Introduction to Applied Ontology and Ontological Analysis

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Applied Ontology: an emerging interdisciplinary area

- Applied Ontology builds on *philosophy, cognitive science, linguistics* and *logic* with the purpose of understanding, clarifying, making explicit and communicating *people's assumptions* about the nature and structure of the world.

- This orientation towards *helping people understanding each other* distinguishes applied ontology from philosophical ontology, and motivates its *unavoidable interdisciplinary nature*.

ontological analysis: study of **content** (of these assumptions) *as such* (independently of their *representation*)
Ontological analysis and conceptual modeling

Conceptual modeling is the activity of *formally* describing some aspects of the *physical* and *social* world around us for the purposes of *understanding* and *communication*

(John Mylopoulos)
Focusing on content
Do we know what to REpresent?

- **First** analysis,
- **THEN** representation…

Unfortunately, this is not the current practice…

- Computer scientists have focused on the **structure of representations** and the **nature of reasoning** more than on the **content** of such representations

Essential **ontological promiscuity** of AI: any agent creates its own ontology based on its usefulness for the task at hand (Genesereth and Nilsson 1987)

No representation without **ontological analysis**!
Logic is neutral about content

...but very useful to describe the formal structure (i.e., the invariances) of content
Kinds of knowledge

**logical**
- Fido is black
- either Fido is black or Fido is not black
- If Jack is a bachelor, then he is not married

**synthetic**
- (assertional)

**analytic**

**terminological**
- Terminological knowledge is about relationships between *terms* and *concepts*
The problem: subtle distinctions in meaning

The e-commerce case:

“Trying to engage with too many partners too fast is one of the main reasons that so many online market makers have foundered.

The transactions they had viewed as simple and routine actually involved many subtle distinctions in terminology and meaning.”

Harvard Business Review, October 2001
Subtle distinctions in meaning...

- What is an application to a public administration?
- What is a service?
- What is a working place?
- What is an unemployed person?

The key problems

- content-based information access (semantic matching)
- content-based information integration (semantic integration)
Signs and concepts
Signs and concepts

- Episodic memory vs. semantic memory:
  - we memorize both specific facts and general concepts
- But what is a concept?
- What does it mean to represent it?
The triangle of meaning - 1

"Cat"

Cat

this cat (or these cats) here...
The triangle of meaning - 2

Concept

Sign ← Referent
Intension and extension

- Intension (concept): part of meaning corresponding to general principles, rules to be used to determine reference (typically, abstractions from experience)
- Extension (object): part of meaning corresponding to the effective reference
- Only by means of the concept associated to the sign “cat” we can correctly interpret this sign in various situations
- The sign’s referent is the result of this interpretation
- Such interpretation is a situated intentional act
Example 1: the concept of *red*
...assuming a constant *conceptual domain*

![Diagram showing mappings between sets](image-url)
Example 2: the concept of *on*

\[
\begin{align*}
\{a, b\} & \quad \{<a,b>\} \\
\{b, a\} & \quad \{<b,a>\} \\
\{b, a\} & \quad {} \\
\end{align*}
\]
Concepts, properties, and relations: terminology issues

- Non-relational concepts are often called *properties*
- Relational concepts are often called *(conceptual) relations*
What is an ontology
Philosophical ontologies

- **Ontology**: the philosophical discipline
  - Study of *what there is* (being qua being...)
  - A liberal reinterpretation for computer science:
    - *content qua content*, *independently of the way it is represented*
  - Study of the *nature* and *structure* of “reality”
- **A (philosophical) ontology**: a structured system of entities assumed to exists, organized in categories and relations.
Computational ontologies

Specific (theoretical or computational) artifacts expressing the intended meaning of a vocabulary in terms of primitive categories and relations describing the nature and structure of a domain of discourse

...in order to account for the competent use of vocabulary in real situations!

Gruber: “Explicit and formal specifications of a conceptualization”

Computational ontologies, in the way they evolved, unavoidably mix together philosophical, cognitive, and linguistic aspects. Ignoring this intrinsic interdisciplinary nature makes them almost useless.
What is a conceptualization

- Formal structure of (a piece of) reality as perceived and organized by an agent, independently of:
  - the vocabulary used
  - the actual occurrence of a specific situation

- Different situations involving same objects, described by different vocabularies, may share the same conceptualization.

\[ \text{same conceptualization} \]
From experience to conceptualization

Conceptualization $\mathbf{C}$
relevant invariants within and across presentation patterns: $\mathbf{D}$, $\mathcal{R}$

$\mathbf{D}$: cognitive domain

$\mathcal{R}$: set of conceptual relations on elements of $\mathbf{D}$
relevant invariants within and across presentation patterns: \( D, \mathscr{R} \)

Ontological commitment \( K \) (selects \( D' \subseteq D \) and \( \mathscr{R}' \subseteq \mathscr{R} \))

Language \( L \)

Interpretations \( I \)

Intended models for each \( I_K(L) \)

Models \( M_{D'}(L) \)

Ontology models

~Good Ontology

Bad Ontology

Perception

Reality

Phenomena

Conceptualization

Perception

Reality

Phenomena
Ontology Quality: Precision and Correctness

- **Good**
  - High precision, max correctness

- **Less good**
  - Low precision, max correctness

- **BAD**
  - Max precision, low correctness

- **WORSE**
  - Low precision, low correctness
Levels of Ontological Precision

tennis
football
game
field game
court game
athletic game
outdoor game
game
athletic game
court game
tennis
outdoor game
field game
football
game(x) → activity(x)
athletic game(x) → game(x)
court game(x) ↔ athletic game(x) ∧ ∃y. played_in(x,y) ∧ court(y)
tennis(x) → court game(x)
double fault(x) → fault(x) ∧ ∃y. part_of(x,y) ∧ tennis(y)

Glossary

Catalog

Taxonomy

Thesaurus

Axiomatic theory

DB/OO scheme

Ontological precision
Why ontological precision is important
Database A: keeping track of fruit stock

<table>
<thead>
<tr>
<th>Variety</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granny Smith</td>
<td>12</td>
</tr>
<tr>
<td>Golden delicious</td>
<td>10</td>
</tr>
<tr>
<td>Stark delicious</td>
<td>15</td>
</tr>
</tbody>
</table>
## Database B: keeping track of juice stock

<table>
<thead>
<tr>
<th>Variety</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granny Smith</td>
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<td>15</td>
</tr>
</tbody>
</table>
Why ontological precision is important

Interpretations allowed by A’s ontology

A - Apple
producer’s intended interpretations

B - Juice
producer’s intended interpretations

Interpretations allowed by B’s ontology

All interpretations of “apple”

Area of false agreement!
When is a precise (and accurate) ontology useful?

1. When *subtle distinctions* are important
2. When *recognizing disagreement* is important
3. When *careful explanation and justification* of ontological commitment is important
4. When *mutual understanding* is more important than interoperability.
Ontologies vs. classifications (1)

What’s the *meaning* of these terms?

What’s the meaning of arcs?
Ontologies vs. classifications (2)

- Classifications focus on:
  - *access*, based on pre-determined criteria (encoded by *syntactic keys*)

- Ontologies focus on:
  - *Meaning* of terms
  - *Nature* and *structure* of a domain
Ontologies vs. Knowledge Bases

- Knowledge base
  - Assertional component
    - reflects *specific (epistemic) states of affairs*
    - designed for *problem-solving*
  - Terminological component (*ontology*)
    - *independent* of particular *states of affairs*
    - Designed to support *terminological services*

**Ontological formulas are (assumed to be)**
*invariant, necessary information*
The two fundamental scenarios for semantic integration

1. *Same domain, same terminology, same conceptualization*: e.g., different processes within a very small, family-managed enterprise (everybody does everything)

2. *Same domain, shared terminology, different conceptualization*: e.g., different branches of a big company with a strong organization structure.

Computational ontologies have been born for 2, but, they are actually used for 1: *just shared data schemes*. The result is the so-called “data sylos” effect.
A single, imperialistic ontology?

• An ontology is first of all *for understanding each other*
  • ...among people, first of all!
  • not necessarily for thinking in the same way

• A single ontology for multiple applications *is not necessary*
  • Different applications using different ontologies can co-exist and co-operate (not necessarily inter-operate)
  • ...if linked (and compared) together by means of a general enough basic categories and relations (*primitives*).

• If basic assumptions are not made explicit, any imposed, common ontology risks to be
  • seriously mis-used or misunderstood
  • opaque with respect to other ontologies
The formal tools of ontological analysis

- Theory of Parts (Mereology)
- Theory of Unity and Plurality
- Theory of Essence and Identity
- Theory of Dependence
- Theory of Composition and Constitution
- Theory of Properties and Qualities

The basis for a common ontology vocabulary

Idea of Chris Welty, IBM Watson Research Centre, while visiting our lab in 2000
Formal Ontology

- Theory of *formal distinctions and connections* within:
  - entities of the world, as we perceive it (*particulars*)
  - categories we use to talk about such entities (*universals*)

- Why *formal*?
  - Two meanings: *rigorous* and *general*
  - Formal logic: connections between truths - neutral wrt *truth*
  - Formal ontology: connections between things - neutral wrt *reality*

- **NOTE:** “represented in a formal language” is not enough for being formal in the above sense!

- *Analytic ontology* may be a better term to avoid this confusion
The Ontological Level
From the logical level to the ontological level

• Logical level (*no structure, no constrained meaning*)
  - $\exists x \ (\text{Apple}(x) \land \text{Red}(x))$

• Epistemological level (*structure, no constrained meaning*):
  - $\exists x: \text{apple} \ \text{Red}(x)$ (*many-sorted logics*)
  - $\exists x: \text{red} \ \text{Apple}(x)$
  - a is a Apple with Color=red (*description logics*)
  - a is a Red with Shape=apple

• Ontological level (*structure, constrained meaning*)
  - Some structuring choices are excluded because of ontological constraints: Apple carries an *identity condition*, Red does not.

*Ontology helps building “meaningful” representations*
The source of all problems: (slightly) different meanings for words

- A (simple-minded) painter may interpret the words “Apple” and “Red” in a completely different way:
  - Three different reds on my palette: Orange, Apple, Cherry
- So an expression like $\exists x: \text{red} \text{ Apple}(x)$ may mean that there is an “Apple” red.
- Two different ontological assumptions behind the Red predicate:
  - adjectival interpretation: *being a red thing* doesn’t carry an identity criterion (uncountable)
  - nominal interpretation: *being a red color* does carry an identity criterion (countable)

**Formal ontological distinctions help making intended meaning explicit**

Ontological analysis can be defined as the process of *eliciting and discovering relevant distinctions* and relationships bound to the very nature of the entities involved in a certain domain, *for the practical purpose of disambiguating terms* having different interpretations in different contexts.
Terminological competence - kinds of properties

How many rock kinds are there?

The answer

- According to Brachman & Fikes 83:
  - It’s a **dangerous question**, only “safe” queries about analytical relationships between terms should be asked
- In a previous paper by Brachman and Levesque on **terminological competence** in knowledge representation [AAAI 82]:
  - “an enhancement mode transistor (which is a kind of transistor) should be understood as different from a pass transistor (which is a role a transistor plays in a larger circuit)”
- These issues have been simply **given up** while striving for logical simplification and computational tractability
- The OntoClean methodology, based on formal ontological analysis, allows us to conclude: **there are 3 kinds of rocks** (appearing in the figure)
Terminological competence - kinds of relations

• Woods’ “What’s in a link?” (1975):
  
  JOHN
  HEIGHT: 6 FEET
  KISSED: MARY

• "no longer do the link names stand for attributes of a node, but rather arbitrary relations between the node and other nodes”
• different notations should be used
Kinds of attributes

JOHN
  HEIGHT: 6 FEET
  RIGHT-LEG: LEG#1
  MOTHER: JANE
  KISSED: MARY

intrinsic quality
part
role
external relation

We need different primitives to express *different structuring relationships* among concepts.

We need to represent *non-structuring relationships* separately.

Current description logics tend to collapse EVERYTHING!
# The Ontological Level

(Guarino 94)

<table>
<thead>
<tr>
<th>Level</th>
<th>Primitives</th>
<th>Interpretation</th>
<th>Main feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logical</td>
<td>Predicates, functions</td>
<td>Arbitrary</td>
<td>Formalization</td>
</tr>
<tr>
<td>Epistemological</td>
<td>Structuring relations</td>
<td>Arbitrary</td>
<td>Structure</td>
</tr>
<tr>
<td><strong>Ontological</strong></td>
<td><strong>Ontological relations</strong></td>
<td><strong>Constrained</strong></td>
<td><strong>Meaning</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(meaning postulates)</td>
<td></td>
</tr>
<tr>
<td>Conceptual</td>
<td>Conceptual relations</td>
<td>Subjective</td>
<td>Conceptualization</td>
</tr>
<tr>
<td>Linguistic</td>
<td>Linguistic terms</td>
<td>Subjective</td>
<td>Language dependence</td>
</tr>
</tbody>
</table>
IAOA
International Association for Ontology and its Applications
From the Statute

“The Association is a non-profit organization the purpose of which is to promote interdisciplinary research and international collaboration at the intersection of philosophical ontology, linguistics, logic, cognitive science, and computer science, as well as in the applications of ontological analysis to conceptual modeling, knowledge engineering, knowledge management, information-systems development, library and information science, scientific research, and semantic technologies in general.”
IAOA: a unique combination of key aspects

1. Interdisciplinarity
2. Cooperation between academy, industry, and communities of practice (with an eye on education)
3. Scientific authoritativeness
4. Openness
5. Legal status
6. Transparent governance
A new journal: **Applied Ontology**

Editors in chief:

Nicola Guarino  
*ISTC-CNR*

Mark Musen  
*Stanford University*

**IOS Press**

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[www.applied-ontology.org](http://www.applied-ontology.org)

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A bit of history - Community building initiatives

• 1993: 1st Int. workshop on Formal Ontology & Information Systems
• 1998: 1st FOIS conference
• 2002: Ontolog forum
• 2005: ECOR, NCOR, JCOR...
• 2006: First public discussion on an ontology association at FOIS (Baltimore)
• 2008: Public assembly at FOIS (Saarbrücken)
• 2011: IAOA Summer Institute on ontology of processes
• 2011: Applied Ontology gets official ISI recognition
• 2009-2012: Several focused conferences (FOMI, WOMO...)
• 2012: IAOA permanent co-organizer of Ontology Summit

• In parallel: various consortia focusing mainly on Semantic Web
Vote NOW for IAOA EC renewal!
The challenges of *interdisciplinarity, language and cultural diversity, openness, and interoperability*

Working at (and in…) the *interfaces* among different Disciplines, Cultures, Languages, Socio-technical systems

…is **HARD**!

- Anyway, these are the main challenges of modern, global, networked society
- Ontologies are certainly intended to address such challenges, and ultimately can contribute to *mutual understanding, social awareness* and *collaborative participation* to the huge socio-technical system which is modern society
A new discipline (or science) is emerging?

Maybe.

See the history of Psychology, Systems Engineering...

See recent proposals for Web Science, Services Science...

For sure, a humble, truly interdisciplinary approach is needed, focusing on letting new ideas, approaches, methodologies emerge from the mutual cross-fertilization of different disciplines.

That’s why we organised this summer school.