Meaning: intuitions

- Meaning has multiple dimensions:
  - Truth conditions.
    `Three is larger than two.` - analytic
    `Dense vectors are better than sparse BoW vectors.` - contingent.
    `Wednesday comes before Friday.` - contingent.
    `A married man is a bachelor.` - contradiction.
  - Entailment.
    `Hari walked quickly.` `Hari walked` - first entails second
    `Hari sold Salma a book.` `Salma bought a book from Hari.`
  - Meaningless.
    `Colourless green ideas sleep furiously.` - no meaning can be attached.
  - Ambiguity.
    `He fed him dog biscuits.`
    `Everyone knows one language.`

Meaning: intuitions - 1

- Language in the form of speech can have pragmatic components.
  `Open the window. The window is open. Is the window open?`
  Command, declarative statement, question. However, all have the same propositional status.

Semantics

- One simple view of semantics is to answer the following question for a linguistic expression or sentence:

  Who did what to whom, and how, when and where?

  This leads to a view of semantics as computing role labels for constituents of a sentence and a case/frame based representation of meaning.
- Another view: Meaning of a (declarative) sentence is a proposition that describes the state of affairs. This leads to a logic based representation of meaning and truth-conditional semantics - that is conditions under which the declarative sentence holds or is true. The major computational problem is to construct the meaning of the sentence from its syntactic constituents.

Central questions

The central questions are:

- How do lexemes (words) have meaning?
- How do linguistic expressions (e.g. sentences) have meaning?
- What is the dependence between sentence meaning and lexeme meaning?

Semantic analysis

- Semantic analysis and representation is much more complex than lexical/ morphological analysis and syntactic analysis.
- There is also much less convergence on what it is and how to represent it.
- To 'understand a linguistic expression' can be viewed differently. It can mean incorporating the information in the linguistic expression into the knowledge base of the individual. In other cases it can mean that the individual responds 'appropriately' to the linguistic expression.
- 'Understanding' is complex. It involves lexical analysis, parsing or syntax analysis, word meaning, resolving references and ambiguity together with its interaction with existing knowledge, context and basic reasoning.

Lexicon and compositional meaning

- Two clear divisions in meaning:
  - Meaning of words or fixed word combinations or lexical meaning.
  - Meaning of word expressions which is combinational or compositional - that is meaning of the expression is composed of the meaning of the parts.
- In practice the above division is not so clear and word meaning is often dependent on the context of occurrence which is the word expression.

Grounding

- The main problem in semantics is 'how to ground' meaning. Circularity and infinite regress must be avoided.
- Representing meaning requires some primitives whose meaning is assumed to be known. One possibility is sensori-motor schemas. More generally, the primitives are chosen by the semanticist. Consequently, there are many representational systems which are not easily interconvertible.

Ambiguity

- Sources of ambiguity in language expressions can be lexical, syntactic, scopal (scope of quantifier), referential (e.g. pronoun).
- Two kinds of lexical ambiguity:
  - Homonymy: Words that are textually/auditorily similar (e.g. bank, light).
  - Polysemy: Different senses of the same word (e.g. bank, see). Polysemy is harder since often the difference in the senses is subtle. Example: bank: as a repository (gene-bank, piggy-bank); as a building (the restaurant next to the bank); as a creditor (the bank has my mortgage); as a savings institution (I bank with SBI); as an investment institution; as an industry or institution (the bank is in trouble, stressed loans has put banking in trouble). See Wordnet for more senses.

Types of semantics

- Vary along two main axes.
  Formal-cognitive and compositional-lexical. So, there are many possible semantic theories.
- Formal theories build representations in First order or higher order logic and are compositional. The predicates, variables and constants map to tokens in the sentence and are otherwise left uninterpreted.
- Cognitive semantic theories claim that semantics is conceptual and constructive, not limited to truth conditionality and reference. Example: frame semantics.
- Generative lexicon is a theory of meaning by Pustejovsky that focuses on lexemes as the basis. A lexeme has a four-level description (argument structure, event structure, qualia structure and lexical inheritance structure) and tries to generate meaning for language expressions using a few generative devices.

- Natural semantic meta-language (NSM). Semantics is described in terms of a standard sub-set of natural language (63 elements for English) called natural primes. The meaning of any sentence has to be composed from the semantics primes - a linguistic paraphrase. An explicated term can be used as a semantic molecule in another explication. Example primes: Substantives: I, you, someone, something, people, body. Time: when, now, before, after, a long time, a short time, for some time, moment. Intensifier: very, more.

Semantic roles

- Deep structure refers to semantic/meaning structures that are transformed to surface structure that we hear in speech or see in text.
- In several languages (e.g. Hindi) the semantic types or roles are often marked morphologically (e.g. ne, ko, se, etc. in Hindi).
- The verb is central and the various NPs play different semantics roles which are signalled on the surface by position and/or morphemes or special words.
- These semantic roles often called deep cases were proposed by Fillmore[1].

[1] C Fillmore, The case for case, in Bach & Harms, Universals in Lingusitic Theory, Holt, Rineheart, Winston, 1968. pp1-88.

Semantic role types

Role	Description	Examples
Agent	Initiator of action, capable of volition	The batsman smashed the ball to the leg-side. The pilot landed the plane.
Patient	Affected by action, undergoes change of state.	Hari shaved his beard. Hari broke the window.
Theme	Entity moving or being located. Object in abstract state or changed state.	Hari threw the ball. The photo hangs above the table. Hari gave the glass away. The glass is mine.
Experiencer	Perceives action but not initiator or in control.	Hari savoured the tasty fruit. Hari saw the dog run out of the house.
Beneficiary	The action benefits this recepient	He gave me a large piece of his chocolate. The parents rented an apartment for their son.

Role	Description	Examples
Instrument	Means used to do the action.	Hari pushed in the nail with a hammer. Hari hit Shyam with a stick.
Location	Place of action or object.	The band played at the Antaragni grounds. There are many secrets behind those closed doors.
Source	Starting point	The march began from the main ground.
Goal	End point or recepient	The march ended in the stadium. Hari lectured to the class.

Three types of roles: obligatory (put - location), optional (hit - instrument), adjunct (location of whole event, temporal dimension) - `(For hours)`$_{tmp-adj}$ `Hari played the flute (in his room)`$_{loc-adj}$.

Problems with semantic labelling

- No agreement on how many and which semantic roles are enough. Some have defined a very large number of roles. Others have tried to define roles as arguments to some conceptually primitive predicates like GO, BE, STAY, CAUSE etc. Example: GO(obj undergoing change, before state, after state) - `Hari drove from Kanpur to Delhi.` There is also debate about which labels apply in specific cases. `The storm blew away the roof.` Is 'storm' an agent? `The puppy licked my fingers.` What is the role of 'my fingers'?
- No commonly agreed rules for identifying roles.
- Levin's[2] verb classes. 3100 verbs - Wordnet has 8000 lemmas. Only 50% of the 3000 Penn treebank verb lemmas covered.

[2] B Levin, English verb classes and alternations: A preliminary investigation, U. of Chicago Press, 1993.

Levin's verb classes - example (1)

Class	Syntactic Frames	Members
break 45.1	John broke the jar. / The jar broke. / Jars break easily.	*break, chip, crack, crash, crush, fracture, rip, shatter, smash, snap, splinter, snip, tear*
cut 21.1	John cut the bread. / *The bread cut. / Bread cuts easily.	*chip, chop, clip, cut, hack, hew, rip, saw, scrape, scratch, slash, slice, snip*
hit 18.1	John hit the wall. / *The wall hit. / *Walls hit easily.	*bang, bash, click, dash, squash, tamp, thump, thwack, whack, batter, beat, bump, butt, drum, hammer, hit, jab, kick, knock, lash, pound, rap, slap, smack, smash, strike, tap*

(2)

Class	Syntactic Frames	Semantic Components
break 45.1	John broke the jar. / The jar broke. / Jars break easily.	**change-of-state**
cut 21.1	John cut the bread. / *The bread cut. / Bread cuts easily.	**change-of-state, recognizable action, sharp instrument**
hit 18.1	John hit the wall. / *The wall hit. / *Walls hit easily.	**contact, exertion of force**

Resources

- Framenet - based on Fillmore's Frame semantics.
- Verbnet.
- Propbank, Nombank.
- Wordnet.

These can used as resources for learning models for automatic labelling.

Learning based role labelling

- Large number of constituents in the parse tree lead to a large negative set. So, learning broken into two parts: a) identification - binary classification to decide whether a constituent can be a role b) categorize the role (multi-class classification).
- A wide variety of features are in use: parse path feature, position, head word, governing category, voice, verb sub-categorization, argument set, argument order, previous role, head word PoS, first/last word/PoS in constituent, constituent context features, temporal cues.
- Standard ML algorithms SVM, decision trees, logistic and softmax regression are used. Earlier systems used probabilities based on counts. But general ML algs. work better.
- Using ML for SLR is an active area of research.

Formal compositional semantics

- Formal semantics (different flavours) work roughly as follows: given a constituent parse of a sentence create an expression via composition in a formal language. A popular choice for the formal language is First order logic (FoL) together with lambda calculus (λ-calculus) for composition and substitution.
- Formal semantics also works with sentences as units. For text one can represent it by a conjunction of representations of the sentences in the text. But this is not an entirely satisfactory way to represent text.
- The formal language usually comes with a proof system. So, logical consequences of statements in the text can, in principle, be formally derived.

Examples

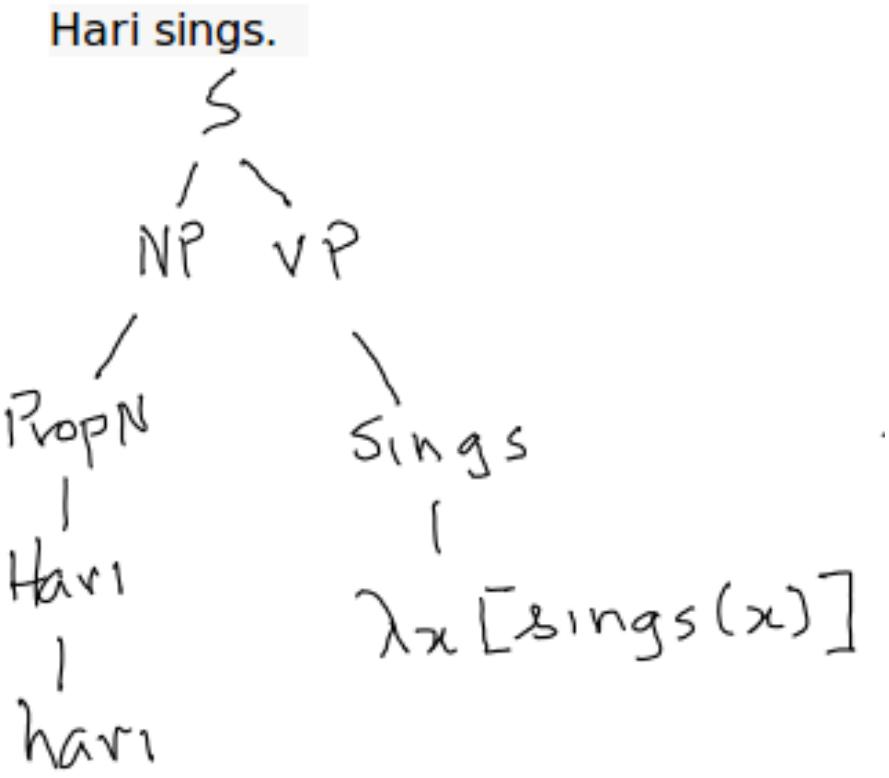

Figure: How composition happens.

$\lambda x \cdot [sings(x)](hari)$

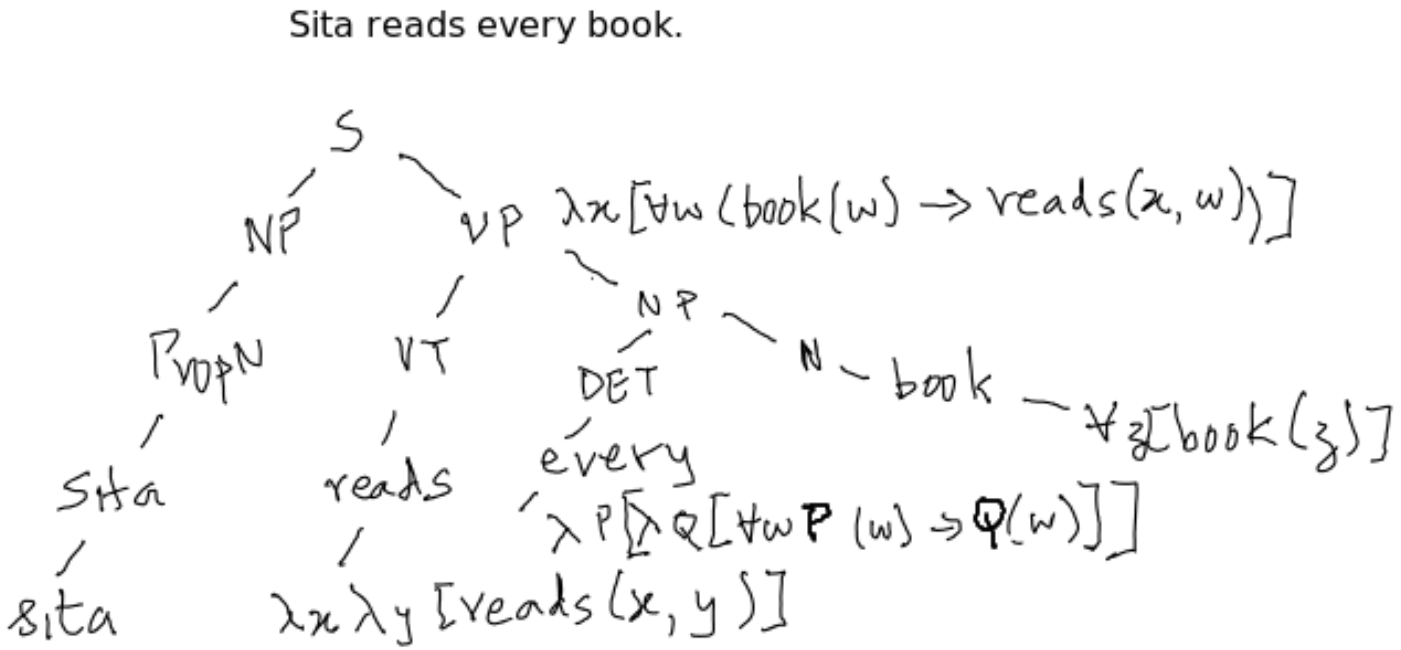

Figure: FoL with composition.

$\lambda x \cdot [\forall w(book(w) \rightarrow reads(x, w))](sita)$

Reduction

- An expression of the form: $(\lambda x \cdot E)\, P$ is called an application. $E[P|x]$ substitute P for all free occurrences of x in E, $x \notin P$. An occurrence of x is said to be bound in the expression $\lambda x \cdot E$. If x is not bound in an expression E then it is free.
- An application can be β-reduced by the rule: $(\lambda x \cdot E)\, P \xrightarrow{\beta} E[P|x]$.

Example

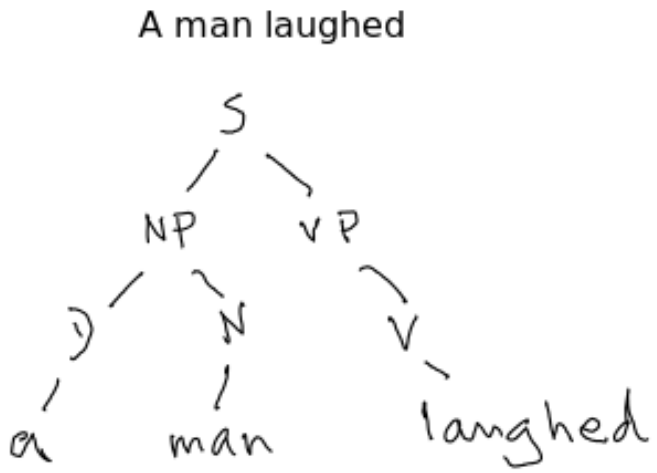

Figure: Sentence to illustrate β-reduction.

$$[\lambda P \lambda Q \cdot \exists x(P(x) \wedge Q(x))]\ \mathit{man}$$

$$\xrightarrow{\beta} (\lambda Q \cdot \exists x(\mathit{man}(x)))\ \mathit{laughed}$$

$$\xrightarrow{\beta} \exists x(\mathit{man}(x) \wedge \mathit{laughed}(x))$$

Grammar with semantic annotations

- Grammars are semantically annotated. So, once the constituent parse is available via a parser that uses the grammar the semantic annotations can be used to construct the expression via β-reduction from leaves to root of the tree. The expression at the root is the meaning of the sentence.
- Example annotations for some rules that can be part of a grammar to parse the previous example:

$$
\begin{aligned}
S &\rightarrow NP\ VP, \quad [NP][VP] \\
NP &\rightarrow D\ N, \quad [D][N] \\
N &\rightarrow man|woman, \quad \text{man}|\text{woman} \\
D &\rightarrow a, \quad \lambda P \lambda Q \cdot \exists x(P(x) \wedge Q(x)) \\
V &\rightarrow laughed, \quad \text{laughed}
\end{aligned}
$$