Language Science & Technology: Cognitive Foundations I

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What do we mean by Cognitive Foundations?

Language is fundamentally a human phenomena.

- It originates in, and is comprehended by the human mind.

The nature of language is shaped by ...

- communicative pressures and goals
- the structure of the world: objects, events, ...
- the processing mechanisms & capacities of the brain

Cognitive investigation of language can reveal a great deal about language, acquisition and use

Computational methods (some from CL) can be used to build computational cognitive models

Important Ideas in the Psychology of Language

Whorfian Hypothesis: language influences cognition

- the language that one speaks affects the way they think

Nativism: the human mind is genetically endowed with innate knowledge of linguistic structure

- Explains language acquisition, and linguistic commonalities

Empiricism: all our linguistic knowledge is derived from our experience with language and the world

- Simplest assumptions

Embodiment: conceptual structure and linguistic structures are shaped by our perceptual structures

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?
  - Evolutionarily & Developmentally
- How does language interact with perception and cognition

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 and ungrammatical sentences are often no problem to interpret.

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 (error rates around 2/1000 words)

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

Cognitive Models of Language Processing

Not just about making computers understand language

- Using to computers to model *human* comprehension
- Computational theories of cognitive processes and mental representations

Similarities to (Computational) Linguistics

- Competence hypothesis
  - Need to recover the meaning of language
  - Shared assumptions about representations
- Similar mechanisms: probabilistic, symbolic, learning …

Differences with Language Technology

Language Technologies are often developed with the aim of doing very limited tasks, accurately and robustly

Can do somethings better/faster than people

- Search 1000s of documents
- Quickly translate text
- Classify texts

Can't do things people do trivially

- Semantically rich, context-sensitive interpretation
- Fast, robust, accurate, learned ...

Cognitive Models of Language Processing

Differences with Computational Linguistics:

- Rich understanding and grounded meaning
- People are highly adaptive, and context sensitive
- People are accurate and fast
- Incremental, word-by-word, and even anticipatory
- Some limitations that computers don't have: memory
- Psychological plausibility of computational mechanisms
  - computationally tractable, biologically plausible

In addition to understanding language, we want to model *on-line human behaviour,* or "performance"

Linguistics and Psycholinguistics

Competence: Knowledge of Language

- Linguistic theories at all levels
  - Phonetics/phonology, morphology, syntax, semantics ...
- Rules and representations

Performance: How Language is Processing

- Use of Knowledge of Language
  - Processes for comprehension and production
- Architectures and Mechanisms

Why Distinguish Competence & Performance?

Sometimes what we do differs from what we know.

Production: we say things we know are wrong

- Spoonerisms: "Mental lexicon" spoken as "Lentil Mexican"
- Agreement: "The key of the office doors are missing"

Comprehension: we can't understand things we know are ok

- Centre embedding:
  - "The mouse that the cat that the dog chased bit fled"
- Garden paths:
  - "The horse raced past the barn fell"

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

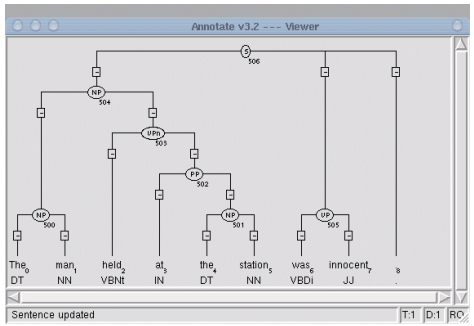
Weak competence: people recover *representations* that are isomorphic to those of linguistic theories

Strong competence: people *directly use* the grammatical knowledge & principles of linguistic theories

The Problem

How do people recover the meaning of an utterance, with respect to a given situation, in real-time?

"The man held at the station was innocent"



Crocker & Brants, *Journal of Psycholinguistic Research*, 2000.

Human Language Processing

How do we represent linguistic knowledge

- How are representations stored during comprehension

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 search for an alternative

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Some General Observations

On the one hand, people seem able to effortlessly, rapidly, and accurately understand language, despite ...

- ... syntactic complexity
- ... ambiguity at various levels (speech, lexical, syn, sem ...)
- ... noise, ungrammaticality

On the other hand, people do sometimes have difficulty ...

- ... with certain kind of complex structures
- ... with certain kinds of ambiguities

Understanding these "weaknesses" sheds light on the nature of language understanding mechanisms

Reading time studies

We can use controlled experiments of reading times to investigate local ambiguity resolution

(a) The man held at the station was innocent (LA)

(b) The man who was held at the station was innocent (UA)

We can compare the reading times of (b) where there is no ambiguity, with (a) to see if & when the ambiguity causes reading difficulty.

- Need a "linking hypothesis" from theory to measures
- Can then manipulate other linguistic factors to determine their influence on on RTs in a controlled manner

Methods for Investigating Human Behaviour

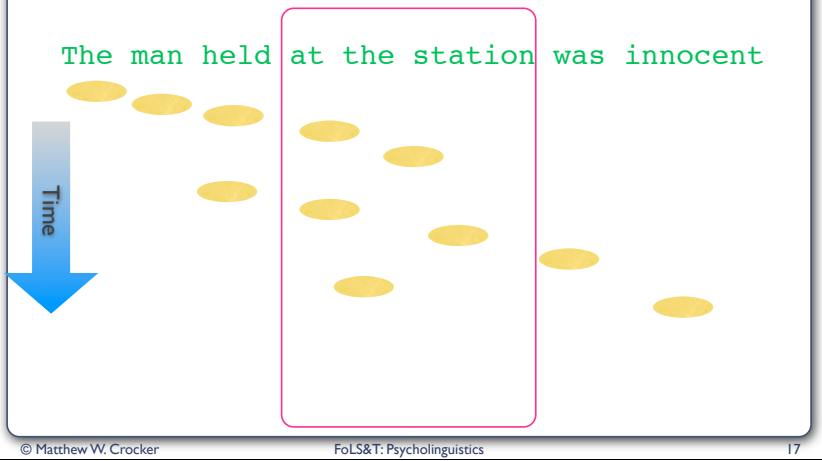
Whole sentence reading times:

The man held at the station was innocent

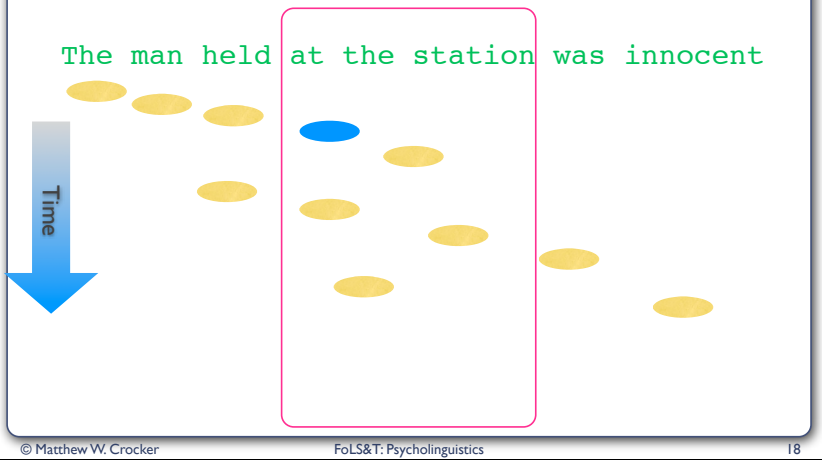
Self-paced reading, central presentation:

Self-paced reading, moving window:

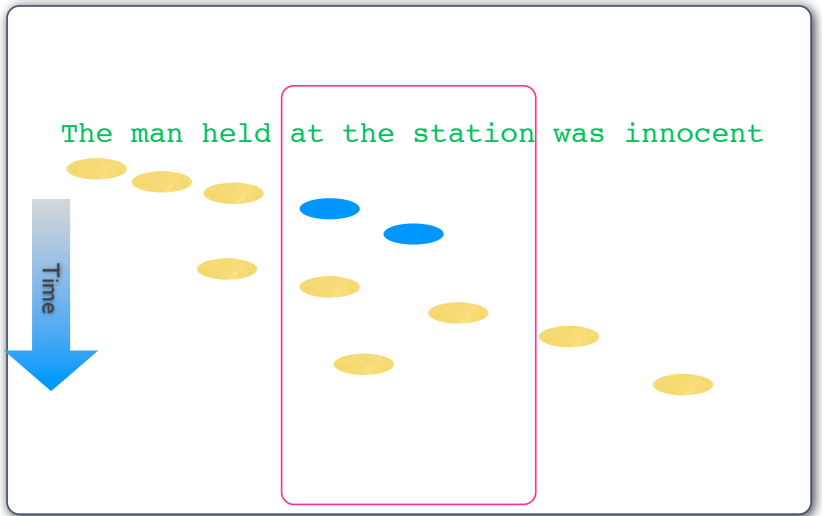
Eye-tracking: Difference Measures



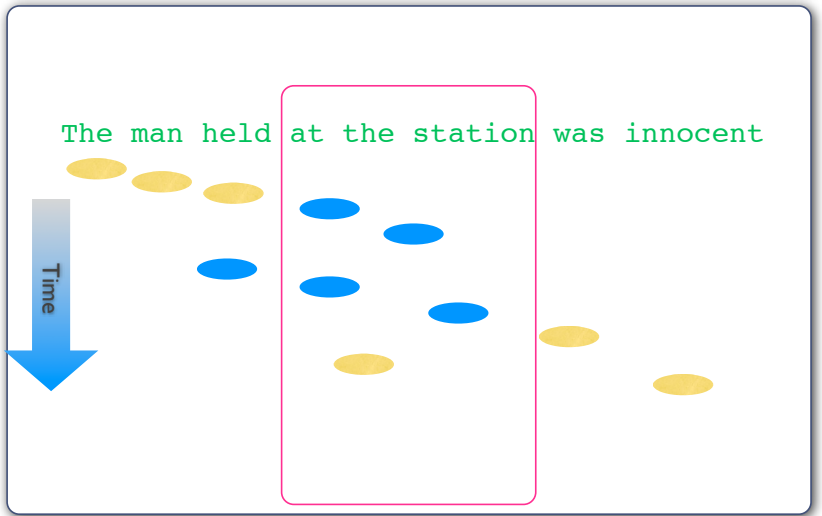
Eye-tracking: First Fixation



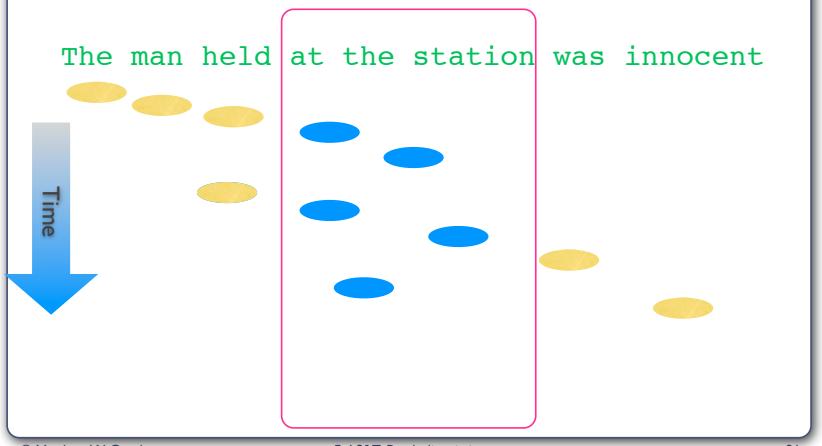
Eye-tracking: First Pass



Eye-tracking: Regression Path



Eye-tracking: Total time



Experiments (continued)

Think about what "confounds" might limit your interpretation of the results (e.g. length, meanings ...)

Create a set of similar sentence pairs that minimize confounds, add "filler" sentences

Choose the right experimental method based on the behavior you're expecting

Run the experiment ... Analyze the data ...

Difference in reading times in the disambiguating region?

- Yes: support for your theory!
- No: "null result", no support for your theory, but also doesn't prove the alternative

Other kinds of experimental methods

Reading-time experiments:

- Natural: reading is an important comprehension modality
- Intuitive: reading times reveal processing complexity

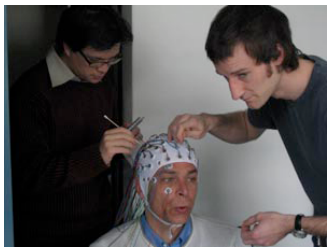
But other methods offer complementary insights:

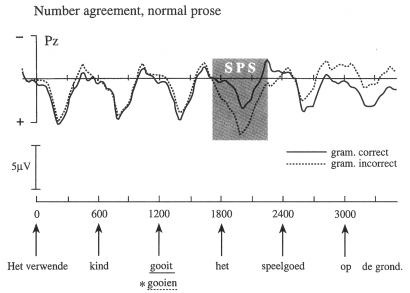
- Neuroscientific methods:
  - associate certain processes with regions of the brain
  - certain kinds of EEG components indicate different kinds of cognitive processing
- Visual attention: reveals interpretation more directly
- These methods can be use with spoken language

Neuroscientific Measures: ERPs

Syntactic and semantic processes are partially revealed by signature patterns in EEGs: Event-Related Potentials (ERPs)

Syntactic Anomaly: P600 or SPS

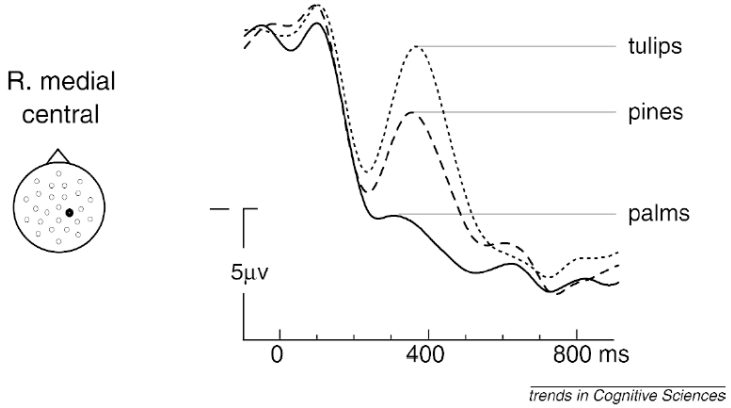




"The spoilt child throw(s) the toy on the ground"

Semantic Anomaly: N400

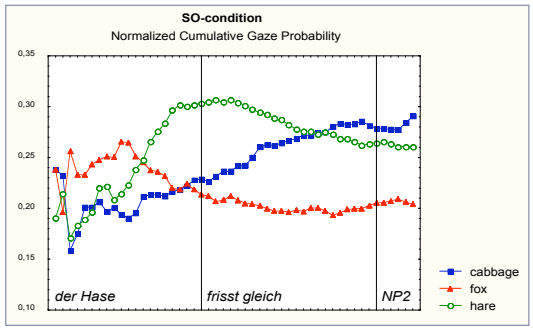
'They wanted to make the hotel look more like a tropical resort.
So along the driveway they planted rows of ...'



Spoken comprehension in visual scenes

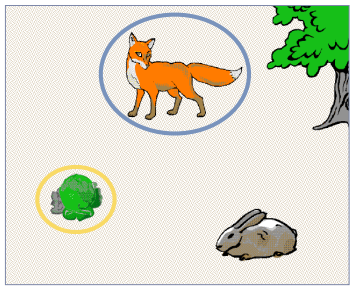
Monitor gaze in the scene as people hear a spoken utterance

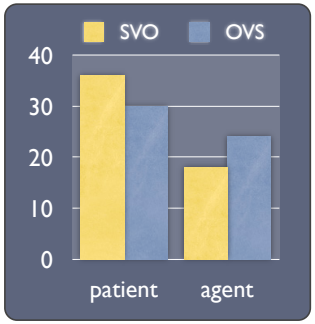
- Listeners fixate objects which are mentioned (180ms)
- Anticipatory eye-movements reflect interpretation



Anticipation in Visual Worlds

Anticipatory eye-movements in visual scenes

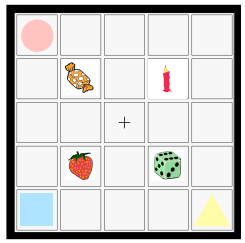




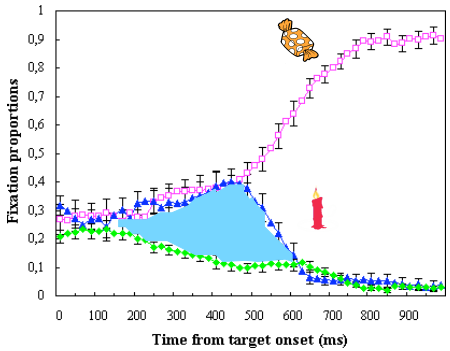
SVO: *Der Hase frisst gleich den Kohl*
OVS: *Den Hasen frisst gleich der Fuchs*

Kamide, Scheepers & Altmann, *JPR*, 2003

Fixations over time, Tanenhaus et al. (1996)



"Pick up the *candle*"



Summary of Experimental Methods

People construct interpretations incrementally:

- People must resolve ambiguity
- Sometimes we must revise our interpretation of the sentence so far

On-line measures can tell us about how/when this occurs

- Reading times, ERPs, gaze in visual scene

We can design experiments which exploit these methods (and others) to investigate the underlying processing architectures and mechanisms

The Modularity Issue

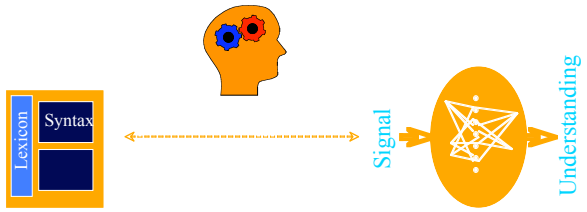
Is language distinct from other other cognitive processes?

- 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 syntax representations
  - Possibly interactive processes
- Procedural autonomy: e.g. lexical access versus syntax
  - Possibly shared representations

How are any such "distinct subsystems" for language processing organised? How do they interact?

- Does organisation affect possible mechanisms?
- Theoretical, computational and empirical arguments for and against 'modularity'?

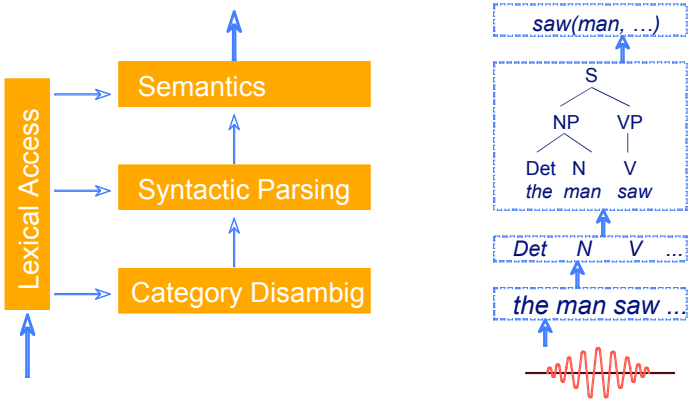
Strong competence and linguistic modularity

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?
- Which of Fodors characteristics do the have/not have?

A Modular Architecture



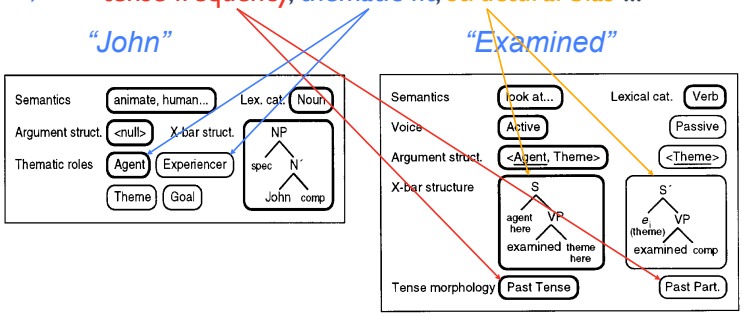
The Interactive Activation Model (MacDonald et al, 1994)

Rich lexical entries; frequency determines 'activations'

Consider: *"John examined the evidence"*

- "examined" is either a simple past or past participle

➡ tense frequency, thematic fit, structural bias …



Kind of Mechanisms

Assume we believe that syntactic structure building is underlies sentence comprehension

Questions:

- What kinds of information are used:
  - lexical, grammatical, frequency, semantics, ...
- What kinds of representations:
  - trees, dependencies, AVMs, distributed representations
- What kind of mechanisms:
  - serial/parallel, symbolic/probabilistic/connectionist