Semantics (Representing Meaning)

Allen’s Chapter 8
J&M’s Chapter 14
Logical Forms

• Logical form of a sentence is the context-independent meaning of the sentence

• “Meaning” has different usages:
  – A warm engine means that the car has been used (implication)
  – “Amble” means to walk slowly (definition)

• Meaning: context independent sense, versus

• Usage: context dependent aspects
Semantic Interpretation

• **Logical Form**: context-independent representation of meaning

• **Semantic Interpretation**: mapping a sentence to its logical form

• **Contextual Interpretation**: mapping the logical form to the final knowledge representation
Figure 8.1  Logical form as an intermediate representation
Semantic Ambiguity

• Ambiguity is a serious obstacle for semantic interpretation

• A word is semantically ambiguous if it maps to more than one sense

• “Kid” is ambiguous between a baby goat and a human child

• “horse” is not ambiguous, though there are colts and mares
Test for semantic Ambiguity

- Certain syntactic constructs require identical class of objects
- *I have two kids and George has three*
- All senses involve some degree of *vagueness*
- *I ran last year and George did too*
Level of ambiguities

• The ambiguity might come from syntactic ambiguity
  Happy cats and dogs live on the farm

• Some may come from the scope of quantifiers
  Every boy loves a dog
  \[ \exists d. \text{Dog}(d) \land \forall b. \text{Boy}(b) \supset \text{Loves}(b, d) \]
  \[ \forall b. \text{Boy}(b) \land \exists d. \text{Dog}(d) \supset \text{Loves}(b, d) \]

• Quantifiers vary with respect to vagueness
  Many people saw the accident
The basic logical form language

- The primitive unit of meaning is the word sense
- These primitives are combined to form the meaning of more complex expressions
- Word senses serve as atoms or constants
- Abstract objects such as events and situations are represented by terms
- Relations and properties are represented by predicates
Examples:

- *Fido is a dog* is represented as 
  \[(\text{DOG}1 \text{ FIDO}1)\]
- *Sue does not love Jack* 
  \[(\text{NOT} (\text{LOVE}1 \text{ SUE}1 \text{ JACK}1))\]
- *I went home and had a drink* 
- *A man entered the room. He walked over the table.* 
  \[(\exists x \; P(x) \land \exists x \; Q(x))\]
- *Need for generalized quantifiers:*
  All, some, more, many, a few, the, a, etc.
## Common Quantifiers

<table>
<thead>
<tr>
<th>Quantifier</th>
<th>Use</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>THE</td>
<td>definite reference</td>
<td>the dog</td>
</tr>
<tr>
<td>A</td>
<td>indefinite reference</td>
<td>a dog</td>
</tr>
<tr>
<td>BARE</td>
<td>bare singular NP (mass term) or</td>
<td>water, food</td>
</tr>
<tr>
<td>BARE</td>
<td>bare plural NP (generics)</td>
<td>dogs</td>
</tr>
</tbody>
</table>

**Figure 8.4** Some common quantifiers
Generalized quantifiers

All dogs bark and most people laughed
(quantifier variable : restriction proposition body proposition)

The logical form of

• Most dogs bark :
  (MOST d1 : (DOG1 d1) (BARK1 d1))

• Most barking things are doges:
  (MOST d2 : (BARK1 d2) (DOG1 d2))
Generalized quantifiers (Cont.)

• *The dog barks:*
  \[(\text{THE } x : (\text{DOG1 } x) \ (\text{BARKS1 } x))\]

• *The happy dog barks:*
  \[(\text{THE } x : (\& \ (\text{DOG1 } x) \ (\text{HAPPY } x)) \ (\text{BARKS1 } x))\]

• *The dogs bark:*
  \[(\text{THE } x : ((\text{PLUR DOG1} ) x) \ (\text{BARKS1 } x))\]
Modal Operators

- Modal operators: to represent verbs such as believe and want, and for tense, and other modalities
- Modal operators look similar to logical operators, but have major differences:
- Terms within the scope of a modal operator may have an interpretation that differs from the logical one
- Let’s assume Jack is known as John to some people,
  If (JACK1 = JOHN22)
  Then (HAPPY1 JACK1) = (HAPPY1 JOHN22),
  But (BELIEVE1 SUE1 (HAPPY1 JACK1)) is not the same as (BELIEVE1 SUE1 (HAPPY1 JOHN22))
- This is called failure of substitutivity in modal contexts
Modal Operators (Cont.)

- Modal (tense) operators: PAST, PRES, AND FUT
  (PRES (SEES1 JOHN1 FIDO1))
  (PAST (SEES1 JOHN1 FIDO1))
  (FUT (SEES1 JOHN1 FIDO1))
- If JOHN1 = PRESIDENT1 at now, it may not be
  (PAST (SEES1 PRESIDENT1 FIDO1))
- P and ~P can be both true in the past (at different times)
  (PAST (HAPPY1 JOHN1)) and
  (PAST (NOT (HAPPY1 JOHN1))) can be both true
Encoding ambiguity in the logical form

- A sentence may have multiple possible syntactical structures
- Each structure may have multiple logical forms
- Each word in the sentence may have multiple senses
- Simply generating all possible logical forms is not practical
- Certain ambiguities can be represented within the logical form (**quasi logical form**)
Encoding ambiguity in the logical form

- Anywhere an atomic sense is allowed, a set of possible atomic senses can be used.
- The noun *ball* has at least two senses: *BALL1, the object used in games, and BALL2, the social event*.
- *Sue watched the ball* is ambiguous

\[(\text{THE } b1 : (\{\text{BALL1, BALL2}\} b1) (\text{PAST } (\text{WATCH1 SUE1 } b1)))\], which abbreviates:
- \[(\text{THE } b1 : (\text{BALL1 } b1) (\text{PAST } (\text{WATCH1 SUE1 } b1)))\]
- \[(\text{THE } b1 : (\text{BALL2 } b1) (\text{PAST } (\text{WATCH1 SUE1 } b1)))\]
Ambiguity regarding scope of quantifiers

• *Every boy loves a dog*

\[(\text{LOVES1 } <\text{EVERY } b1 \ (\text{BOY1 } b1) > <\text{A } d1 \ (\text{DOG1 } d1)>)\]

which abbreviates an ambiguity between:

– \((\text{EVERY } b1 : (\text{BOY1 } b1) (\text{A } d1 : (\text{DOG1 } d1) (\text{LOVES1 } b1 \ d1))))\)

– \((\text{A } d1 : (\text{DOG1 } d1)(\text{EVERY } b1 : (\text{BOY1 } b1) (\text{LOVES1 } b1 \ d1))))\)

• A sentence with 4 quantifier would have 4! (24) possible ordering, and with 5 quantifier would have 5! (120) possible ordering
Ambiguity regarding scope of quantifiers

• A large number of constructs in natural languages are sensitive to scoping
• All generalized quantifier, including THE, are subject to scoping

At every hotel, the receptionist was friendly
Ambiguity regarding scope of quantifiers

- Operators such as negation and tense are also scope sensitive
- *Every boy didn’t run* is ambiguous between
  - (NOT (EVERY \(b_1\) : (BOY1 \(b_1\)) (RUN1 \(b_1\))))
  - (EVERY \(b_1\) : (BOY1 \(b_1\)) (NOT (RUN1 \(b_1\))))
- Quasi logical form of the sentence is:
  (\textless \text{NOT RUN1} \textgreater \textless \text{EVERY } b_1 \text{ BOY}1\textgreater )
Proper names and Pronouns

• Proper names must be interpreted in context: name *John* refers to different people in different situations
• (NAME <variable> <name>), means that variable has the specified name
• *John ran* is represented as
  (<PAST RUN1> (NAME j1 “John”))
• Pronouns are indexical and need a special function, too.
• (PRO <variable> <proposition>)
• *Every man liked him*
  (<PAST LIKE1> <EVERY m1 MAN1> (PRO m2 (HE1 m2))),
  where HE1 is the sense for *he* and *him*
• “He” is often written as (PRO m2 HE1)
1. *John broke the window with the hammer*
2. *The hammer broke the window*
3. *The window broke*

- The verb “break” has verb senses of different arity
  1. \((\text{<PAST BREAK1> } (\text{NAME j1 “John”}) \text{ <THE w1 WINDOW1> <THE h1 HAMMER1>})\)
  2. \((\text{<PAST BREAK2> <THE h1 HAMMER1> <THE w1 WINDOW1>})\)
  3. \((\text{<PAST BREAK3> <THE w1 WINDOW1>})\)
Events in logical form

• Introducing events into logical forms:

  1. John broke it
     
        (∃ e1 : BREAK1 e1 (NAME j1 “John”) (PRO i1 IT1))

  2. John broke it with the hammer
     
        (∃ e1 : (& ( BREAK1 e1 (NAME j1 “John”) (PRO i1 IT1)) (INSTR e1 <THE h1 HAMMER1>)))

• Only one sense of verb break is needed
Case Grammars

• How are noun phrases related to verbs?
• Case Grammar claims: number of possible semantic relationships is small
• Sentences with different syntax but same meanings: identical case analyses
  – John broke the window with a hammer.
  – The hammer broke the window.
  – The window broke.
There is only a limited set of abstract semantic relationships that can hold between a verb and its arguments.

These are often called **thematic** or **case roles**

*John broke the window* is represented as

\[
(\exists e_1 : (\& (\text{BREAK}1\ e_1)
\quad (\text{AGENT} e_1 (\text{NAME}\ j_1 \text{“John”}))
\quad (\text{THEME}\ e_1 <\text{THE}\ w_1\ \text{WINDOW}_1>)))
\]

**General form:**

\[
(\exists e : (\& (\text{Event-p}\ e) (\text{Relation}_1\ e\ \text{Obj}_1) \ldots \ (\text{Relation}_n\ e\ \text{Obj}_n)))
\]

**Abbreviated as:**

\[
(\text{Event-p}\ e [\text{Relation}_1\ \text{Obj}_1] \ldots [\text{Relation}_n\ \text{Obj}_n])
\]
Case and Thematic roles

• The quasi-logical form of *John broke the window* is:

  `<PAST BREAK1> e1
  [AGENT (NAME j1 "John")]
  [THEME <THE w1 WINDOW1>]`
Different forms of representation

• *Mary sees John* is shown as:
  
  $$(\text{PRES} \ (\exists \ l_1 \ (\& \ (\text{SEES} \ l_1 \ l_1) \\
                              \ (\text{AGENT} \ l_1 \ (\text{NAME} \ m_1 \ \text{“Mary”}) \\
                              \ (\text{THEME} \ l_1 \ (\text{NAME} \ J_1 \ \text{“John”}))))))$$

• **Abbreviated form:**

  $$(\text{PRES} \ (\text{SEES} \ l_1 \ [\text{AGENT} \ (\text{NAME} \ m_1 \ \text{“Mary”})] \\
                          \ [\text{THEME} \ (\text{NAME} \ J_1 \ \text{“John”})]))$$

• **Without thematic roles:**

  $$(\text{PRES} \ (\text{SEES} \ (\text{NAME} \ m_1 \ \text{“Mary”}) \\
                    \ (\text{NAME} \ J_1 \ \text{“John”}))))$$
Determining Thematic Roles

• AGENT: instigator of the action (intention, volition, responsibility)

• Test: add a phrase like *intentionally*
  – John intentionally broke the window.
  – *The hammer intentionally broke the window*

• Not all animate subjects are AGENTS
  – *John intentionally died.*
  – *Mary remembered her birthday in order to get some presents.*
Determining Thematic Roles

- THEME: entity undergoing a change or being acted upon
- for a transitive verb X, THEME is usually the answer to “what was Xed?”
- for an intransitive verb, THEME is used for subjects that are not AGENTs
- *The clouds appeared over the horizon.*
Speech Acts

- Different sentences have different purposes
- Each type of sentence indicates a different relation between the speaker and the receiver
- Each types is represented by an operator called a speech act

- (ASSERT (Proposition))
- (Y/N-QUERY (Proposition))
- (WH-QUERY (Proposition))
- (COMMAND (Proposition))
Speech Acts (cont.)

The man ate a peach

(ASSERT (<PAST EAT> e1
[AGENT <THE m1 MAN1>]
[THEME <A p1 PEACH>])))

Did the man eat a peach?

(Y/N-QUERY (<PAST EAT> e1
[AGENT <THE m1 MAN1>]
[THEME <A p1 PEACH>])))

Eat the peach

(COMMAND (EAT e1 [THEME <THE p1 PEACH>])))
**Wh questions**

- A new quantifier WH is needed to represent wh-terms
  - *What*: <WH p1 PHYSOBJ1>
  - Which man: <WH m1 MAN1>
  - *Who*: <WH p1 PERSON1>

- For how many and how much two more quantifiers HOW-MANY and HOW-MUCH are needed:

**What did the man eat?**

(WH-QUERY (<PAST EAT1> e1
  [AGENT <THE m1 MAN1>]
  [THEME <WH w1 PHYSOBJ1>])))
Embedded sentences

- Embedded sentences do not need any new notation

_The man who ate a peach left_

```prolog
(ASSERT (<PAST LEAVE> e1
    [AGENT <THE m1 (& (MAN1 m1)
        (<PAST EAT1> e2
            [AGENT m1]
            [THEME <A p1 PEACH1>])>]))
```