Aren’t words atomic units?

✦ So far we have taken words to be atomic units in both syntax and semantics:
  – Syntax: [S [NP John] [VP saw [NP Mary]]]
    No internal structure to any of these words.
✦ Even in chapters on Semantics (Chapters 17, 18), words are not decomposed in any way:
  – SAW(JOHN,MARY)
    Just use capital letters
✦ Now we are going to look at richer models of the semantics of words: “Lexical Semantics”
Meaning of Words

✦ Lexical Semantics: What is it?

✦ Old view: Words have to be interpreted “in context”

✦ Recent view: Systematic structure for words

Definitions

✦ What is the lexicon?
  – A list of lexemes

✦ What is a lexeme?
  – Word Orthography + Word Phonology + Word Sense

✦ What is the word sense?

✦ What is a dictionary?

✦ What is a lexicon?

✦ What is a computational lexicon?
Lemmatization

- Mapping a wordform to a lemma
  - found → find, found
  - He found the book
  - He was determined to found the institution
- Is morphological parsing the same as lemmatization?
  - Example: “celebrations”
  - Morphology: celebrate + ion + s (root = celebrate)
  - Lemmatization: celebration + s (lemma = celebration)
  - Note: Difference between inflectional & derivational

Homonomy

- What is homonomy?
  - A bank holds investments in a custodial account
  - Agriculture is burgeoning on the east bank

- Variants
  - homophones: “read” vs. “red”
  - homographs: “bass” vs. “bass”
Polysemy

- What is **polysemy**?
  - The *bank* is constructed from red brick
  - I withdrew the money from the *bank*

- Systematic relationship between these senses:
  - BUILDING ↔ ORGANIZATION

- Distinguishing polysemy from homonymy is not straightforward

Metaphor and Metonymy

- Metaphor: Reference to concepts using words whose meanings are appropriate to other completely different kinds of concepts.
  - That doesn’t **scare** Digital

- [Metonymy is a type of polysemy: Use of one aspect of a concept/entity to refer to other aspects of the entity](http://example.com)
  - GM **killed** the Fiero
  - The White House **relayed** the news about the President’s condition

- Systematic relationship can be formalized:
  - Author(Jane Austen wrote Emma) ↔
  - Works of Author(I really love Jane Austen)
**Synonymy**

- **What is synonymy?**
  - How **big** is that plane?
  - How **large** is that plane?
- **Very hard to find true synonyms**
  - A **big** fat apple
  - ?A **large** fat apple
- **Influences on substitutability**
  - subtle shades of meaning differences
  - polysemy
  - register
  - collocational constraints

**Hyponymy**

- **What is hyponymy?**
- Not symmetric
  - Example: **car** is a **hyponym** of **vehicle** and **vehicle** is a **hypernym** of **car**
  - Test: *That is a car* implies *That is a vehicle*
- **What is an ontology?**
  - Ex: CAR#1 is an object of type **car**
- **What is a taxonomy?**
  - Ex: **car** is a kind of **vehicle**. CAR#1 is an object of type **car**
- **What is an object hierarchy?**
WordNet

Most widely used hierarchically organized lexical database for English (Fellbaum, 1998)

WordNet 3.0 has:
- 117,097 nouns (average noun has 1.23 senses)
- 11,488 verbs (average verb has 2.16 sense)
- 22,141 adjectives
- 4,601 adverbs

Demo: http://www.cogsci.princeton.edu/~wn/

Format of WordNet Entries

The noun “bass” has 8 senses in WordNet.
1. bass¹ - (the lowest part of the musical range)
2. bass², bass part¹ - (the lowest part in polyphonic music)
3. bass³, basso¹ - (an adult male singer with the lowest voice)
4. sea bass¹, bass⁴ - (the lean flesh of a saltwater fish of the family Serranidae)
5. freshwater bass¹, bass⁵ - (any of various North American freshwater fish with lean flesh (especially of the genus Micropterus))
6. bass⁶, bass voice¹, basso² - (the lowest adult male singing voice)
7. bass⁷ - (the member with the lowest range of a family of musical instruments)
8. bass⁸ - (nontechnical name for any of numerous edible marine and freshwater spiny-finned fishes)

The adjective “bass” has 1 sense in WordNet.
1. bass¹, deep⁶ - (having or denoting a low vocal or instrumental range)
   “a deep voice”; “a bass voice is lower than a baritone voice”; “a bass clarinet”
Distribution of Senses among WordNet Verbs

Lexical Relations in WordNet

<table>
<thead>
<tr>
<th>Relation</th>
<th>Also called</th>
<th>Definition</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hyponym</td>
<td>Subordinate</td>
<td>From concepts to subtypes</td>
<td>breakfast² — meal¹</td>
</tr>
<tr>
<td>Hypernym</td>
<td>Member-Meronym</td>
<td>From groups to their members</td>
<td>faculty² — professor¹</td>
</tr>
<tr>
<td>Has-Instance</td>
<td>Has-Member</td>
<td>From concepts to instances of the concept</td>
<td>composer² — Bach¹</td>
</tr>
<tr>
<td>Instance</td>
<td>Member-Of</td>
<td>From instances to their concepts</td>
<td>Austen¹ — author¹</td>
</tr>
<tr>
<td>Member Holonym</td>
<td>Has-Part</td>
<td>From members to their groups</td>
<td>cpi² — crew¹</td>
</tr>
<tr>
<td>Part Holonym</td>
<td>Part-Of</td>
<td>From wholes to parts</td>
<td>table² — leg³</td>
</tr>
<tr>
<td>Antonym</td>
<td>Opposites</td>
<td>From parts to wholes</td>
<td>course² — meal¹</td>
</tr>
</tbody>
</table>

Figure 19.2  Lexical relations in WordNet.

<table>
<thead>
<tr>
<th>Relation</th>
<th>Definition</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hyponym</td>
<td>From events to superordinate events</td>
<td>fly² — travel³</td>
</tr>
<tr>
<td>Troponym</td>
<td>From a verb (event) to a specific manner elaboration of that verb</td>
<td>walk¹ — stroll¹</td>
</tr>
<tr>
<td>Entails</td>
<td>From verbs (events) to the verbs (events) they entail</td>
<td>smoke¹ — sleep¹</td>
</tr>
<tr>
<td>Antonym</td>
<td>Opposites</td>
<td>increase³ — decrease³</td>
</tr>
</tbody>
</table>

Figure 19.3  Verb relations in WordNet.
Synsets in WordNet

- Example: \{chump, fish, fool, gull, mark, patsy, fall guy, sucker, schlemiel, shlemiel, soft touch, mug\}
- Definition: “a person who is gullible and easy to take advantage of”.
- Important: This exact synset makes up one sense for each of the entries listed in the synset.
- Theoretically, each synset can be viewed as a concept in a taxonomy
  - Compare to: \( \exists w, x, y, z \) Giving(x) ^ Giver(w,x) ^ Givee(z,x) ^ Given(y,x).
  - WN represents “give” as 45 senses, one of which is the synset \{supply, provide, render, furnish\}.

Hyponomy in WordNet
Word Sense Disambiguation

- For any given lexeme, can its senses be reliably distinguished?
- Assumes a fixed set of senses for each lexical item
- Example: “bank”
  - bank\(^1\) = financial institution (bank manager)
  - bank\(^2\) = sloping mound (river bank)
  - bank\(^3\) = biological repository (blood bank)
  - bank\(^4\) = building belonging to financial institution (bank robber)
  - bank\(^5\) = turning motion, e.g., in aviation (bank left)

Automated Word Sense Disambiguation

- One of the main applications of WordNet is word-sense disambiguation.
- Supervised WSD: A training corpus is manually annotated with WordNet synsets. For each phrase-synset pair a list of words occurring in the context is stored. New phrases are classified according to the closest context vector
Automated Word Sense Disambiguation

- Unsupervised WSD: Given two phrases, consider all possible synsets. Select the two synsets that are closest in the WordNet hierarchy.
- Distance can be defined as:
  - Number of edges (possibly weighted)
  - Word overlap of the glosses

Internal Structure of Words

What are the meaning components underlying word senses?

This is the field of “Lexical Semantics”
Thematic Roles (θ-Roles)

What is a thematic role?
- give: $(\exists \ w, x, y, z) \text{Giving}(x) \land \text{Giver}(w, x) \land \text{Givee}(z, x) \land \text{Given}(y, x)$
- break: $(\exists \ w, x, z) \text{Breaking}(x) \land \text{Breaker}(w, x) \land \text{BrokenThing}(z, x)$

A **thematic role** is a way of expressing this commonality. The subjects of both verbs is an **agent**.

Generic Thematic Roles

<table>
<thead>
<tr>
<th>Thematic Role</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGENT</td>
<td>The volitional causer of an event</td>
</tr>
<tr>
<td>EXPERIENCER</td>
<td>The experiencer of an event</td>
</tr>
<tr>
<td>FORCE</td>
<td>The non-volitional causer of the event</td>
</tr>
<tr>
<td>THEME</td>
<td>The participant most directly affected by an event</td>
</tr>
<tr>
<td>RESULT</td>
<td>The end product of an event</td>
</tr>
<tr>
<td>CONTENT</td>
<td>The proposition or content of a propositional event</td>
</tr>
<tr>
<td>INSTRUMENT</td>
<td>An instrument used in an event</td>
</tr>
<tr>
<td>BENEFICIARY</td>
<td>The beneficiary of an event</td>
</tr>
<tr>
<td>SOURCE</td>
<td>The origin of the object of a transfer event</td>
</tr>
<tr>
<td>GOAL</td>
<td>The destination of an object of a transfer event</td>
</tr>
</tbody>
</table>
Examples of Thematic Roles

<table>
<thead>
<tr>
<th>Thematic Role</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGENT</td>
<td>The waiter spilled the soup.</td>
</tr>
<tr>
<td>EXPERIENCER</td>
<td>John has a headache.</td>
</tr>
<tr>
<td>FORCE</td>
<td>The wind blows debris from the mall into our yards.</td>
</tr>
<tr>
<td>THEME</td>
<td>Only after Benjamin Franklin broke the ice...</td>
</tr>
<tr>
<td>RESULT</td>
<td>The French government has built a regulation-size baseball diamond...</td>
</tr>
<tr>
<td>CONTENT</td>
<td>Mona asked “You met Mary Ann at a supermarket”?</td>
</tr>
<tr>
<td>INSTRUMENT</td>
<td>He turned to poaching catfish, stunning them with a shocking device...</td>
</tr>
<tr>
<td>BENEFICIARY</td>
<td>Whenever Ann Callahan makes hotel reservations for her boss...</td>
</tr>
<tr>
<td>SOURCE</td>
<td>I flew in from Boston.</td>
</tr>
<tr>
<td>GOAL</td>
<td>I drove to Portland.</td>
</tr>
</tbody>
</table>

Diathesis Alternations

- Thematic roles are a shallow semantic language for making simple inferences:
  - John [AGENT] broke the window [THEME]
  - The window [THEME] broke
  - John [AGENT] broke the window [THEME] with a rock [INSTRUMENT]
  - A rock [INSTRUMENT] broke the window [THEME]
- Thematic Grid (θ-grid):
  - [Agent, Theme, Instrument]
  - Sometimes called Case Frame
- Multiple argument realizations are called **verb alternations** or **diathesis alternations**
  - Example: Dative alternation
    - She gave the book to John
    - She gave John the book
Early Theories of Thematic Roles

- 1967–1968: Fillmore; Gruber; Jackendoff
- Each argument of a predicate bears a particular thematic role.
- Gruber/Jackendoff: Account for semantics and use grammar derived to say something about syntax
  - Break vase with hammer: Change of state $\rightarrow$ vase:goal
  - Break vase against wall: Motion $\rightarrow$ vase:theme
- Fillmore: Account for syntax and use that to describe semantics.
  - Test for D(ative): What he did to the house was ruin it
    [ruin assigns D(ative)=affectum]
  - Ungrammatical, not D: *What he did to the house was build it
    [build assigns F(active)=effectum]

Why Posit Thematic Level Distinct from Syntactic Subcategorization?

- Capture similarity between different (but related) uses of same lexical item
  Example:
  - John rolled the ball down the hill
  - The ball rolled down the hill
  - roll: [NP, NPa, PP] $\rightarrow$ [NPb, PP]
- Obviate need for subcategorization frames
  - Mapping from syntax to lexical-semantics
  - Fillmore: General principles for complement selection
    see: NP(NP); go: NP(PP)
  - E. Williams (81): Specifies argument structure and uses general linking routines
Why Posit Distinct Thematic Level? (continued)

-* Fillmore’s algorithm: Realize ‘salient’ token as NP and ‘non-salient’ token as PP; Let Case determine word order
  Example: smear
    John smeared paint on the wall
    John smeared the wall with paint
-* E. Williams’ algorithm:
  theme → NP (always);
  goal → PP_{TO} (dominating NP) or NP_2
  Example: give
    John gave the book to Mary
    John gave Mary the book
    give: [actor,theme,goal]

Primitive Decomposition

-* Representation of the internal structure of words:
  – Jim killed his philodendron
  – Jim did something to cause his philodendron to become not alive
-* Translate “kill” into more complex set of predicates.
-* kill = “cause to become not alive”
-* Criticism of decompositional approach:
  ?John caused Bill to die on Tuesday by shooting him Monday
### Schank’s Primitives

<table>
<thead>
<tr>
<th>Primitive</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATRANS</td>
<td>The abstract transfer of possession or control from one entity to another.</td>
</tr>
<tr>
<td>PTRANS</td>
<td>The physical transfer of an object from one location to another</td>
</tr>
<tr>
<td>MTRANS</td>
<td>The transfer of mental concepts between entities or within an entity.</td>
</tr>
<tr>
<td>MBUILD</td>
<td>The creation of new information within an entity.</td>
</tr>
<tr>
<td>PROPEL</td>
<td>The application of physical force to move an object.</td>
</tr>
<tr>
<td>MOVE</td>
<td>The integral movement of a body part by an animal.</td>
</tr>
<tr>
<td>INGEST</td>
<td>The taking in of a substance by an animal.</td>
</tr>
<tr>
<td>EXPEL</td>
<td>The expulsion of something from an animal.</td>
</tr>
<tr>
<td>SPEAK</td>
<td>The action of producing a sound.</td>
</tr>
<tr>
<td>ATTEND</td>
<td>The action of focusing a sense organ.</td>
</tr>
</tbody>
</table>

### Other Types of Primitives

- **Substantives:** I, YOU, SOMEONE, SOMETHING, PEOPLE
- **Mental predicates:** THINK, KNOW, WANT, FEEL, SEE, HEAR
- **Speech:** SAY
- **Determiners and quantifiers:** THIS, THE SAME, OTHER, ONE, TWO, MANY (MUCH), ALL, SOME, MORE
- **Actions and events:** DO, HAPPEN
- **Evaluators:** GOOD, BAD
- **Descriptors:** BIG, SMALL
- **Time:** WHEN, BEFORE, AFTER
- **Space:** WHERE, UNDER, ABOVE
- **Paronymy and taxonomy:** PART (OF), KIND (OF)
- **Movement, existence, life:** MOVE, THERE IS, LIVE
- **Metapredicates:** NOT, CAN, VERY
- **Interclausal linkers:** IF, BECAUSE, LIKE
- **Space:** FAR, NEAR, SIDE, INSIDE, HERE
- **Time:** A LONG TIME, A SHORT TIME, NOW
- **Imagination and possibility:** IF... WOULD, CAN, MAYBE
Predicate-Independent vs. Predicate-Dependent

**Predicate-Independent (F):**
Syntax first: Single set of roles is chosen independent of the type of predicates involved
- effectum(build)-F
- affectum (ruin)-D
- Test: What John did to the house was ruin/*build it.

**Predicate-Dependent (G/J):**
Semantics first: Roles identified by particular positions arguments occupy wrt primitive predicates
- BE → theme x location \( (be) \)
- CAUSE → agent x theme \( (roll) \)
- CHANGE → theme x source x goal \( (break) \)

Local vs. Non-Local Orientation

**Local (Localist Hypothesis) (G/J):**
- Notions of motion & location are central.
- Motion (GO): Theme = moving object; Source/Goal/Path Location (BE): Theme = located object; Location

**Non-Local Orientation (F):**
- Concerned w/ causal dimension (affected obj)
- Does not distinguish verbs of motion & location
- Can't tell which object moved

**Locative alternation**
- F: break the vase \( (D) \) w/ the hammer \( (I) \)
  break the vase \( (D) \) against the wall \( (L) \)
- G/J: break the vase \( (Goal) \) w/ the hammer \( (Theme) \)
  break the vase \( (Theme) \) against the wall \( (Location) \)
Local vs. Non-Local Approach: Issues

**Local approach** (G/J):
- How do we assimilate abstract verbs to verbs of motion & location?
- Introduce fields (Ident, Exist, etc.): abstract domains.
- Sometimes need a dual representation to account for causal dimension
  Example: Nancy broke the vase with a hammer
  hammer = Theme (Jackendoff) / Instrument (Fillmore)
  E1: CAUSE (Nancy, GOIdent (Vase, Broken))
  E2: CAUSE (Nancy, GOLoc (hammer, vase))
  [E2 causes E1]

**Non-Local approach** (F):
- Attempts to account for this CAUSAL relation
- Notions of motion/location are not given any special consideration

Thematic Hierarchy Constraint

Agent > Instrument > Theme

Used to determine the thematic role of the subject of the sentence

Examples:
- John (A) opened the door (T)
- John (A) opened the door (T) with the key (I)
- The key (I) opened the door (T)

Passive: Run in reverse
- The door (T) was opened by John (A)
**Decomposition vs Non-Decomposition**

- Decompositional/Compositional (Schank, Jackendoff, Gruber) vs. Non-Decompositional (Fillmore)
- What is decompositional (compositional)?
- Why hard? Need to decide on primitives.
  - Jackendoff: LCS
  - Schank: CD
- Exhaustive (Schank) vs. non-exhaustive (Jackendoff)
  - CD: elucidate causal structure
  - LCS: closer to syntactic structure—requires modifiers to differentiate meanings.

**Jackendoff’s Semantic Theory**

- Predicate-centered (Gruber) begins with three basic primitives:
  - GO – all verbs of motion (event)
  - STAY – maintenance of motion (event)
  - BE – state
  - Test: What happened was ___ (event/state)
- PLACEs and PATHs are represented as preposition-like functions (TO, FROM, etc.)
  - The train traveled from D to B
  - The bacteria stayed in his body
  - The statue stands on Cambridge Common
  - Examples:
**Jackendoff (continued)**

- **Others: GO\_Ext:**
  The road goes to Boston (state, not event)
- **ORIENT:**
  The sign points to Philadelphia.
- **Agentive predicates: CAUSE, LET**
  Laura took the bird from the cage.
  \[\text{CAUSE (LAURA, [GO (BIRD, [FROM (CAGE)])])}\]
  Laura released the bird from the cage.
  \[\text{LET (LAURA, [GO (BIRD, [FROM (CAGE)])])}\]
- **CAUSE takes an instrument; LET doesn't.**
  Apparent counterexample:
  Laura took ... with a hanger.
  Laura released ... with a hanger.

**Jackendoff’s Fields**

- **Central notion in J's later work**
- **Allows many generalizations to be stated**
- **GO, STAY, BE extend to fields other than spatial field (Loc)**
- **Localist Hypothesis: focuses on motion/location**
- **Other types of meaning are available (by analogy): use fields to provide distinctions**
  - Possessional: Miriam took the gift.
  - Identificational: The coach turned into a pumpkin.
  - Circumstantial: They led me to believe it.
  - Temporal: We moved the meeting to Tuesday.
Some Cross-Field Generalizations

<table>
<thead>
<tr>
<th>Action</th>
<th>Location</th>
<th>Circumstance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GO</strong></td>
<td>Max came into the room</td>
<td>Max came to be called a hero</td>
</tr>
<tr>
<td><strong>GO_EXT</strong></td>
<td>The highway goes from D to B</td>
<td>Ron's speech went from 2 to 4</td>
</tr>
<tr>
<td><strong>STAY</strong></td>
<td>The iguana stayed in Africa</td>
<td>The iguana stayed ugly</td>
</tr>
<tr>
<td><strong>CAUSE STAY</strong></td>
<td>Bill kept the book on the shelf</td>
<td>Bill kept David working</td>
</tr>
<tr>
<td><strong>BE</strong></td>
<td>Bill is in Africa</td>
<td>Bill is happy</td>
</tr>
<tr>
<td><strong>CAUSE GO</strong></td>
<td>Max pushed through the crowd</td>
<td>Max pushed to get his way</td>
</tr>
<tr>
<td><strong>LET GO</strong></td>
<td>Laura released the bird from the cage</td>
<td>Laura released Fred from washing dishes</td>
</tr>
</tbody>
</table>

Mapping from Input Dependency to English Dependency Tree

Knowledge Resources in English only: (LVD; Dorr, 2001).
Problems with Thematic Roles

- Difficult to come up with a standard set of thematic roles
- Researchers attempting to do so often break up AGENT and THEME into many specific roles
- Difficult to formally define roles, e.g., AGENT = animate, volitional, sentient, causal (but maybe not!)
- Alternate versions of semantic roles: PropBank, FrameNet

Proposition Bank (PropBank)

- Each sense of a verb has specific roles, given the names Arg0, Arg1, Arg2, etc.
- Arg0 represents a “proto-agent”
  - Agent-like” meaning
  - Intentionality, volitionality, causality, etc.
- Arg1 represents a “proto-patient”
  - Patient-like properties
  - Undergoing change of state, causally affected by another participant, etc.
- FrameSet agree.01
  - Arg0: Agreeer
  - Arg1: Proposition
  - Arg2: Other entity agreeing
- Example: [Arg0 John] agreed [Arg1 on everything] [Arg2 with Mary]
FrameNet

- Goal: Make inferences across different verbs (not just across sentences using the same verb)
- Relates these sentences:
  - [Arg1 The price of bananas] increased [Arg2 5%]
  - [Arg1 The price of bananas] rose [Arg2 5%]
- Roles are not specific to a verb—they are specific to a frame
- A frame is a script-like structure containing frame elements
- Core roles:
  - Item = entity that has a position on a scale
  - Attribute = scalar property possessed by item
  - Difference = distance Item changes
  - Example: [Item Oil] rose [Attribute in price] [Difference by 2%]

Selectional Preferences

- Semantic constraints imposed by a lexeme on the concept that can fill roles associated with it.
- Verbs often exhibit type preferences for their arguments:
  - Eat (OBJ: food)
  - Think (SUBJ: intelligent entity)
- Analyzing a corpus with verb-argument pairs, it’s possible to derive the proper semantic types by looking at the hypernyms of the arguments
Selectional Restrictions (continued)

*“I wanna eat someplace that's close to UMD.”
  – Case 1: eat - intransitive (me)
  – Case 2: eat - transitive (Godzilla)
*Why is Case 1 preferred?

\[(\exists \ w,x,y) \ Eating(x) \land Agent(w,x) \land Theme(y,x) \land Isa(y,EdibleThing)\]

Implementation of Selectional Restrictions

Sense 1
hamburger, beefburger --
(a fried cake of minced beef served on a bun)
=> sandwich
  => snack food
  => dish
    => nutriment, nourishment, nutrition...
      => food, nutrient
        => substance
          => matter
            => physical entity
              => entity
Next Time

* Read Chapters 17, 20