Computational Semantics

Giving formalisms meaning

- □ Formal Representations
- □ Some logics:
  - First Order Predicate Logic
  - Lambda Caluclus
- □ Predicates, variables quantifiers
- □ Translating NL to LF
- □ Practical systems
- □ Some typical problems
- □ Anaphora and Discourse

Formal Representation

- □ An unambiguious representation
- □ That has a "semantics":
  – what does your formalism mean
- □ That covers what you want it cover:
  – (and only covers that space)

A semantic formalism

- An **ontology**:
  – the objects, and relations you with to talk about
- Axioms:
  – predicates ("truths") in your world
- Inference mechanism:
  – procedure to prove things in your world
- Good formalisms are:
  – *sound* everything that can be proved true is true
  – *complete* everything that is true can be proved

A semantic formalism: example

- An **ontology**:
  – movie(X), actor(X), starredin(X,Y), directed(X,Y)
- Axioms:
  – movie(StarWars),
  – actor(HarrisonFord)
  – director(GeorgeLucas),
  – starredin(HarrisonFord,StarWars)
  – directed(GeorgeLucas,StarWars)
  – Forall X,Y,Z starredin(X,Y) & directed(Z,Y)
  $\longrightarrow$ directed(Z,X)
- Inference mechanism:
  – is directed(GeorgeLucas,HarrisonFord) true?
  – how do you prove it.

Logics

- Boolean logics:
  – atomic axioms
- First Order Predicate Logic:
  – atoms plus predicates:
  – movie(StarWars)
  – variables and qauntifiers
- Higher Order Logics:
  – arguments may be predicates not just atoms
  – thinks(Alan,directed(Hitchcock,ThreeDaysoftheCondor))

First Order Predicate Logic

- atoms: a,b,c, ...
- predicates: $predA/2$,$predB/2$,$predC/1$
- basic statements: $predA(a, b)$, $predB(b, c)$, $predC(b)$
- compound statements:
  - $A \wedge B$
  - $A \vee B$
  - $\neg A$
  - $A \rightarrow B \equiv \neg A \vee B$
- quantifiers:
  - $\forall X A$
  - $\exists Y A$

First Order Predicate Logic: semantics

Model theoretic semantics

- basic statements:
  – $predA(a, b)$ is true if $[\![\, predA \,]\!]^M([\![\, a \,]\!]^M, [\![\, b \,]\!]^M)$
- compound statements:
  – $A \wedge B$ true if $[\![\, A \,]\!]^M$ and $[\![\, B \,]\!]^M$
  – $A \vee B$ true if $[\![\, A \,]\!]^M$ or $[\![\, B \,]\!]^M$
  – $\neg A$ true if A is false
  – $A \rightarrow B$ true if $[\![\, A \,]\!]^M$ is false or $[\![\, B \,]\!]^M$
- quantifiers:
  – $\forall X A$ is true if for all bindings of X in A, $[\![\, A \,]\!]^M$ is true
  – $\exists Y A$ is true if there exists one binding of Y in A, such that $[\![\, A \,]\!]^M$ is true

Some examples

- $actor(HarisonFord)$
  "Harison Ford is an actor"
- $\exists X actor(X) \wedge director(X)$
  "Someone is a actor and a directory"
- quantifier scope
  – $\forall X \exists Y (man(X) \rightarrow woman(Y) \wedge loves(X, Y))$
  – $\exists Y \forall X (man(X) \rightarrow woman(Y) \wedge loves(X, Y))$

Semantics vs Calculus

- Semantics is meaning
  - Calculus is bunch of symbols
- Model Theoretic Semantics:
  - A symbol a
  - A mapping function $[\![\, a \,]\!]^M$ wrt to M
  - maps a to the bearded Scotsman himself

Words vs Formalism

- What is the meaning of “car”
  - how does it relate to “engine”, “motor”, “transport”
  - “Wordnet” type semantics
- Formalism
  - How do you translate syntatic structure
  - to semantic formalism
  - What are the structural problems

Quantifiers

- Forall X (∀, "universal") and Exists X (∃, "existential"):
  – ∀ X ∃ Y actor(X) & movie(Y) & starredin(X,Y)
- Negation
  – Not ∃ X actor(X) & movie(X)
- Few, Many, Some, less than three ...:
  – ForFew X actor(X) & director(X)
- Don't need no quantifiers ... (?)
  – actor(X) & director(X)
  – but are they existential or universial

Natural Language and Semantics

- HarrisonFord starred in StarWars.
  – starredin(HarrisonFord,StarWars)
- Who starred in StarWars and IndiannaJones.
  – $\exists$ X starredin(X,StarWars) & starredin(X,IndiannaJones)
- Which actor and director starred in StarWars
  – $\exists$ X starredin(X,StarWars) & actor(X) & director(X)
- what does "and" mean:
  – Which actors and directors starred in StarWars
  – $\exists$ X starredin(X,StarWars) & actor(X) & director(X)
  – Which men and women starred in StarWars
  – $\exists$ X starredin(X,StarWars) & man(X) & woman(X)
  – $\exists$ X starredin(X,StarWars) & (man(X) or woman(X))

Quantifier scope

A seat was available for every passenger
A toll free number was available for every customer
A secretary phoned up each director
A letter was sent to each customer

Every man loves a woman
who works at the candy store
Every 5 minutes a man gets knocked down
and he is not too happy about it

Quantifier scope

- Quantifiers can have different scope:
  - Every man loves a woman
  - $\forall$ X (man(X) & $\exists$ Y woman(Y) $\rightarrow$ loves(X,Y)
  - $\exists$ Y (woman(Y) & $\forall$ X man(X) $\rightarrow$ loves(X,Y)
  - Every man is searching for a needle
- Can explicitly find the alternatives:
  - or can preserve the ambiguity
- Some scopes are equivalent
- Some scopes imply others

Compositionality

The meaning of an utterance is a function of the meaning of its parts.

```
S -> NP VP

sem_of(S) = compose(sem_of(NP),sem_of(VP)).
```

Before we had

```
sem_of(NP) ->
   np(X,man(X),Scope,every(X,man(X) --> Scope)).

sem_of(VP) ->
   vp(X,walk(X)).
```

Composition

```
sentence(For) -->
    noun_phrase(X,Scope,For),
    verb_phrase(X,Scope).
```

Lambda Calculus

Better to have a representation for abstractions
in our SRL and have a uniform composition function.

Verb phrase "walks" $\rightsquigarrow \lambda x[walk(x)]$

Noun phrase "John" $\rightsquigarrow$ j

Sentence composition

$$\lambda x[walk(x)](j) \rightsquigarrow walk(j)$$

Lambda calculus

Syntax

λ `VAR TERM`

Semantics ???

Composition: lambda application

$\lambda x[walk(x)](j)$

is equivalent to

$walk(j)$

Beta-reduction

reducing lambda expression plus argument to normal form

Application and Reduction

$\lambda x[walk(x)](j) \rightsquigarrow$
$\quad walk(j)$

$\lambda x \lambda y[like(x, y)](j) \rightsquigarrow$
$\quad \lambda y[like(j, y)]$

$\lambda x \lambda y[like(x, y)](j)(m) \rightsquigarrow$
$\quad like(j, y)]$

$\lambda P[\forall x P(x)](\lambda y[walk(y)]) \rightsquigarrow$
$\quad \forall x \lambda y[walk(y)](x)$
$\quad \forall x[walk(x)]$

Anaphora

- pronouns and other references (definites)
- Anaphora (general term and preceeding referent):
  - The man came in. He sat down
  - My laptop broke. The machine went on fire.
- Cataphora (future reference)
  - That he had no money worried John
- Exophora
  - It is raining.
  - I went to talk yesterday, he was boring.

Anaphora resolution

- Some things easy, some *very* hard
  - may need complete world knowledge
- Introduce new referents in the discourse
  - candidates (male/female/inanimate)
- With pronouns and definites:
  - find likely candidate in context
  - most recent and matching attributes
  - may require complex relationships

Discourse and Dialog

- ☐ Tracking conversations:
- ☐ Tracking sub-dialogs:

1. Alfred and Zohar liked to play baseball.
2. They played it every day after school before dinner.
3. After their game, Alfred and Zohar had ice cream cones.
4. They tasted really good.
5. They were Italian and they often had sprinkles on
6. One day they met a man at the ice-cream parlour.
7. He told them that he had seen them playing.
8. He wanted them to play for his team.

Donkeys

"Every man who owns a donkey beats it"
"If a man owns a donkey, he beats it"

- possible translations
  - $\forall X((man(X) \wedge \exists Y(donkey(Y) \wedge owns(X,Y))) \rightarrow beats(X,Y))$
  - mal-formed as final Y outside scope of $\exists Y$

  - $\forall X \exists Y(man(X) \wedge donkey(Y) \wedge owns(X,Y)) \rightarrow beats(X,Y)$
  - true in model beats a least one of the donkeys he owns.
  - $\exists Y \forall X((man(X) \wedge donkey(Y) \wedge owns(X,Y)) \rightarrow beats(X,Y))$
  - A single donkey jointly owned

  - $\forall X \forall Y((man(X) \wedge donkey(Y) \wedge owns(X,Y)) \rightarrow beats(X,Y))$
  - the most likely meaning

But the most likely meaning has a Universal for an indefinite

Discourse Representation Theory

Hans Kamp (1981)
Johnson and Klein 1986 “Discourse, anaphora and parsing”, COLING 86 (Bonn).

Kamp and Reyle 1993.

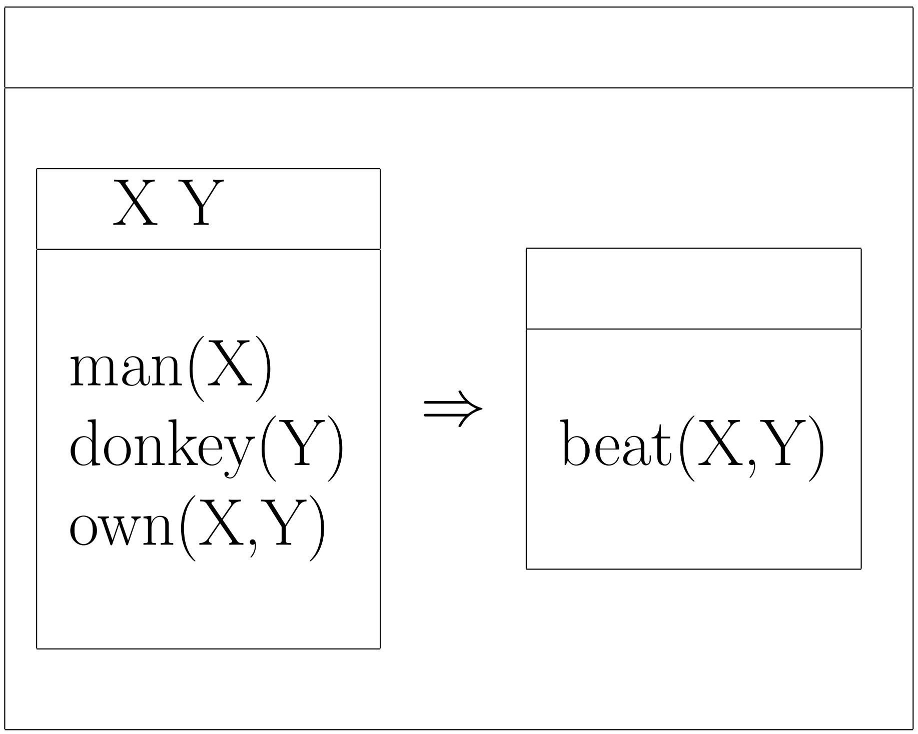
Discourse Representation Structure (DRS)

A man walks $\rightsquigarrow$

X
man(X) walk(X)

- ☐ Discourse markers
- ☐ Conditions

DRT offers a uniform treatment of indefinite NPs whether within the scope of a universal or not.



Summary
Discourse Representation Theory

- ☐ Every in DRSs
  $\Rightarrow$ relation between sub-DRSs
- ☐ Accessibility of markers
- ☐ Donkey anaphora
- ☐ DRT offers a uniform treatment of indefinites,

Marrying Norwegians

"Mary wants to marry a Norwegian"

- Mary knows who her future husband is and he is from Norway
  – $\exists X \exists Y (mary(X) \wedge norwegian(Y) \wedge wants\_to\_marry(X, Y))$

- Mary likes Norway and want so to live there so she want so marry someone, though doesn't know who, who is norwegian.
- "Mary wants to marry a millionaire"

Need higher order semantics to represent this

Situation Semantics

Naming things

- ☐ All basic logics require grounding in semantics
- ☐ Meaning is defined for each part
- ☐ Cannot refer to themselves
- ☐ ‘’The set of all sets” (Russell)
  - – cannot give a constructive definition
- ☐ Need to introduce:
  - – fixed point semantics
  - – Non-well founded set theory (Peter Aczel)
  - – Antifoundation axiom

Other “famous” sentences

- John seeks a unicorn.
- John sees Mary walk and Bill walk or not walk.
- Colorless green ideas sleep furiously.
- Every representative of a company saw most samples.
- Mary gave her mother flowers and so did Jane.

Summary

- ☐ Semantic formalism
  – sound and complete
- ☐ Logic vs Calculus
- ☐ Words vs structure
- ☐ FOPL, Lambda Calculus
- ☐ Quantifiers and Scope
- ☐ Anaphora resolution:
  – find referents of pronouns and definites.