Part I Artificial Intelligence
  1 Introduction
  2 Intelligent Agents

Part II Problem Solving
  3 Solving Problems by Searching
  4 Informed Search and Exploration
  5 Constraint Satisfaction Problems
  6 Adversarial Search

Part III Knowledge and Reasoning
  7 Logical Agents
  8 First-Order Logic
  9 Inference in First-Order Logic

Part V Uncertain Knowledge and Reasoning
  13 Uncertainty
  14 Probabilistic Reasoning

Part V Learning
  18 Learning from Observations

Part VII Communicating, Perceiving, and Acting
  22 Communication
COMMUNICATION AND LANGUAGE

CHAPTER 22
Outline

◊ Communication
◊ Grammar
◊ Syntactic analysis
◊ Problems
Communication

“Classical” view (pre-1953):
  language consists of sentences that are true/false (cf. logic)

“Modern” view (post-1953):
  language is a form of action

Wittgenstein (1953) Philosophical Investigations
Austin (1962) How to Do Things with Words
Searle (1969) Speech Acts

Why?
“Classical” view (pre-1953):
language consists of sentences that are true/false (cf. logic)

“Modern” view (post-1953):
language is a form of action

Wittgenstein (1953) *Philosophical Investigations*
Austin (1962) *How to Do Things with Words*
Searle (1969) *Speech Acts*

Why?
Communication

“Classical” view (pre-1953):
  language consists of sentences that are true/false (cf. logic)

“Modern” view (post-1953):
  language is a form of action

Wittgenstein (1953) *Philosophical Investigations*
Austin (1962) *How to Do Things with Words*
Searle (1969) *Speech Acts*

Why?
Communication

“Classical” view (pre-1953):
language consists of sentences that are true/false (cf. logic)

“Modern” view (post-1953):
language is a form of action

Wittgenstein (1953) *Philosophical Investigations*
Austin (1962) *How to Do Things with Words*
Searle (1969) *Speech Acts*

Why?

To change the actions of other agents
Speech acts achieve the speaker’s goals:
- **Inform**  “There’s a pit in front of you”
- **Query**  “Can you see the gold?”
- **Command**  “Pick it up”
- **Promise**  “I’ll share the gold with you”
- **Acknowledge**  “OK”

Speech act planning requires knowledge of
- Situation
- Semantic and syntactic conventions
- Hearer’s goals, knowledge base, and rationality
Stages in communication (informing)

**Intention**  
S wants to inform H that $P$

**Generation**  
S selects words $W$ to express $P$ in context $C$

**Synthesis**  
S utters words $W$

**Perception**  
H perceives $W'$ in context $C'$

**Analysis**  
H infers possible meanings $P_1, \ldots, P_n$

**Disambiguation**  
H infers intended meaning $P_i$

**Incorporation**  
H incorporates $P_i$ into KB

How could this go wrong?
Stages in communication (informing)

**Intention**  
S wants to inform H that $P$

**Generation**  
S selects words $W$ to express $P$ in context $C$

**Synthesis**  
S utters words $W$

**Perception**  
H perceives $W'$ in context $C'$

**Analysis**  
H infers possible meanings $P_1, \ldots, P_n$

**Disambiguation**  
H infers intended meaning $P_i$

**Incorporation**  
H incorporates $P_i$ into KB

How could this go wrong?
- Insincerity (S doesn’t believe $P$)
- Speech wreck ignition failure
- Ambiguous utterance
- Differing understanding of current context ($C \neq C'$)
Vervet monkeys, antelopes etc. use isolated symbols for sentences

⇒ restricted set of communicable propositions, no generative capacity

(Chomsky (1957): *Syntactic Structures*)

Grammar specifies the compositional structure of complex messages
e.g., speech (linear), text (linear), music (two-dimensional)

A formal language is a set of strings of terminal symbols

Each string in the language can be analyzed/generated by the grammar

The grammar is a set of rewrite rules, e.g.,

\[
S \rightarrow NP \ VP
\]

\[
Article \rightarrow \text{the} \ | \ a \ | \ an \ | \ \ldots
\]

Here $S$ is the sentence symbol, $NP$ and $VP$ are nonterminals
Grammar types

Regular:  nonterminal $\rightarrow$ terminal[nonterminal]

\[
S \rightarrow aS \\
S \rightarrow \Lambda
\]

Context-free:  nonterminal $\rightarrow$ anything

\[
S \rightarrow aSb
\]

Context-sensitive: more nonterminals on right-hand side

\[
ASB \rightarrow AaBB
\]

Recursively enumerable: no constraints

Related to Post systems and Kleene systems of rewrite rules

Natural languages probably context-free, parsable in real time!
Wumpus lexicon

\[
\begin{align*}
\text{Noun} & \rightarrow \text{stench} | \text{breeze} | \text{glitter} | \text{nothing} \\
 & | \text{wumpus} | \text{pit} | \text{pits} | \text{gold} | \text{east} | \ldots \\
\text{Verb} & \rightarrow \text{is} | \text{see} | \text{smell} | \text{shoot} | \text{feel} | \text{stinks} \\
 & | \text{go} | \text{grab} | \text{carry} | \text{kill} | \text{turn} | \ldots \\
\text{Adjective} & \rightarrow \text{right} | \text{left} | \text{east} | \text{south} | \text{back} | \text{smelly} | \ldots \\
\text{Adverb} & \rightarrow \text{here} | \text{there} | \text{nearby} | \text{ahead} \\
 & | \text{right} | \text{left} | \text{east} | \text{south} | \text{back} | \ldots \\
\text{Pronoun} & \rightarrow \text{me} | \text{you} | \text{I} | \text{it} | \ldots \\
\text{Name} & \rightarrow \text{John} | \text{Mary} | \text{Boston} | \text{UCB} | \text{PAJC} | \ldots \\
\text{Article} & \rightarrow \text{the} | \text{a} | \text{an} | \ldots \\
\text{Preposition} & \rightarrow \text{to} | \text{in} | \text{on} | \text{near} | \ldots \\
\text{Conjunction} & \rightarrow \text{and} | \text{or} | \text{but} | \ldots \\
\text{Digit} & \rightarrow 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9
\end{align*}
\]

Divided into \text{closed} and \text{open} classes
Wumpus lexicon

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 | S/HE | Y’ALL ...
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
Wumpus grammar

\[ S \rightarrow NP \ VP \quad \text{l + feel a breeze} \]
\[ \quad \quad | \quad S \ Conjunction \ S \quad \text{l feel a breeze + and + l smell a wumpus} \]
\[ NP \rightarrow \text{Pronoun} \quad \text{l} \]
\[ \quad | \quad \text{Noun} \quad \text{pits} \]
\[ \quad | \quad \text{Article Noun} \quad \text{the + wumpus} \]
\[ \quad | \quad \text{Digit Digit} \quad 3 \ 4 \]
\[ \quad | \quad NP \ PP \quad \text{the wumpus + to the east} \]
\[ \quad | \quad NP \ RelClause \quad \text{the wumpus + that is smelly} \]
\[ VP \rightarrow \text{Verb} \quad \text{stinks} \]
\[ \quad | \quad VP \ NP \quad \text{feel + a breeze} \]
\[ \quad | \quad VP \ Adjective \quad \text{is + smelly} \]
\[ \quad | \quad VP \ PP \quad \text{turn + to the east} \]
\[ \quad | \quad VP \ Adverb \quad \text{go + ahead} \]
\[ PP \rightarrow \text{Preposition} \ NP \quad \text{to + the east} \]
\[ RelClause \rightarrow \text{that} \ VP \quad \text{that + is smelly} \]
Grammaticality judgements

Formal language $L_1$ may differ from natural language $L_2$

Adjusting $L_1$ to agree with $L_2$ is a learning problem!

* the gold grab the wumpus
* I smell the wumpus the gold
  I give the wumpus the gold
* I donate the wumpus the gold

Intersubjective agreement somewhat reliable, independent of semantics!
Real grammars 10–500 pages, insufficient even for “proper” English
Parse trees

Exhibit the grammatical structure of a sentence

I shoot the wumpus
Parse trees

Exhibit the grammatical structure of a sentence

I shoot the wumpus
Parse trees

Exhibit the grammatical structure of a sentence

I shoot the wumpus

NP  VP  NP
Pronoun  Verb  Article  Noun

I  shoot  the  wumpus

Chapter 22
Parse trees

Exhibit the grammatical structure of a sentence

I shoot the wumpus
Parse trees

Exhibit the grammatical structure of a sentence

I shoot the wumpus

Sentence (S) -> Noun Phrase (NP) -> Pronoun (I) -> Verb Phrase (VP) -> Verb (shoot) -> Article Phrase (NP) -> Article (the) -> Noun (wumpus)
Most view syntactic structure as an essential step towards meaning;
“Mary hit John” ≠ “John hit Mary”

“And since I was not informed—as a matter of fact, since I did not know that there were excess funds until we, ourselves, in that checkup after the whole thing blew up, and that was, if you’ll remember, that was the incident in which the attorney general came to me and told me that he had seen a memo that indicated that there were no more funds.”
Syntax in NLP

Most view syntactic structure as an essential step towards meaning;

“Mary hit John” ≠ “John hit Mary”

“And since I was not informed—as a matter of fact, since I did not know that there were excess funds until we, ourselves, in that checkup after the whole thing blew up, and that was, if you’ll remember, that was the incident in which the attorney general came to me and told me that he had seen a memo that indicated that there were no more funds.”

“Wouldn’t the sentence ’I want to put a hyphen between the words Fish and And and And and And and Chips in my Fish-And-Chips sign’ have been clearer if quotation marks had been placed before Fish, and between Fish and and, and and and And, and And and and, and and and And, and And and and, and and and Chips, as well as after Chips?”
Context-free parsing

Bottom-up parsing works by replacing any substring that matches RHS of a rule with the rule’s LHS

Efficient algorithms (e.g., chart parsing, Section 22.3) $O(n^3)$ for context-free, run at several thousand words/sec for real grammars

Context-free parsing $\equiv$ Boolean matrix multiplication (Lee, 2002)

$\Rightarrow$ unlikely to find faster practical algorithms
BNF notation for grammars too restrictive:
- difficult to add “side conditions” (number agreement, etc.)
- difficult to connect syntax to semantics

Idea: express grammar rules as logic

\[
X \rightarrow YZ \quad \text{becomes} \quad Y(s_1) \land Z(s_2) \implies X(Append(s_1, s_2))
\]

\[
X \rightarrow \text{word} \quad \text{becomes} \quad X(["\text{word}"])
\]

\[
X \rightarrow Y \mid Z \quad \text{becomes} \quad Y(s) \implies X(s) \quad Z(s) \implies X(s)
\]

Here, \( X(s) \) means that string \( s \) can be interpreted as an \( X \)
Now it’s easy to augment the rules

\[
NP(s_1) \land EatsBreakfast(Ref(s_1)) \land VP(s_2) \\
\Rightarrow NP(Append(s_1, ["who"], s_2))
\]

\[
NP(s_1) \land Number(s_1, n) \land VP(s_2) \land Number(s_2, n) \\
\Rightarrow S(Append(s_1, s_2))
\]

Parsing is reduced to logical inference:

\text{Ask}(KB, S(["I", "am", "a", "wumpus"]))

(Can add extra arguments to return the parse structure, semantics)

Generation simply requires a query with uninstantiated variables:

\text{Ask}(KB, S(x))

If we add arguments to nonterminals to construct sentence semantics, NLP generation can be done from a given logical sentence:

\text{Ask}(KB, S(x, At(Robot, [1, 1])))
Real human languages provide many problems for NLP:

- ambiguity
- anaphora
- indexicality
- vagueness
- discourse structure
- metonymy
- metaphor
- noncompositionality
Ambiguity

Squad helps dog bite victim
Ambiguity

Squad helps dog bite victim
Helicopter powered by human flies
Ambiguity

Squad helps dog bite victim
Helicopter powered by human flies
American pushes bottle up Germans
Ambiguity

Squad helps dog bite victim
Helicopter powered by human flies
American pushes bottle up Germans
I ate spaghetti with meatballs
Ambiguity

Squad helps dog bite victim
Helicopter powered by human flies
American pushes bottle up Germans
I ate spaghetti with meatballs
   salad
Ambiguity

Squad helps dog bite victim
Helicopter powered by human flies
American pushes bottle up Germans
I ate spaghetti with meatballs
  salad
  abandon
Ambiguity

Squad helps dog bite victim
Helicopter powered by human flies
American pushes bottle up Germans
I ate spaghetti with meatballs
    salad
    abandon
    a fork
Ambiguity

Squad helps dog bite victim
Helicopter powered by human flies
American pushes bottle up Germans
I ate spaghetti with meatballs
    salad
    abandon
    a fork
    a friend
Ambiguity

Squad helps dog bite victim
Helicopter powered by human flies
American pushes bottle up Germans
I ate spaghetti with meatballs
   salad
   abandon
   a fork
   a friend

Ambiguity can be lexical (polysemy), syntactic, semantic, referential
Anaphora

Using pronouns to refer back to entities already introduced in the text

After Mary proposed to John, they found a preacher and got married.
Anaphora

Using pronouns to refer back to entities already introduced in the text.

After Mary proposed to John, they found a preacher and got married.

For the honeymoon, they went to Hawaii.
Anaphora

Using pronouns to refer back to entities already introduced in the text

After Mary proposed to John, they found a preacher and got married.

For the honeymoon, they went to Hawaii

Mary saw a ring through the window and asked John for it
Anaphora

Using pronouns to refer back to entities already introduced in the text

After Mary proposed to John, they found a preacher and got married.

For the honeymoon, they went to Hawaii

Mary saw a ring through the window and asked John for it

Mary threw a rock at the window and broke it
Indexicality

Indexical sentences refer to utterance situation (place, time, S/H, etc.)

*I am* over *here*

Why did *you* do *that*?
Metonymy

Using one noun phrase to stand for another

I’ve read Shakespeare

Chrysler announced record profits

The ham sandwich on Table 4 wants another beer
Metaphor

“Non-literal” usage of words and phrases, often systematic:

I’ve tried killing the process but it won’t die. Its parent keeps it alive.
basketball shoes
Noncompositionality

basketball shoes
baby shoes
Noncompositionality

basketball shoes
baby shoes
alligator shoes
Noncompositionality

basketball shoes
baby shoes
alligator shoes
designer shoes
Noncompositionality

basketball shoes
baby shoes
alligator shoes
designer shoes
brake shoes
Noncompositionality

basketball shoes
baby shoes
alligator shoes
designer shoes
brake shoes
red book
Noncompositionality

basketball shoes
baby shoes
alligator shoes
designer shoes
brake shoes

red book
red pen
Noncompositionality

basketball shoes
baby shoes
alligator shoes
designer shoes
brake shoes

red book
red pen
red hair
Noncompositionality

basketball shoes
baby shoes
alligator shoes
designer shoes
brake shoes

red book
red pen
red hair
red herring
Noncompositionality

basketball shoes
baby shoes
alligator shoes
designer shoes
brake shoes

red book
red pen
red hair
red herring

small moon
Noncompositionality

basketball shoes
baby shoes
alligator shoes
designer shoes
brake shoes

red book
red pen
red hair
red herring

small moon
large molecule
Noncompositionality

basketball shoes
baby shoes
alligator shoes
designer shoes
brake shoes

red book
red pen
red hair
red herring

small moon
large molecule
mere child
Noncompositionality

basketball shoes
baby shoes
alligator shoes
designer shoes
brake shoes

red book
red pen
red hair
red herring

small moon
large molecule
mere child
alleged murderer
basketball shoes
baby shoes
alligator shoes
designer shoes
brake shoes

red book
red pen
red hair
red herring

small moon
large molecule
mere child
alleged murderer
real leather
Noncompositionality

basketball shoes
baby shoes
alligator shoes
designer shoes
brake shoes

red book
red pen
red hair
red herring

small moon
large molecule
mere child
alleged murderer
real leather
artificial grass