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Boeing Technology
Phantom Works

Ontologies Ontologies Everywhere – but Who Knows What to Think?

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About this Talk

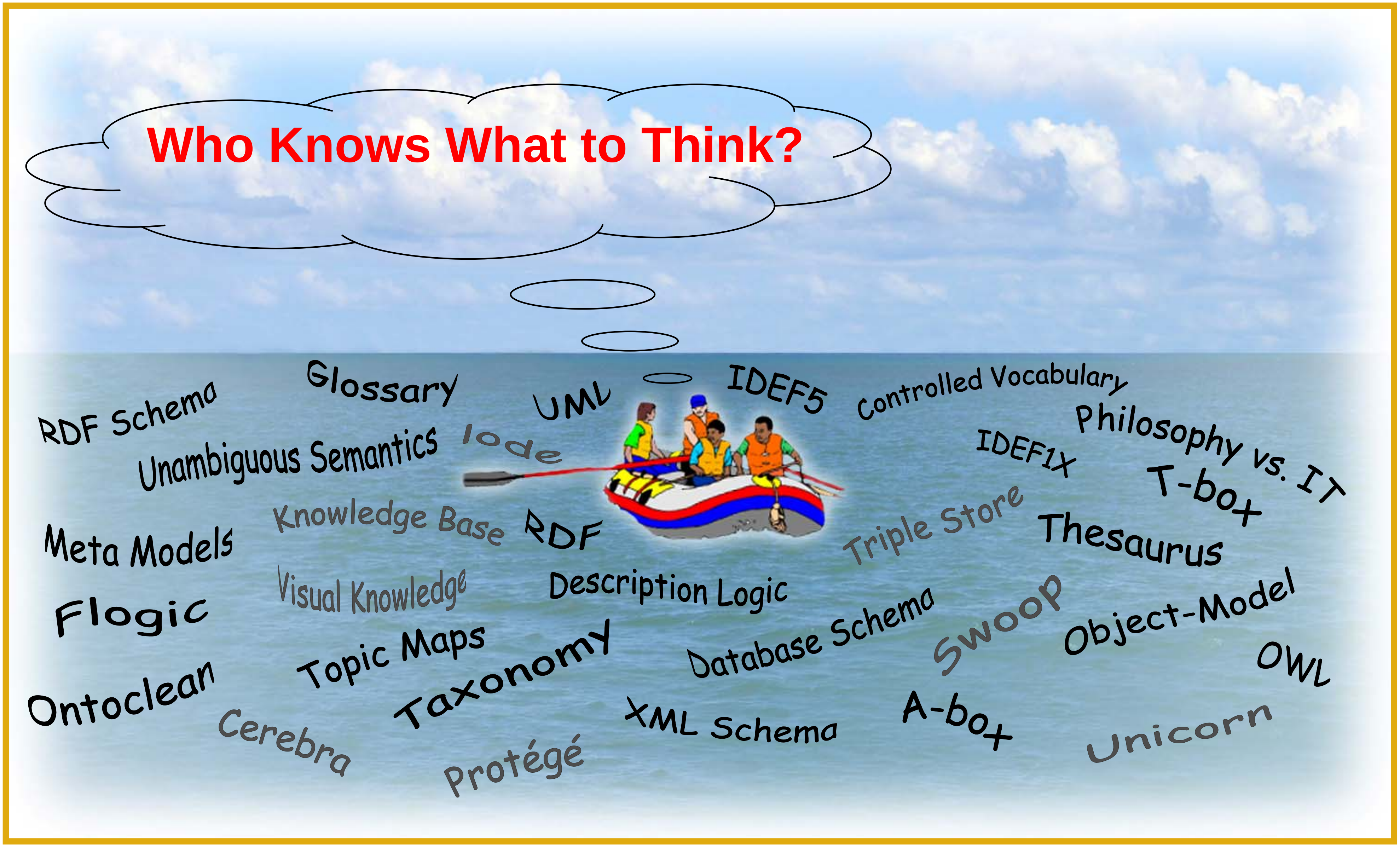
What it is NOT:

- **Overview of Ontology & Protégé Activities at Boeing**
- **A Detailed Look at a Particular Project or Approach**
- **Strongly focused on Protégé, *per se***

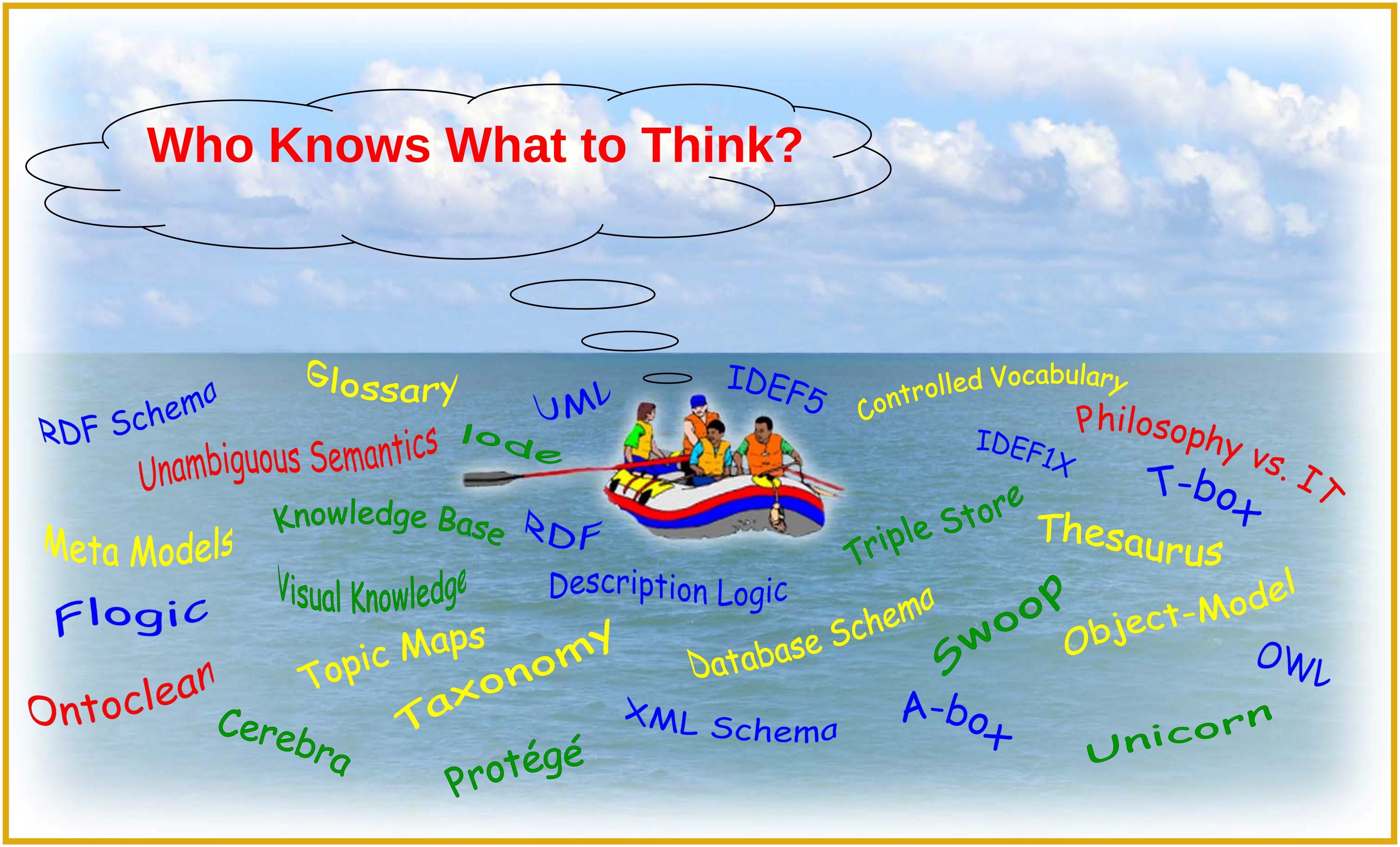
GOALS:

- **To quench a thirst for understanding 'ontologies'**
- **To cover interesting and fun ontology-related topics**
- **Stimulate thinking about key issues**
- **Something for everyone (including a short nap?)**

Ontologies Ontologies Everywhere, but…



Ontologies Ontologies Everywhere, but…



Three Questions

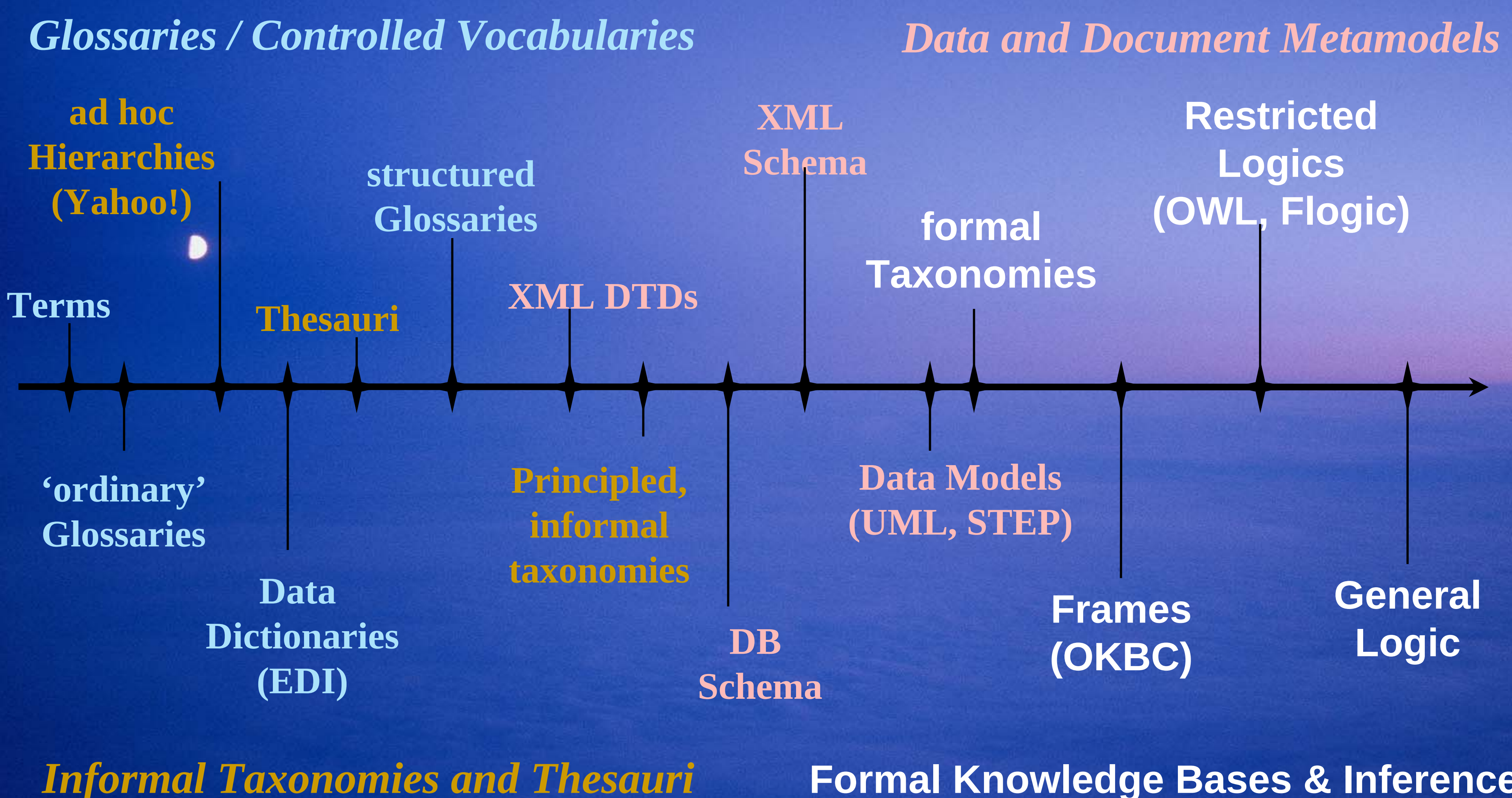
1. **What is the difference between an Ontology and a:**
   Taxonomy? XML/DB Schema? Thesaurus? UML Model?
   Ontology – as a branch of philosophy?

2. **When people say things like:**
   "Ontologies Have Unambiguous Semantics"
   - *What do you think they mean?*
   - *Do you believe them?*
   - *Why or Why not?*

3. **Are Natural Language Comments important for Ontology Engineering?**
   - *Why or Why not?*
   - *Is there a way to leverage natural language semantics?*

Questions to the AUDIENCE!

A Plethora of 'Ontology-Like Things'



Many Different Ways of Expressing Meaning

Common Threads among 'Ontology-Like Things'

- **These terms reflect ill-defined notions that are used in many different ways by many different communities.**
  Meta-Model, Schema, Ontology, Glossary, Taxonomy, Thesaurus, Controlled Vocabulary, Data Dictionary, Data Model, Object Model, etc

- **A way for a community to agree on common terms for capturing meaning or representing knowledge in some domain.**

- **All have been called 'ontologies'**

Differences

- **What notation or language is used to specify the meaning?**
- **How is meaning specified?**
- **What is the purpose for representing information about a given domain?**

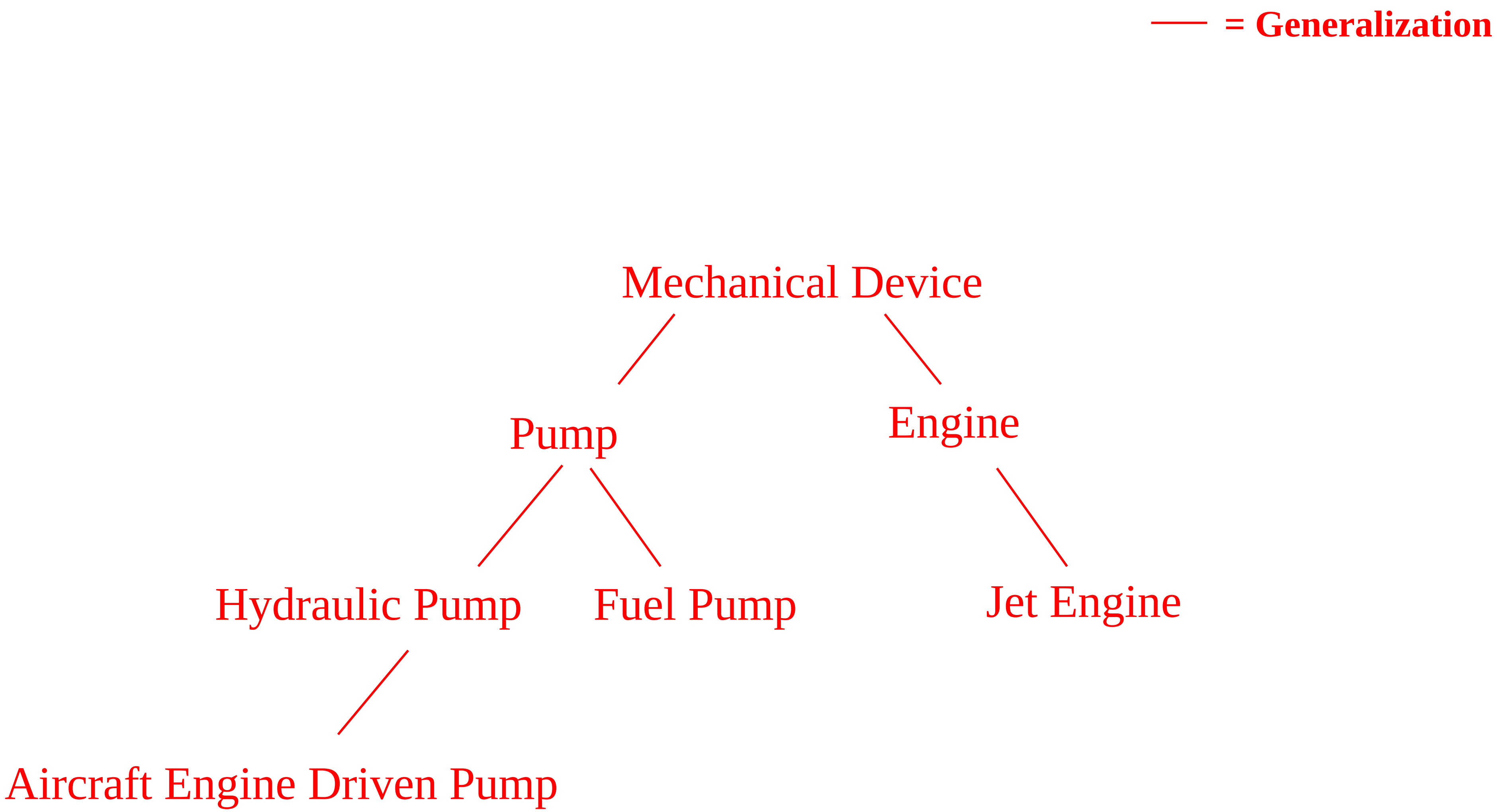
Example: Controlled Vocabulary / Glossary

Pump: "A mechanical device for raising, compressing, or transferring fluids"

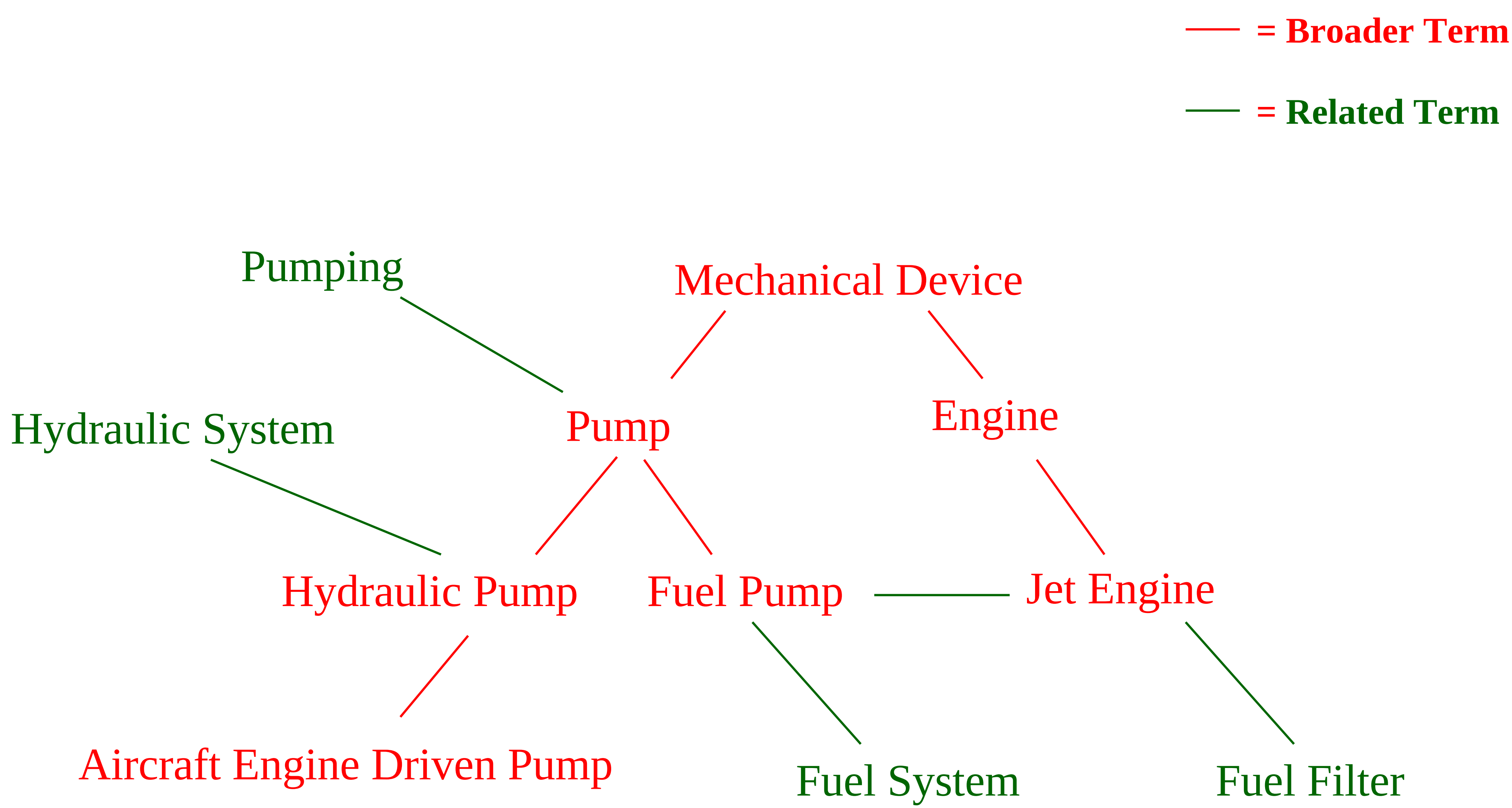
Engine: "a machine that turns energy into mechanical motion"

Mechanical Device: "a physical device with parts that move relative to each other"

Example: Taxonomy

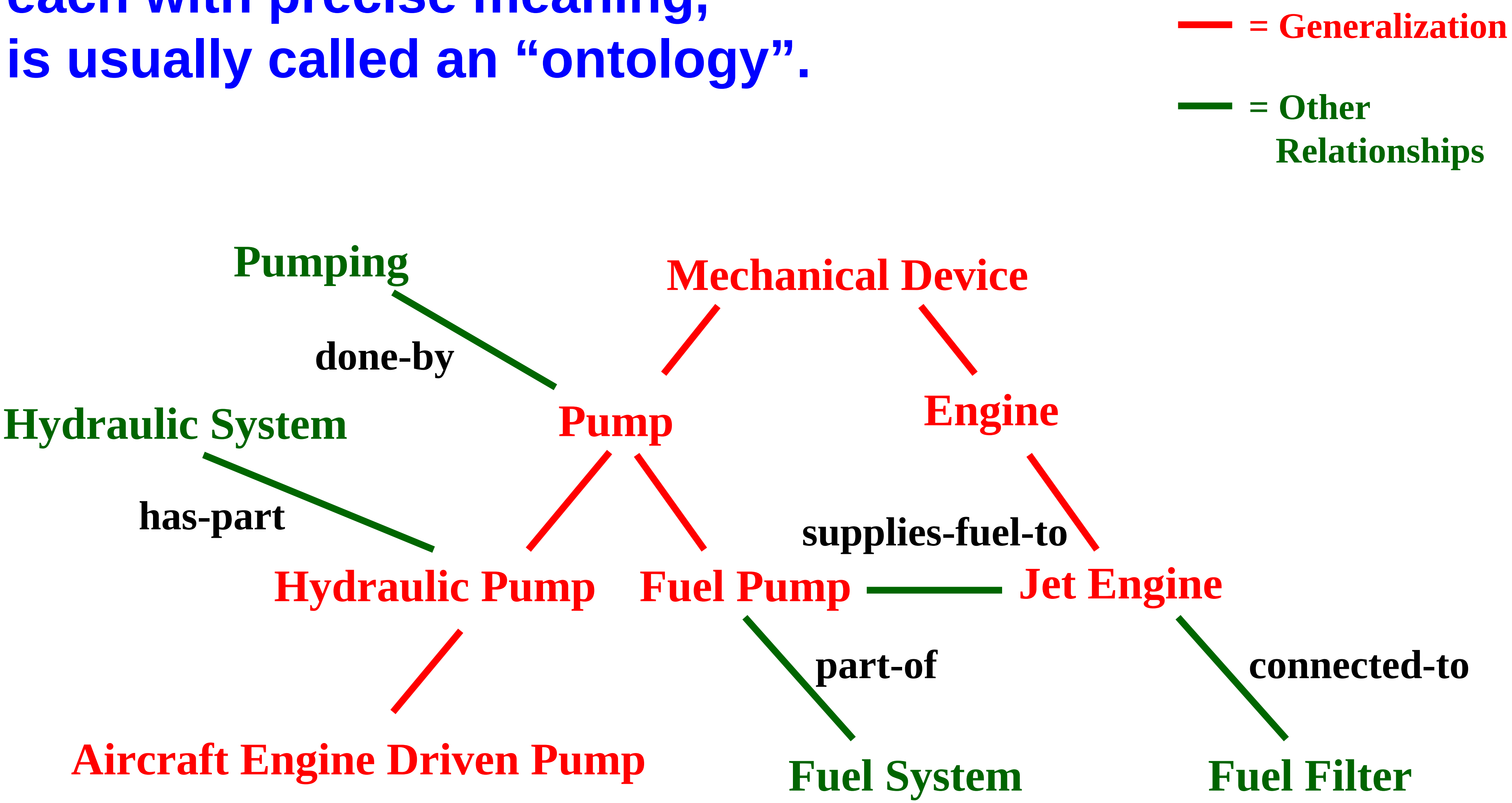


Example: Thesaurus

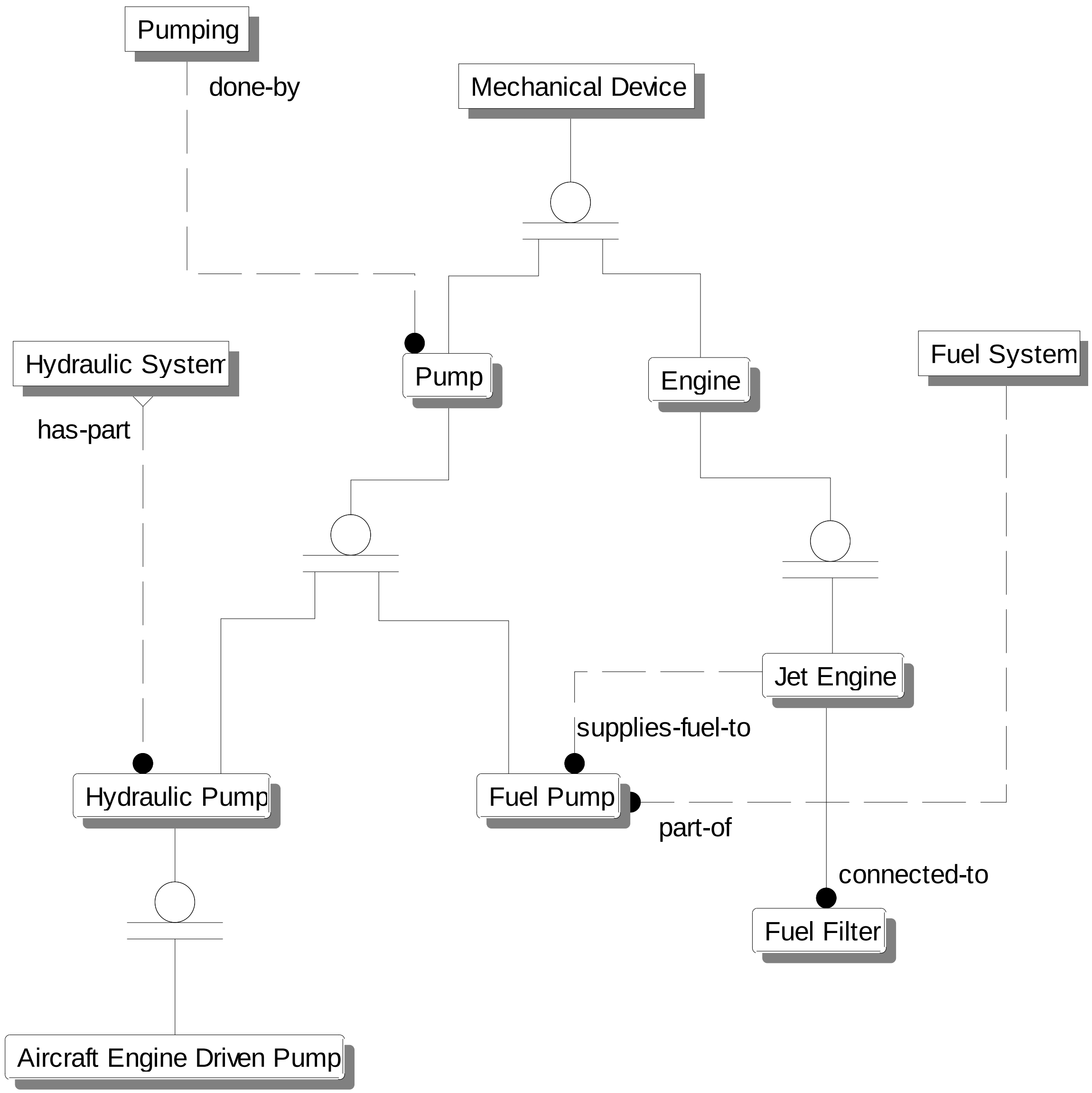


Ontology: Strict Taxonomy + Formal Relationships

- **Taxonomy with multiple link types, each with precise meaning, is usually called an "ontology".**



Logical Model: IDEF1X Notation

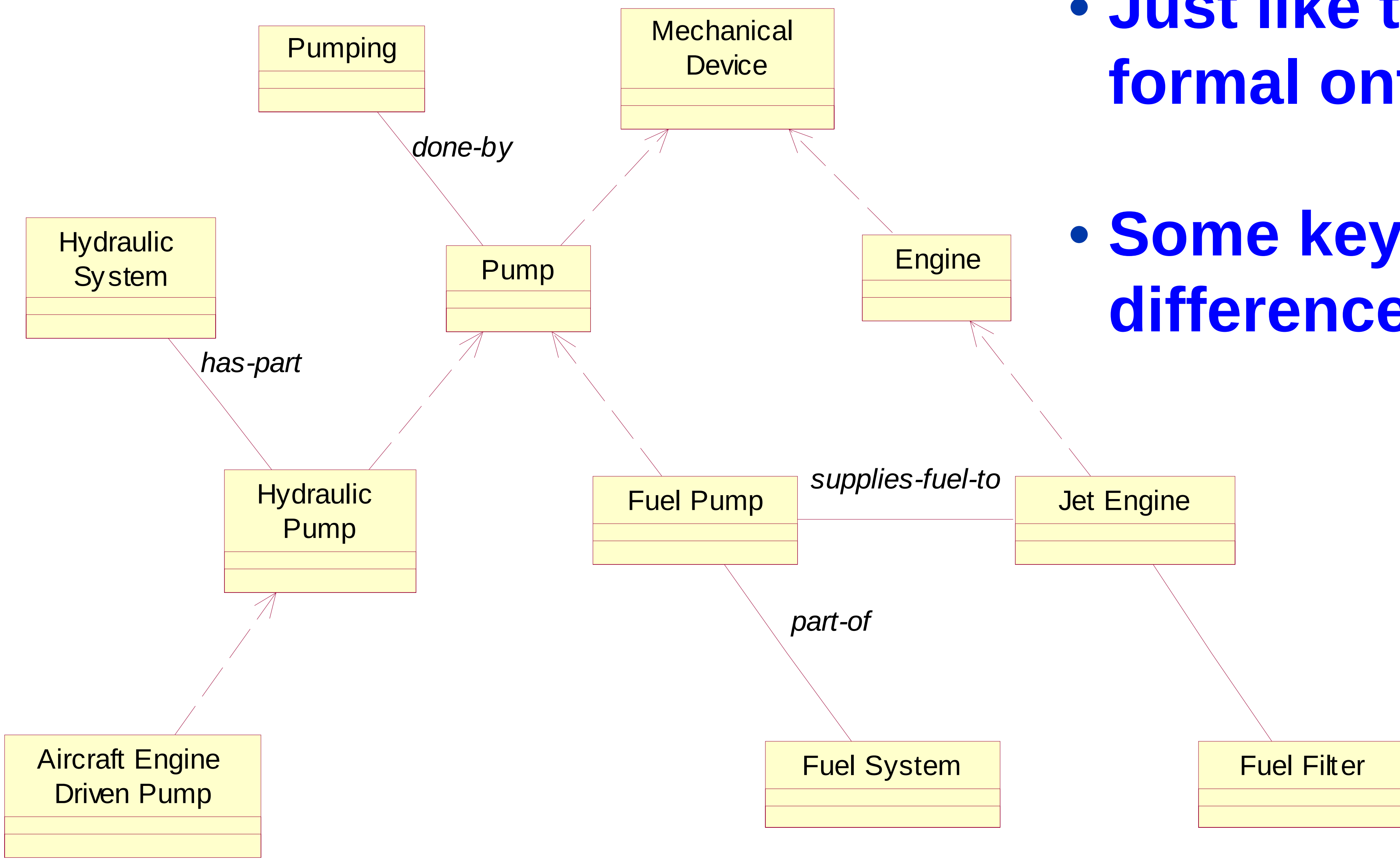


- **Just like the formal ontology**
- **Some key differences**

Database Schema vs. Ontologies

Database Schema	Ontologies
Focus on DATA	**FOCUS on Meaning**
DB Constraints • to ensure integrity • may hint at meaning	**Ontology Axioms** • to specify meaning • maybe for integrity
No ISA hierarchy	**ISA Hierarchy is Backbone**
SQL Engines • querying, views • data integrity	**Theorem Provers** • infer new information • ensure consistency
Instances Central	**Instances Optional**
Data Dictionary • separate artifact	**'Comments'** • part of the ontology

UML Class Diagram



- **Just like the formal ontology**
- **Some key differences**

Object Models vs. Ontologies

Object Models

Increasingly Formal

Static & Less Flexible
- classes fixed
- instance of same one class forever

Attributes
- defined locally to a class
- no hierarchies

Class Hierarchy
- for structuring convenience & object creation

Ontologies

Rigorously Formal

Dynamic & Flexible
- change/edit classes at runtime
- membership of multiple classes changes over time

Relations / Properties
- independent of a specific class
- hierarchies

Class Hierarchy
- to support inference

Summary: Comparing Ontology-Like Things

	Ctld. Vocab	Taxonomy	Thesaurus	Ontology	Data Models	Object Models
Definition	Defined terms, controlled	Controlled vocab. in a hierarchy.	Controlled vocab. in a network.	*specification of a conceptualization*	Specification of DB structure	Specification of a software application domain
Notation	Free text, Definition structure varies.	Strict: tree Or: multi-parent	Broader/narrower (maybe taxonomy) Gnl. association;	Logics, Taxonomy as backbone + atts. & relations.	e.g. ER diagrams Entities & Relations	Hierarchy of classes, rel's attributes & methods
Meaning	Nrl lang def's Dictionary; common usage	Nrl lang def's + meaning of link Strictness & Precision varies. Isa, partOf, similarTo …	Nrl lang def's + meaning of links. B/N: various mng's Gnl Assoc'n: no specific meaning	Logics w/ fml. semantics. Isa hierarchy; Dom/Range constraints; cardinality. Nrl. language comments in the ontology.	Precise, not logic-based. Focus on data, not meaning (e.g. toss rel'n names). Data dictionary separate.	Increasingly formal. Isa hierarchy, Aggregation / Composition, Dom/Range constraints; cardinality.
Purpose	Human communi-cation (HC)	HC + Structure info. base; browsing	HC + Structure digital libraries; indexing, browsing & search	Union of all the others & more.	HC + Structure (and validate) databases.	HC + Structure software systems.

Ontology: Philosophy vs. Information Technology

Similarities:

- **Both require careful study/analysis of what exists i.e., conceptual modeling**
  - **Objects:** concrete/abstract, real/ideal, [in]dependent
  - **Relationships:** dependencies, properties
- **Both document the output of the study/analysis:**
  - **in 'natural language'**
  - **as a logical theory**
  - **for sharing and reuse in a larger community.**

Ontology: Philosophy vs. Information Technology

Similarities:

- **Both use natural language as a source of knowledge to reveal the objects and relationships of interest.**

- **Both use formal logic as a key analytical tool.**

Differences: Purpose

- **Ph: The end: an understanding of the world**
  Why: *"because its there"*

- **IT: The beginning: an understanding of the world**
  The middle: a machine-sensible model
  The end: a software application that does something useful

  Why: because it helps the bottom line

  Range of specific purposes …

Ontology: Philosophy vs. Information Technology

More Differences:

- **Ph: Grammatically, not countable vs.**
  IT: Can have one or more 'ontologies';

- **Ph: Subject area extremely general vs.**
  IT: Focused on a specific domain (usually);

- **Ph: Main focus is on what is, ultimate truth vs.**
  IT: What is useful or important in a specific context;

- **Ph: Source of knowledge is the world itself vs.**
  IT: experts, books, etc in a given field of study.

More Differences: Output of the study/analysis

- **Ph: Natural language output is a formal academic paper vs.**
  IT: may be a paper, or may just be informal documentation;

- **Ph: Computational output, None (historically) vs.**
  IT: Machine-sensible model to support computer processing
  - **browsing and search**
  - **automated reasoning and inference .**

Varying degrees of formality

Three Questions

1. **What is the difference between an Ontology and a:**
   Taxonomy? XML/DB Schema? Thesaurus? UML Model?
   Ontology, as a branch of philosophy?

2. **When people say things like:**
   "Ontologies Unambiguously Represent Knowledge"
   - *What do you think they mean?*
   - *Do you believe them?*
   - *Why or Why not?*

3. **Are Natural Language Comments important for Ontology Engineering?**
   - *Why or Why not?*
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"Unambiguous Semantics"

- "The benefit of ontologies is the rich, and unambiguous, semantics they define.
  Folktologies: Beyond the Folksonomy vs.. Ontology Distinction

- Unambiguous semantics allow question answerers to infer that objects are the same, objects are related, objects have certain restrictions, …
  SWANS: Substance of the Semantic Web

- "OWL-S is a … core set of markup language constructs for describing the properties and capabilities of … Web services in unambiguous, computer-interpretable form."
  OWL-S 1.1 Release

- Ontologies can provide [a] way of explicitly specifying the semantics for each terminology in an unambiguous fashion.
  Ontology and Semantic Interoperability

Example: Semantics and Ambiguity

Using the following different languages/notations, express the meaning of the terms: pump; fuel pump & has part

- **a glossary or controlled vocabulary**
- **a taxonomy**
- **a thesaurus**
- **UML**
- **OWL**

What can we say about which alternatives are more or less "semantically unambiguous"? Why?

Meaning and Ambiguity

We've see most of this already, except for OWL.

```
Pump  a owl:Class ;
      rdfs:subClassOf uo:PhysObj.
      rdfs:subClassOf [a owl:Restriction;
                       owl:onProperty hasPart;
                       owl:someValuesFrom Piston].

FuelPump a owl:Class;
         rdfs:subClassOf Pump.


hasPart a owl:TransitiveProperty, owl:ObjectProperty;
        rdfs:domain uo:PhysObj;
        rdfs:range  uo:PhysObj.
```

What do we Know from this Simple Ontology?

From the formal semantics of OWL, we know that:

- **Every Fuel Pump is also a Pump.**
  IF FuelPump(?X) **THEN** Pump(?X).

- **Every Pump has at least one Piston as a Part.**
  IF Pump(?X)
  THEN PhysObj(?X) &
  (Exists ?P) Piston(?X) & hasPart(?X,?P).

- **The hasPart relationship is transitive**
  IF hasPart(?X,?Y) & hasPart(?Y,?Z)
  THEN hasPart(?X,?Z).

What do we Know from this Simple Ontology?

From the formal semantics of OWL, we know that:

- **Both instances in any hasPart relation are Physical Objects**

```
IF hasPart(?X,?Y)
THEN PhysObj(?X) & PhysObj(Y).
```

Ooops...

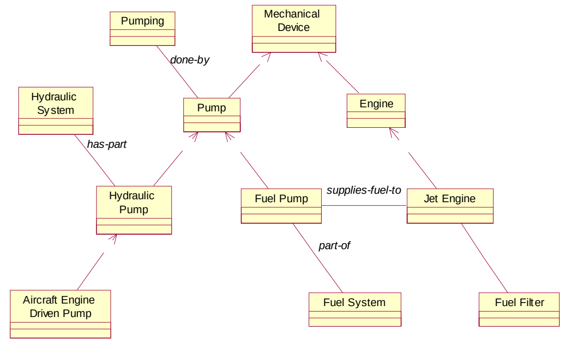
For Example

```
IF hasPart(university_of_edinburgh,
           ai_department)
THEN PhysObj(ai_department) &
     PhysObj(university_of_edinburgh).
```

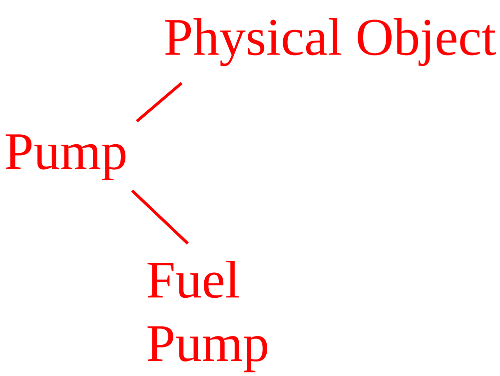
- Some additional things about 'PhysObj' from the UO ontology.
- Little else….

Which are More/Less "Semantically Ambiguous?

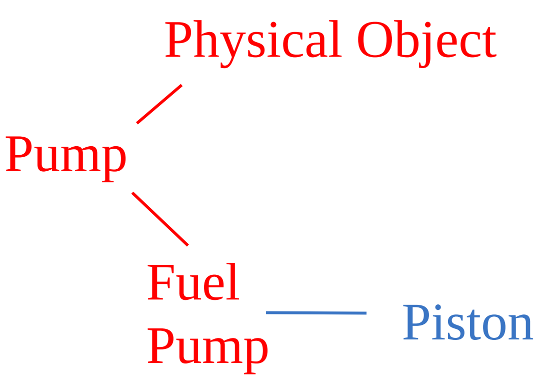
Controlled Vocabulary: A mechanical device for raising, compressing, or transferring fluids.



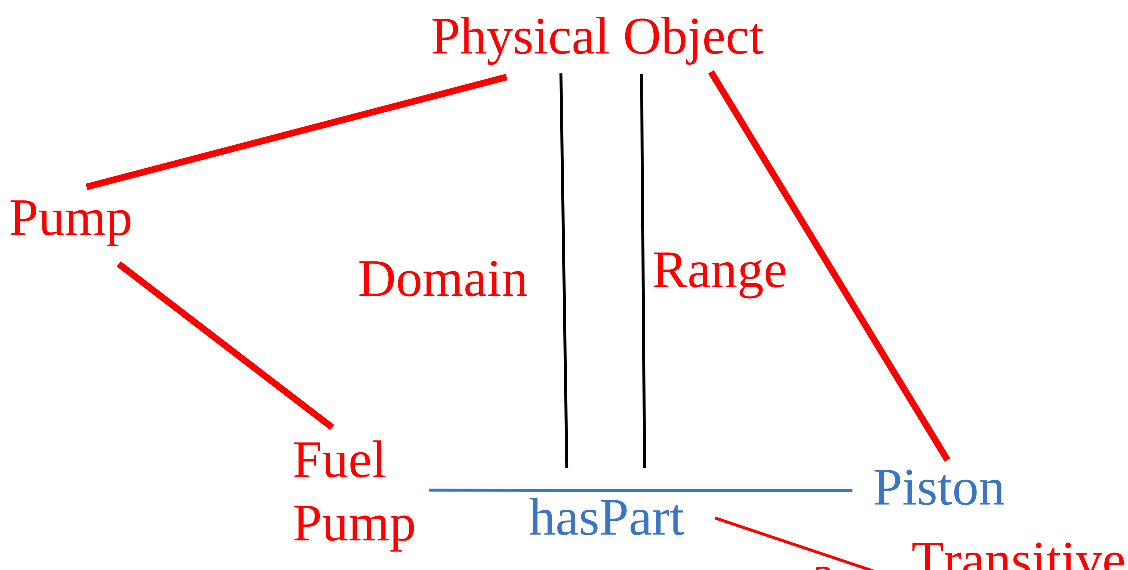
UML



Taxonomy



Thesaurus



OWL

"Semantically Unambiguous" is itself Ambiguous!

Semantics of WHAT?

- language constructs & inference procedures
  - e.g. `Class, subClassOf`
- terms & expressions in the language
  - e.g. `subclass(FuelPump, Pump)`
    `transitiveRelation(hasPart)`

Unambiguous for WHO?

- an end user of an application?
- the computer?
- someone writing code that uses an ontology?
- semantic technology software developers?

What KIND of Semantics?

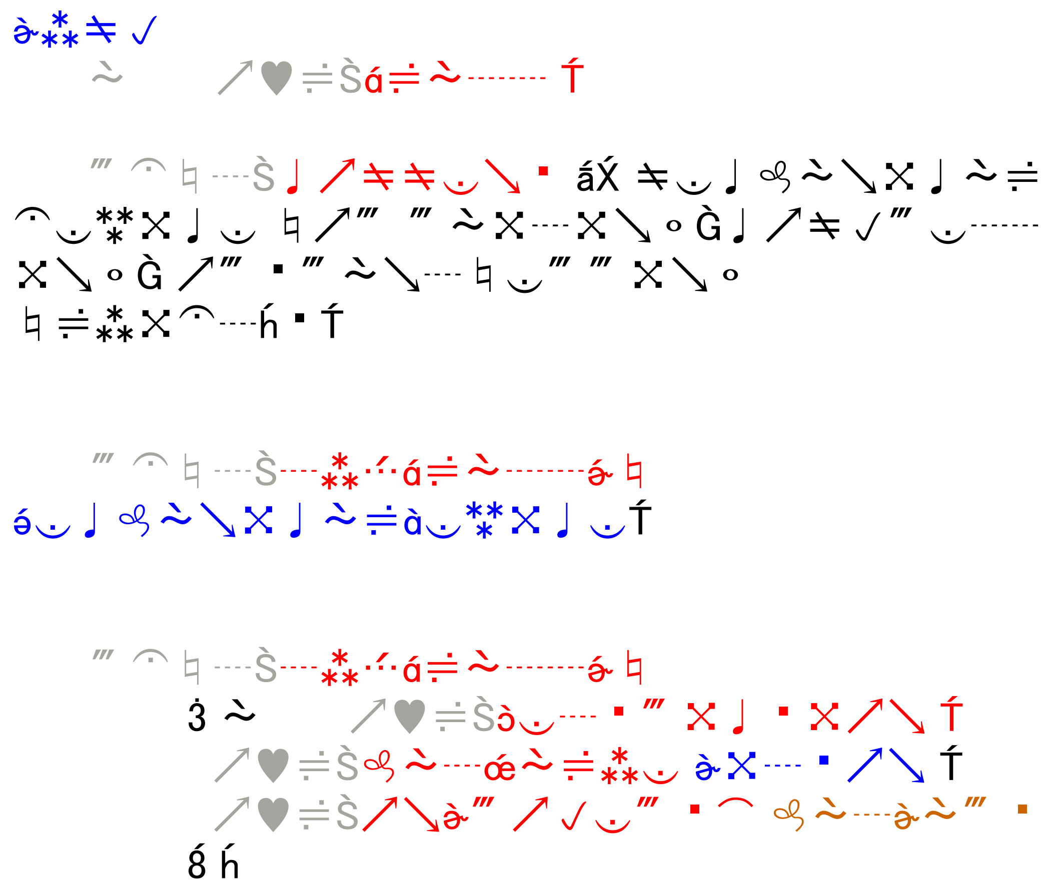
- model theoretic, axiomatic, real world

How Can a Machine Access Meaning?

Pump
a owl:Class ;
rdfs:comment "A mechanical device for raising, compressing, or transferring fluids.";

rdfs:subClassOf PhysicalObject;

rdfs:subClassOf
[a owl:Restriction ;
owl:hasValue Piston ;
owl:onProperty hasPart
] .



What the Human Sees

What the Computer Sees

How Does the Machine Know What to Do?

Humans encode that knowledge into the machine

Either:

- Hardwire the meaning into the application
- Encode procedures to discover that meaning (at least partially)

More Semantics means Less need for hardwiring.

For Example: Finding Relevant Documents

Simple Task:

Find documents about mechanical devices.

The purpose of this review is to remind operators of the

existence of the Operations Manual Bulletin 80-1, which provides

information regarding flight operations with low fuel quantities,

and to provide supplementary information regarding main tank

boost pump low pressure indications.

747 **FUEL PUMP** LOW PRESSURE INDICATIONS

When operating 747 airplanes with low fuel quantities for short

Semantics for the Computer

Hey, I know this ontology, so now I know something about Fuel Pump.

Shared Hydraulics Repository (SHR)

Pump
  a owl:Class ;
  rdfs:comment "A mechanical device for raising, compressing, or transferring fluids.";
  rdfs:subClassOf PhysicalObject;
  rdfs:subClassOf
    [a owl:Restriction ;
      owl:hasValue Piston ;
      owl:onProperty hasPart
    ] .

What the heck is a Fuel Pump?

The purpose of this review is to remind operators of the

existence of the Operations Manual Bulletin 80-1, which provides

and to provide supplementary information regarding main tank

boost pump low pressure indications.747 <concept id=fuel-pump>**FUEL PUMP**</concept> LOW PRESSURE INDICATIONS

When operating 747 airplanes with low fuel quantities for short

Semantic Annotation

<concept id=**fuel-pump**>FUEL PUMP</concept>

fuel-pump

a owl:class;
rdfs:subClassOf **SHR:pump**

What do they really mean by "Unambiguous Semantics"?

The language of OWL has an explicit formal semantics.

Major benefit related to inferencing.

Enables the human to encode inference engines that meet the language specification.

Helps to ensure correctness and consistency among different implementations.

BUT: don't be fooled…

The Same Axioms Can Mean Different Things


```
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      rdfs:subClassOf [a owl:Restriction;
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FuelPump a owl:Class;
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hasPart a owl:TransitiveProperty, owl:ObjectProperty;
        rdfs:domain uo:PhysObj;
        rdfs:range  uo:PhysObj.
```

The Same Axioms Can Mean Different Things


```
ə⁂≠✓  a owl:Class ;
      rdfs:subClassOf uo:əꝏ⌒····ə́·∴$.
      rdfs:subClassOf [a owl:Restriction;
                       owl:onProperty ꝏ∼̀····ə∼̀‴ ▪;
                       owl:someValuesFrom əX···· ▪↗↘].

í⁂◡≐ə⁂≠✓ a owl:Class;
         rdfs:subClassOf ə⁂≠✓.


ꝏ∼̀····ə∼̀‴ ▪ a owl:TransitiveProperty, owl:ObjectProperty;
        rdfs:domain uo:əꝏ⌒····ə́·∴$;
        rdfs:range  uo:əꝏ⌒····ə́·∴$.
```

The Same Axioms Can Mean Different Things


```
DigitalSLR  a owl:Class ;
      rdfs:subClassOf uo:DigitalCamera.
      rdfs:subClassOf [a owl:Restriction;
                       owl:onProperty hasMoreMegapixels;
                       owl:someValuesFrom CameraPhone].

CanonDigitalSLR a owl:Class;
         rdfs:subClassOf DigitalSLR.


hasMoreMegapixels a owl:TransitiveProperty,
                    owl:ObjectProperty;
        rdfs:domain uo:DigitalCamera;
        rdfs:range  uo:DigitalCamera.
```

Don't Be Fooled

Ontology Terms are [virtually] Always Ambiguous!!!

- **… even if there is an unambiguous formal semantics for the ontology language.**
  - **e.g. DC: Creator, or DC: Date, or MyLogistics: DeliveryDate**
- **Adding more axioms can remove ambiguity.**

  Only add axioms if needed, ambiguity is inevitable.
- **All meaning bottoms out in natural language & common usage.**
- **Fully automated discovery of meaning – impossible?**

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The Role of Comments in Ontology Engineering

Many people think

- "they're just comments" and don't pay that much attention.

BUT comments are valuable, they:

- can be a vehicle for reaching agreement
- can specify and/or document the formalization (i.e. logical theory)
- fill in many [semantic] blanks in the logical theory, [which in turn]
- helps ensure a shared understanding [that is]
- critical for collaborative ontology engineering [and]
- very helpful for ontology evolution & maintenance

Therefore, it is important:

- to have comments,
- of high quality!

Comments / Documentation / Annotations

- **Overall Goals:**
  - convey intended meaning
    "to provide a human-readable description of a resource" **[W3C]**
  - sometimes extra-logical instructions for machine processing

- **Factual knowledge critical to understanding a concept** (if you're lucky)**:**
  - intrinsic properties & distinguishing characteristics
  - examples: both positive and negative

- **Other background information**
  - references, dates, authors, …historical information
  - things that may not be appropriate for formalization
  - **whatever you wish…**

Approaches / Guidelines for "Good" Definitions

Ontology Engineering:

- **Enterprise Ontology Experiences** – Uschold et al., 1998
  Informal general guidelines, some early ideas, small part of larger effort, no computer implementation.

- **Glosses** – Jarrar, 2006
  Informal general guidelines, part of a larger ontology engineering effort, exploit linguistic resources; existing prototype.

Data Dictionaries:

- **Database Lexicography** – Coen, 2002
  Highly structured guidelines, major focus: better data dictionaries & databases; exploit linguistics technology & resources; implementation – industrial use.

Good Definitions and "Glosses"

- **Start with the principle supertype;**
  e.g. Invoice: a business document that …
- **Focus on intrinsic characteristics, distinguishing properties & examples;**
- **Refer to other defined terms;**
  (prefer clarity to 'nice' text)
- **Ensure consistency among all definitions;**
- **Use existing terms before inventing new ones –ensures understandability and future interoperability;**
- **Accurately specify/reflect axioms of the logical theory.**

Opportunities & Challenges

- **Automatic generation of text from logical definitions**
  - easy to do poorly…hard to do well.
- **Automatic generation of logical definitions from carefully crafted text.**
  - major thrust of research, knowledge acquisition
- **"Semantic synch" between logical axioms and text definitions**
  - is anyone doing this?
- **Semantic dependency analysis & consistency checking of text definitions** (+ maintenance guidance)
  - **database lexicography**

Database Lexicography

Lexicography: art or craft of compiling, writing and editing dictionaries.

Database Lexicography:

- **lexical dependency analysis to improve data design.**

Why?

- **data model design is often the most expensive, difficult and important phase of software development.**
- **better maintenance: avoid *fossilized* data designs**

How?

- **tool support for building better data models**
- **ensure semantic consistency**
- **design for change**

Database Lexicography: Basic Approach

- **Treat data dictionary as a first class object**
  Rules for "good definitions"

- **Identify and measure semantic dependencies,**
  This supports ability to:
  - Detect circularity
  - Measure "lexical stability"
  - Detect "dependency inversions"
  - Predict impact of changes

RESULTS:

- Guides the data designer in how to correct problems;
- Improved data design & evolution.

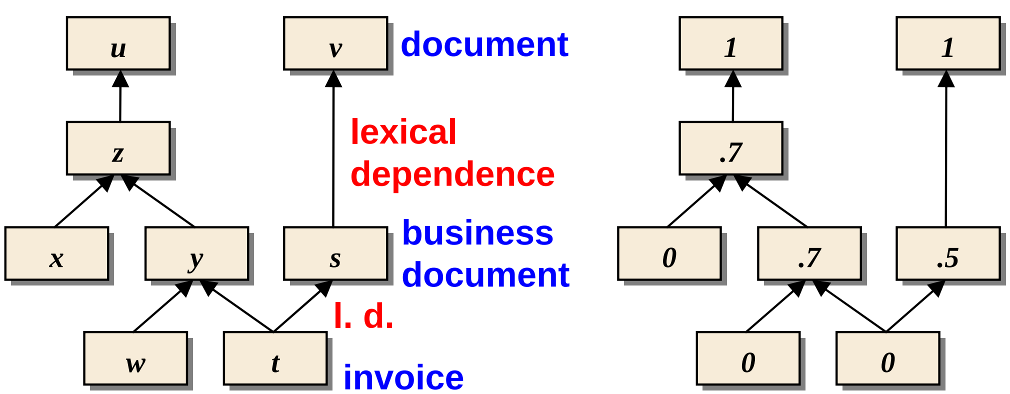
Lexical/Semantic Dependency

- **Data dictionary entry: <term, definition>**
  e.g. <"invoice", "a business document that …">
  e.g. <"business document", "a document that …">

- **Entry <t,d> is lexically dependent on <t',d'>**
  IF t' is contained in d (i.e. substring)**.**

i.e. "defined in terms of"

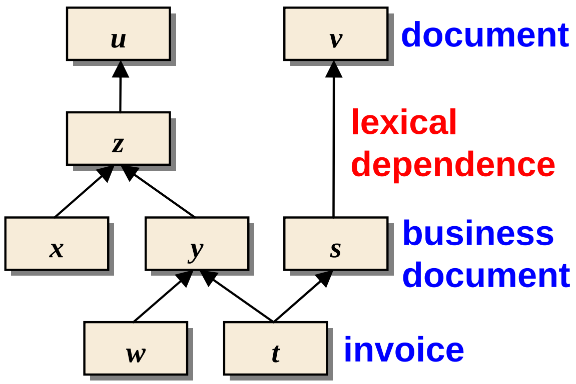
- **Formal metrics to determine 'desirability' of semantic dependencies.**

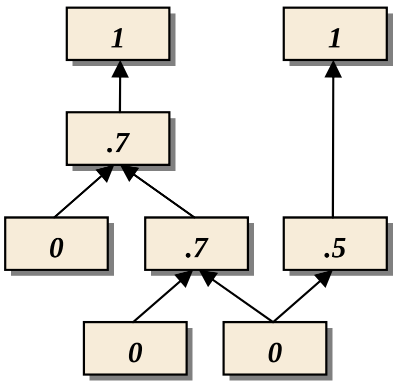


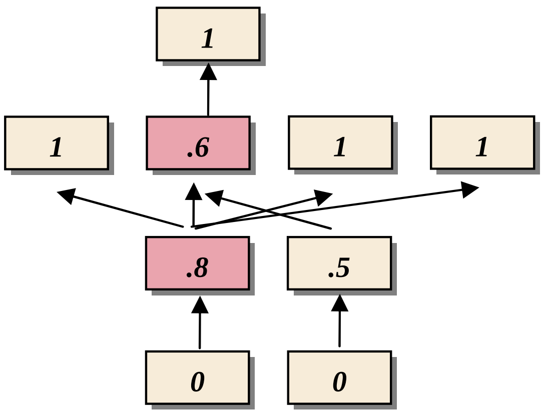
Lexical/Semantic Dependency

- **Lexical Stability: measures the difficulty of modifying the semantics of a dictionary entry.**
  - calculated from lexical dependencies
  - more stable means more difficult

- **Dependency Inversion: a more stable definition depends on a less stable one**
  - evidence of fossilization (not good!).







Rules for Data Dictionary Entries

General:

- Succinct and precise;
- Every lexical dependency must be reflected in the physical or logical model;

Attributes and Domains

- Every domain is defined in terms of a primitive data type, or an exhaustive enumeration of a set of typed values;

Inheritance & Aggregation:

- Each holonym/hypernym lexical dependency is reflected in the logical or physical model and vice versa.

Rules for Data Dictionary Entries

Existential Entailment

- Existence dependence in the model requires lexical dependence in the definitions;

Interface

- Definitions relating things at the physical / logical model interface must be lexically dependent.

Collectively: these rules guarantee that the data dictionary presents an integrated representation of the logical and physical data models. I.e. "semantic synch"

Managing Change

- **Compute lexical stability & find dependency inversions**
- **Predict the impact of changes**
- **Suggest preferred changes to minimize impact**
- **Significant cost reductions in the long term**
- **No Free Lunch!**
- **Analogous to OntoClean?**

Database Lexicography: Summary

- **All meaning is grounded in natural language semantics.**
- **There is a lot of meaning in a Data dictionary that is not exploited** (e.g. in ER modeling tools).
- **Data dictionary *should* define elements of data models.**
- **Lexer: a tool for managing knowledge in data dictionaries.**

So What Does all this Have to Do with Ontologies?

- **Leverage linguistic knowledge to reduce ambiguity.**
- **Perhaps something analogous can be done to support ontology engineering, and evolution?**
- **Age of "Ontology-Driven Software Engineering" where Ontologies replace Database Schema?**
- **Open research question.**
- **With much potential for practical benefit.**

Takeaways

- **Many ways to express meaning**
  - much overlap
  - many important differences: purpose; culture, formality

- **Formal semantics not the be all and end all**

- **Take comments seriously!**
  - Use principled guidelines for defining things.
  - Leverage natural language semantics
  - You can do serious analysis on comments
    & achieve major benefits
  - Maintain "semantic synch"
  - Build Plug-Ins for Protégé?

Acknowledgements

- **Woody Pidcock for material comparing different 'ontology-like things'**
- **Dave VanRossum & Janet Jones for preparing data model & UML diagrams**
- **Chris Menzel in preparing Philosophy vs. IT slides**
- **Peter Clark & other Boeing colleagues for reviewing this talk.**

References

- **Vocabularies, Taxonomies, Thesauri, Meta-models**

  http://www.metamodel.com/article.php?story=20030115211223271

  http://www.ontopia.net/topicmaps/materials/tm-vs-thesauri.html

- **XML Schema and Ontologies**

  http://www.cs.man.ac.uk/~horrocks/Publications/download/2001/etai01.pdf

- **Introduction to Ontologies with Semantic Integration Focus**

  http://www.sigmod.org/sigmod/record/issues/0412/12.uschold-9.pdf

References

- **Unambiguous Semantics**

  - Uschold, M. *Where are the Semantics on the Semantic Web?* AI Magazine, 24(3), pp 25-36. Fall 2003.

- **Glosses & Definitions for Ontology Engineering**

  - Jarrar, M. Towards the notion of gloss, and the adoption of linguistic resources in formal ontology engineering. *Proceeding of the 15th International World Wide Web Conference*, WWW2006. Edinburgh, Scotland. May 2006. ACM, 2006
  - Michael, J. and Mejino, Jose L V and Rosse, Cornelius (2001) The Role of Definitions in Biomedical Concept Representation. In *Proceedings, American Medical Informatics Association Fall Symposium*, pages pp. 463-467. http://sigpubs.biostr.washington.edu/archive/00000148/

- **Database Lexicography**

  - Coen, G. 2002. Database lexicography. Data & Knowledge Engineering 42, 3 (Sep. 2002), pp 293-314

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