What is Semantics?

- Semantics is meaning:
  - John laughed -> laughed(john)
  - Nobody laughed -> ∀x [¬Laugh(x)] or ∃x [laugh(x)]

- But isn't this just translation?
  - Bachelor
  - A man who has never married.

- Semantic Representations

- What can we do with this?
  - Inference,
  - Resolution of ambiguity

- Can we accurately represent natural language?

- How can we automatically build a semantic representation?

Meaning Representation Languages

- Natural Language (NL) -> Meaning Representation Language (MRL)
  - MRLs must have a well defined syntax and semantics (e.g.)
    - A formal logic
    - A database query language (e.g. SQL)
    - A semantic network

- Must be precise and computationally well-understood (unlike English!)

- Verifiability
  - Provide a mapping from language to facts about the world

Overview

- Part 1
  - Semantics
  - First Order Predicate Logic as a NL semantics language

- Part 2
  - Discourse Representation Theory

- Part 3
  - Coursework!
MRL requirements

- **Unambiguous**
  - Ambiguous NL sentences should map onto distinct MRL representations
    - John saw the girl with the telescope
      - $\exists x \text{ saw}(\text{John}, X) \& \text{isa}(X, \text{girl}) \& \text{carry}(\text{John}, \text{telescope})$
      - $\exists x \text{ saw}(\text{John}, X) \& \text{isa}(X, \text{girl}) \& \text{carry}(X, \text{telescope})$

- **Canonical Form**
  - One possible representation per meaning even with alternative NL representations
    - The dog chased the cat $\rightarrow$ chase(dog,cat)
    - The cat was chased by the dog $\rightarrow$ chase(dog,cat)

The Principle of Compositionality

(Frege's Principle)

- The meaning of the whole is a function of the meaning of the parts.

    "The boy saw a girl burst the red balloon"

Questions

1. What are the "parts" the meanings of which combine to give the meaning of the "whole"?
2. How are meanings combined?
3. What are the minimal units of meaning?
4. How is meaning to be represented?

Expressibility and Inference

- **Should support Inference**
  - "John bought a new ride yesterday"
  - "The car was a red corvette."
  - "the car" $\rightarrow$ "a new ride"
    (therefore)
  - John owns a car

- Representation should be as expressive as required.
  - i.e. capable of expressing the subject matter required for the application
  - e.g. a salary database requires quantification
    "List all managers"
  - This is an application-specific issue
  - Representational power comes with a price.
  - The more expressive the logic, the less tractable/provable

First Order Predicate Calculus

- **Terms:**
  - Constants ($a = \text{Joebloggs}$)
  - Variables ($X = \text{degreeclass}$)

- **Predicates:**
  - studies($\text{Joebloggs}, \text{NLP}$) or $Sjn \text{ S=} \text{studies j=} \text{joeb bloggs}, n=\text{nlp}$

- **Functions:**
  - "the hardest module", "location of lecture" $\text{Location(NLP)}$.

- **A set of logical connectives:** and or, not, etc.

- **A small set of inference rules:** modus ponens, modus tollens etc.

- **Quantification:**
  - $\forall X \text{ [Student(X)]}$
  - $\exists X [\text{achieve}(X, \text{first})]$

- **Truth-conditional semantics - statements about the world are true or false.**
Logical Connectives & Semantics

- Restricted set
  &, V, ->, ~
- But this set can be extended (for example XOR)
- Logical operators don't correspond to our linguistic notions of meaning
  - “Do you want milk or sugar with your coffee”
  - If it's snowing then it's winter.
  - If the moon is made of cheese then it's winter.
- Any proposition is either true or false.
- Proof theory
  - Natural Deduction, Semantic Tableaux, Prolog (?) etc.

Quantification

- The Universal and Existential operators greatly increase FOPC's expressibility
  - “All men are mortal” \( \forall x [\text{men}(x) \rightarrow \text{mortal}(x)] \)
  - “Some lawyers are honest” \( \exists x [\text{lawyer}(x) \& \text{honest}(x)] \)
- Negation
  - Negation can change any universal to an existential and vice versa
  - Because FOPC is truth conditional these statements are equivalent
    \( \forall x [\text{men}(x) \rightarrow \text{mortal}(x)] \leftrightarrow \neg \exists x [\text{men}(x) \& \text{mortal}(x)] \)
    \( \exists x [\text{lawyer}(x) \& \text{honest}(x)] \leftrightarrow \neg \forall x [\text{lawyer}(x) \rightarrow \text{honest}(x)] \)

Some possible answers to our questions

1. what are the "parts" the meanings of which combine to give the meaning of the "whole"?
   - Meaningful "parts" correspond to syntactic constituents, i.e. syntactic generalizations are also semantic generalizations.
2. how are meanings combined?
   - The rule-to-rule hypothesis
     - Given the answer to 1, we might suppose a one-to-one correspondence between syntactic rules and semantic rules, e.g.
       - Syntax: \( S \rightarrow NP \& VP \)
       - Semantics: \( S = f(NP',VP') \)
   - Actually, the minimal units are word senses (but see lectures 2 & 3)
3. what are the minimal units of meaning?
   - Given 1, one might suppose the minimal units of meaning are just the lexical items (i.e. words).
4. how is meaning to be represented?
   - Predicate-argument structure (if FOPC = MRL)

Predicate Argument Structure

- Specifies relationships between concepts in the sentence
- Constructed by semantic interpretation, using grammar
- Build up during parse (augment grammar with semantic builders)
- generated from the parse tree after parsing
- Important aspect is link between subcategorisation and semantic role of a predicates arguments, e.g.
  - NP give NP PP
  - NP was given PP PP
  - The man gave a bone to the dog
  - A bone was given to the dog by the man
- Both correspond to the predicate argument structure
  - give(man, bone, dog)
Categories

- Language is often used to categorise
  - “NLP is a kind of AI module”
  - “The Lahore is a Indian Restaurant”
- Unary predicate for categories
  - hard_module(Nlp)
  - indian_restaurant(Lahore)
- Problem we can’t represent information about categories
  - most_popular(Lahore, Indian_restaurant)
  - This is syntactically not allowed.
- Reification
  - Represent categories as objects (terms) with membership predicates
    - isa(Lahore, Indian_restaurant)
    - AKO(Indian_restaurant, Restaurant)
- We’ll see more of this when we discuss ontologies later in the term

Problems

- The above method doesn’t work
- Consider the following
  I ate. Eating1(Speaker)
  I ate a sandwich. Eating2(Speaker, Sandwich)
  I ate a sandwich at my desk. Eating3(Speaker, Sandwich, Desk)
  I ate at my desk. Eating4(Speaker, Desk)
  I ate lunch. Eating5(Speaker, Lunch)
  I ate a sandwich for lunch. Eating6(Speaker, Sandwich, Lunch)
  - FOPC predicates have fixed arity (so fixed number of arguments)
  - This means we’ll have separate predicates for every “type” of eating
- Meaning Postulates
  \( \forall x, y, z \, \text{Eating3}(x,y,z) \Rightarrow \text{Eating2}(x,y) \)

Events

- Events are often described in NL
  - “make a reservation for 8 pm at the Lahore”
- naïve approach
  - For any event create a predicate with as many arguments as required
    - lecture(Nlp, Small_poynting, 3pm, Monday, MarkLee)
- For any event described by a verb
  - create a predicate with as many arguments as noun_phrases, prepositional phrases.
    - “Mark lectured NLP to the class using powerpoint”
    - lecture(Nlp, Mark, Powerpoint)
- Problems
  - Too many commitments
  - Missing information might not exist (I can eat outside of meal times)
  - Does not individuate events
    \( \exists X \, \exists Y \, \text{Eating}(\text{Speaker}, \text{Sandwich, Lunch, Desk}) \)
    \( \exists X \, \exists Y \, \text{Eating}(\text{Speaker}, \text{Lunch, Desk}) \)
    \( \text{Eating}(\text{Speaker, Sandwich, Lunch, Desk}) \)
    (c.f. Prolog Unification)
Explicit Events

- Unfortunately we can’t do this
  - There is no way to explicitly express that two events are the same.
  - i.e. \( e = e' \)
- Reification
  - There is no need to specify a fixed number of arguments
  - Instead additional information can be glued on using conjunctions
  - We can explicitly say two events were the same
- (See Davidson, 1967 for a fuller account)

Indefinite versus definite Noun phrases

- Russell was one of the first philosophers to propose FOPC as a MRL (1950s)
- Central to his account is that indefinite NPs (e.g. a dog) are translated using an existential quantifier.
  - "A dog barked" \( \rightarrow \exists X \[ \text{dog}(X) \land \text{barked}(X) \] \)
  - We need to be careful with scope elements like "not" & "every"
  - "A dog didn’t bark" \( \rightarrow \neg \exists X \[ \text{dog}(X) \land \text{barked}(X) \] \)
  - "Every child owns a dog" \( \rightarrow \forall X \[ \text{child}(X) \rightarrow \exists Y \[ \text{dog}(Y) \land \text{owns}(X,Y) \] \]

This works nicely in such cases

Discourse Problems

- Russell’s account doesn’t scale up very well to discourse.
  - Discourse is a coherent sequence of sentences with later sentences updating previous sentences. (obviously!)
- How to interpret definite NPs?
  - (i) A dog arrived.
  - (ii) The dog barked.
  - \( \exists X \[ \text{dog}(X) \land \text{arrived}(X) \] \)
  - ?
- We want to keep asserting predicates about the variable \( X \) but any further occurrences of \( X \) will be outside the scope of the existential quantifier.

Fullstops are conjunctions

- One solution is to regard fullstops as conjunctions.
- Therefore the scope of a quantifier extends throughout the text
- (Is this realistic?)
- Truth-Conditional Semantics
  - \( \exists X \; \text{Proposition}(X) \leftrightarrow \neg \forall X \; \neg \text{Proposition}(X) \)

A delegate arrived. She signed in
Donkey Sentences

- We need to be very careful how quantification is used when representing natural language
- "Every Farmer who owns a donkey beats it"
  \[\forall X [\text{Farmer}(X) \land \exists Y [\text{donkey}(Y) \land \text{owns}(X,Y)] \rightarrow \text{beats}(X,Y)]\]
- "Every child who owns a dog loves the dog"
  \[\forall X \forall Y [\text{child}(X) \land \text{dog}(Y) \land \text{owns}(X,Y)] \rightarrow \text{loves}(X,Y)]\]
- "A dog" should give us a universal quantifier
- This should be available for presuppositions elsewhere

Discourse Representation Structure

- DRT represents the discourse context as a DRS
- A set of referents
  - the entities which have been introduced into the context
- A set of conditions
  - predicates which are known to hold of these entities
- "The prime minister frisked the security guard"

Discourse Representation Theory

- Kamp (1981)
- NL discourse interpreted in context of a representation \(R\)
- Interpretation updates \(R\) to generate \(R'\)
- Key structure is a Discourse Representation Structure
- All noun phrases are discourse referents
- quantification is controlled by context (when the referent is introduced)
- Processing of discourse is incremental
  - new sentences update or add structure to DRS
- Inference is supported by a set of rules
  - (broadly equivalent to FOPC but with a model-theoretic semantics rather than truth conditional interpretation)

Sentences update Context

- Sentence meaning is an update operation on a context
  - Each sentence is interpreted in a context
  - The result is a new context
  - The prime minister frisked the security guard
  - A dog arrived
Presuppositions

- A sentence can make presuppositions about the kinds of context in which it can be interpreted
- "The dog barked" presupposes that there is a dog in the discourse context
- Presuppositions are represented as DRS
- The general representation of a sentence is
  - A single assertion DRS;
  - A set of presupposition DRSs (which use dotted lines)
- The dog chased a cat

Presupposition Resolution

- A presupposition is essentially a query to execute on the discourse context
- A presupposition is resolved if the query is successful
- Any variable bindings returned by the query are carried over to the assertion DRS
- The assertion DRS is then merged with the context DRS

Indefinite NPs in DRT

- Recall
- We're trying to find a representation of indefinite NPs which systematically deals with
  - when they introduce new discourse referents
  - when they behave like quantifiers
- In DRT an indefinite NP always contributes a DRS

- To make this structure behave in different ways
  - Sub-DRSs are introduced by Scope elements such as quantifiers & negation
  - When we process a phrase inside a scope element we add material to the sub-DRS

<table>
<thead>
<tr>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>dog(X)</td>
</tr>
</tbody>
</table>

A sub-DRS for negation

Consider the sentence A dog did not bark
- First create an empty sentence DRS
- Then process the negation
- Then process the sentence “A dog barked” inside the sub-DRS

(Equivalent to \( \exists X(\neg \text{dog}(X) \& \text{bark}(X)) \))
Accessibility

- DRS now has two separate functions
  - Modelling context updates and presuppositions
  - Modelling indefinites under negation

- Accessibility restrictions can be used to block
  - Indefinites in the scope of negation can’t be used to resolve presuppositions

  “A dog did not bark. The dog was very big” (??)

Donkey Sentences

- We now have all the machinery to deal with donkeys
- Every child who owns a dog loves the dog.
- Here’s what the sentence needs to mean
  \( \forall X \forall Y [\text{child}(X) \& \text{dog}(Y) \& \text{owns}(X,Y)] \rightarrow \text{loves}(X,Y) \)
- “A dog” needs to introduce a universal quantifier
- The variable it introduces must be available for presuppositions elsewhere in the sentence

A sub-DRS for quantification

- Quantifiers also introduce sub-DRS structures
- Every child owns a dog

  \( \forall \_ \rightarrow \\
\)

  The material in the noun introduced by the quantifying determiner goes into the left-hand DRS. The rest goes into the right

Translating DRSs to predicate logic

- There’s a simple translation from a DRS to an expression in first order logic

  For each referent in the DRS create an existential quantifier.
  Join all the conditions together with the connective &

  A context DRS is really just a notational variation of predicate logic.
  What’s important is how it’s built.

A,B,C
dog(A), cat(C), man(B)
chase(A,C)
Some final comments about DRT

1) It provides a framework for expressing the meaning of a sentence as an operation of updating contexts/
   - Elegant treatment of indefinite NPs and Presupposition

2) It provides a way of giving a single denotation of the indefinite determiner “a” which works in different contexts
   - to introduce new individuals
   - to introduce quantified variables

3) The combination of 1 and 2 allows the formulation of a very nice theory of how pronouns can refer back to quantified variables.

Further Reading

- FOPC as Semantics
  Jurafsky and Martin Chapter 14
  (Chapter 15 details how to augment CFGs to produce semantics)

- DRT