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C2 Theory
Overview, Recent Developments, and Way Forward

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Institute for Defense Analyses

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Agenda

- What is “C2 Theory”?
- Evolution of Theory – 1995 to 2016
- Battlefield of 2050 and the Implications for C2
- Frontiers of C2 Research

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What is “C2 Theory”?

- C2 Theory focuses on answering a set of ‘strategic-level’ questions in the context of military and civil-military missions and the environments in which these missions take place, including:
  - How do C2 concepts, approaches, and capabilities need to evolve to meet the challenges posed by complex enterprises undertaking complex missions (Complex Endeavors)?
  - What will S&T trends and the capabilities they enable affect the ‘ battlefields’ of the future and our ability to exercise C2?
  - How can we more effectively and efficiently accomplish the functions associated with C2?
  - What is the C2 value chain and how can it be observed and measured?

C2 Theory

C2 Theory builds upon, applies, and integrates theories and evidence from disparate disciplines

organizational design

perception

network science

military history

communication

management

sensemaking

team building

autonomy

cybersecurity

robotics

collaboration

leadership

decision making

agility

sociology

control theory

culture

knowledge management

psychology

Information science

simulation

risk management

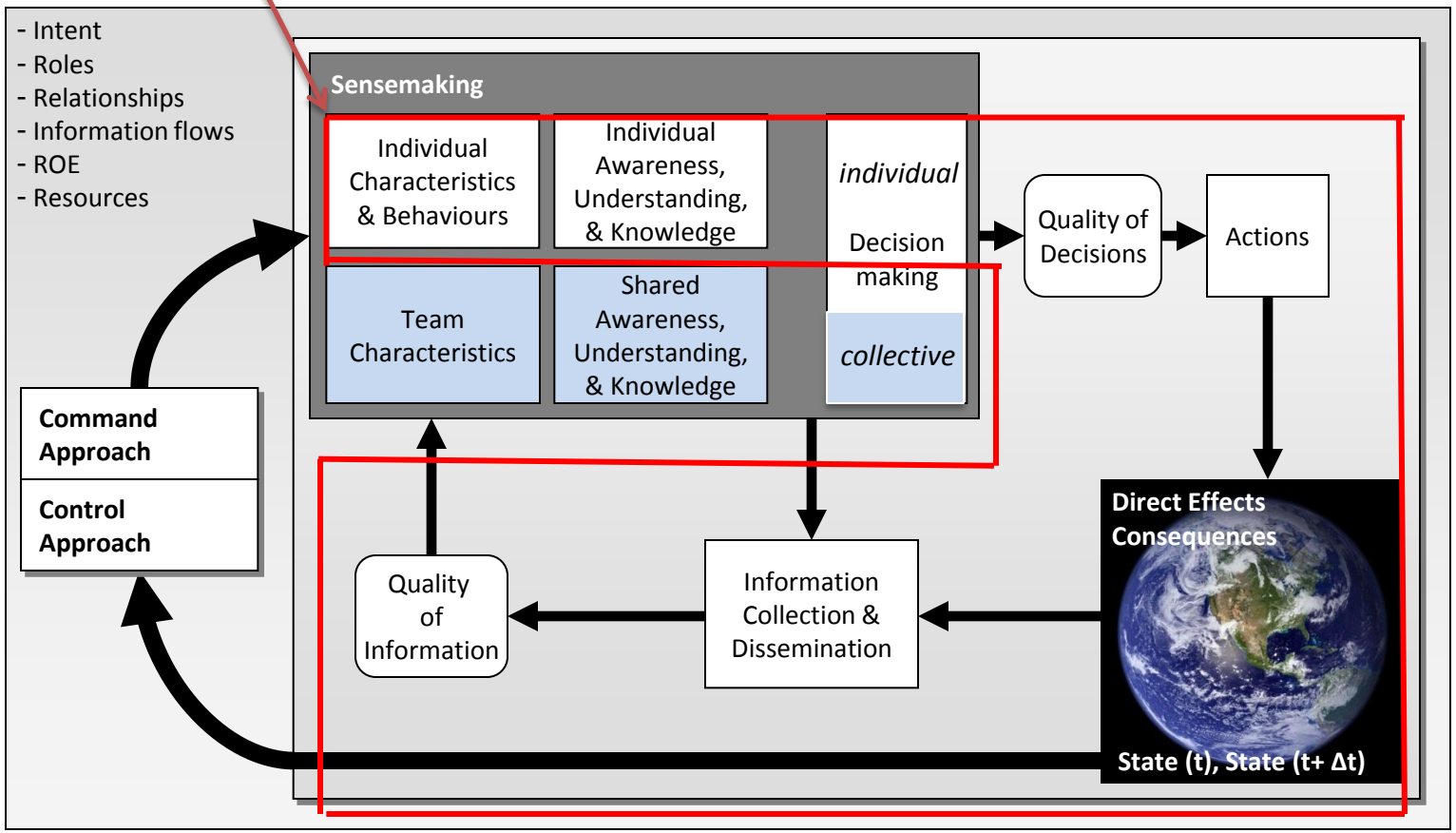
game theory

and many more

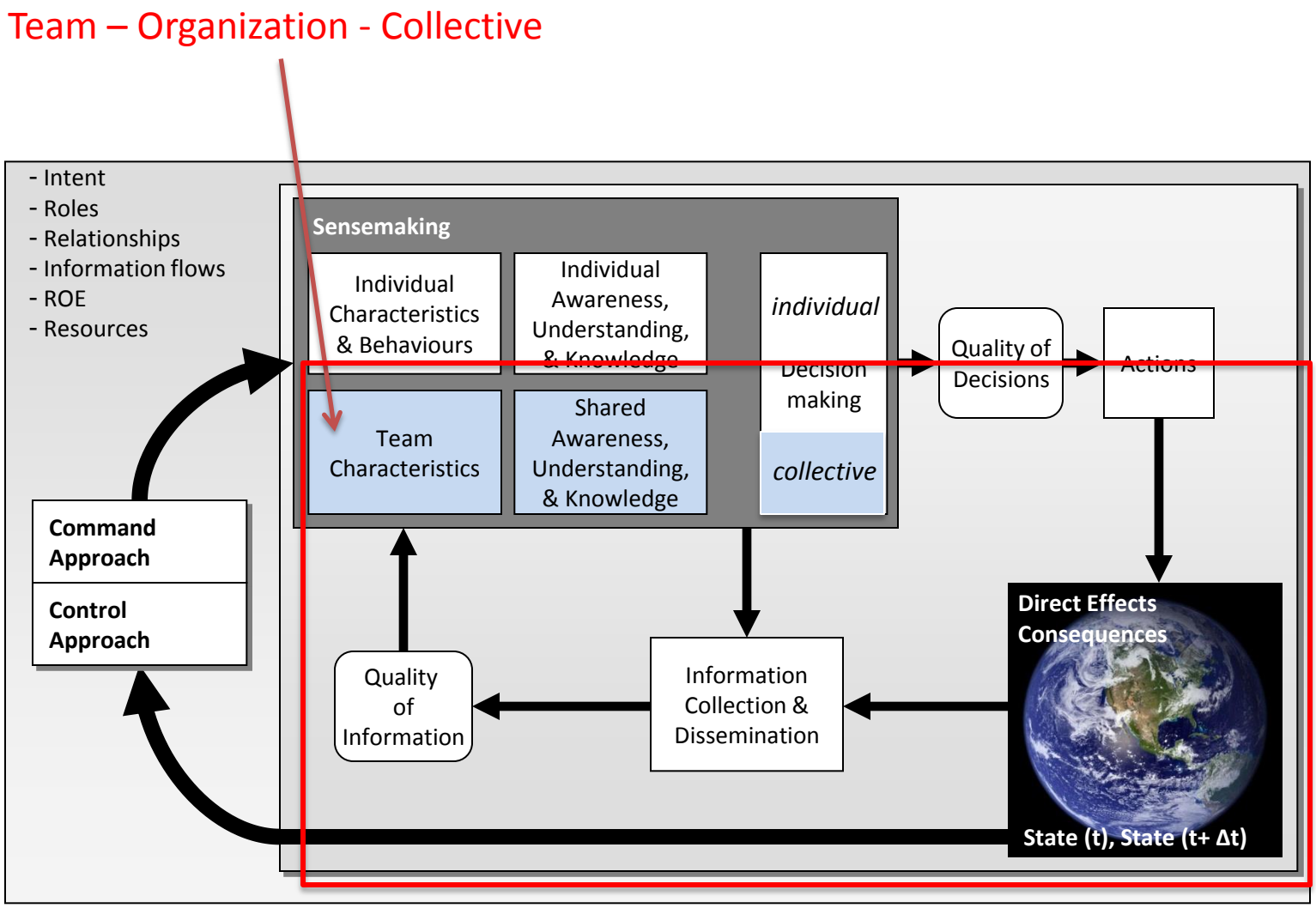
complex systems

Three Perspectives on C2

Commander (an individual)

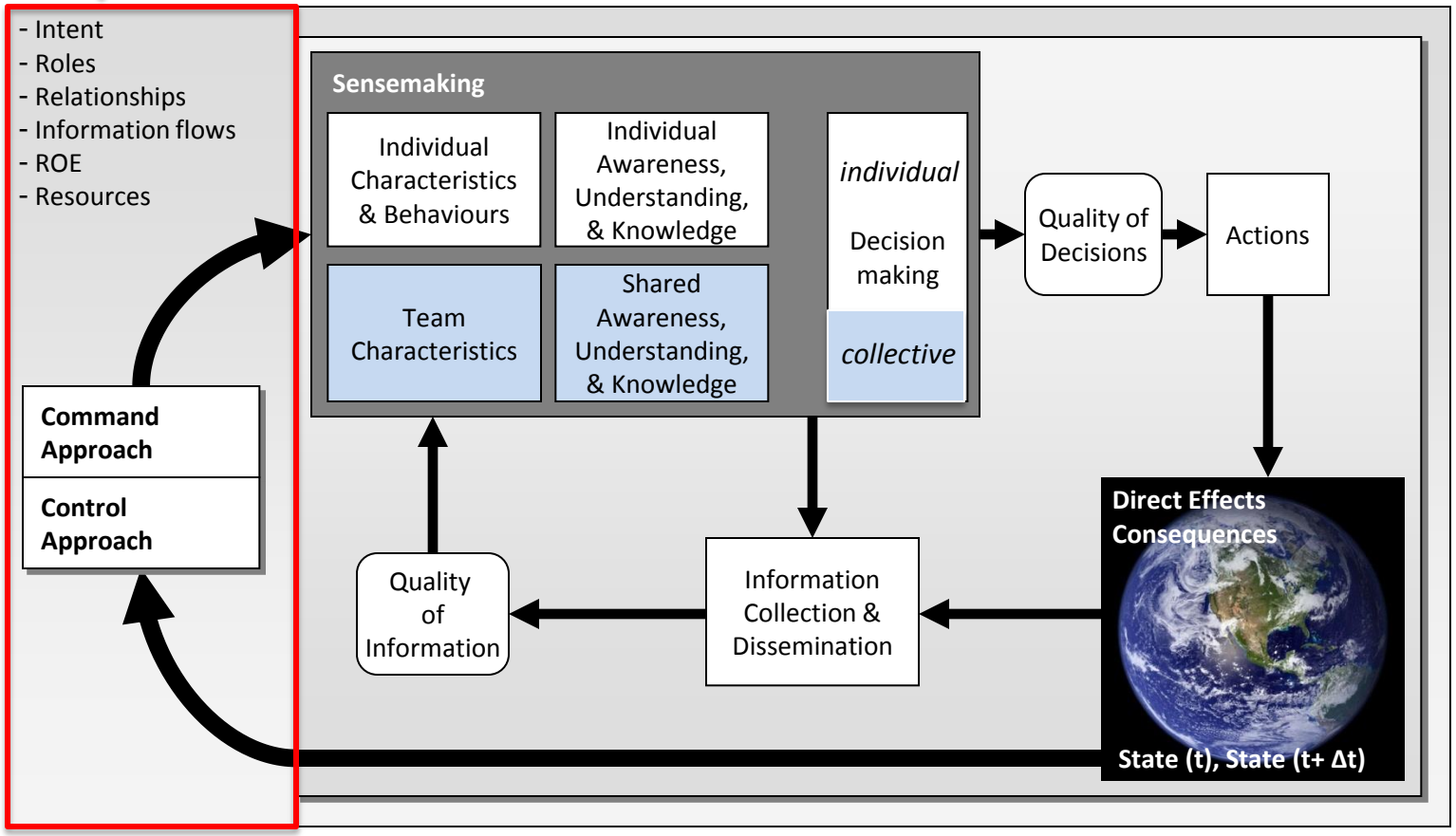


Three Perspectives on C2



Three Perspectives on C2

Approach to Command and Control - Creates the conditions that shape how C2 functions are carried out on the battlefield and determine C2 effectiveness

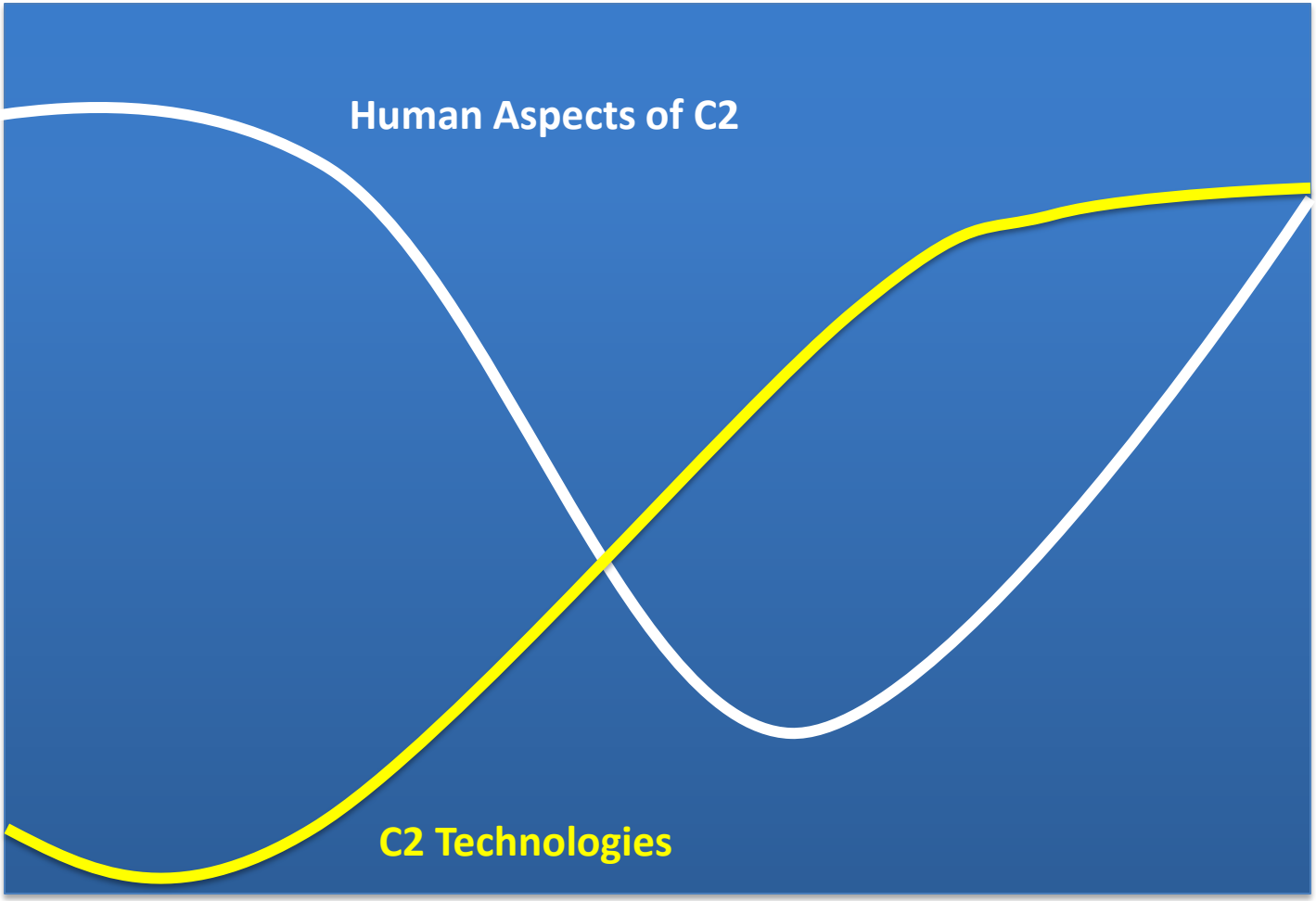


Evolution of C2 Theory 1995-2016

- Circa 1995
- Cooperative Engagement
- Network Centric Warfare (now NEC) and Maturity Model
- C2 Approach Space
- C2 Agility
- C2 of Composite Networks

Shifting Focus and Emphasis

from C2 to C3 to C3I to C4ISR and Back to C2



CCRP 1995-6

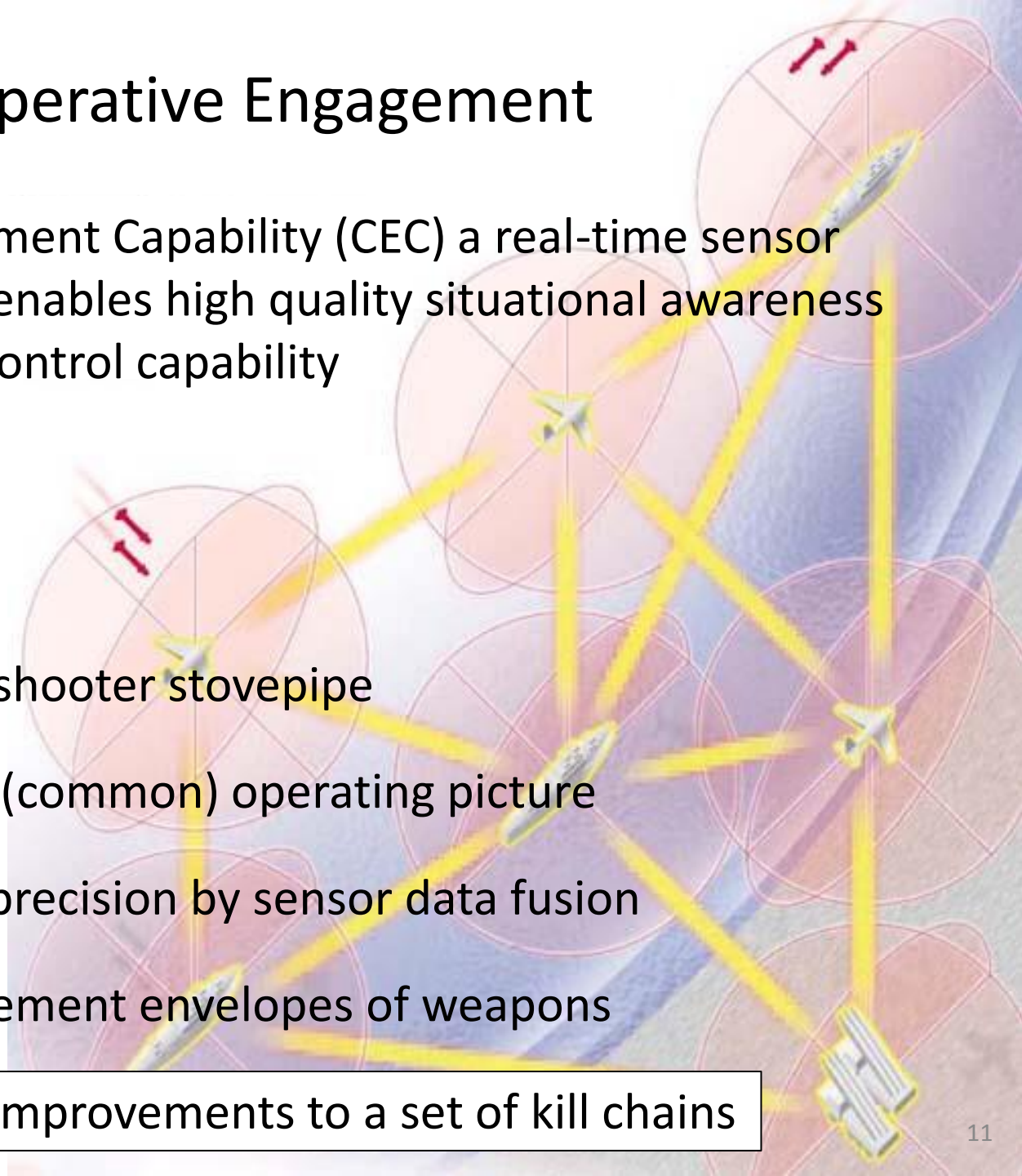
What is Information War?

Unintended Consequences of Information Age Technologies

Command Arrangements for Peace Operations

Cooperative Engagement

- Cooperative Engagement Capability (CEC) a real-time sensor netting system that enables high quality situational awareness and integrated fire control capability

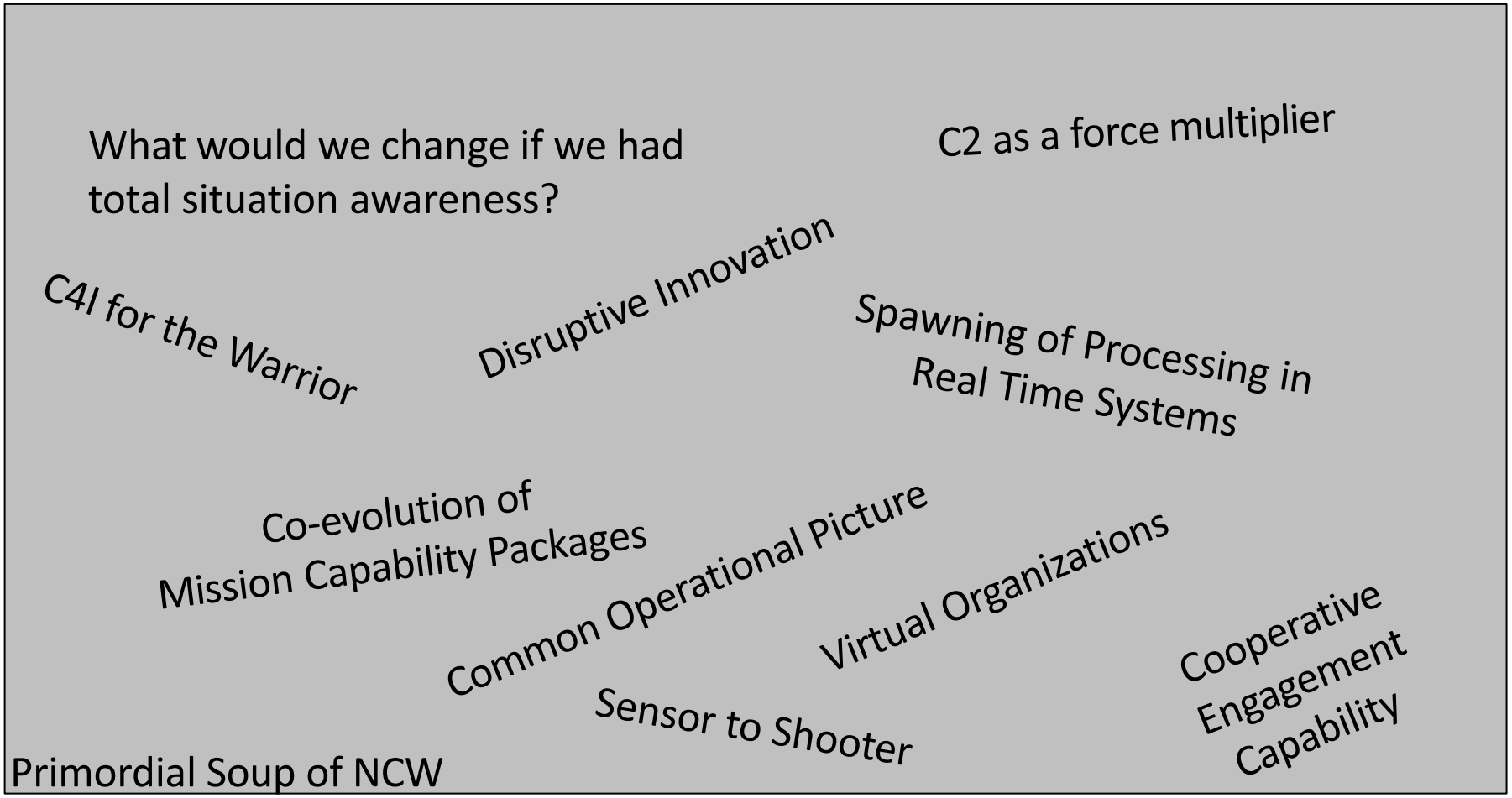


- Broke the sensor to shooter stovepipe
- Developed a shared (common) operating picture
- Improved targeting precision by sensor data fusion
- Extended the engagement envelopes of weapons

focus on improvements to a set of kill chains

Origins of Network Centric Warfare?

NCW is an approach to operations that embraces Information Age concepts and is enabled by Information Age technologies



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What is Network Centric Warfare?

- NCW = an Information Age Transformation
- A new way of thinking about
  - how we accomplish our missions
  - how we organize and interrelate to one another
  - how we acquire and field the systems that support us
- NCW is not all about technology or a collection of systems; rather NCW is enabled by an increasingly capable infostructure
- NCW can be successfully practiced at various levels of maturity under difference circumstances

Tenets

A ***robustly networked force*** improves ***Information Sharing***

Information Sharing and ***Collaboration*** enhances ***Quality of Information*** and ***Shared Situational Awareness***

Shared situational awareness enables ***Collaboration*** and ***Self-synchronization***

These, in turn, dramatically increase ***mission effectiveness.***

IDA Evolution of Terminology – NCW ➔ NCO

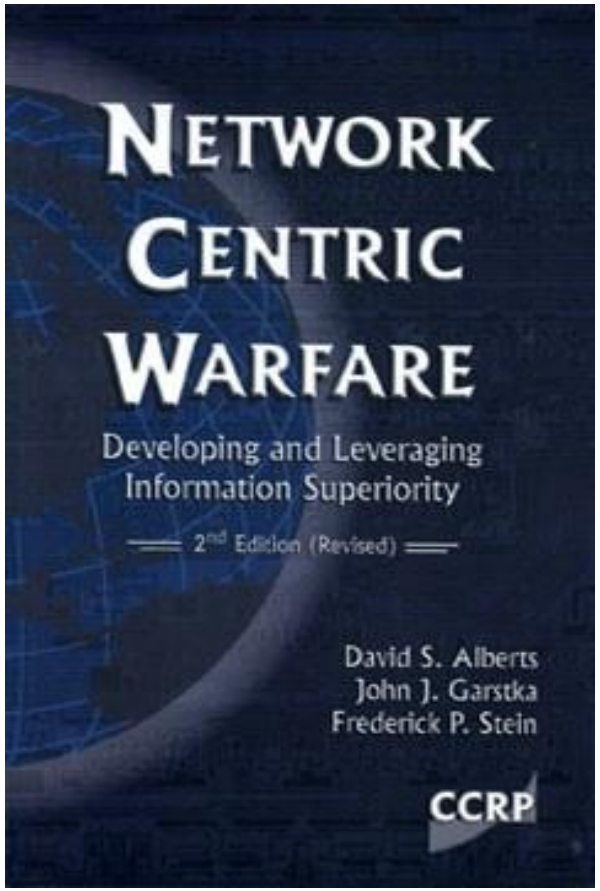
- The “W” in NCW was deliberate - to emphasize the point that NCW was not about information technology and communications networks but rather about warfare

- The change to Network Centric Operations (NCO) was intended to counter the view that network-centric concepts and capabilities were only applicable to high-end combat rather than to the full mission spectrum including non-kinetic missions

NCW
(published 1999)

"This publication will assist the joint warfighting community in taking the necessary steps to pursue the change associated with the ongoing revolution in military affairs.

The emerging evidence for network-centric warfare as the intellectual basis for Joint Vision 2010." *CJCS*



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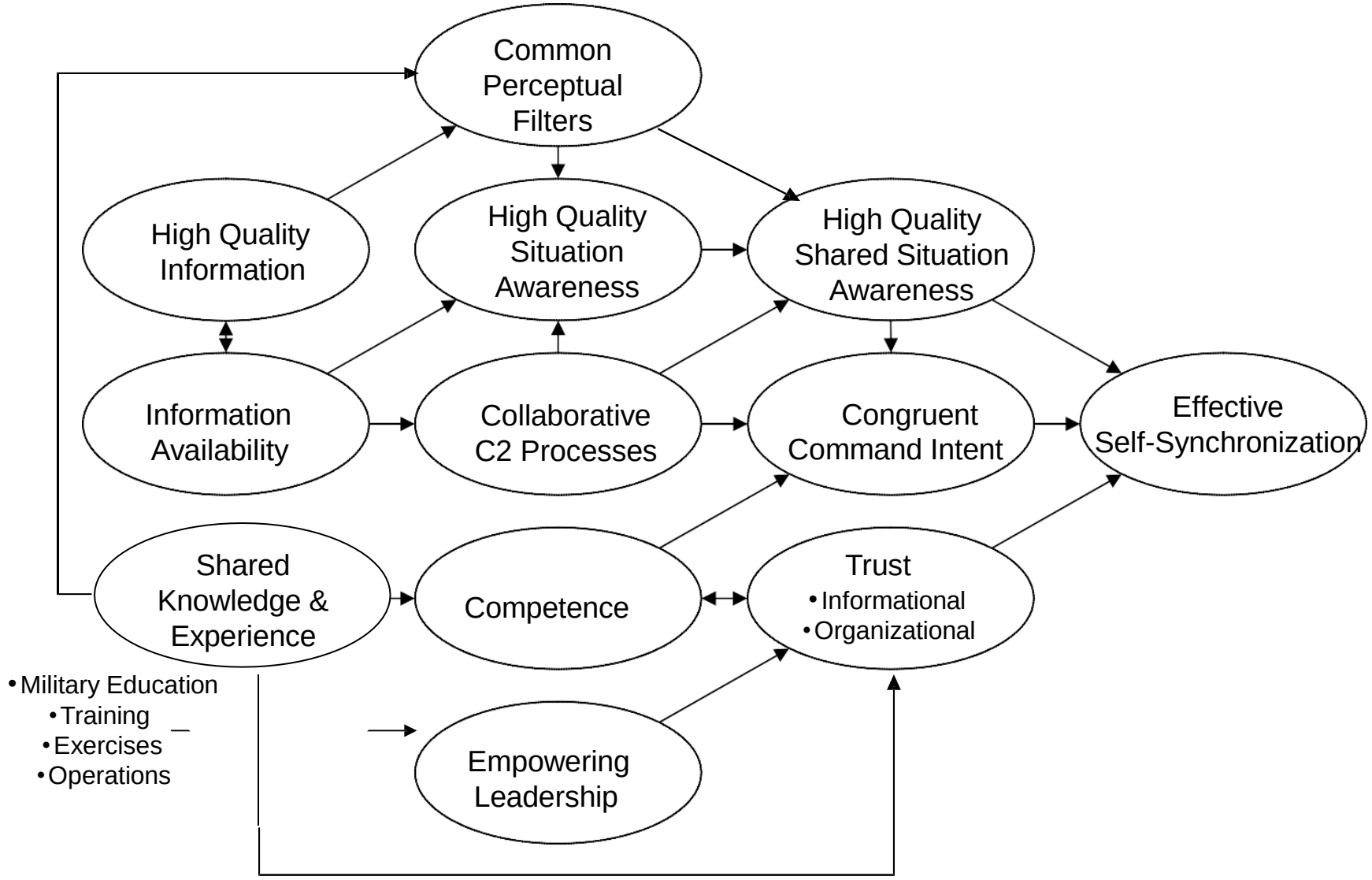
Evolution of Terminology
(network-centric v. network-enabled)

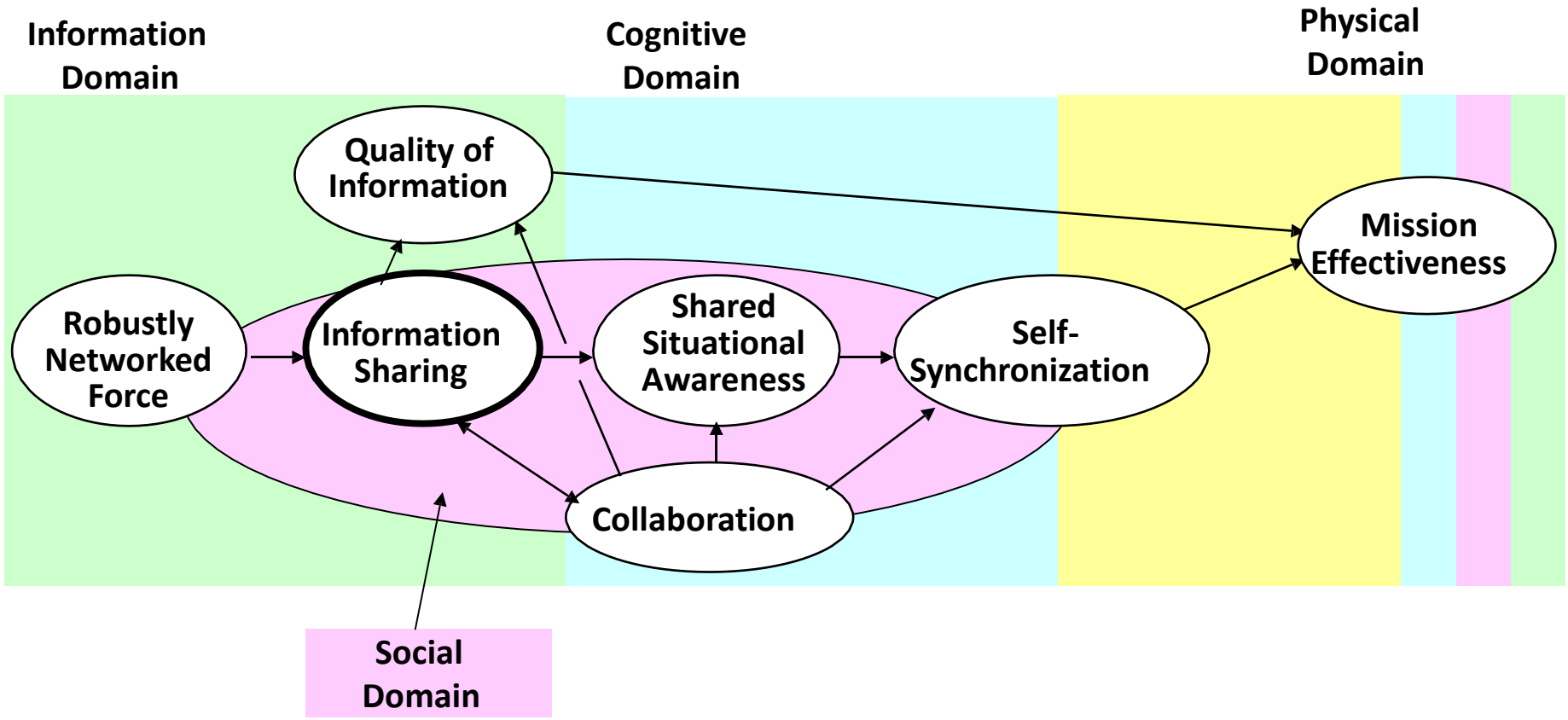
- The term “network-centric” was chosen as a direct contrast to the then existing “platform-centric” mindset
- The network-centric proposition was that, for a given investment, one could generate more value by “networking the force” than by adding platforms
- Thus, it was networking (of entities) that is central to military operations, not individual platforms
- Many misunderstood the term network-centric and focused on the technology as an end unto itself
- The adoption of the term “network enabled” was an attempt to make sure that the emphasis remained on the operations that were enabled, not on the technical networks

Conditions for Self-Synchronization

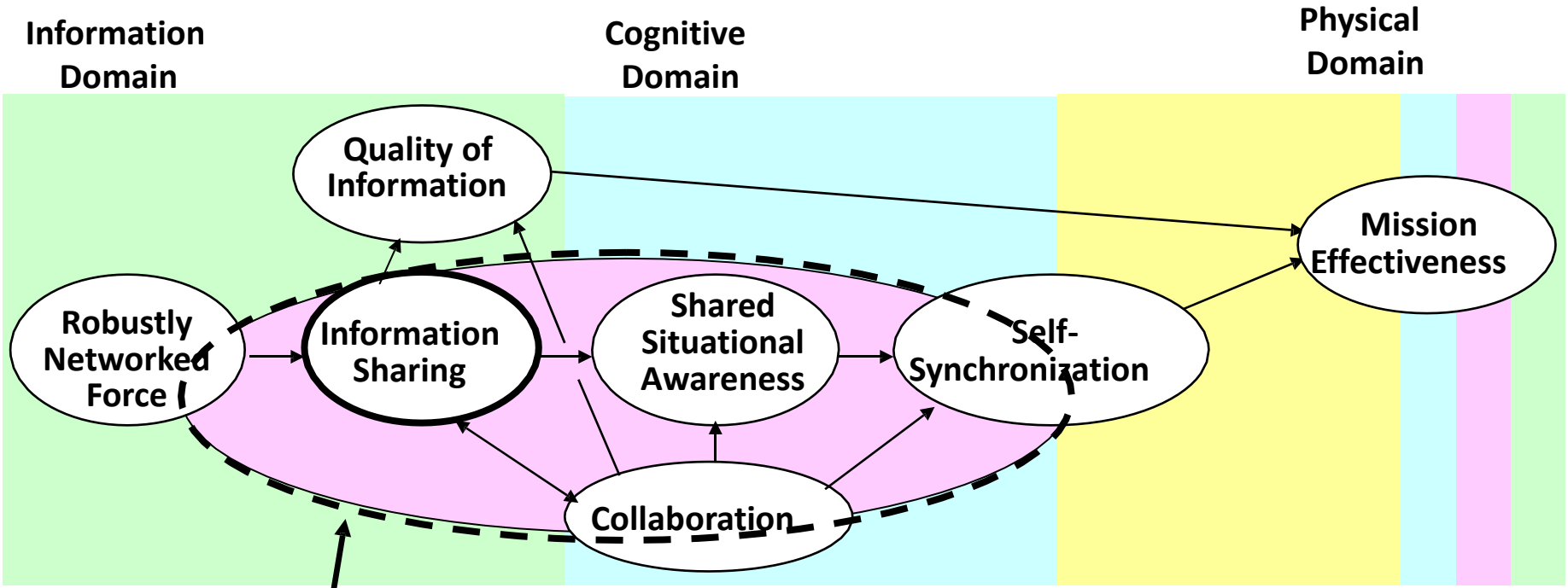


Network-Enabled Value Chain

involves multiple domains



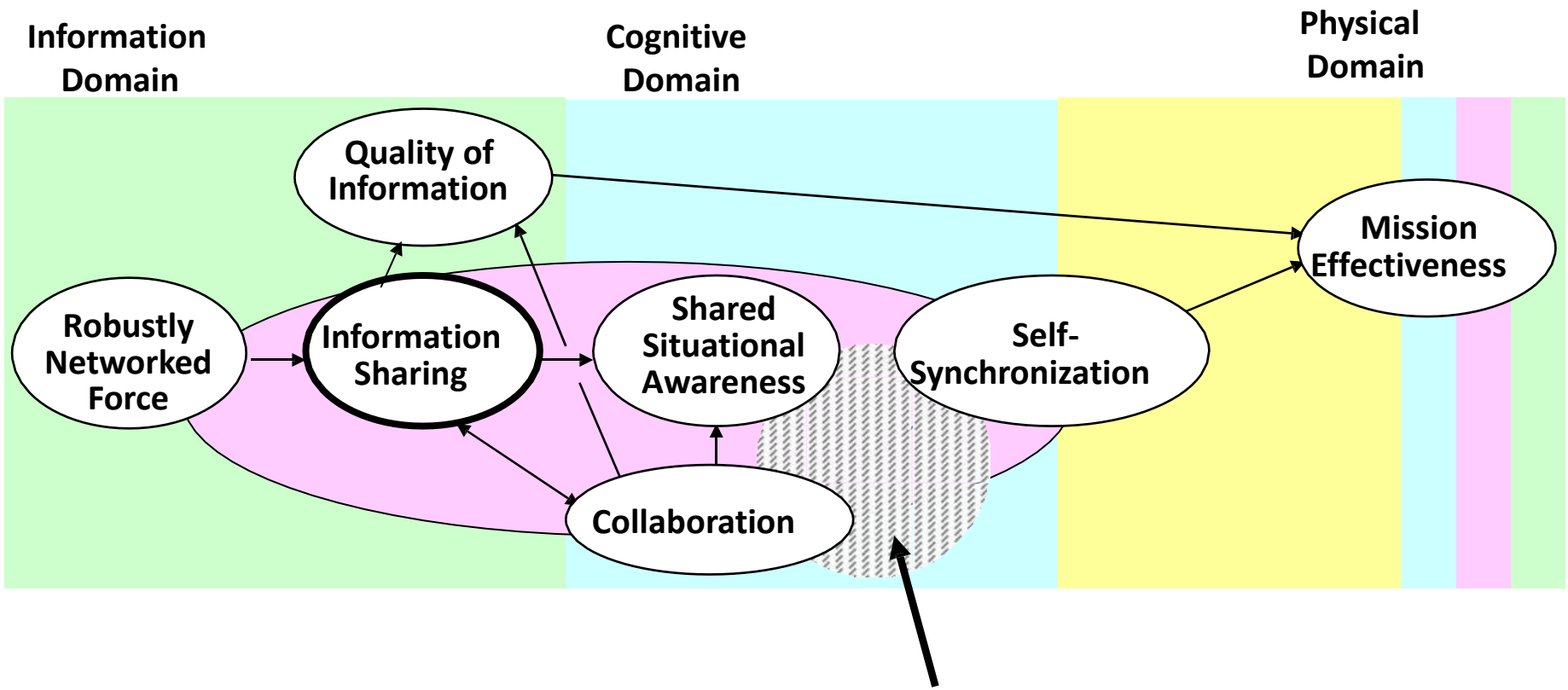
Co-evolution



New & Co-evolved

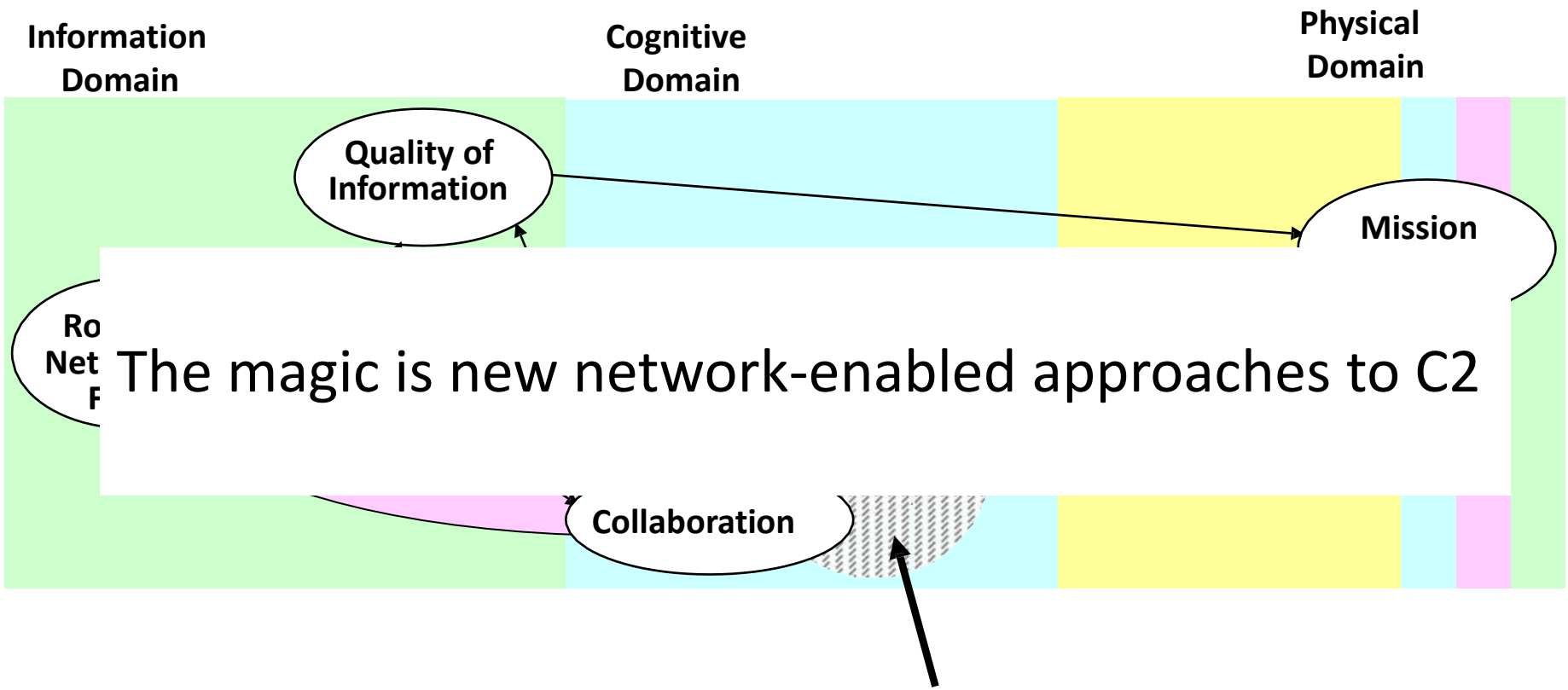
- concepts of operations
- organization (roles, relationships)
- processes

The Magic of NEC



This is where the magic of NEC happens

The Magic of NEC



Network Enabled C^2
(NEC^2)

- Information flows must be freed from the chain of command
- Patterns of Interaction must be less constrained
- Roles and responsibilities need to change appropriately
- One Size Does Not Fit All

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Network Enabled C^2 (NEC^2)

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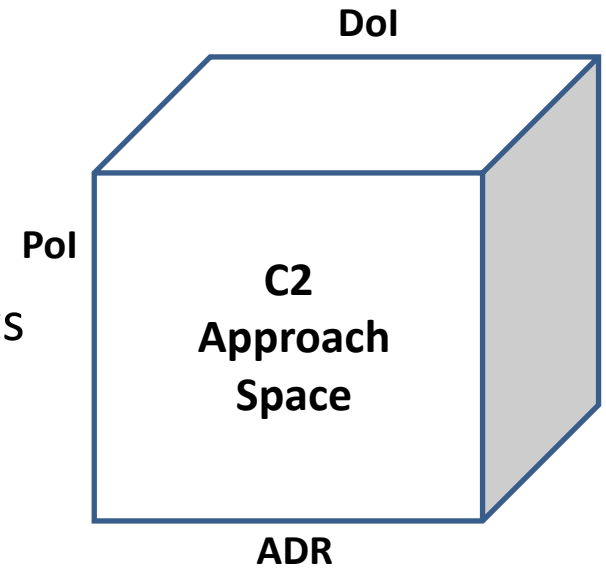
We needed a new construct to help us think about C2 Approaches that helps us to compare and contrast their differences.

C2 Approach Space

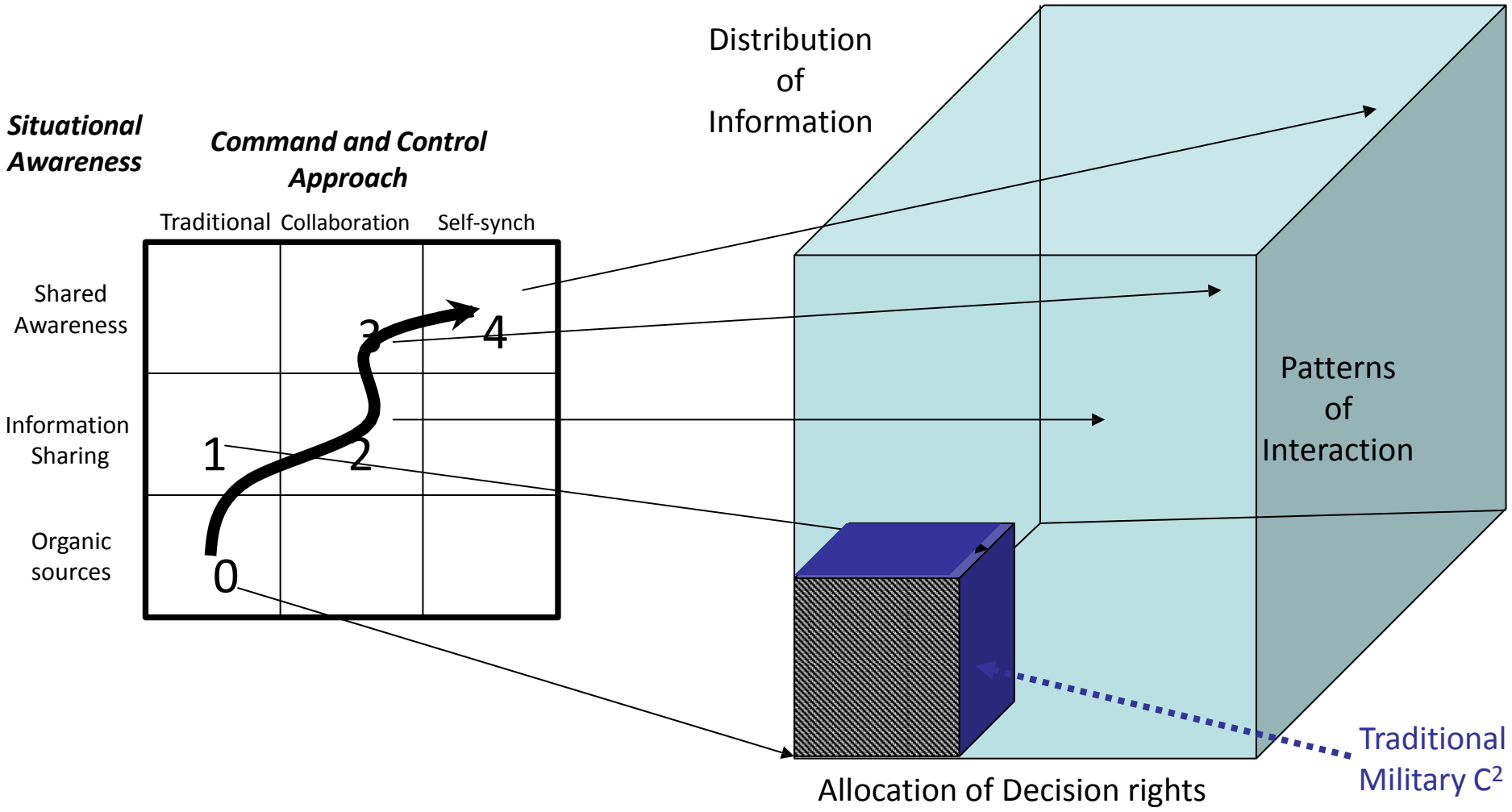
- There are a great many possible approaches to accomplishing the functions that we associate with Command and Control.
- Developing the "option space" for Command and Control requires that major differences between possible approaches are identified.
- These differences are reflected in the dimensions of the C2 Approach Space (options available)

  Allocation of Decision Rights (ADR)
  Patterns of Interaction (PoI)
  Distribution of Information(DoI)

- A region in the C2 approach Space represents a specific approach to C2



NCW Migration and the C^2 Approach Space



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Necessary C^2-related Changes

- Access to information to ensure that those who need it can get it
- Authority and processes that are consistent with who knows what and when they know it
- Doctrine and tactics to exploit information advantage
- Systems requirements to provide needed capabilities
- Policies to enable and encourage wide-spread sharing of information and collaboration

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C2 Agility

- There are *many ways* to accomplish the functions associated with Command and Control
- No one approach to accomplishing the functions associated with command and control fits all missions or situations whether for a single entity or a collection of independent entities (a collective)
- The most appropriate approach will be a function of the endeavor and the prevailing circumstances
- Therefore, Entities (and Collectives) will need to be able to employ more than one approach
- C2 Agility is the ability to appropriately move around in the C2 Approach Space in response to changing missions and circumstances
- Agile C2 systems and processes are required for C2 Agility and to make specific approaches to C2 more agile

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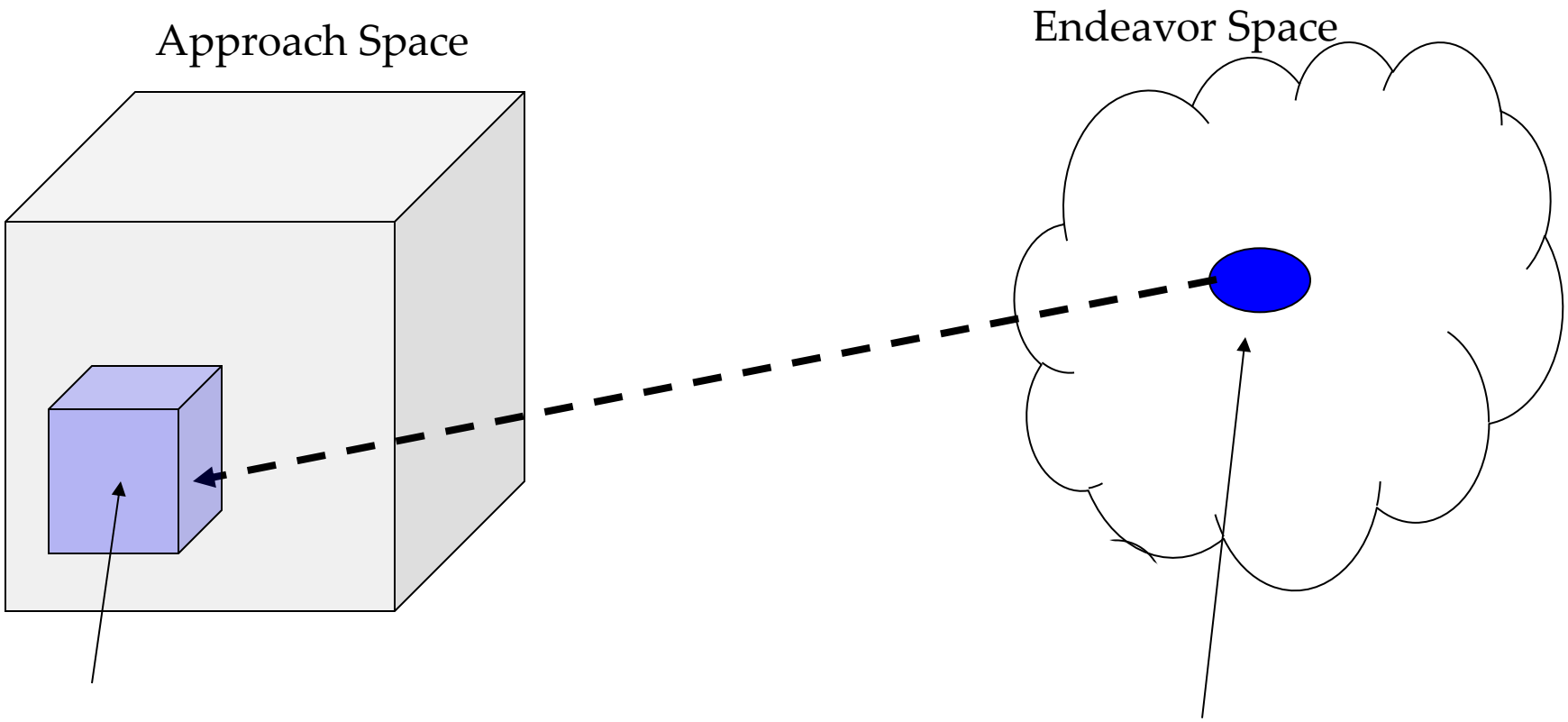
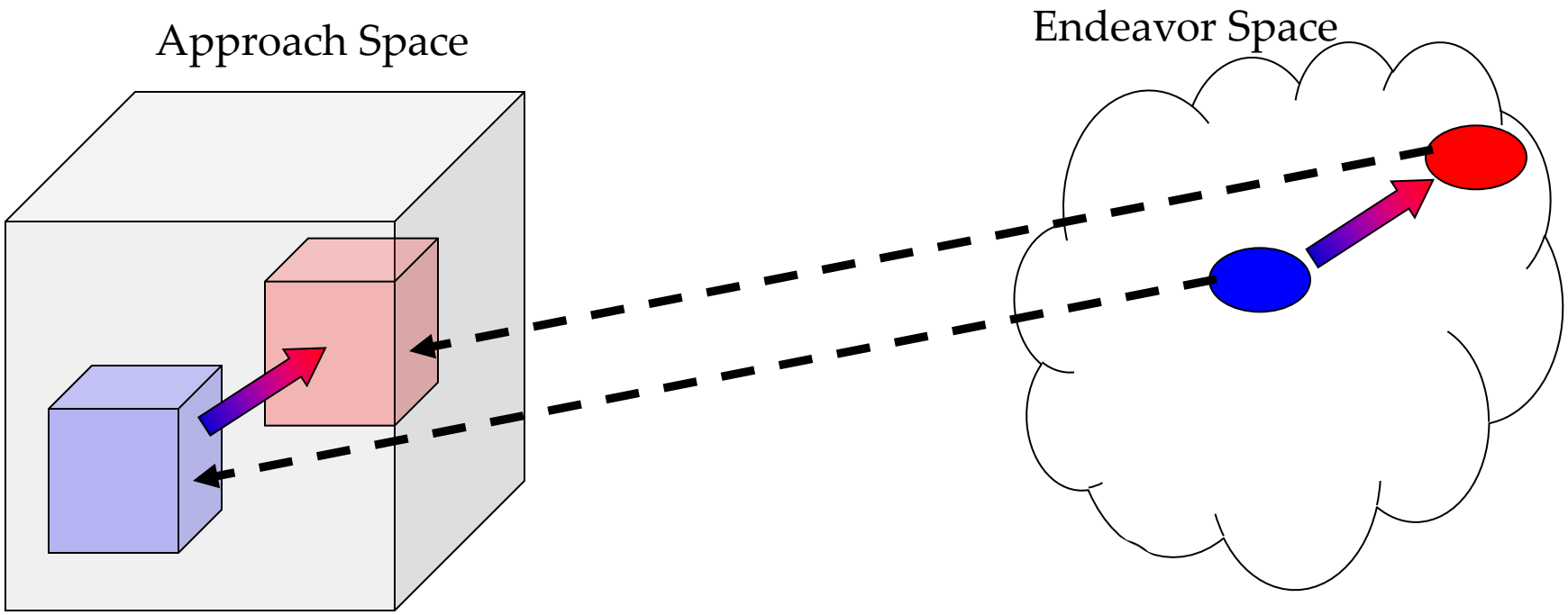
C2 Agility



This is a most appropriate C2 Approach for this particular set of circumstances

C2 Agility

When circumstances change, a different approach might be more appropriate

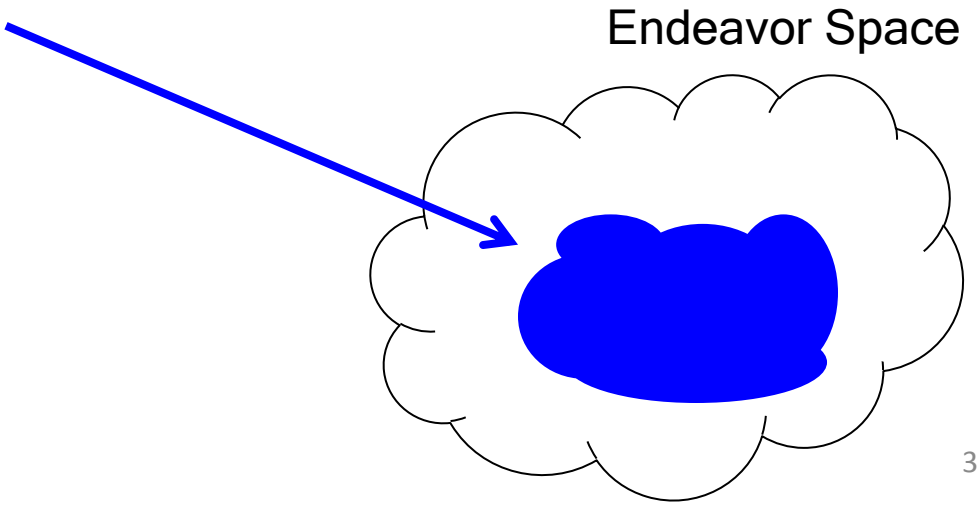


C2 Agility involves recognizing the significant of a change in circumstances, understanding the most appropriate C2 Approach for the circumstance and being able to transition to this approach.

Measuring C2 Agility

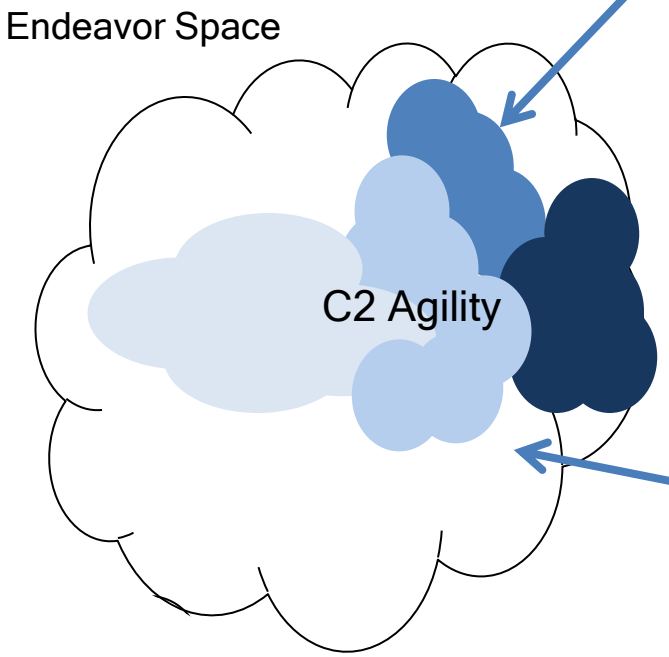
- The degree of agility possessed by an entity is a function of its ability to successful operate over an appropriate set of circumstances (Endeavor Space)
- A scalar measure of agility is defined as the area of the region in the Endeavor Space where an entity can successfully operate

$$\text{Agility} = \frac{\text{Area of } \bullet}{\text{Area of } \circ}$$



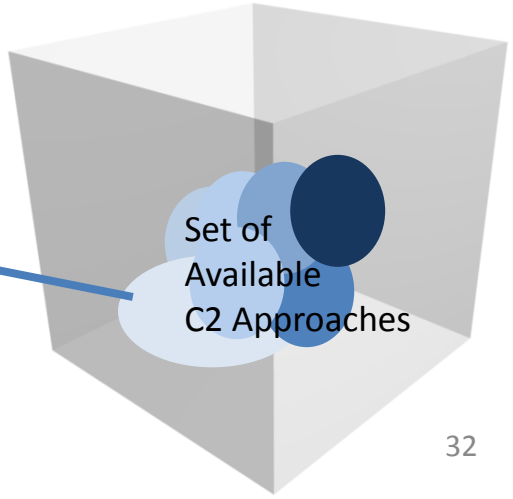
C2 Agility

- C2 Agility = f (C2 Approach Agility, C2 Maneuver Agility)



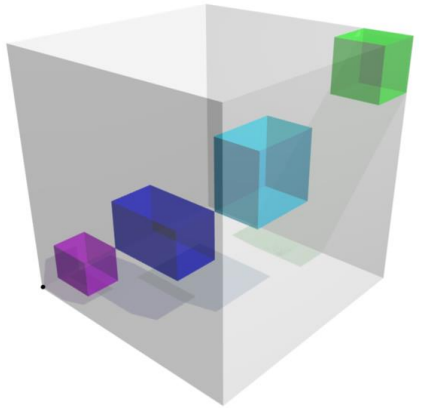
C2 Approach Agility is the area of the region in the Endeavor Space where an entity can operate successfully by employing a given approach to C2

C2 Maneuver Agility is the ability to recognize the C2 approach appropriate for the circumstances and transition to this approach in a timely manner. It is a function of the set of C2 Approaches available to the entity.

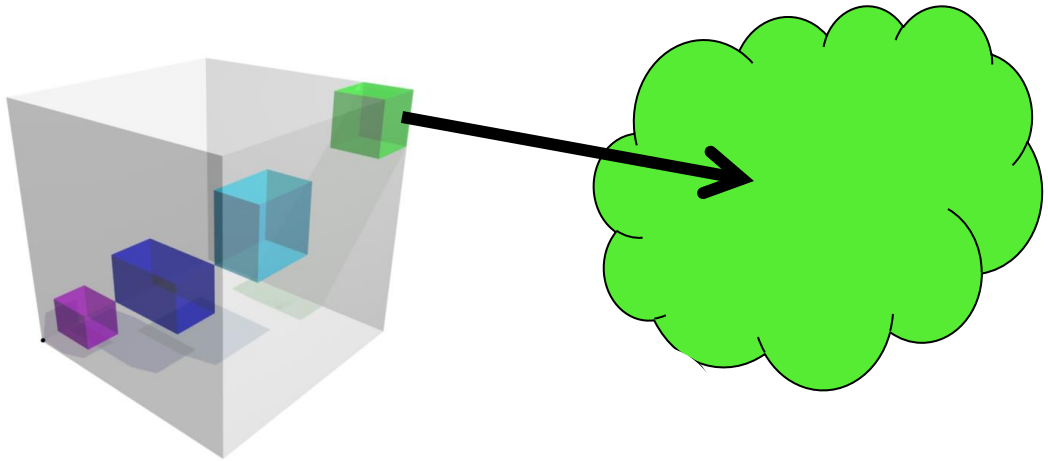


C2 Agility Hypotheses

H1: Each C2 Approach is located in a distinct region of the C2 Approach Space

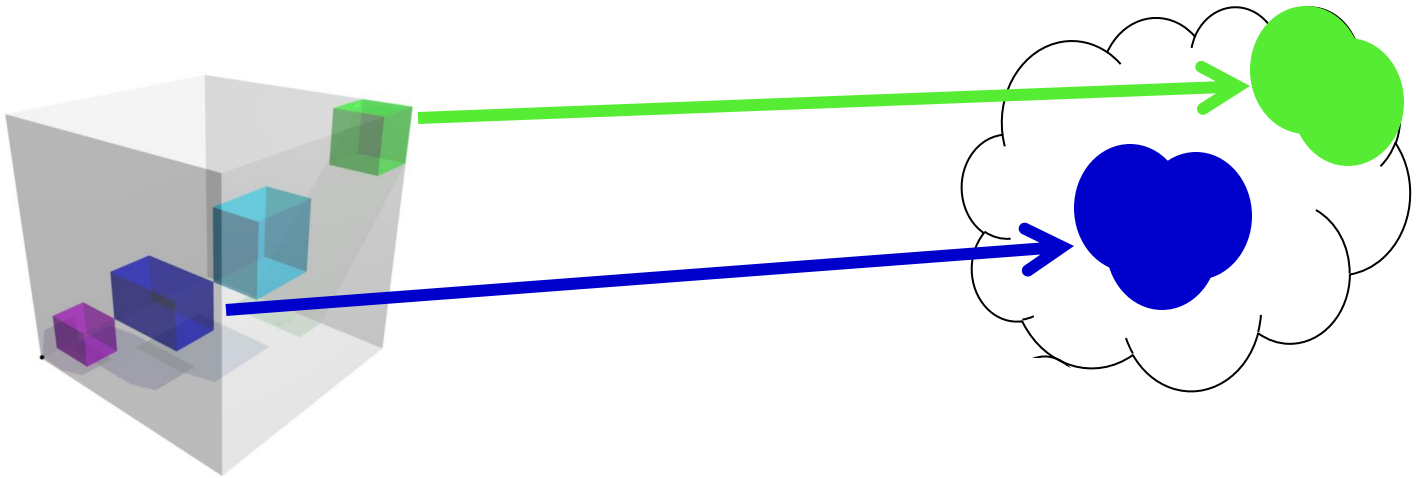


H2: No one approach is always the most appropriate



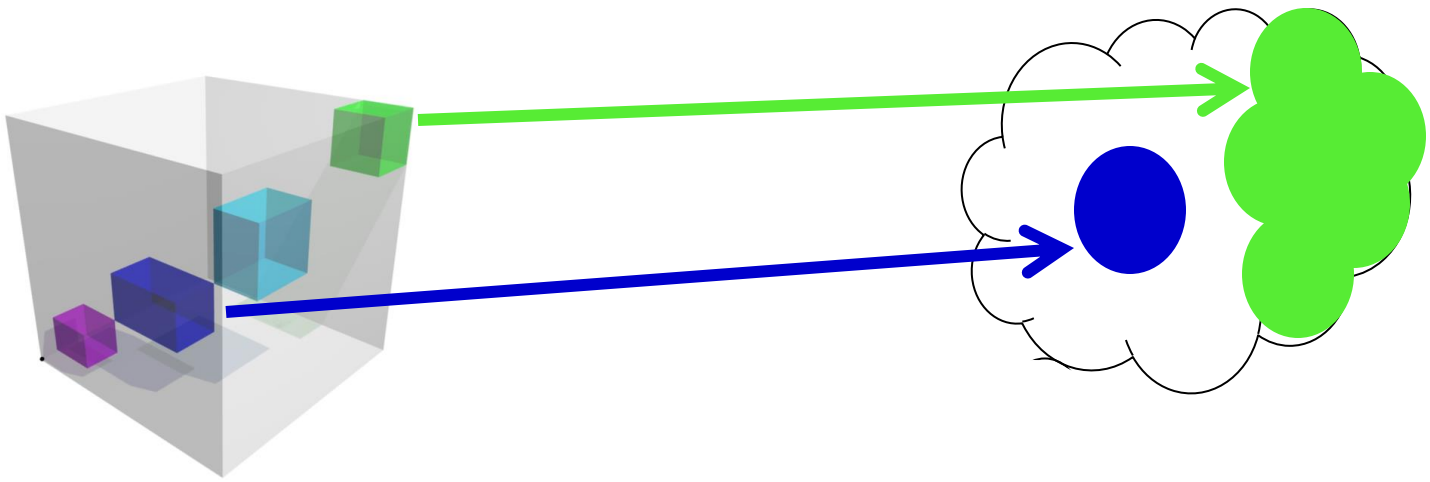
C2 Agility Hypotheses

H3: More network-enabled approaches are more appropriate for Complex Endeavors; while less network-enabled approaches are more appropriate for less complex missions/circumstances



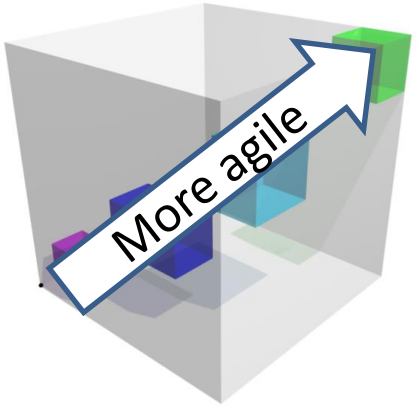
C2 Agility Hypotheses

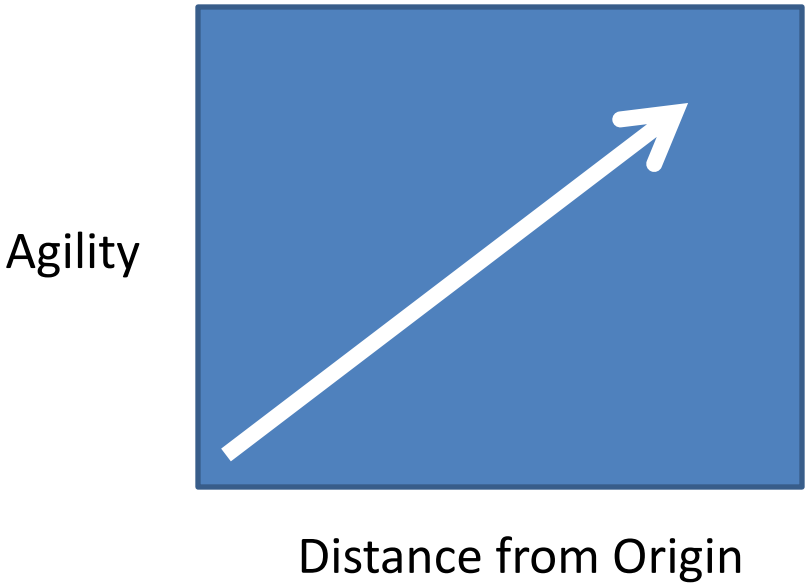
H4: More network-enabled approaches are more agile (have greater C2 Approach Agility)



C2 Agility Hypotheses

H5: The dimensions of the C2 approach Space are positively correlated with agility





C2 Agility Hypotheses

H6: More network-enabled approaches are better able to maintain their intended positions in the C2 Approach Space

H7: On-diagonal (balanced) approaches are more agile

H8: Increasing C2 Maneuver Agility increases agility

H9: More mature C2 capability is more agile than the C2 Approach Agility of the most network-enabled approach available

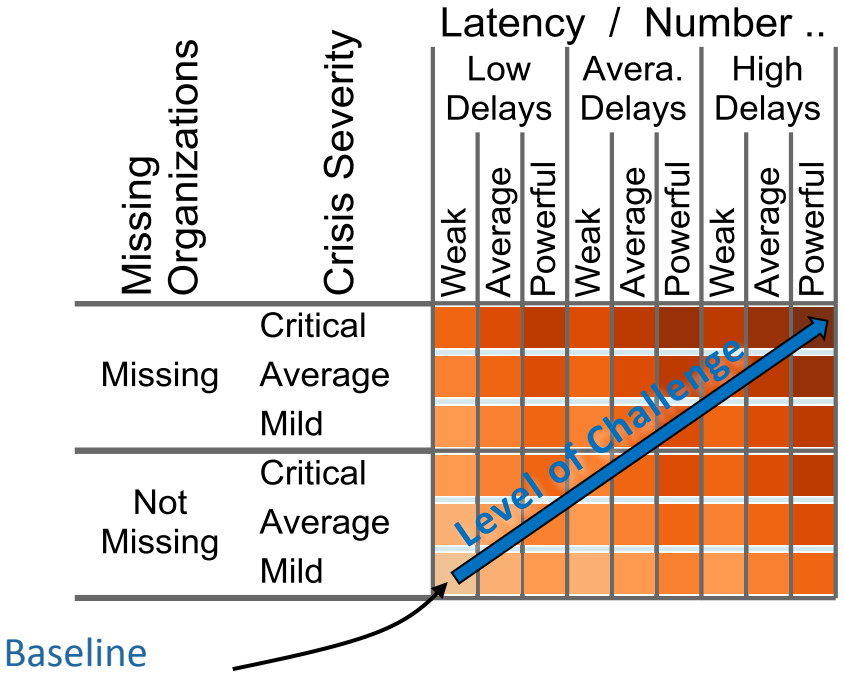
H10: Self monitoring is required for C2 Maneuver Agility

H11: The six enablers of agility are collectively exhaustive and thus all instances of observed agility can be traced to one or more of these enablers

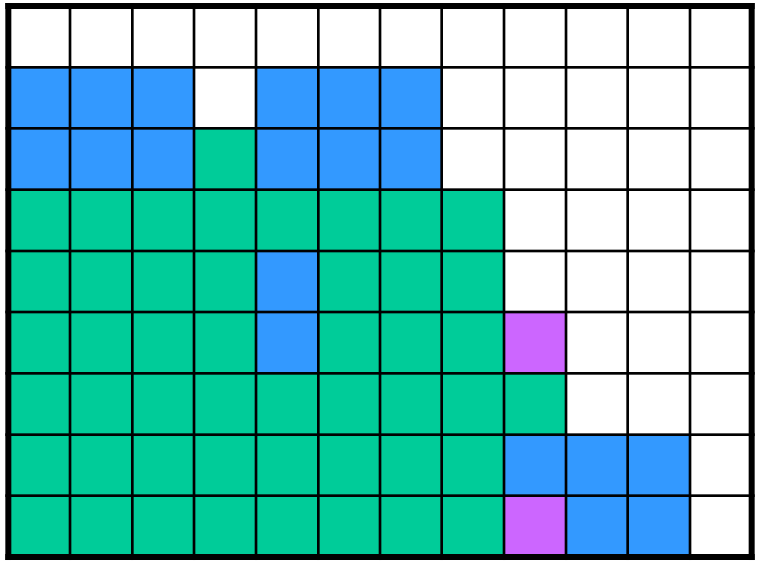
H12: Each of these enablers is positively correlated with agility

Creating an Endeavour Space

- The Endeavor Spaces were populated by combining all possible values of multiple variables, each one corresponding to an aspect of the situation
- Heat maps show the progressive degree of challenge of the Endeavour Spaces
  - Darker shades of orange represent most challenging circumstances
  - Values were normalized across the experiments



Comparative Agility Map



Endeavor Space

with varying conditions of signal to noise
and with varying requirements
for shared situation awareness and response time

Source: Alberts, D.S. The Agility Imperative, 2010 Part V: Agility Experiments

C2 Agility Elevator Speech

NATO SAS-104

C2 Agility dynamically adjusts who and how decisions are made, how we work together and how information is shared. Agility is required because the world is dynamic, conditions and circumstances change, missions maybe unfamiliar, and what is currently working may not work well or continue to work well. C2 Agility Theory informs and helps institutionalize best practices.

Agenda

- What is “C2 Theory”?
- Evolution of Theory – 1995 to 2016
- Battle Field of 2050 and Implications for C2
- Implications for C2 Research

Battlefield of 2050

Army Research Office (ARO) and Army Research Laboratory (ARL) Workshop

- Fewer human warriors, but with superhuman capabilities, both cognitively and physically enhanced
- Ubiquitous intelligent systems with varying degrees of autonomy
- Networked by the Military Internet of Things (IoT)
- Battle for the information domain
  - cover, concealment, and cloaking v persistent surveillance
  - deception and misinformation v. big data analysis
- Battle for cyberspace dominance

The entity that can effectively command and control this heterogeneous collection of battlefield assets and capabilities will have a decisive advantage

Battlefield of 2050

Army Research Office (ARO) and Army Research Laboratory (ARL) Workshop

- Fewer human warriors, but with superhuman capabilities, both cognitively and physically enhanced
- means
- increased span of control of intelligent robots and agents
- Battle for the information domain
  - cover, concealment, and cloaking v persistent surveillance
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Battlefield of 2050

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- N
- E
- E

means

the Allocation of Decision Rights to
large numbers of robots and agents

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Battlefield of 2050

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means

more dependence on a composite network

The entity that can effectively command and control this heterogeneous collection of battlefield assets and capabilities will have a decisive advantage

Battlefield of 2050

Army Research Office (ARO) and Army Research Laboratory (ARL) Workshop

means

a target rich environment that requires prioritization

&

standoff capabilities to avoid targeting

or

fleeting targets and increased surprise

- Battle for the information domain
  - cover, concealment, and cloaking v persistent surveillance
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Battlefield of 2050

Army Research Office (ARO) and Army Research Laboratory (ARL) Workshop

- Fewer human warriors, but with superhuman capabilities,
-
-
-

means

persistent attacks that will require effective cybersecurity defenses and adaptive networks to minimize degraded network connectivity, network performance and data quality

- Battle for cyberspace dominance

The entity that can effectively command and control this heterogeneous collection of battlefield assets and capabilities will have a decisive advantage

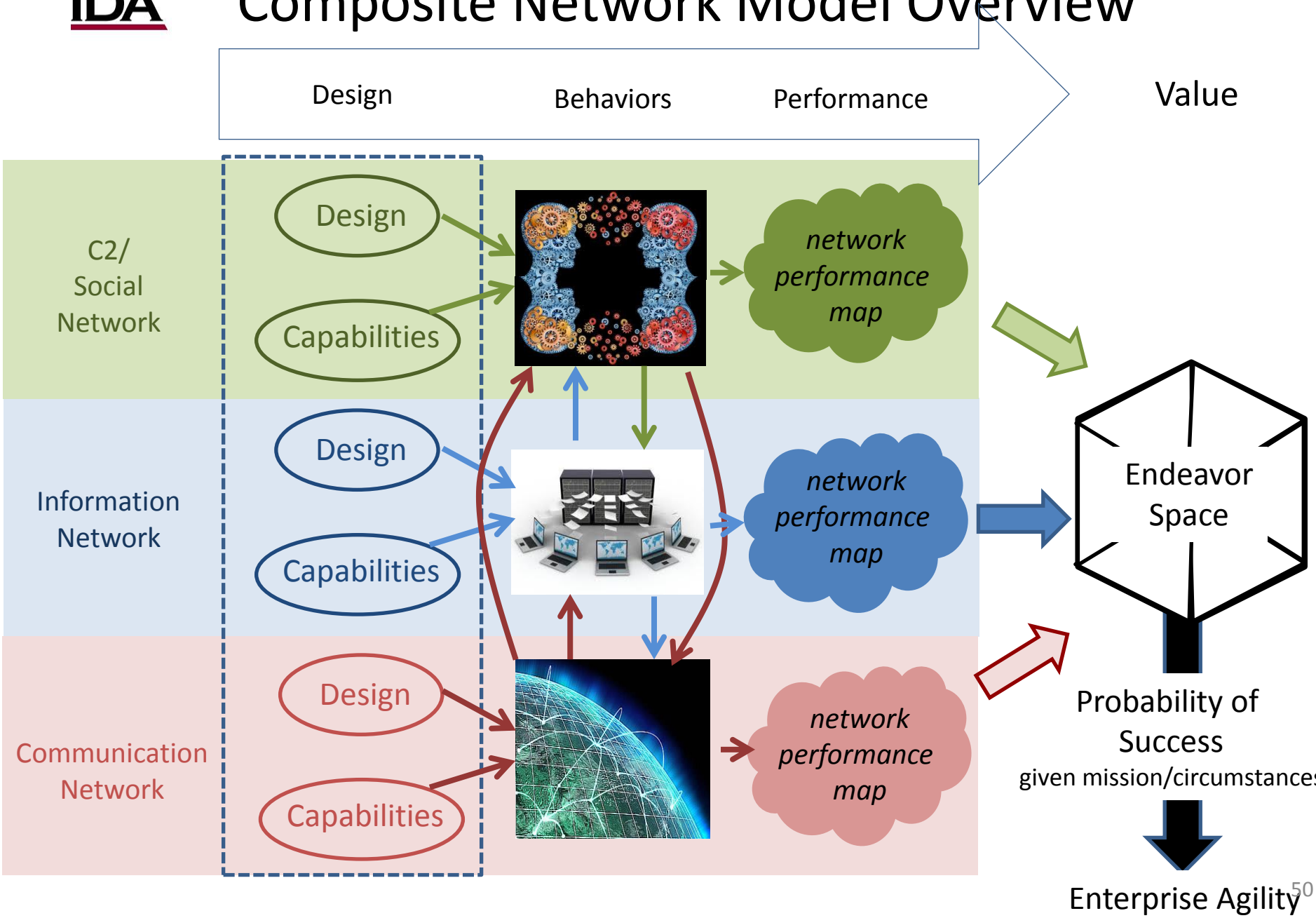
C2 Battlefield 2050 Challenge

Command and Control of
a heterogeneous collection of networked battlefield assets
with varying degrees of
intelligence, experience, autonomy, and agility
in a dynamic, unpredictable, and contested environment.

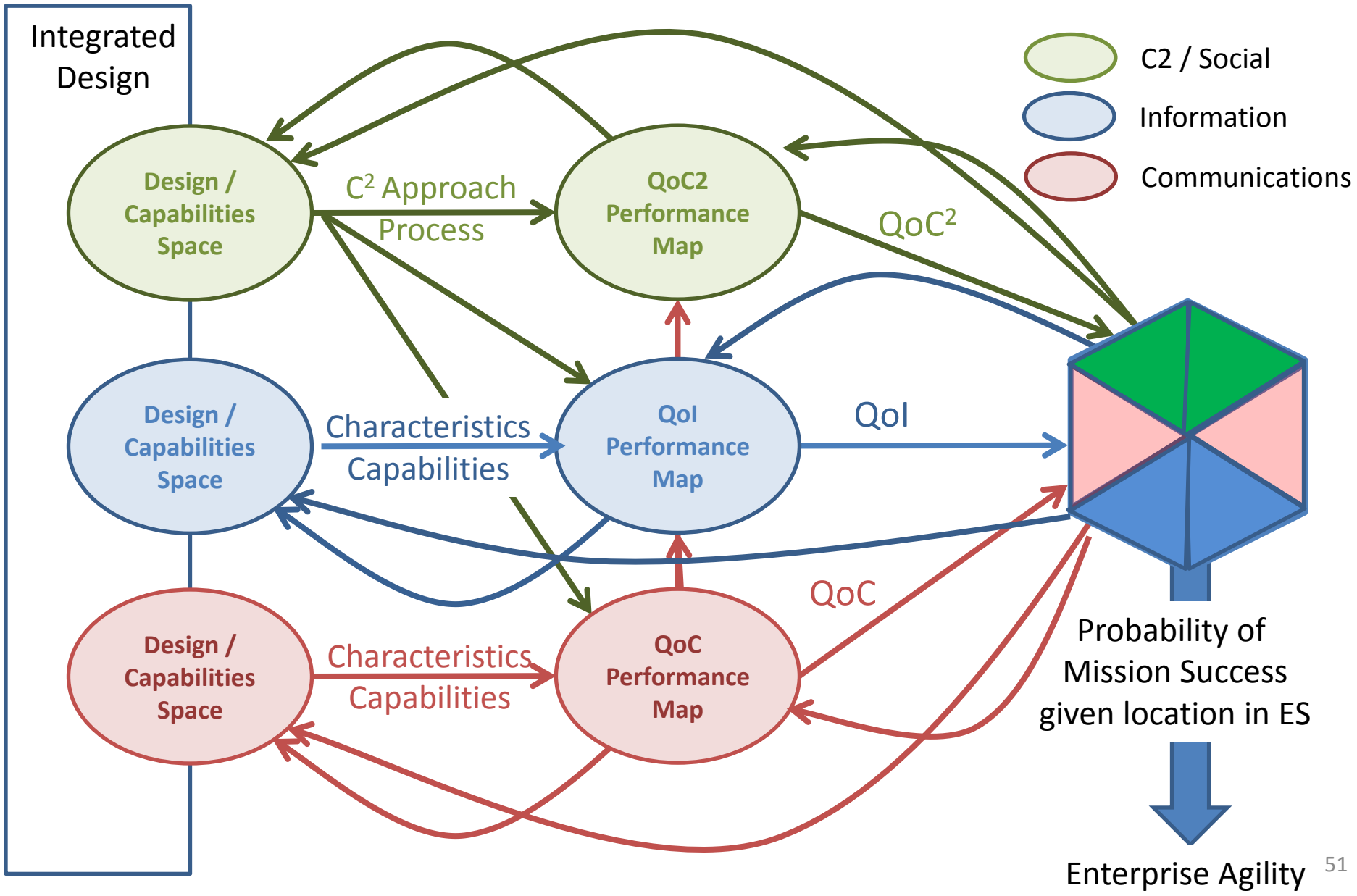
Battlefield 2050 Composite Network

- A Composite Network is a heterogeneous collection of intelligent interdependent networks
  - Social networks consisting of humans, robots and agents that can be influenced / controlled
  - Information networks that respond to or generate requests for information and disseminate information
  - Communication networks that provide connectivity, routing and related services for both the social and information networks
- Social, Information, and Communication Networks can include agents that make them self-aware with the ability to sense the state of the network and modify its behaviors accordingly

Composite Network Model Overview



Integrated Design and C2



C2 Approaches for Composite Networks

- Social / Cognitive Network

Commanders can maneuver in the C2 Approach Space within organizational design constraints

- Information and Communications Networks

Commanders can tune a set of the specific network design parameters values within network design constraints

Effective C2 of Composite Networks requires a holistic approach

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Frontiers of C2 Agility Research

- Composite Networks
  - Integrated Design, Cyber Security, Automation and autonomy
  - Monitoring and agile behaviors
  - Integrated C2
- C2 Agility
  - Measurement
  - Visualization for commanders
  - Endeavor Space
- Coalition / Collective C2
  - Harmonizing entity C2 Approaches with the Collective

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Thoughts?
Questions?

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Backup Slides

Traditional Military C^2 Assumptions

- Someone is recognized as "in charge"
- A single chain of command exists
- Patterns of interaction are defined by doctrine
- Information distribution follows the chain of command

NCW and C^2

NCO

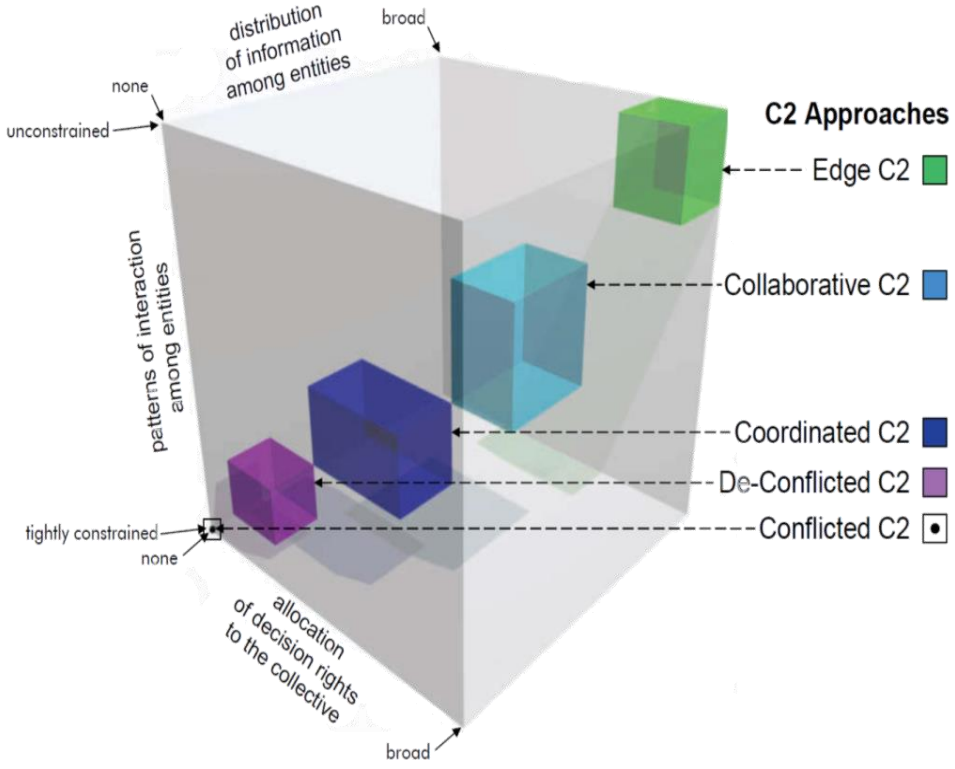
Is NCW an existential threat to traditional C^2?

NEC

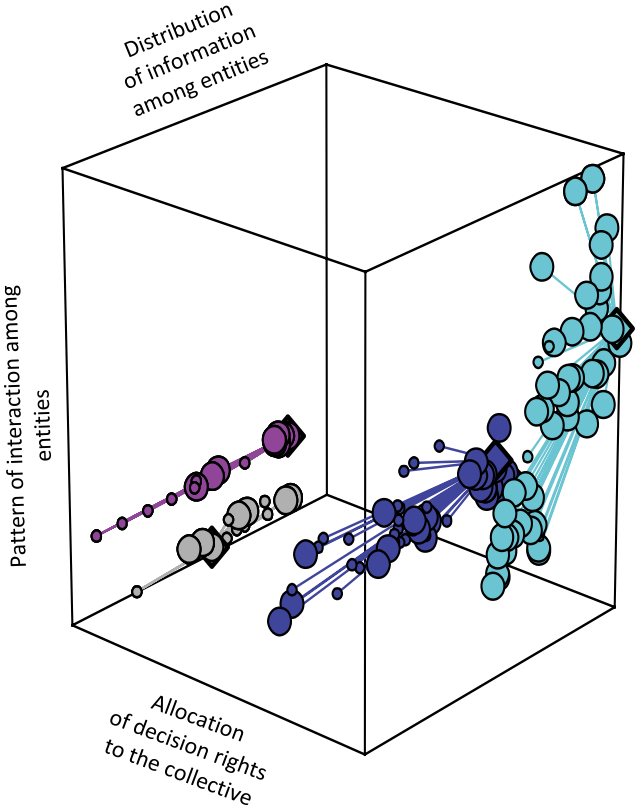
Approaches in the C2 Approach Space

H1: Each of the NATO C2 Maturity Model approaches is located in a distinct region of the C2 Approach Space

Theoretical Locations



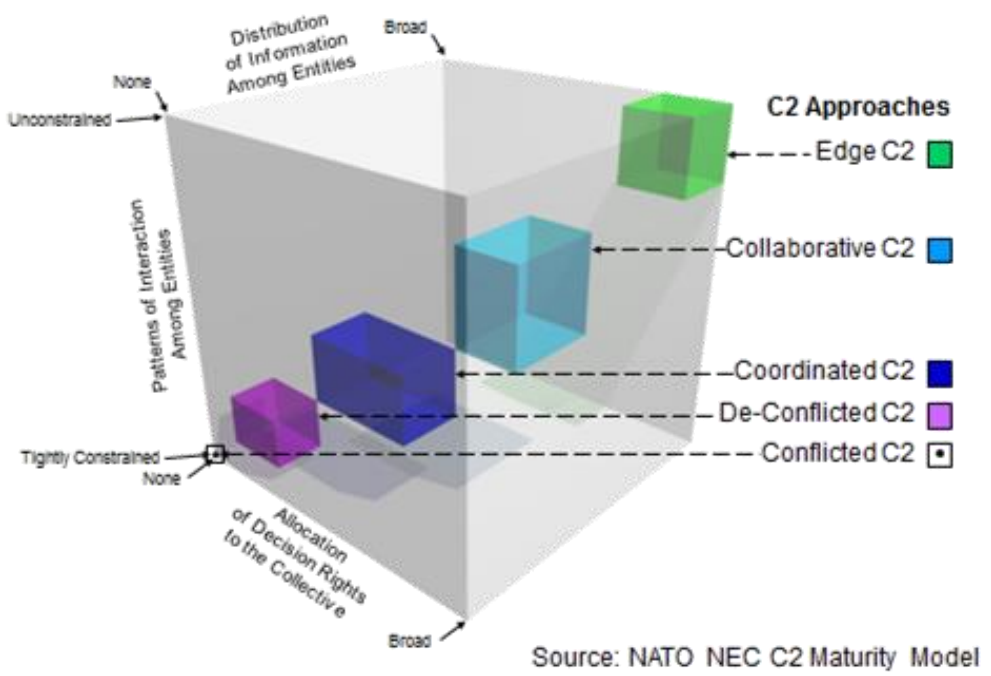
Observed Locations (IMAGE)



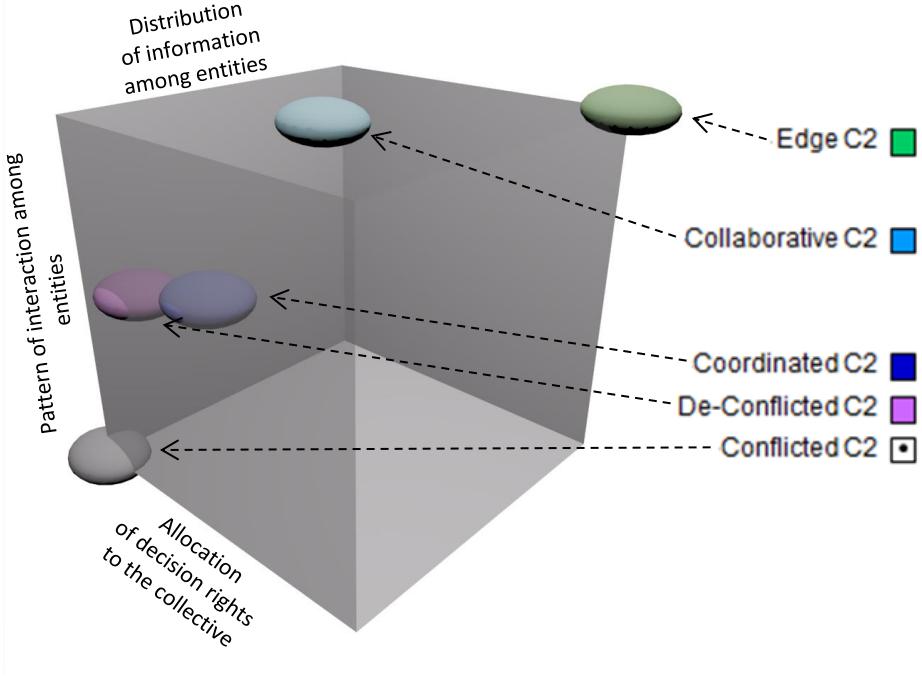
Success Failure Baseline Degraded Conditions

C2 Approach Locations – Meta Analysis

Conceptual Model



Experimental Results

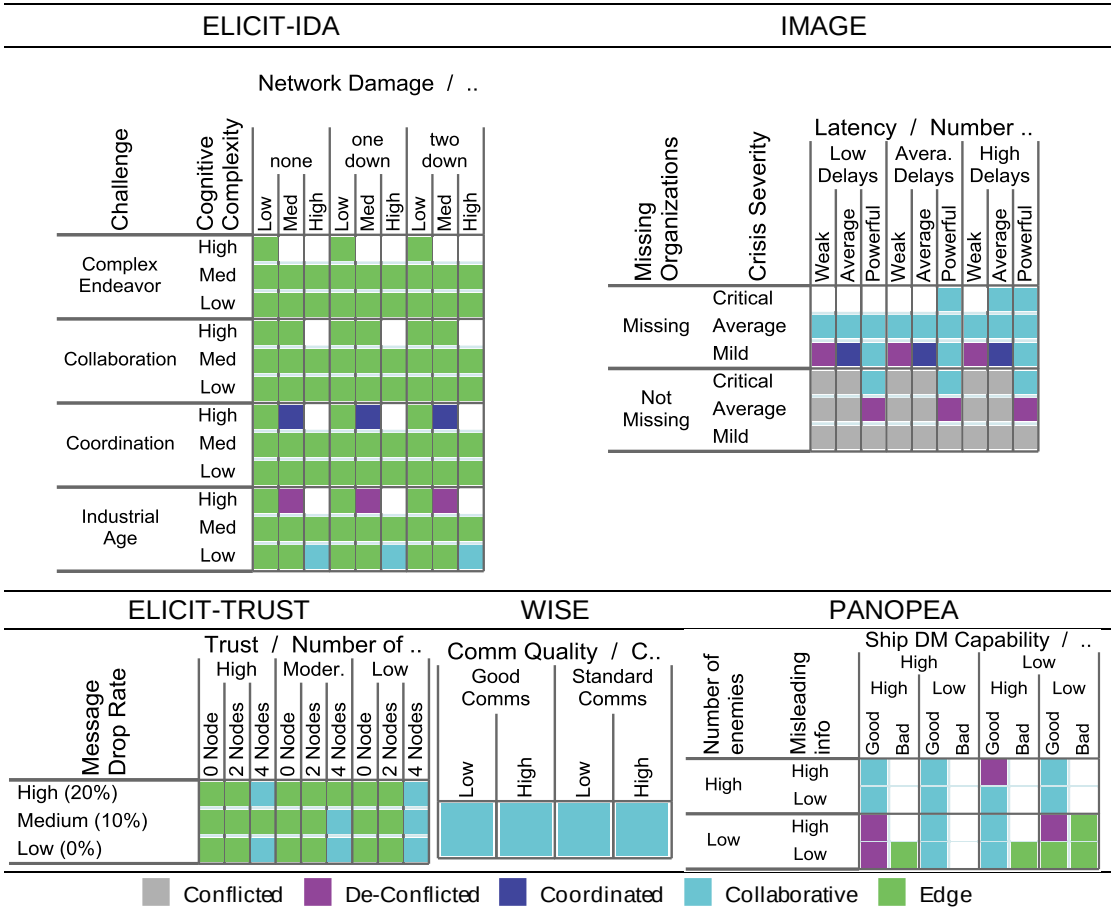


Combined results show that C2 approaches are located in distinct regions of the C2 Approach Space

No 'One Size' Fits All

H2: No one approach to C2 is always the most appropriate

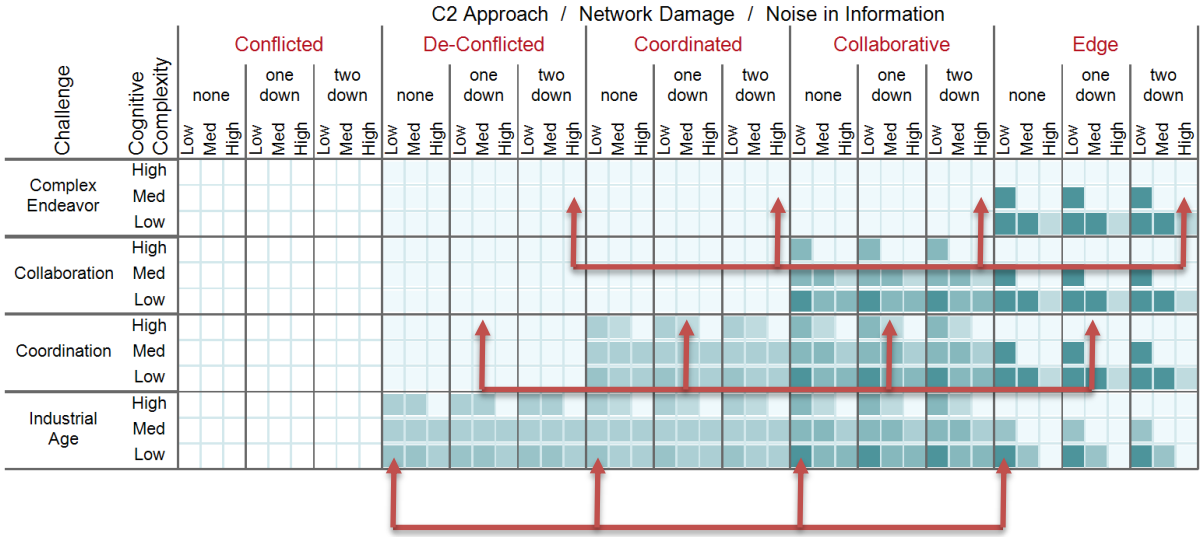
H3: More network-enabled approaches to C2 are more appropriate for more challenging circumstances; however, less network-enabled C2 approaches to C2 are more appropriate for some circumstances

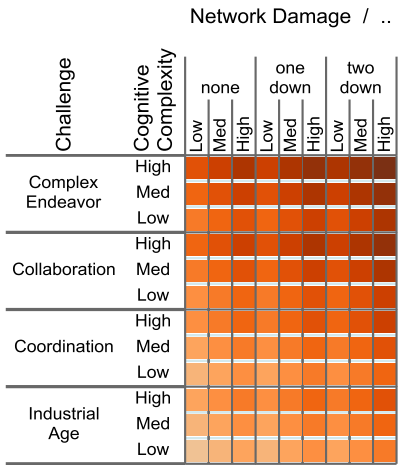


More Network-Enabled = More Agility

H4: More network-enabled approaches to C2 are more agile

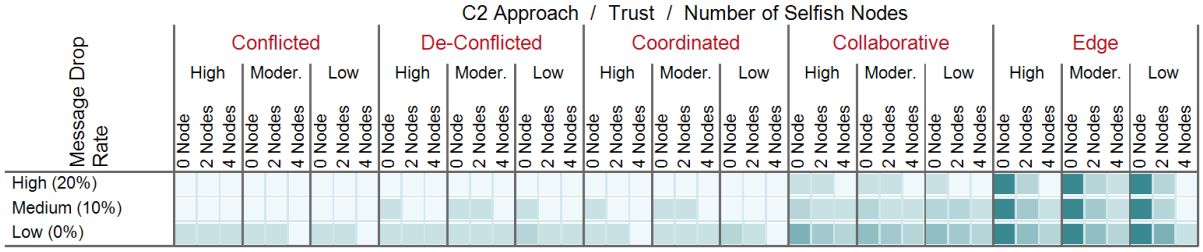
ELICIT-IDA





Same circumstance tested un different C2 Approaches

ELICIT-TRUST



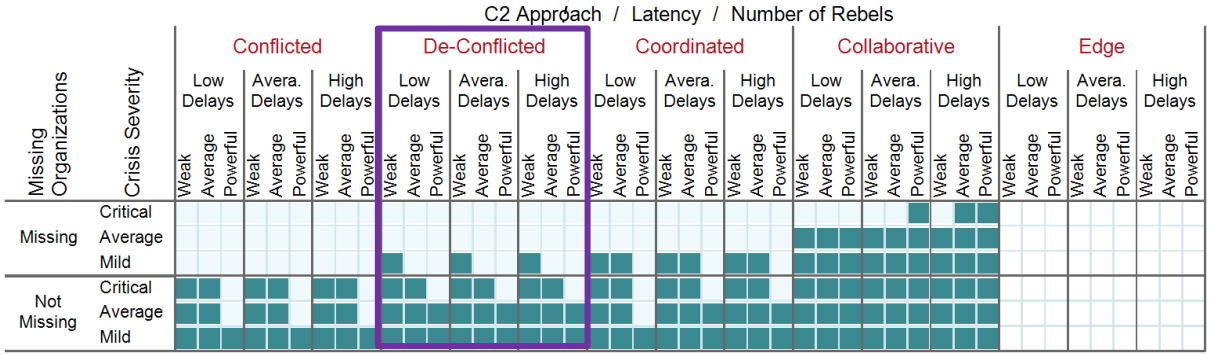
- Darker shades of teal correspond to higher levels of mission success (1), lighter ones to failure (0)
- Blank squares represent non-simulated cases

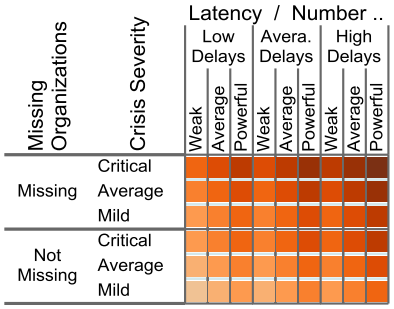
More Network-Enabled = More Agility

IDA

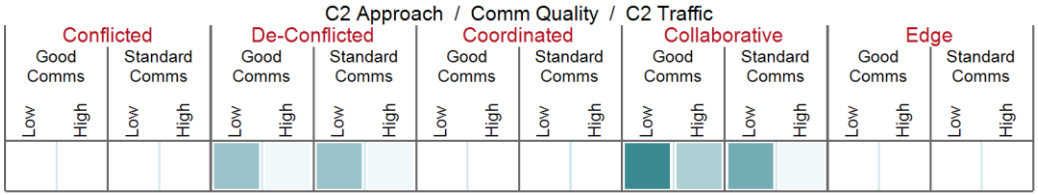
De-Conflicted was successful in 27 out of 54 circumstances
Agility Score (IMAGE, De-Conflicted) = 27/54 = 0.50

IMAGE

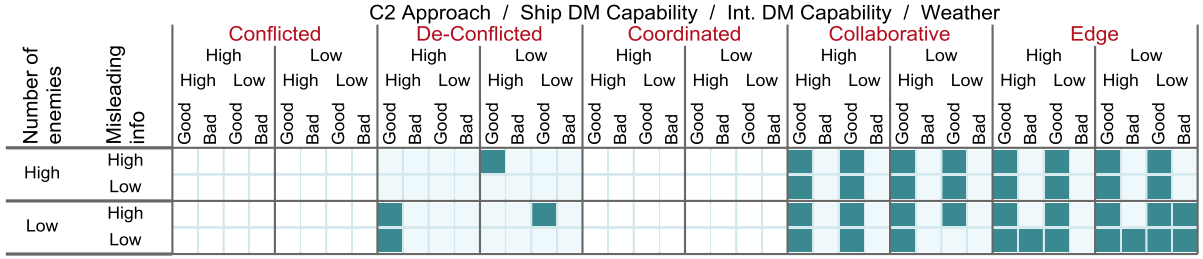




WISE



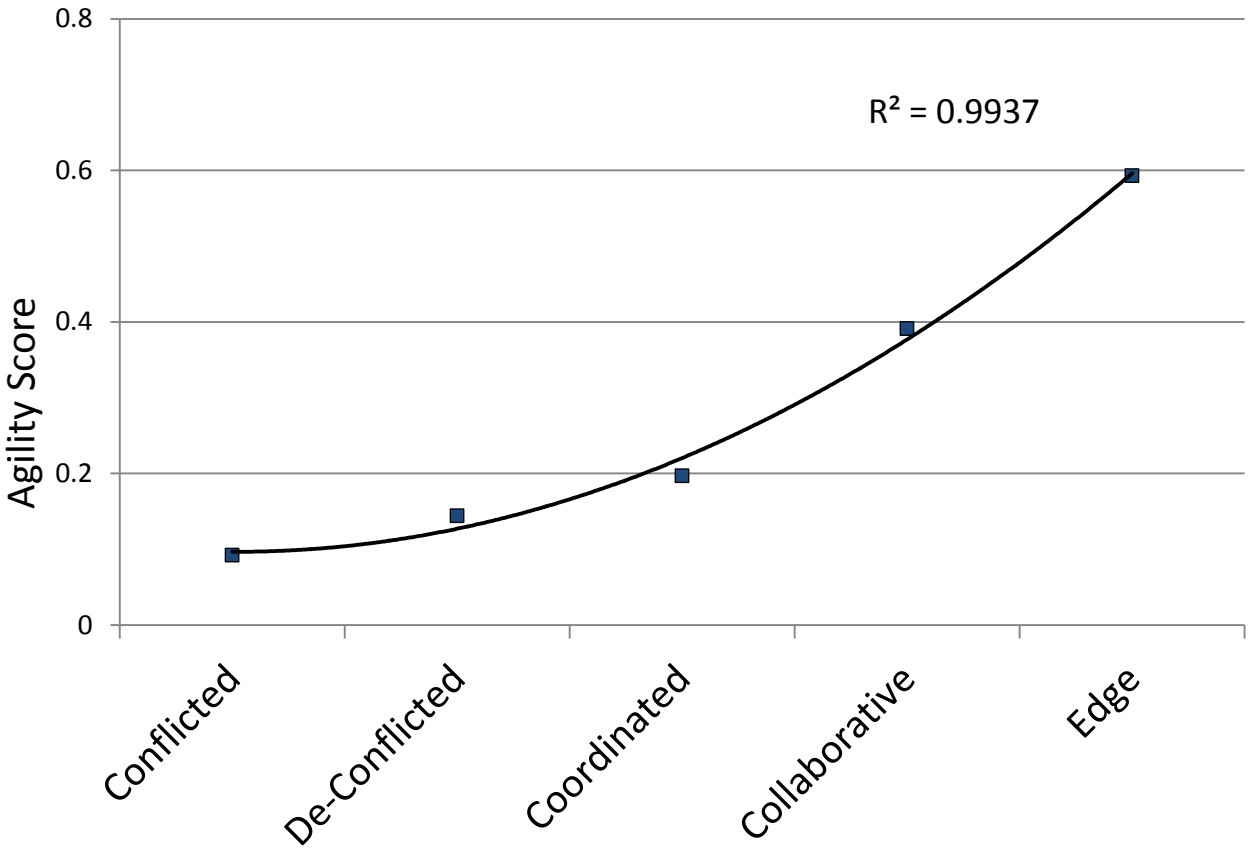
PANOPEA



- Darker shades of teal correspond to higher levels of mission success (1.0), lighter ones to failure (0.0)
- Blank squares represent non-simulated cases

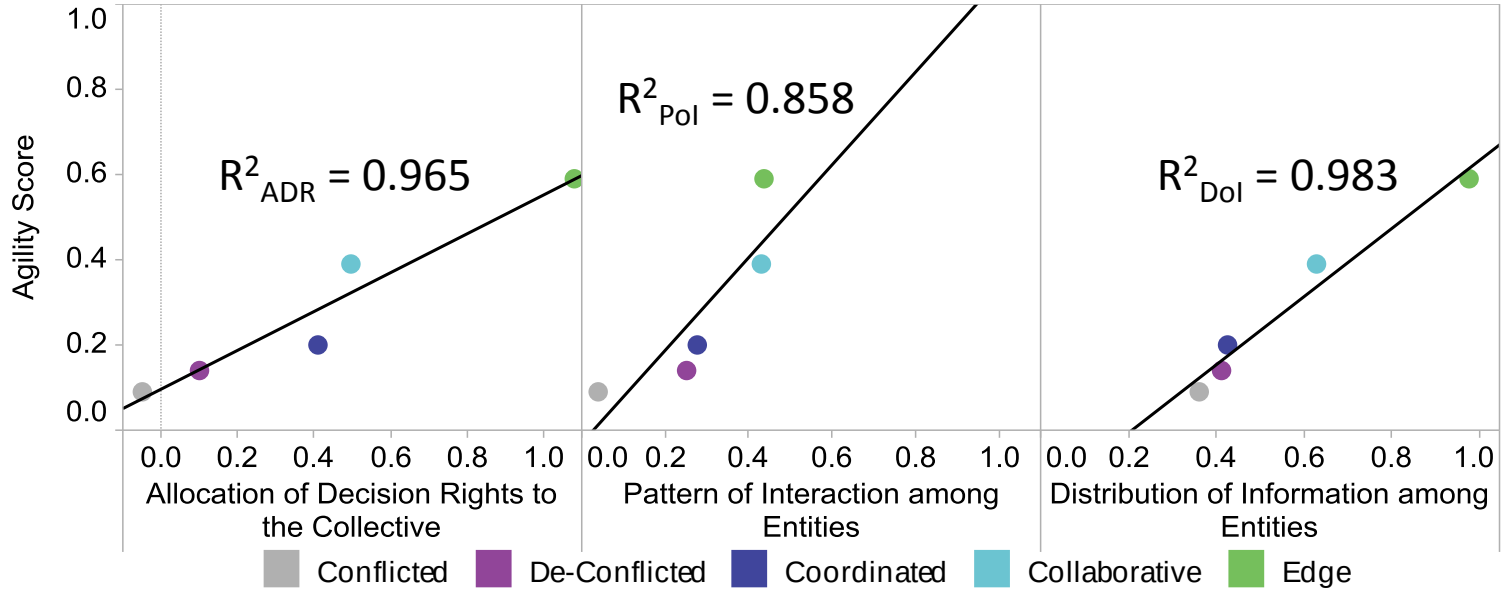
More Network-Enabled = More Agility

- Results suggest that Agility accelerates as C2 approaches become more network-enabled
- The relation between C2 Approach and Agility Score is quadratic ($R^2 = 0.99$)



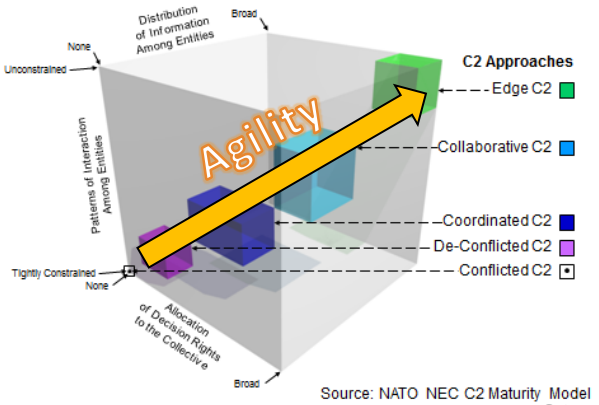
C2 Approach Space → Agility

H5: The dimensions of the C2 Approach Space are positively correlated with agility



- Individually: Agility Score is strongly correlated to each dimension of the C2 Approach Space
- Collectively (multiple regression):

Agility Score = 0.030 + 0.460 x Allocation of decision rights
– 0.269 x Patterns of interaction
+ 0.274 x Distribution of information

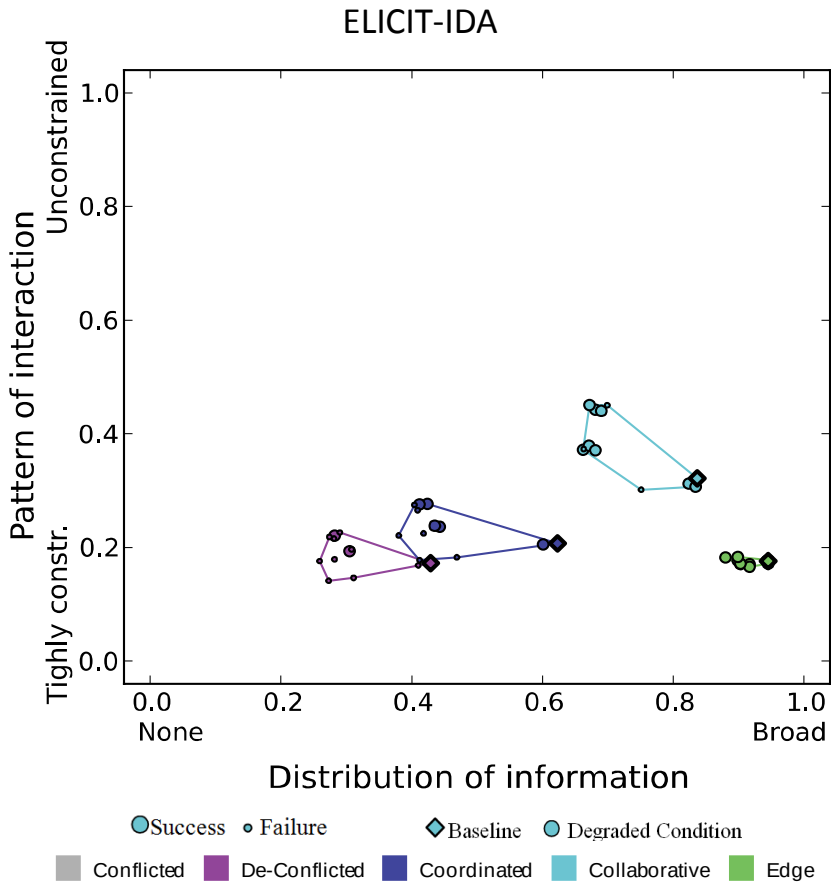


Source: NATO NEC C2 Maturity Model

Location Variations in C2 Approach Space

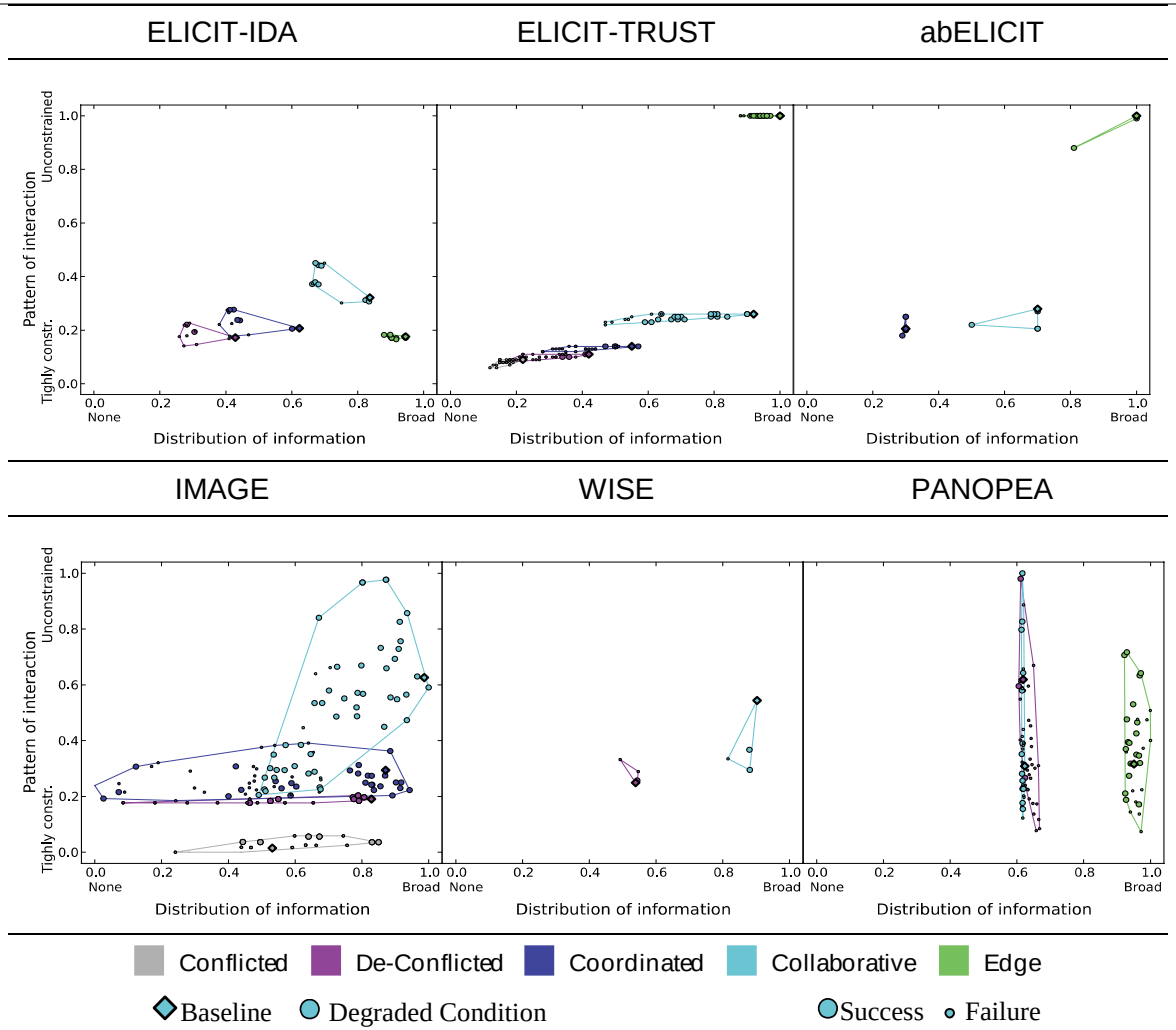
H6: More network-enabled C2 approaches are better able to maintain their position in the C2 Approach Space

- Only patterns of interaction and distribution of information were affected by circumstances
- The deviation was measured by the spreading, calculated from the area occupied by all circumstances



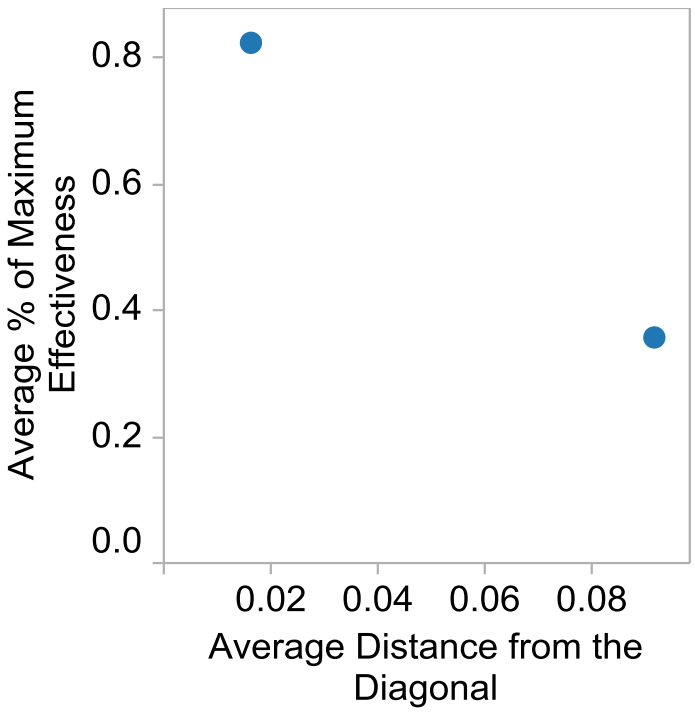
Location Variations in C2 Approach Space

H6: More network-enabled C2 approaches are better able to maintain their position in the C2 Approach Space



On vs. Off Diagonal

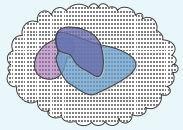
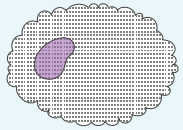
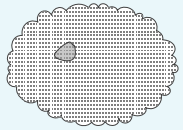
H7: On-diagonal (balanced) approaches to C2 are more agile



C2 Approach	On-Diagonal Group	Off-Diagonal Group
Average % Maximum Effectiveness	82%	36%
Average Distance from Diagonal	0.02	0.09

C2 Maturity → C2 Agility

H9: More mature C2 capability is more agile than the most agile C2 Approach that can be adopted

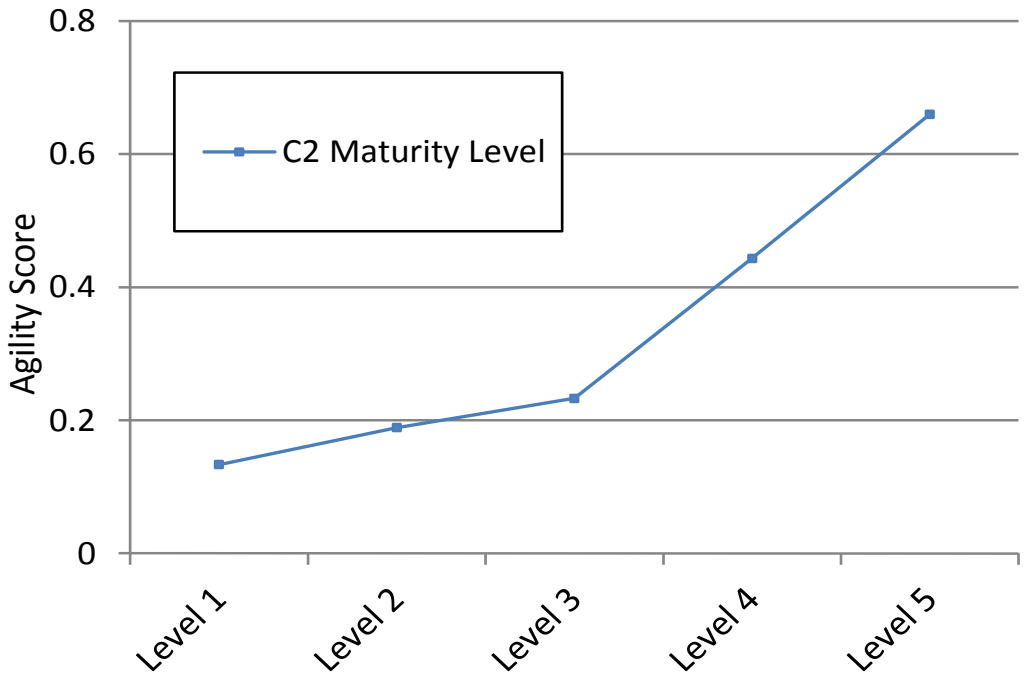
C2 Maturity Levels	Contents of C2 Toolkit	C2 Approach Decision Requirement	Transition Requirements	Region of the Endeavor Space where a collective is successful
Level 5	Edge C2 Collaborative C2 Coordinated C2 De-Conflicted C2	Emergent	Edge C2 Collaborative C2 Coordinated C2 De-Conflicted C2	
Level 4	Collaborative C2 Coordinated C2 De-Conflicted C2	Recognize 3 situations and match to appropriate C2 approach	Collaborative C2 Coordinated C2 De-Conflicted C2	
Level 3	Coordinated C2 De-Conflicted C2	Recognize 2 situations and match to appropriate C2 approach	Coordinated C2 De-Conflicted C2	
Level 2	De-Conflicted C2	N/A	None	
Level 1	Conflicted C2	N/A	None	

Adapted from the Alberts, D.S. (2011). Agility Advantage, CCRP

Conflicted De-Conflicted Coordinated Collaborative Edge

C2 Maturity → C2 Agility

H9: More mature C2 capability is more agile than the most agile C2 Approach that can be adopted



C2 Maturity → C2 Agility

Experimental results suggest more
an imbricated model than a complementary one