Ch. 22 – Agents that Communicate

Chapter Outline

- Communication as action
- Types of communicating agents
- Formal grammar for subset of English *
- Syntactic analysis
- Definite clause grammar
- Augmenting a grammar *
- Semantic interpretation
- Ambiguity and disambiguation

* student presentations
Communication

• Definition: *Communication*
  – Intentional exchange of information
  – Production and perception of “signs”
  – Shared system of conventional signs

Communication as Action

• Speech act
  – not necessarily producing sound
  – but act of producing language
• Communicating agents can:
  – Inform each other
  – Query about world
  – Answer questions
  – Request / command actions
  – Promise / offer
  – Share experiences
Communication as Action

- Hard part:
  - Decide when to “speak”
  - Decide what to “say”
  - Similar to planning
  - Non-determinism due to:
    - misunderstanding
    - ambiguity

Fundamentals of Language

- Formal language
  - Set of strings
  - String = sequence of symbols (terminal symbols)
  - Most formalisms based on *phrase structure*
    - Noun phrase can combine with verb phrase to make a sentence
  - NP, VP, S = non-terminal symbols
  - Example grammar rule:
    - S → NP VP
Steps of communication

- Speaker $S$ wants to convey proposition $P$ to hearer $H$ using words $W$:
  - Speaker:
    - Intention – $S$ wants $H$ to believe $P$
    - Generation – $S$ chooses words $W$
    - Synthesis – $S$ utters words $W$
  - Hearer
    - Perception – $H$ perceives $W'$
    - Analysis – $H$ infers the $W'$ has possible meanings $P_1, \ldots, P_n$
    - Disambiguation – $H$ infers $S$ intended to convey $P_i$
    - Incorporation – $H$ decides to believe $P_i$
Types of communicating agents

• Two types:
  – Share common internal representation language
  – Share communication language – no assumptions about internal representation

Common Internal Representation Language

• Direct access to each others KBs
• Through TELL and ASK interface
• “telepathic” communication

• Problems:
  1. Need naming policy to avoid using same symbol
  2. Relating symbols introduced by different agents
  3. Reconciling differences in KBs
  4. Vulnerable to sabotage
Share Communication Language

- Most agents communicate this way
- More flexible
- Less vulnerable to sabotage

Formal grammar for subset of English

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Syntactic Analysis
Building a Parse Tree

function BOTTOM-UP-PARSE(words, grammar) returns a parse tree

    forest ← words
    loop do
        if LENGTH(forest) = 1 and CATEGORY(forest[1]) = START(grammar) then
            return forest[1]
        else
            i ← choose from {1…LENGTH(forest)}
            rule ← choose from RULES(grammar)
            n ← LENGTH(RULE-RHS(rule))
            subsequence ← SUBSEQUENCE(forest, i, i+n-1)
            if MATCH(subsequence, RULE-RHS(rule)) then
                forest[i…i+n-1] ← [MAKE-NODE(RULE-LHS(rule), subsequence)]
            else fail
        end
    end

Parsing Example

<table>
<thead>
<tr>
<th>forest</th>
<th>subsequence</th>
<th>rule</th>
</tr>
</thead>
<tbody>
<tr>
<td>The wumpus is dead</td>
<td>The wumpus</td>
<td>Article → the</td>
</tr>
<tr>
<td>Article wumpus is dead</td>
<td>wumpus</td>
<td>Noun → wumpus</td>
</tr>
<tr>
<td>Article Noun is dead</td>
<td>Article Noun</td>
<td>NP → Article Noun</td>
</tr>
<tr>
<td>NP is dead</td>
<td>is</td>
<td>Verb → is</td>
</tr>
<tr>
<td>NP Verb dead</td>
<td>dead</td>
<td>Adjective → dead</td>
</tr>
<tr>
<td>NP Verb Adjective</td>
<td>Verb</td>
<td>VP → Verb</td>
</tr>
<tr>
<td>NP VP Adjective</td>
<td>VP Adjective</td>
<td>VP → VP Adjective</td>
</tr>
<tr>
<td>NP VP</td>
<td>NP VP</td>
<td>S → NP VP</td>
</tr>
</tbody>
</table>
Definite clause grammar

- Need a way to associate meaning with each string
- Use first-order logic
- Non-terminal symbol becomes predicate
  \[ S \rightarrow NP \ VP \quad NP(s_1) \land VP(s_2) \Rightarrow S(\text{Append}(s_1,s_2)) \]
  \[ \text{Noun} \rightarrow \text{stench} \quad (s=\text{“stench”} \lor \ldots) \Rightarrow \text{Noun}(s) \]
- More verbose than BNF notation
  - Use special notation for DCG
    \[ X \rightarrow Y \; Z \quad Y(s_1) \land Z(s_2) \Rightarrow X(\text{Append}(s_1,s_2)) \]
    \[ X \rightarrow \text{word} \quad X(\text{“word”}) \]
    \[ X \rightarrow Y \mid Z \mid \ldots \quad Y'(s_1) \lor Z'(s_2) \lor \ldots \Rightarrow X(s), \quad Y’=\text{logic translation of Y} \]

DCG Augmentations

- Non-terminals augmented with extra arguments
  - \[ NP(\text{sem},s) \quad \text{sem} \text{ represents semantics of } NP \; s \]
- Variable on RHS of DCG rule
  - Represents single symbol of input string
    - \[ \text{Double} \rightarrow \text{w w} \quad \text{Word repeated twice} \]
- Logical test on RHS of rule
  - \[ \text{Digit(sem)} \rightarrow \text{sem} \{0 \leq \text{sem} \leq 9\} \]
Augmenting a grammar

- Student presentation

Semantic interpretation

- Get a set of possible interpretations
- Later use disambiguation to determine correct one
- Grammar for small subset of English
  - \( \varepsilon_1 \) – what is its semantics?
  - How to represent time, events, etc.
Grammar for $\varepsilon_1$

\[
S \rightarrow NP(Subj) \ VP | \ ...
\]

\[
NP(case) \rightarrow Pronoun(case) | Noun | Article Noun | ...
\]

\[
VP \rightarrow VP \ NP(Objective) | ...
\]

\[
PP \rightarrow Preposition \ NP(Objective)
\]

\[
Pronoun(Subj) \rightarrow I | you | he | she | ...
\]

\[
Pronoun(Obj) \rightarrow me | you | him | her | ...
\]

Semantics of $\varepsilon_1$

- Logical form
  - “Every agent smells a wumpus”
  \[
  \forall a \ Agent(a) \Rightarrow \exists w \ Wumpus(w) \land \exists e \in \text{Perceive}(a, w, Nose) \land \\
  \text{During}(Now, e))
  \]

- Intermediate form – mediate between syntax and semantics
  - Structurally similar to syntax
  - Can be translated into first-order logical sentence
  - Sometimes called quasi-logical form

\[
\exists e \in \text{Perceive}(\forall a \ Agent(a), \exists w \ Wumpus(w), Nose) \land \\
\text{During}(Now, e))
\]
Converting quasi-logical form to logical form

- Final step in semantic interpretation
- Turn quantified terms into real terms
- For each quantified term \([q \ x \ P(x)]\) in \(QLF\)
  - Replace quantified term with \(x\)
  - Replace \(QLF\) with \(q \ x \ P(x) \ op \ QLF\)
    - Where \(op\) is \(\Rightarrow\) when \(q\) is \(\forall\)
    - And \(op\) is \(\wedge\) when \(q\) is \(\exists\)

Example

- “Every dog has his day”
  - Quasi-logical form:
    \(\exists \ e \ e \in Has(\forall \ d \ Dog(d)), [\exists \ a \ Day(a)] ,Now\)
- Two possible logical interpretations
  \(\forall \ d \ Dog(d) \Rightarrow \exists \ a \ Day(a) \wedge \exists \ e \ e \in Has(d,a,Now)\)
  - Each dog has his own day.
  \(\exists \ a \ Day(a) \wedge \forall \ d \ Dog(d) \Rightarrow \exists \ e \ e \in Has(d,a,Now)\)
  - There is a special day that all dogs share.
Pragmatic Interpretation

- Resolving *indexicals* – refer directly to current situation
  - I, today, there, etc.
  - Use knowledge of who speaker is, where speaker is, etc.
- Resolving *anaphora* – previously mentioned objects
  - He, it, etc.
  - Get help from syntax – refer to previous sentences
    - John was hungry. He ate dinner.
  - Has to be handled with disambiguation

Ambiguity

- Lexical ambiguity – word has more than one meaning
  - Right hand side, right answer
- Syntactic (structural) ambiguity – which words fit which part of speech
  - The agent heard a scream in the room.
- Referential ambiguity – anaphoric expressions
  - “it” can stand for anything
- Pragmatic ambiguity – speaker and hearer disagree on current situation
  - Last Saturday
- Local ambiguity – substring can be parsed several ways
  - Larger context may resolve ambiguity
  - A + B + C
Disambiguation

- Hearer maintains model of world
  - New speech act – add possible interpretations to model as hypothesis
- Uncertain reasoning – decide which interpretation is best
- Requires combination of four models:
  1. World model – probability that fact occurs in world
  2. Mental model – prob. Speaker forms intention of communication fact
  3. Language model – prob. String will be chosen
  4. Acoustic model – prob. Sequence of sounds generated

Disambiguation

- Probabilistic context-free grammar (PCFG)
  \[ S \rightarrow NP \ VP \ (0.9) \]
  \[ S \rightarrow S \ Conjunction \ S \ (0.1) \]
- Problem:
  - Context-free – semantics are hard
  - Need context-sensitive model
  - Studied further in Ch. 24
Ontologies

\textit{The philosophical study of the nature of being}

- Specification of ontological commitments
- Description of concepts and relationships used to interact

Ontologies

- Ontologies define classes, functions, object constants, and axioms to constrain meaning
- Allows unambiguous interpretation of logical sentences
Example Ontology 1

```
Vessel
  +------------------+
  |                  |
  |                  |
  +------------------+
  |                  |
  |                  |
  +------------------+
  |      Ship      |
  |                |
  +------------------+
  |                  |
  |                  |
  +------------------+
  |      Boat       |
  |                |
  +------------------+
  |                  |
  |                  |
  +------------------+
  | Sail boat       |
  |                |
  +------------------+
  |                  |
  |                  |
  +------------------+
  | Motor boat      |
  |                |
  +------------------+
  |                  |
  |                  |
  +------------------+
  | Hull            |
  |                |
  +------------------+
  | Engine          |
  |                |
  +------------------+
```

Example Ontology 2

```
Boat
  +------------------+
  |                  |
  |                  |
  +------------------+
  |                  |
  |                  |
  +------------------+
  | Keel            |
  |                |
  +------------------+
  | Motor           |
  |                |
  +------------------+
  | Sail            |
  |                |
  +------------------+
```
Translation

- How do we map objects from one ontology to another?

Agent Communication Languages (ACL)

- Agents are typically defined at a “high” level
- Low level languages and protocols of distributed computing are not compatible
Desired Features

- ACL should support an *intentional* communication
- The language should *not* define protocols
  - Transport protocols
  - High level coordination protocols
  - Constraints on valid exchanges

ACL Requirements (1-3)

- Seven categories
  - Form
    - Declarative, syntactically simple, easy to read – Extensible
  - Content
    - Provide communicative primitives – not content language
  - Semantics
    - Well-defined semantics, grounded in theory
    - Include time and space
    - Exhibit canonical form
ACL Requirements (4-7)

- Implementation
  - Efficient for speed and bandwidth – Simple interface
- Networking
  - Fit modern technology
  - Serve as a substrate for higher-level protocols
- Environment
  - Tool for coping with dynamic, heterogeneous systems
- Reliability
  - Includes errors and security

A Proposed ACL

- The Knowledge Query Manipulation Language (KQML) is an attempt to create a standard ACL
- Based on
  - Speech act theory
  - Separates language from how you use it
KQML Example

(ask-one
  :sender joe
  :content (PRICE IBM ?price)
  :receiver stock-server
  :reply-with ibm-stock
  :language LPROLOG
  :ontology NYSE-TICKS)

(tell
  :sender stock-server
  :content (PRICE IBM 14)
  :receiver joe
  :in-reply-to ibm-stock
  :language LPROLOG
  :ontology NYSE-TICKS)

KQML

- KQML defines a message format and message handling protocol
- Communicates an attitude about the message content
- Language *performatives* define permissible actions agents may attempt during communication