Ontological Analysis and Conceptual Modeling: Why and How

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Thanks to Giancarlo Guizzardi and the LOA people.
Data
More data
Data and concepts
Kant:
concepts without data are *empty*,
data without concepts are *blind!*
Plato: good concepts carve reality at its joints
...But, even preserving the joints, communication problems arise

- different assumptions about proper boundaries of cuts
- different names for them
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)
A computational ontology is a specific artifact expressing the *intended meaning* of a *vocabulary* in a machine-readable form.

...in terms of *primitive* categories and relations describing the *nature* and *structure* of a *domain of discourse*.

Gruber (93): “Explicit and formal specification 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*. 
Ontologies as *fine prints*

An ontology is like a *contract's fine print*, one of those ad-hoc glossaries that clarify the way a certain term is used within the contract. They are often ignored, but *can save a business in critical situations.*

Ontologies have therefore a *contractual nature*: depending on how carefully they are designed, serious consequences may occur.
“IT WAS a $3.5 billion question: was the crashing of two aeroplanes into New York's twin towers in September 2001 one event or two?”

“In most disaster insurance, “occurrence” is carefully defined...”
relevant invariants within and across presentation patterns: $D, \mathcal{R}$

Ontological commitment $K$ (selects $D' \subset D$ and $\mathcal{R}' \subset \mathcal{R}$)

Language $L$

Interpretations $I$

Intended models

Models $M_{D'}(L)$

Models admitted by the ontology

~Good Ontology
Intended interpretations and interpretations admitted by an ontology
Why ontological precision is important

Agent A: *Intended* interpretation of service as a commitment

Agent B: *intended* interpretation of service as an action

Interpretations *admitted* by A’s (lightweight) ontology

Interpretations *admitted* by B’s (lightweight) ontology

Area of false agreement!
When precision is not enough

Only one binary predicate in the language: \textit{on}

Only three blocks in the domain: \(a, b, c\).

Axioms (for all \(x, y, z\)):
\[
\begin{align*}
on(x, y) & \implies \neg on(y, x) \\
on(x, y) & \implies \neg \exists z \left( on(x, z) \land on(z, y) \right)
\end{align*}
\]

Non-intended \textbf{models} are excluded, but the rules for the competent usage of \textit{on} in different \textbf{situations} are not captured.
The reasons for ontology inaccuracy

• In general, a single intended *model* may not discriminate between positive and negative *examples* because of a *mismatch* between:
  • Cognitive domain and domain of discourse: lack of *entities*
  • Conceptual relations and ontology relations: lack of *primitives*

• Capturing all intended models is not sufficient for a “perfect” ontology
  *Precision*: non-intended *models* are excluded
  *Accuracy*: *counter-examples* are excluded
When is a precise and accurate ontology useful?

The benefits of adopting a well-founded, precise and accurate ontology are *not only those of achieving a common agreement*, but -often more importantly- those of making explicit and understanding the *reasons of disagreement*, and therefore the actual obstacles to interoperability.
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 (now at Google Research), 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*?
  • Formal logic: connections between truths - neutral wrt *truth*
  • Formal ontology: connections between things - neutral wrt *reality*
  • Two meanings: *general* and *rigorous*

• 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 double role of formal ontological analysis in conceptual modeling

- Clarifying and making explicit the ontological nature of basic *modeling constructs*
  - resulting in a modeling language whose constructs are specified at the *ontological level*, i.e., with clear ontological constraints specified
  - examples: OntoClean, OntoUML

- Clarifying and making explicit the ontological nature of the *domain of discourse*
  - providing guidelines for *reification choices*
  - providing *modeling patterns* that allow to express relevant constraints on the domain.
First role of ontological analysis: constraining modeling constructs

SORTAL

Apple

color = red

NON-SORTAL

Red

sort = apple
Sortal vs. non-sortal types

OntoClean meta-property

Whilst the non-sortals (a.k.a. *characterising* properties) only carry a principle of application for their instances, sortal types carry both a principle of application and a principle of identity

\[
\text{Sortal Type} \quad \{\text{Person, Apple, Student}\}
\]

\[
\text{Non-Sortal Type} \quad \{\text{Insured Item, Red}\}
\]
Taxonomic constraints

Since the principle of identity supplied by a sortal is inherited by its subclasses, we have that:

A Non-sortal type cannot appear in a conceptual model as a subtype of a sortal
A better model
Distinctions among sortals

- **Type**
  - **ObjectType**
    - **Sortal Type**
      - **Rigid Sortal Type** {Person, Organization}
      - **Anti-Rigid Sortal Type** {Student, Teenager, FootballPlayer}
    - **Non-Sortal Type** {Insurable Item}
Roles and external Dependence (D+)

A type $T$ is **externally dependent** iff its definition involves (at least) another property $Q$ such that, for every instance $x$ of $P$, there exists an instance $y$ of $Q$ which is external to $x$, in the sense that $x$ is not a part of $y$, and $y$ is not a part of $x$.

**Roles** are *anti-rigid* and *externally dependent* types.

$$\text{Student}(x) = \text{def} \ \text{Person}(x) \land \exists y \ \text{School}(y) \land \text{enrolled-at}(x,y)$$
Modeling roles

```
«kind›Person

«role›Student

enrolled-at

1..*

1..*

«kind›School
```
An important ontological constraint for roles

An anti-rigid type cannot be a supertype of a Rigid Type
Second role of *ontological analysis*: characterising the domain of discourse
The reification move

- Our *domain of discourse* is typically much smaller than our *cognitive domain*.

- When a property or a relation holds, it presupposes some *hidden entities* we can’t talk of, unless we put them in the domain of discourse.

- The act of putting in the domain of discourse an entity otherwise hidden, although presupposed by the language, is called *reification*.

- Reification allows us to *talk* of these hidden entities, adding details about them.

- Typical examples:
  - **Qualities**: Mary’s beauty is raw and wild.
  - **Events**: the marriage lasted two years.
  - **Relationships**: the relationship with my boss was very difficult initially, but it’s better now.
What to reify?

The *ontological answer*: those entities that are responsible for the truth of our propositions.

**Ontological analysis** as a search for truthmakers:

- *What* makes our statements about the world *true*?
- *When*…? (*Where*…?)

- *How do we believe the world is*, when we say
  - This rose is red
  - John is married with Mary
  - My name is Nicola

- Ontological analysis is all about *making truth-makers explicit*
Properties and their truthmakers, 1

(\textit{strong truthmaking})

- The truthmaker of a property $P$, holding for $x$, is a suitable $y$ \textit{in virtue of which} $P(x)$ holds.
- What’s the meaning of \textit{in virtue of}?
- Standard answer: in virtue of $y = \text{in virtue of the } \textit{existence} \text{ of } y$
  - $\text{rose}(a)$ holds in virtue of the existence of a certain rose denoted by $a$ ($x = y$ in this case)
  - $\text{red}(a)$ holds in virtue of the existence of a certain redness \textit{event} (actually, a \textit{state})

Strong truthmakers: their mere existence entails the proposition’s truth

Important distinctions among properties can be made according to the nature of their truthmakers
**Weak truthmaking: denying truthmaker essentialism**

- **Strong truthmaking:** $P(x)$ holds in virtue of the *mere existence* of something …i.e., in virtue of *whether* something exists in any possible world (*essentialism*)

- **Weak truthmaking:** $P(x)$ holds in virtue of the *way* something is …i.e., in virtue of *how* $y$ is (*either essentially or contingently*)

---

J. Parsons, “There is no ‘truthmaker’ argument against nominalism,” 1999.
Individual qualities as \textit{minimal} weak truth-makers

What’s the \textit{minimal} weak truthmaker of ‘This rose is red’?

The rose’s corolla, or –more exactly– \textit{its color}!

Both the rose, its corolla and the color of its corolla are all weak truth-makers. The corolla’s color is the \textit{minimal} one.

‘This rose is red’ cannot become false without a \textit{change} in an individual quality.
Descriptive properties and individual qualities

- Some properties hold in virtue of *what* things are (i.e., in virtue of *mere existence*):
  - person(John)
- Other properties hold in virtue *how* things are:
  - tall(John)

- Descriptive properties select (are *about*) a certain *aspect* of an individual – something that can allow a *comparison* with another individual.

- Such comparable aspects of individuals are called *individual qualities*, or just qualities: *the height of John* is an individual quality.

Individual qualities are *minimal weak truth-makers* of *descriptive* properties.
Individual qualities as *aspects* of things

- Are **specific aspects** of things we use to **compare** them: they are directly comparable, while objects and events can only compared with respect to a quality kind.

- **Inhere** in specific individuals. This means that they are *existentially dependent* on such individuals, *and* their properties affect the properties of such individuals.

- Are distinct from their values (a.k.a. **qualia**), which are abstract entities representing what exactly resembling individual qualities have in common, and organized in **quality spaces**. Each quality type has its own quality space.

- At different times, may keep their identity while “moving” in their quality space.

- Properties **hold**, qualities **exist**.
Qualities

Quality attribution

Rose

Red-obj

Rose1

Color

Color of rose1

Inheres

Has-value

Red-region

Red421

Color-space

Has-part

q-location

Has-part

Has-value

Red-obj

Rose

Rose1
The distinction between *strong and weak truthmakers* and the introduction of *individual qualities* as a distinguished ontological category opens up a number of *reification options* for actually including such truthmakers in a conceptual model.
Example: different truthmaking patterns for color properties

Strong TMP (why the property holds)

Weak TMP (how the property holds)

Full TMP (how and why the property holds)
Sometimes, we must talk of a relationship...

- **Reifying** relationships allows us to talk of:
  - their nature
  - the way they change in time
  - their interaction with the world
  - how they compare with similar relationships

- Guarino & Guizzardi, “We need to discuss the relationship”: revisiting relationships as modeling constructs. CAISE 2015
Common view: a relation is a class of *tuples*. ‘*Relationship*’ is just another name for ‘*tuple*’

In *relational databases*, a *relationship type* is set of tuples.

Yet, different relationships may involve the same tuples, so each relationship seems to have a unique “meaning” (*intension*) conveyed by its *name*.

We suggest a different view:

- A relation is a *mathematical* entity (a subset of the cartesian product of at least two sets)
- A relationship is an *ontological* entity. What accounts for the *way* things are connected.
The cardinality problem

This problem only emerges for *contingent* relations (because they may hold in different *ways*).
The relator construct [Guizzardi 2005]
Descriptive relationships are sums of qualities (or modes)

- Talking of \( \text{in-love}(\text{John}, \text{Mary}) \) means talking of \( \text{John's love for Mary} \) and \( \text{Mary's love for John} \)

- Talking of the \( \text{taller-than}(\text{John}, \text{Mary}) \) means talking of the \( \text{height of John} \) and the \( \text{height of Mary} \).

These relations hold \textit{in virtue of} some qualities (or modes) of their relata: each of them is a \textit{weak truthmaking component} (wt-component).
Classifying relations according to their truthmakers

- **Descriptive relations** hold in virtue of how their arguments are: $Heavier(x,y)$; $Works-for(x,y)$
  Their wt-components are qualities inhering in the arguments or in their parts.
  They may have objects or events as strong truthmakers.

- **Non-descriptive relations** hold in virtue of what their arguments are: $Part(x,y)$; $Dependent(x,y)$; $Inheres-in(x,y)$; $Born-in(x,y)$
  Their wt-components are not qualities.
  They may have objects or events as strong truthmakers.

- **Internal relations** are such that all of their wt-components are independent
  - $Heavier(x,y)$.

- **External relations** are such that some of their wt-components are not independent
  - $Works-for(x,y)$; $Born-in(x,y)$
### Classifying relations and relationships

<table>
<thead>
<tr>
<th>Internal</th>
<th>Descriptive</th>
<th>Non-Descriptive</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Comparative relationships among objects and events</td>
<td>Comparative relationships among qualities</td>
</tr>
<tr>
<td></td>
<td>Child of</td>
<td>Participation</td>
</tr>
<tr>
<td></td>
<td>Works for Married to Friend of</td>
<td>Parthood</td>
</tr>
<tr>
<td></td>
<td>2 meters away</td>
<td>Participation</td>
</tr>
<tr>
<td>External</td>
<td></td>
<td>Existential dependence</td>
</tr>
<tr>
<td>Material (Guizzardi)</td>
<td></td>
<td>Born in Forming a given shape Parts of the same whole</td>
</tr>
</tbody>
</table>

Parthood

Comparative relationships among qualities

Existential dependence

Parts of the same whole

Forming a given shape

Born in

Participation

2 meters away
Truthmaking patterns for internal descriptive relations (comparative relations)
Truthmaking patterns for *one-sided* external descriptive relations
Full truthmaking pattern for two-sided external descriptive relations
Contractual compliance as a relationship of relationships
Is a new discipline (or science?!?) emerging?

Maybe.

See the history of Psychology, Systems Engineering...

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