

CSE842: Natural Language Processing

Lecture 14: Semantic Analysis

Announcement

- Homework 3 Assignment is posted on the Angel.
 - Due date: **March 16** at the beginning of the lecture
- Start to think about your final project
 - You can work on your own or as a team of two members.
 - You are encouraged to come up with your own topics relevant to your respective research fields that need NLP.
 - A list of potential topics will be made available shortly.

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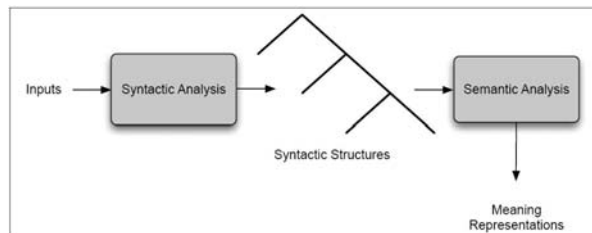
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Semantic Analysis

Assigning meaning representation to linguistic inputs

Several approaches:

- Syntax-driven semantic analysis
- Semantic grammars
- Information extraction -> separate lecture!



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Syntax-Driven Semantic Analysis

- Key ideas: Principle of Compositionality (Frege)
 - The meaning of a sentence is composed by the meaning of its parts
 - Which parts? Words?
- How to make this principle useful?
 - Account for the meaning not solely for the words, but also
 - Ordering
 - Grouping
 - Relations among the words

} Syntactic Components and Relations

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Semantic Augmentations to Context-Free Grammars

- Augmenting context-free grammar rules with semantic attachments
- What are attachments?
 - Instructions that specify how to compute the meaning representation of a construction from the meanings of its consistent parts
- Abstract:
 $A \rightarrow \alpha_1 \dots \alpha_n$ syntactic constituent
 $\{f(\alpha_j \text{sem}, \dots, \alpha_k \text{sem})\}$ semantic attachment
A.sem can be computed by running the function f on some subset of the semantic attachments of A's constituents.

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Semantic Attachments

- Extend each grammar rule with instructions on how to map the components of the rule to a semantic representation (grammars are getting complex)
 $S \rightarrow NP VP \{VP.sem(NP.sem)\}$
- Each semantic function is defined in terms of the semantic representation of choice
- Problem: how to define these functions and how to specify their composition so we always get the meaning representation we want from our grammar?

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Example

Maharani closed: closed(maharani)

- Associating constants with constituents
 - ProperNoun \rightarrow Maharani {Maharani}
- Defining functions to produce these from input
 - NP \rightarrow ProperNoun {ProperNoun.sem}
 - Assumption: meaning reps of children are passed up to parents for non-branching constituents
- Verbs here are where the action is
 - VP \rightarrow Verb {Verb.sem}
 - Verb \rightarrow closed $\{\lambda x.Closed(x)\}$

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How do we combine these pieces?

– $S \rightarrow NP VP \{VP.sem(NP.sem)\}$



$\lambda x.Closed(x)$ (Maharani)

Closed(Maharani)

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Lambda Notation for Semantic analysis

- Semantic attachment to grammar rules consist primarily of λ -reduction
 - One element of an attachment serves as a functor and the rest serve as arguments to it
- Lexicon introduces meaning representation

More to Handle

Every restaurant closed

$$\forall x \text{ Restaurant}(x) \rightarrow \exists e, \text{ Closed}(e) \wedge \text{ ClosedThing}(e, x)$$

Rationale to arrive at this meaning representation:

- “Every Restaurant” $\rightarrow \forall x \text{ Restaurant}(x)$
- normally embedded in expressions that try to say sth about all the restaurants (nuclear scope).

$$\forall x \text{ Restaurant}(x) \rightarrow Q(x)$$

- Ultimately, we want to replace “Q” with the logical expression corresponding to the nuclear scope.

$$\lambda Q. \forall x \text{ Restaurant}(x) \rightarrow Q(x)$$

- How to arrive the semantic representation for “every restaurant”?

Let’s take a look at the grammar rules with their semantic attachments:

NP \rightarrow Det Nominal {Det.Sem(Nominal.Sem)}

Det \rightarrow every { $\lambda P. \lambda Q. \forall x P(x) \rightarrow Q(x)$ }

Nominal \rightarrow Noun {Noun.Sem}

Noun \rightarrow restaurant { $\lambda x. \text{Restaurant}(x)$ }

Steps for processing “every restaurant”

$\lambda P. \lambda Q. \forall x P(x) \rightarrow Q(x)$ ($\lambda x. \text{Restaurant}(x)$)

$\lambda Q. \forall x \lambda x. \text{Restaurant}(x) (x) \rightarrow Q(x)$

$\lambda Q. \forall x \text{Restaurant}(x) \rightarrow Q(x)$

- What about the rest?

Let’s take a look at the grammar rules with their semantic attachments:

S \rightarrow NP VP {NP.Sem(VP.Sem)}

VP \rightarrow Verb {Verb.Sem}

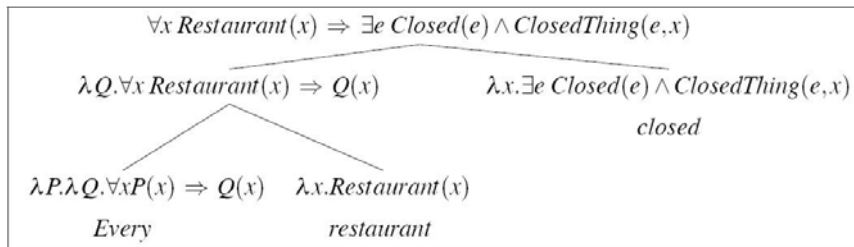
Verb \rightarrow closed { $\lambda x. \exists e \text{ Closed}(e) \wedge \text{ClosedThing}(e, x)$ }

Steps for processing the rest

$\lambda Q. \forall x \text{Restaurant}(x) \rightarrow Q(x)$ ($\lambda y. \exists e \text{ Closed}(e) \wedge \text{ClosedThing}(e, y)$)

$\forall x \text{Restaurant}(x) \rightarrow \lambda y. \exists e \text{ Closed}(e) \wedge \text{ClosedThing}(e, y) (x)$

$\forall x \text{Restaurant}(x) \rightarrow \exists e \text{ Closed}(e) \wedge \text{ClosedThing}(e, x)$



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Back to the Previous Example

Maharani closed

$\exists e \text{ Closed}(e) \wedge \text{ClosedThing}(e, \text{Maharani})$

If use the following rule for S

$S \rightarrow \text{NP VP } \{\text{NP.Sem}(\text{VP.Sem})\}$

Need to update the lexicon accordingly:

ProperNoun \rightarrow Maharani $\{\lambda x. x(\text{Maharani})\}$

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- Functional Characterization of Semantic Attachment
 - Associating complex, function-like λ -expressions with lexical items
 - Copying semantic values from children to parents
 - Applying the semantics of one of the children of a rule to the semantics of the other children of the rule through λ -reduction.
- Still, a lot more problems need to be solved:
 - Quantifier scope ambiguity
 - E.g., Every restaurant has a menu
 - Use context and world knowledge
- Many extra abilities need to be introduced
 - Store and retrieve approaches
 - Constrain-based approaches

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Problems with Syntactic-Driven Semantics

- Syntactic structures often don't fit semantic structures very well
 - Important semantic elements often distributed very differently in trees for sentences that mean 'the same'

I like music. Music is what I like.

 - Parse trees contain many structural elements not clearly important to making semantic distinctions
 - Syntax driven semantic representations are sometimes pretty bizarre
- Alternative: Semantic Grammar

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Semantic Grammars

- An alternative to taking syntactic grammars and trying to map them to semantic representations is defining grammars specifically in terms of the semantic information we want to extract
 - Domain specific: Rules correspond directly to entities and activities in the domain
- I want to go from Boston to Baltimore on Thursday, September 24th*
- TripRequest → Need-spec travel-verb from City to City on Date
 - ...

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Drawbacks of Semantic Grammars

- Lack of generality
 - A new one for each application
 - Large cost in development time
- Can be very large, depending on how much coverage you want it to have
- If users go outside the grammar, things may break disastrously

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Summing Up

- Hypothesis: Principle of Compositionality
 - Semantics of NL sentences and phrases can be composed from the semantics of their subparts
- Rules can be derived which map syntactic analysis to semantic representation (Rule-to-Rule Hypothesis)
 - Lambda notation provides a way to extend FOPC to this end
 - But coming up with rule2rule mappings is hard
- Idioms, metaphors perplex the process
- Semantic grammar could be an alternative to syntax-driven approach

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Lexical Semantics

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What is lexical semantics?

- Meaning of Words
- Lexical Relations
- WordNet
- Thematic Roles
- Selectional Restrictions

Lexeme

- Lexeme is an entry in the lexicon that includes
 - an orthographic representation
 - a phonological form
 - a symbolic meaning representation or sense
- Dictionary entries:
 - Red *n*: the color of blood or a ruby
 - Blood *n*: the red liquid that circulates in the heart, arteries and veins of animals
 - Right *adj*: located nearer the right hand esp. being on the right when facing the same direction as the observer
 - Left *adj*: located nearer to this side of the body than the right

- Do dictionaries give us definitions?
 - Some are circular
 - All are defined in terms of other lexemes
 - You have to know something to learn something
- What can we learn from dictionaries?
 - Relations between words:
 - Oppositions, similarities, hierarchies

Homonymy

- Homonyms: Words with same form but different, *unrelated* meanings, or senses (multiple lexemes)
 - A **bank** holds investments in a custodial account in the client's name.
 - As agriculture is burgeoning on the east **bank**, the river will shrink even more
- Similar phenomena
 - homophones - read and red (different orth. form)
 - homographs - bass and bass (different phon. form)

Polysemy?

- Word with multiple but *related* meanings (same lexeme)
 - *They rarely serve red meat.*
 - *He served as U.S. ambassador.*
 - *He might have served his time in prison.*
- What's the difference between polysemy and homonymy?
 - Homonymy: distinct, unrelated meanings
 - Polysemy: distinct but related meaning
 - Different etymology?
 - Coincidental similarity?
 - sperm bank, egg bank, blood bank vs. bank bank

Synonymy

- Substitutability: different lexemes with the same meaning
 - *How big is that plane?*
 - *How large is that plane?*
 - *How big are you? Big brother is watching.*
- What influences substitutability?
 - Polysemy (large vs. old sense)
 - register: He's really cheap/?parsimonious.
 - collocational constraint: roast beef, ?baked beef
 - convention: economy fare/?price

Hyponymy

- General: hypernym (superordinate)
 - “vehicle” is a hypernym of “car”
- Specific: hyponym (underneath)
 - “car” is a hyponym of “vehicle”
- Test: That is a *car* implies that is a *vehicle*
- What is ontology? Object in some domain
- What is taxonomy? Structuring of those objects
- What is object hierarchy? Structured hierarchy that supports feature inheritance

WordNet

- Lexical database
 - George Miller et al. at Princeton
 - <http://www.cogsci.princeton.edu/~wn>
 - Most widely used hierarchically organized lexical database for English
 - Synset: set of synonyms, a dictionary-style definition (or gloss), and some examples of uses --> a concept
 - Databases for nouns, verbs, and modifiers (adjectives & adverbs)
- Lexical relationships are implemented as semantic networks, where applications can traverse to find synonyms, antonyms, hierarchies,...

Event Participants

- An important aspect of lexical meaning has to do with the semantics of events.
- Predicate-argument structure for representing an event
 - neo-Davidsonian reification of events
- Semantic constraints on the arguments of event predicates:
 - Semantic roles: thematic roles
 - Selectional restriction

Thematic Roles

- John broke a glass

$\exists e, y, \text{Breaking}(e) \wedge \text{Breaker}(e, \text{John})$
 $\wedge \text{BrokenThing}(e, y) \wedge \text{GlassWare}(y)$

- Mary opened a jar

$\exists e, y, \text{Opening}(e) \wedge \text{Opener}(e, \text{Mary})$
 $\wedge \text{OpenedThing}(e, y) \wedge \text{Container}(y)$

Thematic Roles

A set of roles:

- agent, theme: *John broke a glass*
- experiencer: *John broke an angle in the football game*
- force, result, content, instrument, beneficiary, source, goal,...

The dog ate the cheeseburger.

What is *cheeseburger*?

The sniper shot his victim with a rifle.

What is *rifle*?

Proposition Bank (PropBank)

- Annotate the Penn TreeBank (release 2) with predicate-argument information
- The semantic roles are defined with respect to an individual verb sense.
- Corpus can be used for automatic learning for surface realization of each argument

PropBank

- General procedure
 - Select for each verb the roles that occur most frequently
 - Use Arg0, Arg1,... Arg5. Arg0 usually stands for Agent, Arg1 for patient or direct object, Arg2 for instrument, indirect object, etc. What each Arg stands for depends on a specific verb sense.

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PropBank

Arguments are defined based on each verb

BUY	SELL	PAY
Arg0: buyer	Arg0: seller	Arg0: buyer
Arg1: thing bought	Arg1: thing bought	Arg1: price paid
Arg2: seller	Arg2: buyer	Arg2: seller
Arg3: price paid	Arg3: price paid	Arg3: thing bought
Arg4: benefactive	Arg4: benefactive	Arg4: benefactive

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Word Senses in PropBank

APPLY
"ask for"

Arg0: applier
Arg1: thing applied for
Arg2: entity applied to

"Boyer and Cohen ...
applying for a patent
on their gene-splicing
technique"

APPLY
"associate with"

Arg0: applier
Arg1: thing applied
Arg2: applied to

"Gen-Probe ... to
apply existing
technology to an
array of diagnostic
products"

APPLY
"smear"

Arg0: applier
Arg1: substance
Arg2: surface
Arg3: instrument

"Sterile maggots
could be bought
to apply to a
wound"

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Functional Tags in PropBank

ArgM-DIR: directionals	walk along the road
ArgM-LOC: locatives	walk around the countryside
ArgM-MNR: manner	works well with others
ArgM-TMP: temporal	in 1987
ArgM-EXT: extent	raised prices by 15%
ArgM-REC: reciprocals	John and Mary killed each other
ArgM-PRD: predication	Mary called John an idiot
ArgM-PRP: purpose	I live to eat
ArgM-DIS: discourse	also, however
ArgM-ADV: other adverbial	generally?
ArgM-MOD: modal	possibly
ArgM-NEG: negative	did not
ArgM: bare ArgM	adjuncts not related to verb, e.g. extraposed modifier

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Examples

1. [Arg0 Big Fruit Co.] increased [Arg1 the price of bananas]
2. [Arg1 The price of bananas] was increased again by [Arg0 Big Fruit Co.]
3. [Arg1 The price of bananas] increased [Arg2 5%].

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What about

1. [Arg1 The price of bananas] *rosed* [Arg2 5%].
2. [Arg1 The price of bananas] *increased* [Arg2 5%].
3. There has been a [Arg2 5%] *rise* [Arg1 in the price of bananas].

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FrameNet

- Roles in the FrameNet are specific to a frame.
- Developed by Charles Fillmore and Collin Baker at the International Computer Science Institute (ICSI), UC Berkeley since mid 1990s. <http://www.icsi.berkeley.edu/~framenet>
- Relate English words to underlying semantic “frames”
 - Frames are networked using several relations
 - Based on corpus analysis

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Some FrameNet Frames

Frame: TRANSPORTATION

Frame elements: MOVER, MEANS, PATH

Scene: MOVER moves along PATH by MEANS

Frame: DRIVING

Inherit: TRANSPORTATION

Frame elements: DRIVER (=MOVER), VEHICLE (=MEANS), RIDER (=MOVER), CARGO (=MOVER)

Scenes: DRIVER starts VEHICLE; DRIVER controls VEHICLE; DRIVER stops VEHICLE

Annotation:

Now [_D Van Cheele] was **driving** [_R his guest] [_P back to the station].

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Hierarchy of Frames

Event:	Theme, Cause, Result, Place, Time
↓	
Action:	Actor, Means, Manner
↓	
Action-Intentional:	(Actor.type = Sentient)
↓	
Crime-against-People:	Perpetrator (=Actor), Victim (=Theme), Weapon (=Means)
↓	
Assault:	Assailant (=Perpetrator), (Intention = "bodily harm"), Threat = Action-on-Bodily-Target
↓	
Assault-with-deadly-weapon:	(Weapon.type = "deadly")

FrameNet provides a deeper level of inference than the hierarchical structure of WordNet.

Selectional Restriction

- A semantic constraint imposed by a lexeme (e.g., verb) on the concepts that can fill the various argument roles associated with it
I want to eat someplace that is close to ICSI
- Selectional restrictions are associated with particular senses, not entire lexemes.
 - *They served Chinese food last night.*
 - *Which airlines serve Denver?*