Logics for Data and Knowledge Representation

Alessandro Agostini
agostini@dit.unitn.it

Fausto Giunchiglia
fausto@dit.unitn.it

University of Trento

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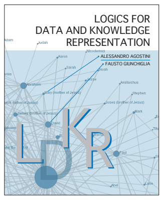
Contextual Ontologies C-OWL



- Ontologies & Contexts
- OWL: global semantics
- Limits of OWL
  - C-OWL
  - Mappings

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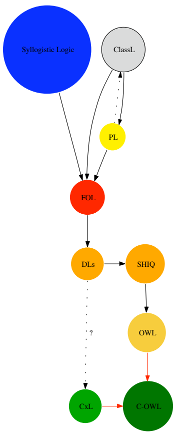
Logics Dependencies

- The web ontology language OWL builds upon a specific DL called *SHIQ* ...
- ... and the web context ontology language C-OWL builds upon CxL
- The logic dependencies diagram is on the right...



Ontologies / DL / OWL

- Formal conceptualizations that:
  - capture a shared understanding of a domain of interest (e.g. classification);
  - (in CS) provide a computable (machine manipulable) model of the domain.

Problem: the shared understanding contrasts with the local understanding (local knowledge)!

Introduction

- C-OWL is a context logic based ontology language for the World Wide Web.
- C-OWL extends OWL in two steps:
  1. moving from ontologies to contexts
  2. adding kinds of mappings among contexts.
- We shall see the very basics of C-OWL and its relationships with context logic CxL.

Ontologies vs Contexts (Ontologies)

- Ontologies are shared models of a domain that encode a view which is common to a set of different parties.
- Ontologies are best used in applications where the core problem is the use and management of common representations.

Examples: bio-informatics, knowledge management inside organizations, etc.

Ontologies: Pro's and Contra's

- **Strengths**:
  + "easy" exchange of information;
  + define a common understanding of terms, and thus make it possible to communicate between systems on a semantic level.
- **Weaknesses**:
  - used only with consensus about contents;
  - building and maintaining may be hard in dynamic/open/distributed domains (Web).

Ontologies vs Contexts (Contexts)

- Contexts are local models that encode a party's subjective view of a domain.
- Contexts are best used in those applications where the core problem is the use and management of local representations with a need for a controlled form of globalization
  - In Context Logic "controlled globalization" is maintaining locality within compatibility.

Contexts: Pro's and Contra's

- **Strengths**:
  + encode not shared interpretations;
  + "easy" to define and to maintain (none or limited consensus needed).
- **Weaknesses**:
  - communication achieved by constructing explicit mappings;
  - new topics and/or new parties requires the explicit definition of new mappings.

Contextual Ontologies

- How ontologies can be contextualized?
- An ontology is contextualized or, also, it is a contextual ontology, when its contents are kept local, where "local" implies not shared with other ontologies.
- Contextual ontologies are mapped with the contents of other ontologies via explicit "context mappings" (technical logical notion)

Contextual Ontologies

- A contextual ontology is a combination :
  Ontology + Context mappings.
- Key idea in two steps:
  1. Share as much as possible (extended OWL "Import" construct).
  2. Keep it local whenever sharing does not work (C-OWL context mappings).

Contextual Ontologies (Two Remarks)

1. In many (most in the Web?) cases sharing does not work and produces undesired results. This is the "famous" problem of

   semantic heterogeneity.

2. Using context allows for incremental, piece-wise construction of the Semantic Web (bottom-up vs. top-down approach).

Restarting OWL

- OWL can be described within a formal framework, more adequate to be used with a contextualized interpretation.
- Patel-Schneider and Hayes' semantics for OWL can be restarted in this framework.
- Reference: "OWL Web Ontology Language Semantics and Abstract Syntax" available at http://www.w3.org/TR/owl-semantics/

A Global Semantics for OWL

- Let I be a set of indexes.
  - Intuitively, I might be thought of as the set of URI's of a set of ontologies.
- Definition. An index OWL ontology is a pair $<i, O_i>$, where $i \in I$ and $O_i = <T_i, A_i>$ is a

  DL KB of the logic *SHOIN*(**D**) in a language L_i (T_i is a TBox and A_i is an ABox; both are meant to be written in the language L_i)

Formulas in O_i (Example)

- Suppose that C, D, E, F are DL concepts and R, S are DL roles.
- The following concepts can appear in O_i:
  - $C, D, E, F, i : C, (i : C), j : E$ for any $j \in I$
  - $C \sqcap D, C \sqcap (j : E), \geq nF.\top$ for $n \in N, j : C^-$
  - $\forall R. C \sqcap E, \exists (i : R).C, \exists (j : S).C \sqcap (j : F)$

Local Languages

- Definition. A local concept (role, individual) w.r.t. i (i-concept, i-role, i-individual) is a concept (role, individual) that appears in O_i either without index or with index equal to i. The (local) language of O_i is denoted by L_i.
- Definition. The local language of O_i, denoted by L_i, is the disjoint union of the set of local concepts, roles and individuals w.r.t. i.

Foreign Languages

- Definition. For $i,j \in I$ with $i \neq j$, a foreign concept (role, individual) w.r.t. i (j-foreign object w.r.t. i) is a concept (role, individual) that is *not local*, i.e. that appears in O_i but is defined in some ontology O_j.
- Definition. The j-foreign language of O_i, denoted by L_j, is the disjoint union of j-foreign concepts, roles and individuals w.r.t. i.

Example

- These concepts and roles are local w.r.t. i:
  - $C, D, i : C, C \sqcap D, \geq nF.\top, \exists (i : R).C, \forall R. C \sqcap E$
  - R
- These concepts / roles are j-foreign w.r.t. i:
  - $j : E, \; C \sqcap (j : E), j : C^-, \exists (j : S).C \sqcap (j : F)$
  - S

OWL Space

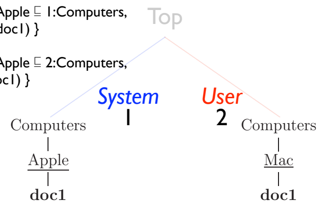
- By means of foreign concepts, roles and individuals, two ontologies can refer to the same semantic object in a third ontology.
- Definition. An OWL space is a family of index OWL ontologies $\{<i, O_i>\}_{i \in I}$ such that for every $i,j \in I$, $j \neq i$, the (local) language of O_i contains the j-foreign language of O_i.

Example

- OWL Space $\{<1, O_1>, <2, O_2>\}$

O_1 = {1:Apple ⊑ 1:Computers, 1:Apple(doc1) }

O_2 = {2:Apple ⊑ 2:Computers, 2: Mac(doc1) }



A Global Semantics for OWL (cont')

- Definition. An OWL interpretation for the OWL space $\{<i, O_i>\}_{i \in I}$ is a pair (Δ, I), where:

  Δ is a non-empty set of objects (domain);
  I is function such that for all $i \in I$,

  1. for every i-concept name A, $I(i, A) \subseteq \Delta$;
  2. for every i-role name R, $I(i, R) \subseteq \Delta \times \Delta$;
  3. for every i-individual name *a*, $I(i, a) \in \Delta$.

Remark

- The interpretation function I can be extended to all concepts representable in *SHOIN*(**D**) DL.
- An OWL interpretation (Δ, I) is a global interpretation, since language is interpreted against a global domain (the set Δ).
- The above overall approach is called the global semantics approach to OWL.

A Global Semantics for OWL (cont')

- An OWL interpretation (Δ, I) for $\{<i, O_i>\}_{i \in I}$ satisfies O_i for a fixed $i \in I$ if it satisfies every fact and every axiom of O_i according to Patel-Schneider and Hayes' OWL semantics.
  In symbols: $(\Delta, I) \models O_i$.
- (Δ, I) satisfies $\{<i, O_i>\}_{i \in I}$ if $(\Delta, I) \models O_i$ for all $i \in I$.
  In symbols: $(\Delta, I) \models \{<i, O_i>\}_{i \in I}$

Limitations of OWL (Expressive Power)

- The OWL ontology language has some strong limitations in its expressive power.
- Three situations where limits appear are:
  1. directionality of information flow;
  2. local domains;
  3. context mappings.
- We need to enrich ontologies with the capability to cope with 1, 2, and 3.

Limitations of OWL (1)

- **Directionality of information flow**:
  - sometimes we need to keep track of the source and the target ontology of a specific piece of information.

Let's see an example...

Example 1 (Bouquet *et. al*. 2003)

- Suppose that O_2 extends O_1, e.g. by importing O_1 and adding some new axioms:
  - O_1 contains: $A \sqsubseteq B$, $C \sqsubseteq D$ ($1{:}A \sqsubseteq 1{:}B$, $1{:}C \sqsubseteq 1{:}D$)
  - O_2 extends O_1 with axiom: $B \sqsubseteq C$ ($1{:}B \sqsubseteq 1{:}C$)
- Directionality is fulfilled if $B \sqsubseteq C$ does not affect what is stated in O_1 (O_1's consistency)
- We would like to derive transitivity of $\sqsubseteq$, i.e. $A \sqsubseteq D$ ($1{:}A \sqsubseteq 1{:}D$) in O_2 but *not in* O_1.

Example 2 (Bouquet *et. al*. 2003)

- A special form of directionality is the propagation of inconsistency.
- Let O_1, O_2 as in the previous example and suppose that O_2 extends O_1 by adding two (individual) axioms (*facts*): $1{:}A(a)$, $1{:}\neg D(a)$.
- O_2 becomes inconsistent, for $O_2 \vdash 1{:}A \sqsubseteq 1{:}D$.
- We would like to keep O_1 consistent.

Limitations of OWL (2)

- **Local domains**:
  - sometimes we need to give up the hypothesis that all ontologies are interpreted in a single global domain.

Let's see an example...

Example 3 (Bouquet *et. al*. 2003)

- Let O_{WCM} organize knowledge of a World-wide organization on Car Manufacturing.
- Suppose that O_{WCM} contains the "standard" description of a car with its components.
- Suppose O_{WCM}'s interpretation domain Δ is the totality of cars with their components.

Example 3 (cont') (Bouquet *et. al*. 2003)

- Suppose O_{WCM} contains:
  1. Individual constants for diesel engine and petrol engines: Diesel, Petrol
  2. Axioms stating that cars have exactly one engine which is either diesel or petrol, and that these two engines are different:
     $Car \sqsubseteq (\exists 1) hasEngine.\{Diesel, Petrol\}$
     $Diesel \neq Petrol$

Example 3 (cont') (Bouquet *et. al.* 2003)

- Suppose *Ferrari* accepts O_{WCM}'s standard descriptions and imports O_{WCM} into $O_{Ferrari}$.
- Suppose $O_{Ferrari}$ contains, in addition:
  1. Individual constants for petrol* engines: F23, F34i (*Ferrari does *not* produce diesel engines!)
  2. Axioms stating that F23≠F34i and that

Ferrari⊑(WCM : Car⊓∃(WCM : hasEngine).{F23,F34i})

Example 3 (cont') (Bouquet *et. al.* 2003)

- According to an OWL interpretation I for OWL space {<WCM,O_{WCM}>,<Ferrari,$O_{Ferrari}$>} either
  I(WCM,Diesel) = I(Ferrari,F23) or
  I(WCM,Diesel) = I(Ferrari,F34i).
- In the new (local) semantics, we would like to avoid this, since (we assumed that) Ferrari produces only petrol engines (e.g.F23,F34i).

Limitations of OWL (3)

- **Context mappings**:
  - we need to be able to state that two elements (concepts, roles, individuals) of two ontologies are contextually related, for instance because they both refer to the same object in the world.

    Let's see an example...

Example 4 (Bouquet *et. al.* 2003)

- Let O_{FIAT} organize the manufacturing viewpoint of FIAT (Italian car company).
- Let O_{Sale} organize the marketing viewpoint of some (unspecified) car vendor.
- Clearly, O_{FIAT} and O_{Sale} are very different.
- Still concepts in O_{FIAT} and O_{Sale} can describe the same real-world class of objects, e.g. as do these concepts: Sale : Car and FIAT : Car.

Example 4 (cont') (Bouquet *et. al.* 2003)

- There can be many reasons for wanting to integrate information about a class of objects viewed form different perspectives.
- For instance one might need to build a new concept which contains (some of) the information in Sale : Car and FIAT : Car.
- We would like to state a relation between two concepts in (very) different ontologies.

Example 4 (Remark)

- In OWL we cannot build a relation between Sale : Car and FIAT : Car, since it cannot be stated via OWL axioms.
- Take axiom Sale : Car ≡ FIAT : Car. It means

  that I(Sale,Car) = I(FIAT,Car) for <u>every</u> OWL interpretation I for {<FIAT,O_{FIAT}>,<Sale,O_{Sale}}, i.e. manufacturing and marketing viewpoints coincide <u>*at the instance level*</u> : Not the case!

C-OWL Overview

- Context OWL (C-OWL) is an ontology language whose syntax and semantics have been obtained *by extending the OWL syntax and semantics* to allow for the representation of "contextual ontologies".
- **Main References**:
  1.[Bouquet, Giunchiglia, *et. al.*, ISWC-03] (*)
  2.[Giunchiglia, Marchese, Zaihrayeu JDS-07]

A Local Semantics for OWL

- A local semantics for OWL is given by following the limitations of OWL.
- The new local semantics for OWL provide us to overcome these limitations.
- This argument is technical: Please see the paper "C-OWL: Contextualizing Ontologies" in the Proc. ISWC-03 (preprint available at http://dit.unitn.it/~ldkr/#Resources.)

A Local Semantics for Directionality

- To model directionality, we need to
  1. consider all (local) index OWL ontologies of an OWL space **O** = $\{<i, O_i>\}_{i\in I}$;
  2. split a OWL interpretation (global) for **O** into a family of "local interpretations," one for each ontology $<i, O_i>$ in **O**;
  3. allow for $<i,O_i>$ to be locally inconsistent, (i.e., not to have a local interpretation).

Directionality (technical note)

- We associate to each index OWL ontology $\{<i, O_i>\}$ of the OWL space a special "interpretation" *H*, called a hole.
- A hole *H* = (Δ,H) for **O** = $\{<i,O_i>\}_{i\in I}$ satisfies

  O if it satisfies all facts and all axioms in **O**.
  In symbols: *H* |= **O**
- So *H* satisfies every set of axioms in an OWL space, possibly contradictory.

Local Domains

- The OWL global semantics assumes the existence of a unique shared domain, so that each ontology of an OWL space $\{<i, O_i>\}_{i\in I}$

  describes the properties of the universe.
- In many cases this is not true as, for instance, an ontology on cars is not supposed to speak about medicines, or food.

A Local Semantics for Local Domains

- To model local domains, we need to
  1. associate to each ontology of an OWL space **O** = $\{<i, O_i>\}_{i\in I}$ a local domain;
  2. allow for local domains to overlap, as we have to cope with the case where two ontologies refer to the same object.
- O_{FIAT} and O_{Abarth} may refer to the same car, e.g. *500*, as Abarth is a racing brand of FIAT.

Local Domains (technical note)

- Definition. An OWL interpretation with local domains for the OWL space $\{<i, O_i>\}_{i \in I}$ is a family $\{(\Delta_i, I_i)\}_{i \in I}$, where each (Δ_i, I_i), called a local interpretation of O_i, is either an OWL interpretation of $\{<i, O_i>\}$ or a hole.

Context Mappings

- We need to be able to state that a certain property holds between two elements of two different ontologies (e.g., O_{FIAT}, O_{Sale}).
- E.g., Sale:Car ≡ FIAT:Car isn't an OWL axiom.
- The problem is not only semantic.
- Handling properties between two ontologies requires an extension of the OWL syntax.

Bridge Rules

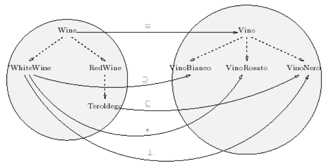
- The basic notion towards the definition of context mappings are "bridge rules."
- Definition. Let I be a set of indexes. A bridge rule from i ∈ I to j ∈ I is a statement of one of the four following forms,

$$i{:}x \xrightarrow{\sqsubseteq} j{:}y, \quad i{:}x \xrightarrow{\sqsupseteq} j{:}y, \quad i{:}x \xrightarrow{\equiv} j{:}y, \quad i{:}x \xrightarrow{\perp} j{:}y, \quad i{:}x \xrightarrow{*} j{:}y,$$

where x and y are concepts, or individuals, or roles of the languages L_i and L_j.

Bridge Rules Example

- A set of bridge rules from concepts (on wine) described by L_E (English) and concepts described by L_I (Italian) is represented here



Ontology (Context) Mappings

- Definition. Let an OWL space $\{<i,O_i>\}_{i \in I}$ and i,j ∈ I be given. A (context) mapping M_{ij} from O_i to O_j is a set of bridge rules from i to j.
- Remark 1: Mappings are directional, $M_{ij} \neq M_{ji}$.
- Remark 2: Mappings can be empty. $M_{ij} = \varnothing$ means that O_j can't interpret any i-foreign concept into some i-concept (ie. local to O_i).

Context Mappings vs. OWL Importing (1)

- A mapping M_{ij} can be used to represent the OWL importing of O_i into O_j.
- This happens under these conditions:
  - $M_{ij} = \{ i{:}x \xrightarrow{\equiv} j{:}y \mid x \in O_i \text{ and } y \in O_i \}$

    (M_{ij} represents the operation of mapping all of O_i into an equivalent subset S of O_j);
  - $S = O_j$.

Context Mappings vs. OWL Importing (2)

- OWL importing O_i into O_j is not exactly the same as mapping O_i to O_j with M_{ij}.
- Similarity: information goes from i to j.
- Difference:
  - OWL importing duplicates in O_j the i-foreign elements with no changes;
  - M_{ij} translates the semantics of O_i into O_j.

Contextual Ontology

- Definition. A contextual ontology (or: an OWL ontology *contextualized*) in an OWL space $\mathbf{O} = \{<i,O_i>\}_{i \in I}$ is a pair

  $(<j,O_j>, \{M_{ij} \mid i \in I\})$

  where:
  - $<j,O_j>$ is an (index) OWL ontology (in $\mathbf{O}$);
  - $\{M_{ij} \mid i \in I\}$ is a set of context mappings from O_i to O_j for every source ontology O_i.

Context Mappings (Two technical defs.)

- To give a formal interpretation of context mappings we need two "technical" notions:
- A context space is a pair $(\{<i,O_i>\}_{i \in I},\{M_{ij}\}_{i,j \in I})$.
- Let $\{<i,O_i>\}_{i \in I}$ and family $\{(\Delta_i,I_i)\}_{i \in I}$ of local interpretations be given. A domain relation r_{ij} from $i \in I$ to $j \in I$ is a subset of $\Delta_i \times \Delta_j$.

A Semantics for Context Spaces

- We extend the OWL interpretation to cope with *context spaces* and *domain relations*.
- Definition. An interpretation for a context space $(\{<i,O_i>\}_{i \in I},\{M_{ij}\}_{i,j \in I})$ is a pair $<\{(\Delta_i,I_i)\}_{i \in I}, \{r_{ij}\}_{i,j \in I}>$, where $\{(\Delta_i,I_i)\}_{i \in I}$ is an OWL interpretation with holes and local domains for $\{<i,O_i>\}_{i \in I}$, and $r_{ij} \subseteq \Delta_i \times \Delta_j$ for all $i,j \in I$.

Satisfiability of Bridge Rules

- An interpretation $\mathbf{I}=<\{(\Delta_i,I_i)\}_{i \in I},\{r_{ij}\}_{i,j \in I}>$ for a context space $(\{<i,O_i>\}_{i \in I},\{M_{ij}\}_{i,j \in I})$ satisfies a bridge rule from $i \in I$ to $j \in I$ if the following holds:

$$\mathfrak{I} \models i:x \xrightarrow{\sqsubseteq} j:y \ \textit{if} \ r_{ij}(x^{\mathcal{I}_i}) \subseteq y^{\mathcal{I}_j};$$
$$\mathfrak{I} \models i:x \xrightarrow{\sqsupseteq} j:y \ \textit{if} \ r_{ij}(x^{\mathcal{I}_i}) \supseteq y^{\mathcal{I}_j};$$
$$\mathfrak{I} \models i:x \xrightarrow{\equiv} j:y \ \textit{if} \ r_{ij}(x^{\mathcal{I}_i}) = y^{\mathcal{I}_j};$$
$$\mathfrak{I} \models i:x \xrightarrow{\perp} j:y \ \textit{if} \ r_{ij}(x^{\mathcal{I}_i}) \cap y^{\mathcal{I}_j} = \emptyset;$$
$$\mathfrak{I} \models i:x \xrightarrow{*} j:y \ r_{ij}(x^{\mathcal{I}_i}) \cap y^{\mathcal{I}_j} \neq \emptyset;$$

(notation: $\mathbf{I}$ is $\mathfrak{I}$ in the picture)

Models

- Definition.
  An interpretation $\mathbf{I} = <\{(\Delta_i,I_i)\}_{i \in I},\{r_{ij}\}_{i,j \in I}>$ for a context space $(\{<i,O_i>\}_{i \in I},\{M_{ij}\}_{i,j \in I})$ is a model for the context space if $\mathbf{I}$ satisfies all the bridges rules in M_{ij} for all $i,j \in I$.

Example 3 (cont') (Bouquet *et. al.* 2003)

- Reminder: According to an OWL interpretation I for the OWL space {<WCM,O_{WCM}>,<Ferrari,$O_{Ferrari}$>}, either:

  I(WCM,Diesel) = I(Ferrari,F23) or
  I(WCM,Diesel) = I(Ferrari,F34i).

- We would like to avoid this, and to state that F23 and F34i are two petrol engines.

Example 3 (cont') (Bouquet *et. al.* 2003)

- We employ the following context mapping: $M_{WCM,Ferrari}$ = {WCM : Petrol $\xrightarrow{\sqsupseteq}$ Ferrari : F23, WCM : Petrol $\xrightarrow{\sqsupseteq}$ Ferrari : F34i} (*)
- The domain relation $r_{WCM,Ferrari}$ (r_{WF}) in any interpretation

  $<\{(\Delta_i, I_i)\}_{i\in I}, \{r_{ij}\}_{i,j\in I}>$

  satisfying all bridge rules in (*) is such that $\{I_{Ferrari}(F23), I_{Ferrari}(F34i)\} \subseteq r_{WF}(I_{WCM}(Petrol))$.

Example 4 (cont') (Bouquet *et. al.* 2003)

- Reminder: we might need to build a new concept which contains (some of) the information in, say: Sale : Car and FIAT : Car.
- We would like to state a relation between the concepts Sale : Car and FIAT : Car under two hypotheses:

1. they belong to (very) *different* ontologies
2. they describe the *same class* of objects

Example 4 (cont') (Bouquet *et. al.* 2003)

- The hypothesis that Sale : Car and FIAT : Car describe the same class of objects (cars) can be captured by asserting the bridge rule:

  Sale : Car $\xrightarrow{\equiv}$ FIAT : Car (*)

- The domain relation $r_{SaleFIAT}$ in any interpretation $<\{(\Delta_i, I_i)\}_{i\in I}, \{r_{ij}\}_{i,j\in I}>$ satisfying (*) is such that $r_{SaleFIAT}(I_{Sale}(Car)) = I_{FIAT}(Car)$.

Summary

- Ontologies represent shared knowledge, Contexts keep knowledge local (*not shared*)
- Contextual ontologies share as much as possible, keep local whenever necessary
- C-OWL (Context OWL) is built from: OWL + Local Semantics (LMS)+ Mappings
- LMS extends OWL' *semantics*; Mappings extend OWL' *syntaxt* by using bridge rules

C-OWL & The SW Research Challenges

- How often in the (semantic) web we'll import ontologies and how often we'll define context mappings?
  - Diversity as a defect or as a feature?
- Shouldn't the SW be a web of semantic links? If yes, are these context mappings?
- Couldn't the SW be built from discovering context mappings, i.e. semantic matching?