Applying Semantic Technology to Early Stage Defense Capability Planning Analysis Based on JCIDS Artifacts

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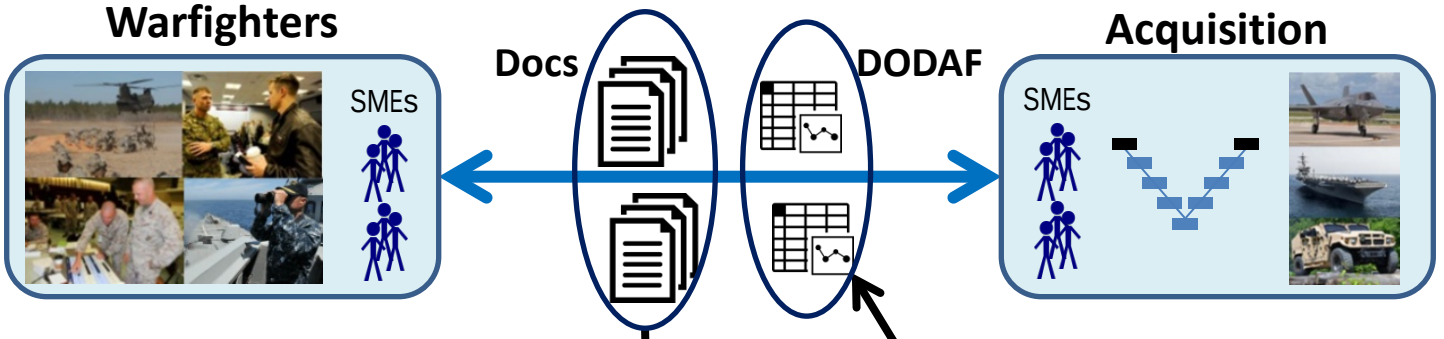
Agenda

- Goals of JCIDS Semantic Architecture Framework Research
- Joint Capability Enterprise Architecture
- Exploratory Experiments
- Systematizing Method for Manual Use
- Leveraging Semantic Technology
- Next Steps

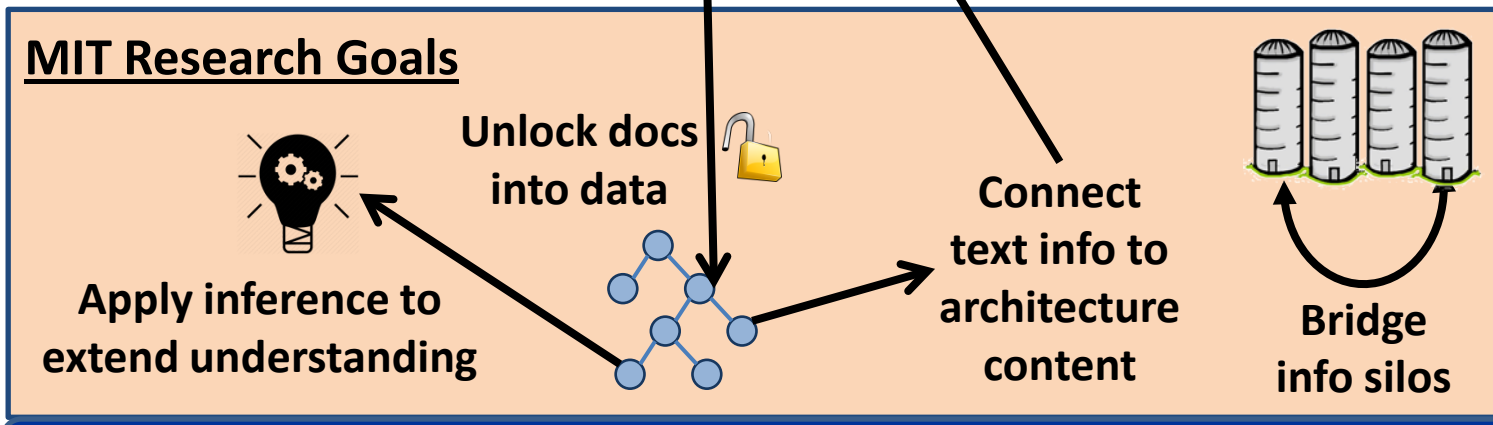
JCIDS (Joint Capabilities Integration and Development System) A Systematic Process for Warfighters to Develop, Validate, and Control Capability Requirements for Acquisition

LIMITATIONS OF CURRENT JCIDS PROCESS

- Necessarily Document-Driven
- DODAF Architecture Not Fully Integrated
- Silos of Information by Capability/Program and Date of Writing



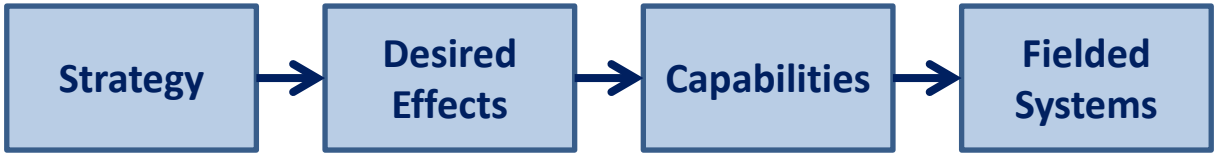
MIT Research Goals



Joint Capability Enterprise Architecture (JCEA)

System of Systems Complexity is Inherent in JCIDS

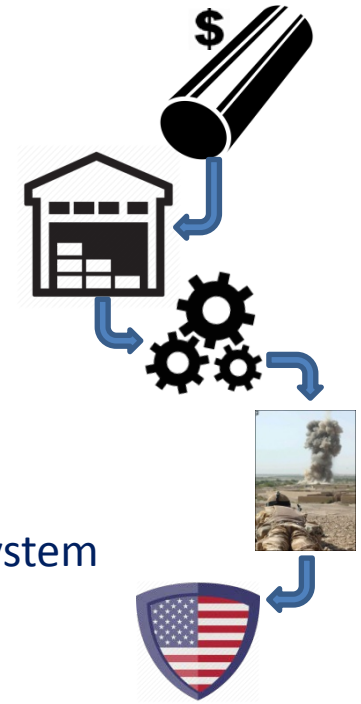
Value Proposition for Capability-Based Planning (Aldrich Study, 2004)



Capability-Based Planning Works Backwards from Goals to Factor Out Systems Needed

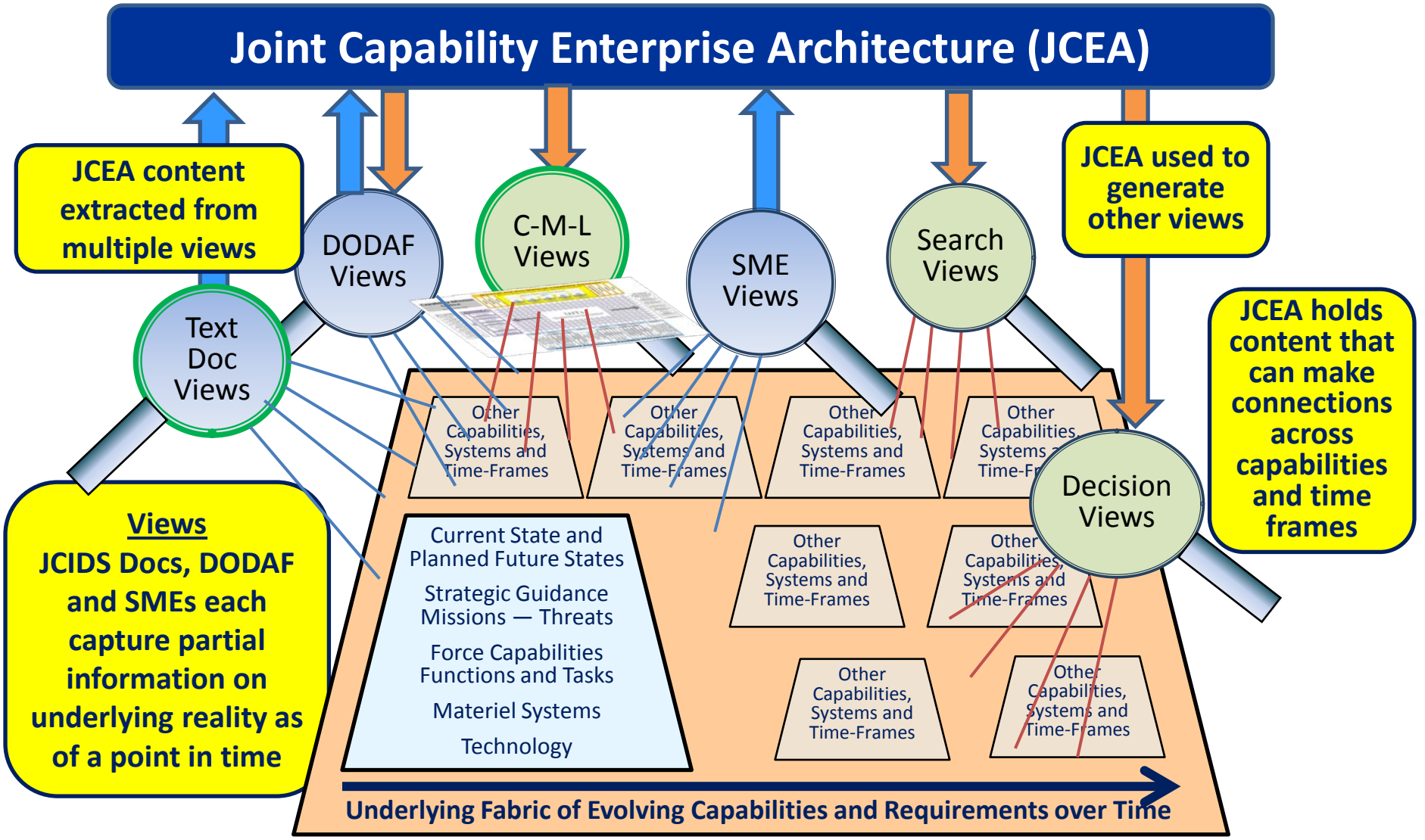
Not as Simple and Linear as it Looks

Investment decisions must be made **years or decades in advance**
... within limited and changing **budget constraints**
... to assure that Services will have the **capabilities on hand**
... to **supply resources** to combatant commanders
... to be **dynamically integrated** into joint task forces
... to achieve **effects** needed to accomplish **future missions**
... in support of **national strategy**



Question: How to Manage the Inherent Complexity of the Problem?

- **Combinatorics** of the solution space vs. need to **limit scope** of each system
- **Dynamic effects** of decision lead times and necessity for **integration**
- **Uncertainty** on critical factors affecting the design
  e.g., strategy, threats, budgets, technology, related program outcomes



Ontology defines slots that structure data extracted from documents and DODAF

Ontology also defines relationships among data elements in the JCEA model

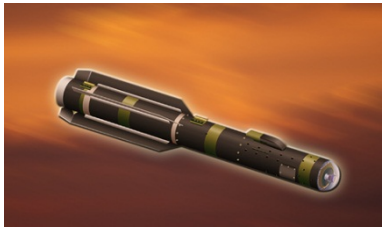
Defining Semantics: Empirical Review of Documents

- Broad review of 88 unclassified sample JCIDS documents to build familiarity, recognize patterns, and discern 'ground truth'
- Detailed deep-dive into three capability documents (ICD, CDD, CPD)
  - 1) what ***SHOULD*** be in document?
  - 2) what ***WAS*** in document?
  - 3) what is ***ESSENTIAL*** in document?
- Documents selected for deep-dive experiment:
  - 3 different stages of development (ICD, CDD, CPD)
  - 3 different functional areas staffed by different FCBs
  - All in Air domain with documents staffed in 2007-2009

ICD
Logistics

Joint Future Theater Lift (JFTL)
Move cavalry with armor

CDD
Force Application



Joint Air-to-Ground Missile (JAGM)
Replace HELLFIRE,TOW and Maverick

CPD
Battlespace Awareness

Extended Range UAS (MQ 1C)
Dedicated support to Division

Found implicit interdependencies across separately staffed capabilities.

Framing a Joint Capability Enterprise Architecture: Capability Categories – Joint Capability Areas

"To support needs definition, gap and excess analysis, major trade analyses, and capabilities planning, DoD's capabilities must be divided into manageable groups, or capability categories." – Aldrich Study (2004)

2005 – Original JCAs
- 4 top level categories (operational, functional, domain, institutional)
- **22 Tier 1** with 240 subordinate JCAs

→

- Too many **overlaps** and **redundancies**
- **Unnecessary complexity** for use as a taxonomy

2007 – Revised JCAs
- **9 Tier 1** JCAs, 6 Tiers
- Functional only
- Aligned with FCBs
- Operational dimension removed

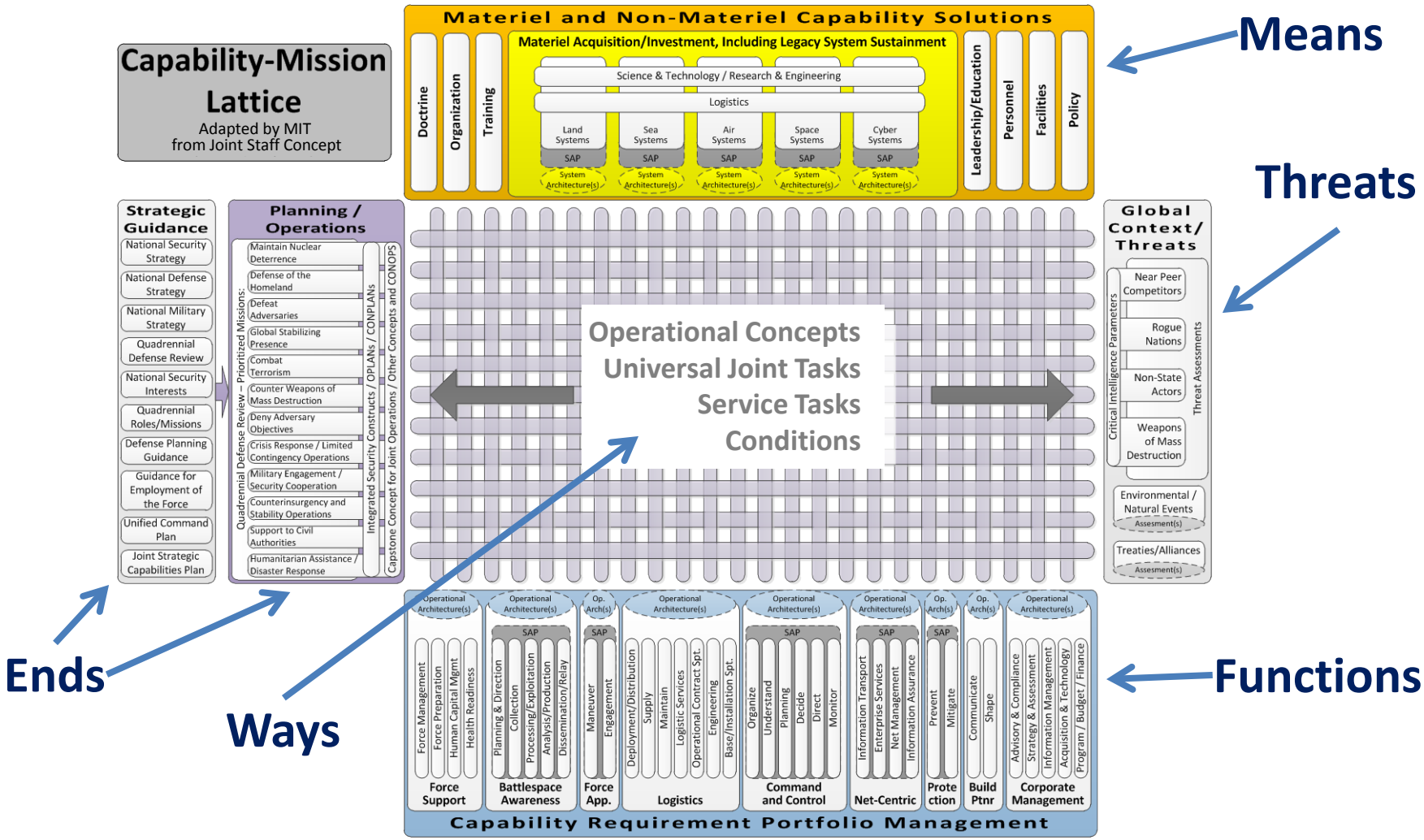
Empirical Observations from Docs

- Most JCIDS docs use **multiple** Tier 1 JCAs
- JCAs are used as a framework for describing **operational attributes** of capabilities not just **desired effects**

Conclusions

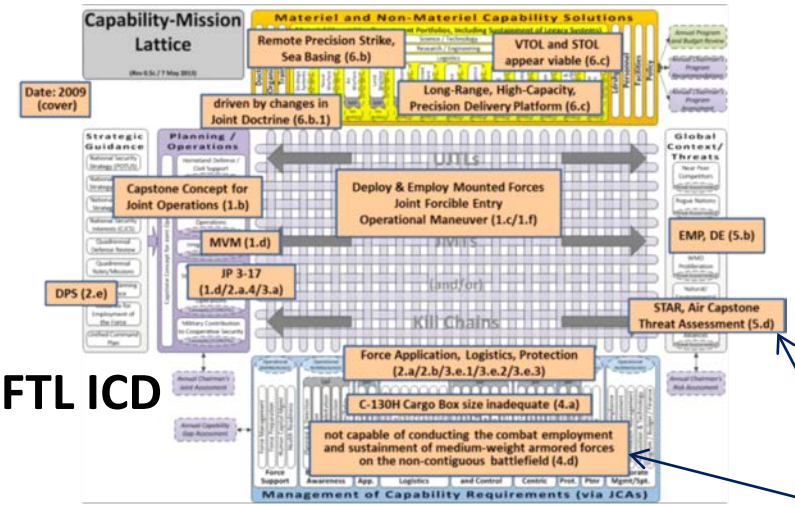
- **JCAs alone are insufficient to categorize capabilities**
- **A multidimensional category structure is preferable to a single taxonomy**

Framing a Joint Capability Enterprise Architecture: Joint Staff Capability Mission Lattice (CML)

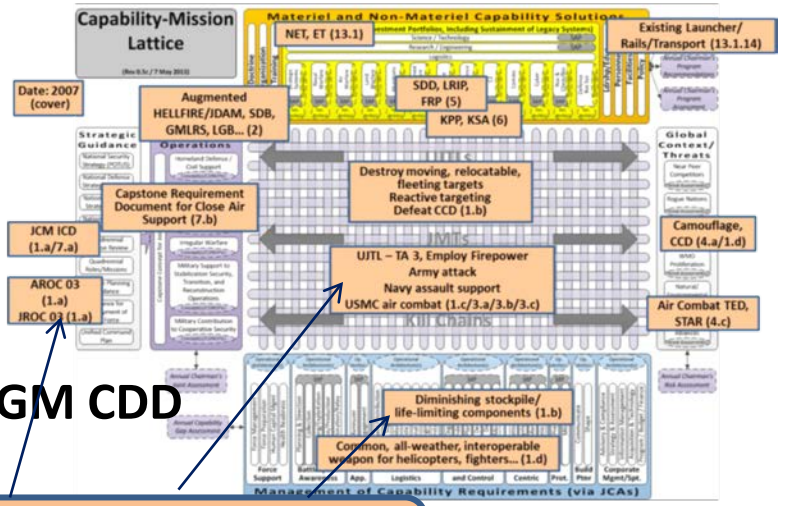


Basic ontology from Capability Mission Lattice has been expanded to include elements required in JCIDS Manual and taxonomies/frameworks in use

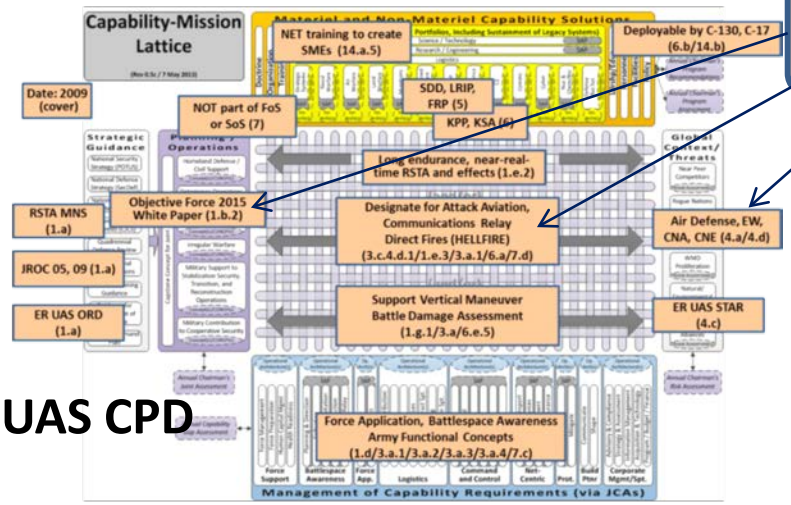
Using C-M-L Ontology to Find Interdependencies



JFTL ICD



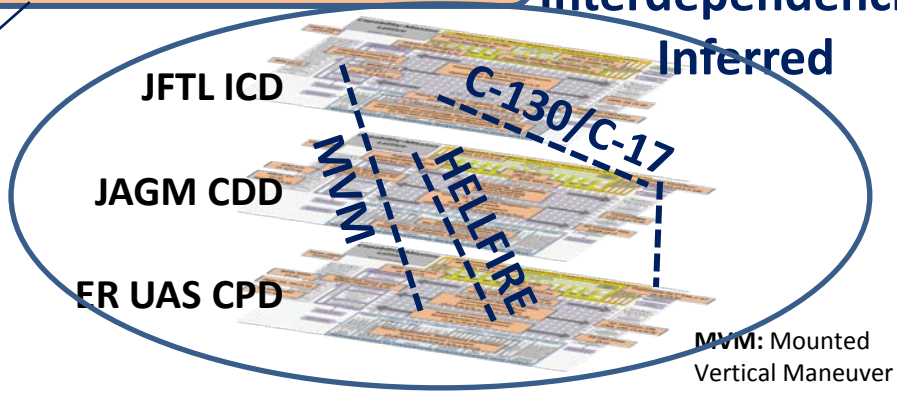
JAGM CDD



ER UAS CPD

Phrases from JCIDS Docs attached to Ontology Slots

Interdependencies Inferred



MVM: Mounted Vertical Maneuver

The C-M-L based ontology can help identify interdependencies between systems that are not apparent in documents or with current taxonomies

Systematizing Semantic Architecture Framework JCIDS Ontology Design Task

Central goal: Define a semantic knowledge base that captures the portfolio of capabilities & gaps early in development

Ontology and **architecture** frame the knowledge base

- Ontology also captures and connects essential military and requirements process subject domain knowledge

Requirements documents provide the **content**

- Text of documents (interpreted against ontology)
- Structured information in tables and DODAF artifacts attached in structured form suitable for machine use
- Images such as OV-1 (hard to extract info from)

Additional content will come from **SME annotations** as an ontology-based knowledge base is put into use

Data captured and organized in a semantic architecture framework will continue to be accessible and reusable as SMEs rotate in and out and as circumstances change

Overview of ICD Ontology Design based on 2015 JCIDS Manual and Capability-Mission-Lattice

Metadata

Cover Page

Operational Context

- **Time Frame**
- **Strategic Guidance**
- **ROMO**
- **Operational Concepts**

Threats

- **Threat context**
- **Expected operational environment**
- **Current threats**
- **Anticipated threats**

Capability Req'ts

- **Define Capability Requirements in Lexicon of:**
  - Time Frame
  - ROMO
  - Org / Unit Type
  - JCAs
  - UJTL Tasks
  - Service Tasks
  - Conditions
  - Supported and supporting tasks
- **Operational Attributes**
  - Metrics
  - Objective Values

Capability Gaps

- **Match to Current Capabilities**
  - Legacy fielded
  - In Development
  - Rapidly fielded
  - Predecessor system if recap or next gen
- **Identify Gaps for each Operational Attribute (O/A):**
  - Current capability O/A metric value
  - Gap from current to objective value
- **Operational Impact of Gap**

Recommendations

- **Materiel Solutions Suggested for AoA**
  - Evolution of fielded system
  - Replacement or recap of fielded system
  - Transformational capability solution
- **Technology Leverage to reduce Operational Risk**
  - Functionality
  - Affordability
- **DOTmLPF-P Recommendations**

A. References

B. Acronyms

C. Glossary

D. DODAF

Example: JFTL ICD Extracted Capability Gaps

Gap Num	Functional Concept	Gap Description	Reason for Gap
1	**IOM**	Inability to operate into austere, short, unimproved landing areas	Proficiency
		Inability to perform operational maneuver with medium weight armored vehicles and personnel or reposition medium weight armored vehicles and personnel by airlift	Proficiency
		Inability to reposition forces with combat configured medium weight armored vehicles via air	Proficiency
2	**OMSD**	Inability to operate into austere, short, unimproved landing areas	Proficiency
		Deliver cargo weights equivalent to the weight of combat configured medium weight armored vehicles to austere, short, unimproved landing areas.	Proficiency
		Conduct precision air delivery of supplies, to the point of need/point of effect over strategic and operational distances with required velocity.	Proficiency
3	**DMSS**	Inability to operate into austere, short, unimproved landing areas	Proficiency
	DES	Deliver cargo weights equivalent to the weight of combat configured medium weight armored vehicles to austere, short, unimproved landing areas.	Proficiency
		Conduct precision air delivery of supplies, to the point of need/point of effect over strategic and operational distances with required velocity.	Sufficiency
4	**JFEO**	Inability to transport forces over strategic and operational distances to points of need by passing traditional PODs, and to operate on austere, short, unimproved landing areas.	Proficiency
		Inability to deploy and employ forces, with combat configured medium weight vehicles, via air across the global battle space from strategic, operational and tactical distances	Proficiency

Ontology Concept in Yellow

Document Data in Blue

Example: Compare Gap Operational Attributes

Operational attribute	Gaps by Functional Concept				Operational attribute values
	1	2	3	4	
	IOM	OMSD	DMSS/ DES	JFEO	
Cargo handling			X	X	No MHE
Combat Radius	X	X	X	X	As determined in AoA
Cruise Speed	X	X	X	X	As determined in AoA
Fuel efficiency	X	X	X	X	Fuel efficiency must be greater than that of the C-130J
In-flight Refuel Speed (as Receiver)		X	X	X	As required
Payload Weight & Dimensions	X	X	X	X	Combat configured medium weight armored vehicles (Army ground combat vehicles, Stryker)
Precision Delivery	X	X			~25 – 50 km of objective
			X	X	Point of need/point of effect
Precision Landing	X	X	X	X	Routine 0 ft takeoff & land (VTOL) to routine <1500 ft takeoff and land (STOL)1 over a 50’ obstacle into austere, complex, urban or unprepared landing areas independent of external navigation aids
Secure Communications	X	X	X	X	Interoperable, secure, encrypted, voice and data, beyond line of sight/over the horizon
Self Deploy		X			2,400 nm
Survivability	X	X	X	X	Ability to effectively integrate with future joint forces for threat suppression/mitigation in a low to medium threat environment

Ontology Concept in Yellow

Document Data in Blue

Semantics-Based Inference Can Help Fill in Missing Data and Inconsistencies in JCIDS Documents

Capturing Implicit Information

Documents reviewed often have **inconsistent data**

- Most have current JCAs; some have 2005 JCAs; some have JFCs
- JCAs often used for multiple purposes
- Some have UJTs; most do not

SMEs can make sense of documents despite gaps & other inconsistencies

Ontology-based data capture – combined with inference rules – can allow automation to **follow same logic used by SMEs**

Connecting to other Knowledge

Example of how can semantic inference can help:

- Joint Future Theater Lift (JFTL) ICD has no UJTs
- JFTL ICD references JP 3-17 (Air Mobility Operations) and Joint Forcible Entry by name
- Joint Forcible Entry (JFEO) defined by JP 3-18
- UJTL database ties UJTs to definitional docs JP 3-17 and JP 3-18
- By combining these fragments of information, UJTs for JFTL can be inferred

Semantic architecture provides the benefits of capturing the true capability provided by a system by interpreting text within a document.

Semantic Ontology Experiments

Developed an **ICD ontology** containing 150 data slots based on draft 2015 JCIDS Manual, C-M-L, and other frameworks

Manual text extraction experiments

- 6 ICDs as sources, 3 SMEs perform extraction
- Into Excel form structured by the ontology
- Reliability varied: some data were consistently extracted; other data inconsistent

A parallel project showed potential for applying natural language processing to **automate text extraction**

SMEs built a **practical relational database** by focusing on the more consistent areas and for wider sample of JCIDS documents

Experiment showed that **DODAF views can be generated** from data extracted from JCIDS documents

MIT continuing research is focused on formalizing and systematizing methods to extend the scope and value of the results

Research on Technologies and Methods for Storing and Accessing Semantic Knowledge

1) Documents repository (current as-is state)

2) Relational or spreadsheet data

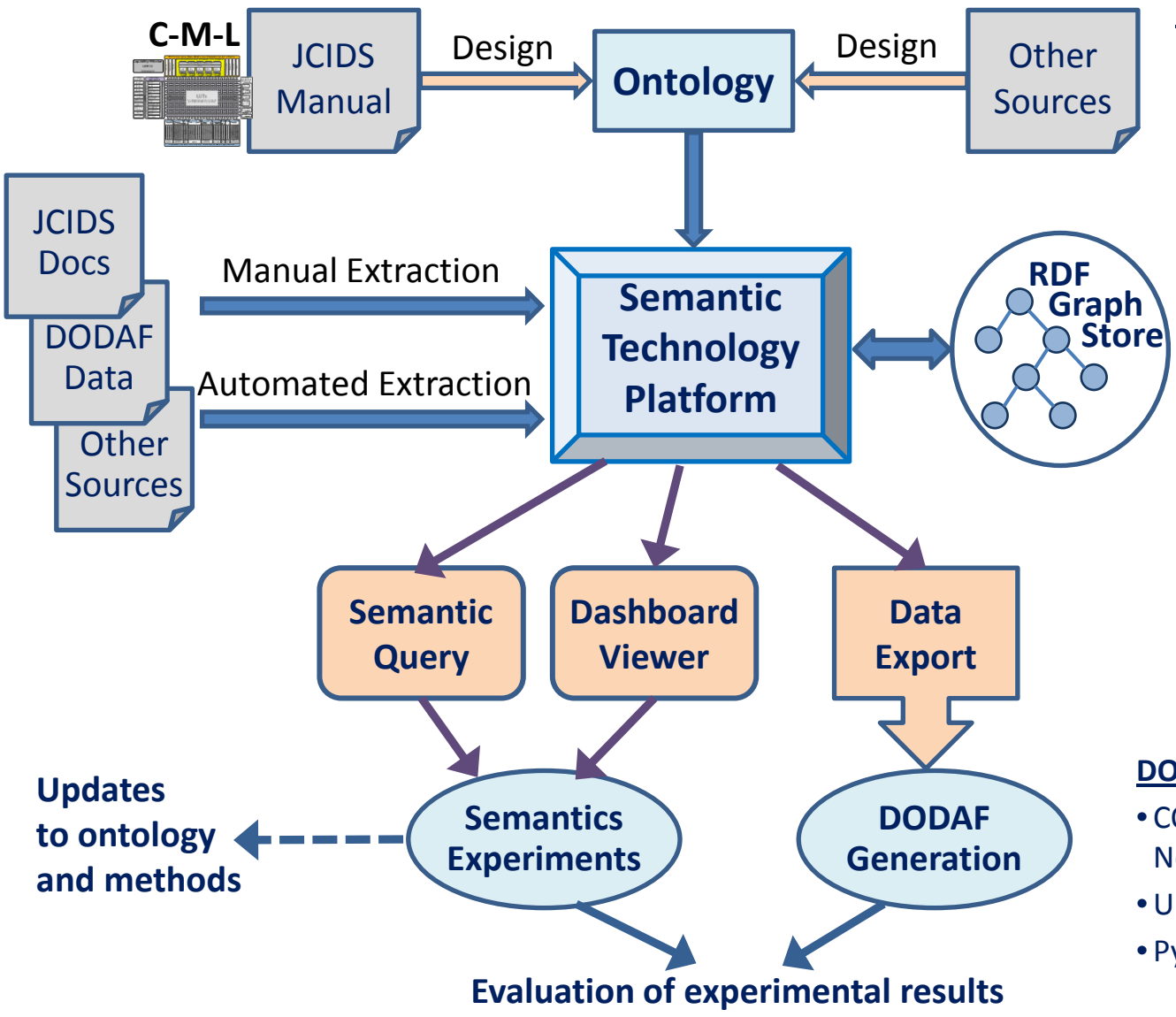
3) DODAF architecture structured data

- New 2015 JCIDS Manual requires DODAF views to be submitted with requirements documents for validation
- Research is exploring how to connect text document content to DODAF data and artifacts

4) Semantic data store with inference rules

- Facts stored as **RDF Triples** (subject-predicate-value)
- **Flexibility** from capturing facts in small pieces
- Facts can be combined in multiple ways by **inference rules** and **semantic query**

Semantics Technology Proof-of-Concept Prototype Design Overview

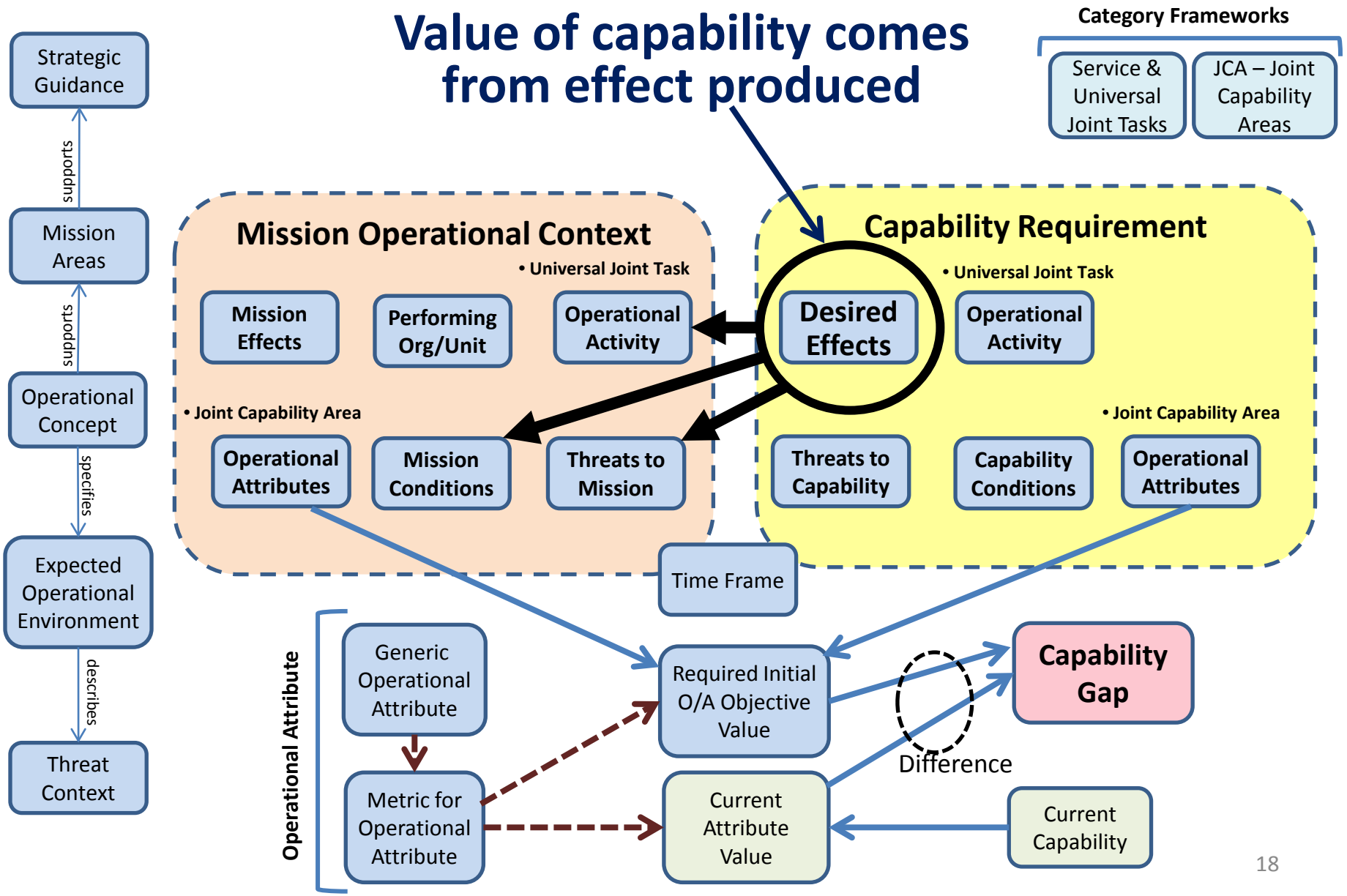


Ontology – design based on
- JCIDS Manual
- Capability-Mission-Lattice
- other terminology frameworks

Semantic Technology Tools
- Built on Semantic Web industry standards such as OWL, RDF, SPARQL & cyber-security
- Includes tools for working with ontology and data
- Highly flexible data store and semantic query/search
- Technology used allows research results to be ported to other COTS product sets

DODAF Generation Tools
- COTS/GOTS tools, such as NoMagic/MagicDraw/CAMEO
- UPDM interface (probable)
- Python to convert data format

Connections in Capability Requirements Ontology



JCIDS Semantic Architecture Framework

Enables Capability Enterprise Architecture

- Multi-dimensional grouping of capabilities by category framework properties
- Logically deriving capability dimensions and similarities from operational attributes
- Capturing and retaining SME knowledge across silos and over time

Identifies Capabilities Dependencies

- Tracing capabilities to assumptions, conditions, and threats
- Tracking interfaces and connections among capabilities
- Inferring dependencies based on **effects produced** and **effects needed**

Supports Systems Engineering

- Trade space identification for capability requirements planning
- Trade space exploration at the capabilities portfolio level

MIT Research is investigating and developing methods to apply semantic technology to Joint Capability Enterprise Architecture

Goals for Semantic Architecture (2016)

Unlocking Knowledge

- **Decompose documents into conceptual elements** independent of language, to enable translation of across terminology, frameworks, and taxonomies.
- **Identify implicit interconnections and interdependencies** across separately staffed capability requirements (including different time periods, different functional areas, and different services or components).
- **Connect text to architecture** to create a more complete picture in a form suitable for inference.
- **Generate DODAF artifacts** from ontology-based data extracted from text documents.

Supporting Decisions

- **Provenance**: Maintain time-varying continuity of requirements across development stages and across separate branching threads.
- **Drill down**: Make conceptual connections across different levels of architecture (e.g. SoS vs. Systems, KPPs vs. DODAF) as designs evolve.
- **Track changes to assumptions** (e.g., strategic direction, mission profiles, threats, operational concepts, technology available).
- **Support systems engineering methods** such as Trade Space Exploration and Epoch-Era Analysis.

References

Aldridge, Pete et al. (2004). Improving DOD Strategic Planning, Resourcing and Execution to Satisfy Joint Capabilities. Joint Defense Capabilities Studies, Jan 2004.

Ahmed, Col. L. Najeeb (2014) Improving Trade Visibility and Fidelity in Defense Requirements Portfolio Management: A Formative Study of the Joint Capabilities Integration and Development System using Enterprise Strategic Analysis and Semantic Architecture Engineering. Unpublished MIT SDM Thesis.

Allemang, Dean & Hendler, Jim (2011). *Semantic Web for the Working Ontologist*. Waltham, MA: Morgan Kaufman.

U.S. Dept of Defense. *JCIDS Manual* (12 Febuary 2015)

Acknowledgements

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