Computational Psycholinguistics

Lecture 1: **Introduction**

Matthew W. Crocker
crocker@coli.uni-sb.de

Computational *Psycho*linguistics

"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 about both mental rules and representations, and about cognitive processes
- Computational psycholinguistics seeks to realize such theories as implemented computational 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

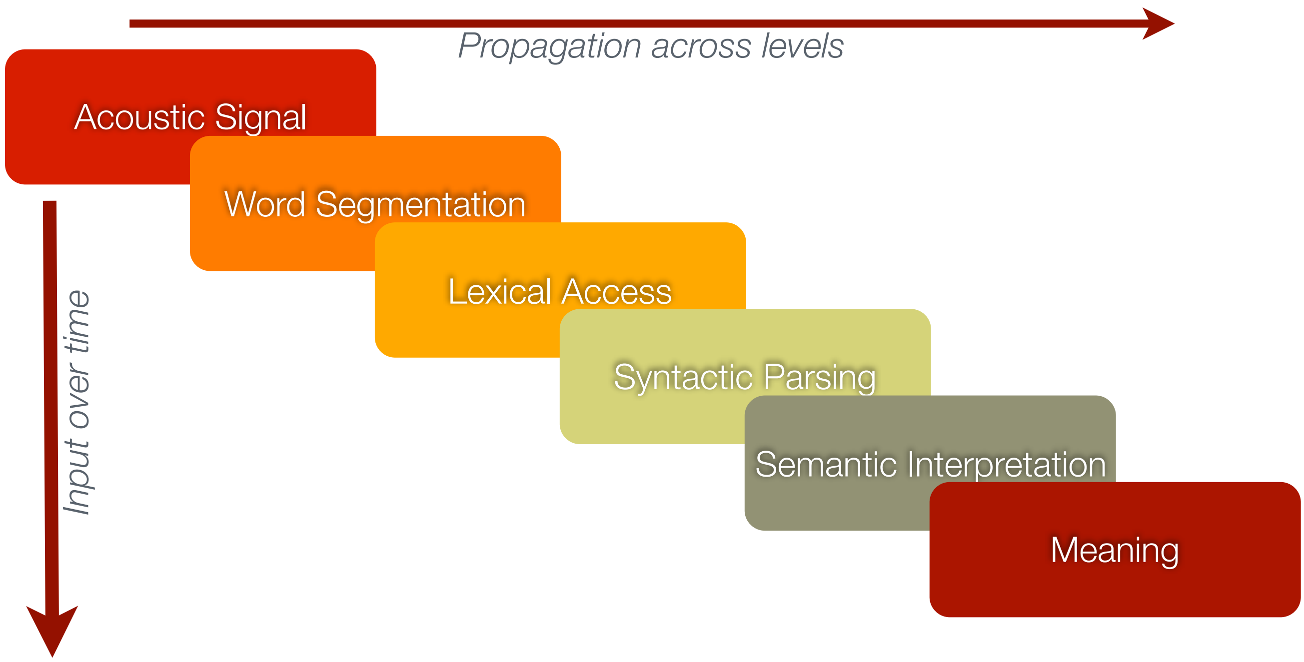
Areas of Psycholinguistics

- 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:
  - interaction with task, context
  - the immediate environment
- 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



So what ...

- Speech streams include no discrete boundaries to indicate where one word ends and another begins.
- We understand non-fluent speech, fragments, interruptions 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 ...

But things don't alway go smoothly…

- Police police police police police.
  - *Internal affairs investigates the detectives that monitor other police.*
- The boat floated down the river sank.
  - *The boat that we floated down the river eventually sank.*
- The child put the candy on the table in his mouth.
  - *The child put the candy that was on the table in his mouth.*
- The editor authors the newspaper hired disliked resigned.
  - *The editor that reporters that the newspaper hired disliked resigned.*
- In New York, someone is hit by a car every 10 minutes ..
  - *… and the poor guy is getting tired of it.*

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 <u>insect</u> & <u>spy device</u> 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

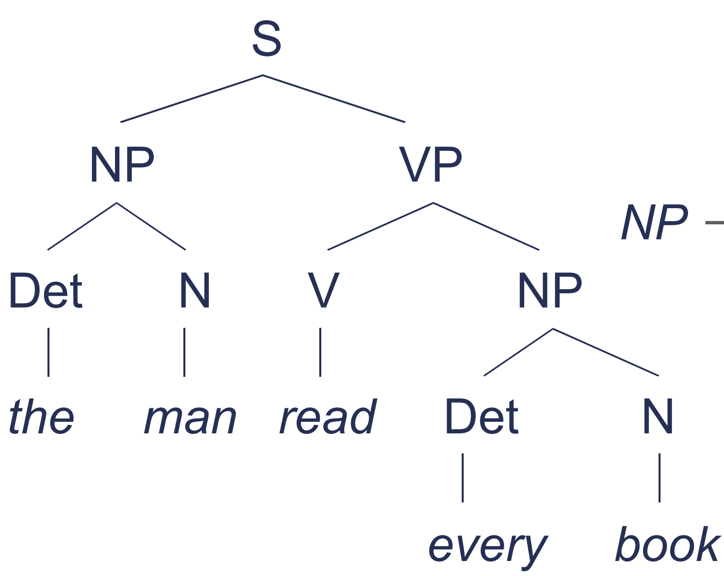
Context Free Grammars

- Context-free grammar rules:

S → NP VP	Det → the
PP → P NP	Det → every
VP → V NP	N → man, woman
VP → V	N → book
NP → NP PP	P → with
NP → Det N	V → read, reads

- 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 → Ds.

Simple example



S → NP VP

NP → Det N   *VP → V NP*

NP → Det N

Theories of Linguistic Knowledge

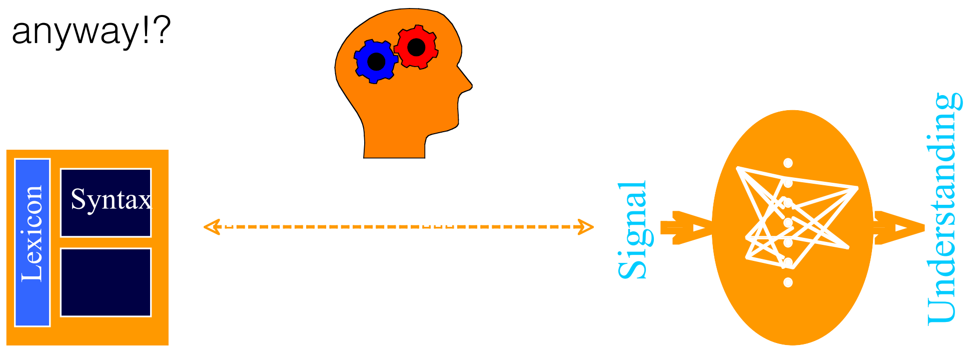
- Theories of Syntax
  - **Representations**: Trees, feature structures, dependencies
  - **Structure building**: PS-rules, transformations, unification, composition, tree substitution
  - **Constraints on representations**: Case marking, theta-Criterion, c-command, binding principles, head-foot principle
- 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!?



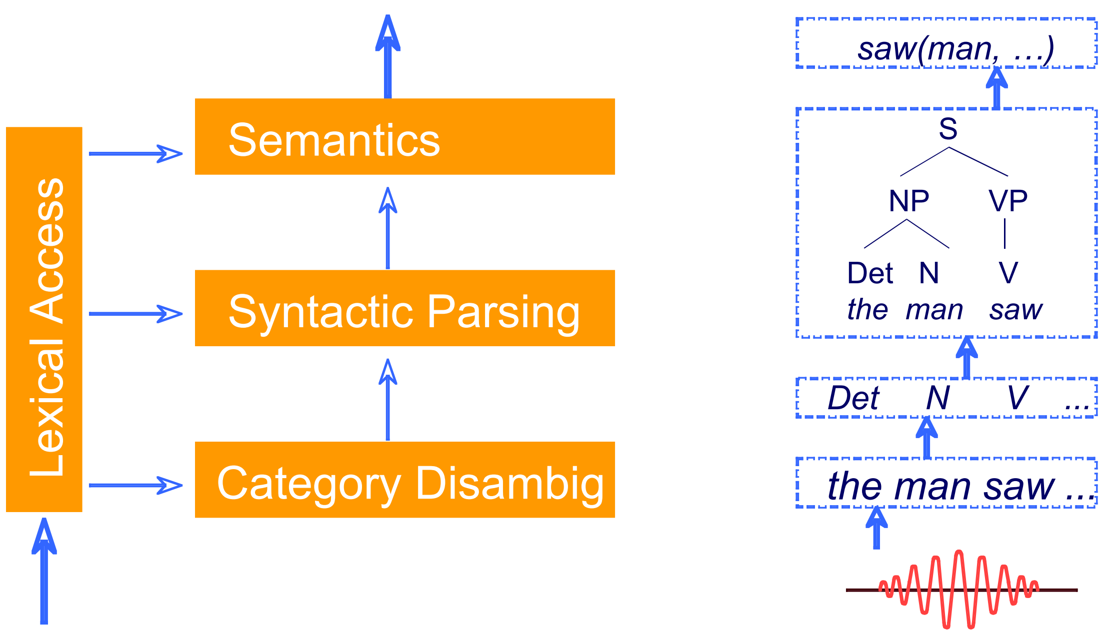
Architectures and Mechanisms

- 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?

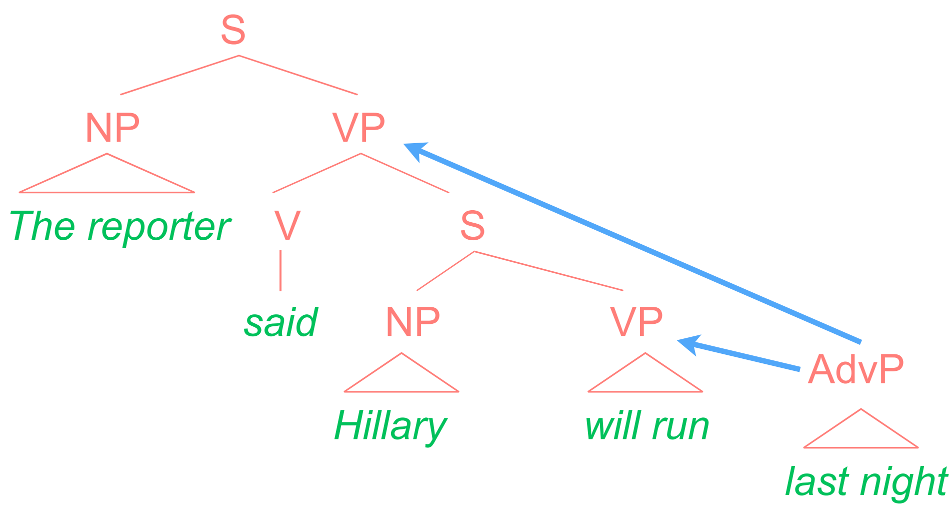
A Modular Architecture



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 resolve lexical 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
- Rational, probabilistic parsing models:
  - Symbolic parsers augmented with probabilities, derived from experience
- Information theoretic approaches:
  - Modeling communication as a *bounded* 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
- For Wednesday: Install SWI-Prolog on your laptops, and bring them … if you can't, then partner with someone.
  - http://www.swi-prolog.org

SWI Prolog

Course details

- Weekly lectures (Mon 2-4pm) and tutorials (Wed 2-4pm)
    - Participation in, and completion of, all tutorials is required!
- Assessment: Final Exam (100%), Date: Mon, February 3, 2020
    - 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