

C2 Domain Ontology Within Our Lifetime

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Bottom Line Upfront

- ❖ Development of a practical C2 domain ontology is feasible in the near to mid term
- ❖ Efforts should follow the principles and best practices of the Applied Ontology community while reusing existing C2 modeling artifacts to the extent practical

What is “Ontology”?



Philosophy-based Definitions

➤ *Merriam Webster:[7]*

1. *a branch of metaphysics concerned with the nature and relations of being*
2. *a particular theory about the nature of being or the kinds of things that have existence*

➤ *Wikipedia: [8]*

- *The study of the nature of being, existence or reality in general, as well as of the basic categories of being and their relations. Traditionally listed as a part of the major branch of philosophy known as metaphysics, ontology deals with questions concerning what entities exist or can be said to exist, and how such entities can be grouped, related within a hierarchy, and subdivided according to similarities and differences*

Philosophy-Based definitions emphasize REALITY...

Information Science Definitions

➤ *Wikipedia [12]*

- *A formal representation of a set of concepts within a domain and the relationships between those concepts. It is used to reason about the properties of that domain, and may be used to define the domain*

➤ *Gruber [13]*

- *A formal, explicit specification of a shared conceptualization*

... Information Science definitions emphasize CONCEPTS

Key Terms and Concepts

- Realism vs Relativism
- Realist Fallibilism
- Realistic Perspectivism
- Universals
- Particulars
- Classes
- Relations
- Tuples
- Entity Levels

Level 1 Entities (reality): *The objects, processes, qualities, states, etc. in reality.*

Level 2 Entities (concepts): *Cognitive representations of this reality on the part of researchers and others.*

Level 3 Entities (artifacts): *Concretizations of these cognitive representations in (for example textual or graphical) representational artifacts.*

From Smith [6]

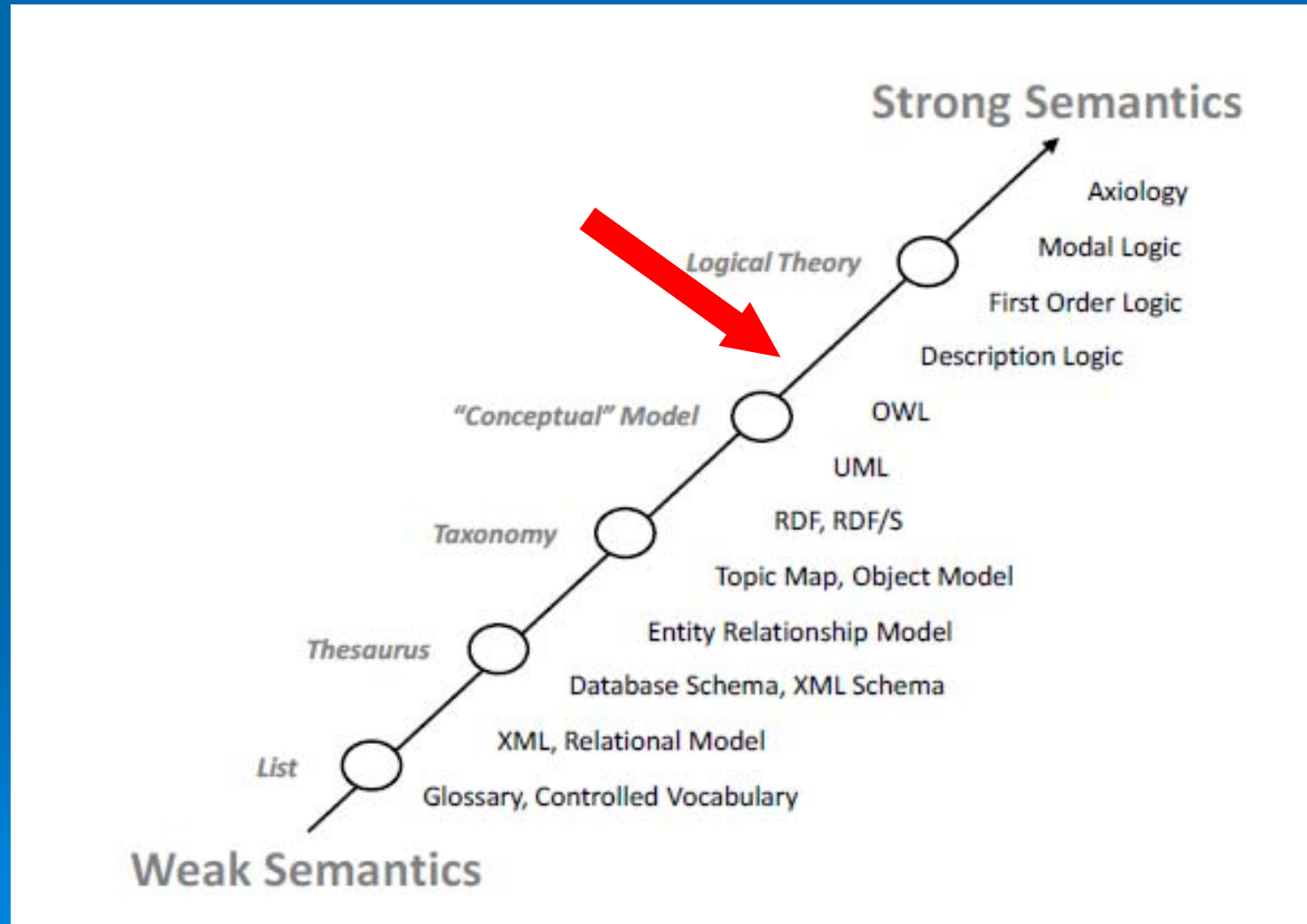
C2 Domain Ontology Working Definition

- **C2 Domain Ontology:** *A composite formalized representational artifact, comprising a taxonomy as proper part, whose representational units designate C2 universals, defined classes, and relations between them. The C2 domain ontology may be used as a reference to describe and reason about C2 in general, or about C2 particulars when applied to a dataset pertaining to these particulars*

Recommended artifacts per C2 Ontology Technical Exchange, Jan 2009: [17]

1. A natural language vocabulary explicitly describing C2 representational units
2. An OWL-DL instantiation of the C2 representational units
3. Rules (e.g. constraints) expressed in a logic language such as SWRL

Ontology and the Semantics Spectrum



Ontology Types & Applications



Ontology Applications

- Describe something (the world, a particular domain)
- Organize information
- Integrate disparate information representations
- Infer information about something by applying ontological relations
- Advance knowledge about something

Common Ontology Types

- Reference Ontologies
- Application Ontologies
- Ontology Levels
 - Formal or Upper Level Ontologies
 - Intermediate or Mid-Level Ontologies
 - Regional, Lower-level, Material, or Domain Ontologies

Simple Post Office Ontology Illustrating Ontological Levels

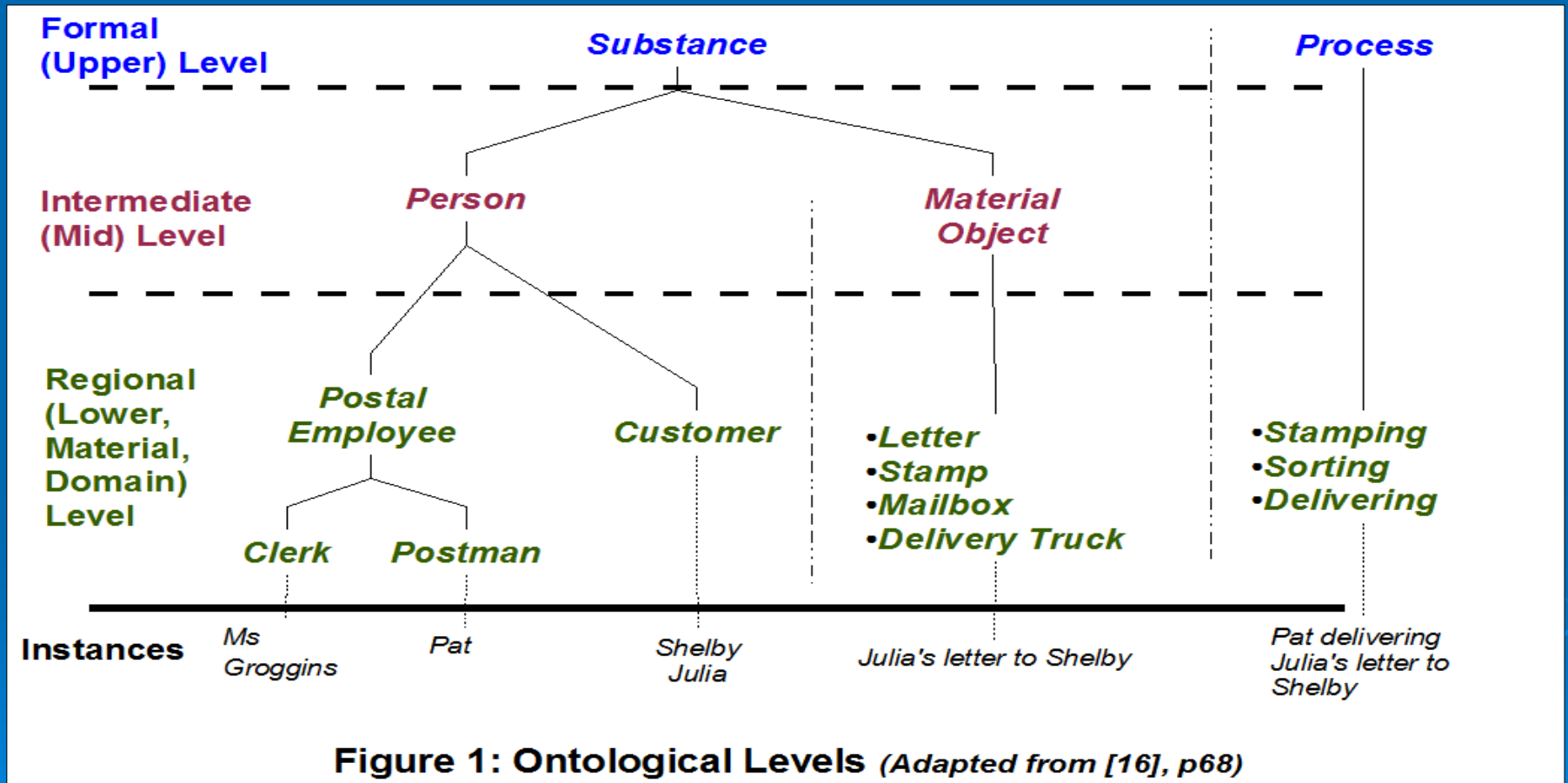


Figure 1: Ontological Levels (Adapted from [16], p68)

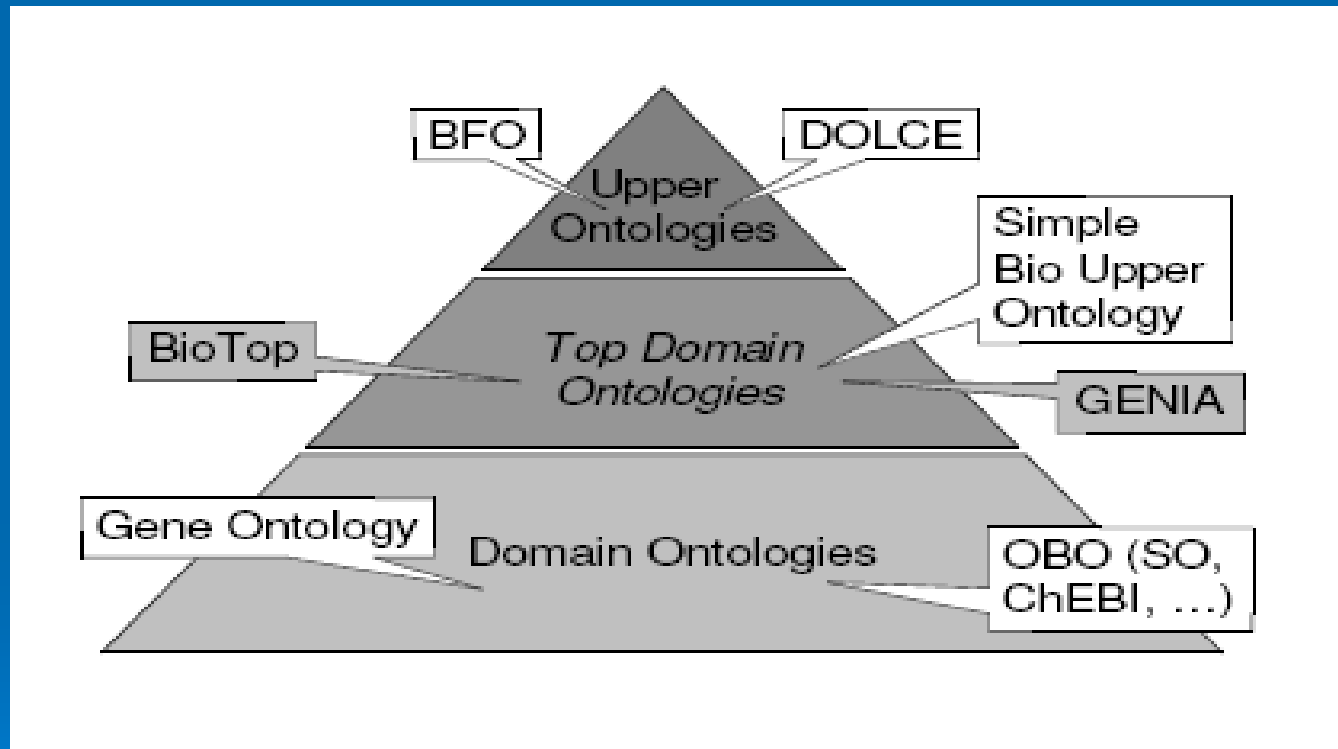
Sample Upper Level or Formal Ontologies

- Basic Formal Ontology (BFO) [24][25]
- Suggested Upper Merged Ontology (SUMO) [26]
- Descriptive Ontology for Language and Cognitive Engineering (DOLCE) [27]

Sample Biological Domain Ontologies

- **Genome Ontology (GO) [28]**
 - Describes gene products by associated processes, cellular components, and molecular functions
 - 24,000 terms organized into 3 ontologies
- **Unified Medical Language System (UMLS) Semantic Network [29]**
 - Thesaurus-like ontology
 - 1 million biomedical concepts & 5 million concept names stemming from 100 controlled vocabularies and classification systems
- **Open Biological Ontology (OBO) Foundry [30]**
 - 60+ biomedical ontologies from participating members
 - Vision to become interoperable through a common design philosophy

Biological Domain Ontological Layering



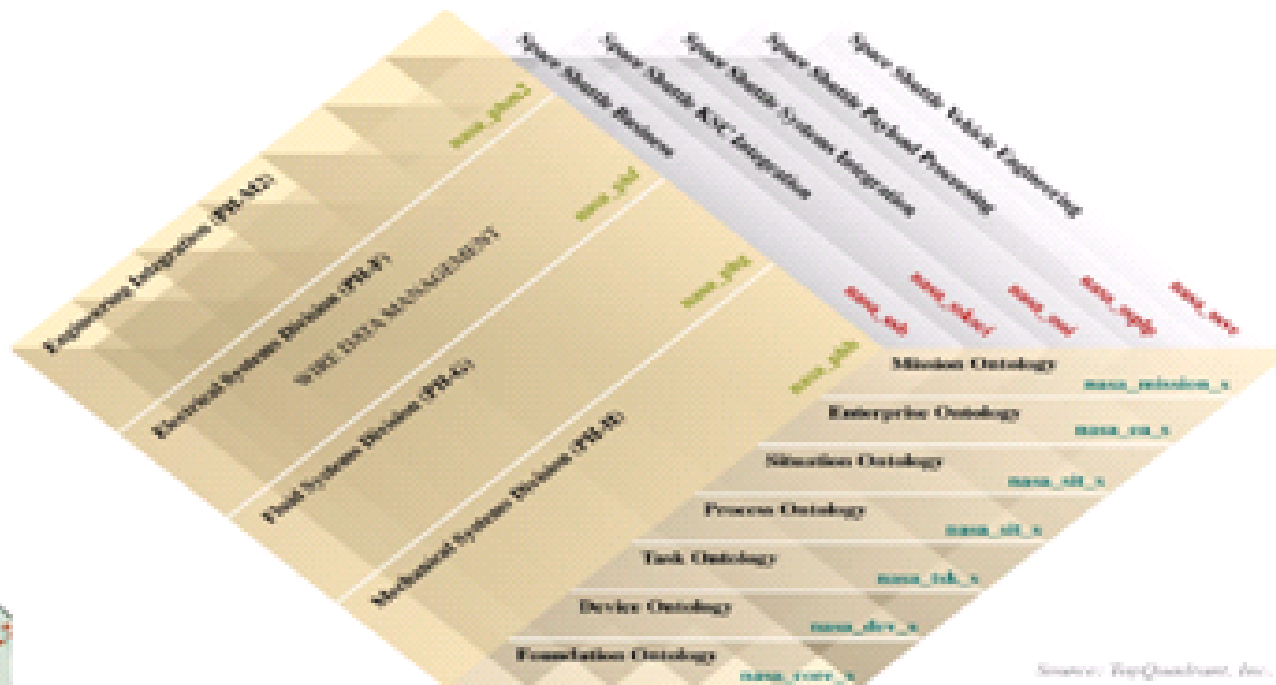
*Figure 2: Ontological Layering in the Biological Domain
(Stenzhorn [37])*

NASA Domain Ontologies

- NASA Exploration Initiative Ontology Models (NexIOM) [31]
 - Supports NASA Constellation Program
 - Family of approximately 140 ontologies working across hundreds of datasets
 - Formalizes the way NASA computers and personnel refer to NASA elements, their scientific and engineering disciplines, related work activities, and their interrelationships
 - Facilitates information retrieval, aggregation, reasoning, etc. to generate information, enable interoperability, and inform decisions

NASA Ontology Architecture

NASA Ontology Architecture is organized by Domain, Discipline, Organization – each with levels of specificity.



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Additional Ontology Artifacts

- Numerous ontology artifacts available through online libraries and search engines, e.g.
 - SchemaWeb
 - <http://www.schemaweb.info/eb>
 - OntoSelect
 - <http://olp.dfki.de/OntoSelect/>
- Illustrates the growing popularity of web-based ontology solutions
- However...

Ontology Caveat

Not all ontology is good ontology

- Many (most?) ontology development efforts are not following basic principles and best practices of Applied Ontology, e.g. with respect to:
 - Precise definition of vocabulary terms
 - Useful and appropriate classification schemes
 - Proper use of basic ontological relations
 - Methods for partitioning a domain
 - Rationale and benefits of the realist perspective
 - Reuse of existing formal, intermediate, and domain ontologies
- As a result, many (most?) ontologies do not accurately represent their domain and/or do little to solve information integration problems

C2 Domain Ontology



C2 Domain Ontology Rationale

- C2 demands the ability to organize, integrate, and understand large quantities of information
- Application Areas
 - Operational C2
 - C2 Concept Development
 - C2 Training
 - C2 Capability Management

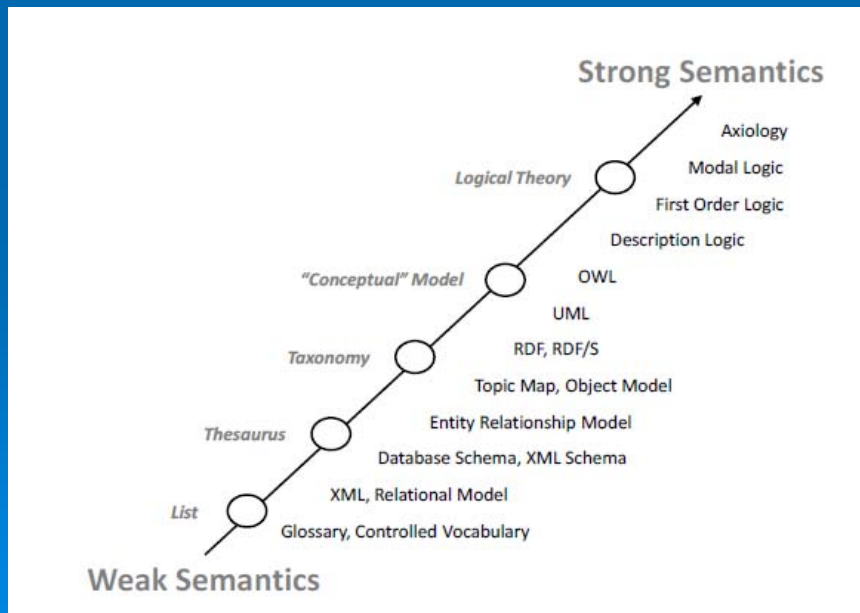
Potential C2 Ontology Contributors

C2 Data Models & XML Schemas

- C2 Core
- JC3IEDM
- C2 COI Artifacts

C2 Taxonomies

- Joint Capability Areas
- Universal Joint Task List



C2 Capability Models

- C2 Architecture Products
- NATO C2 Conceptual Model

Joint Capability Areas (JCAs) [41]

Tier 1 JCAs:

Command and Control

Force Application
Battlespace Awareness
Net-Centric
Building Partnerships
Logistics
Force Support
Corporate Management & Support

Tier 2 C2 JCAs:

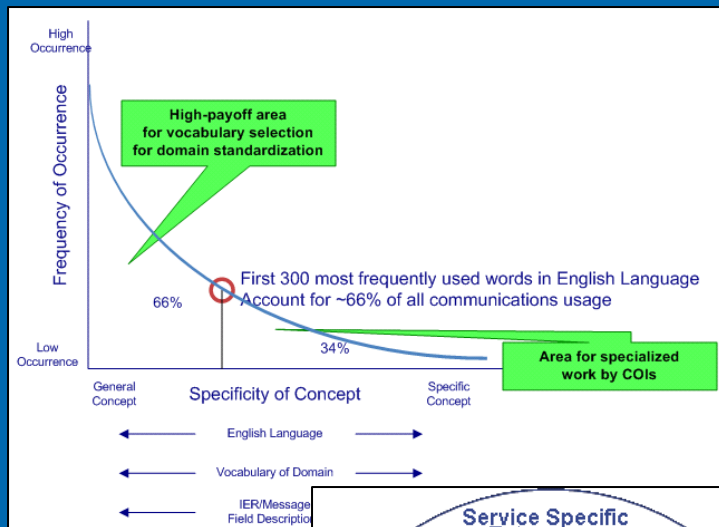
Organize
Understand
Planning
Decide
Direct
Monitor

5.3 Planning

5.3.1 Analyze problem
5.3.1.1 Analyze Situation
5.3.1.2 Document Problem Elements
5.3.2 Apply Situational Understanding
5.3.2.1 Evaluate Operational Environment
5.3.2.2 Determine Vulnerabilities
5.3.2.3 Determine Opportunities
5.3.3 Develop Strategy
5.3.3.1 Determine End State
5.3.3.2 Develop Assumptions
5.3.3.3 Develop Objectives
5.3.4 Develop Courses of Action
5.3.4.1 Assess Available Capabilities
5.3.4.2 Understand Objectives
5.3.4.3 Develop Options
5.3.5 Analyze Course of Action
5.3.5.1 Establish Selection Criteria
5.3.5.2 Evaluate Courses of Actions

- U.S. DoD authoritative management construct for partitioning military capabilities
- Provides taxonomy and vocabulary for defining C2 from a process perspective
- Tier 1 JCA's may be considered an intermediate ontology-like construct that relates C2 to the larger DoD capability domain
- US Joint Staff J7 maintains an authoritative mapping between JCAs and the Universal Joint Task List (UJTL) [43]

C2 Core Vocabulary and Conceptual Model

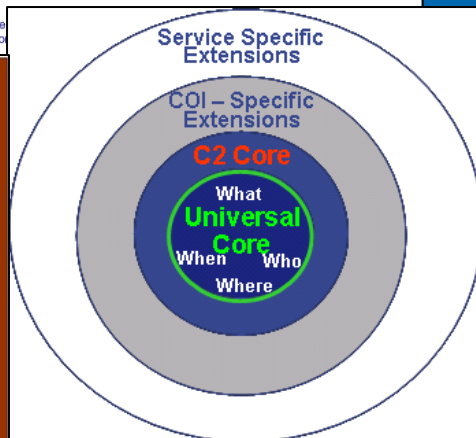
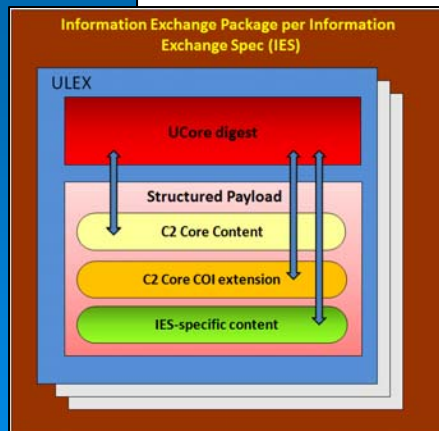


➤ Emerging U.S. DoD approach to facilitate understandable and interoperable C2 data sharing

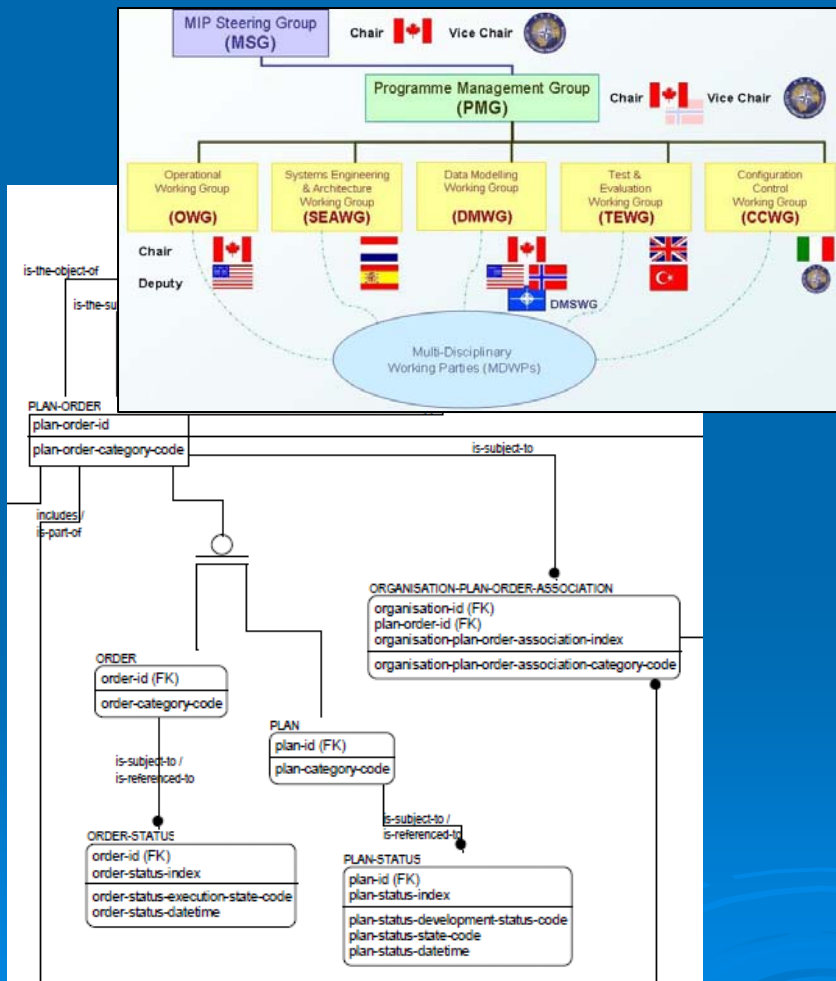
➤ Includes a conceptual model and vocabulary for commonly exchanged C2 data

➤ Extended from the U.S. Universal Core [5][44], which may be considered an intermediate ontology-like construct

➤ COIs and mission-specific constructs extend from C2 Core to lower domains

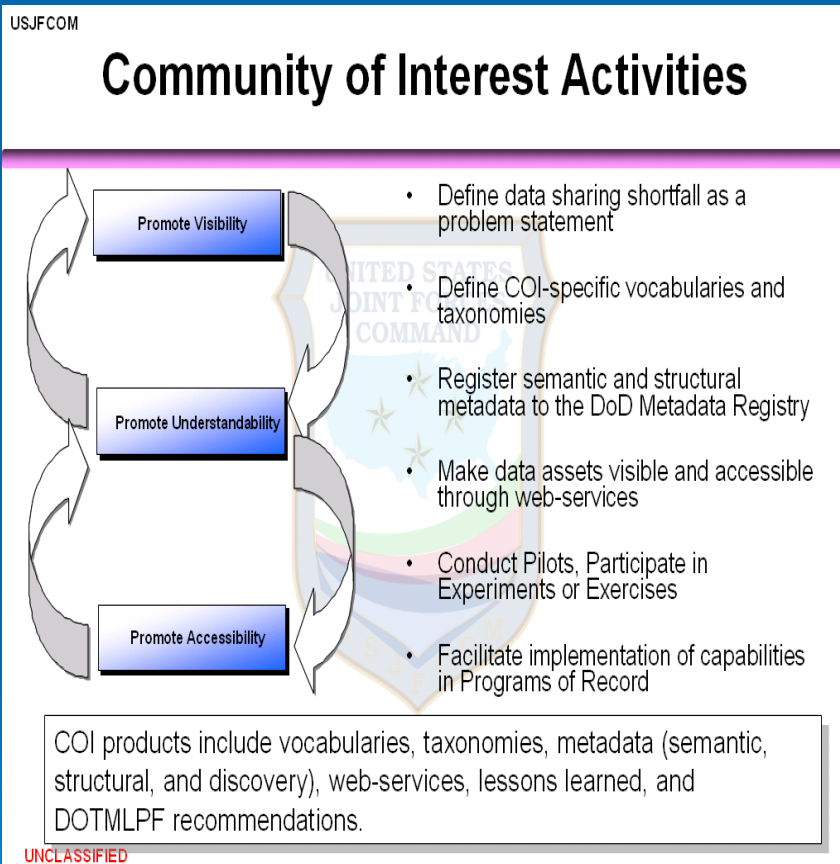


Joint Consultation Command and Control Information Exchange Data Model (JC3IEDM)



- Doctrinally based, comprehensive product based on ~ 20 years of C2 domain expert inputs [46][47]
- Relevant artifacts include conceptual and logical data models, extensive vocabulary, and rules set
- Numerous papers exploring relevance of JC3IEDM to a C2 domain ontology (ICCRTS, SISO)
- OWL-DL and SWRL are required to capture the model itself as well as rules governing the relationships between JC3IEDM entities

COI and Program Vocabularies

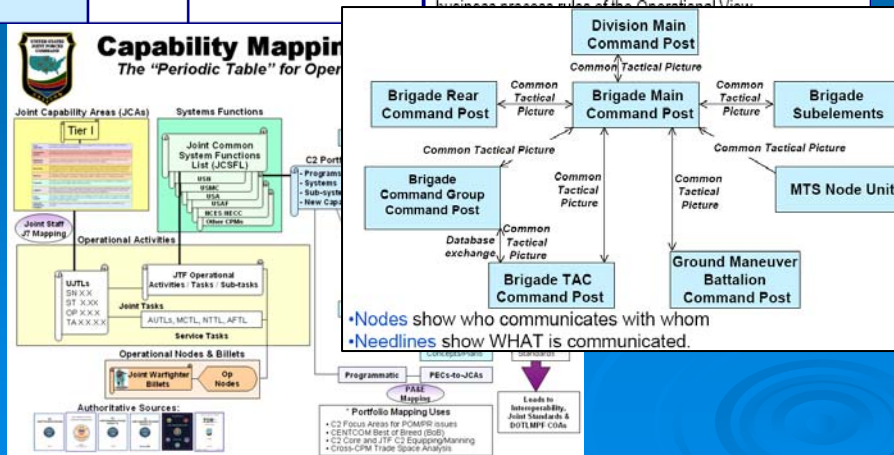


- Numerous C2-related COIs producing semantic products to facilitate data sharing for a specific mission
 - Maritime Domain Awareness
 - Time Sensitive Targeting
 - Joint Air and Missile Defense
 - Meteorology and Oceanography
 - Global Force Management
- Not domain ontologies, but share entities with and/or model part of the C2 domain
- May also serve as lower ontologies for C2 domain and provide “bottom-up” perspective

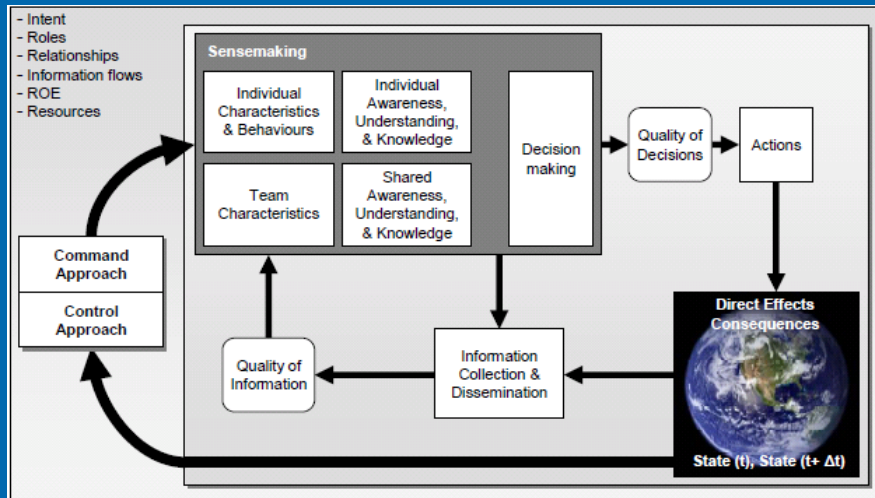
C2 Architecture Products

Applicable View	Framework Product	Framework Product Name	General Description
All Views	AV-1	Overview and Summary Information	Scope, purpose, intended users, environment depicted, analytical findings
All Views	AV-2	Integrated Dictionary	Architecture data repository with definitions of all terms used in all products
Operational	OV-1	High-Level Operational Concept Graphic	High-level graphical/textual description of operational concept
Operational	OV-2	Operational Node Connectivity Description	Operational nodes, connectivity, and information exchange needlines between nodes
Operational	OV-3	Operational Information Exchange Matrix	Information exchanged between nodes and the relevant attributes of that exchange
Operational	OV-4	Organizational Relationships Chart	Organizational, role, or other relationships among organizations
Operational	OV-5	Operational Activity Model	Capabilities, operational activities, relationships among activities, inputs, and outputs; overlays can show cost, performing nodes, or other pertinent information
Operational	OV-6a	Operational Rules Model	One of three products used to describe operational activity—identifies business rules that constrain operation
Operational	OV-6b	Operational State Transition Description	One of three products used to describe operational activity—identifies business process responses to events
Operational	OV-6c	Operational Event-Trace Description	One of three products used to describe operational activity—traces actions in a scenario or sequence of events
Operational	OV-7	Logical Data Model	Documentation of the system data requirements and structural business process rules of the Operational View

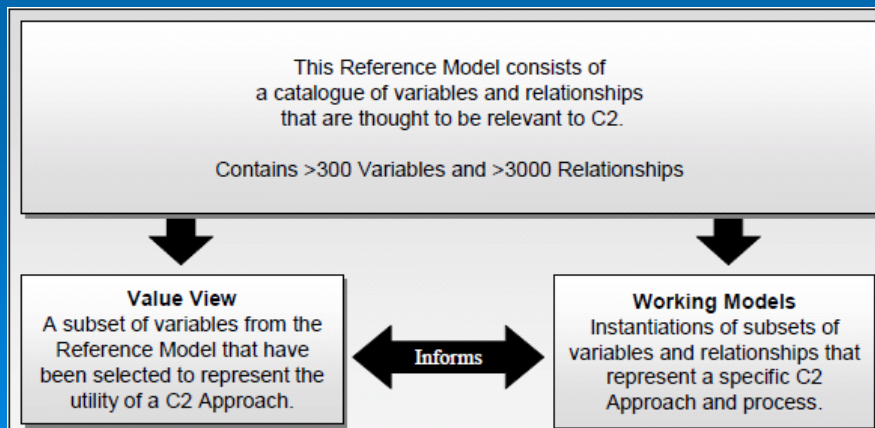
- U.S. DoD, NATO, and coalition partners have been developing C2 operational architectures for several years
- Architectural artifacts describe operational entities, relationships between them, information that is exchanged, and relevant processes. (Ontology-like)
- Large scale integrated architecture efforts such as the JFCOM JTF C2 architecture are akin to C2 domain models
- In the U.S., C2 architecture products have been mapped to JCA's and the UJTL



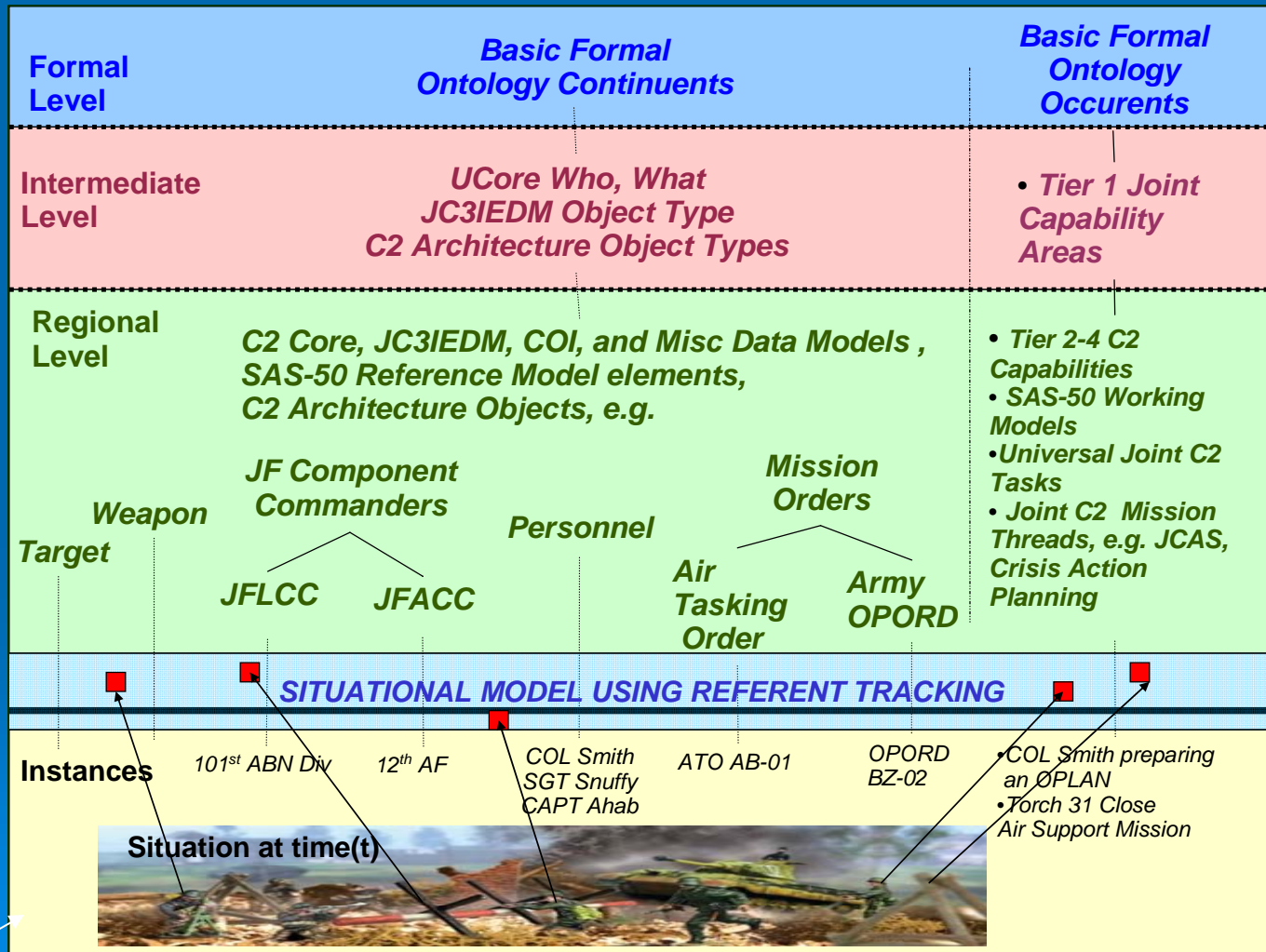
NATO C2 Conceptual Model (SAS-050 [56])



- Conceptual model of C2 intended to capture knowledge and serve as point of departure for further exploration
- Main components are Reference Model, Value View, Working C2 process models
- Generic process view of C2 not specific to any operational domain. (an intermediate ontology?)
- C2 Reference Model contains wealth of information regarding C2 entities and relationships
- Includes provision for human dimensions of C2



Ontological Layering of C2 Artifacts



Referent Tracking Concept Illustration from Cuesters [58]

Conclusions, Recommendations, and Challenges



Summary and Conclusion

- Ontology has been used successfully (for thousands of years) to capture and represent domain knowledge and facilitate practical understanding, reasoning, and information integration
- Based on successes in the biological and other domains, the authors conclude that development of a practical (but partial) C2 domain ontology is feasible in the near to mid term
- Efforts should follow the principles and best practices of the Applied Ontology community while reusing existing C2 modeling artifacts to the extent practical

Practical Recommendations for Realizing a C2 Domain Ontology

- Identify relevant and feasible applications that can be achieved in the near to mid term
- Establish a common approach to C2 ontology specification
- Adopt the realist perspective
- Leverage existing C2 ontology-like artifacts
- Include key stakeholders in an open process
- Foster C2 community Applied Ontology awareness and expertise

Long Term Challenges

- Scope, complexity, diversity, and unclear partitions and boundaries of C2
- Process-based nature and strong human element of C2
- Dependencies on other warfighting domains that do not have ontologies in place
- Time and resource requirements
- Constantly evolving nature of warfare

Questions?



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