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?

Language Comprehension

- How people map the unfolding linguistic **signal → meaning** ?
  - A theory of **mental representations** of sentence meaning
  - **Neurophysiological and behavioural indices** of online comprehension
  - **Mechanisms** that **incrementally recover meaning representation** from the signal, that is consistent with empirical measures
- What informs the development of our models/theories?
  - **Linguistic** adequacy
  - **Empirical** coverage
  - **Rationality** and simplicity

What is it?

Using computational techniques to better understand and model how people map between the linguistic signal and it's meaning:

- 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

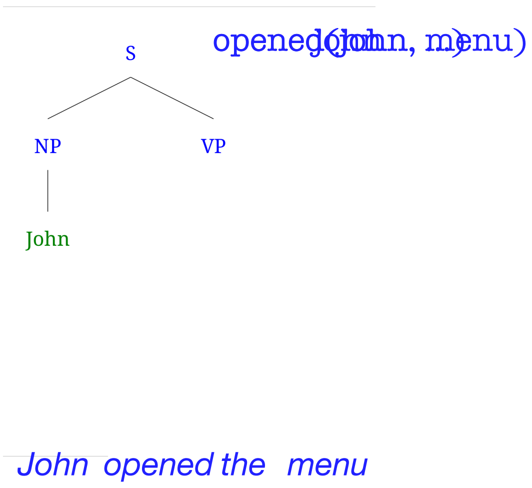
Computational psycholinguistics seeks to realize such theories as implemented computational models of human knowledge and behavior

Incremental Language Comprehension

1. Hear/read the next word of the sentence

2. **Access** what they know about that word from **long term memory**

3. **Integrate** that word into an unfolding representation of utterance meaning in **working memory**



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

- Later 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

- Now, will LLMs there is interest again in evaluating the psychological plausibility of those model …

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

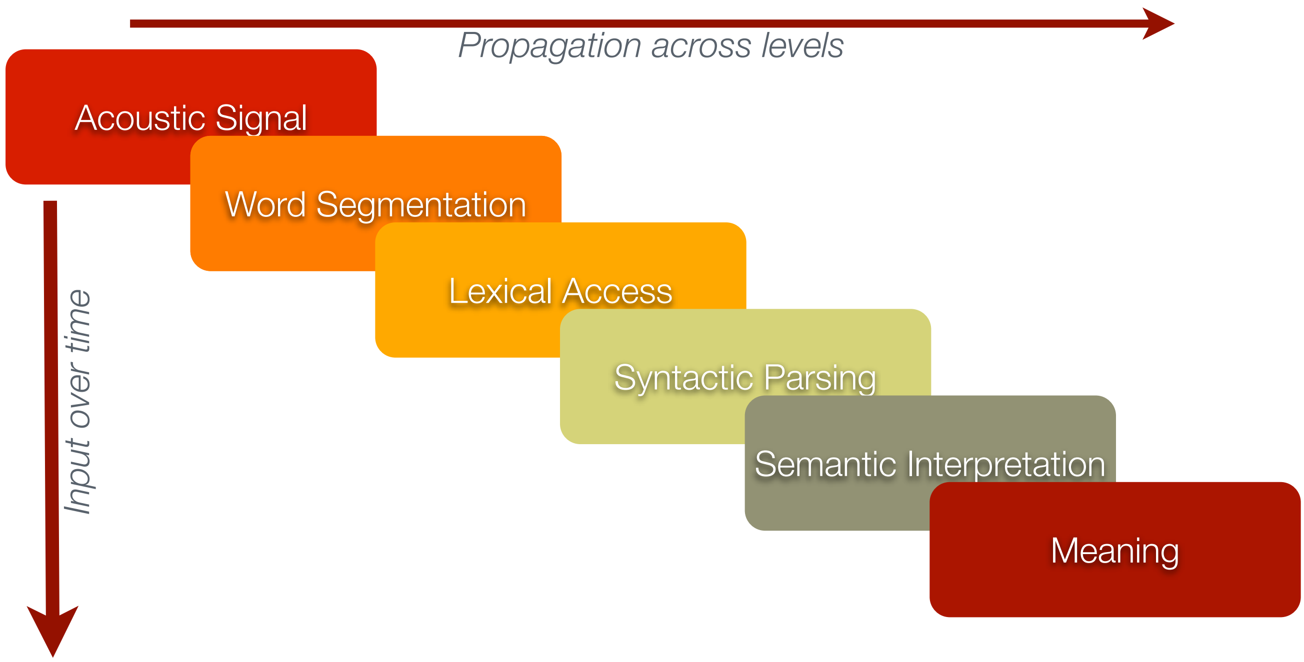
Language is complex & dynamic

- 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 ...

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

Noise: We understand non-fluent speech, fragments, interruptions and non-native speakers. Incomplete sentences are no problem for us.

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

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

Speed: 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 sailed down the river sank.

- *The boat that was sailed 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 reporters 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

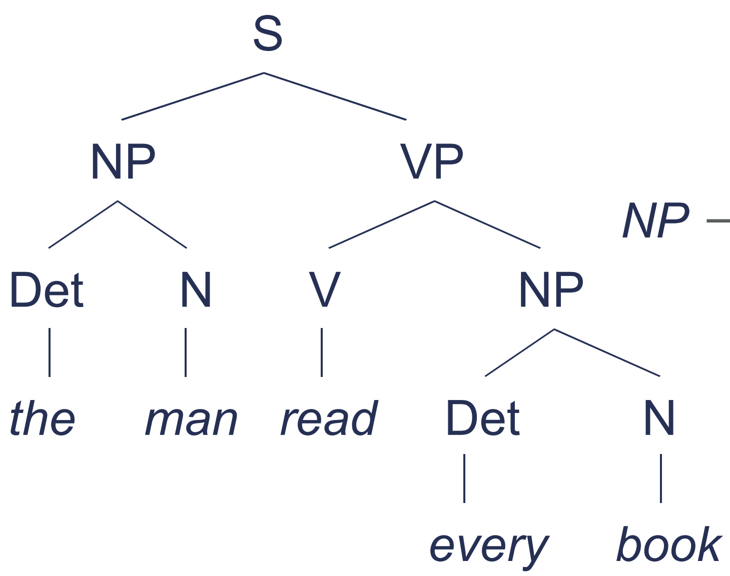
Context-free grammar rules:

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 utilise 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

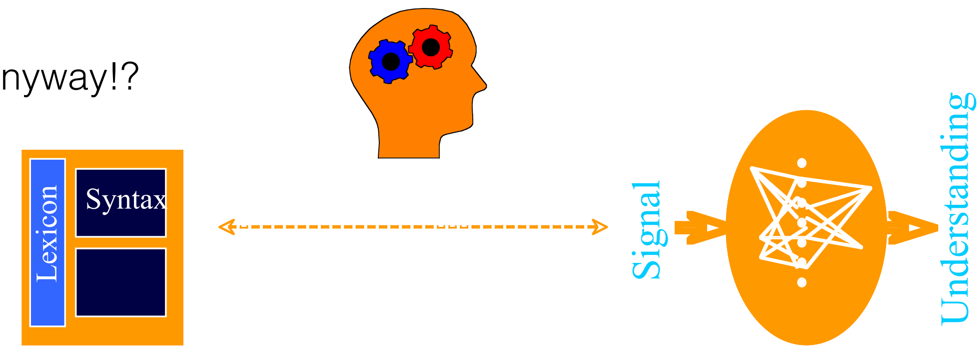
Jerry Fodor argued that language is distinct from other cognitive & perceptual processes:

- e.g. vision, smell, central 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?

- How does architecture affect possible mechanisms?
- What is the interface and bandwidth between modules?

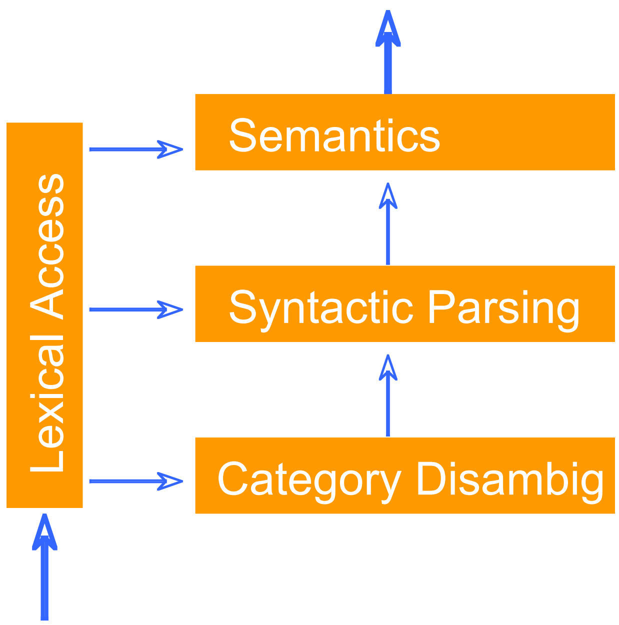
Strong competence & modularity

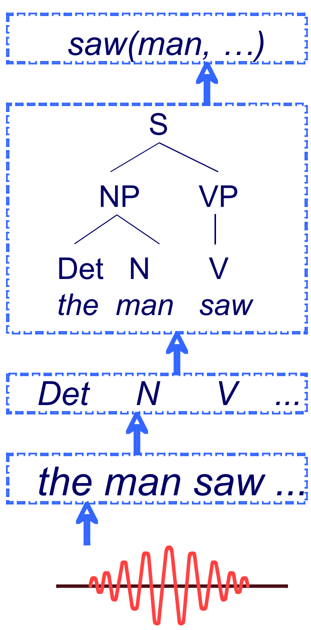
Fodor's proposals emphasis language as a module, distinct from other perceptual cognitive abilities

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/semantics: Forster, Swinney …

- all possible word meanings temporarily available
- no *immediate* influence of syntactic context

> (P) For several weeks following the exterminator's visit they did not find a single *bug* anywhere in the apartment.
>
> (S) For several months following the discovery that they were being watched by the C.I.A. they kept checking the phone for a *bug* or phone tap.
>
> INSECT CUSTOM SPY TAN

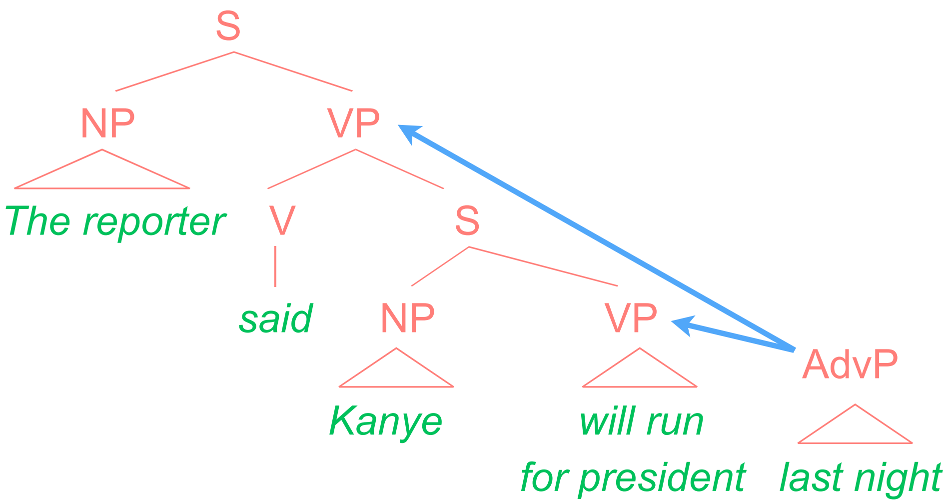
Dissociation in language impairment at different levels

- lexical, syntactic, semantic; production versus comprehension

Attachment Preferences

Modular syntax versus semantics: Kimball, Frazier …

- initial attachment ambiguities resolved by purely structural preferences
- no immediate effect of semantics or context



Against linguistic modularity

Empirical evidence from on-line methods

- “immediate” influence of animacy, frequency, plausibility, context …

  The woman sent the flowers

  The patient sent the flowers was pleased

Appropriate computational frameworks:

- symbolic constraint-satisfaction systems
- connectionist systems & competitive activation models

Unification-based Linguistic Theory: HPSG

- multiple levels of representation within a powerful 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:

- Prolog implementations of incremental parsing algorithms
- Prolog implementation of incremental category disambiguation
- TnT statistical POS tagger
- Roark's incremental statistical parser

For Wednesday: Install SWI-Prolog on your computers, try it out!

- Or you can run it on our servers, you WILL need an account:
  ```
  %ssh -l your_login login.coli.uni-sb.de
  %swipl
  ```
- `http://www.learnprolognow.org/`

SWI Prolog

http://www.swi-prolog.org

Course details

Weekly **lectures** (**Mon** 2:15-3:45pm) and **tutorials** (**Wed** 2:15-3:45pm)

- Participation in, and completion of, all tutorials is required!
- Handed out in Teams, get as far as you can before tutorial. We'll discuss in tutorials.

Assessment: **Final Exam (100%)**, Date: Mon, February 5, 2024

- **All tutorial assignments** must be successfully completed to sit the exam

All done via **Teams**:

- Course materials (lectures, overheads, key readings, tutorial sheets)
- **Submission of tutorials via Teams**: due before the following lecture
- Discussion/chat

Contact: crocker@coli.uni-sb.de