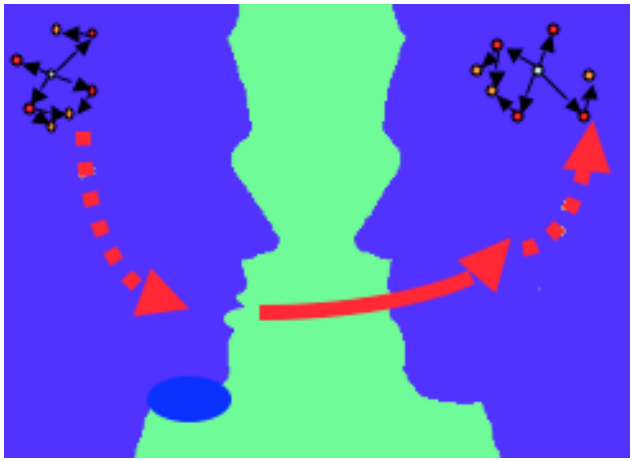
Cognitive Foundations

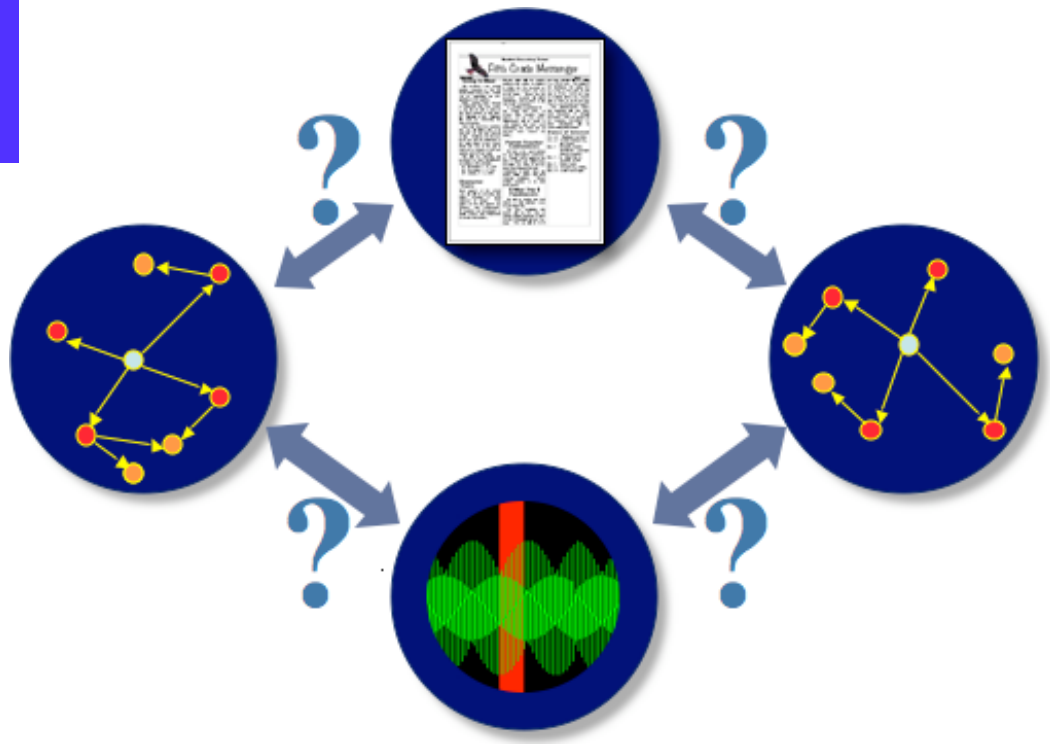
Foundations of
Language Science and Technology

Garance PARIS

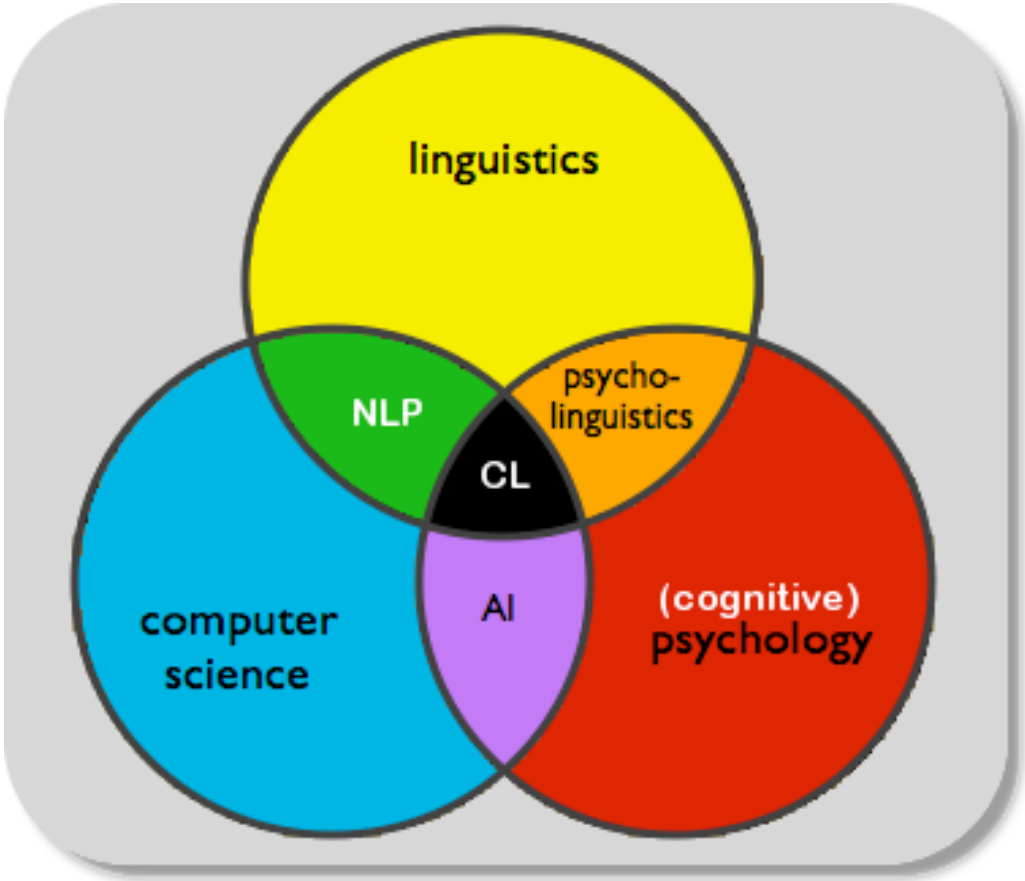
10th November 2008

Review (1): The Miracle





Review (2): An Interdisciplinary Field



The three motivations of computational linguistics:

- Theoretical motivations (linguistic & cognitive): Understand, check and improve linguistic and cognitive theories
- Practical motivation: Language technology applications

Defining Language

- Language is specifically human
- Animal communication does not have the same properties
- Some features of human language:
  - infinite and "double-articulated", hierarchically organized
  - semanticity and arbitrariness
  - social/cultural phenomenon and learnable (bird songs are innate, but isolated children do not develop language)
  - spontaneous usage, creativity
  - ability to refer to things remote in time and place
  - meta-language, reflection, inner speech
  - ability to lie
  - ...

Nativism vs. Empiricism

- Since 1950s-1960s ("The Cognitive Revolution"): First attempts to explain language processes (Chomsky)
  - Language is very complex, at least "context-sensitive" (type 1)
  - Distinction between competence and performance: Actual language data is very noisy and often ambiguous, but we can still deal with it in "real-time" (incrementally)
  - Therefore language skills must be in part innate ("principles")
  - This also explains universal properties of language
- Empiricism: Linguistic knowledge is acquired from experience with language and with the world

Fascinating...

- Language is extremely complex...
  - Speech streams include no 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 with an error rate of around 2/1000.
- Yet we understand it incrementally, in “real time”. We are so fast, we can even finish each others sentences!

Humans vs. Computers

- People:
  - are sensitive to context and adapt to circumstances
  - are accurate, fast, robust
  - process language incrementally
  - but have limitations on memory and work-load
- Computers:
  - can do some things better/faster than people: search 1000s of text, classify them, ...
  - can usually only do well very limited NLP tasks
  - can't do things people do trivially: build semantically rich, context-sensitive interpretations

Natural Language vs. Programming Languages

- Ambiguity, malformed utterances:
  - Pervasive in natural language at all levels of analysis
  - We use context to disambiguate and often don't even notice the ambiguity or error
  - Programming languages must be unambiguous and cannot deal with malformations
- Natural Language is highly redundant
- Distinction between competence and performance does not apply to programming languages:
  - If a sentence is licensed by the grammar rules, it can be parsed, otherwise it cannot (including garden-paths sentences and center-embeddings)

Different "Dimensions"

- Various levels of linguistics analysis
- Representation and knowledge, processing, acquisition language disorders
  - William's syndrom: IQ=50% but good language ability
  - Wernicke's aphasia: Speak fluently, but content does not really make sense + neologisms (e.g.:
    "[...] but I have had that, it was ryediss, just before the storage you know, seven weeks, I had personal friends [...]"
  - Broca's aphasia: Normal IQ, comprehension ok, production non-fluent, few function words, no intonation
  - Language Specific Impairment: normal IQ, language appropriate, problem with grammatical morphemes, poor memory
- Comprehension vs. Production
- Written language vs. speech

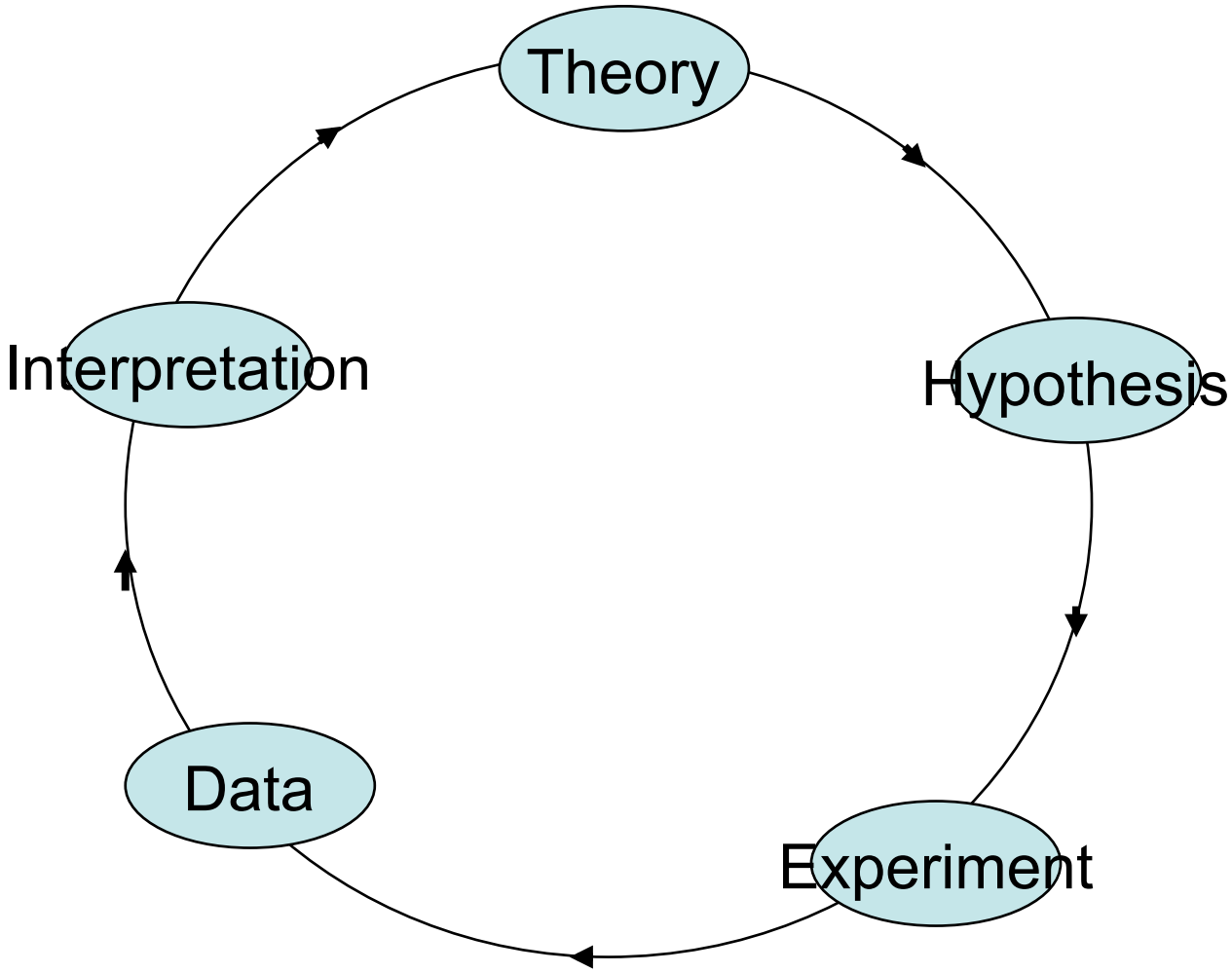
Data, data, more data…

- Introspection ("arm-chair linguistics") is extremely subjective
- Psycholinguistics is an empirical science: Theories are checked against data
- Two types of data collection:
  - Observation of natural data: corpus studies, collections of speech errors, long-term observation of what stages children go through in acquiring language, observation of your own behavior (e.g. garden-path effects), ...
  - More importantly: ***Experimental*** work

What is an "Experiment"?

- Not just an attempt to see if something will work
- Systematic observation of a particular behavior under controlled circumstances
- Given a hypothesis, variation of a (single) factor to observe its influence on the way people comprehend/ produce language
- Anything else that could influence the participants' behavior is kept constant or otherwise controlled
- Therefore, if you observe a difference between conditions, it must be due to our manipulation

The Research Cycle



Some Research Questions

- How do people recognize words? What factors influence auditory and written word-recognition?
- How do people understand sentences?
  - How do they parse them? (top-down, bottom-up, ...)
  - Do ambiguous sentences take longer?
  - When there is an ambiguity, do people pursue both analyses concurrently or do they try one first and re-analyze? (Is the parser parallel or serial?)
  - When they make a mistake, how do they recover?
  - Why are some grammatical sentences difficult to understand?
- Do different levels of analysis influence each other or not, and how much / by what mechanism (modularity)?
- How do people produce language? What are the steps from concept to sound?
- How do bilinguals / 2nd language learners deal with several languages?

(Some) Psycholinguistic Paradigms

- Pen-and-Paper methods:
  - Rating studies, e.g. on a 7 point scale:
    - How similar are the words “water” and “rain”, “dog” and “puppy”
    - How grammatical is the sentence *“The boy read the bread”*?
  - Sentence completion, e.g.

    “The man raced the horse…”

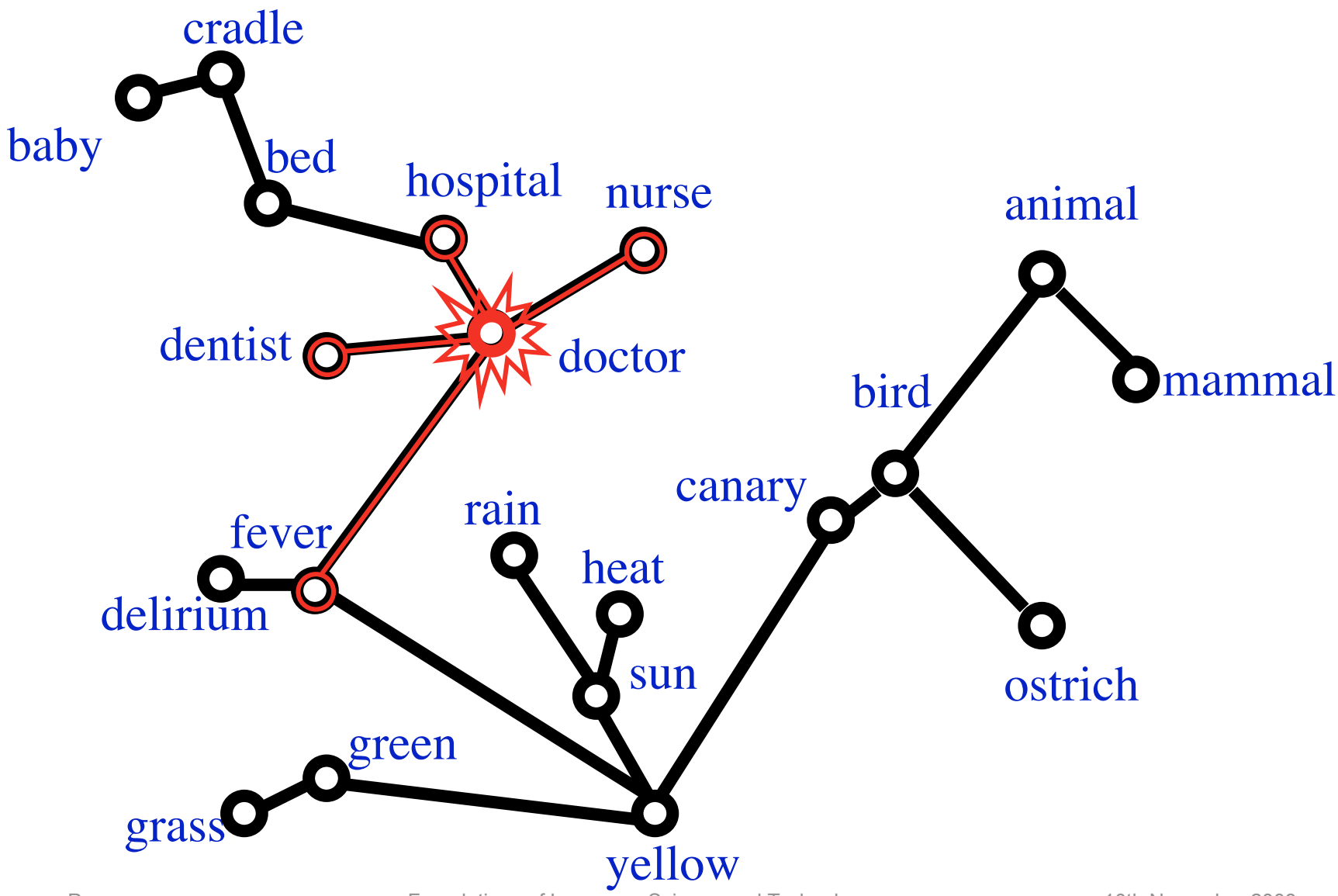
    “The child gave…”
- Nowadays on the web:

  `http://www.language-experiments.org`

Between On-Line and Off-Line

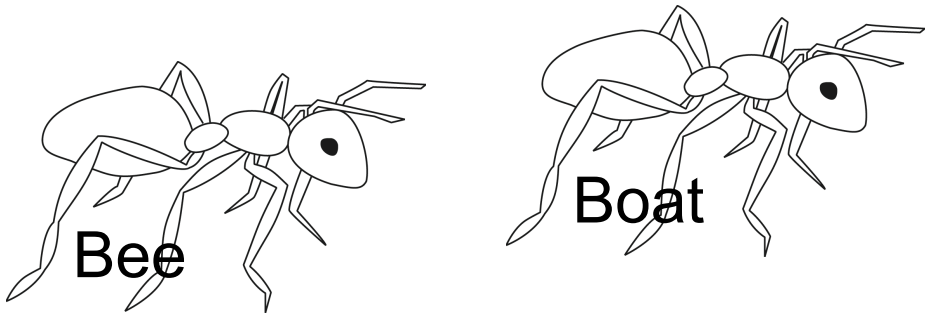
- Visual or auditory lexical decision
  - Stimuli: Words and pseudo-words (e.g. “poce”)
  - Task: Press yes if the stimulus is word, no otherwise
  - Demo: http://www.essex.ac.uk/psychology/experiments/lexical.html
  - Requires access to words in mental lexicon
  - Only word stimuli are analyzed
  - Properties of the words are manipulated (e.g. frequency)
- Priming
  - Show 1st stimulus (the “prime”)
  - Show 2nd stimulus (the “target”)
  - Depending on the 1st stimulus, reaction times to 2nd vary
  - E.g. Meyer and Schwaneveldt (1971): People are faster on "doctor" if preceded by "nurse" than if preceded by "butter”

Spreading activation



Paradigms (2)

- Cross-Modal Lexical Priming
  - Prime: spoken stimulus, Target: visual
- Phoneme-monitoring
  - Subjects listen to sentences or lists of unrelated words
  - Task: Press a button as soon as they hear a stimulus that contains the target sound
- Gating
  - Stimuli: Increasingly long segments of spoken words
  - Task: Guess what the word is
- Picture-Word Interference (production)



Paradigms (3)

- Self-Paced Reading
  - Readers are presented with a blank sentence template
  - Each time a key is pressed, a word / phrase / segment is revealed
  - Latencies between key presses are measured

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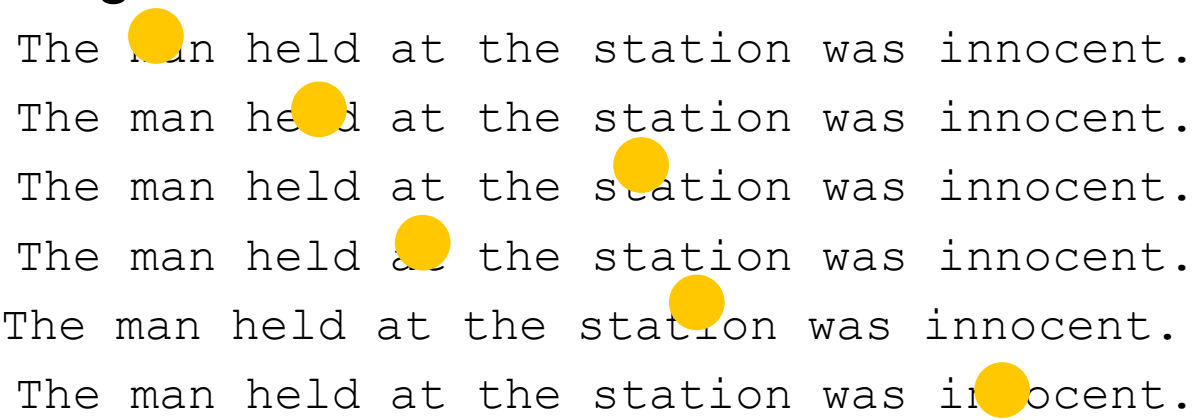
--- --- ---- -- --- ------- --- --------.
The man held -- --- ------- --- --------.
--- --- ---- at the station --- --------.
--- --- ---- -- --- ------- was innocent.
```

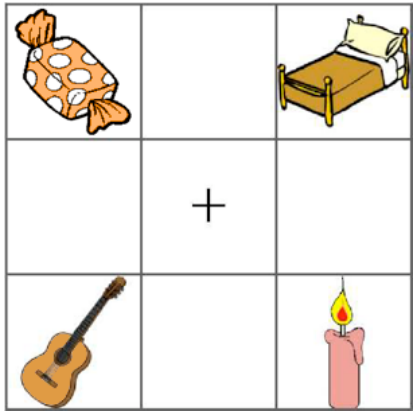
- Eye-tracking with written materials

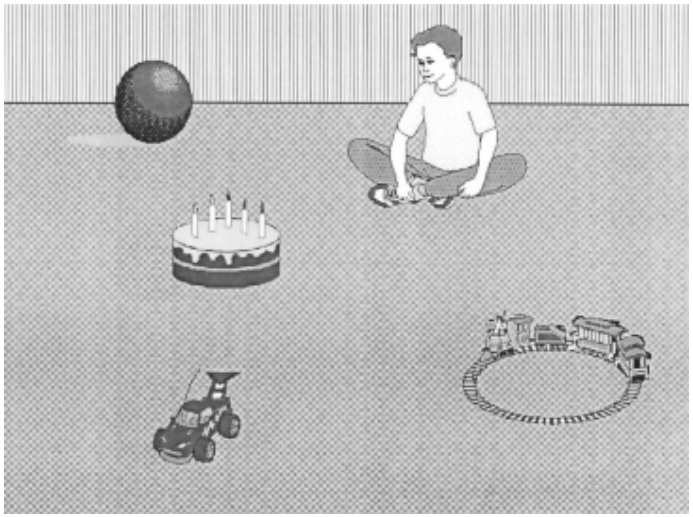


Paradigms (4):

Eyetracking in Visual Worlds:

- Show participants a scene / several objects
- Give them simple instructions to follow, e.g. “pick up the candy”, or have them listen to a description of the scene
- Eye-movements follow input at phoneme level or below
- People even ***anticipate*** if the structure of the sentence allows it

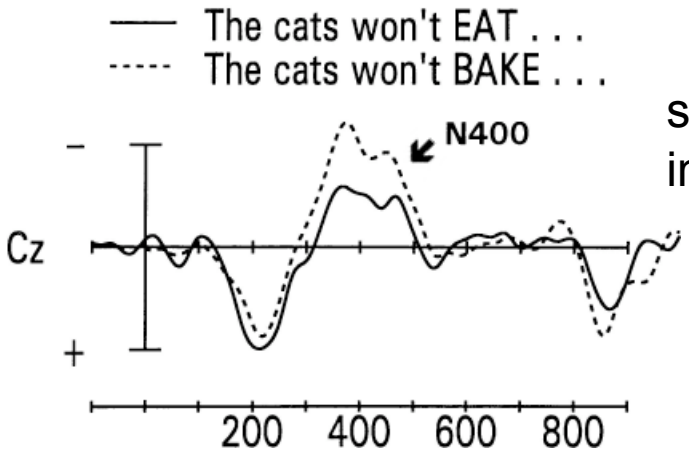




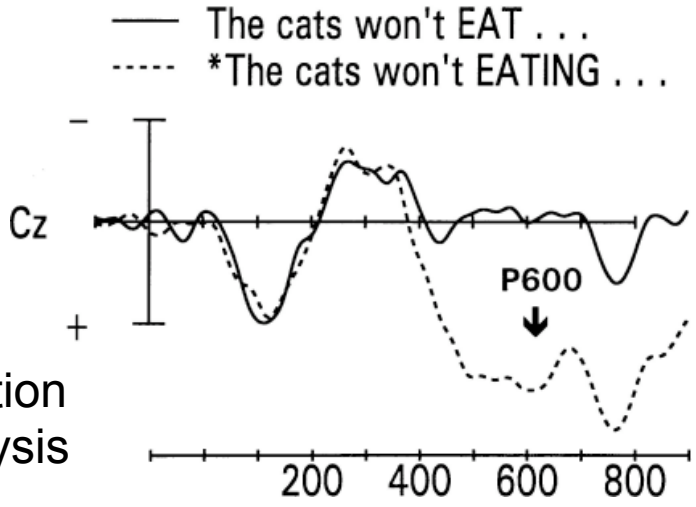
Paradigms (5):

Event-Related Potentials

- Subjects wear electrodes as for EEG
- They read sentences which are incorrect either semantically or syntactically
- The voltage change on the surface of scalp is measured and compared to correct sentences



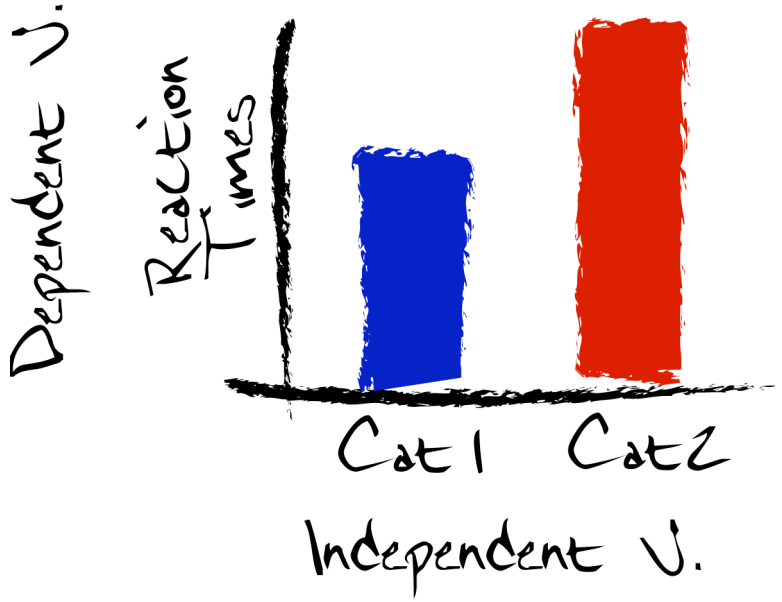
semantic integration



syntactic disambiguation and re-analysis

Two Types of Variables

- The independent variable is the variable that you manipulate; it may have several “levels”
  - e.g. word length, frequency, semantic relationship, ...
- The dependent variable is the one you measure
  - e.g. reaction times, number of errors, proportion of looks to an object, voltage on brain surface, ...
- If you find a difference in your dependent variable, you say that you found an effect of the independent variable



No IV manipulation = No Experiment

- Example: Does sleep deprivation affect reaction times?
  - Deprive one group of people of sleep and then measure their RTs
  - Compare to a control group
- IV manipulation: sleep deprivation
- If we find a difference (and the groups were similar) we can draw a conclusion about a causal relationship: Sleep deprivation ***affects*** RTs .
- The same people in reversed condition would likely have produced similar results

No IV manipulation = No Experiment

- Bad example: Do smart people react faster?
  - Divide people into two groups: one smart, one dumb
  - Measure RTs.
- We are not manipulating the IV. Subjects are not assigned to one group randomly.
- We can't make any causal claim because other factors could be correlated with intelligence (motivation, attention to the task, etc.)

No IV manipulation = No Experiment

- Give people a number of sentences to read and record their reading times or their comprehension
- Based on the data, try to group the sentences in groups of similar types and try to infer backwards what characteristics lead to the reading time patterns or comprehension patterns
- This isn't an experiment!
  - Nothing manipulated beforehand
  - Grouping of sentences after the fact (***post-hoc)***
- No strong conclusions can be drawn
  - Only speculations about the cause
  - There may be correlations but no causal link

The Ideal Case

- Manipulate the IV and hold all other variables constant
- Nearly impossible, especially with human participants
  - different skills, IQ, experiences, and genes
  - how well they slept last night, how much they ate for lunch,...
- Instead: Avoid systematic confounds
  - Make sure there is no systematic assignment of subjects to conditions and no systematic differences in the sets of materials you use (use of databases/corpora and/or run pretests, then evenly distribute the effects of confounding factors)
  - To reduce subject variance, use same subjects in both conditions: ***within-subjects***
  - Counterbalance presentation
  - Control for order effects: Rotate through possible alternatives

That's it for Today!

Thanks to Berry Claus, Matt Crocker, Alissa Melinger, Andrea Weber, and others, who provided slides for me to work from :-)