Lecture 18: Compositional Semantics and Semantic Parsing
Key Challenge of Meaning

• We actually say very little - much more is left unsaid, because it’s assumed to be widely known.

• Examples:
  • Grading assignments
  • Restaurant menus
  • Learning to use a new piece of software
Meaning Representation Languages

• Symbolic representation that does two jobs:
  • Conveys the meaning of a sentence
  • Represents (some part of) the world

• Today we’ll use first-order logic.
A MRL Should Be Able To ...

- Verify a query against a knowledge base
  - Do CMU students follow politics?
- Eliminate ambiguity
  - CMU students enjoy visiting Senators.
- Cope with vagueness
  - Sally heard the news.
- Cope with many ways of expressing the same meaning (canonical forms)
  - The candidate evaded the question.
  - The question was evaded by the candidate.
- Draw conclusions based on the knowledge base
  - Who could become the 45th president?
- Represent all of the meanings we care about
Model-Theoretic Semantics

- Model: a simplified representation of the world: objects, properties, relations (domain).
- Non-logical vocabulary
  - Each element denotes a well-defined part of the model
  - Such a mapping is called an interpretation
A Model

- **Domain**: Noah, Karen, Rebecca, Frederick, Green Mango, Casbah, Udipi, Thai, Mediterranean, Indian
- **Properties**: Green Mango and Udipi are crowded; Casbah is expensive
- **Relations**: Karen likes Green Mango, Frederick likes Casbah, everyone likes Udipi, Green Mango serves Thai, Casbah serves Mediterranean, and Udipi serves Indian
- n, k, r, f, g, c, u, t, m, i
- Crowded = \{g, u\}
- Expensive = \{c\}
- Likes = \{(k, g), (f, c), (n, u), (k, u), (r, u), (f, u)\}
- Serves = \{(g, t), (c, m), (u, i)\}
Some English

• Karen likes Green Mango and Frederick likes Casbah.
• Noah and Rebecca like the same restaurants.
• Noah likes expensive restaurants.
• Not everybody likes Green Mango.

• What we want is to be able to represent these statements in a way that lets us compare them to our model.

• Truth-conditional semantics: need operators and their meanings, given a particular model.
First-Order Logic

• **Terms** refer to elements of the domain: **constants**, **functions**, and **variables**
  - Noah, SpouseOf(Karen), X

• **Predicates** are used to refer to sets and relations
  - Serves(Casbah, Mediterranean)

• Logical connectives: ∧ (and), ∨ (or), ¬ (not), ⇒ (implies), ...

• Quantifiers ...
Quantifiers in FOL

- Two ways to use variables:
  - refer to one anonymous object from the domain (**existential**: \( \exists \); “there exists”)
  - refer to all objects in the domain (**universal**: \( \forall \); “for all”)
- a restaurant near CMU that serves Indian food
  \( \exists x \text{ Restaurant}(x), \text{Near}(x, \text{CMU}), \text{Serves}(x, \text{Indian}) \)
- All expensive restaurants are far from campus
  \( \forall x \text{ Restaurant}(x), \text{Expensive}(x) \Rightarrow \neg \text{Near}(x, \text{CMU}) \)
Extension: Lambda Notation

- A way of making anonymous functions.
- \( \lambda x. (\text{some expression mentioning } x) \)
  - Example: \( \lambda x. \text{Near}(x, \text{CMU}) \)
  - Deeper example: \( \lambda x. \lambda y. \text{Serves}(y, x) \)
- Lambda reduction: substitute for the variable.
  - \( \lambda x. \text{Near}(x, \text{CMU}) \)(Lulu’s Noodles) becomes \( \text{Near}(\text{Lulu’s Noodles, CMU}) \)
Inference

• Big idea: extend the knowledge base, or check some proposition against the knowledge base.

• **Forward chaining** with modus ponens:
  • given $\alpha$ and $\alpha \Rightarrow \beta$, we know $\beta$.

• **Backward chaining** takes a query $\beta$ and looks for propositions $\alpha$ and $\alpha \Rightarrow \beta$ that would prove $\beta$.
  • Not the same as backward reasoning (abduction).
  • Used by Prolog

• Both are sound, neither is complete.
Lots More To Say About MRLs!

- See chapter 17 for more about:
  - Representing events and states in FOL
  - Dealing with optional arguments (e.g., “eat”)
  - Representing time
  - Non-FOL approaches to meaning
First-Order Worlds, Then and Now

• Interest in this topic waned during the 1990s and 2000s.
• It’s come back, with the rise of semi-structured databases like Wikipedia.
  • Lay contributors to these databases may be helping us to solve the knowledge acquisition problem.
• Also, lots of research on using NLP, information extraction, and machine learning to grow and improve knowledge bases from free text data.
  • “Read the Web” project here at CMU.
Connecting Syntax and Semantics
Semantic Analysis

- Goal: transform a NL statement into MRL (today, FOL).
- We’re assuming a very literal, inference-free version of meaning!
- Sometimes called “semantic parsing.”
Compositionality

• The meaning of an NL phrase is determined by combining the meaning of its sub-parts.

• There are obvious exceptions ("hot dog," "straw man," "New York," etc.).

• Big idea: start with parse tree, build semantics on top using FOL with λ-expressions.
An Example

- Noah likes expensive restaurants.
- \( \forall x \text{ Restaurant}(x), \text{ Expensive}(x) \Rightarrow \text{ Likes}(\text{Noah}, x) \)
An Example

- Noah likes expensive restaurants.

\[ \forall x \text{ Restaurant}(x), \text{Expensive}(x) \Rightarrow \text{Likes}(\text{Noah}, x) \]
An Example

- Noah likes expensive restaurants.
- $\forall x \text{ Restaurant}(x), \text{ Expensive}(x) \Rightarrow \text{ Likes}(\text{Noah}, x)$

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An Example

• Noah likes expensive restaurants.

• ∀x Restaurant(x), Expensive(x) ⇒ Likes(Noah, x)
An Example

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An Example

- Noah likes expensive restaurants.

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Alternative (Following SLP)

- Noah likes expensive restaurants.
- $\forall x \text{ Restaurant}(x), \text{ Expensive}(x) \Rightarrow \text{ Likes}(\text{Noah}, x)$

$\lambda f.f(\text{Noah})$

$S \rightarrow \text{NP} \text{ VP} \{ \text{NP}.\text{sem}(\text{VP}.\text{sem}) \}$
Quantifier Scope Ambiguity

• Every man loves a woman.

• ∀u Man(u) ⇒ ∃x Woman(x) ∧ Loves(u, x)
• ∃x Woman(x) ∧ ∀u Man(u) ⇒ Loves(u, x)
This Isn’t Quite Right!

• “Every man loves a woman” really is ambiguous.
  • A seat was available for every customer
  • A toll free number was available for every customer
  • A secretary phoned up each director
  • A letter was sent to each customer
• This gives only one of the two meanings.
• One approach is to delay the quantifier processing until the end, then permit any ordering.
Questions?