

L95: Introduction to Natural Language Syntax and Parsing

Lecture 8: Formal Semantics

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Organisational

- You read for today: Section 6 (Semantics of English)
- You finished for today: Logic worksheet (assumed read & understood)
- **Today:** Formal semantics (some explanations beyond logic worksheet)
- Next time: Feedback on Assignment 4

Reading for next week (pragmatics):

- Section 7 in the handout

Formal Semantics

- Logical truth-conditional semantics
- Use concept of truth to relate linguistic expressions to actual states of affairs in the world
- has a mechanism of determining whether a statement is true (model-theory)
- and a mechanism for determining whether a statement is constructable according to the axioms and rules of inference in the logical system (proof-theory)
- Proof-theoretic method:
 - a) translate sentences into formulas of predicate / first-order logic (FOL)
 - b) pass these formulae to a theorem prover.

Syntax/Semantics Interface

- Semantic productivity: we can express an unlimited number of meanings
- Therefore, we need recursive rules that can produce an infinite set of propositions.
- Semantic rules must be sensitive to syntactic structure (e.g. because of ambiguity)
- Principle of Compositionality: the meaning of a sentence (its propositional content) will be a productive, rule-governed combination of the meaning of its constituents.
- Sometimes unclear which module should handle the ambiguity, syntax or semantics:
 - **a** Competent women and men go far
 - **b** He fed her dog biscuits
 - **c** Everyone knows one language

Propositions

What we study in formal semantics are **propositions**.

- Propositions are states of affairs (meanings) in the real world.
- Propositions are the semantic value of a sentence.
 - *The window is open*

Interpretation of a Proposition

We can evaluate the truth of the proposition

Rover barks and nobody chases Kitty.

with respect to the following model:

chase:	$\{ \langle l, k \rangle, \langle l, l \rangle, \langle l, r \rangle \}$
sleep:	$\{ \}$
bark:	$\{ r \}$

- The meaning of a proposition is its truth conditions.
- A proposition is true or false depending on the state of affairs that obtain in the world.
- Knowing the meaning of a proposition is to know what the world would need to be like for the sentence to be true.
- We call this a model of the world.

Semantic Diagnostics

Contradictions:

- It is raining and it is not raining
- A bachelor is a married man
- Kim killed Sandy but she walked away

Entailment

- **a** Kim walked slowly
- **b** Kim walked
- **c** Kim sold Sandy the book
- **d** Sandy bought the book from Kim

Truth of **a** entails truth of **b**

Truth of **c** entails truth of **d**

Semantic synonymy

- **a** Kim is a bachelor
- **b** Kim is an unmarried man

Semantic synonymy is maintained under entailment

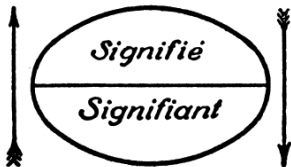
De Saussure

The arbitrariness of the sign



Signifier and signified

The arbitrariness of the sign



De Saussure divided the sign into two components:

- the signifier (or “sound-image”)
- the signified (or “concept”).

Today, following Hjelmslev, the **signifier** is interpreted as the material form (something which can be seen, heard, touched, smelled or tasted) and the **signified** as the mental concept.

Referring expressions

- The meanings of referring expressions (e.g. *Kim*, *he*) are taken to be individual entities in the model.
- Predicates are functions from individual entities to truth-values.
- (As you know, truth-values are the meanings of propositions)
- The functions can also be characterised in terms of sets in the model; this extended notion of reference is usually called denotation.

Denotations of different PoS

- The semantic values of words are combined to produce the semantic values of phrases.
- The semantic value of a sentence is a proposition, which is true or false
- Then what are the semantic values of all the other PoS and phrases?
- Denotation: the appropriate 'links' between a linguistic expression and the world (in such a way that they combine together to build propositions in our logic).
- Proper names – denotes one individual in the world
- Intransitive verbs – denotes set of individuals that have the property in a particular model
 - snores(Kim)
- Transitive verbs? Definite descriptions (e.g. *the dog*)?
- Logics worksheet

Internal and external nature of meaning

- External meaning: statements about the world
- Internal meaning: Inner states; how we perceive the world (what we know, which inferences we make)
 - External meaning is taken as basic definition of meaning
 - The Internal meaning can be built on top of such a theory based on external meaning.

Extensional and Intensional Semantics

- *The morning star is the evening star.*
- This sentence represents a “big deal” in astronomical discovery.
- But if referring expressions refer only to the objects they denote in the world, the meaning of this sentence would be a tautology:
 - *Venus is Venus.*
- Intensional logics extend the meaning of *the morning star* beyond just its denotation (*Venus*) to the concept it conveys (*star seen in morning*; sometimes called “sense”).
- But these logics use higher-order logical constructs and thus go beyond FOL.

Scope and Scope Ambiguity

Everyone knows one language

$$\forall x : \textit{person}(x) \exists y : \textit{language}(y) \wedge \textit{know}'(x, y)$$

$$\exists y : \textit{language}(y) \forall x : \textit{person}(x) \wedge \textit{know}'(x, y)$$

Practical Example: Alexander Kuhnle (2019)'s PhD thesis

- Idea: test Visual QA systems on model-theoretically verifiable images
- Simultaneous generation of unlimited sentences and pictures



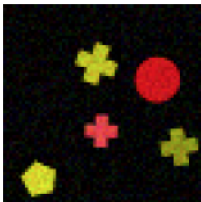
At least half the triangles are red.

More than a third of the shapes are cyan squares.

More than one of the seven cyan shapes is a square.

From: Kuhnle (2019)

Kuhnle (2019): model



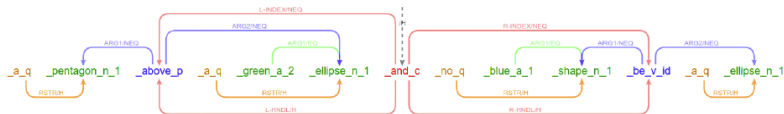
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{ color: {name: black, shade: 0.0}, noise-stddev: 0.1, size: 64, objects:  
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    rotation: 0.53, shape: {name: circle, extent: {x: 0.12, y: 0.12}} },  
    { center: {x: 0.92, y: 0.73}, color: {name: yellow, shade: -0.42},  
    rotation: 0.73, shape: {name: cross, extent: {x: 0.09, y: 0.09}} ] }
```

From: Kuhnle (2019)

Kuhnle (2019): Under the hood

“A pentagon is above a green ellipse, and no blue shape is an ellipse.”

↑ ACE + ERG realisation ↑



↑ Component DMRS mapping ↑

$\exists a$	$a.shape=pg$	$a.y>b.y$	$\exists b$	$b.color=gr$	$b.shape=el$	\wedge	$\neg\exists c$	$c.color=bl$	true	$c=d$	$\exists d$	$d.shape=el$
	$\exists a : a.shape=pg$	$a.y>b.y$		$\exists b : b.color=gr \wedge b.shape=el$		\wedge		$\neg\exists c : c.color=bl$		$c=d$		$\exists d : d.shape=el$
	$\exists a : a.shape=pg \wedge [\exists b : b.color=gr \wedge b.shape=el \wedge a.y>b.y]$					\wedge	$\neg\exists c : c.color=bl \wedge [\exists d : d.shape=el \wedge c=d]$					
$(\exists a : a.shape=pg \wedge [\exists b : b.color=gr \wedge b.shape=el \wedge a.y>b.y]) \wedge (\neg\exists c : c.color=bl \wedge [\exists d : d.shape=el \wedge c=d])$												

From: Kuhnle (2019)

Kuhnle (2019): problems with alternative VQA datasets



- What object is shining on the animal?
- What objects is the cat sitting behind?
- How many cats?

From: Kuhnle (2019)

Pragmatics/Semantics Interface

- Speech Act theory (Searle, Austin): Sentences have propositional content, utterances are social acts that achieve effects.
- **Locution** is what was literally said and meant, **Illocution** is what was done, and **Perlocution** is what happened as a result.
- Example: “Is there any salt?”
- Important in order to do semantics: there is a logical truth-conditional substrate to the meaning of natural language utterances (namely “propositional content” or “logical form”)
- Underspecification: context-dependent aspects of a proposition include reference resolution, such as some uses of personal pronouns, here, this, time of utterance, speaker etc.

Semantic Features and Relations

- Non-model-theoretic expressions of meaning
- (e.g., *man* (main sense) = *HUMAN+*, *MALE+*, *ADULT+*)
- word meanings can also be expressed in terms of relations like hyponymy (is-a, superordinate-of); cf. WordNet
- (e.g., *man* is a hyponym of *human* which is in turn a hyponym of *animal*.)
- can be used for if we have the expressive power to represent general rules or meaning postulates
 - *If any individual has the property of being a man then that individual has the property of being human* OR
 - *Any individual that is male and human and an adult is also a man.*

Thematic Roles

- Another kind of semantic notation without denotation
- Also called theta-roles, semantic cases, semantic roles
- Arguments in predicates can be labelled with “Agent” and similar
 - **(a) Kim** (agent) **kissed Sandy** (patient/theme)
 - **(b) Sandy** (experiencer) **enjoyed being kissed**
 - **(c) Sandy** (agent) **gave Kim** (goal/benefactive) **a pen** (theme)
 - **(d) Sandy** (agent) **flew the plane** (patient/theme) **from London** (locative/source) **to Paris** (locative/goal)
 - **(c) Sandy** (?) **flew from London to New York.**
- Agents are usually subjects of verbs denoting events and often cause these events to come about.

Next Time

- From Semantics to Pragmatics
- Def: meaning transmitted in an utterance above and beyond propositional content
- Speech acts, presuppositions, Gricean Maxims of Cooperation