Logic, Ontology and Planning: the Robot’s Knowledge
Lecture 2

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Course Overview

1. Ontology
Ontology

- Motivating the use of ontology
- Ontological analysis and Formal ontologies
- What is the role of (formal) ontology?
- Basic ontological notions
- DOLCE
- The Protégé environment
- Examples in Protégé
I’m reconsidering the organization of my photo collection. It consists of digital and printed photos.

Here is my actual organization: there is a container "Photo" with three sections ("Bachelor", "Spouse" and "Work"), each with a refinement.

Q1: Would you say that this classification is good?
I’m thinking that a different organization could ease the classification and search of my photos.

Q2: Would you now say that this classification is good?
Let’s turn to ontology.

Ontology is based on introspection and understanding. The first thing to do is to ask a few questions:

- do I understand the topic?
- why is there a problem?
- what is the problem about?
**Question:** what do I refer to when I say ‘photo’?

My photo collection and ontology

- **Photo**
  - **Photo creation**
  - **Photo content**
  - **Photo object**

**Event feature**
- Location (home)
- Location (my office)
- Situation (holiday)
- Period (spouse)
- Event motivation

**Content feature**
- Scene (meeting)
- Scene (party)
- Subjects (myself)
- Subjects' role (spouse/friend)
- Background

**Object feature**
- Author
- Size
- Faulty
- Printing tech.

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Now that you got the idea, can you tell what this is?

Try again distinguishing:

- What is it?
- What is it for?
- How can it be used?
- What does it stay for?

We now have several classification criteria for this object...
Both the photo classifications we saw before are good for some purpose and bad for others.

**Two (+two) scientific questions:**

- Given a purpose, can one build a good classification for that purpose? How?
- Can one build a good purpose-independent classification? How?

One can answer these questions in different ways:

1. ad hoc modeling
2. purpose-driven methodology
3. general classification methodology

Ontological analysis and ontological modeling help in the second and third approaches.
Classifying what?

In our life (driven by social and functional tasks) there are three main types of thing we need to distinguish and organize:

- objects (what is there)
- events (what happens)
- roles (what counts as what)

and to manage these we need to talk about: properties, features, types... and their relationships
We need to find:

- a strategy to list possible entities;
- a strategy to coherently classify these entities;
- a language that allows to distinguish and relate them;
- a way to mention/represent the entities we want to talk about;
- a knowledge repository to make all this information accessible over time.
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Ontological analysis vs ontologies

Here is a basic distinction.

**Ontological Analysis:**
this refers to the study, guided by ontological principles, of a topic or a problem. The goal of the study is the understanding of the types of entities involved, the types of relations involved, the situations that are considered possible. O.A. is the hard part in ontology research and is the part that determines the quality of your work in ontology.

**Ontologies:**
these are “specifications of a conceptual system” concerned with the understanding of entities of interest and their relationships. Briefly, a set of explicit constraints on a domain. An ontology states the way we see the world and is often written in a machine-readable language. A good ontology is built based on an ontological analysis of the domain.
Ontological analysis should not be confused with domain and requirement analyses (broadly understood):

Domain analysis is the study of the topic or problem from the viewpoint of the expert. It starts from the traditional and consolidated view of the domain with the goal of classifying the topic or problem within the known knowledge system.

Requirement analysis is the study of the needs that make the understanding of the topic or a solution to the problem relevant. Requirement analysis elicits the constraints that should be satisfied by the understanding (e.g. the capacity to make certain predictions) or by the solution (e.g. avoiding certain situations).
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REALITY (SCENARIO)
ONTOLOGY (GRID)

MODEL

MODELER
The information flow from reality to models

Conceptualization

Language $L$

Interpretations $I$

Intended models for each $I_k(L)$

relevant invariants across presentation patterns: $D$, $R$

Ontological commitment $K$ (selects $D' \subseteq D$ and $R' \subseteq R$)

Perception

Presentation patterns

Reality

Phenomena

Bad Ontology

~Good Ontology

Models $M_D(L)$

Ontology models
Ontology models

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

Ontology models

Perception

Presentation patterns

Reality

Phenomena

Interpretations

\( I \)

Language

\( L \)

Bad Ontology

~Good Ontology

relevant invariants across presentation patterns:

\( D, R \)

Ontological commitment \( K \)

(selects \( D'^D \) and \( R'^R \))

Conceptualization

State of affairs

State of affairs

Perception

Reality

Presentation patterns

Reality

Phenomena

Perception

Reality

Phenomena
Flow step 2

- **Language** $L$
- **Intended models for each** $I_K(L)$
- **Ontological commitment** $K$ (selects $D', D$ and $R', R$)
- **Interpretations** $I$
- **Ontology models** $M_{D'}(L)$
- **Bad Ontology**
- **~Good Ontology**

**Conceptualization**

- Relevant invariants across presentation patterns: $D, R$

**Perception**

- Presentation patterns

**Reality**

- Phenomena

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Role of ontology

Ontology

Language $L$

Intended models for each $I_K(L)$

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

Interpretations $I$

Conceptualization

relevant invariants across presentation patterns: $D$, $\mathcal{R}$

Perception

Models $M_D(L)$

Reality

Phenomena

$\sim$Good Ontology

Bad Ontology

Ontology models

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What is in a foundational ontology?

Foundational ontologies are the most general formal ontologies. They characterize general terms like entity, event, process, spatial and temporal location...

and basic relations like parthood, participation, dependence, identity...

The purpose is:

1. to provide a formal description of entities and relationships that are common in all domains/perspectives

2. to provide a consistent and unifying view
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The ontology toolkit (1)

Formal and ontological tools for ontology construction:

- **Basic distinctions:**
  - Entities
  - Properties, Qualities, Attributes
  - Relations

- **Basic techniques:**
  - Stacking
  - Reification
  - Modularity

(co-location)
Formal and ontological tools for ontology construction:

- Basic relations:
  - identity
  - IS_A (subclass) (btw two classes)
  - instantiation (btw an individual and a class)
  - parthood (btw two individuals ‘in the same class’)
  - connection (btw two individuals ‘in the same class’)
  - inheritance, exemplification (btw an entity and a property)
  - constitution (btw individuals ‘in different classes’)
  - composition (btw several individuals ‘in the same class’)
  - dependence
A variety of perspectives

Ontological choices:

- object vs event
- abstract vs physical
- event vs (ongoing) process
- role vs property
- co-location vs extensionality
- linear vs branching time
- relational vs absolute space
- ...

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Representing properties

Entities have properties and qualifications, some may change in time: color, weight, social conditions, duration, etc.

Here are some alternatives to represent properties.

1. **Extensional predicate**: [e.g. categories, essential qualities]
   extensional, absolute, needs a temporal parameter for change.
   \( P(x) \) or \( P(x, t) \).

2. **Reified property (constant)**: [e.g. roles]
   intensional, contextual, dynamic. The reified property can be seen as a concept or definition, \( C \), modeled via a classification relation (CF).
   \( CF(x, y, t) \equiv \text{‘concept } x \text{ classifies entity } y \text{ at time } t’ \).

3. **Individual quality**: [e.g. properties with changing values]
   an individual quality is a parasitic entity used to model aspects of its host. It exists as long as its host does (dependence).
   \( I(x, y) \equiv \text{‘the individual quality } x \text{ inheres in the entity } y \text{’} \).
Representing properties

Recall the different properties: extensional, reified, individual. Let’s discuss the following:

- “being a screwdriver”
  candidate for a category: \( \text{Screwdriver}(x) \)

- “being a disassembly tool”
  candidate for a role: \( \text{CF}(\text{DisassemblyTool}, x, t) \)

- “being material”
  candidate for a essential quality: \( \text{Material}(x) \)

- “having 1kg mass”
  candidate for an individual quality: \( \mathcal{I}(1\text{kgMass}, x) \)

- “being intentionally manufactured”
- “being round”
- “being brief”
Entity stacking

Not only the properties but also the entities can be conceptualized in different ways.
E.g.: can different entities be in the same location?

- the table / the wood
- the heart / the muscle

Is there just one entity that encompasses both
  - the table and the wood (a *table-shaped bulk of atoms*; a *wooden table object*),
  - the heart and the tissue bundle (a *heart-shaped muscle*; a *muscle-made heart*),
or do we recognize several entities that are co-located and interconnected?

Note: any answer depends on a choice of essential properties. We need to be aware of this connection to model it.
Entity stacking

Some alternatives for modeling “table”:
- only matter (holes, corners etc. are features of the shape)
- matter in a context
- only object (may include immaterial parts)
- only simple object in a context
- matter vs object
- matter vs object vs artifact

Q.: which ontological relationships link co-located entities?
- constitution
- composition
- parthood
- dependence
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Basic information

**DOLCE** (cf. [Masolo et al. 2002]):

- is built with a *descriptive* attitude
- provides a rich axiomatization
  - 37 basic categories
  - 7 basic relations
  - 80 axioms, 100 definitions (and 20 theorems)
- provides rigorous quality criteria and documentation
- it is a consistent theory
- it is the most used foundational ontology in European projects
Basic categories in DOLCE - 1

Objects (Endurants) and Events (Perdurants)

these are distinct categories connected by a relation called *Participation*.

E.g.:
- My body participates to this talk.
- John’s car tomorrow will participate to his traveling to office.
- You participate to the event called your life.
Basic categories in DOLCE - 2

Objects (3D continuants):
- Need a time-indexed parthood relation
- Exist in time
- Can genuinely change in time
- May have non-essential parts
- Are fully given whenever they are present (wholly presence, no temporal parts)

Events (4D occurrences):
- Do not need a time-indexed parthood relation
- Happen in time
- Do not change in time (as a whole...)
- All parts are essential
- Only some proper parts are present whenever they are present (partial presence, temporal parts)
Qualities

Qualities inhere in Objects (Physical Qualities) or in Events (Temporal Qualities) and correspond to ‘individualized properties’, i.e. they inhere only in a specific entity.

E.g.:

- ‘the color of this particular table’ (which is different from the color of that other table, no matter how similar they are).
- The velocity of this particular movement (which is different from the velocity of another movement, no matter how similar they are).

etc.

Each object or event comes with certain qualities that permanently inhere to it and are unique of it.

Physical Qualities are not instantaneous: ‘the color of this particular table’ can change in time.
Basic categories in DOLCE - 4

Each kind of Quality is associated to a Quality-space (another category) representing the space of the values that qualities can assume.

Properties hold because qualities have certain locations in their quality spaces.

- Quality-spaces are neither in time nor in space. Different quality-spaces associated to the same kind of Qualities are admitted.

- Space and Time are specific quality spaces; different quality-spaces for space and time are admitted.

Different Objects/Events can be spatio-temporally co-located: a relation called constitution formalizes colocalization.
The DOLCE Taxonomy

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The relations across the taxonomy
The properties of a gripper

- **Endurant**
  - Physical Endurant
  - Gripper_73

- **Quality**
  - Weight-quality
  - Indiv. weight-quality of Gripper_73

- **Quality-space**
  - Weight-Space
  - Weight_421

- **Parthood**
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Protégé is a free, open-source ontology editor and framework for building intelligent systems.

It has a plug-in architecture that can be adapted to build (even complex) ontology-based applications. Developers can integrate the output with rule systems or problem solvers.

Protégé fully supports the latest OWL 2 Web Ontology Language and RDF specifications from the World Wide Web Consortium.

It is based on Java, is extensible, and provides a plug-and-play environment

https://protege.stanford.edu/
https://protegewiki.stanford.edu/wiki/Main_Page
How to build an ontology in Protégé

1. Start Protégé
2. Create a new project:
   File -> New
3. A new empty Protégé project is created
4. Save it in your local file
   (you can change name but keep the ".owl" extension)
Basic steps in Protégé: new ontology
Basic steps in Protégé: adding a class

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Basic steps in Protégé: building the hierarchy

Class hierarchy: EventQuality

- Thing
  - Object
    - MaterialObject
      - Agentive
  - Event
    - PhysicalEvent
    - SocialEvent
  - Quality
    - EventQuality
    - ObjectQuality

Description: EventQuality

Equivalent To

SubClass Of
- Quality

General class axioms
Basic steps in Protégé: the ontology graph
Basic steps in Protégé: relations (ObjectProperty)

Create a new OWLObjectProperty

Name: HasQuality

IRI: http://www.semanticweb.org/stefano/ontologies/2018/0/untitled-ontology-38#HasQuality

New entity options...

Asymmetric

Reflexive

Irreflexive

Domains (intersection)

Ranges (intersection)

Disjoint With

SuperProperty Of (Chain)
Basic steps in Protégé: Domain and Range

Object property hierarchy:

- topObjectProperty
  - HasEventQuality

Annotations of HasEventQuality:

Characteristics of HasEventQuality:
- Functional
- Inverse functional
- Transitive
- Symmetric
- Asymmetric
- Reflexive
- Irreflexive

Description of HasEventQuality:
- Equivalent To
- SubProperty Of
- Inverse Of
- Domains (intersection)
  - Event
- Ranges (intersection)
  - EventQuality
- Disjoint With
Several toy ontologies are available on the web for practicing.

Typical examples are:

- (American) pizza ontology,
- the wine ontology,
- the animal ontology, and
- the university ontology.

(You can find these searching on the web.)
Opening an ontology in Protégé

Source:
https://protegewiki.stanford.edu/wiki/Protege4GettingStarted

Select “Open OWL ontology” from the Welcome screen and find the pizza.owl file on your filesystem.

you may also open pizza.owl directly from the Web: Start Protege, File menu -> Open from URL, and enter
http://protege.stanford.edu/ontologies/pizza/pizza.owl

The file opens by default to the “Active Ontology” tab which shows an overview of the pizza ontology, including:
– metrics on its contents,
– annotations about the ontology as a whole, and other imported ontologies (if any imports exist).

The drop-down on the toolbar displays the currently active ontology.
Navigation

From the “Entities” tab one can explore all of the classes, properties, and individuals in an ontology.

Each tab includes several views which can be resized, removed, floated, split, and layered.

When a class, property or individual is selected in the trees on the left-hand side, the right pane changes to display the selection immediately.

Most views implement hypertext navigation so that links can be followed easily regardless of which view you are using. Opening up the hierarchies and selecting a class or property displays the appropriate description on the right. Backward and forward navigation is possible with the left and right arrow buttons in the toolbar, which act just like a Web browser.
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Building an ontology

Basic steps for ontology development and ontology population:

1. fix the domain and scope of the ontology,
2. consider reusing existing ontologies,
3. list important terms for the ontology,
4. define the classes and the class hierarchy,
5. define the properties of classes,
6. define the relations among classes,
7. add instances
Exercise: structure an ontology

In everyday life and in our work we see many thing:

- trees
- mountains
- roads
- buildings
- chairs
- machines
- people
- dogs
- water
- blue (colors)
- transparency
- kissing
- walking
- contract signing
- duration
- ...

We know they are different and each of us can explain why.

If our explanations are coherent and well motivated, then we can use them to build an ontology.
How do we classify what we "see"?

Let us organize the list:

- trees, mountains, roads, water, buildings, chairs, machines, people and dogs are material objects
- people, dogs and (some) machines are material agentive objects
- blue and transparency are qualities (of material objects)
- kissing and walking are physical events
- contract signing is a physical social event
- duration is a quality (of events)

This organization corresponds to an ontology that uses three main classes: Object, Event and Quality.

Let us call it: oEq Ontology.
The taxonomy of OEQ

Note: a straight line connecting a class A and a class B (with B below A) stands for: B is a subclass of A
Exercise

Write this ontology in Protégé
(15 leaf classes plus the OEQ hierarchy)

Fix: classes and relations with domain and range
End of Lecture 2