Formal semantics and corpus-based approaches to predicate-argument structure

Katrin Erk
Sebastian Pado
ESSLLI 2006

Structure

1. History of Semantic Roles
2. Contemporary Frameworks
3. Difficult Phenomena (from an empirical perspective)
4. Role Semantics vs. Formal Semantics
5. Cross-lingual aspects

Agenda

- Formal (sentence) semantics: a brief reminder of the basics
- Sources of world knowledge:
  - Ontologies
  - Corpus-based approaches
  - Frame-semantic analysis as a corpus-based approach based on something resembling an ontology
- Problems in combining the two
Formal (sentence) semantics: a brief reminder

- Sentence semantics:
  - Represent meaning of a sentence as a logic formula
  - The formula is then interpreted using model-theoretic semantics
- See e.g. LTF Gamut: Logic, Language, and Meaning

Representing the meaning of a sentence as a logic formula

- Peter is a student: \texttt{\textit{student}}\texttt{('peter')}
- Peter is not a student: \texttt{\neg \textit{student}}\texttt{('peter')}
- Only Peter is a student: \texttt{\forall x.\textit{student}}\texttt{(x) \iff x=Peter}
- Every child loves Asterix: \texttt{\forall x.\textit{child}}\texttt{(x) \rightarrow \textit{love}}\texttt{(x, Asterix)}
- Everybody has a fault: \texttt{\forall x.\textit{person}}\texttt{(x) \rightarrow \exists y.\textit{fault}}\texttt{(y) \land \textit{have}}\texttt{(x,y)}

Representing the meaning of a sentence using logic: issues

- Compositionality: The meaning of an expression is completely determined by the meanings of its components
  - life: \texttt{\textit{life}}
  - hit: \texttt{\lambda x, y.\textit{hit}}\texttt{(y, x)}
- Some important phenomena and questions:
  - Scope ambiguity, as shown in the "everybody has a fault" example
  - Plural
  - Negation
Model-theoretic semantics

- Interpreting a logic language by mapping components to a domain
- An interpretation of a first-order logic consists of
  - a nonempty universe (domain) D
  - an interpretation function I:
    - maps each n-place predicate symbol to a function from $D^n$ to \{true, false\}
    - \(I(\text{sleep}')\): true for all entities that sleep, false for all other entities

Model-theoretic semantics cont'd

- Interpretation function I:
  - maps each n-place predicate symbol to a function from $D^n$ to \{true, false\}
    - \(I(\text{sleep}')\): true for all entities that sleep, false for all other entities
  - Equivalently: I maps a predicate symbol p to the set of entity tuples for which p holds
    - \(I(\text{sleep}')\) is the set of all entities that sleep
    - \(I(\text{hit}')\) is the set of entity pairs \((e_1, e_2)\) such that \(e_1\) hits \(e_2\)

Formal (sentence) semantics and inferences

- Representation of sentence meaning as a logic formula: Then a theorem prover can be used to infer new knowledge from text
  - All humans are mortal. $\forall x. \text{human}(x) \rightarrow \text{mortal}(x)$
  - Socrates is human. $\text{human}(s)$
  - So Socrates is mortal. $\text{mortal}(s)$
- For more sophisticated inferences, world knowledge is needed. Where can we get it?
Formal (sentence) semantics and lexical knowledge

- Sentence semantics: "The meaning of life is life"
- The meaning of a word w: represented as w'.
- Different readings of w: w₁, w₂, ...
- Interpretation is performed by interpretation function, which maps w' to the domain
- Additional lexical information can be included in the form of axioms
  - documentation: there exists an event that is a documenting event and of which this documentation is the result

Agenda

- Formal (sentence) semantics: a brief reminder of the basics
- Sources of world knowledge:
  - Ontologies
  - Corpus-based approaches
  - Frame-semantic analysis as a corpus-based approach based on something resembling an ontology
- Problems in combining the two

Sources of world knowledge:

- Ontologies typically contain:
  - Inheritance relations between concepts
  - Axioms
Sources of world knowledge: corpus-based approaches

- Lexical acquisition: learning lexical and world knowledge from corpora
  - Selectional preferences: Resnik 96
  - Hyponymy: Hearst 92
  - Causal connections, happens-before, ...: VerbOcean, Chklovsky & Pantel 04
  - Part-whole relations: Girju et al 05

Frame-semantic analysis: corpus-based, with ontology

- Annotated corpus data with Frame-semantic analyses exists:
  - English FrameNet data
  - German SALSA data
- FrameNet has some properties of an ontology:
  - Frames have definitions (in natural language, though)
  - Frames are linked by Inheritance, Using, Subframe links

Frame-semantic analysis cont’d

- Lexical acquisition: learning additional knowledge about frames from corpora?
  - Selectional preferences for semantic roles
  - Inheritance relations between frames
Frame-semantic analysis as partial semantic analysis

- Formal (sentence) semantics: complete representation of sentence meaning
- Frame-semantic analysis:
  - Represents just frames and roles
  - Ignores negation, plural, scope
- Next up: example for complete frame-semantic analysis of a text

Frame-semantic analysis for contiguous text (from FrameNet webpage)

1. Why CAN’t we TEACH education teaching our CHILDREN to READ, WRITE, and reckon? It’s not that we don’t KNOW how to, because we do. It’s that we don’t.

   - Why CAN’t we teach our children to read, write and reckon?

   - Why CAN’t we teach our children to READ, WRITE, and reckon?

FrameNet example cont’d:

All words in capitals are predicates

1. The ART of change-ringing is PECULIAR, especially to the ENGLISH, who, by origin and culture, most admire the LOVELIEST, most charming buildings of CHURCHES. The STANDS of BELL-SOUNDING, from its TOWER, attracting people by religion to EVENSONG.

2. “The Nine Tailors”

3. ASLACTON, England - OF, active, all SCENES, situation that EVOKES the RURAL, by one, England; this is one OF the LOVELIEST, And most charming buildings of CHURCHES. The STANDS of BELL-SOUNDING to its TOWER, attracting people by religion to EVENSONG.
Why integrate sentence semantics with something like frame-semantic analysis?

- Carlson (1984): a semantics that critically relies on semantic roles for semantics construction
- Our argument is different:
  - Not that semantics construction would need semantic roles
  - But that formal semantics can profit from ontology-based and corpus-based approaches that add lexical and world knowledge

Agenda

- Formal (sentence) semantics: a brief reminder of the basics
- Sources of world knowledge:
  - Ontologies
  - Corpus-based approaches
  - Frame-semantic analysis as a corpus-based approach based on something resembling an ontology
- Problems in combining the two

Integrating sentence semantics with frame-semantic analysis

- Modular combination?
  - Sentence semantics yields meaning representation for a sentence
  - Frame-semantic analysis adds knowledge about predicate meaning and meaning or argument positions
- Problems with vagueness again:
  - A problem for theorem provers
  - A problem for model-theoretic semantics
A problem for theorem provers

- Two types of non-certain knowledge from sense and role analysis:
  - defeasible information: “birds can fly”
  - more-or-less information
    - “falsehood” in conceptualization of “lie”
    - selectional preferences learned from corpora

- How can theorem provers deal with this?
  - Propositional logic: Bayesian networks
  - First-order logic: currently an active research area in the AI community

A problem for model-theoretic semantics

- Discussing the problem for theorem provers, we have assumed that we can integrate the information coming from the frame-semantic analysis into our sentence semantics. But can we?

- Interpretation function maps each n-place predicate symbol to a function from \( D^n \) to \{true, false\}

- What is the interpretation of “lie’”?

  - Interpretation function: each event in the domain is either a lie, or it isn’t

- It is not possible to model with an interpretation function a concept with fuzzy boundaries, i.e. the intuition that some event can be “kind of a lie”, “a little bit of a lie”.

- So: If we want to use an interpretation function, boundaries have to be made strict.
We stop here.
This is an introductory class, after all.

Summary

- Formal (sentence) semantics:
  - Representing the meaning of the whole sentence
  - Resulting formulas can be fed into a theorem prover for inferences
  - Lexical meaning not at focus

- Ontologies and corpus-based approaches can furnish additional lexical and world knowledge

- Frame-semantic analysis as an ontology-based and corpus-based approach
  - Represents only part of the sentence meaning

Summary

- Combining formal sentence semantics with frame-semantic analyses or a similar approach:
  - Aim: augment lexical and world knowledge

- Problems with vagueness:
  - Non-certain knowledge difficult for theorem provers:
    - Defeasible knowledge
    - More-or-less knowledge
  - Problem with model-theoretic semantics: Categories with “fuzzy boundaries” cannot be represented
References
