COMMUNICATION

Chapter 22

Outline

- Communication as Action
- Formal Grammar
- Syntactic Analysis (Parsing)
- Augmented Grammars
- Semantic Interpretation
- Ambiguity and Disambiguation
- Discourse Understanding

Communication

- Communication
  - Intentional exchange of information brought about by the production and perception of signs drawn from a shared system of conventional signs
- Humans use language to communicate most of what is known about the world
- The Turing test is based on language

Communication as Action

- Speech act
  - Language production viewed as an action
- Speaker, hearer, utterance
- Examples:
  - Query: “Have you smelled the wumpus anywhere?”
  - Inform: “There’s a breeze here in 3 4.”
  - Request: “Please help me carry the gold.” “I could use some help carrying this.”
  - Acknowledge: “OK”
  - Promise: “I’ll shoot the wumpus.”

Fundamentals of Language

- Formal language: A (possibly infinite) set of strings
- Grammar: A finite set of rules that specifies a language
- Rewrite rules
  - nonterminal symbols (S, NP, etc)
  - terminal symbols (he)
  - S $\rightarrow$ NP VP
  - NP $\rightarrow$ Pronoun
  - Pronoun $\rightarrow$ he

Chomsky Hierarchy

Four classes of grammatical formalisms:

- Recursively enumerable grammars
  - Unrestricted rules: both sides of the rewrite rules can have any number of terminal and nonterminal symbols

    $AB \rightarrow C$
- Context-sensitive grammars
  - The RHS must contain at least as many symbols as the LHS

    $ASB \rightarrow AXB$
- Context-free grammars (CFG)
  - LHS is a single nonterminal symbol

    $S \rightarrow XYa$
- Regular grammars

  $X \rightarrow a$ $X \rightarrow aY$

Component Steps of Communication

SPEAKER:

- Intention

  Know(H,¬Alive(Wumpus,S_3))

- Generation

  “The wumpus is dead”

- Synthesis

  [thaxwahmpaxsihzdehd]

Component Steps of Communication

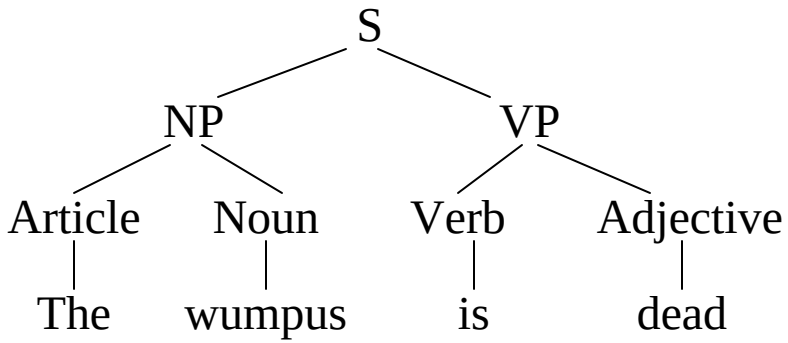
HEARER:

- Perception:

  "The wumpus is dead"

- Analysis

  (Parsing):



(Semantic Interpretation): $\neg$Alive(Wumpus, Now)
Tired(Wumpus, Now)

(Pragmatic Interpretation): $\neg$Alive($Wumpus_1$, S_3)
Tired($Wumpus_1$, S_3)

Component Steps of Communication

HEARER:

- Disambiguation:

  $\neg$Alive(Wumpus$_1$,S$_3$)

- Incorporation:

  TELL(KB, $\neg$Alive(Wumpus$_1$,S$_3$))

Formal Grammar

- The lexicon for ε_o:

Noun → stench | breeze | glitter | wumpus | pit | pits | gold | …
Verb → is | see | smell | shoot | stinks | go | grab | turn | …
Adjective → right | left | east | dead | back | smelly | …
Adverb → here | there | nearby | ahead | right | left | east | …
Pronoun → me | you | I | it | …
Name → John | Mary | Boston | Aristotle | …
Article → the | a | an | …
Preposition → to | in | on | near | …
Conjunction → and | or | but | …
Digit → 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9

Formal Grammar

- The grammar for ε_o:

S	$\rightarrow$	NP VP	I + feel a breeze
	|	S Conjunction S	I feel a breeze + and + I smell a wumpus
NP	$\rightarrow$	Pronoun	I
	|	Name	John
	|	Noun	pits
	|	Article Noun	the + wumpus
	|	Digit Digit	3 4
	|	NP PP	the wumpus + to the east
	|	NP RelClause	the wumpus + that is smelly

Formal Grammar

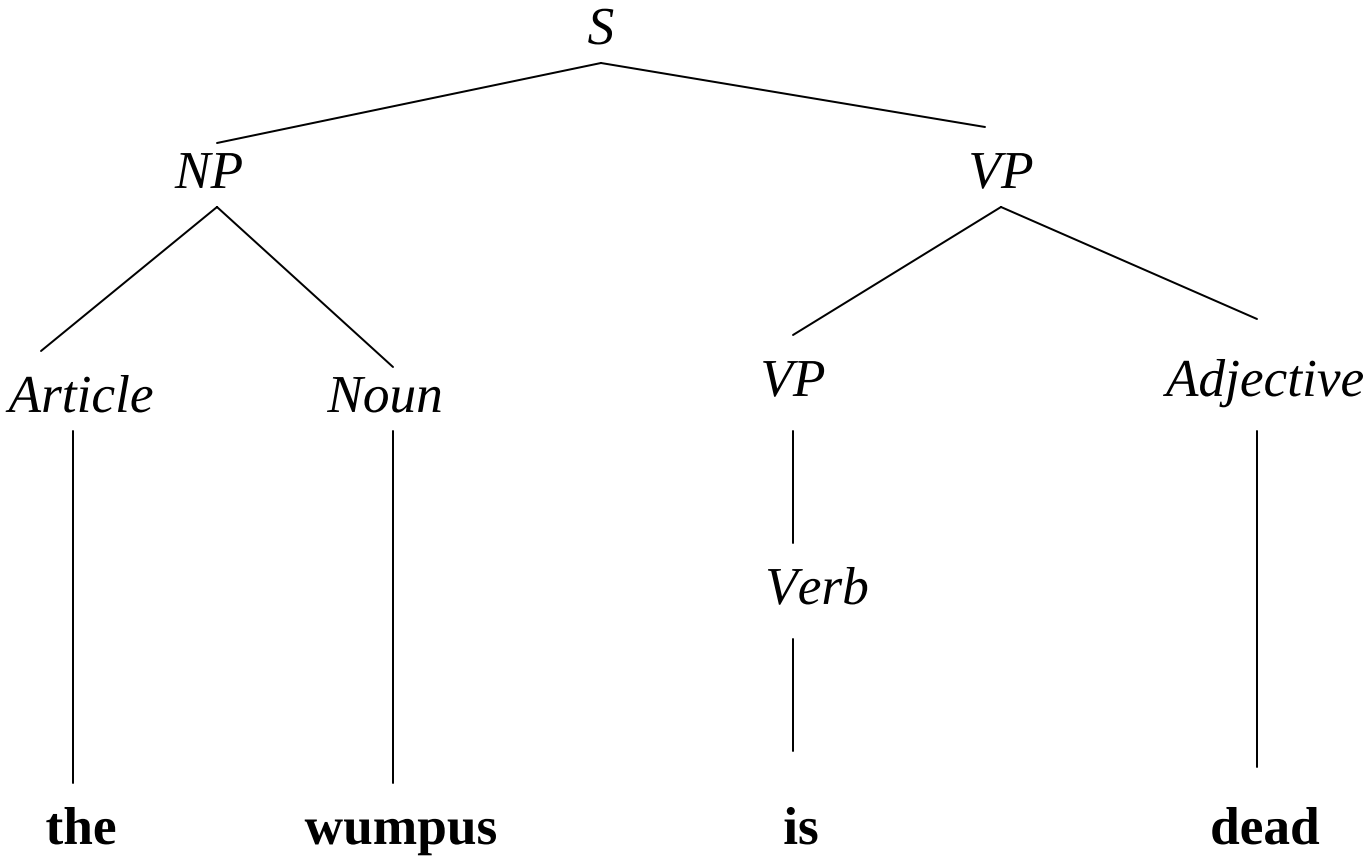
- The grammar for ε_o (continued):

VP→	Verb	stinks
|	VP NP	feel + a breeze
|	VP Adjective	is + smelly
|	VP PP	turn + to the east
|	VP Adverb	go + ahead
PP →	Preposition NP	to + the east
RelClause→	that VP	that + is smelly

Formal Grammar

- Parts of speech
  - Open class: noun, verb, adjective, adverb
  - Closed class: pronoun, article, preposition, conjunction, …
- Grammar
  - Overgenerate: “Me go Boston”
  - Undergenerate: “I think the wumpus is smelly”

Parse Tree



Syntactic Analysis (Parsing)

- Parsing: The process of finding a parse tree for a given input string
- Top-down parsing
  - Start with the S symbol and search for a tree that has the words as its leaves
- Bottom-up parsing
  - Start with the words and search for a tree with root S

Trace of Bottom-up Parsing

List of nodes	Subsequence	Rule
the wumpus is dead	**the**	Article → **the**
Article **wumpus is dead**	**wumpus**	Noun → **wumpus**
Article Noun **is dead**	*Article Noun*	NP → Article Noun
NP **is dead**	**is**	Verb → **is**
NP Verb **dead**	**dead**	Adjective → **dead**
NP Verb Adjective	*Verb*	VP → Verb
NP VP Adjective	*VP Adjective*	VP → VP Adjective
NP VP	*NP VP*	S → NP VP
S		

Subjective & Objective Cases

- Overgeneration:
  - S $\rightarrow$ NP VP $\rightarrow$ NP VP NP $\rightarrow$ NP Verb NP
  - Pronoun Verb NP $\rightarrow$ Pronoun Verb Pronoun

She loves him

*her loves he

She ran towards him

*She ran towards he

Handling Subjective & Objective Cases

S	→	NPs VP | …
NP_s	→	$Pronoun_s$ | Name | Noun | …
NP_o	→	$Pronoun_o$ | Name | Noun | …
VP	→	VP NPo | …
PP	→	Preposition NP_o
$Pronoun_s$	→	**I** | **you** | **he** | **she** | **it** | …
$Pronoun_o$	→	**me** | **you** | **him** | **her** | **it** | …

- Disadvantage: Grammar size grows exponentially

Augmented Grammars

- Handling case, agreement, etc
- Augment grammar rules to allow parameters on nonterminal categories
  - NP(Subjective)
  - NP(Objective)
  - NP(case)

Definite Clause Grammar (DCG)

- The grammar for $\varepsilon 1$:

S	→	NP(Subjective) VP | …
NP(case)	→	Pronoun(case) | Name | Noun | …
VP	→	VP NP(Objective) | …
PP	→	Preposition NP(Objective)
Pronoun(Subjective)	→	**I** | **you** | **he** | **she** | **it** | …
Pronoun(Objective)	→	**me** | **you** | **him** | **her** | **it** | …

Definite Clause Grammar (DCG)

- Each grammar rule is a definite clause in logic:
  - $S \rightarrow NP\ VP$
  - $NP(s1) \wedge VP(s2) \Rightarrow S(s1 + s2)$
  - $NP(case) \rightarrow Pronoun(case)$
  - $Pronoun(case, s1) \Rightarrow NP(case, s1)$
- DCG enables parsing as logical inference:
  - Top-down parsing is backward chaining
  - Bottom-up parsing is forward chaining

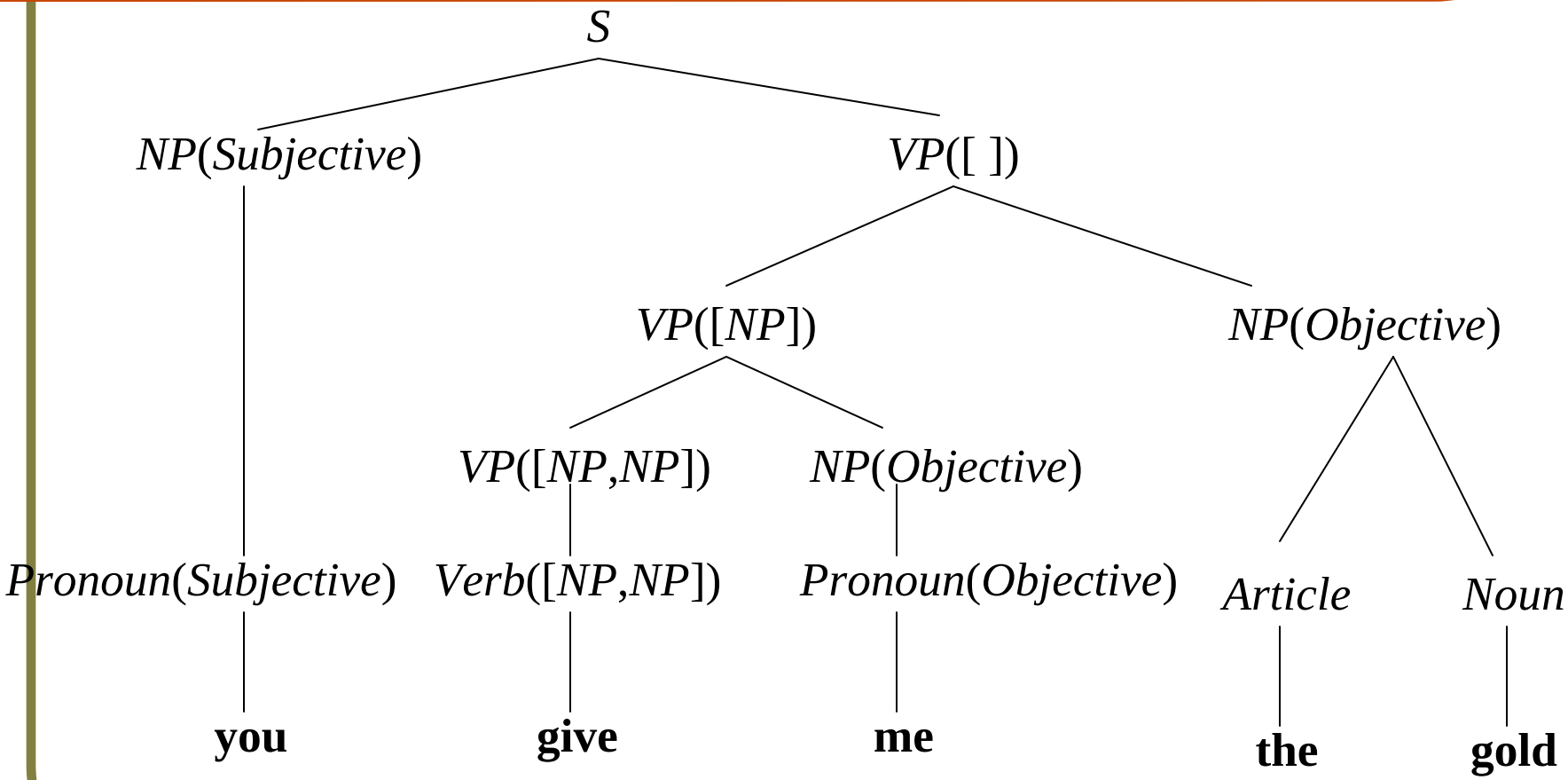
Verb Subcategorization

Verb	Subcats	Example Verb Phrase
give	[*NP*,*PP*] [*NP*,*NP*]	give the gold to me give me the gold
smell	[*NP*] [*Adjective*] [*PP*]	smell a wumpus smell awful smell like a wumpus
is	[*Adjective*] [*PP*] [*NP*]	is smelly is in 2 2 is a pit
died	[]	died
believe	[*S*]	believe the wumpus is dead

Verb Subcategorization

S	→	NP(Subjective) VP([ ])
VP(subcat)	→	Verb(subcat)
	|	VP(subcat + [NP]) NP(Objective)
	|	VP(subcat + [Adjective]) Adjective
	|	VP(subcat + [PP]) PP
VP(subcat)	→	VP(subcat) PP
	|	VP(subcat) Adverb
Verb([NP,NP])	→	**give** | **hand** | …

Parsing Using Verb Subcategorization



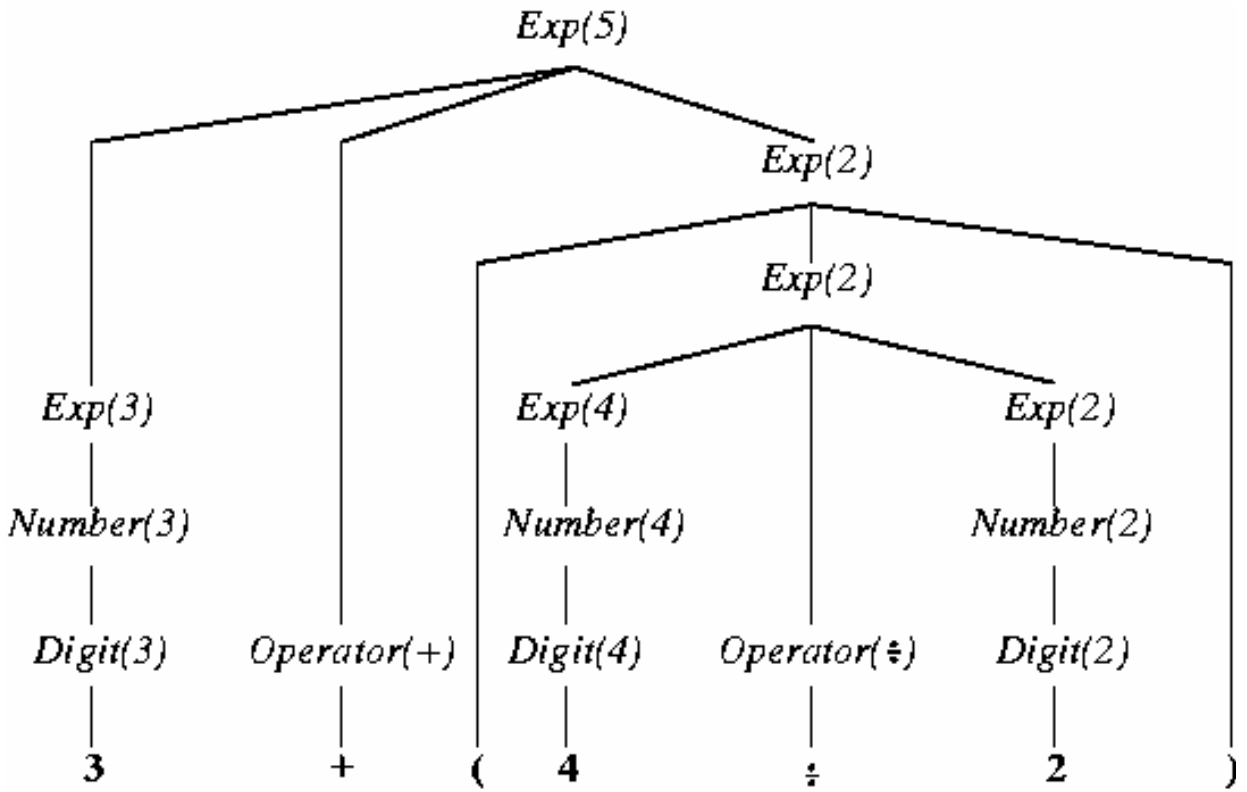
Semantic Interpretation

- Semantics: meaning of utterances
- First-order logic as the representation language
- Compositional semantics: meaning of a phrase is composed of meaning of the constituent parts of the phrase

Semantic Interpretation

$$\begin{aligned}
\text{Exp}(x) &\rightarrow \text{Exp}(x_1)\ \text{Operator}(op)\ \text{Exp}(x_2) \\
&\qquad \{\ x = \text{Apply}(op, x_1, x_2)\ \} \\
\text{Exp}(x) &\rightarrow (\ \text{Exp}(x)\ ) \\
\text{Exp}(x) &\rightarrow \text{Number}(x) \\
\text{Number}(x) &\rightarrow \text{Digit}(x) \\
\text{Number}(x) &\rightarrow \text{Number}(x_1)\ \text{Digit}(x_2)\ \{\ x = 10 \times x_1 + x_2\ \} \\
\text{Digit}(x) &\rightarrow x\ \{\ 0 \le x \le 9\ \} \\
\text{Operator}(x) &\rightarrow x\ \{\ x \in \{\ +, -, \times, \div\ \}\}
\end{aligned}$$

Semantic Interpretation



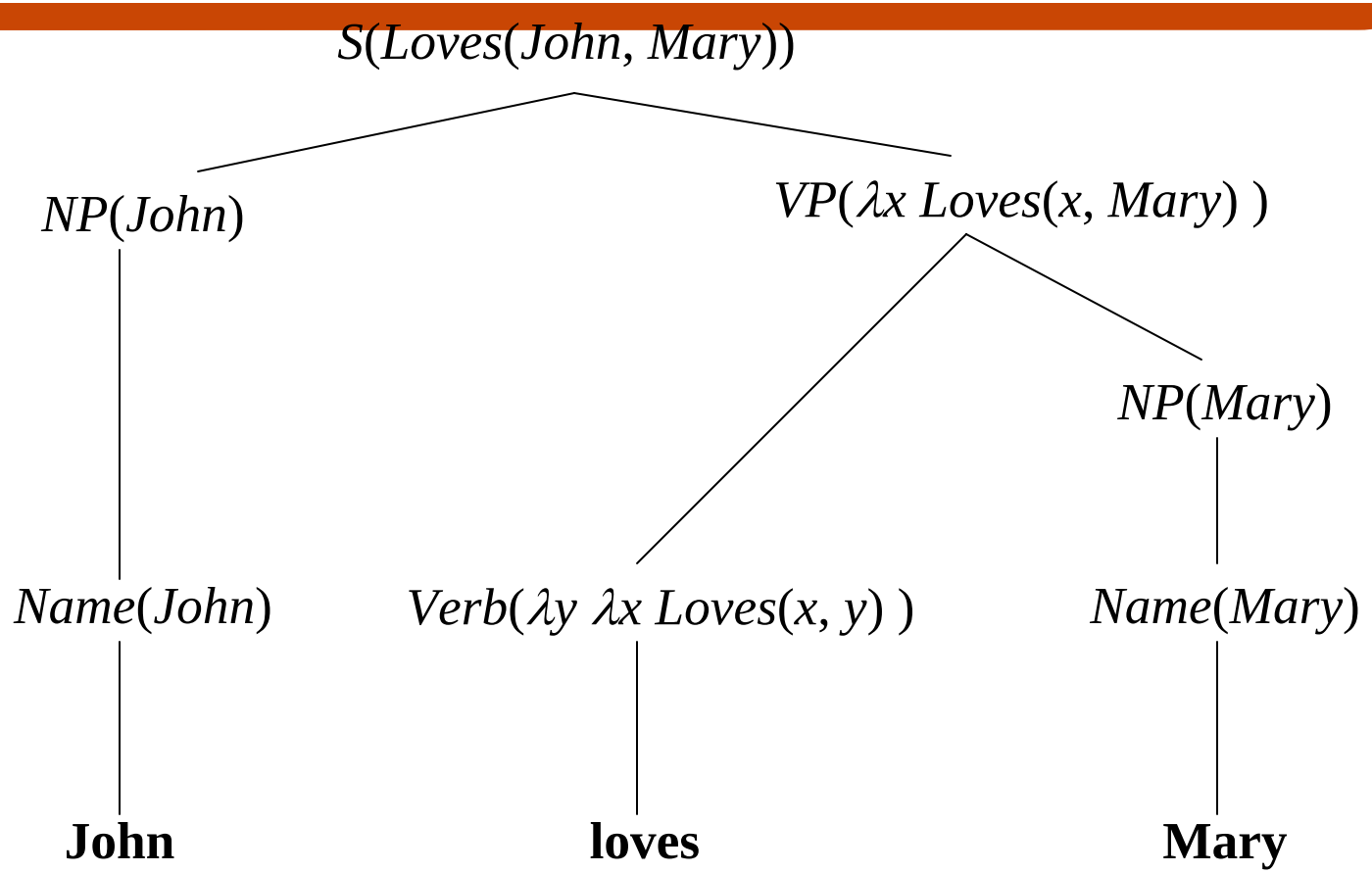
Semantic Interpretation

John loves Mary
Loves(John, Mary)

$(\lambda y\ \lambda x\ \text{Loves}(x,y))\ (\text{Mary}) \equiv \lambda x\ \text{Loves}(x, \text{Mary})$
$(\lambda x\ \text{Loves}(x, \text{Mary}))\ (\text{John}) \equiv \text{Loves}(\text{John}, \text{Mary})$

S(rel(obj))	$\rightarrow$	NP(obj) VP(rel)
VP(rel(obj))	$\rightarrow$	Verb(rel) NP(obj)
NP(obj)	$\rightarrow$	Name(obj)
Name(John)	$\rightarrow$	**John**
Name(Mary)	$\rightarrow$	**Mary**
Verb($\lambda y\ \lambda x$ Loves(x,y))	$\rightarrow$	**loves**

Semantic Interpretation



Pragmatic Interpretation

- Adding context-dependent information about the current situation to each candidate semantic interpretation
- Indexicals: phrases that refer directly to the current situation
  - “I am in Boston today”

    (“I” refers to speaker and “today” refers to now)

Language Generation

The same DCG can be used for parsing and generation

- Parsing:
  - Given: S(sem, [John, loves, Mary])
  - Return: sem = Loves(John, Mary)
- Generation:
  - Given: S(Loves(John, Mary), words)
  - Return: words = [John, loves, Mary]

Ambiguity

- Lexical ambiguity
  - “the **back** of the room” vs. “**back** up your files”
  - “In the **interest** of stimulating the economy, the government lowered the **interest** rate.”
- Syntactic ambiguity (structural ambiguity)
  - “I smelled a wumpus in 2,2”
- Semantic ambiguity
  - “the IBM lecture”
- Pragmatic ambiguity
  - “I’ll meet you next Friday”

Metonymy

Denotes a concept by naming some other concept closely *related* to it

- Examples:
  - Company for company's spokesperson ("IBM announced a new model")
  - Author for author's works ("I read Shakespeare")
  - Producer for producer's product ("I drive a Honda")

Metonymy

- Representation of “IBM announced”

$$\exists m, x, e \;\; x = IBM \wedge e \in Announce(m) \wedge After(Now, e) \wedge Metonymy(m, x)$$

$$\forall m, x \;\; (m = x) \Rightarrow Metonymy(m, x)$$

$$\forall m, x \;\; x \in Organizations \wedge Spokesperson(m, x) \Rightarrow Metonymy(m, x)$$

Metaphor

Refer to concepts using words whose meanings are appropriate to other completely different kinds of concepts

- Example: corporation-as-person metaphor:
  - Speak of a corporation as if it is a person and can experience emotions, has a mind, etc.
  - "That doesn't **scare** Digital, which has grown to be the world's second-largest computer maker."
  - "But if the company changed its **mind**, however, it would do so for investment reasons, the filing said."

Disambiguation

$$\arg\max_{intent} Likelihood(intent \mid words, situation)$$

- Disambiguation is like diagnosis
- The speaker's intent to communicate is an unobserved cause of the words in the utterance
- The hearer's job is to work backwards from the words and from knowledge of the situation to recover the most likely intent of the speaker

Discourse Understanding

- Discourse: multiple sentences
- Reference resolution: The interpretation of a pronoun or a definite noun phrase that refers to an object in the world
- “John flagged down the waiter. He ordered a ham sandwich.”
  - “He” refers to “John”
- “After John proposed to Mary, they found a preacher and got married. For the honeymoon, they went to Hawaii.”
  - “they”? “the honeymoon”?

Discourse Understanding

- Structure of coherent discourse: Sentences are joined by coherence relations
- Examples of coherence relations between S1 and S2:
  - Enable or cause: S1 brings about a change of state that causes or enables S2
    - "I went outside. I drove to school."
  - Explanation: the reverse of enablement, S2 causes or enables S1 and is an explanation for S1
    - "I was late for school. I overslept."
  - Exemplification: S2 is an example of the general principle in S1
    - "This algorithm reverses a list. The input [A,B,C] is mapped to [C,B,A]."
  - Etc.