

# 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]

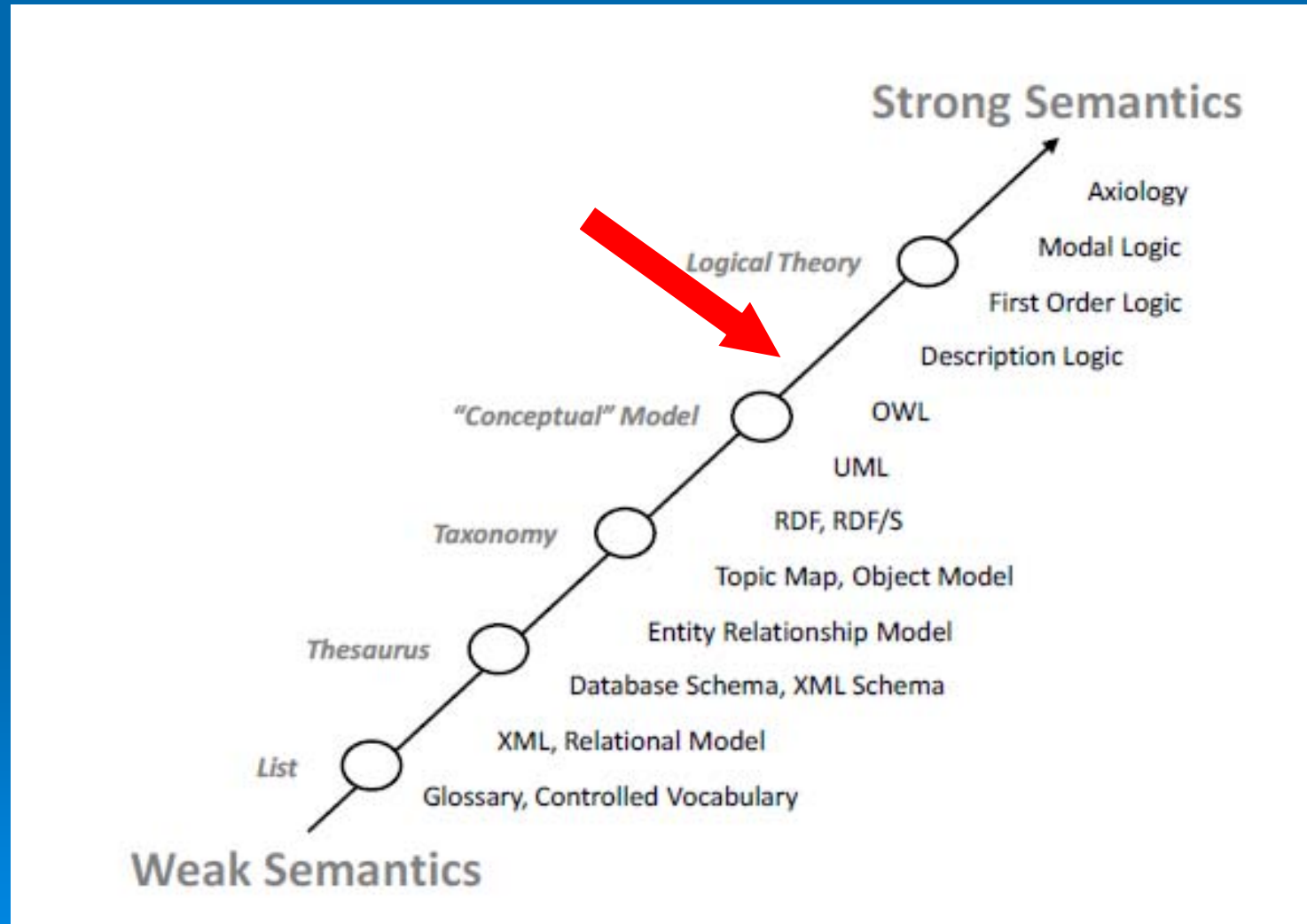
# C2 Domain Ontology Working Definition

- **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

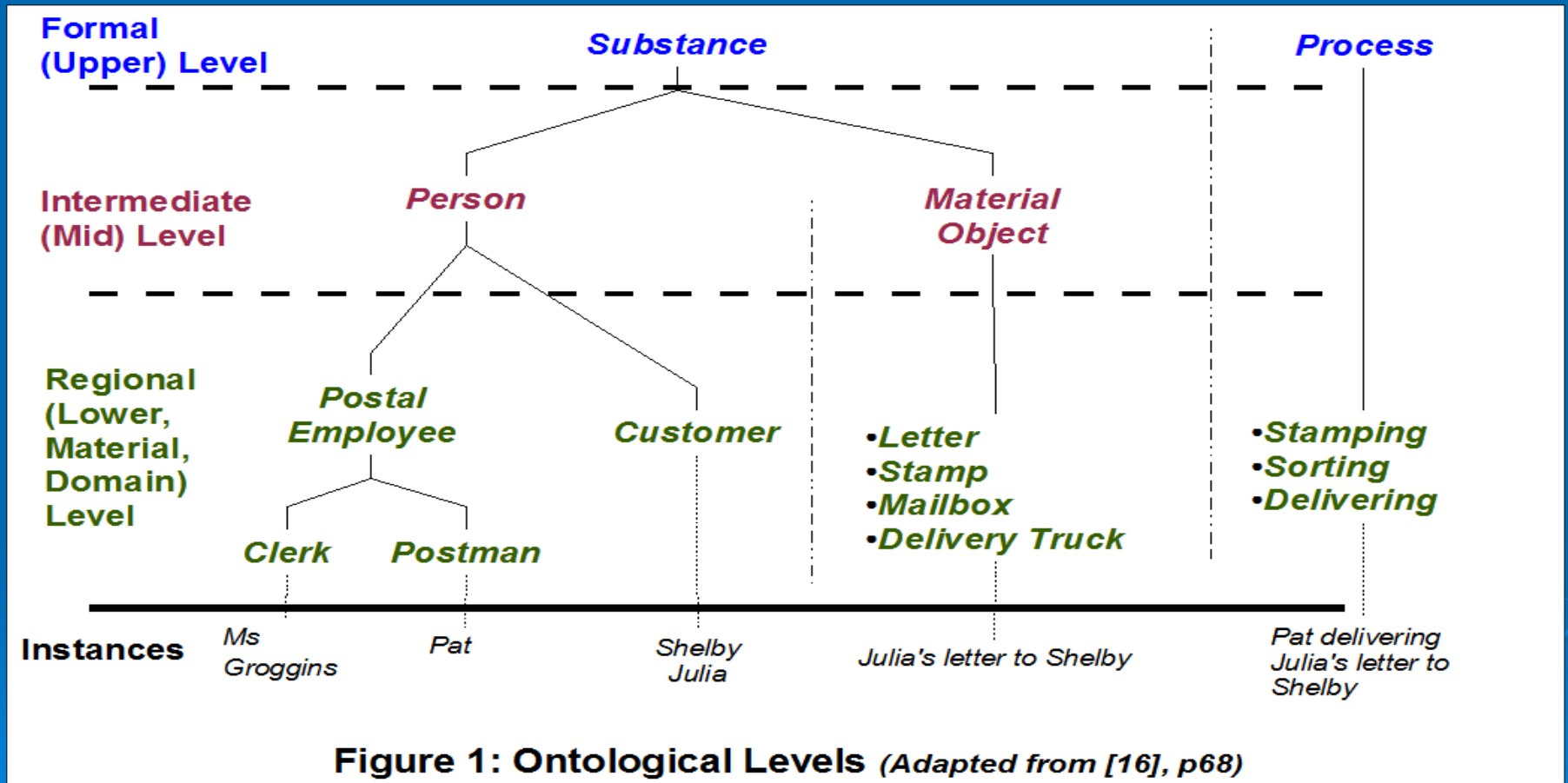


Figure 1: Ontological Levels (Adapted from [16], p68)

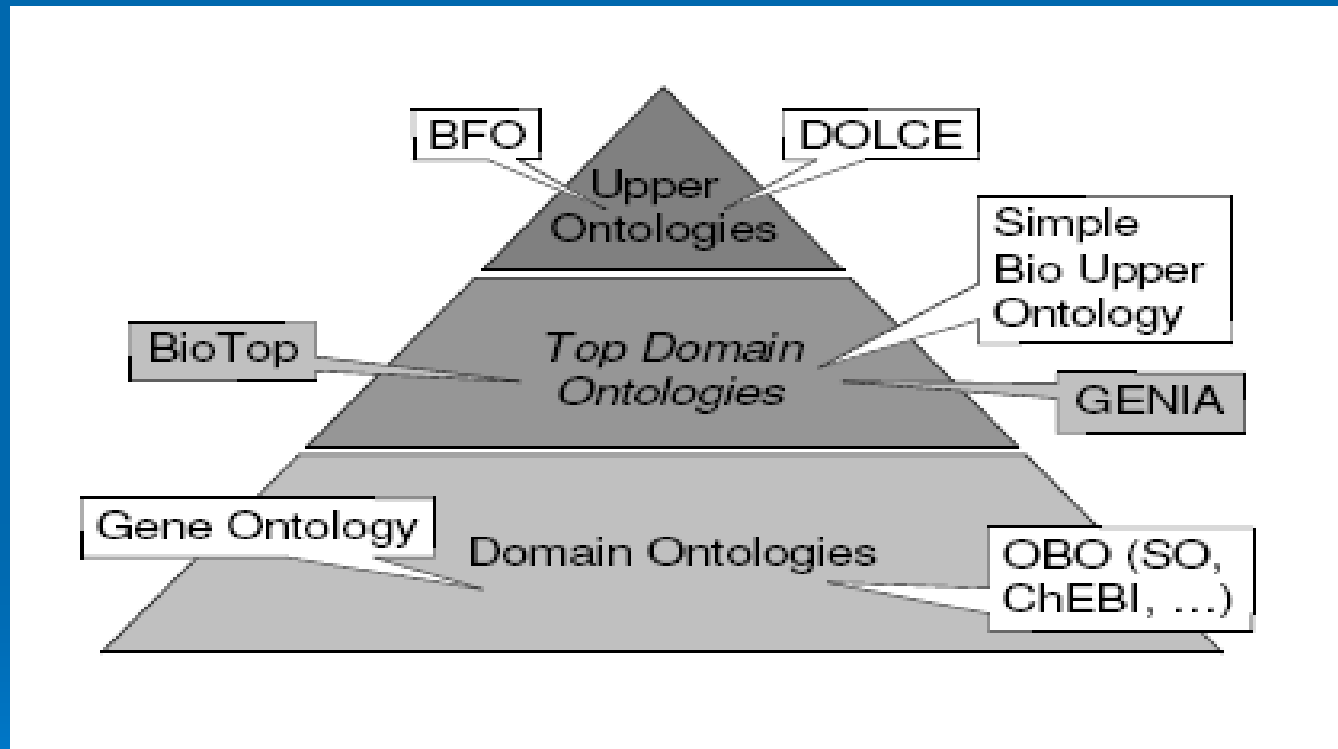
# Sample Upper Level or Formal Ontologies

- 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])*

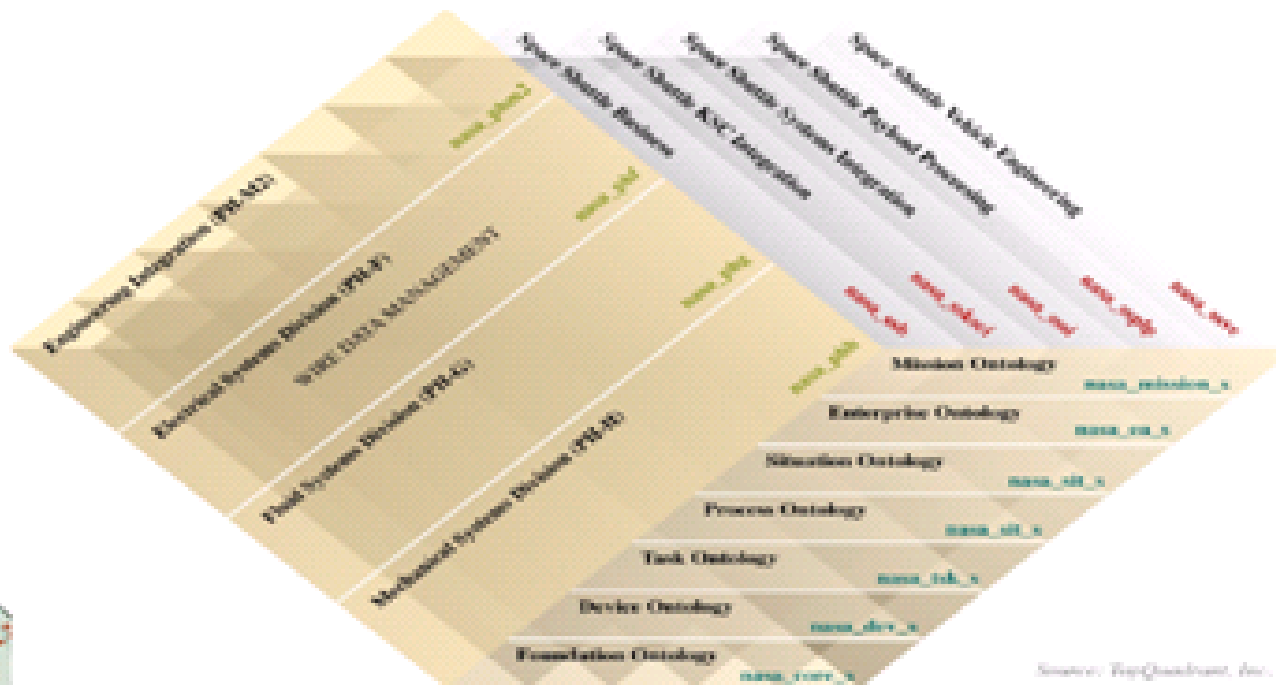
# NASA Domain Ontologies

- 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

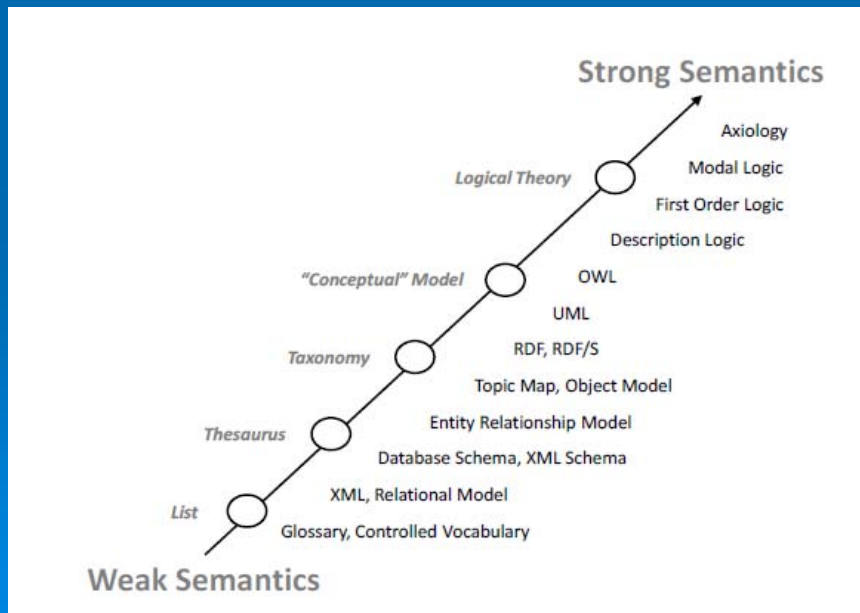
# Potential C2 Ontology Contributors

## 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:

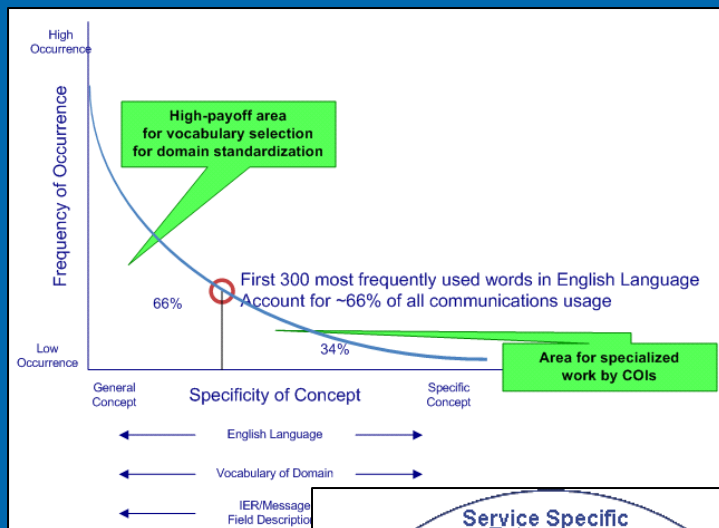
Organize  
Understand  
**Planning**  
Decide  
Direct  
Monitor

### **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

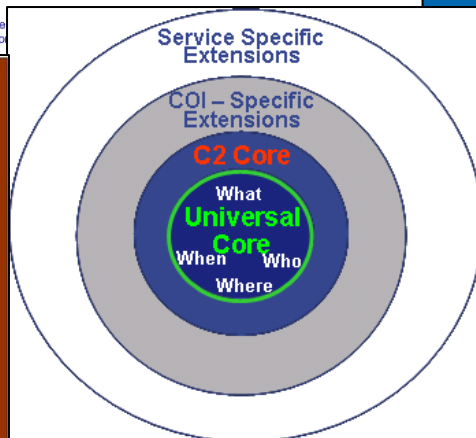
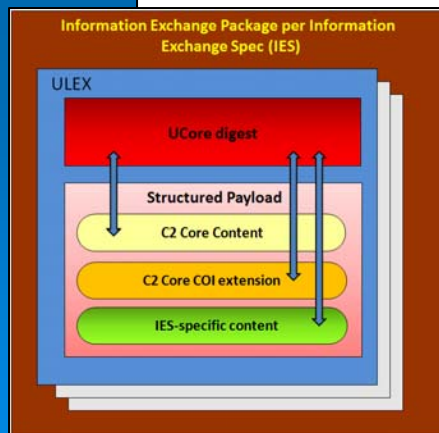


➤ Emerging U.S. DoD approach to facilitate understandable and interoperable C2 data sharing

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

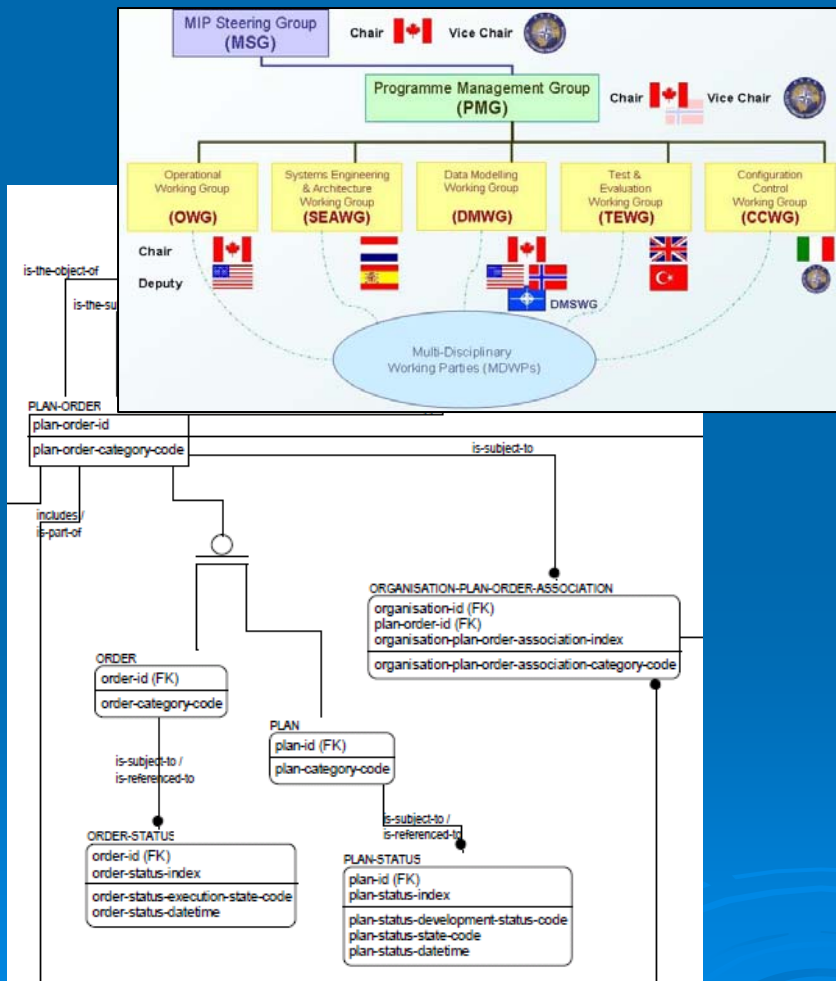
➤ Extended from the U.S. Universal Core [5][44], which may be considered an intermediate ontology-like construct

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



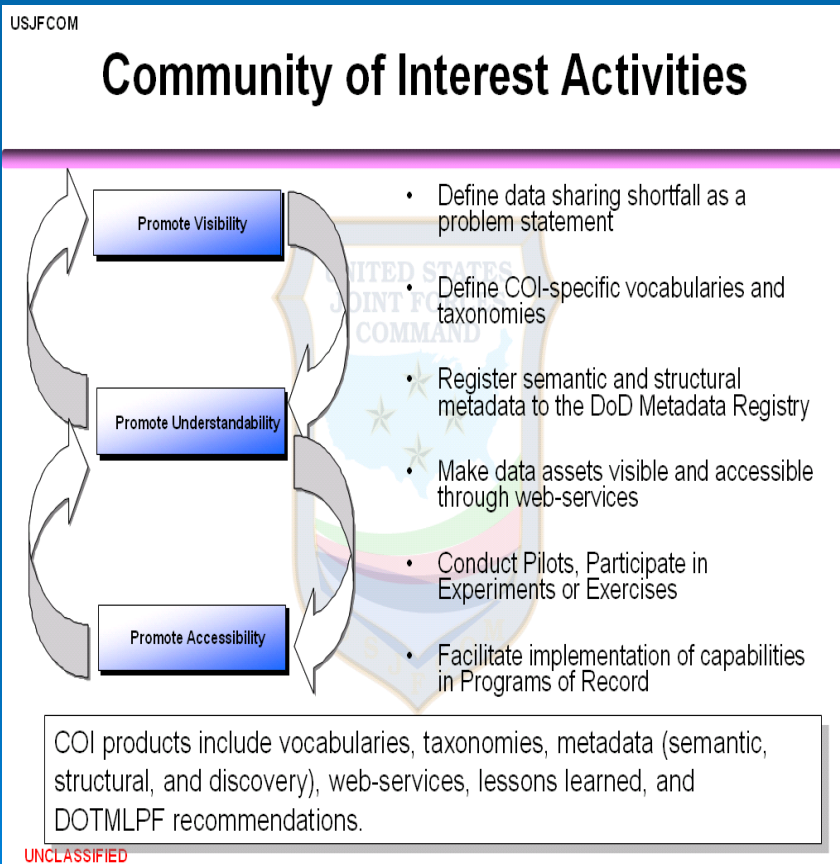


# Joint Consultation Command and Control Information Exchange Data Model (JC3IEDM)



- 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

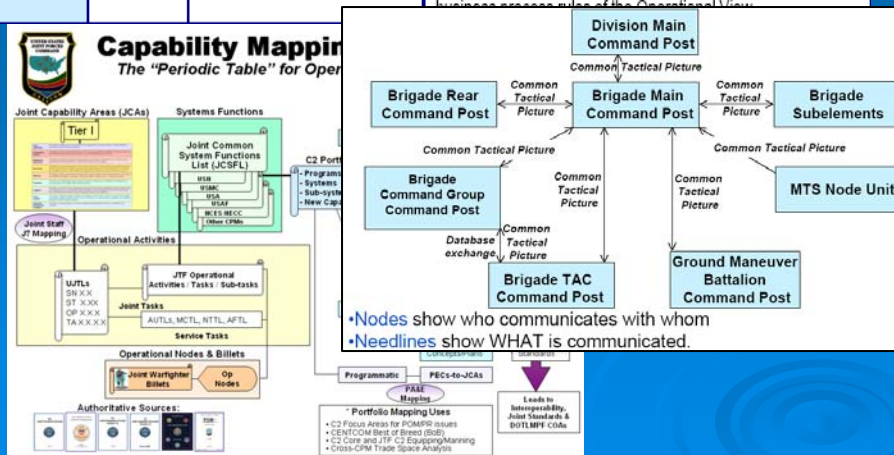


- Numerous C2-related COIs producing semantic products to facilitate data sharing for a specific mission
  - Maritime Domain Awareness
  - Time Sensitive Targeting
  - Joint Air and Missile Defense
  - Meteorology and Oceanography
  - Global Force Management
- Not domain ontologies, but share entities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

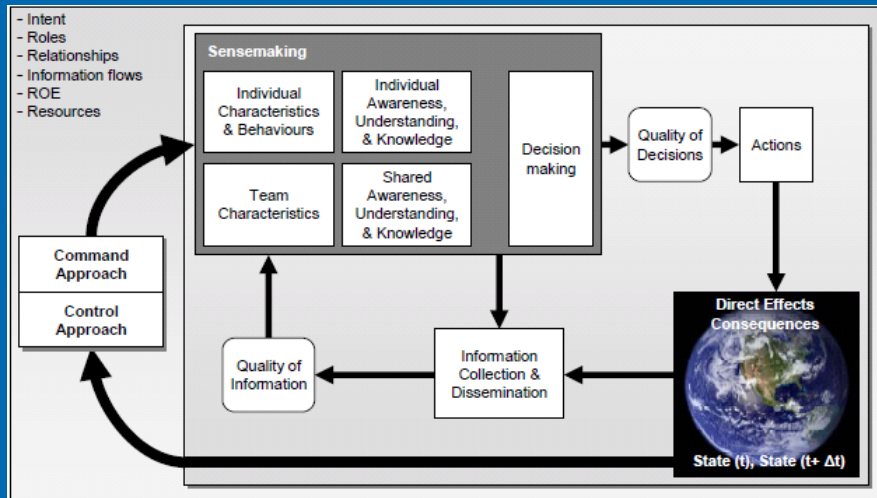
# C2 Architecture Products

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

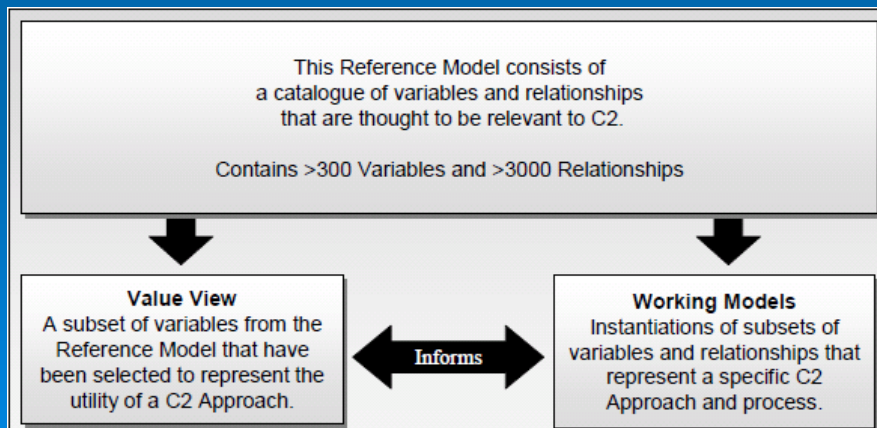
- U.S. DoD, NATO, and coalition partners have been developing C2 operational architectures for several years
- Architectural artifacts describe operational entities, relationships between them, information that is exchanged, and relevant processes. (Ontology-like)
- Large scale integrated architecture 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



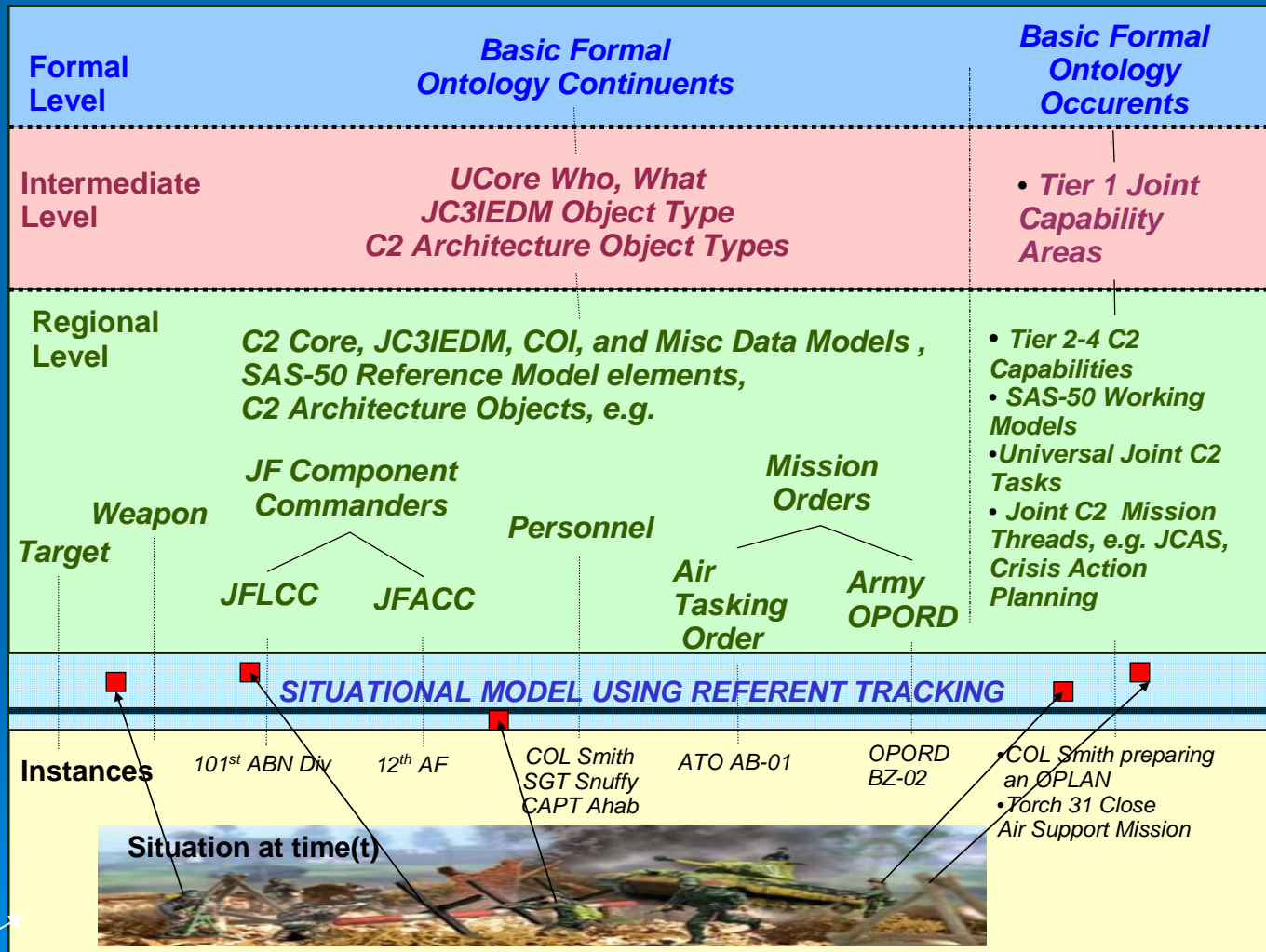
# NATO C2 Conceptual Model (SAS-050 [56])



- 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?



# References

- [1] U.S. Department of Defense Chief Information Office: *Department of Defense Net-Centric Data Strategy*, May 2003.
- [2] NATO C3 Board: *NATO Net-Enabled Capability Data Strategy*, 20 Dec 2005.
- [3] U.S. Department of Defense Chief Information Office: *Department of Defense Net-Centric Services Strategy: A Strategy for a Net-Centric, Service-Oriented Enterprise*, May 2007
- [4] United States Joint Forces Command: *Joint Operating Environment 2008, Challenges and Implications for the Future Joint Force*, 25 Nov 2008.
- [5] Meyerriecks, D., Davis, S., Pipher, J., Guthrie, P.: *Independent Assessment Team Report on C2 Data*, Institute for Defense Analyses, IDA Paper P-4404, Nov 2008.
- [6] Smith, B. Et al, *Towards a Reference Terminology for Ontology Research and Development in the Biomedical Domain*, KR-MED 2006 "Biomedical Ontology in Action", November 8, 2006, Baltimore, Maryland, USA
- [7] Merriam Webster Online Dictionary, <http://www.merriam-webster.com/dictionary/ontology>
- [8] Wikipedia, <http://en.wikipedia.org/wiki/Ontology>
- [9] Smith, B., and Klagges, B. : *Philosophy and Biomedical Information Systems*, Applied Ontology An Introduction, Chapter 1, pg 22., Transaction Books, Rutgers University, NJ, 2008.
- [10] Johansson, I., *Four Kinds of Is\_A Relations*, Applied Ontology An Introduction, pp 235-254, Transaction Books, Rutgers University, NJ, 2008.
- [11] Munn, L., Smith, B.: *Applied Ontology An Introduction*, Transaction Books, Rutgers University, NJ, 2008.
- [12] Wikipedia, [http://en.wikipedia.org/wiki/Ontology\\_\(information\\_science\)](http://en.wikipedia.org/wiki/Ontology_(information_science))
- [13] Gruber, T: *A Translation Approach to Portable Ontology Specifications*, Knowledge Acquisition, 1993
- [14] Deborah L. McGuinness and Frank van Harmelen, Editors,: [OWL Web Ontology Language Overview](#), W3C Recommendation, 10 February 2004.
- [15] Smith, B., *A Realist Logic with Applications*, Applied Ontology An Introduction, pp 109-124, Transaction Books, Rutgers University, NJ, 2008.

# References

- [16] Grenon, P., *A Primer on Knowledge Management and Ontological Engineering*, Applied Ontology An Introduction, pp 57-82, Transaction Books, Rutgers University, NJ, 2008.
- [17] C2 Ontology Technical Exchange, 15-16 Feb 2009, Buffalo NY
- [18] SWRL semantic rule web language combining OWL and RuleML  
<http://www.w3.org/Submission/SWRL/>
- [19] U.S. DoD Metadata Registry, <https://metadata.dod.mil/mdr/homepage.html>
- [20] Bittner, T., Smith, B., *A Theory of Granular Partitions*, Applied Ontology An Introduction, pp 125-158, Transaction Books, Rutgers University, NJ, 2008.
- [21] Johnson, W., *Logic:Part I*, Cambridge: Cambridge University Press. 1921.
- [22] Hennig, B., *What is Formal Ontology*, Applied Ontology An Introduction, pp 39-56, Transaction Books, Rutgers University, NJ, 2008.
- [23] Husserl, E., *Ideas: General Introduction to Pure Phenomenology*. (W.R. Gibson, Trans.) London. Collier-Macmillan. 1931.
- [24] Basic Formal Ontology (multiple references and artifacts): <http://www.ifomis.org/bfo/BFO>
- [25] Masolo, C., et al: *The WonderWeb Library of Foundational Ontologies Preliminary Report*, WonderWeb Deliverable D17, ISTC-CNR, May 2003.
- [26] Suggested Upper Merged Ontology (SUMO) portal: <http://www.ontologyportal.org/SUO>
- [27] Descriptive Ontology for Linguistics and Cognitive Engineering (DOLCE) portal:  
<http://www.loa-cnr.it/DOLCE.html>;
- [28] The Gene Ontology Consortium. "Gene Ontology: tool for the unification of biology". *Nature Genetics* **25**: 25–29, 2000. Also, <http://www.geneontology.org/>
- [29] Bodenreider, Olivier. The Unified Medical Language System (UMLS): integrating biomedical terminology. *Nucleic Acids Research*, 32, D267-D270. 2004.
- [30] Open Biomedical Ontologies (OBO) Foundation candidate ontologies:  
<http://www.obofoundry.org/>

# References

- [31] Hodgson, R., NASA NexIOM Ontologies, Briefing at the C2 Ontology Technical Exchange, National Center for Ontological Research (NCOR), Buffalo, NY, USA, January 15-16, 2009
- [32] SchemaWeb (online directory of RDF schemata expressed in RDFS, OWL and DAML+OIL): <http://www.schemaweb.info/eb>
- [33] OntoSelect, <http://olp.dfki.de/OntoSelect/>
- [34] Smith, B., Klagges, B., *Bioinformatics and Philosophy*, Applied Ontology An Introduction, pp21-38, Transaction Books, Rutgers University, NJ, 2008.
- [35] Jansen, L., *Classifications*, Applied Ontology An Introduction, pp 159-172, Transaction Books, Rutgers University, NJ, 2008.
- [36] Schwarz, U., Smith, B., *Ontological Relations*, Applied Ontology An Introduction, pp 219-234, Transaction Books, Rutgers University, NJ, 2008.
- [37] Stenzhorn, H. et al, *Towards a Top-Domain Ontology for Linking Biomedical Ontologies*, Studies in health technology and informatics, 2007.
- [38-40] Deleted.
- [41] Joint Chiefs Staff J7 Joint Capability Areas portal: [http://www.dtic.mil/futurejointwarfare/cap\\_areas.htm](http://www.dtic.mil/futurejointwarfare/cap_areas.htm)
- [42] CJCSM 3170.01 Series, "Operations of the Joint Capabilities Integrated Development System", May 2007.
- [43] CJCSM 3500.04E, *Universal Joint Task Manual*, 25 Aug 2008.
- [44] Universal Core (Ucore) portal: <https://collab.core.gov/CommunityBrowser.aspx?id=18954&lang=en-US>
- [45] *Military Domains: An Evaluation*. MITRE Technical Report 04B000006, Sep 2004. [45] Semi, S., Pulvermacher, M., Obrst, L. : *Toward the Use of an Upper Ontology for U.S. Government and U.S.*
- [46] Joint Consultation Command and Control Information Exchange Data Model (JC3IEDM) specification, [http://www.mip-site.org/publicsite/04-Baseline\\_3.0/JC3IEDM-Joint\\_C3\\_Information\\_Exchange\\_Data\\_Model/](http://www.mip-site.org/publicsite/04-Baseline_3.0/JC3IEDM-Joint_C3_Information_Exchange_Data_Model/)
- [47] NATO Open Systems Working Group: NATO C3 Technical Architecture Volumes 1-5, Version 7.0, 15 December 2005.
- [48] Dorion, e. Et al.: *Towards a Formal Ontology for Military Coalition Operations*, 10th International Command and Control Research and Technology Symposium, June 2005.

# References

- [49] Matheus, C., Olicny, B.: *On the Automatic Generation of an OWL Ontology Based on the Joint C3 Information Exchange Data Model*, 12th International Command and Control Research and Technology Symposium, June 2007.
- [50] Turnitsa, C. and Tolk, A.. 2005. *Evaluation of the C2IEDM as an Interoperability-Enabling Ontology*, Proceedings of the European Simulation Interoperability Workshop, Toulouse, France, 2005.
- [51] Wartik, S. : *A JC3IEDM OWL-DL Ontology*, Briefing at the C2 Ontology Technical Exchange, National Center for Ontological Research (NCOR), Buffalo, NY, USA, January 15-16, 2009.
- [52] Office of the Assistant Secretary of Defense for Networks and Information Integration/Department of Defense Chief Information Officer, *Guidance for Implementing Net-Centric Data Sharing*, DoD Directive 8320.02b, April 2006.
- [53] Department of Defense Architecture Framework Working Group, Office of the Assistance Secretary of Defense (Networks and Information Integration): DoD Architectural Framework Version 1.0, 9 Feb 2004.
- [54] NATO NC3 Board: NATO Architecture Framework (NAF) Ver 3, AC/322(SC/1-WG/1)N(2007)004, 28 Jun 2007.
- [55] U.S. Joint Forces Command, *Joint Common Systems Functions List*, <https://www.us.army.mil/suite/page/419489>, Sep 2008.
- [56] NATO Research and Technology Organization, *Exploring New Command and Control Concepts and Capabilities*, TR-SAS-050, April 2007.
- [57] Ceusters, W.: *Use of Ontologies in a World in Flux*, Briefing at the C2 Ontology Technical Exchange, National Center for Ontological Research (NCOR), Buffalo, NY, USA, January 15-16, 2009
- [58] Ceusters, W., Smith, B.: *Tracking Referents in Electronic Health Records*, Journal of Biomedical Informatics, Volume 39 Issue 3, pp 362-378, June 2006.
- [59] Chairman of the Joint Chiefs of Staff, U.S. Department of Defense: "Joint Publication 1-02, DoD Dictionary of Military and Associated Terms", as amended through 17 OCT 2008. Also, <http://www.dtic.mil/doctrine/jel/doddict>
- [60] Joint Electronic Library, <http://www.dtic.mil/doctrine/>