UNIVERSITÄT LEIPZIG

Ontological Usage Schemes

A Working Proposal for the Ontological Foundation of Language Use

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Onto.Com Workshop @ ER 2011
November 2, 2011

Three Theses

on representation language semantics wrt interoperability

Theses on ontological and formal semantics

1. **distinguish** ontological and formal semantics
2. **establish** ontological and formal semantics **in parallel**
3. define ontological semantics regarding the **use of a language**

Outline

Background

- ontologies require representation languages
  - first-order logic (FOL)
  - description logic (DL)
  - Unified Modeling Language (UML)
  - ...
- top-level ontologies: to be offered in multiple formats
  - General Formal Ontology (GFO)

consequence

need for semantics-preserving translations

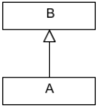
(between ontology representations, but applicable in general)

Motivation

observations on semantics-preserving translations

semantics-preserving translations

- well-established for formal semantics, e.g. preserving $T \models \phi$
  - between individual logics like DL and FOL
  - formal frameworks, e.g. based on institutions
- less clear for semi-formal languages, e.g. UML and DL

e.g. 

vs. $A \sqsubseteq B$

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- less clear for **non-standard** translations

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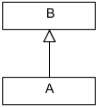
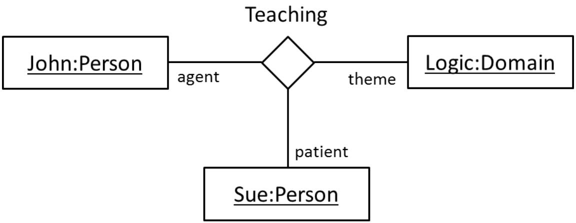


vs. $A \sqsubseteq B$ vs. specializes(A, B)

Toy Example

"John is teaching logic to Sue."

UML



FOL

Person(john)
Person(sue)
Domain(logic)

Teaching(john, sue, logic)

Person(john)
Person(sue)
Domain(logic)

Teaching(t_1)
hasAgent(t_1, john)
hasPatient(t_1, sue)
hasTheme(t_1, logic)

DL

Correspondences

regarding the example "John is teaching logic to Sue."

(Syntax)	UML	FOL	DL
John	object (entity with identity . . .)	ind. constant $\in U$	individual $\in \Delta$
Person	class (set of objects)*	1-ary predicate $\subseteq U$	concept $\subseteq \Delta$
Teaching	3-ary association (collection of links)*	3-ary predicate $\subseteq U^3$	concept $\subseteq \Delta$
agent	association end	(*argument position*)	role $\subseteq \Delta \times \Delta$

[* extensional aspect only]

[U and Δ: domain of discourse of the logic]

Revisiting Thesis 1

(Syntax)	**UML**	**FOL**	**DL**
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formal $\neq$ ontological semantics

- formal semantics: (encoding into) abstract notions
- as yet: semantics-preserving = preserving formal semantics
- side effects:
  - accumulation of encodings
  - (partially) unsuitable notion of conceptual equivalence

Revisiting Thesis 2

(Syntax)	**UML**	**FOL**	**DL**
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keep formal and ontological semantics in parallel

- formal: precise, well-understood, often purpose-specific
- ontological: required for meaning-preserving translations

Revisiting Thesis 3

(Syntax)	**UML**	**FOL**	**DL**
John	object (entity with identity ...)	ind. constant $\in U$	individual $\in \Delta$
Person	class (set of objects)*	1-ary predicate $\subseteq U$	concept $\subseteq \Delta$
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dependence on the use of a language L

- ontological analysis of used identifiers

  (formal semantics usually starts from abstract syntax categories)

- hence: multiple definitions of ontological semantics for L

Defining Ontological Semantics

the approach of Ontological Usage Schemes

Assumption: let ontological semantics be defined for L_Ω

- (referential, model-theoretic semantics, avoiding encodings)
- based on an ontology Ω_{base} (formalized in L_Ω)

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Ontological Usage Scheme, for any language L

- general idea: $L \xrightarrow[\text{(acc. to ontological analysis)}]{\text{translation}} L_\Omega$
  - should apply to specific use of L
  - ontological foundation is "built-in"
- more precise definition in the paper $\mathcal{S}(L) = (L, L_\Omega, \Omega_{base}, \varepsilon, \sigma, \tau)$

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  - ontological foundation is "built-in"
- more precise definition in the paper $\mathcal{S}(L) = (L, L_\Omega, \Omega_{base}, \varepsilon, \sigma, \tau)$
- *ontological image* for $R \subseteq L$:

  deductive closure of $\Omega_{base} \cup \bigcup_{t \in Tm(R)} \sigma(t) \cup \bigcup_{e \in R} \tau(e)$

Sample Ontological Usage Scheme

corresponding to the formal translation of ALC into FOL, $\mathcal{S}(\mathrm{ALC}) = (\mathrm{ALC}, \mathrm{FOL}, \mathcal{CR}, \varepsilon, \sigma, \tau)$

ALC SYNTAX	MAPPINGS (ε, σ, τ; AUXILIARY: $\hat{\tau}_x^V$)
Vocabulary	
$C \in N_C$	$\varepsilon(C) = \{\varepsilon_C\}$
	$\sigma(C) = \{\varepsilon_C :: \text{Cat}, \varepsilon_C \trianglerighteq \text{Ind}\}$
$R \in N_R$	$\varepsilon(R) = \{\varepsilon_R, q_1(\varepsilon_R), q_2(\varepsilon_R)\}$
	$\sigma(R) = \{\varepsilon_R :: \text{Reln}, q_1(\varepsilon_R) :: \text{RoleCat}, q_2(\varepsilon_R) :: \text{RoleCat}, \text{RoleBase}^2(\varepsilon_R, q_1(\varepsilon_R), q_2(\varepsilon_R))\}$
$a \in N_I$	$\varepsilon(a) = \{\varepsilon_a\}$
	$\sigma(a) = \{\varepsilon_a :: \text{Ind}\}$
Concepts	
$C \in N_C$	$\hat{\tau}_x^V(C) = x :: \varepsilon_C$
$C \sqcap D$	$\hat{\tau}_x^V(C \sqcap D) = x :: \hat{\tau}_x^V(C) \wedge x :: \hat{\tau}_x^V(D)$
$\neg C$	$\hat{\tau}_x^V(\neg C) = x :: \text{Ind} \wedge \neg x :: \hat{\tau}_x^V(C)$
$\exists R.C$	$\hat{\tau}_x^V(\exists R.C) = \exists y(y :: \text{Ind} \wedge \text{rel}^2(\varepsilon_R, q_1(\varepsilon_R), x, q_2(\varepsilon_R), y) \wedge \hat{\tau}_y^{V \cup \{y\}}(C))$ (for any new variable $y \notin V$)
TBox and ABox axioms (where C, D concepts, $a, b \in N_I$)	
$C \sqsubseteq D$	$\tau(C \sqsubseteq D) = \{\forall x \,.\, \hat{\tau}_x^{\{x\}}(C) \rightarrow \hat{\tau}_x^{\{x\}}(D)\}$
$C = D$	$\tau(C = D) = \{\forall x \,.\, \hat{\tau}_x^{\{x\}}(C) \leftrightarrow \hat{\tau}_x^{\{x\}}(D)\}$
$C(a)$	$\tau(C(a)) = \{\hat{\tau}_a^{\emptyset}(C)\}$
$R(a, b)$	$\tau(R(a,b)) = \{\text{rel}^2(\varepsilon_R, q_1(\varepsilon_R), \varepsilon_a, q_2(\varepsilon_R), \varepsilon_b)\}$

Discussion

applications & benefits

- reasoning over conceptual contents of representations
- basis for defining conceptual equivalence

  e.g. Teaching example ⟶ common ontological image

  - thus justifying non-standard translations
  - opinion: preserving implicit semantics should be secondary
- constraining / approving language use; re-engineering

  e.g. declaring Teaching and Person disjoint

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related work in conceptual modeling

- (semi-formal) mappings of language constructs to ontologies
- seemingly aiming at one-to-one mappings

  of abstract syntax and ontological categories
- applied mainly for constraining / checking language use

Conclusions

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translations into logical theories extending a formalized ontology

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THANK YOU! Any comments or questions?

Part I

Appendix

Direct Ontological Semantics for FOL Syntax

(How) does "bootstrapping" ontological semantics work?

- FOL syntax
- model-theoretic semantics where models are collections / pluralities of entities
- entities interpret individual constants
- logical constants as usual

predication

- no uniform semantic definition
- *predication definitions* must be added (within theories)
- except for fundamental predicates, defined by
  - natural language phrases (according to an ontology for them)
  - axiomatically within theories, i.e., every theory extends Ax_{fund}

Ontology of “Categories & Relations”