Major concepts and goals of (computational) semantics and pragmatics

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CS 244U: Natural language understanding
April 2

Plan and goals

Emphasis on learning theories of semantic and pragmatics.

1. Linguistic objects: utterances, syntax, semantic representation, denotations
2. Goals of semantics
3. Goals of pragmatics

Associated readings

- Beaver, David and Joey Frazee. To appear. Semantics. *The Oxford Handbook of Computational Linguistics*, 2nd edn.
- Potts, Christopher. To appear. Pragmatics. *The Oxford Handbook of Computational Linguistics*, 2nd edn.

Note: this is too much material for one day/week/month! The goal is largely to make you aware of general concepts and terminology that will be relevant throughout the term.

Linguistic objects

$$\langle u, t, r, d \rangle$$

- *u*: the utterance
- *t*: the syntactic structure
- *r*: the semantic representation
- *d*: the denotation (meaning)

(The denotation might under-represent or mis-represent the speaker's intended message. We'll return to that issue in the context of pragmatics.)

Seeking a framework: two opposing views

"We should avoid being overly swayed by what appears to be the most promising approach of the day. As a field, I believe that we tend to suffer from what might be called serial silver bulletism, defined as follows: the tendency to believe in a silver bullet for AI, coupled with the belief that previous beliefs about silver bullets were hopelessly naïve." (Levesque 2013)

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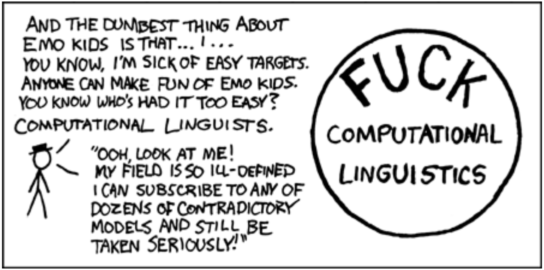


Mouseover: "Chomskyists, generative linguists, and Ryan North, your days are numbered." https://xkcd.com/114/

Utterances

Utterances are events in the world. Corpora record them.

- A list of strings
- A sound sequence
- A character sequence
- Role of an intentional agent (and that agent's intentions)

To keep things simple, I'll assume that utterances are lists of strings (ignoring the fact that tokenization is nontrivial).

Syntax

$$\langle u, t, r, d \rangle$$

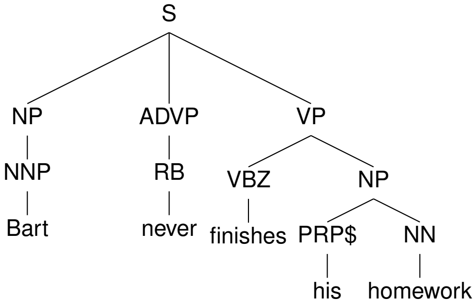
- u: the utterance
- t: the syntactic structure
- r: the semantic representation
- d: the denotation (meaning)

(The denotation might under-represent or mis-represent the speaker's intended message. We'll return to that issue in the context of pragmatics.)

Treebank-style

Utterance: [‘Bart’, ‘never’, ‘finishes’, ‘his’, ‘homework’]

```
(S
  (NP (NNP Bart))
  (ADVP (RB never))
  (VP (VBZ finishes)
      (NP (PRP$ his)
          (NN homework))))
```

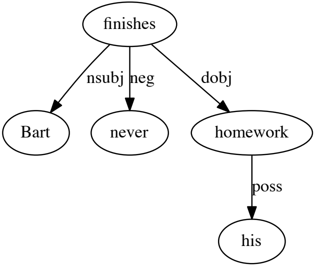


(Marcus et al. 1994)

Stanford dependencies

Utterance: [‘Bart’, ‘never’, ‘finishes’, ‘his’, ‘homework’]

```
nsubj(finishes-3, Bart-1)
neg(finishes-3, never-2)
poss(homework-5, his-4)
dobj(finishes-3, homework-5)
```



(de Marneffe et al. 2006; de Marneffe et al. 2013)

Categorial grammar proof-tree

Utterance: ['Bart', 'never', 'finishes', 'his', 'homework']

$$\dfrac{\text{Bart : NP} \qquad \dfrac{\text{finishes : (S\textbackslash NP)/NP} \qquad \dfrac{\text{his : NP/N} \qquad \text{homework: N}}{\text{his homework : NP}}}{\text{finishes his homework : S\textbackslash NP}}}{\text{Bart finishes his homework : S}}$$

(Lambek 1958; Steedman 2000)

Shallow chunking

Utterance: [‘Bart’, ‘never’, ‘finishes’, ‘his’, ‘homework’]

NP chunked: [[‘Bart’], ‘never’, ‘finishes’, [‘his’, ‘homework’]]

(Greenwood 2005; Bird et al. 2009)

Bag of n-grams

Utterance: [‘Bart’, ‘never’, ‘finishes’, ‘his’, ‘homework’]

$$\begin{bmatrix} \text{‘Bart’} & \mapsto & 1 \\ \text{‘never’} & \mapsto & 1 \\ \text{‘finishes’} & \mapsto & 1 \\ \text{‘his’} & \mapsto & 1 \\ \text{‘homework’} & \mapsto & 1 \end{bmatrix}$$

$$\begin{bmatrix} \text{‘<s> Bart’} & \mapsto & 1 \\ \text{‘Bart never’} & \mapsto & 1 \\ \text{‘never finishes’} & \mapsto & 1 \\ \text{‘finishes his’} & \mapsto & 1 \\ \text{‘his homework’} & \mapsto & 1 \\ \text{‘homework </s>’} & \mapsto & 1 \end{bmatrix}$$

Typically, these do double-duty as semantic representations.

Semantic representation

$$\langle u, t, r, d \rangle$$

- *u*: the utterance
- *t*: the syntactic structure
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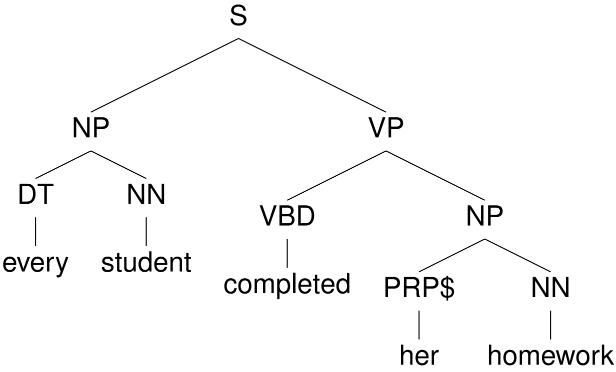
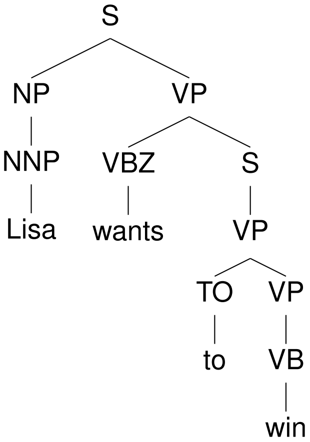
(The denotation might under-represent or mis-represent the speaker's intended message. We'll return to that issue in the context of pragmatics.)

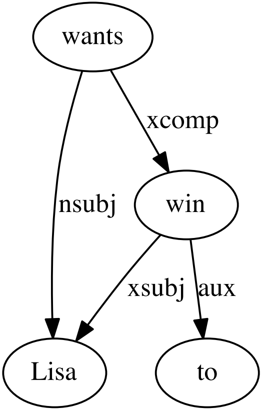
Logical forms (Carpenter 1997)



- First-order logic:
  $\forall x\ (\mathbf{student}(x) \rightarrow (\mathbf{complete}(x, \mathbf{homework\text{-}of}(x))))$
- Lambda calculus:
  $((\mathbf{every\ student})\ \ (\lambda x\ (\mathbf{complete}\ (\mathbf{homework\text{-}of}\ x)\ x)))$

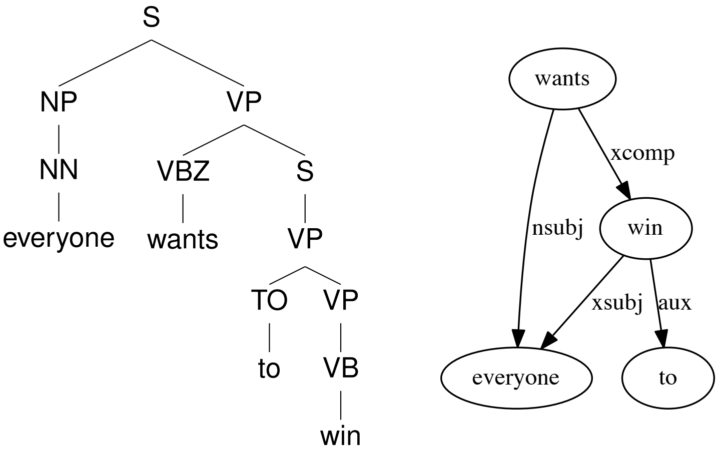
Stanford dependencies





want(**lisa**, **win**(**lisa**))

Stanford dependencies



$$\forall x\ \mathbf{want}(x, \mathbf{win}(x))$$

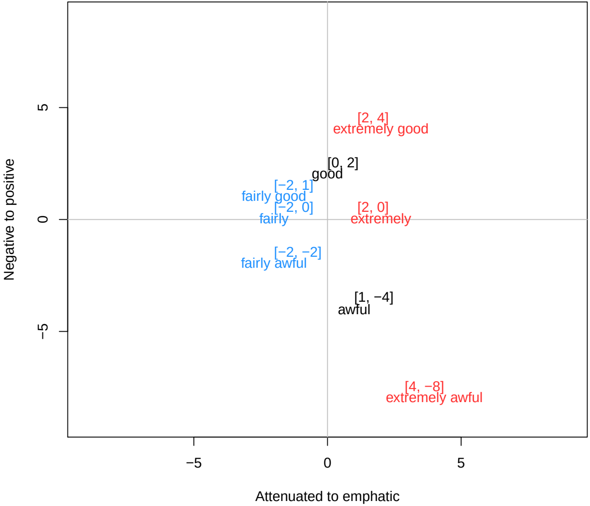
!!! $\forall x\ \mathbf{want}(x, \forall y\ \mathbf{win}(y))$

Semantic role labels

1. [$_{\text{Agent}}$ Doris] caught [$_{\text{Theme}}$ the ball] with [$_{\text{Instrument}}$ her mitt].
2. [$_{\text{Agent}}$ Sotheby's] offered [$_{\text{Recipient}}$ the heirs] [$_{\text{Theme}}$ a money-back guarantee].
3. [$_{\text{Stimulus}}$ The response] dismayed [$_{\text{Experiencer}}$ the group].
4. [$_{\text{Experiencer}}$ The group] disliked [$_{\text{Stimulus}}$ the response].
5. [$_{\text{Agent}}$ Kim] sent [$_{\text{Theme}}$ a stern letter] to [$_{\text{Goal}}$ the company].

(Gildea and Jurafsky 2000; Palmer et al. 2010)

Distributed representations



(Collobert et al. 2011; Huang et al. 2012)

Denotations

$$\langle u, t, r, d \rangle$$

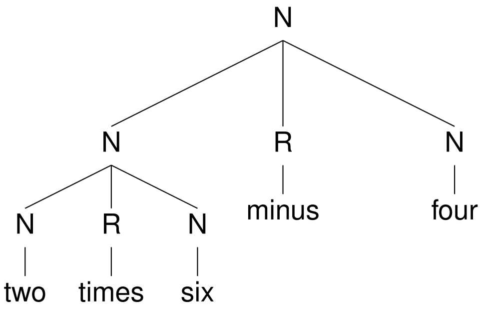
- u: the utterance
- t: the syntactic structure
- r: the semantic representation
- d: the denotation (meaning)

(The denotation might under-represent or mis-represent the speaker's intended message. We'll return to that issue in the context of pragmatics.)

Model

1. Utterance: [‘two’, ‘times’, ‘six’, ‘minus’, ‘four’]

2. Syntax:



3. Logical form: **((2 * 6) – 4)**

4. Denotation: 8

Database

$[\![\cdot]\!]$ maps semantic representations to their denotations

	$[\![$**alien**$]\!]$	$[\![$**bladerunner**$]\!]$	$[\![$**aliens**$]\!]$	$[\![$**cameron**$]\!]$	$[\![$**scott**$]\!]$	$[\![$**weaver**$]\!]$	$[\![$**ford**$]\!]$
$[\![$**movies**$]\!]$	**T**	**T**	**T**	F	F	F	F
$[\![$**people**$]\!]$	F	F	F	**T**	**T**	**T**	**T**
$[\![$**actors**$]\!]$	F	F	F	F	F	**T**	**T**
$[\![$**directors**$]\!]$	F	F	F	**T**	**T**	F	F
$[\![$**acted**$]\!]$	F	F	F	F	F	**T**	**T**
$[\![$**sang**$]\!]$	F	F	F	F	F	F	F
$[\![$**okay**$]\!]$	**T**	**T**	F	**T**	**T**	**T**	**T**
$[\![$**great**$]\!]$	F	**T**	F	**T**	F	**T**	F

$$
\begin{aligned}
[\![\textbf{some}]\!] &= \text{the } Q \text{ such that } Q(f)(g) = \mathbf{T} \text{ iff } \{x : f(x) = \mathbf{T}\} \cap \{x : g(x) = \mathbf{T}\} \neq \emptyset \\
[\![\textbf{no}]\!] &= \text{the } Q \text{ such that } Q(f)(g) = \mathbf{T} \text{ iff } \{x : f(x) = \mathbf{T}\} \cap \{x : g(x) = \mathbf{T}\} = \emptyset \\
[\![\textbf{never}]\!] &= \text{the } F \text{ such that } F(f) = \text{the } g \text{ such that } g(d) = \mathbf{T} \text{ iff } f(d) = \mathrm{F} \\
[\![\textbf{and}]\!] &= \text{the } C \text{ such that } C(f)(g) = \text{the } h \text{ such that } h(d) = \mathbf{T} \text{ iff } f(d) = g(x) = \mathbf{T} \\
[\![\textbf{or}]\!] &= \text{the } C \text{ such that } C(f)(g) = \text{the } h \text{ such that } h(d) = \mathbf{T} \text{ iff } \mathbf{T} \in \{f(d), g(d)\}
\end{aligned}
$$

A programming language

```
kim = 'kim'; mel = 'mel'; hal = 'hal'

person = (lambda d : d in (kim, mel))
run = (lambda d : d in (kim, hal))
happy = (lambda f : (lambda d : f(d) and d in (mel,)))

def every(f):
    def scope(g):
        for d in (kim, mel, hal):
            if f(d) and not g(d):
                return False
        return True
    return scope
```

Examples

```
>>> person(kim)
True
>>> every(happy(person))(run)
False
```

A robot's inner life

"Go left to the end of the hall."

```
(do-sequentially
  (turn-left
  (do-until
    (or
      (not
        (exists forward-loc))
      (room forward-loc))
    (move-to forward-loc)))
```

"Go to the third junction and take a right."

```
(do-sequentially
  (do-n-times 3
    (do-sequentially
      (move-to forward-loc
      (do-until
        (junction current-loc
        (move-to
          forward-loc))))
  (turn-right))
```

"Go straight down the hallway past a bunch of rooms until you reach an intersection with a hallway on your left."

```
(do-sequentially
  (do-until
    (and
      (exists left-loc)
      (hall left-loc))
    (move-to forward-loc))
  (turn-left))
```

go to	the	second	junction	and	go left
S/NP $(move\text{-}to\ forward)$	NP/NP $[null]$	NP/N $(do\text{-}n\text{-}times\ 2\ x)$	N $(until\ (junction\ current\text{-}loc)\ y)$	$S\backslash S/S$ $(do\text{-}seq\ g\ f)$	S $(turn\text{-}left)$

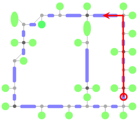
NP: $(do\text{-}n\text{-}times\ 2\ (until\ (junction\ current\text{-}loc)\ y))$

$S\backslash S$: $(do\text{-}seq\ g\ turn\text{-}left)$

NP: $(do\text{-}n\text{-}times\ 2\ (until\ (junction\ current\text{-}loc)\ y))$

S: $(do\text{-}n\text{-}times\ 2\ (until\ (junction\ current\text{-}loc)\ (move\text{-}to\ forward)))$

S: $(do\text{-}seq\ (do\text{-}n\text{-}times\ 2\ (until\ (junction\ current\text{-}loc)\ (move\text{-}to\ forward)))\ (turn\text{-}left))$



(a) Map trace

"Go straight down the hallway past a bunch of rooms until you reach an intersection with a hallway on your left; turn left there."

(b) English phrase

```
(do-sequentially
  (do-until
    (and
      (exists left-loc)
      (hall left-loc))
    (move-to forward-loc))
  (turn-left current-loc))
```

(c) RCL commands

(Matuszek et al. 2012)

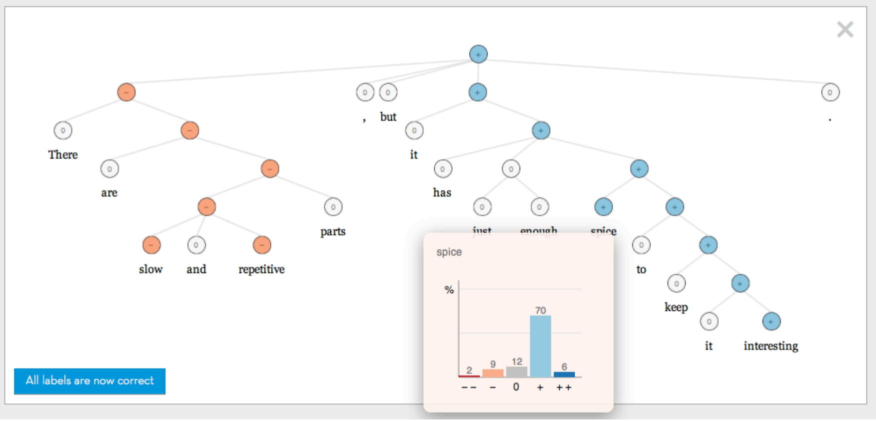
High-level summary meaning

Utterance	Denotation
Jaws is amazing.	5 stars
Jaws has weak special effects but is enjoyable.	3 stars
Blade Runner is outstanding.	5 stars
There are slow and repetitive parts, but it has just enough spice to keep it interesting.	4 stars

Table: Evaluative denotations.

High-level summary meaning

"There are slow and repetitive parts, but it has just enough spice to keep it interesting."



From http://nlp.stanford.edu/sentiment/

High-level summary meaning

Utterance	Denotation
Unsure how the interview will go	anxious, excited
I'm going to ace this class!	optimistic
Remembering my beloved dog Tobi.	depressed, lonely

Table: Mood denotations.

Language itself

- **hippo** is characterized by entailing **mammal**, contradicting **desk**, being consistent with **hungry**, . . .
- **most** is characterized by entailing **some**, being entailed by **every**, contradicting **no**, . . .
- **some hippo** is characterized by entailing **some mammal**, contradicting **no hippo**, . . .
- **some hippo charged** is characterized by entailing **some mammal charged** and **some hippo moved**, contradicting **no hippo moved**, . . .

(MacCartney 2009; MacCartney and Manning 2009)

Goals of semantics

1. Word meanings
2. Connotations
3. Compositionality
4. Syntactic ambiguities
5. Semantic ambiguities
6. Entailment and monotonicity
7. Question answering

Learning goals for semantics

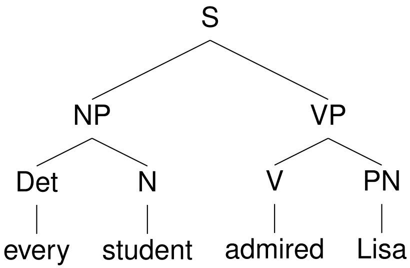
$$\langle u, t, r, d \rangle$$

- Classification: $u \mapsto d$
- Topic modeling: $u \mapsto d$
- Semantic parsing: $u \mapsto r$ (Zettlemoyer and Collins 2005)
- Interpretation: $u \mapsto r \mapsto d$ (Liang et al. 2013)
- Interpretation: $u \mapsto r \mapsto d$ (Socher et al. 2013)
- Interpretation: $u \mapsto r \mapsto d$ (Bowman 2014)

Compositionality

Compositionality

The meaning of a phrase is a function of the meanings of its immediate syntactic constituents and the way they are combined.



(Montague 1974; Partee 1984; Janssen 1997; Werning et al. 2012)

Word meanings

$$
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[\![\textbf{planet}]\!] &= \text{the planet function} \\
[\![\textbf{doctor}]\!] &= \text{the doctor function} \\
[\![\textbf{love}]\!] &= \text{the love function}
\end{aligned}
$$

Connotations

1. Ed was relieved from his pain.

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1. Ed was relieved from his pain.
2. The pool hustler relieved Sally of her money.

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4. We relieved Ed from his chores.

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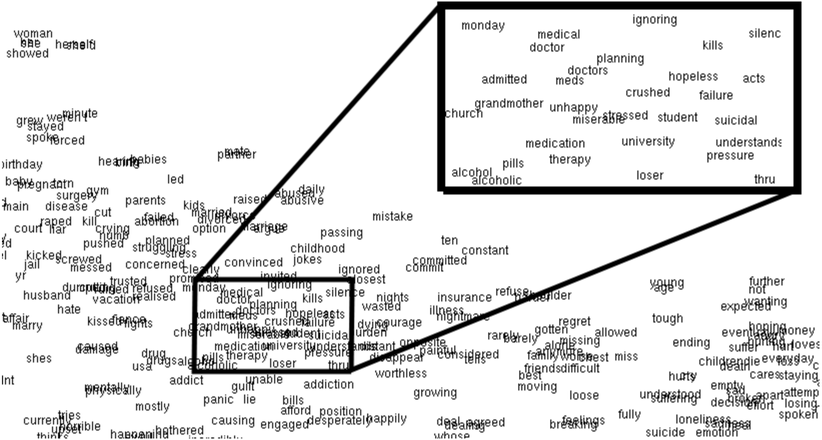
5. We relieved Ed from his vacation.
6. tax relief
7.

x	relieves	*y*	from	*z*
↑		↑		↑
reliever-of-pain		blameless afflicted		cause

Connotations



(from Maas et al. 2011)

Syntactic ambiguity

Arising in the mapping from utterances *u* to denotations *t*

$$\langle u, t, r, d\rangle$$

1. Scientists count whales from space.

Crash blossoms from
http://languagelog.ldc.upenn.edu/nll/?cat=118

Syntactic ambiguity

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Syntactic ambiguity

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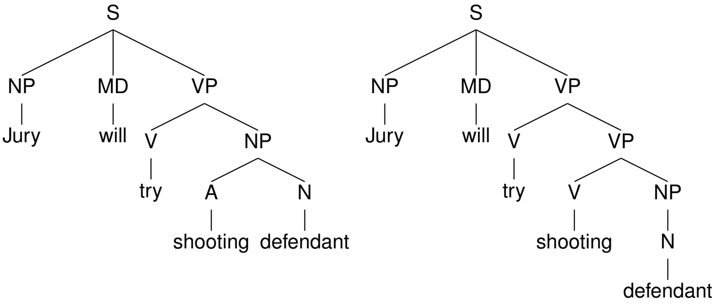
3. Jury will try shooting defendant.



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Semantic ambiguity

Arising in the mapping from utterances t to r

$$\langle u, t, r, d \rangle$$

1. All that glitters is not gold.

Semantic ambiguity

Arising in the mapping from utterances t to r

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1. All that glitters is not gold.
2. “Every pothead isn’t a bad guy,” he said. “But every bad guy is a pothead.”

http://www.texasmonthly.com/story/behind-the-sierra-blanca-border-checkpoint-drug-busts

Semantic ambiguity

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3. A squirrel was hiding in every corner.
4. Every desk contained a pen.
5. A piece of gum was chewed by every student.

$$\forall x\ (\mathbf{student}(x) \rightarrow \exists y\ (\mathbf{gum}(y) \wedge \mathbf{chewed}(x, y)))$$

$$\exists y\ (\mathbf{gum}(y) \wedge \forall x\ (\mathbf{student}(x) \rightarrow \mathbf{chewed}(x, y)))$$

Vagueness

- Arises when a term's denotation can't be precisely delimited.
- Ambiguities can be enumerated and characterized in terms of the grammar, and fully resolved.
- Vagueness typically cannot be resolved (only reduced or managed).
- Vagueness is crucial for the flexible, expressive nature of language, allowing fixed expressions to make different distinctions in different contexts and helping people to communicate under uncertainty.

Examples

1. Jesse is tall.
2. I am here now.
3. Many students attended the event.

(Kamp and Partee 1995; Graff 2000; Kennedy 2007)

Entailment and monotonicity

A student smoked.

A Swedish student smoked. A student smoked cigars.

(Hoeksema 1986; van Benthem 2008)

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$\Uparrow$ $\Uparrow$

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Every student smoked.

⇙ ⇖

Every Swedish student smoked. Every student smoked cigars.

Few students smoked.

Few Swedish students smoked. Few students smoked cigars.

(Hoeksema 1986; van Benthem 2008)

Entailment and monotonicity

A student smoked.

$\Nearrow$ $\Nwarrow$

A Swedish student smoked. A student smoked cigars.

No student smoked.

$\Swarrow$ $\Searrow$

No Swedish student smoked. No student smoked cigars.

Every student smoked.

$\Swarrow$ $\Nwarrow$

Every Swedish student smoked. Every student smoked cigars.

Few students smoked.

$\Swarrow$ $\Searrow$

Few Swedish students smoked. Few students smoked cigars.

(Hoeksema 1986; van Benthem 2008)

Question answering

Examples

1. Which states border California?

Question answering

Examples

1. Which states border California?
2. Which states border Germany?

Question answering

Examples

1. Which states border California?
2. Which states border Germany?
3. Which U.S. states border no state?

Question answering

Examples

1. Which states border California?
2. Which states border Germany?
3. Which U.S. states border no state?
4. Where can I buy socks?

Question answering

Examples

1. Which states border California?
2. Which states border Germany?
3. Which U.S. states border no state?
4. Where can I buy socks?
5. How old is Frank Sinatra?

Question answering

Examples

1. Which states border California?
2. Which states border Germany?
3. Which U.S. states border no state?
4. Where can I buy socks?
5. How old is Frank Sinatra?
6. What’s it like to sleep on the Space Station?

Question answering

Do you like my new haircut?

Question answering

Do you like my new haircut?

1. Yes.

Question answering

Do you like my new haircut?

1. Yes.
2. No.

Question answering

Do you like my new haircut?

1. Yes.
2. No.
3. Sort of.

Question answering

Do you like my new haircut?

1. Yes.
2. No.
3. Sort of.
4. Not really.

Question answering

Do you like my new haircut?

1. Yes.
2. No.
3. Sort of.
4. Not really.
5. You look like Prince.

Question answering

Do you like my new haircut?

1. Yes.
2. No.
3. Sort of.
4. Not really.
5. You look like Prince.
6. It's shorter on the sides!

(de Marneffe et al. 2010; Kim and de Marneffe 2013;
data: http://compprag.christopherpotts.net/iqap.html)

Computational approaches

What kinds of data and models do we need? What practical concerns might arise? What new insights might we gain?

1. Word meanings (WordNet, VSMs)
2. Connotations (VSMs, FrameNet)
3. Compositionality (semantic parsing, etc.)
4. Syntactic ambiguities (parsing)
5. Semantic ambiguities (semantic parsing)
6. Entailment and monotonicity (RTE)
7. Question answering (dialogue, information retrieval)

Goals of pragmatics

1. Indexicality
2. Coreference and anaphora
3. Commitment (veridicality, factuality)
4. Speech acts
5. Presupposition
6. Gricean pragmatics
7. Conversational implicature

Indexicality

Indexicals get their semantic value from the context of utterance.

Examples

1. Where am I?
2. Is there pizza near here?
3. Let's go to a local bar now.
4. I will be there in 10 minutes.
5. Chris must be in his office.
6. Can I go to the bathroom?
7. That chair [pointing] looks broken.
8. It looks hungry.

An exciting area for computational work since our portable devices have so much contextual information.

(Montague 1970; Kaplan 1989; Haas 1994)

Coreference and anaphora

1. On homecoming night Postville feels like Hometown, USA, but a look around this town of 2000 shows it's become a miniature Ellis Island. This was an all-white, all-Christian community . . . For those who prefer the old Postville, Mayor John Hyman has a simple answer.

(Karttunen 1971; Recasens et al. 2011; Levesque 2013)

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3. Kim didn't understand an exam question even after reading it twice.

4. The town councillors refused to give the angry demonstrators a permit because they {feared/advocated} violence.

(Karttunen 1971; Recasens et al. 2011; Levesque 2013)

Commitment (veridicality, factuality)

1. It might be pneumonia.
2. It is not pneumonia.
3. They said it would be amazing, but they were wrong.
4. They said Shelia, who is in competent, is fit to watch the kids.
5. Rollercoasters are boring.
6. It's clear that we need to invade Canada.

(Saurí and Pustejovsky 2009; de Marneffe et al. 2012; http://www.christopherpotts.net/ling/data/factbank/)

Speech acts

Speech-acts broadly categorize utterances based on the speaker's intentions for their core semantic content, indicating whether it is meant to be asserted, queried, commanded, exclaimed, . . .

1. *Please don't rain!* (plea)
2. Host to visitor: *Have a seat.* (invitation)
3. Parent to child: *Clean your room!* (order)
4. Navigator to driver: *Take a right here.* (suggestion)
5. To an ailing friend: *Get well soon!* (well-wish)
6. To an enemy: *Drop dead!* (ill-wish)
7. Ticket agent: *Have your boarding passes ready* (request)

(Examples from Lauer and Condoravdi 2010; see also `http://compprag.christopherpotts.net/swda.html`)

Presupposition

1. The dog is grumpy.
   a. Presupposes: there is a unique salient dog *d*
   b. Asserts: *d* is grumpy
2. Ed realizes that it is Friday.
   a. Presupposes: it is Friday
   b. Asserts: Ed believes that it is Friday
3. Ed doesn't realize that it is Friday.
   a. Presupposes: it is Friday
   b. Asserts: Ed does not believe that it is Friday
4. Why did you murder Prof. Jones?
   a. Presupposes: you murdered Prof. Jones
   b. Queries: your reasons for the killing
5. Sam quit smoking.
   a. Presupposes: Sam smoked in the past
   b. Asserts: Sam does not smoke at present

(Beaver and Geurts 2012; Potts To appear)

Gricean pragmatics (Grice 1975)

The Cooperative Principle: Make your contribution as is required, when it is required, by the conversation in which you are engaged.

- **Quality**: Contribute only what you know to be true. Do not say false things. Do not say things for which you lack evidence.
- **Quantity**: Make your contribution as informative as is required. Do not say more than is required.
- **Relation (Relevance)**: Make your contribution relevant.
- **Manner**: (i) Avoid obscurity; (ii) avoid ambiguity; (iii) be brief; (iv) be orderly.

Goal of modern theories is to derive the effects of these maxims from more basic principles of cooperativity (Benz et al. 2005; Vogel et al. 2013; Bergen and Goodman 2014).

Conversational implicature

Speaker *S* saying *u* to listener *L* conversationally implicates *q* iff

1. *S* and *L* mutually, publicly presume that *S* is cooperative.
2. To maintain 1 given *u*, it must be supposed that *S* thinks *q*.
3. *S* thinks that both *S* and *L* mutually, publicly presume that *L* is willing and able to work out that 2 holds.

(Hirschberg 1985; Potts To appear)

Conversational implicature: example

A: Which city does Barbara live in?

B: She lives in Russia.

Implicature: B does not know which city Barbara lives in.

1. *Contextual premise*: B is forthcoming about Barbara's personal life.
2. Assume B is cooperative.
3. Assume, towards a contradiction, that B does know which city Barbara lives in (the negation of the implicature).
4. Supplying the city's name would do better on Relevance and Quantity than supplying just the country name.
5. The contextual assumption is that B will supply such information.
6. This contradicts the cooperativity assumption (2).
7. We can therefore conclude that the implicature is true.

Computational approaches

What kinds of data and models do we need? What practical concerns might arise? What new insights might we gain?

1. Indexicality (?)
2. Coreference and anaphora (COREF)
3. Commitment (RTE; BioNLP)
4. Speech acts (Stolcke et al. 2000)
5. Presupposition (?)
6. Gricean pragmatics (dialogue agents)
7. Conversational implicature (dialogue agents)

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