Computational Psycholinguistics

Lecture 1: Introduction

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Computational Psycholinguistics

• “To understand and model the processes that underlie the human capacity to understand language”

• How does the human language processor work?

• How is it realized in the brain?

• How can we model it computationally?

• Where does it come from?

• How does language interact with other cognitive systems and the environment?
What is it?

• Using computational techniques to better understand and model how people produce and comprehend language

• Competence: Principles that relate utterances to underlying meaning?

• Performance: How do people establish this relationship during on-line language processing?

• Computational psycholinguistics seeks cognitively plausible theories about both mental rules and representations, and about cognitive processes

• Computational psycholinguistics seeks to realize such theories as implemented, predictive models of human knowledge and behavior

Different from NLP?

• Early NLP (e.g. Winograd, 1983) clearly viewed itself as building models of human understanding

• Proposals were heavily informed by intuitions about how people understand, and linguistic theories about mental representations

• Modern NLP has shifted emphasis:

  • Application: do limited tasks accurately and robustly, often without real understanding (e.g. spam filters, IR, document clustering, summarization)

  • Deep NLU: Emphasis is on representations, coverage and efficiency. Little concern with cognitive plausibility
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**Areas of Psycholinguistics**

| • Speech perception and articulation |
| • visual word recognition |
| • Lexical access and lexical choice |
| • The mental lexicon |
| **Sentence processing:** |
| • syntactic, semantic, pragmatic |
| • Discourse and dialogue |
| • Anaphora, priming, alignment |
| • Situated language processing: |
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| • Embodied language processing: |
| • grounding language in action/perception systems of the brain |
| • Language Acquisition and Development |
| • Language Evolution |
Models of Sentence Processing

- Language is complex & dynamic
  - multiple levels of representation & knowledge
  - each level has rich internal structure, unique constraints & representations
  - processing unfolds over time: both across levels, and in response to signal
  - levels interact in dynamically, and in complex ways
- We need computational models to understand ...
  - the dynamics & interactions of processing; the role of processing limitations
  - relate processing with empirical data; make predictions

Sound to Meaning over Time

Propagation across levels

- Acoustic Signal
- Word Segmentation
- Lexical Access
- Syntactic Parsing
- Semantic Interpretation
- Meaning

Input over time
So what ... 

• Speech streams include no discrete boundaries to indicate where one word ends and another begins.

• We understand stammering non-fluent politicians and non-native speakers. Incomplete sentences are no problem for us.

• We deal with ambiguity all the time without breaking down. Computer parsers often maintain thousands of possible interpretations.

• We have a vocabulary of about 60,000 words. We access somewhere between 2-4 words/second (low error rates ~ 2/1000 words)

• We understand speech even faster than we can produce it. We are so fast, we can even finish each others sentences.

Human language processing

• People are highly accurate in understanding language

• People process language rapidly, in real-time

• People understand and produce language incrementally

• People even anticipate what’s going to be said next

• People rapidly adjust to context, and are robust

• People achieve this despite limitations on processing resources

• People do make some interesting errors, and exhibit breakdown in certain situations ...
Human language processing

- People are highly **accurate** in understanding language
- People process language **rapidly**, in **real-time**
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**Lexical access**

- Visual & spoken word recognition
  - Central importance of lexical frequency
- Incremental & parallel access
  - words with similar onset & offset are activated (*beetle* vs *beaker* vs *speaker*)
- Multiple meanings
  - “Bug”: both **insect** & **spy device** senses are accessed initially
- Rapid decay of non-preferred sense
- Key issue: Bottom-up versus Top-down “selection”
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
- Unlike lexical access, it can’t simply be ‘retrieval’
- **Compositional**: interpretation must be constructed on-line, rapidly
- Even for sentences with novel structures, or words used in novel positions

Context Free Grammars

- Context-free grammar rules:
  
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  \begin{align*}
  S & \rightarrow \text{NP} \ \text{VP} \\
  PP & \rightarrow \text{P} \ \text{NP} \\
  VP & \rightarrow \text{V} \ \text{NP} \\
  VP & \rightarrow \text{V} \\
  \text{NP} & \rightarrow \text{NP} \ \text{PP} \\
  \text{NP} & \rightarrow \text{Det} \ \text{N}
  \end{align*}
  \]
  
  \[
  \begin{align*}
  \text{Det} & \rightarrow \text{the} \\
  \text{Det} & \rightarrow \text{every} \\
  \text{N} & \rightarrow \text{man, woman} \\
  \text{N} & \rightarrow \text{book} \\
  \text{P} & \rightarrow \text{with} \\
  \text{V} & \rightarrow \text{read, reads}
  \end{align*}
  \]

- Node admissibility criterion:
  
  - A tree is admitted by the grammar, if for each non-terminal node, \(N\), with daughters \(Ds\), there is a rule in the grammar of the form: \(N \rightarrow Ds\).
Simple example

Theories of Linguistic Knowledge

• Theories of Syntax

• **Representations:** Trees, feature structures, dependencies

• **Structure building:** PS-rules, transformations, unification, composition, tree substitution

• **Constraints on representations:** Case marking, theta-Criterion, c-command, binding principles, head-foot principle

• Competence Hypothesis

• The mechanisms of language comprehension directly utilize the rules and representations of the linguistic theory
The Competence Hypothesis

- Knowledge: **Competence hypothesis**
  - Need to recover the meaning of sentences/utterances
  - Assumptions about (levels of) representations
    - Linguistic theory is isomorphic to human linguistic knowledge
    - Comprehension and production share same knowledge
  - **Weak competence**: people recover representations that are isomorphic to those of linguistic theories
  - **Strong competence**: people directly use the grammatical knowledge & principles of linguistic theories

The Modularity Issue

- Is language distinct from other cognitive & perceptual processes?
  - e.g. vision, smell, reasoning ...
- Do distinct modules exist **within** the language processor?
  - e.g. word segmentation, lexical access, syntax ...
- What is a module anyway!?
Architectures and Mechanisms

• What does “distinct” mean:
  • Representational autonomy: e.g. phonological versus logical representations
    • Possibly interactive processes
  • Procedural autonomy: e.g. lexical access versus parsing
    • Possibly shared representations

• How is the language module organized/interact with other systems?
  • Does architecture affect possible mechanisms?
  • What is the interface and bandwidth between modules?

Strong competence & modularity

• Fodor’s proposals emphasis language as a module, distinct from other perceptual cognitive abilities

• Linguistic theories suggest that language itself may consist of sub-levels: phonology, morphology, syntax, semantics ...
  • Each with different rules and representations
  • Do these correspond to distinct processes?
  • Are these processes modules?
A Modular Architecture

Support for Linguistic Modularity

- Modular lexical access versus syntax: Forster
  - all possible word meanings temporarily available
  - no immediate influence of syntactic context
- Modular syntax versus semantics: Frazier
  - initial attachment ambiguities resolved by purely structural preferences
  - no immediate effect of semantics or context
- Dissociation in language impairment at different levels
  - lexical, syntactic, semantic; production versus comprehension
Attachment Preferences

Against linguistic modularity

- Empirical evidence from on-line methods

  - “immediate” influence of animacy, frequency, plausibility, context …
    - The woman sent the flowers was pleased
    - The patient sent the flowers was pleased

- Appropriate computational frameworks:
  - symbolic constraint-satisfaction systems
  - connectionist systems & competitive activation models
  - Homogenous/Integrative Linguistic Theory: HPSG
  - multiple levels of representation within a unified formalism
Human Language Processing

• We understand language incrementally, word-by-word
  
  • *How do people construct interpretations?*

• We must resolve local and global ambiguity
  
  • *How do people decide upon a particular interpretation?*

• Decisions are sometimes wrong!
  
  • *What information is used to identify we made a mistake?*
  
  • *How do we find an alternative interpretation?*

• Answers can reveal important details about the underlying mechanisms

Roadmap

• Theories of sentence processing:
  
  • modularity, parsing strategies, information sources, reanalysis

• Symbolic parsing models:
  
  • incremental parsing, ambiguity resolution, memory load, probabilistic models

• Probabilistic parsing models:
  
  • Symbolic parsers augmented with probabilities, derived from experience

• Information theoretic approaches:
  
  • Modeling communication as a rational probabilistic problem
Tutorials

• We’ll be using various software packages and programs to make some of the concepts more concrete:
  
  • Prolog implementations of incremental parsing algorithms
  
  • Prolog implement of incremental HMM POS tagging
  
  • TnT statistical POS tagger
  
  • Roark’s incremental statistical parser

Course details

• Weekly lectures (Monday 2-4pm) and tutorials (Wednesday 2-4pm)
  
  • Participation in, and completion of, all tutorials is required!

• Assessment: Final Exam (100%), Date: Wed, February 10, 2016
  
  • All tutorial assignments must be successfully completed to sit the exam

• Course materials (overheads and most readings) will be made available on the course homepage (linked from general course page)

• Contact: please e-mail first – crocker@coli.uni-sb.de

• Tutor: Jesús Calvillo – iesus.calvillo@gmail.com