Natural Language Processing: Part II Overview of Natural Language Processing (L90): ACS

Lecture 6: Compositional Semantics

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Outline of today's lecture

Alternative forms of semantic representation

- Logical form and lambda calculus
- Dependency structures

Inference

Recognising Textual Entailment task

Sentence meaning as logical form

Kitty chased Rover.
Rover was chased by Kitty.

Logical form (simplified!):

$$\text{chase}'(k, r)$$

k and r are constants (*Kitty* and *Rover*), chase' is the predicate corresponding to *chase*.

- Sentence structure conveys some meaning: obtained by syntactic representation plus rules of semantic composition.
- Principle of Compositionality: meaning of each whole phrase derivable from meaning of its parts.

Semantic composition rules are non-trivial

Ordinary pronouns contribute to the semantics:

It barked.
$\exists x[bark'(x) \wedge \text{PRON}(x)]$

Pleonastic pronouns don't:

It rained.
$rain'$

Similar syntactic structures may have different meanings.
Different syntactic structures may have the same meaning:

Kim seems to sleep.
It seems that Kim sleeps.

Differences in presentation but not in truth conditions.

Lambda calculus and composition

$(\lambda x.t)$ is a lambda abstraction
(ts) is an application

- One semantic composition rule per syntax rule.
- `S -> NP VP`
  $\text{VP}'(\text{NP}')$
- Rover barks:
  VP *bark* is $\lambda x[\text{bark}'(x)]$
  NP *Rover* is r

  $$\lambda x[\text{bark}'(x)](r) \;=\; \text{bark}'(r)$$

Transitive verbs

Kitty chases Rover

- Transitive verbs: two arguments (NOTE the order)
  `Vtrans -> chases`
  $\lambda x[\lambda y[\text{chase}'(y, x)]]$
- `VP -> Vtrans NP`
  $\text{Vtrans}'(\text{NP}')$
- Example: $\lambda x \lambda y[\text{chase}'(y, x)](r) = \lambda y[\text{chase}'(y, r)]$
- `S -> NP VP`
  $\text{VP}'(\text{NP}')$
- Example: $\lambda y[\text{chase}'(y, r)](k) = \text{chase}'(k, r)]$

Grammar fragment using lambda calculus

```
S -> NP VP
```
$VP'(NP')$

```
VP -> Vtrans NP
```
$Vtrans'(NP')$

```
VP -> Vintrans
```
$Vintrans'$

```
Vtrans -> chases
```
$\lambda x \lambda y[chase'(y, x)]$

```
Vintrans -> barks
```
$\lambda z[bark'(z)]$

```
Vintrans -> sleeps
```
$\lambda w[sleep'(w)]$

```
NP -> Kitty
```
k

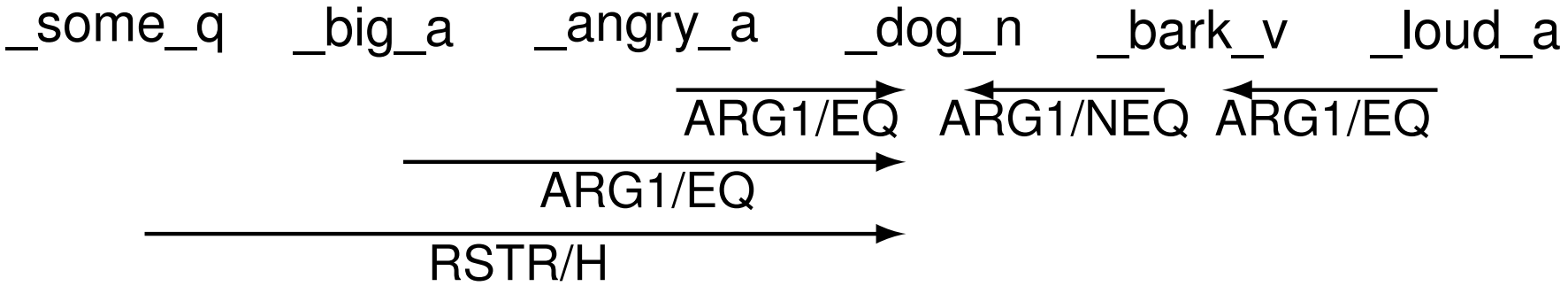
Beyond toy examples . . .

- Use first order logic where possible (e.g., event variables, next slide).
- However, First Order Predicate Calculus (FOPC) is sometimes inadequate: e.g., *most*, *may*, *believe*.
- Quantifier scoping multiplies analyses:
  Every cat chased some dog:
  $\forall x[\text{cat}'(x) \implies \exists y[\text{dog}'(y) \wedge \text{chase}'(x, y)]]$
  $\exists y[\text{dog}'(y) \wedge \forall x[\text{cat}'(x) \implies \text{chase}'(x, y)]]$
- Often no straightforward logical analysis
  e.g., Bare plurals such as *Ducks lay eggs*.
- Non-compositional phrases (multiword expressions): e.g., *red tape* meaning bureaucracy.

Event variables

- Allow first order treatment of adverbs and PPs modifying verbs by reifying the event.
- Rover barked
- instead of $\text{bark}'(r)$ we have $\exists e[\text{bark}'(e, r)]$
- Rover barked loudly
- $\exists e[\text{bark}'(e, r) \wedge \text{loud}'(e)]$
- There was an event of Rover barking and that event was loud.

Semantic dependencies



It turns out this can be equivalent to:

$$\text{\_some\_q}\ (x,\ \text{\_big\_a}(x) \wedge \text{\_angry\_a}(x) \wedge \text{\_dog\_n}(x),\ \text{\_bark\_v}(e3,x) \wedge \text{\_loud\_a}(e3))$$

which in this case can be converted into FOPC:

$$\exists x\ [\ \text{\_big\_a}(x) \wedge \text{\_angry\_a}(x) \wedge \text{\_dog\_n}(x) \wedge \text{\_bark\_v}(e3,x) \wedge \text{\_loud\_a}(e3)\ ]$$

Natural language inference

- Inference on a knowledge base: convert natural language expression to KB expression, valid inference according to KB.
  - \+ Precise
  - \+ Formally verifiable
  - \+ Disambiguation using KB state
  - \- Limited domain, requires KB to be formally encodable
- Language-based inference: does one utterance follow from another?
  - \+ Unlimited domain
  - +/- Human judgement
  - -/+ Approximate/imprecise
- Both approaches may use logical form of utterance.

Lexical meaning and meaning postulates

- Some inferences validated on logical representation directly, most require lexical meaning.
- meaning postulates: e.g.,

$$\forall x[\text{bachelor}'(x) \rightarrow \text{man}'(x) \wedge \text{unmarried}'(x)]$$

- usable with compositional semantics and theorem provers
- e.g. from 'Kim is a bachelor', we can construct the LF $\text{bachelor}'(\text{Kim})$ and then deduce $\text{unmarried}'(\text{Kim})$
- Problematic in general, OK for narrow domains or micro-worlds.

Lexical meaning and meaning postulates

- Mother, definition of?

Lexical meaning and meaning postulates

Lexical meaning and meaning postulates

The Pregnant Mother

Don'ts

- Smoking

Smoking is associated with adverse effects on both the pregnant mother and her foetus. It can cause an increased risk of miscarriage, premature separation of placenta, premature birth and a low birth weight baby. There is also a long-

Men jailed over pregnant mother crash death

His wife Aneta, 26, who was 14 weeks pregnant, and sitting next to the couple's three-year-old daughter in the rear of the car, suffered injuries to her liver and heart from the impact.

Pregnant mother, 26, walks into traffic holding her two-year-old son ...
https://www.dailymail.co.uk/.../Pregnant-mother-26-walks-traffic-holding-two-year-old-...
1 day ago - **Pregnant mother**, 26, walks into traffic holding her two-year-old son and kills herself in front of a tractor-trailer - but her toddler miraculously survives. ... A **pregnant mother** died earlier this month after she walked into traffic holding her two-year-old son, who miraculously ...

Recognising Textual Entailment (RTE) shared tasks

T: The girl was found in Drummondville earlier this month.

H: The girl was discovered in Drummondville.

- DATA: pairs of text (T) and hypothesis (H). H may or may not follow from T.
- TASK: label TRUE (if follows) or FALSE (if doesn't follow), according to human judgements.

RTE using logical forms

- T sentence has logical form T′, H sentence has logical form H′
- If T′ $\implies$ H′ conclude TRUE, otherwise conclude FALSE.

T The girl was found in Drummondville earlier this month.

T′ $\exists x, u, e[\text{girl}'(x) \wedge \text{find}'(e, u, x) \wedge \text{in}'(e, \text{Drummondville}) \wedge \text{earlier-this-month}'(e)]$

H The girl was discovered in Drummondville.

H′ $\exists x, u, e[\text{girl}'(x) \wedge \text{discover}'(e, u, x) \wedge \text{in}'(e, \text{Drummondville})]$

MP $[\text{find}'(x, y, z) \implies \text{discover}'(x, y, z)]$

- So T′ $\implies$ H′ and we conclude TRUE

More complex examples

T: Four Venezuelan firefighters who were traveling to a training course in Texas were killed when their sport utility vehicle drifted onto the shoulder of a highway and struck a parked truck.

H: Four firefighters were killed in a car accident.

Systems using logical inference are not robust to missing information: simpler techniques can be effective (partly because of choice of hypotheses in RTE).

More examples

T: Clinton's book is not a big seller here.

H: Clinton's book is a big seller.

T: After the war the city was briefly occupied by the Allies and then was returned to the Dutch.

H: After the war, the city was returned to the Dutch.

T: Lyon is actually the gastronomic capital of France.

H: Lyon is the capital of France.

SNLI (Stanford NL Inference corpus); 2015

- Situations are grounded in visual scenes/captions
- Crowd-sourced; two separate steps
- Very large (570K pairs)

Two dogs are running through a field.		
Positive example	**Negative example**	**Neutral example**
$\Rightarrow$	$\not\Rightarrow$	$\Rightarrow$?
There are animals outdoors.	*The pets are sitting on a couch.*	*Some puppies are running to catch a stick.*

More SNLI examples

A man inspects the uniform of a figure in some East Asian country. The man is sleeping.	CCCCC
An older and younger man smiling. Two men are smiling and laughing at the cats playing on the floor.	NNENN
A black race car starts up in front of a crowd of people. A man is driving down a lonely road.	CCCCC
A soccer game with multiple males playing. Some men are playing a sport.	EEEEE
A smiling costumed woman is holding an umbrella. A happy woman in a fairy costume holds an umbrella.	NNECN

Next time ...

- Lexical semantics and semantic relations
- Grounding