Roadmap

- Computational Semantics
  - AI-completeness
  - More tractable parts
    - Lexical Semantics
    - Word Sense Disambiguation
    - Semantic Role Labeling
    - Resources

- Meaning Representation
  - Representational requirements
  - First-Order Logic
    - Syntax & Semantics
Tasks in Computational Semantics

- Computational semantics aims to extract, interpret, and reason about the meaning of NL utterances, and includes:
  - Defining a meaning representation
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  - Developing methods for reasoning about these representations and performing inference from them
Complexity of Computational Semantics

- Requires:
  - Knowledge of language: words, syntax, relationships between structure and meaning, composition procedures
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- Effectively AI-complete
  - Need representation, reasoning, world model, etc
Major Subtasks

- Hopefully more tractable....
- Computational lexical semantics:
  - Representing word meaning, interword relations, and word-structure relations
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  - Selecting the meaning of an ambiguous word in context
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  • Representing word meaning, interword relations, and word-structure relations

• Word sense disambiguation:
  • Selecting the meaning of an ambiguous word in context

• Semantic role labeling:
  • Identifying the thematic roles played by arguments in predicate
Lexical Semantics

- Synonymy:
  - Couch/sofa; filbert/hazelnut; car/automobile
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  - Up/down; in/out;
Lexical Semantics

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- Hyponymy:
  - Car ISA vehicle; mango ISA fruit; dog ISA mammal
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- Decomposition:
  - Swim: GO FROM place1 TO place2 by SWIMMING
Word Sense Disambiguation

- Bank:
  - I withdrew money from the bank
Word Sense Disambiguation

- Bank:
  - I withdrew money from the bank
    - Financial institution
  - After the boat capsized, he climbed up the muddy bank
Word Sense Disambiguation

- Bank:
  - I withdrew money from the bank
    - Financial institution
  - After the boat capsized, he climbed up the muddy bank
    - Riverside
  - The plane had to bank steeply.
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  - The plane had to bank steeply.
    - Turn
Example: “Plant” Disambiguation

There are more kinds of plants and animals in the rainforests than anywhere else on Earth. Over half of the millions of known species of plants and animals live in the rainforest. Many are found nowhere else. There are even plants and animals in the rainforest that we have not yet discovered.

Biological Example

The Paulus company was founded in 1938. Since those days the product range has been the subject of constant expansions and is brought up continuously to correspond with the state of the art. We’re engineering, manufacturing and commissioning world-wide ready-to-run plants packed with our comprehensive know-how. Our Product Range includes pneumatic conveying systems for carbon, carbide, sand, lime and many others. We use reagent injection in molten metal for the…

Industrial Example

Label the First Use of “Plant”
Semantic Role Labeling

- John broke the window.

- John broke the window with a rock.

- The rock broke the window.

- The window was broken by John.
Semantic Role Labeling

- \( \text{John}_{\text{AGENT}} \) broke the window\( \text{window}_{\text{THEME}} \).
Semantic Role Labeling

- John_{AGENT} broke the window_{THEME}.

- John_{AGENT} broke the window_{THEME} with a rock_{INSTRUMENT}.
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- 

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- The rock\textsubscript{INSTRUMENT} broke the window\textsubscript{THEME}.
- The window\textsubscript{THEME} was broken by John\textsubscript{AGENT}.
Semantic Resources

- Growing number of large-scale computational semantic knowledge bases
  - Dictionaries:
    - Longman Dictionary of Contemporary English (LDOCE)
  - WordNet(s)
  - PropBank
  - FrameNet
  - Semantically annotated corpora: SEMCOR, etc
WordNet

- Large-scale, manually constructed sense hierarchy
  - ISA hierarchy, other links

- Pod:
  - 1(n) {pod, cod, seedcase} (the vessel that contains the seeds of a plant (not the seeds themselves)
  - 2 (n) {pod, seedpod} (a several-seeded dehiscent fruit as e.g. of a leguminous plant)
  - 3 (n) {pod} (a group of aquatic mammals)
  - 4 (n) {pod, fuel pod} (a detachable container of fuel on an airplane)
  - 5 (v) {pod} (take something out of its shell or pod) pod peas or beans
  - 6 (v) {pod} (produce pods, of plants)
WordNet Taxonomy View

Sense 1
hamburger, beefburger --
(a fried cake of minced beef served on a bun)
=> sandwich
  => snack food
  => dish
    => nutriment, nourishment, nutrition...
    => food, nutrient
    => substance
    => matter
      => physical entity
      => entity
Computational semantics aims to extract, interpret, and reason about the meaning of NL utterances, and includes:

- Defining a meaning representation

- Developing techniques for **semantic analysis**, to convert NL strings to meaning representations

- Developing methods for reasoning about these representations and performing inference from them
Representing Meaning

\[ \exists e, y \, Having(e) \land Haver(e, Speaker) \land HadThing(e, y) \land Car(y) \]

First-order Logic

Semantic Network

Conceptual Dependency

Frame-Based

\[
\text{Car} \quad \uparrow \text{POSS-BY} \\
\text{Speaker}
\]

Having

Haver: Speaker

HadThing: Car
Meaning Representations

- All structures from set of symbols
- Representational vocabulary
Meaning Representations

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- Symbol structures correspond to:
  - Objects
Meaning Representations

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  - Representation of meaning of linguistic input
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- Can be viewed as:
  - Representation of meaning of linguistic input
  - Representation of state of world
Representational Requirements

- Verifiability
- Unambiguous representations
- Canonical Form
- Inference and Variables
- Expressiveness
  - Should be able to express meaning of any NL sent
Verifiability

- Can a system compare
  - Description of state given by representation to
  - State of some world modeled by a knowledge base (kb)?
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- E.g.
  - Input: Does Maharani server vegetarian food?
  - Representation: Serves(Maharani,VegetarianFood)
  - KB: Set of assertions about restaurants
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  - If not, False
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  - KB: Set of assertions about restaurants
  - If representation matches in KB -> True
  - If not, False or Don’t Know
    - Is KB assumed complete or incomplete?
Unambiguous Representations

- Semantics is ambiguous:
  - *I wanna eat someplace close to UW*
Unambiguous Representations

- Semantics is ambiguous:
  - *I wanna eat someplace close to UW*
    - Eat at someplace  OR eat the restaurant

- (Final) Representation must be unambiguous, e.g.,
  - $E_1 = \text{want}(l,E_2)$
  - $E_2 = \text{eat}(l,O_1,\text{Loc}_1)$
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• Resolving the ambiguity?
  • Later
Canonical Form

- Input can have many meanings, and
- Many inputs can have same meaning
  - Flights from Seattle to Chicago
Canonical Form

- Input can have many meanings, and
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  - Flights from Seattle to Chicago
  - Are there any flights from Seattle to Chicago?
Canonical Form

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Canonical Form

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  - Which flights are flown from Seattle to Chicago?
- Could all have different forms
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- Could all have different forms
  - Difficult to test in KB
- Single canonical form allows consistent verification
Canonical Form

- Issue:
Canonical Form

- Issue:
  - Pushes ambiguity resolution into semantic analysis
- Different surface forms, but same underlying meaning
Canonical Form

- **Issue:**
  - Pushes ambiguity resolution into semantic analysis

- **Different surface forms, but same underlying meaning**
  - **Words:** E.g., food, fare, dishes
    - Word senses, synonymy
    - Word sense disambiguation
Canonical Form

- Issue:
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- Different surface forms, but same underlying meaning
  - Words: E.g., food, fare, dishes
    - Word senses, synonymy
    - Word sense disambiguation
  - Syntactic alternations:
    - E.g. active vs passive
    - Interrogative vs declarative forms, topicalization, etc
Inference

- Can vegetarians eat at Maharani?
- Does Maharani serve vegetarian food?
Inference

- Can vegetarians eat at Maharani?
- Does Maharani serve vegetarian food?

- Meanings are not identical, but
Inference

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- Does Maharani serve vegetarian food?

- Meanings are not identical, but
- Linked by facts in the world

- *Inference* allows system to draw valid conclusions from meaning rep. and KB

- Serves(Maharani,VegetarianFood) =>
- CanEat(Vegetarians,AtMaharani)
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Variables

- *I want a restaurant that serves vegetarian food.*
- Can we match this in KB?
Variables

- *I want a restaurant that serves vegetarian food.*
- Can we match this in KB?
  - No restaurant specified, so no simple assertion match
- Solution:
  - Variables
    - Serves(x, VegetarianFood)
Variables

- I want a restaurant that serves vegetarian food.

- Can we match this in KB?
  - No restaurant specified, so no simple assertion match

- Solution:
  - Variables
    - Serves(x, VegetarianFood)
  - True if variable can be replaced by some object s.t. resulting proposition can match some assertion in KB
Meaning Structure of Language

- Human languages
  - Display basic predicate-argument structure
- Employ variables
- Employ quantifiers
- Exhibit a (partially) compositional semantics
Predicate-Argument Structure

- Represent concepts and relationships
- Words behave like predicates:
Predicate-Argument Structure

- Represent concepts and relationships
- Words behave like predicates:
  - Verbs, Adj, Adv:
    - Eat(John,VegetarianFood); Red(Ball)
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- Subcategorization frames indicate:
Predicate-Argument Structure

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- Some words behave like arguments:
  - Nouns: Eat(John,VegetarianFood); Red(Ball)
- Subcategorization frames indicate:
  - Number, Syntactic category, order of args
Semantic Roles

- Roles of entities in an event
  - E.g. John\textsubscript{AGENT} hit Bill\textsubscript{PATIENT}

- Semantic restrictions constrain entity types
  - The dog slept.
  - ?The rocks slept.

- Verb subcategorization links surface syntactic elements with semantic roles
First-Order Logic

- Meaning representation:
  - Provides sound computational basis for verifiability, inference, expressiveness
- Supports determination of propositional truth
- Supports compositionality of meaning
- Supports inference
- Supports generalization through variables
First-Order Logic

- **FOL terms:**
- **Constants:** specific objects in world;
  - $A, B, Maharani$
  - Refer to exactly one object; objects referred by many
First-Order Logic

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  - **Functions:** concepts refer to objects, e.g. Frasca’s loc
    - *LocationOf(Frasca)*
    - Refer to objects, avoid using constants
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    - $\text{LocationOf}(\text{Frasca})$
    - Refer to objects, avoid using constants

- **Variables:**
  - $x, e$; as in $\text{LocationOf}(x)$
FOL Representation

- **Predicates:**
  - Relations among objects
    - Maharani serves vegetarian food. =>
    - Serves(Maharani, VegetarianFood)
    - Maharani is a restaurant. =>
    - Restaurant(Maharani)
FOL Representation

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  - Allow compositionality of meaning
    - Maharani serves vegetarian food and is cheap.
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  - *Serves*(Maharani, VegetarianFood) ∧ *Cheap*(Maharani)
FOL Representation

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Variables & Quantifiers

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Variables & Quantifiers

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- Variables refer to:
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  - All objects in some collection

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Variables & Quantifiers

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- Quantifiers:
  - $\exists$: existential quantifier: “there exists”
    - Indefinite NP, one such object for truth
    - A cheap restaurant that serves vegetarian food
      $\exists x \text{Restaurant}(x) \land \text{Serves}(x, \text{VegetarianFood}) \land \text{Cheap}(x)$
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      \[ \exists x \text{Restaurant}(x) \land \text{Serves}(x, \text{VegetarianFood}) \land \text{Cheap}(x) \]
  - $\forall$: universal quantifier: “for all”
    - All vegetarian restaurants server vegetarian food.
      \[ \forall x \text{VegetarianRestaurant}(c) \Rightarrow \text{Serves}(x, \text{VegetarianFood}) \]
Lambda Expressions

- Lambda notation: (Church, 1940)
  - Just like lambda in Python
  - Allows abstraction over FOL formulas
    - Supports compositionality
  - Applied to logical terms to form exp.
    - Binds formal params to term

- Essentially unnamed function w/params
  - Application substitutes terms for formal params
Examples

$\lambda x. P(x)$
$\lambda x. P(x)(A)$
$P(A)$

$\lambda x. \lambda y. \text{Near}(x, y)$
$\lambda x. \lambda y. \text{Near}(x, y)(\text{Bacaro})$
$\lambda y. \text{Near}(\text{Bacaro}, y)$
$\lambda y. \text{Near}(\text{Bacaro}, y)(\text{Centro})$
$\text{Near}(\text{Bacaro}, \text{Centro})$
Lambda Expressions

- Currying;
  - Converting multi-arguments preds to sequence of single argument preds
- Why?
Lambda Expressions

- Currying;
  - Converting multi-arguments preds to sequence of single argument preds
- Why?
  - Incrementally accumulates multiple arguments spread over different parts of parse tree