
INF5390 – Kunstig intelligens

Agents That Communicate

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Outline

- Communication and action
- Language structures
- Parsing and semantics
- Steps of communication
- Summary

AIMA Chapter 23: Natural Language
for Communication

Communication and language

- One definition of *communication*
 - ✓ Communication is the intentional exchange of information brought about by the production and perception of signs drawn from a shared system of a limited number of conventional signs
- Humans use *language* to communicate
 - ✓ Language is a “shared system of a limited number of conventional signs”
 - ✓ Its structure is sufficiently rich to allow an unbounded number of qualitatively different messages

Communication as action

- To produce messages in a language is one of the *actions* available to an agent
- This action is called a *speech act* (can be spoken, written, etc.)
- In a speech act, an *utterance* consisting of *words* is delivered from a *speaker* to a *hearer*
- Different types of speech acts serve different purposes

Some types of speech acts

- *Inform* Provide information to hearer
- *Query* Ask for information
- *Answer* Inform in response to query
- *Request* Ask hearer to perform action
- *Deny* Refuse to perform action
- *Command* Request with no option to deny
- *Promise* Commit to future action
- *Offer* Propose to do future action
- *Acknowledge* Confirm e.g. request or offer
-

Planning and understanding speech acts

- Deciding *when* a speech act is called for, and decide *which* one to use, is equivalent to *planning*
- *Understanding* a speech act is similar to *diagnosis* or *plan recognition*
- I.e., one can use methods from other parts of AI in implementing *perception* and *action* in communicating agents

Natural and formal languages

- *Natural languages* are a rich field of empirical and logical study, including in AI
- *Formal languages* are invented ones, in contrast to natural languages, and include logic, etc.
- Formal language *concepts* are being used in analysis of natural languages

Formal language concepts

- A formal language is a set of *strings* (*sentences*)
 - ✓ "The wumpus is dead"
- A string is a sequence of symbols taken from a finite set called the *terminal symbols* (*words*)
 - ✓ "dead", "is", "wumpus", "the"
- A *phrase* is a substring of a sentence. There are different categories (symbolized by *nonterminal symbols*) of phrases
 - ✓ *NP* (noun phrase): "the wumpus"
 - ✓ *VP* (verb phrase): "is dead"

Formal language concepts (cont.)

- The structure (grammar) of a language can be defined using a *phrase structure*, i.e. combinations of terminal and nonterminal symbols
 - ✓ $NP VP$
- *Rewrite rules* define how a single nonterminal symbol (phrase) may be replaced by a structure
 - ✓ $S \rightarrow NP VP$

A grammar for a fragment of English

- **Lexicon**
 - ✓ List of valid words
 - ✓ Categories: Noun, verb, adjective, ..
- **Grammar**
 - ✓ Rules for valid sentences
 - ✓ Nonterminals: Sentence (S), noun phrase (NP) ..
- **Parsing**
 - ✓ Analyze a given sequence of lexicon words as a tree-structure allowed by grammar rules

Lexicon of the fragment

Noun → *stench* | *breeze* | *glitter* | *nothing*
| *wumpus* | *pit* | *pits* | *gold* | *east* | ...

Verb → *is* | *see* | *smell* | *shoot* | *feel* | *stinks*
| *go* | *grab* | *carry* | *kill* | *turn* | ...

Adjective → *right* | *left* | *east* | *south* | *back* | *smelly* | ...

Adverb → *here* | *there* | *nearby* | *ahead*
| *right* | *left* | *east* | *south* | *back* | ...

Pronoun → *me* | *you* | *I* | *it* | ...

Name → *John* | *Mary* | *Boston* | *UCB* | *PAJC* | ...

Article → *the* | *a* | *an* | ...

Preposition → *to* | *in* | *on* | *near* | ...

Conjunction → *and* | *or* | *but* | ...

Digit → **0** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9**

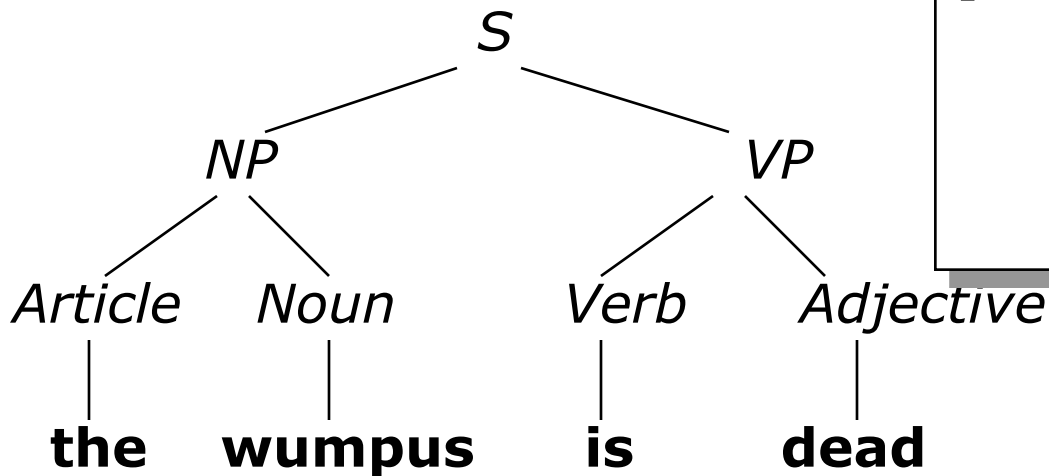
Divided into **closed** and **open** classes

Grammar of the fragment

S	$\rightarrow NP VP$	I + feel a breeze
	$S Conjunction S$	I feel a breeze + and + I smell a wumpus
NP	$\rightarrow Pronoun$	I
	$Noun$	pits
	$Article Noun$	the + wumpus
	$Digit Digit$	3 4
	$NP PP$	the wumpus + to the east
	$NP RelClause$	the wumpus + that is smelly
VP	$\rightarrow Verb$	stinks
	$VP NP$	feel + a breeze
	$VP Adjective$	is + smelly
	$VP PP$	turn + to the east
	$VP Adverb$	go + ahead
PP	$\rightarrow Preposition NP$	to + the east
$RelClause$	$\rightarrow \mathbf{that} VP$	that + is smelly

Parsing

- Search for a *parse tree* for a given sentence, e.g.
PARSE("the wumpus is dead", grammar, S)



```
[S: [NP: [Article: the
          [Noun: wumpus]]
     [VP: [Verb: is
          [Adjective: dead]]]]
```

Top-down vs. bottom-up parsing

- Top-down parsing

- ✓ Initial parse tree is the root with unknown children [$S: ?$]
- ✓ At each step, select leftmost node in the tree with unknown children and look for grammar rules with LHS that matches the node. Replace $?$ with RHS and repeat
- ✓ Stop when leaves of the tree exactly matches the string

- Bottom-up parsing

- ✓ Initial list of words, seen as list of singleton parse trees
- ✓ At each step, replace each sequence of parse trees that matches an RHS of a grammar rule, with the corresponding LHS, and repeat
- ✓ Stop when the tree is the single node S

Semantic interpretation

- Having analyzed the sentence, we need to interpret its *meaning*; i.e. decide its semantic content
- We adopt first-order logic (FOL) as the representation language
 - ✓ E.g., "the wumpus is dead and John loves Mary" has the meaning: $Dead(Wumpus) \wedge Loves(John, Mary)$
- Compositional semantics
 - ✓ The meaning of the entire sentence is composed of the meanings of its constituents

Augmenting grammar for semantics

- Each category of the grammar is *augmented* with a single argument that represents the semantics
 - ✓ NP becomes $NP(obj)$ - where obj is the FOL term that represents the noun phrase
 - ✓ VP becomes $VP(rel)$ - where rel is the FOL relation (predicate) that represents the verb
 - ✓ Also needs λ -expressions for verbs:
 - $\lambda x \text{ Loves}(x, \text{Mary})$ - the predicate of variable x such that x loves *Mary*
 - $(\lambda x \text{ Loves}(x, \text{Mary}))(\text{John})$ - the predicate applied to the argument *John*, yielding $\text{Loves}(\text{John}, \text{Mary})$

Semantically augmented grammar fragment

$S(\text{rel}(\text{obj})) \rightarrow NP(\text{obj}) VP(\text{rel})$

$VP(\text{rel}(\text{obj})) \rightarrow \text{Verb}(\text{rel}) NP(\text{obj})$

$NP(\text{obj}) \rightarrow \text{Name}(\text{obj})$

$\text{Name}(\text{John}) \rightarrow \mathbf{John}$

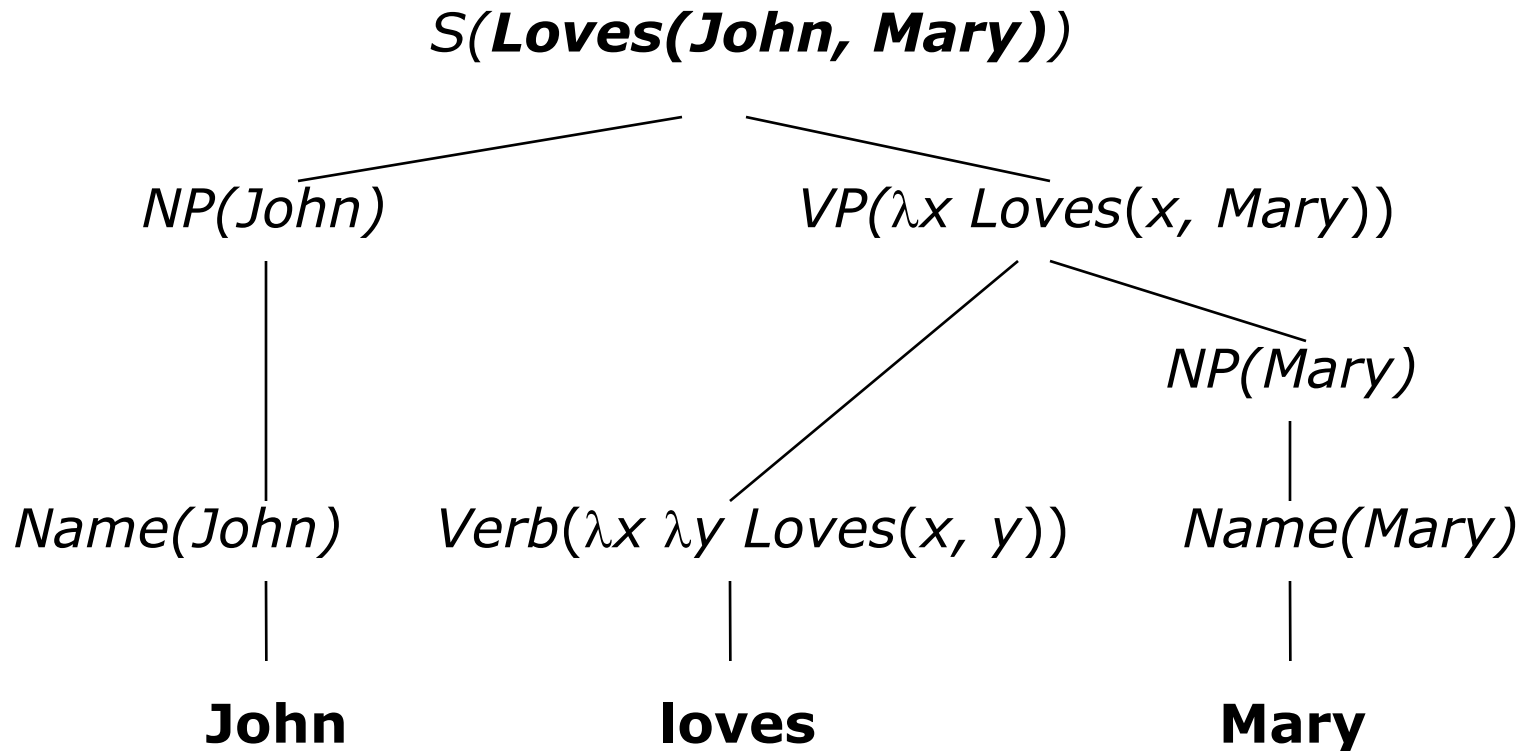
$\text{Name}(\text{Mary}) \rightarrow \mathbf{Mary}$

$\text{Verb}(\lambda x \lambda y \text{Loves}(x, y)) \rightarrow \mathbf{loves}$

Can be extended:

- Time
- Tense
- Quantification
- Pragmatics
- Etc.

Deriving semantics during parsing



Steps of communication

Speaker S wants to convey proposition P
to hearer H using words W

Speaker S

- *Intention*
 S wants H to believe P
- *Generation*
 S chooses the words W
- *Synthesis*
 S utters the words W

Hearer H

- *Perception*
 H perceives W' (ideally= W)
- *Analysis*
 H infers that W' may mean P_1, \dots, P_n
- *Disambiguation*
 H infers that S intended P_i (ideally= P)
- *Incorporation*
 H decides to (dis)believe P_i

Speaker steps in more detail

- *Intention*

- ✓ Speaker decides *that* there is something to say, e.g. by reasoning about beliefs and goals of hearer
 - $Know(H, \neg Alive(Wumpus, S3))$

- *Generation*

- ✓ Speaker uses knowledge about language in deciding *what* to say
 - “The wumpus is dead”

- *Synthesis*

- ✓ Finally, the sentence is *uttered* via the “speech act organ” (printer, screen, speech synthesizer, ..)

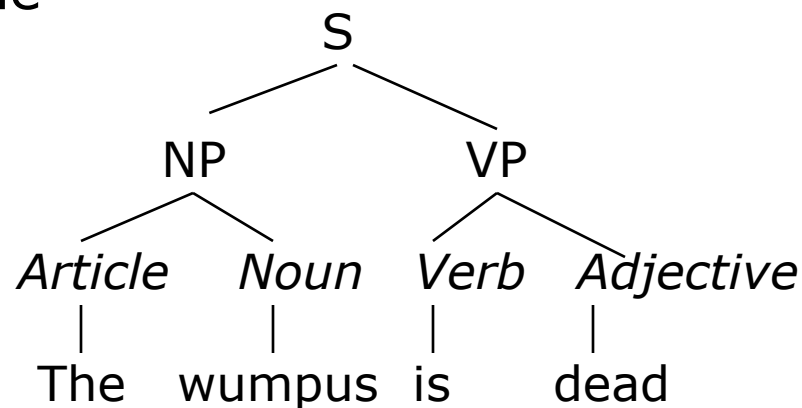
Hearer steps in more detail

- *Perception*

- ✓ The utterance is received, e.g. by speech recognition, scene analysis, ..

- *Analysis*

- ✓ *Parsing*: Recognizing constituent phrases (*parse tree*)
- ✓ *Interpretation*: Extract meaning as expression in e.g. logic



$\neg \text{Alive}(\text{Wumpus}, S3)$
 $\text{Tired}(\text{Wumpus}, S3)$

Hearer steps in more detail (cont.)

- *Disambiguation*
 - ✓ Analysis may yield different interpretations, and the agent must choose the most *probable* one, e.g. using probabilistic reasoning
 - $\neg\text{Alive}(\text{Wumpus}, S3)$
- *Incorporation*
 - ✓ Finally, the agent updates its knowledge base with the new information
 - $\text{TELL}(\text{KB}, \neg\text{Alive}(\text{Wumpus}, S3))$

Summary

- Agents need to *communicate* in order to achieve certain goals, such as getting the other agent to believe something or to do something
- Sending a signal is called a *speech act*, of which many types may be identified: inform, request, deny, promise, etc.
- *Formal languages* (incl. subsets of natural language) used for communication may be defined by a *lexicon* and a *grammar*

Summary (cont.)

- Efficient techniques have been developed for *parsing* the structure of sentences and interpreting the intended *semantics*
- Communication involves *speaker* and *hearer* steps and methods have been developed to handle each of the steps for a range of formal languages
- In addition to language communication, (some) agents need to interact with their environment through vision, tactile sensing, robotic locomotion and manipulation, etc.