Introduction to Ontologies and Their Uses in Linguistics

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Outline I

• Introduction

• Part I: What are ontologies?
  – Philosophical ontology vs. computer ontologies
  – Conceptual vs. realist ontologies
  – Upper-level vs. domain ontologies
  – Approaches to ontology building
  – Uses of ontologies
Outline II

• Part II: Ontologies and linguistics
  – Relationship between ontologies and lexical resources
    • Similarities
    • Problems with lexicons
  – Usefulness of natural languages for ontologies
  – Uses of ontologies in linguistics
INTRODUCTION
The Basic Idea I

• Categorizing & relating
• Data
  – Vocabularies (e.g. lexicons, terminologies, thesauri, lexical networks)
  – Concepts (e.g. knowledge representations, topic maps, library classifications)
  – Things (e.g. taxonomies, ontologies)
The Basic Idea II

• To organize knowledge in a coherent and meaningful way, according to some guiding principle(s)

• To help
  – Human beings
  – Machines

• For example, in
  – Capturing and sharing knowledge
  – Semantic tagging
  – Data query
Ice Cream Ontology

http://www.emiliosanfilippo.it/?page_id=1172
Dead_Ball_Situations [Hypernymy]

ruhender_Ball
dead-ball_position
set-piece
set-play

coup_de_pied_arrêté

direkter_Freistoß
direct_free-kick
coup_franc_direct

indirekter_Freistoss
indirect_free-kick
coup_franc_indirect

Elfer
Elfmeter
Strafstoß
penalty
spot-kick

coup_de_pied_de_réparation
penalty

Fahrkarte
Fehlschuss
penalty_miss

[Link to more information](http://www.kicktionary.de/CONCEPT_HIERARCHIES/Hypernymy_Dead_Ball_Situations.html)
Word to search for: planet

Display Options: (Select option to change)

Key: "S:" = Show Synset (semantic) relations, "W:" = Show Word (lexical) relations

Display options for sense: (gloss)

Noun

- S: (n) planet, major planet (astronomy) any of the nine large celestial bodies in the solar system that revolve around the sun and shine by reflected light; Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto in order of their proximity to the sun; viewed from the constellation Hercules, all the planets rotate around the sun in a counterclockwise direction
- S: (n) satellite, planet (a person who follows or serves another)
- S: (n) planet (any celestial body (other than comets or satellites) that revolves around a star)
  - direct hypernym / inherited hypernym / sister term
    - S: (n) celestial body, heavenly body (natural objects visible in the sky)
    - S: (n) natural object (an object occurring naturally; not made by man)
      - S: (n) whole, unit (an assemblage of parts that is regarded as a single entity)
      - S: (n) object, physical object (a tangible and visible entity; an entity that can cast a shadow)
      - S: (n) physical entity (an entity that has physical existence)
        - S: (n) entity (that which is perceived or known or inferred to have its own distinct existence (living or nonliving))
CATEGORIES (What's This?)

Fields of Science

- Aeronautics and Aerospace (171)
- Agriculture (1749)
- Animals, Insects, and Pets@
- Anthropology and Archaeology@
- Artificial Life (47)
- Astronomy (2585)
- Biology (17489)
- Chemistry (1155)
- Cognitive Science (70)
- Complex Systems (19)
- Computer Science (1215)
- Earth Sciences (4338)
- Ecology (896)
- Energy (564)
- Engineering (3224)
- Forensic Science (120)
- Geography (4040) NEW
- Geology and Geophysics@
- Hydrology@
- Information Technology (80)
- Life Sciences (19)
- Mathematics (1608)
- Medicine@
- Meteorology@
- Nanotechnology (55)
- Oceanography@
- Paleontology@
- Physics (1818)
- Psychology@
- Space (1544)

Additional Science Categories

- Alternative Science (1013)
- Amateur Science (14)
- Booksellers@
- Business and Industry@
- Chats and Forums (17)
- Education (424)
- Events (42)
- History of Science (101)
- Institutes (51)
- Measurements and Units (238)
- Museums and Exhibits (123)
- News and Media (206)
- Organizations (142)
- Reference (94)
- Science and Society (165)
- Science Humor@
- Science Job and Employment Resources@
- Scientific Journals@
- Scientific Research (165)
- Scientists (39)
- Sports Science@
- Web Directories (38)

http://dir.yahoo.com/science/
http://bioportal.bioontology.org/ontologies/FMA/?p=classes&conceptid=http%3A%2F%2Fsig.uw.edu%2Ffma%23Head
The Zebrafish Anatomy (ZFA) Ontology and the Gene Ontology (GO)


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Similarities & Differences

• Similarities
  – Hierarchical organizations
  – Categories represented with terms, yet more or less language-independent

• Differences
  – Explicit vs. implicit relations
  – Explicit vs. implicit definitions
    ➔ More or less rigorous classifications
  ➔ Not all are ontologies
PART I
WHAT ARE ONTOLOGIES?
Ontology in Philosophy

- Subdomain of metaphysics
- Dates back to Aristotle’s *Categories*
- Study of the kinds of things that exist in the world, their properties, and their relations to each other

E.g. Aristotle’s classification of that which exists in 10 categories: substance, quantity, quality, relation, place, time, situation, condition, action, and passion
Ontology in Information Science and Engineering

• Knowledge-representation of a domain
• Using a controlled vocabulary
• With formally defined (in logical language)
  – Categories/classes/concepts (OBJECT, PROCESS, QUALITY, etc.)
  – Relations (is_a, has_part, etc.)
• To yield a lexical or taxonomical framework
From Categorizing to Ontologies

• Many ways of categorizing things
• Two main approaches
  – Realist: according to what and how things are
  – Conceptual: according to how human beings conceptualize things

➔ Two approaches to ontologies
  ➔ Realist ontologies
  ➔ Conceptual ontologies
Realist Ontologies

• Ontologies which represent the kinds of entities in reality and the relations between these entities

• “The terms used in these ontologies represent what is general or repeatable in reality at successively more specific levels.” (Smith et al. 2012)
species, genera

instances

frogs

siamese

cat

mammal

animal

organism

substance

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Accidents: Species and instances

this individual accident of redness
(this token redness – here, now)

Scarlet

R232, G54, B24

Quality

Color

Red
Conceptual Ontologies

• “An ontology is an explicit specification of a conceptualization.” (Gruber et al. 1995)

• “A conceptualization is an abstract, simplified view of the world that we wish to represent for some purpose.” (Gruber et al. 1995)

• “Ontology in the traditional philosophical sense thus comes to be replaced by the study of how a given language or science conceptualizes a given domain.” (Smith 2003, p. 157)
Ontology for Searching Hotels

http://readwrite.com/2008/05/13/semantic_travel_search_uptake
Main Differences

Realist Ontologies
- Represent things in the world
- Categories = universals (types) and instances (particulars)
- Single inheritance (asserted vs. inferred hierarchy)
- E.g. DOG is_a ANIMAL & DOG bearer_of PET ROLE
- Hierarchical relation: is_a

Conceptual Ontologies
- Represent concepts
- Categories = extensions of particulars
- Multiple inheritance allowed
- E.g. DOG is_a ANIMAL & DOG is_a PET
- Hierarchical relation: subclass relation (expresses inclusion in a set)
Conceptual Ontologies: Shortcomings

• Same domain may be represented with different incompatible ontologies
• Generate redundancies across ontologies
• Categories and relations often specific to particular ontologies

→ Limit interoperability of ontologies within and across domains
Different Levels of Ontologies

• Philosophers provide basic ontological distinctions to define general categories and relations

• Engineers can use these distinctions to model computer ontologies
  – *Upper-level ontologies* ➔ *reference or foundational ontologies*
  
  that provide the basis for
  – *Mid-Level ontologies* ➔ *cross-domain ontologies*
  – *Low-level ontologies* ➔ *domain or applied ontologies*
The Level of an Ontology

“The level of an ontology is determined by the degree of generality of the types in reality which its nodes represent.” (Smith et al. 2012)
Upper-Level Ontologies

• Limited to very general categories and relations ➔ completely domain neutral (e.g., time, space, inherence, instantiation, identity, measure, quantity, functional dependence, process, event, attribute, boundary)

• Provide a common neutral backbone for domain ontologies
  – Allow for the integration of domain ontologies
  – Avoid redundancies
Examples of Upper-Level Ontologies

• Basic Formal Ontology (BFO)
• Descriptive Ontology for Linguistic and Cognitive Engineering (DOLCE)
• Suggested Upper Merged Ontology (SUMO)
BFO 2.0

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Figure 2: Taxonomy of DOLCE basic categories.
Mid-Level Ontologies

• Cover entities and relations of many domain ontologies (e.g., database, person, organization)
• Do not include domain-specific entities and relations
Examples of Mid-Level Ontologies

• **Information Artifact Ontology (IAO):** information entities  
  (e.g., *newspaper, data item, serial number, map, is_about*)

• **Ontology for Biomedical Investigations (OBI):** terms for the description of biological and clinical investigations across various biological and technological domains  
  (e.g., *blood plasma, centrifuge, principal components analysis*)

• **Ontology of General Medical Science (OGMS):** entities involved in a clinical encounter used across medical disciplines  
  (e.g., *disease, diagnosis, patient, healthcare provider*)
Low-Level Ontologies

• Also called *domain* or *applied ontologies*
• Define domain-specific categories
• Can be based on upper- and mid-level ontologies
• Often include domain-specific relations
Neurological Disease Ontology (ND)

https://code.google.com/p/neurological-disease-ontology/
Approaches to Ontology Building

• Top-down
  – Determine the categories and relations beforehand and then categorize instances in these categories
  – Mainly upper-level ontologies

• Bottom-up
  – Analyze texts (e.g. with NLP methods) to extract terms and relations
  – Build a domain ontology

• Can be combined
Why Do We Need Ontologies?

• Allow humans
  – To learn and understand the terminology and related knowledge of a domain
  – Enhance communication with agreed upon vocabularies
  – Ease access to data in companies, to books in libraries, to information on the Internet, etc.

• Allow computers
  – To reason about the objects of the domain
  – To share information in a standardized format
ontologies = standardized labels designed for use in annotations to make the data cognitively accessible to human beings and algorithmically accessible to computers
ontologies = high quality controlled structured vocabularies used for the annotation (description, tagging) of data, images, emails, documents, ...
compare: legends for maps

Cretaceous
- K: Mainly clastic sedimentary rocks

Devonian
- D: Mainly carbonate and evaporite

Paleoproterozoic
Athabasca Group
- Points Lake Subgroup
  - PP0: Carswell Formation
  - PPO: Douglas Formation
- William River Subgroup
  - PL: Otherside Formation
  - PLO: Locker Lake Formation
  - Upper Wolverine Point Sequence
    - 'b': Member
    - 'a': Member
    - PPO: Undifferentiated
  - PP0: Lower Wolverine Point Sequence
  - PPO: Upper Manitou Falls Sequence
  - PP0: Lower Manitou Falls Sequence
  - PP0: Fair Point Sequence
  - PP0: William River Subgroup (undifferentiated)

Archean and Paleoproterozoic
- PP: Granitoid rocks (Paleoproterozoic)
- AR: High-grade metasedimentary rocks
- AR: Variably retrogressed granitoid gneisises
- AR: Granitoid rocks (Archean)

- Approx. erosional edge of the Western Canada Sedimentary Basin
- Approx. erosional edge of the Athabasca Basin
- Mappable unconformity in the Athabasca Group

Cross Sections
- A - A': Mine Site
- B - B': Uranium Deposit
common legends allow (cross-border) integration

**Cretaceous**
- Mainly clastic sedimentary rocks

**Devonian**
- Mainly carbonate and evaporite

**Paleoproterozoic**

**Athabasca Group**

- **Points Lake Subgroup**
  - PP\(_D\) Carswell Formation
  - PP\(_D\) Douglas Formation

- **William River Subgroup**
  - Locker Lake - Otherside Sequence
    - PP\(_W\) Otherside Formation
    - PP\(_W\) Locker Lake Formation
  - Upper Wolverine Point Sequence
    - PP\(_W\) ‘b’ - Member
    - PP\(_W\) ‘a’ - Member
    - PP\(_W\) Undifferentiated
  - PP\(_W\) Lower Wolverine Point Sequence
  - PP\(_W\) Upper Manitou Falls Sequence
  - PP\(_W\) Lower Manitou Falls Sequence
  - PP\(_W\) Shea Creek Sequence
  - PP\(_W\) Fair Point Sequence
  - PP\(_W\) William River Subgroup (undifferentiated)

**Archean and Paleoproterozoic**

- PP\(_A\) Granitoid rocks
- AR\(_P\) High-grade metasedimentary rocks
- AR\(_P\) Varibly retrogressed granitoid gneisses
The Gene Ontology

MouseEcotope

<table>
<thead>
<tr>
<th>Tool</th>
<th>Species model</th>
<th>Consequences for multiple responses</th>
<th>GO Terms</th>
<th>Microarrays supported</th>
<th>Time to process (in days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Otam-Express</td>
<td>m&lt;sup&gt;2&lt;/sup&gt; Isogenic, Hypomorphic, Transgenic</td>
<td>None</td>
<td>Not applicable</td>
<td>Fire, False, False, False</td>
<td>120 commercial strain (Fire, False, False, False)</td>
</tr>
<tr>
<td>Glycolysis</td>
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<td>None</td>
<td>Not applicable</td>
<td>False, False, False, False</td>
<td>120 commercial strain (Fire, False, False, False)</td>
</tr>
<tr>
<td>GlyProt</td>
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<td>None</td>
<td>Not applicable</td>
<td>False, False, False, False</td>
<td>120 commercial strain (Fire, False, False, False)</td>
</tr>
<tr>
<td>GlycoScribe</td>
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<td>None</td>
<td>Not applicable</td>
<td>False, False, False, False</td>
<td>120 commercial strain (Fire, False, False, False)</td>
</tr>
<tr>
<td>Metabolite</td>
<td>m&lt;sup&gt;2&lt;/sup&gt; Isogenic, Hypomorphic, Transgenic</td>
<td>None</td>
<td>Not applicable</td>
<td>False, False, False, False</td>
<td>120 commercial strain (Fire, False, False, False)</td>
</tr>
</tbody>
</table>

GlyProt

sphingolipid transporter activity
The Gene Ontology

MouseEcotope

MouseEcotope

GluChem

DiabetInGene

GlyProt

Holliday junction helicase complex
The Gene Ontology

MouseEcotope

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</tr>
</thead>
<tbody>
<tr>
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<td>p2, N-terminal, Hypersensitive, T03's extract</td>
<td>27 Tissues, Brain, Hypersensitive, T03's extract</td>
<td>Fire, True</td>
<td>172 commercial arrays (128 Expression, Hypersensitive)</td>
<td>7, 18, 28</td>
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<td>GeneNet</td>
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<td>Robo's extract</td>
<td>True, T03's extract</td>
<td>Not applicable</td>
</tr>
<tr>
<td>EAMetab</td>
<td>Robo's extract</td>
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<td>Robo's extract</td>
<td>True, T03's extract</td>
<td>Not applicable</td>
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<td>GoldMining</td>
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<tr>
<td>BrainAssociate</td>
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<tr>
<td>ToxDO</td>
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<td>DiabetInGene</td>
<td>Hypersensitive</td>
<td>None</td>
<td>Robo's extract</td>
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GlpProt

sphingolipid transporter activity
Impact of Environment and Social Gradient on *Leptospira* Infection in Urban Slums

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Abstract

From: http://www.ploscompbiol.org/doi/pcbi.1000361

Background

Leptospirosis has become an urban health problem as slum settlements have expanded worldwide. Efforts to identify interventions for urban leptospirosis have been hampered by the lack of population-based information on *Leptospira* transmission determinants. The aim of the study was to estimate the prevalence of *Leptospira* infection and identify risk factors for infection in the urban slum setting.

Methods and Findings

We performed a community-based survey of 3,171 slum residents from Salvador, Brazil. *Leptospira* agglutinating antibodies were measured as
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Does That Look Familiar?

Think about semantic tagging in linguistics
PART II
ONTOLOGIES AND LINGUISTICS
Ontology

= strong semantic indexing (tagging) system

biology
medicine
government
military
? google
? commerce
Similarities With Lexical Resources

Lexicons

• Structure of lexicons
  – Word senses
  – Lexico-semantic relations

• Hierarchical organization
  – Inclusion of meaning

• Relations between word senses
  – Hyperonymy/hyponymy
  – Meronymy/holonymy
  – Synonymy
  – Antonymy
  – etc.

Ontologies

• Structure of ontologies
  – Categories
  – Ontological relations

• Hierarchical organization
  – Type/sub-type/instance

• Relations between things
  – is_a
  – part_of/has_part
  – etc.

Why Not Just Use Lexicons?

• They are linguistic objects (Hirst 2009)
  – They represent only lexicalized meanings(categories (lexical gaps) ⇒ omit distinctions that we would want in an ontology
  – Often linguistic categorizations are not a reliable reflection of the world ⇒ include distinctions that we would not want in an ontology
    • E.g. realization of verbs arguments, countable vs. mass distinction, Chinese classifier for “long and rope-like objects”
The Problem With (Actually Existing) Lexicons

• They promote the development of silos (roach motels for data)
• They do not allow us to exploit today’s technologies
• They do not combine natural language understandability with computational adequacy
• They do not scale
In contrast, Ontologies Are...

Controlled vocabularies *(not lexicons)*
plus definitions of terms in a logical language

A. for tagging *(search, retrieval, ...)*
B. for reasoning *(early warning, analysis ...)*

➡️ WordNet is not an ontology
However...

Natural languages can help

• To make ontologies understandable for humans
  – Natural language labels (terms)
  – Definitions

• To create ontologies from texts
Ontology Building From Texts

Figure 1. Ontology Learning Layer Cake (Buitelaar 2005)
Uses of Ontologies in Linguistics

- **Relates to:** lexical semantics, natural language processing (NLP), corpus linguistics, terminology

- **Can be used for:** semantic tagging, semantic modeling, word sense disambiguation, etc.
Particularly Important for...

- NLP applications requiring semantic and pragmatic analysis of texts (e.g., machine translation, information retrieval, automatic summarization, language generation)

→ Research in lexical semantics: ontologies used as frameworks or metalanguages for modeling meaning of words
Ontology-Based NLP

• World modeling to support multilingual applications
  → Use a language-independent ontology
  → Map it to lexicons

• Examples
  – Cimiano et al. (2007): LexOnto
Other Example in Lexical Semantics

Carita Paradis (2005)
• Uses ontological categories to model lexical meaning
• Study how different construals explain meaning shifts in context
• Based on Lyons’ three upper-level categories
  – First-order entities: physical objects that exist in three-dimensional space, at any point in time, and that are publicly observable
  – Second-order entities: entities that are located in time and are said to occur rather than exist (events, processes, and states)
  – Third-order entities: abstract entities that are outside both space and time
Uses of Ontology-Like Categories and Relations in Terminology

• Study the conceptual structure of terms, e.g., to predict the structure of the neologisms in a particular domain

• Analyze the conceptual structure of concepts or definitions, e.g., to create computer tools to help in definition writing

• Extract and structure domain-knowledge to create ontologies

• Understand the structure of conceptual systems (conceptual analysis, conceptology)

• Enrich search functions in terminological databases through onomasiological searches

• Normalize mono- or multilingual terminologies
Using BFO to Model Definition Contents

• Come to my next talks to learn about
  – The Basic Formal Ontology (BFO)
  – Its application to the creation of models for definition writing
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• Barry Smith, *An Introduction to Ontology: From Aristotle to the Universal Core*, Training course in eight lectures, “1. Ontology as a Branch of Philosophy” slides. (http://ontology.buffalo.edu smith/IntroOntology_Course.html)