Introduction to Psycholinguistics

Lecture 3: Sentence Processing

Matthew W Crocker

Computeralinguistik
Universität des Saarlandes

What makes up Psycholinguistics?

- Computational models of the representations, architectures and mechanisms that underlie human language processing.
  - Linguistics:
    - Wow people represent linguistic knowledge
  - Psycholinguistics:
    - How people use this knowledge to produce and understand language
  - Computational Models:
    - Implementations of psycholinguistic theory, using linguistic representations.
    - More complete theory: models and predicts human behaviour
  - Experiments & Data:
    - Descriptive studies of human language processing
      - Off-line: grammaticality judgement, completions, global reading time (?)
      - On-line: "word-by-word", self-paced reading, eye-tracking, ERP
    - Test prediction of theories and computer models
    - Corpus data: word-frequency, category and sense bias, subcategorization
Sentence Processing

Sentence processing is the means by which the words of an utterance are combined to yield and interpretation

- All people do it well
- It is a difficult task: complexity and ambiguity
- Not simple ‘retrieval’, like lexical access
- Compositional: interpretation must be built, rapidly, even for novel word/structure input

What are the architectures, mechanisms and representations underlying this process?

- Architectures: modularity vs. interaction
- Mechanisms: how is input mapped to interpretations using knowledge
- Representations: How is knowledge encoded

A Simple Theory of Grammar

The Grammar

- S → NP VP
- NP → PN
- NP → Det N
- NP → NP PP
- PP → P NP
- VP → V
- VP → V NP
- VP → V NP PP

The Lexicon

- Det = {the, a, every}
- N = {man, woman, book, hill, telescope}
- PN = {John, Mary}
- P = {on, with}
- V = {saw, put, open, read, reads}
A Generated Sentence

the man read every book

S → NP VP
NP → Det N VP → V NP
Det N V NP
the man read Det N
every book

Semantic Composition

Theories of meaning and knowledge representation
Semantic composition:
- lexical competence + semantic operations

“the man read every book”

S \(\forall y \ y \text{book}(y) \land \text{read}(x, y)\)
NP → Det N VP → V NP
Det N V NP
the man read Det N
every book

∀ y \ y \text{book}(y) \land \text{read}(x, y)
∀ y \ y \text{book}(y) \land \text{read}(x, y)
∀ y \ y \text{book}(y) \land \text{read}(x, y)
∀ y \ y \text{book}(y) \land \text{read}(x, y)
∀ y \ y \text{book}(y) \land \text{read}(x, y)
∀ y \ y \text{book}(y) \land \text{read}(x, y)
Semantic Ambiguity

- **Word sense ambiguity**: a word may have more than one sense
  - *Stock* (soup vs investments), *bank* (money repository vs side of river),

- **Anaphoric underspecification**: anaphoric expressions derive their meaning from context:
  - *She, it, the book, every man*

- **Scope ambiguity**: the interpretation of sentence constituents may be controlled by the interpretation of other constituents
  - “In New York, a man is mugged every 10 minutes”

Syntactic Ambiguity

- **Lexical ambiguity** occurs when a word may be rewritten by more than one category:
  - **N** → {saw, hammer, book ...}
  - **V** → {read, saw, witnessed, ...}

- **Structural ambiguity** occurs when a sentence may be generated in more than one way by the PS rules:

  *The spy saw the cop with the gun/binoculars*

  - The *gun* is usually interpreted as a modifier of the *cop*
  - The *binoculars* is usually interpreted as an instrument of *saw*
PP Attachment Ambiguity

- **PPs** may attached to **NPs**, and **VPs**:
  - *John saw the man with the telescope*

```
S
  NP
    PN [John]
  VP
    V [saw]
    NP [the man with the telescope]
    PP
```

Local Ambiguity: NP/S complements

- **Local ambiguity** occurs during incremental parsing, when there is insufficient local information to determine the correct structure:

```
S
  NP
    The athlete
  VP
    V [realised]
    NP [his goals] or S [were unattainable]
```

*When the NP is encountered we don’t know whether to attach it as direct object, or embedded subject.*
Processing and Ambiguity

- What if an utterance may be interpreted in more than one way:
  - "I saw the man on the bench in the park with a telescope"
  - choose a single parse/interpretation
  - determine all possible interpretations

- Incrementality
  - Local ambiguity:
    - "I knew the solution to the problem was incorrect"
  - How much is interpreted incrementally?
  - What are the implications for parsing and understanding?

- Most evidence suggest people …
  - … are consciously aware of only one interpretation at any time, and
  - … construct interpretations on a word-by-word basis (at least!)

Mechanisms for syntactic processing

- Human syntactic processing requires a solution to the problem of *local and global ambiguity*

- Serial/backtracking:
  - Initial disambiguation: rule (or structure?) selection strategy
  - Reanalysis: reparsing? parse repair? …

- Parallel:
  - Preferences: ranking strategy
  - Limitations: what structures to forget
  - Reanalysis: reranking/adjusting

- Parsing/Ranking strategies:
  - Structural, syntactic
  - Interactive: semantics, discourse, …
  - Probabilistic
From Theory to Data

- We want to understand, and ideally model, sentence comprehension
  - Organisations, mechanisms, representations, acquisition, interaction …

- What methods can we use to get at these issues:
  - Introspection is notoriously unreliable
  - Direct: Neuroscientific methods are not (yet!) that revealing …
  - Behaviour: Rather we focus on observed behaviour
    - Judgements on meaning or grammaticality
    - Unconscious measure, e.g. reading times, priming …

- Why do we focus on ambiguous or “pathological” sentences?
  - Ambiguity is more common than you think, yet usually not problematic
  - Understanding how people cope with ambiguity can reveal a lot about the underlying architectures and mechanisms
  - Easier to investigate minimal pairs: similar sentences, with one difference

Linking Hypotheses

- Linking Hypothesis:
  - Need to relate the theory to some observed measure
  - Typically impossible to predict measures completely

- Common view: Theories of parsing typically determine …
  - which information sources are used when
  - which representation is preferred/constructed when ambiguity arises
  - If the sentence is consistent with that representation, processing should be easier than if it is not
    - Preferred sentences should have faster reading times in the disambiguating region than dispreferred

- Don’t overfit the data: remember, our theories are about sentence comprehension, not reading times …
  - Must explain competence, and possible other behavioural measures
Evidence from reading times

- Language comprehension entails the incremental recovery of an interpretation for an utterance/sentence:
  - Grammar, lexicon, parser, semantics, world knowledge, situation
    - [Diagram of tree structures]

- Ambiguity: two possible structures
  - How do we know which one people build first?
  - Reading times increase when disambiguated towards the dispreferred interpretation.

Pickering, Traxler & Crocker, 2000

The Modularity Issue

- What is the architecture of the mind and brain?
  - How is computation achieved/organised?
Architectures and Mechanisms

- Are there distinct modules within the human language processor?
  - What does “distinct” mean?
  - Representational autonomy: e.g. parse trees vs conceptual representations
    - Possibly shared procedures
  - Procedural autonomy: e.g. parser versus interpreter
    - Possibly shared representations

- If so…
  - How are any such “distinct subsystems” for language processing organised?
  - How do they interact?

- How does the architecture affect possible mechanisms?
  - Serial (backtracking), parallel (bounded?), underspecified …
  - Kinds of ambiguity resolution strategies?
  - What are the implications for semantic processing?

- What are the arguments for and against ‘modularity’?
  - Theoretical, computational and empirical

Towards a theory of parsing

- Syntax mediates the mapping sound to meaning
  - If syntax exists, the construction of syntactic representations must precede semantics or be part of the same system.

- The construction of syntactic dependencies and semantic interpretations occurs incrementally, word-by-word.

- Little evidence of “conscious parallelism”

- Ambiguity and incrementality entail making decisions and building interpretations in the face of “uncertainty”:
  - What kinds of mechanisms are used to deal with ambiguity?
  - What kinds of linguistic knowledge inform the decision making process?
  - What does this tell us about the architecture of the sentence processor?
A Modular Model

Parser operates incrementally:
- Each word it attached into the Current Partial Phrase Marker

The parser operates serially:
- A “race” to find an analysis: first wins
- Reanalyse if the analysis is thematically impossible

Ambiguity resolution strategies:
- Minimal Attachment: *Adopt the analysis which requires postulating the fewest nodes*
- Late Closure: *Attach material into the most recently constructed phrase marker*
- Active Filler Strategy: *Associate fillers with possible gaps (traces) as early as possible.*
**Minimal Attachment: VP Attachment**

\[ \text{John saw the man with the telescope} \]

\[
\begin{array}{c}
\text{S} \\
\text{NP} \\
\text{PN} \\
\text{John} \\
\text{V} \\
\text{saw} \\
\text{VP} \\
\text{NP} \\
\text{PP} \\
\text{Det} \\
\text{N} \\
\text{P} \\
\text{NP} \\
\text{the} \\
\text{man} \\
\text{with} \\
\text{the} \\
\text{telescope} \\
\text{S} \\
\text{NP} \\
\text{PN} \\
\text{John} \\
\text{V} \\
\text{saw} \\
\text{VP} \\
\text{NP} \\
\text{PP} \\
\text{Det} \\
\text{N} \\
\text{P} \\
\text{NP} \\
\text{the} \\
\text{man} \\
\text{with} \\
\text{the} \\
\text{telescope} \\
\end{array}
\]

**Late Closure**

\[ \text{Prefer ‘low attachment’} \]

\[
\begin{array}{c}
\text{S} \\
\text{NP} \\
\text{The reporter} \\
\text{V} \\
\text{said} \\
\text{NP} \\
\text{the plane} \\
\text{VP} \\
\text{crashed} \\
\text{AdvP} \\
\text{last night} \\
\end{array}
\]
NP/S Complement Ambiguity

- The student knew the solution to the problem.
- The student knew the solution was incorrect.

Ambiguities revisited: [preferred/dis-preferred]

- NP/VP Attachment Ambiguity:
  - “The cop [saw [the burglar] [with the binoculars]]”
  - “The cop saw [the burglar [with the gun]]”
- NP/S Complement Attachment Ambiguity:
  - “The athlete [realised [his goal]] last week”
  - “The athlete realised [[his shoes] were across the room]”
- Clause-boundary Ambiguity:
  - “Since Jay always [jogs [a mile]] the race doesn’t seem very long”
  - “Since Jay always jogs [[a mile] doesn’t seem very long]”
- Red. Relative-Main Clause Ambiguity:
  - “[The woman [delivered the junkmail on Thursdays]]”
  - “[The woman [delivered the junkmail]] threw it away]”
- Relative/Complement Clause Ambiguity:
  - “The doctor [told [the woman [that he was in love with]] [to leave]]”
  - “The doctor [told [the woman] [that he was in love with her]]”