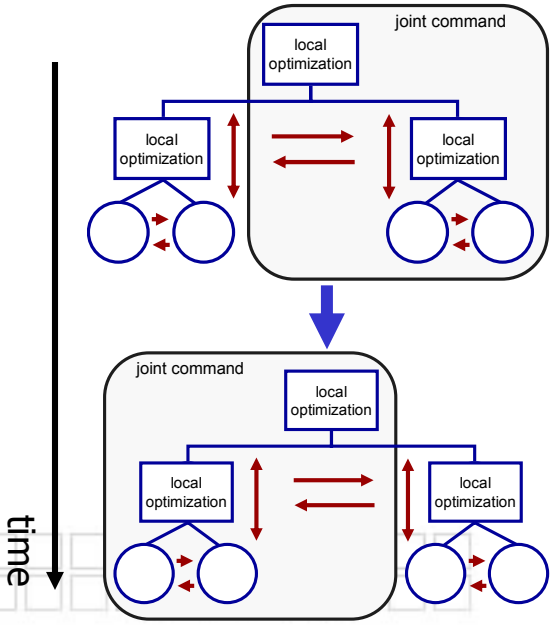


Types of Organizations

	Hierarchy	Heterarchy	Hybrid
Pros	▪ Reduce complexity ▪ Limited functionality of individual cells	▪ Flexibility ▪ Improved fault tolerance ▪ Independent operations	▪ Benefits of both hierarchy and heterarchy ▪ Adaptability
Cons	▪ Lack of flexibility ▪ Slow response time ▪ High sensitivity ▪ Low fault-tolerance	▪ Lack of control ▪ Lack of global view ▪ Sensitivity of collaboration rules ▪ Redundancy	▪ Difficulty to design and control ▪ Need understanding of current structure by all nodes

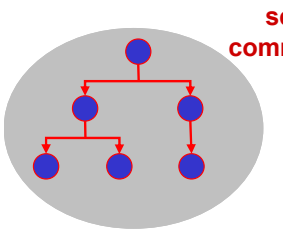




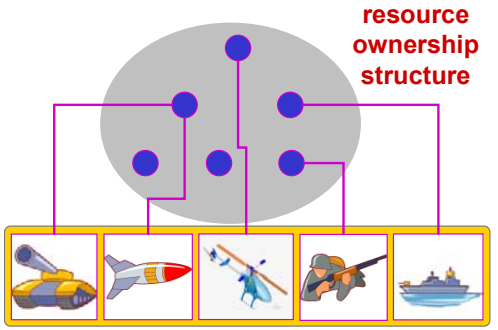


Structures in an Organization

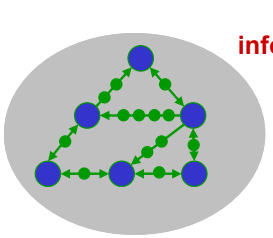
- **Command**
  - Who makes command decisions
  - Who supports whom
    - Execution planning and directing



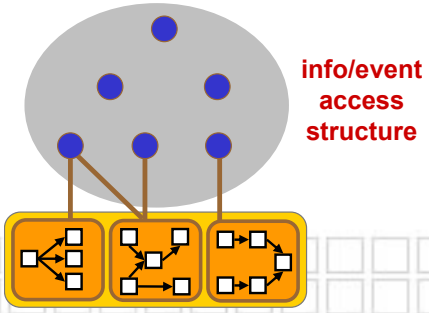
- **Control**
  - Who controls what resources
    - Capabilities to execute mission



- **Communication**
  - Who talks to whom
    - Synchronizing operations



- **Information**
  - Who observes what
    - Knowledge of the environment



Example: Call for Fires Process

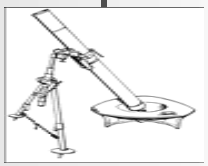
•Troop Commander
•Troop FEC

•Fires BN FDC

•firing battery 1

•firing battery 2

•firing battery 3



• Recon Troop
120mm Mortar
Section

• Squad Leader
• Platoon Leader
• COLT Team Leader

Target
Requires Call for fire

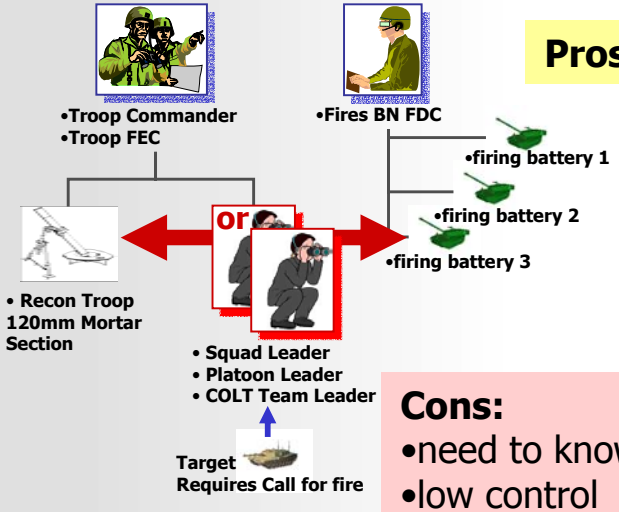
Various Control Processes:

Modes
- Autonomous
- Fires BN Directed

Forms
- Centralized
- Decentralized
- Pre-designated

Examples of Alternative CFF Processes

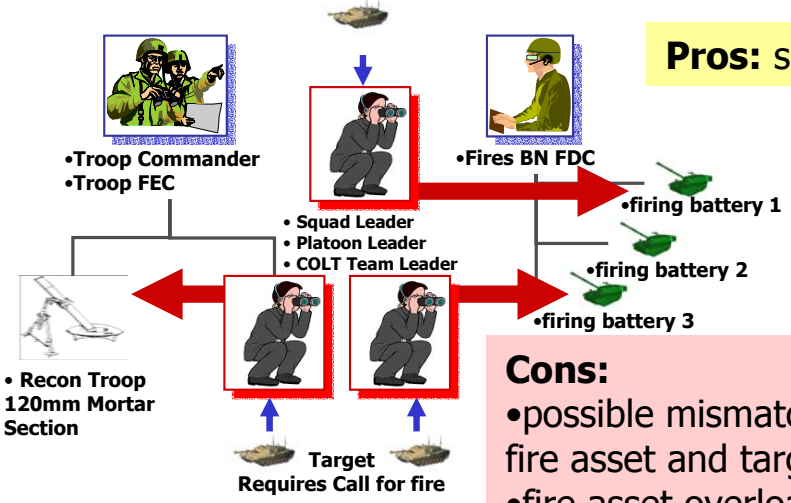
Decentralized & Autonomous



Pros: speed

Cons:
- need to know asset status
- low control

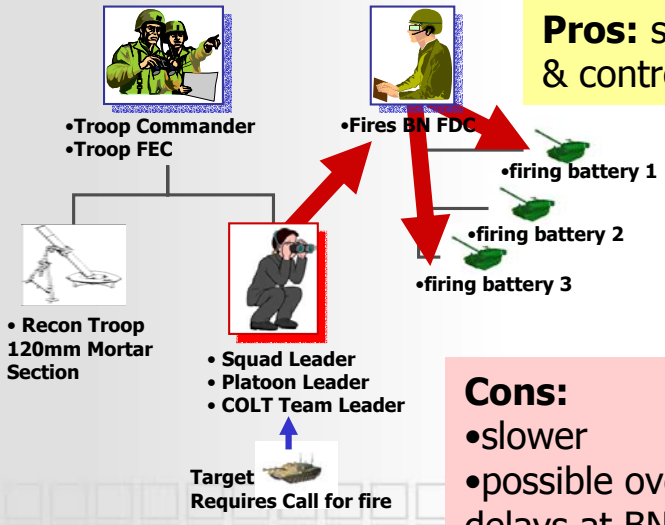
Pre-designated & Autonomous



Pros: speed

Cons:
- possible mismatch between fire asset and target
- fire asset overload

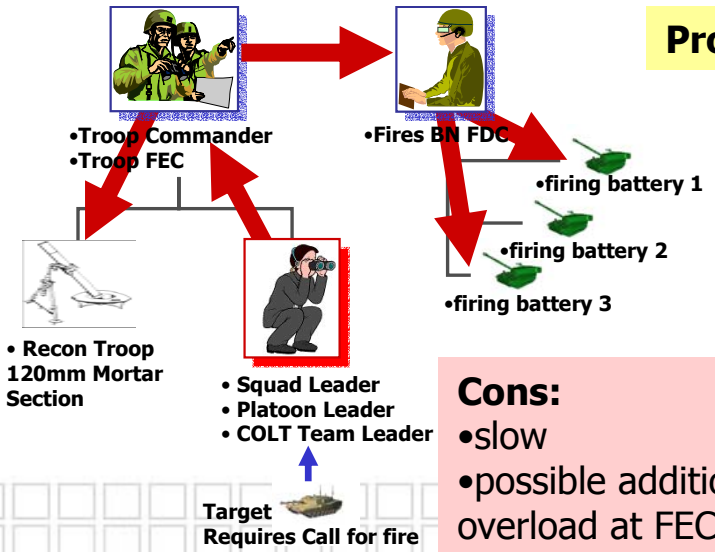
Decentralized & BN FDC Directed



Pros: some speed & control

Cons:
- slower
- possible overload and delays at BN FDC

Centralized & BN FDC Directed



Pros: control

Cons:
- slow
- possible additional delays and overload at FEC & BN FDC

Design Challenges

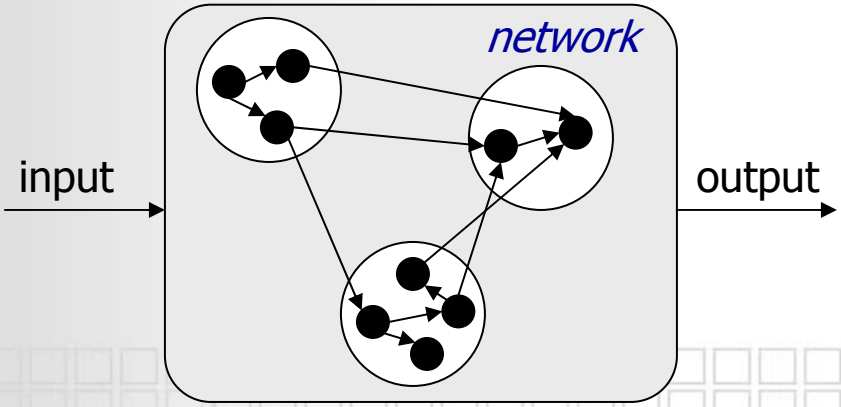
Challenge 1: **Identification of interactions between decision-makers (DM)**

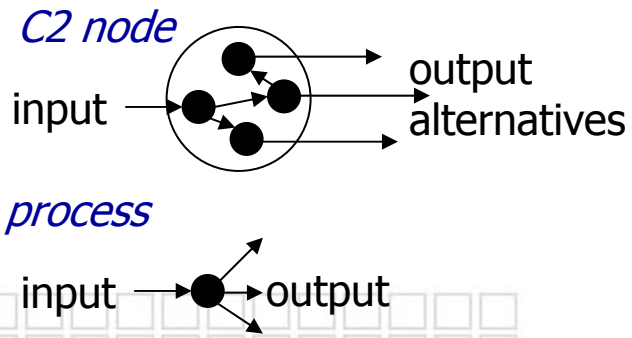
Challenge 2: **Interaction constraints & node effectiveness**

Challenge 3: **Complexity & influence of (sub)structures and processes on each other**

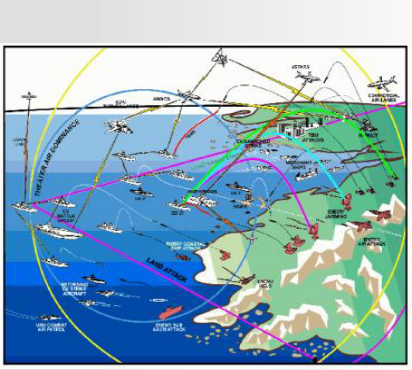
Modeling approaches:

- Use flow model with cost and capacity constraints
- Model constraints on information access, processing speed, information loss
- Model transfer of information in the C2 network
- Heuristic algorithms to maintain network robustness
- Local / distributed decision making

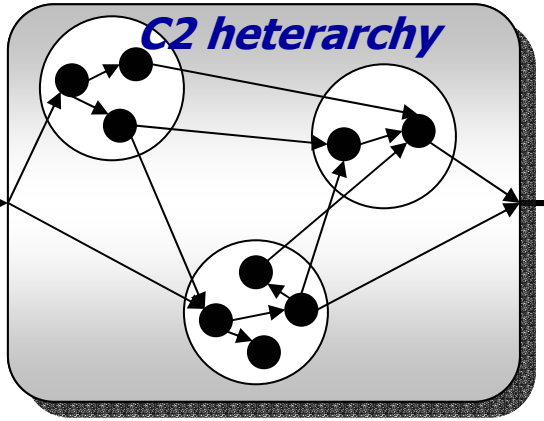




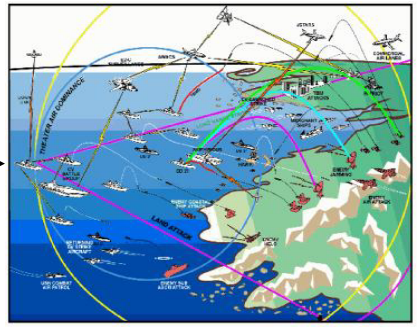
Process Flow

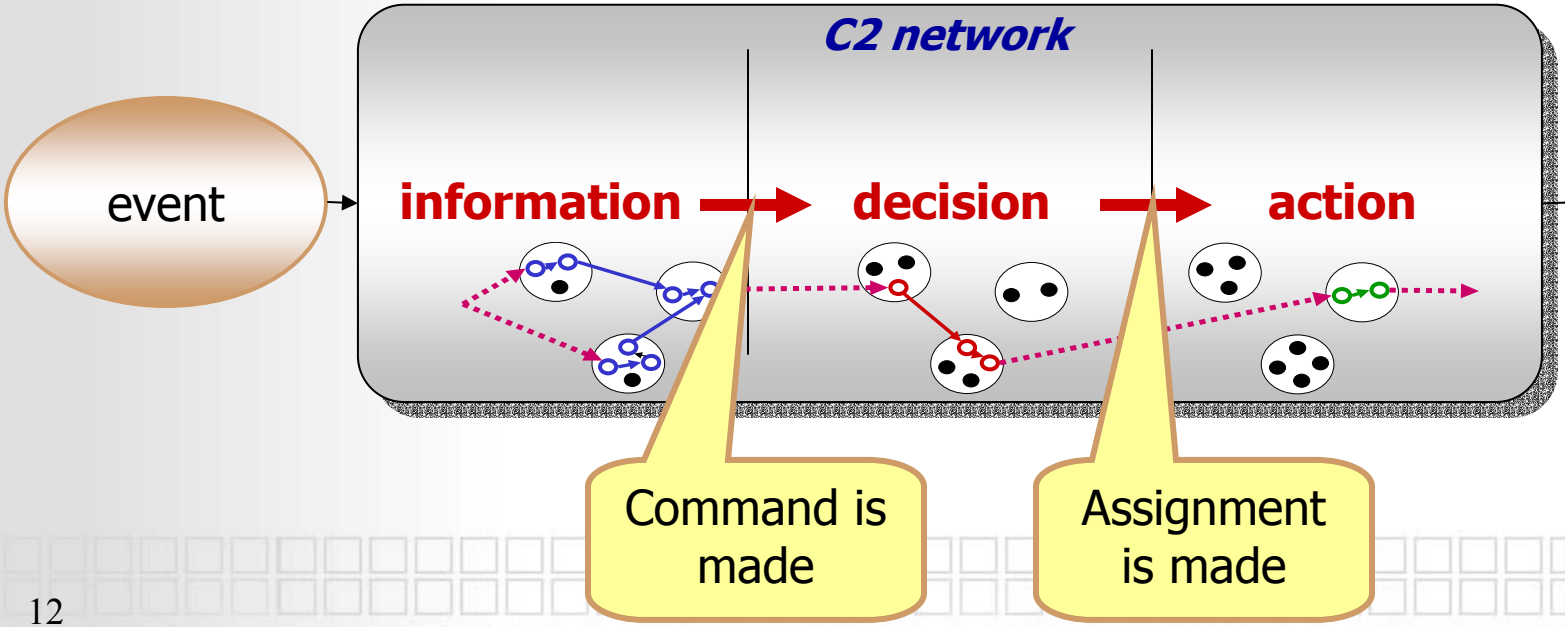


information

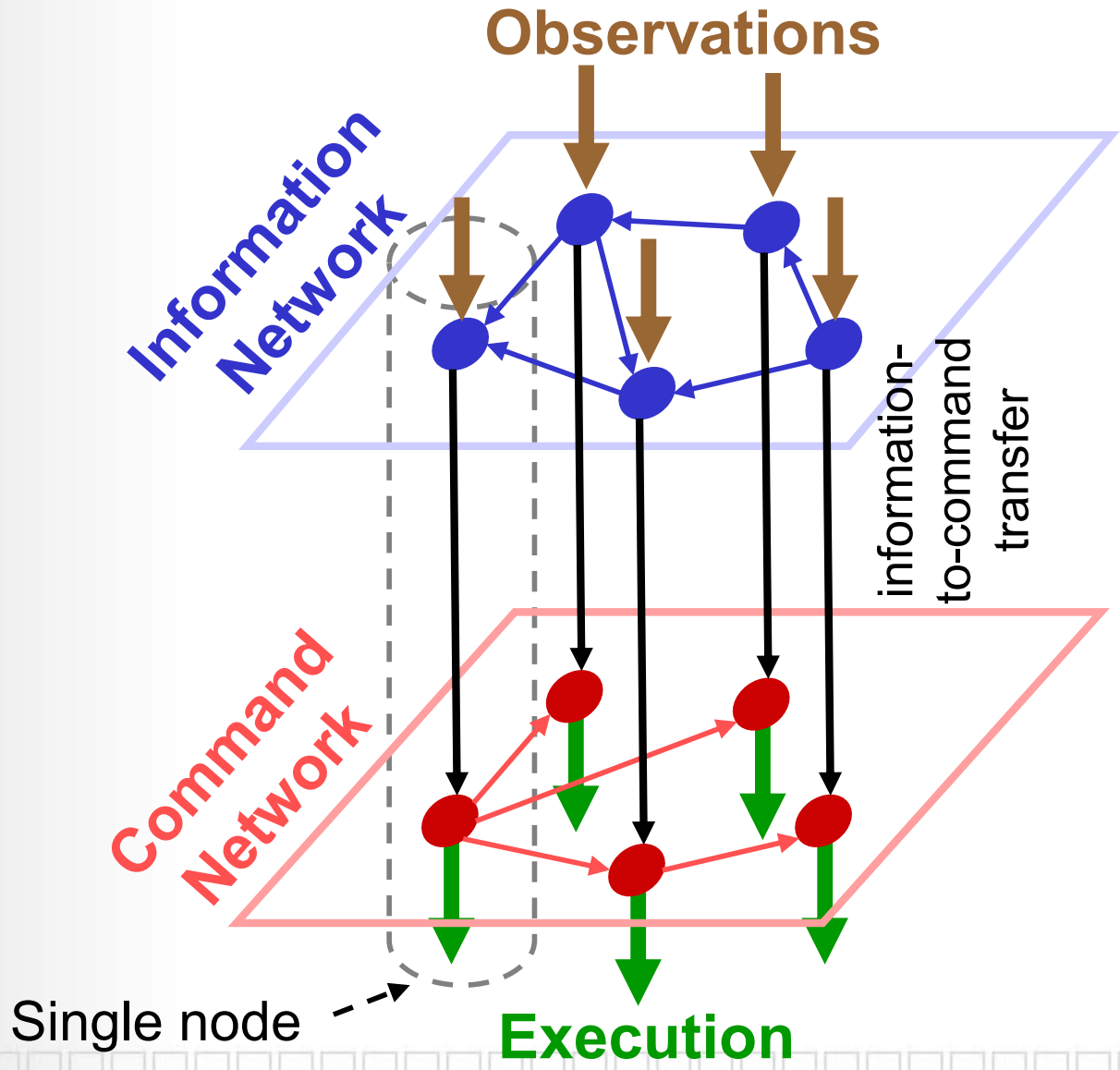


actions





Combined Information-Command Network



Modeling Attributes

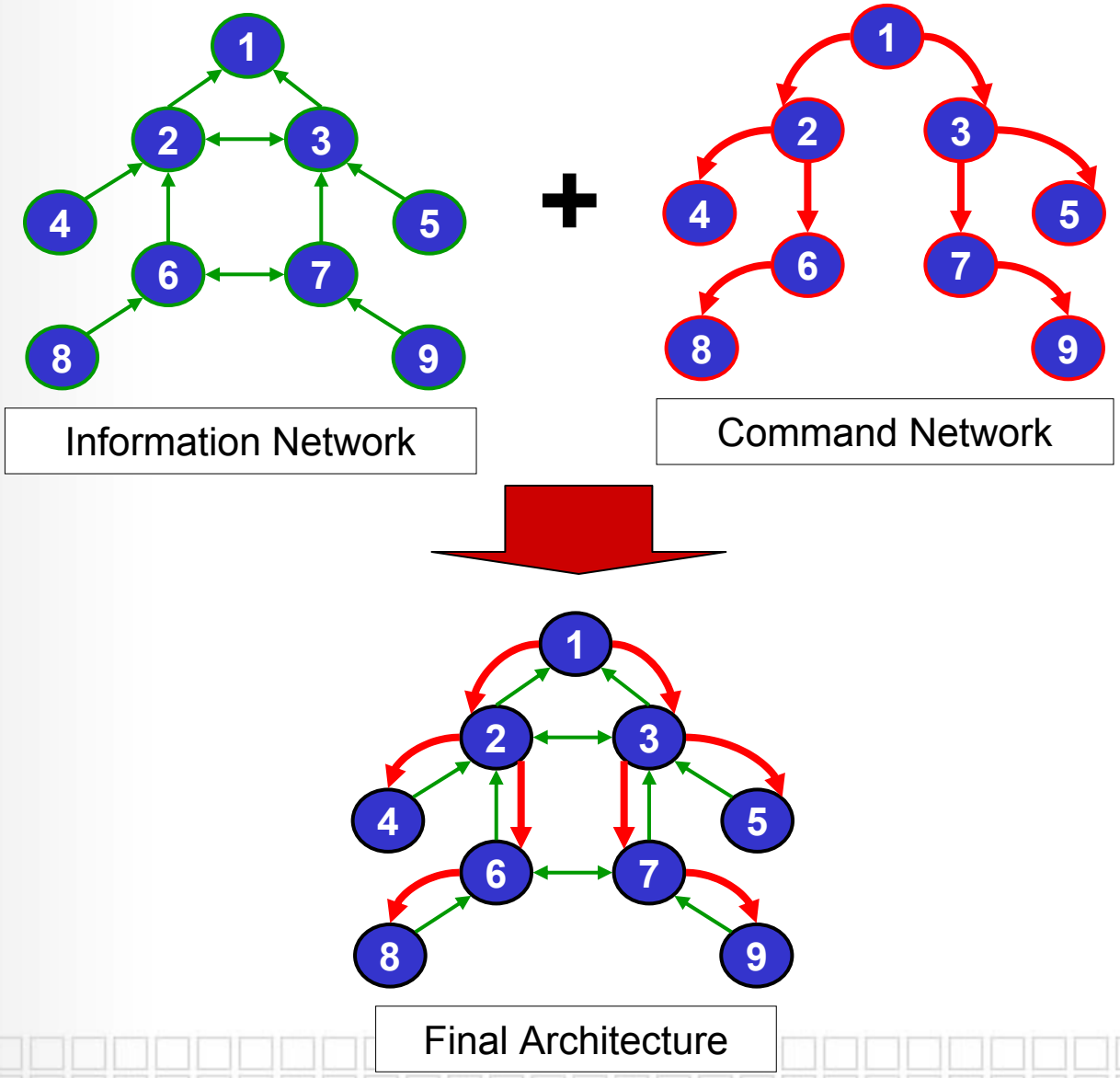
Constraints
- How much can you **do**
  - Execution load
- How much can you **communicate**
  - Communication load
- How much can you **observe**
  - Observation load
- How much can you **decide** on
  - Command & control load

- Modeling of individual performance
  - Based on expertise/resources
    - **Breadth** – generalization
    - **Depth** – specialization
  - Expertise determines efficiency of observation, command, and execution
  - Communication loss is due to different expertise

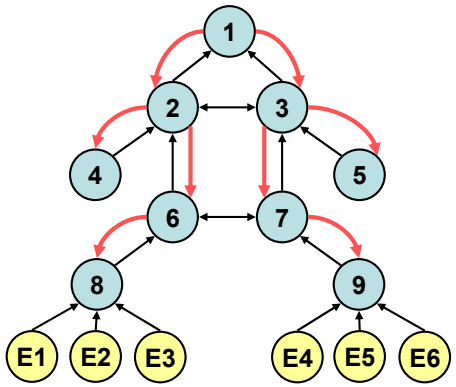
- Performance is modeled by:
  - **Efficiency**
    - How efficiently can you do execution, communication, observation, command
  - **Loss**
    - How much information is lost
    - What is the cost of information loss
  - **Cost**
    - How difficult is it to maintain the structure
    - What is the maintenance/design cost
  - **Delays**
    - Delays in execution, communication, etc. due to overload

Objectives
- Maximize execution & command efficiency
- Minimize information loss
- Minimize design/maintenance cost
- Minimize communication overhead
- Minimize delays

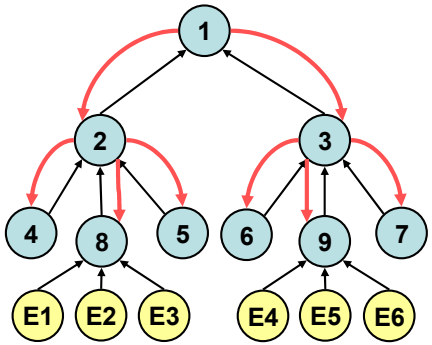
Example of Hybrid Structure



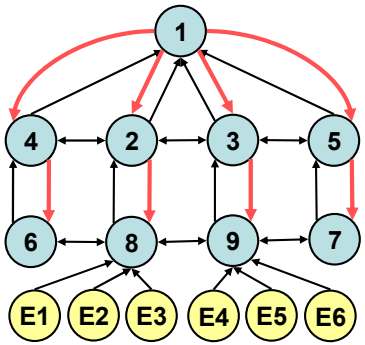
Sample Results



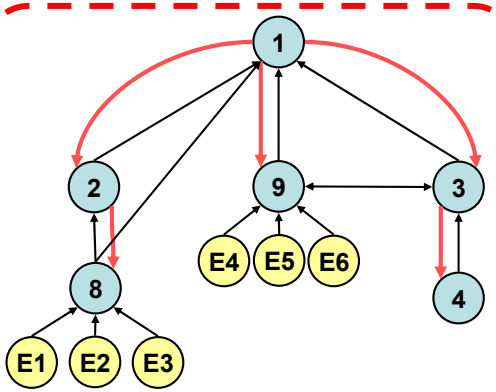
Structure **A**



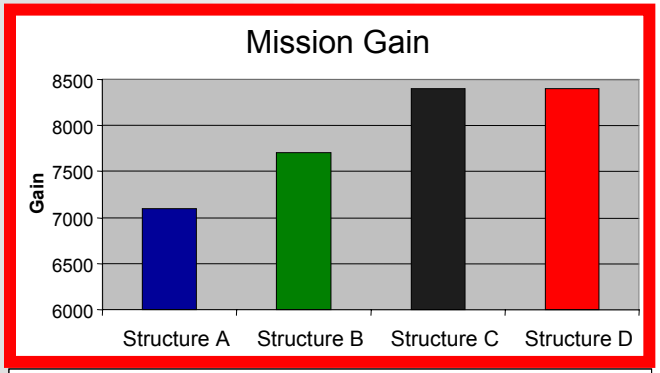
Structure **B**

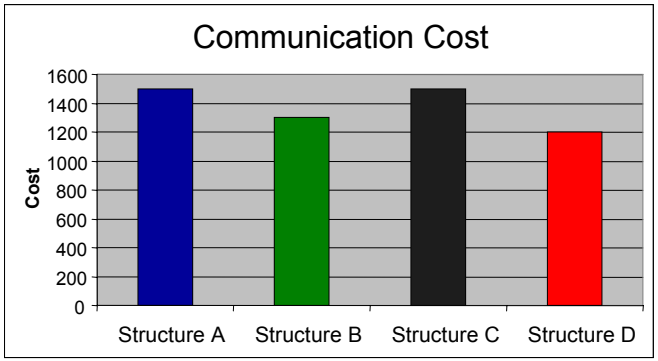


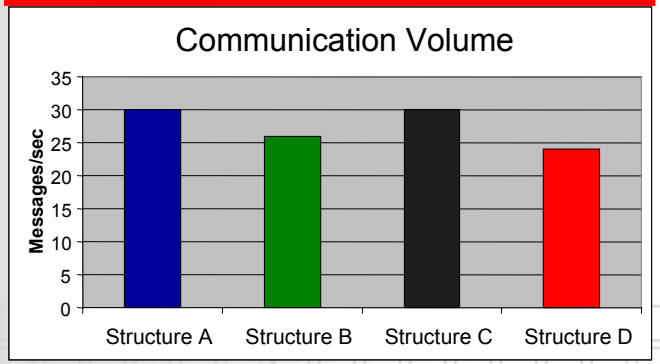
Structure **C**

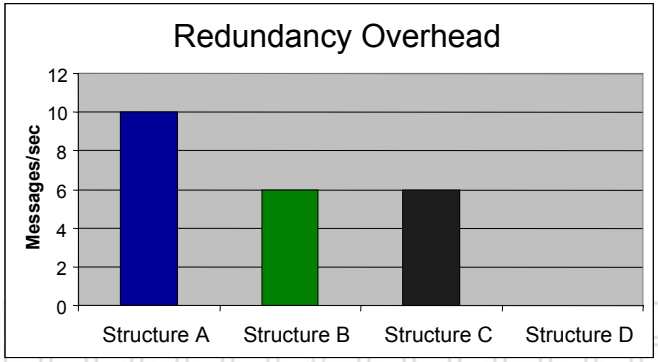


Structure **D**









- Agent node
- Event/observation node
- Command network
- Information network

- Increase the accumulated mission execution effectiveness (gain) while decreasing the communication overhead, cost and volume
- **Optimal network allows better access to efficient nodes**

Future Research Directions

- Consider network robustness constraints
- Implement **multi-commodity** problem formulation
- Consider problem of **unsplittable** or partially splittable flows
- Consider flow **transfer** and generation
- Consider error propagation
- **Test all of the above in humans-in-the-loop experimental and field environments**

Conclusions

- A systematic approach to design inter-dependent C2 organizational structures
  - Command, control, communication, & information dimensions
- A trade space to test benefits and limitations of hierarchical, heterarchical, and hybrid structures

→ Applications:

- Potential to provide science-based solutions to support the design and evaluation of future network-based command structures such as FORCEnet, Unit of Employment, etc…

Acknowledgments

- Aptima
- University of Connecticut
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