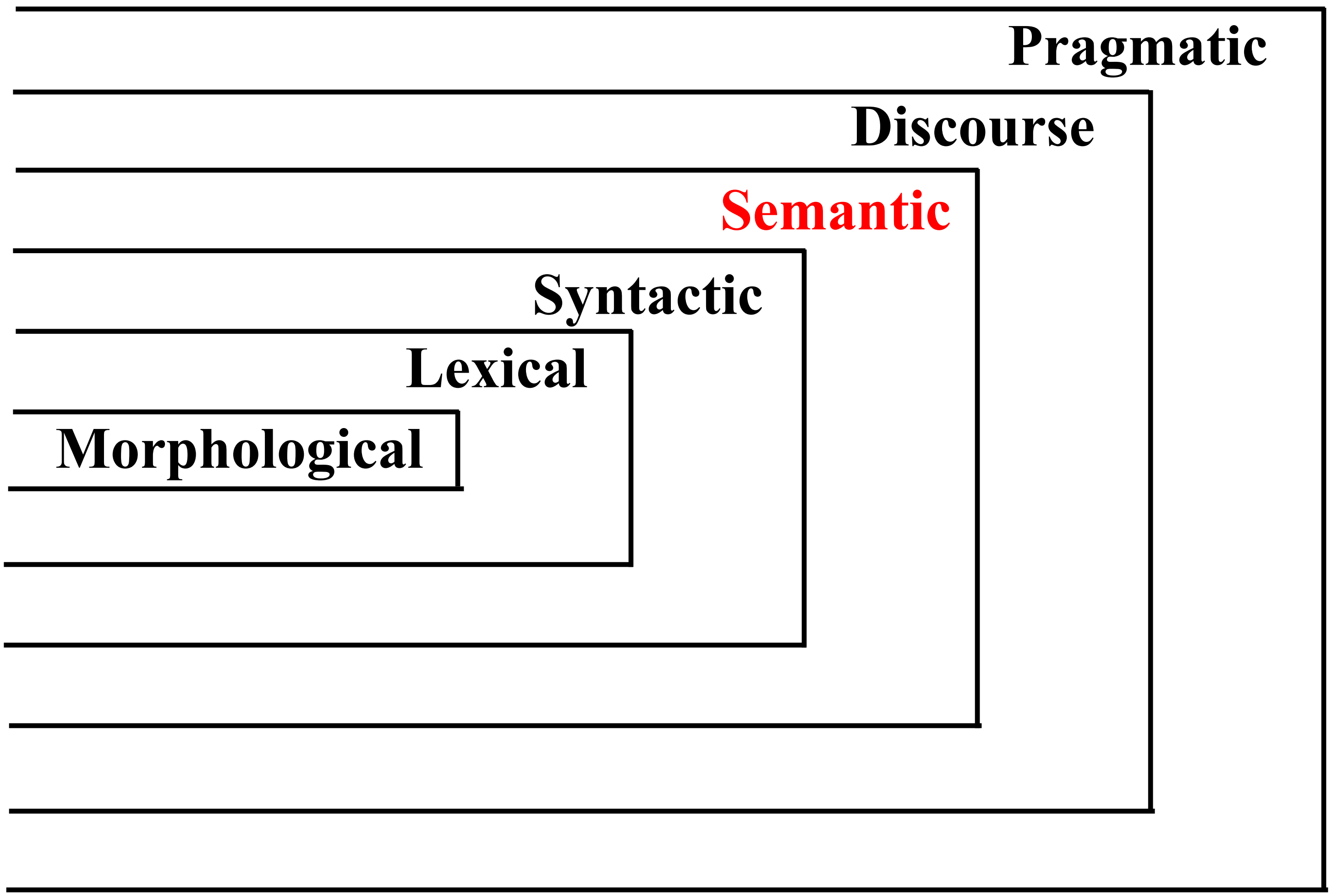
Semantic Processing and Semantic Representations

Synchronic Model of Language



Semantic Processing

- Implement the human ability to understand the meaning of sentences in their language.
  - Given text (or speech) give a semantic representation of the meaning
- Generative semantic theories (e.g. Katz and Fodor, "The structure of semantics", 1964) advocates a decompositional semantics that can build up the semantics of sentences using
  - *semantic markers* as the interpretation of syntactic words and
  - *selectional restrictions* on applying semantic relations.
    - The agent of the verb "kick" must be something active
- Semantic processing attempts to build representations of the meaning of sentences in a decompositional way based on the syntax of the language.
  - i.e. syntactic phrase structure should map to semantic structure

Related tasks for semantic processing:

- Detect non-syntactic ambiguities. If a sentence is two ways ambiguous, characterize the meaning of each reading.

  The bill is large.

  - Related Topics:
    - Word Sense Disambiguation: if a word has more than one sense, decide the sense of the word as it occurs in a sentence
      The bill is large but I have enough money to cover it.
    - Semantic similarity of words
- Decide if one sentence is a paraphrase of another (two way).

  Your marks on the tests were excellent.

  You scored very high on the exams.
- Entailment: decide if the truth of one sentence implies the truth of another (one way).

  John lives in Toronto.
  implies *John's residence is in Canada.*

Relation between Syntax and Semantics in NLP

- Syntactic analysis:
  - determines the syntactic category of the words
  - decides phrase structure – how words are grouped
  - assigns structural analysis to a sentence
- Semantic analysis:
  - creates a representation of the meaning of a sentence
- Clearly syntactic structure affects meaning (e.g. word order, phrase attachment).
  - "*The man with the telescope watched Mary.*"
  - "*Mary watched the man with the telescope.*"
- But meaning can determine syntactic structure
  - Recall that lexicalized statistical parsing used head word affinities (probabilities) to help determine parsing.

Building blocks of semantic systems

- Semantics that words (or base noun phrases) represent – the objects
  - Entities – individuals such as a particular person, location or product
    - John F. Kennedy, Washington, D.C., Cocoa Puffs
  - Concepts – the general category of individuals such as
    - person, city, breakfast cereal

Building blocks of semantic systems

- Semantics indicated by verbs, prepositional phrases and other structures
  - Relations between entities and concepts
    - John F. Kennedy “is-a” person
  - Relations between entities or between concepts
    - Hierarchy of specific to more general concepts
    - Wide variety of other relations
  - Predicates representing verb structures, sometimes called events
    - Semantic roles, case grammar
    - Can also be used for relations between objects

Semantic Representation

- A representation shows how to put together entities, concepts, relations and predicates to describe a situation or "semantic world"
  - Enables reasoning about that semantic world
- Some possible knowledge representation approaches:
  - First Order Logic
  - Semantic Nets
  - Conceptual Dependency
  - Frames
  - Rule-Based
  - Conceptual Graphs
  - Case Grammer

Why do we need semantic representations?

- To link the surface, linguistic elements to the non-linguistic knowledge of the world
  - Many words, few concepts
- To represent the variety at the lexical level at a unified conceptual level
  - Unambiguous representations; canonical forms
- Structures composed from a set of symbols
  - All languages have a predicate-argument structure
  - Correspond to relationships that hold among concepts underlying constituent words and phrases of a sentence, and then across sentences
- Can be used to reason, both to verify what is true in the world and to infer knowledge from the semantic representation

First Order Logic for Semantic Representation

- Also known as Predicate Calculus
- A symbolic language whose symbols have precisely stated meanings and uses
  - The symbols can be used as meanings in the real world
  - Typically express properties of entities in the world
- Example – *if Socrates is a man, then Socrates is a mortal*
  Man (Socrates) -> Mortal (Socrates)

- First Order Logic (FOL) often used in AI systems found in such applications as robotics and computational control systems
  - Allows a natural language interface to such systems
  - Systems have automatic reasoning to make decisions or supply information

FOL language

- FOL uses terms to represent objects in the real world
  - Constants are specific objects in the world - entities
    - Socrates, Pastabilities
  - Functions represent concepts about objects
    - LocationOf (Pastabilities)
      - Note the value of a function is a concept or entity
  - Variables are used to stand for any object
    - X
- FOL uses predicates to state relations between objects
    - Note the value of a predicate is True or False representing facts in the world
  - "IsRestaurant" could be a predicate that when applied to an object returns True if it is a restaurant
    - IsRestaurant (Pastabilities)
  - If "Serves" is a predicate taking a restaurant and a type of food as arguments, we can state that a restaurant serves a type of food
    - Serves (Pastabilities, VegetarianFood)

FOL language, operations and quantifiers

- FOL uses connectives *and* and *or* to combine statements
  - Serves (Pastabilites, VegetarianFood) ^ IsExpensive(Pastabilities)
- FOL uses the implication connection to mean if the first statement is true, then the second one is also true
  - Serves(Pastabilities, VegetarianFood) => IsRestaurant(Pastabilities)
    - Is this true?
- FOL uses the existential quantifier to assert that an object with particular properties exists

  ∃ X IsRestaurant(X) ^ Serves(X, VegetarianFood)
- FOL uses the universal quantifier to assert that particular properties are true for all objects (using ∀ for the "forall" symbol)
  - ∀ X IsRestaurant(X) => Serves(X, VegetarianFood)

  (this is definitely false because not all restaurants serve vegetarian food)

Example - Syracuse Restaurant Semantic World

- Objects: Pastabilities, ElCanjelo, FunkNWaffles, # *restaurants in Syracuse*
  VegetarianFood, MexicanFood, EclecticFood # *types of food*
  SyracuseUniversity, TheWarehouse # *locations in Syracuse*
- Functions: LocationOf( ) # gives the location of the argument
- Predicates: IsRestaurant( ) # true if the argument is a restaurant
  Serves (,) # true if the 1st argument serves the type of food in the 2nd arg
  Near (,) # true if the 1st arg location is near the 2nd arg location
- FOL representation of example sentences:
  - More than one sentence could map to the same representation
    The restaurant El Canjelo serves Mexican food.
    El Canjelo is a restaurant specializing in Mexican food.
    IsRestaurant(ElCanjelo) ^ Serves(ElCanjelo, MexicanFood)
  - Some information (restaurant is new) may not be in the semantic world
    Funk N Waffles is a new eclectic restaurant near Syracuse University.
    IsRestaurant(FunkNWaffles) ^ Serves(FunkNWaffles, EclecticFood)
    ^ Near (LocationOf(FunkNWaffles), SyracuseUniversity)

Reasoning with FOL

- FOL allows inference to make conclusions of new information
  - Inference rule is called “modus ponens”, informally is if-then reasoning
    if we know that A is true and we know that A => B is true,
    we can conclude that B is true

- This type of inference has efficient implementations to allow systems to reason from facts given in the semantic world or in text.
  - For example, reasoning could find answers for a question answering system
    Find me a restaurant serving Mexican food near the Warehouse
  - Find the X such that
- IsRestaurant(X) ^ Serves(X, MexicanFood) ^ Near(LocationOf(X)), TheWarehouse)

Events in First Order Logic

- So far the predicates have captured state, properties that remain unchanged over some period of time
- Events denote changes in some state and can have a host of participants, props, times and locations.
- One way to give events in FOL is to state the existence of an event that has all the participants, etc.

I ate a turkey sandwich for lunch at my desk on Tuesday.

∃ e Eating(e) ^ Eater(e, Speaker) ^ Eaten(e, TurkeySandwich)
^ Meal(e, Lunch) ^ LocationOf(e, Desk) ^ Time(e, Tuesday)

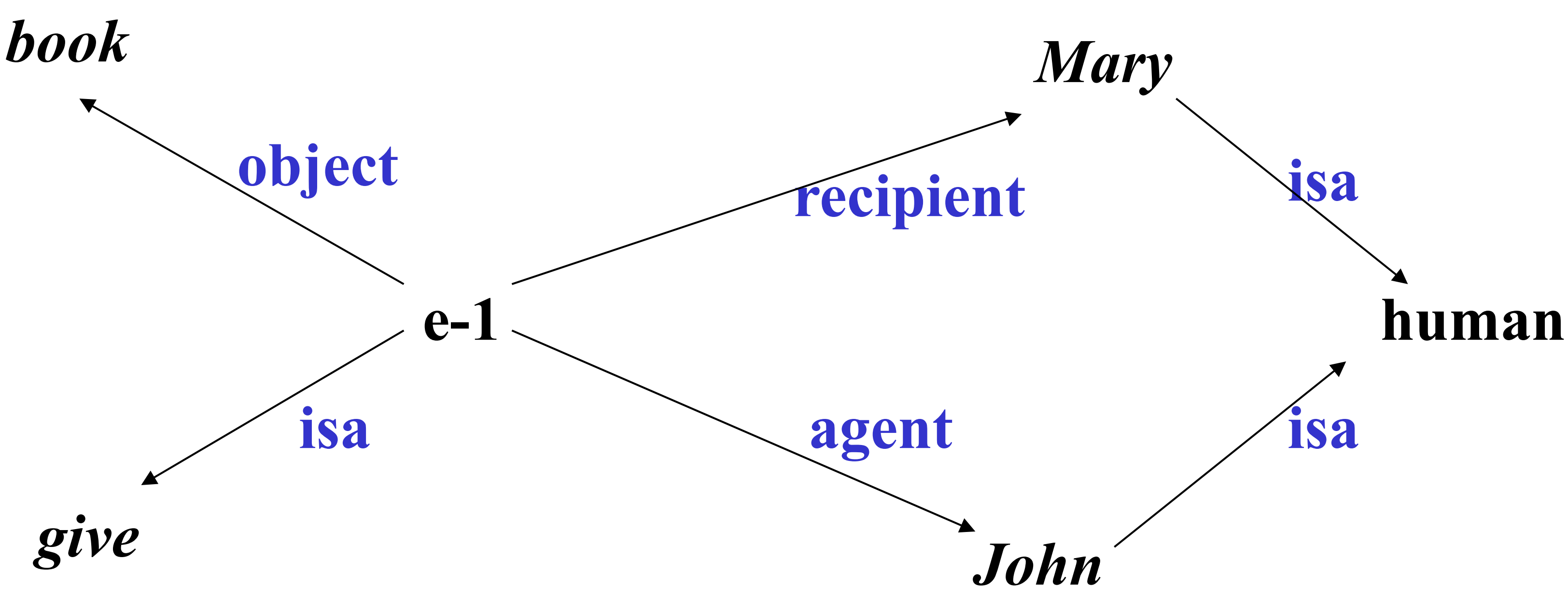
Difficulties with First Order Logic

- Problem for NLP:
  - 'semantics' of logic does not necessarily equate to 'meaning' in the real world
  - Not everything is as clear cut as required by a formal logic
  - May not be enough "real world" predicates in the FOL system to capture semantics of text
    - This is a problem for all the semantic representations
    - Semantic systems better developed for objects and actions
    - Not as well developed to represent ideas and beliefs
  - See Cyc Corp efforts to embody all world knowledge in (essentially) First Order Logic in their "Knowledge Base"
    - http://www.cyc.com/cyc/technology/whatiscyc_dir/whatsincyc

Semantic Networks

- A network or graph of nodes joined by links where:
  - nodes represent concepts (book, human) and entities (John, Mary)
  - links (labelled, directed arcs) represent relations (e.g. ISA)

John gives a book to Mary.



Frames

- A type of structured representation or *schema*
- Introduced by Marvin Minsky in 1975
  - "A Framework for Representing Knowledge"
  - Most widely referenced paper on knowledge representation
  - Explicitly attempts to represent human processing

- A way of grouping information about an entity or an event in terms of a record of 'slots' and 'fillers'
  - Each object has a frame with slots
  - One slot filled by the name of the object that the node stands for
  - Other slots filled with a property or relation and the value of the property or the entity that is related

Example of Frames

- Wikipedia Info Box is an example of a frame structure
  - Slot names are properties or relations
  - An property value is information such as a date or height
  - A relation value is another entity, which may have its own frame
- More formal frame systems (such as those for information extraction) require uniformity of slot names and value syntax

Name	Barack Obama
Birthdate	August 4, 1961
Birthplace	Honolu, Hawaii
Height	6' 1" (1.85 m)
Parents	Barack Obama Sr., Ann Dunham
Children	Natasha Obama, Malia Ann Obama

- Reasoning with Frames can use FOL:
  (∃ X) (Name(X) = Barack Obama) ^ Birthplace(X) = Honolulu) etc.

Applications of Semantic Representations

- Semantic representations are used to represent entities with their properties and relations in information extraction and question answering systems
- Semantic representations are used in reasoning in AI systems such as robot manipulations
  - Could also be used in dialog systems
  - Works best in a small environment where the amount of world knowledge needed is small

- Paraphase task: two sentences map to the same semantic representation
- Entailment task: the semantics of the first sentence implies the semantics of the second under reasoning

Getting Semantic Representation from Text

- Use a syntactic parse tree to identify predicates and possible relations structures
- Algorithms map syntactic structure to relations, given the words in the text
  - Semantic role labeling is one important algorithm (next section)
  - Some systems employ a First Order Logic mapper
  - Watson (IBM question answering system) mapped dependency parses to frames