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Natural Language Processing: How do humans process language?

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Outline

1. Motivation
2. Models of human language
3. Practical Connections to NLP

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Motivation

What does NLP have to do with humans, at all?

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Fundamental questions of linguistics

- What do you know when you know a language?
- What do you know when you understand an utterance?

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Linguistics & NLP

Too much theory is bad? But why?

- “Every time I fire a linguist, the performance of the speech processing system goes up.” (Frederick Jelinek)
- Does it mean we should refrain from linguistic inspiration?
  - (NLP already does that. Ask a linguist.)
- Cf. the good, bad, and ugly parts of artificial neural networks

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Levels of Abstraction

Linguists and Engineers tend to have different focus

- Computational: what is explained?
  - Description of linguistic performance vs. explanation of linguistic competence
- Algorithmic: how is it done?
  - Cognitive realism, computational complexity/efficiency
- Implementational: how is is realized?
  - Neurological plausibility

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What this lecture is about

A very short introduction to:

- Grammar theory
  - What is language built of?
- Cognitive linguistics
  - How does language work in the mind?

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Insights *from* linguistics

Get a better understanding of what should work in language processing

- After all, it's natural language processing
- Comparison gives confidence:
  - NLU system behaviour vs. L1 acquisition
  - Observation of similar effects/errors, e.g., garden path sentences
  - Human performance is the ultimate (utopic?) benchmark!
  - We're not inventing something new…

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Insights *for* linguistics

We don't yet know how human language really works

- Very conflicting hypotheses, most of which work only on a computational level
- New ideas:
  - Shallow processing
  - Distributed, implicit, usage-based knowledge
  - Computational construction grammar
  - Computational semantics (λ calculus)

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Some words of caution

Be warned!

- This is will be an extremely rough, simplified, and incomplete overview
- It is biased in favour of Cognitive Linguistics (and a bit against Generative Grammar)
- Linguistic theory is not rigorously formal
  - "Theory" = "proposed descriptive model", not "axiomatic system"
- If you're interested: go to the linguistics department
  - Sprache und Kognition, Sprachen der Welt, …
  - Learn more languages (for grammar, not talking)

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Models of human language

Some examples from different areas of linguistics and cognitive science

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Cognitive abilities develop in similar ways

- Typical progress:
  - Statistical learning (expectation & surprise)
  - Inductive learning (categorization & abstraction)
  - Social learning (imitation, intention, theory of mind)
- Sensomotory system has an important influence in learning!
- Critical periods vs. extreme robustness

Language acquisition

Language learning tends to follow a U-shaped progress

- Phases:
  - Simplification: How do you do dese…work/tortillas/in English
  - Overgeneralization: Yesterday I didn't painting; it noises
  - Restructuring How do you…make this/like it; how…do cut it
- Cf. exploration vs. exploitation in reinforcement learning
- Computational and associative learning

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Creolization processes

Figure: Hotel room signs in Tok Pisin (Papua New Guinea)

https://commons.wikimedia.org/wiki/File:
Tok-Pisin_New-Guinea-Pidgin_Pidgin-English_Melanesian-Pidgin_Papua-New-Guinea-Hotel-Room-Door-Sign_(DSC_3096).jpg

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Linguistic nativism

Is *langage*[1] special?

- Is language based on common cognitive machanisms?
  - Categorization, association, memory, hierarchy…
- Or is there a specialized, innate language mechanism?
  - Mental grammar, language acquisition device, Universal Grammar

[1] This is not a typo, but French.

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Universal Grammar

Generative Grammar = trees + transformations

- Grammatical construal in terms of rules
  - from deep structure to surface structure
- Exlaining all languages in terms of principles and parameters
  - Solution to fast, one-shot L1 acquisition

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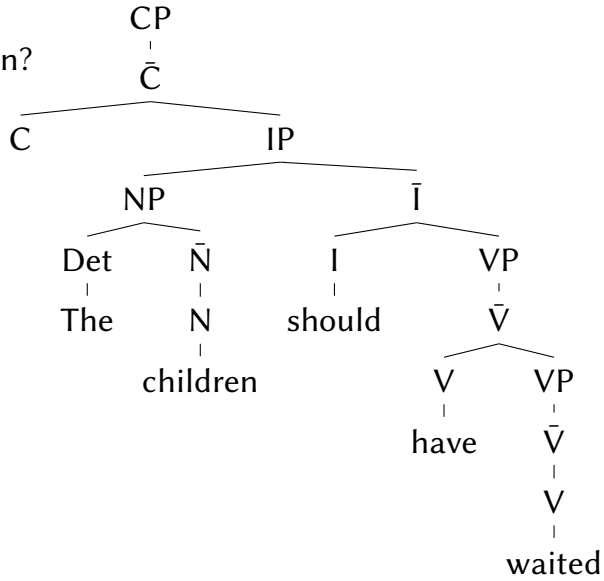
Models of human language

Triangles in the brain?



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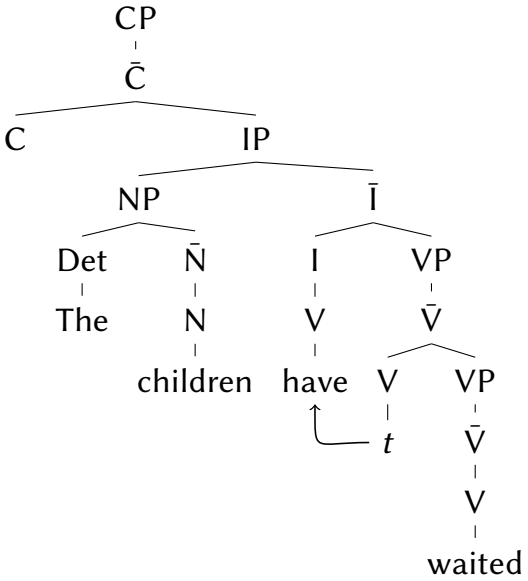
Triangles in the brain?



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Limits of Universal Grammar

Criticism of this kind of analysis

- Explicitely not empirical (at least by Chomsky)
  - Against “behaviourism”, focus on competence
  - Tends to categorize everything in terms of recursive symbolic structures
  - Good for English – what about Chinese? Pirahã? *Conversational* English?
- Computationally complex, cognitively… difficult to explain

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Pushing the Boundaries of Generative Grammar

Language processing is basically an inverse problem:

- Colorless green ideas sleep furiously
- The Sally hugged him the Thomas
- Time flies like an arrow
- The apartment that the maid who the service had sent over was decorated
- Keine Kopfverletzung ist zu harmlos um sie nicht zu ignorieren

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Representations of meaning

Language is conveying mental state through symbols

- Grammar is only an “artifact” to structure the transportation of mental state
  - Or: only an instrument for performative utterance
- Semantics from a cognitive perspective: meaning is…
  - perspectivic (relative to utterance context)
  - dynamic (system changes with environment)
  - encyclopedic (association with experiences & culture)
  - determined by usage (a system derived from concrete experience)

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Some cognitive approaches to semantics and grammar

- How is meaning represented?
  - Prototypes, radial networks, schemata, …
  - Metaphor
- How is meaning expressed through form?
  - Construction grammar, grammatical construal, usage-based grammar…
  - Information structure

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Information Structure (aka Information Packaging)

Conveying more information beyond denotation

- Intonation can focus different parts of an utterance
  - John only introduced Bill to Sue
  - John only introduced Bill to Sue
  - John only introduced Bill to Sue
  - John only introduced Bill to Sue
- Differences in meaning independent of linguistic form!

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Information Structure (aka Information Packaging)

Constructions that relate meaning in conversation[2]

- Different pragmatic practices are associated with:
  - As for John, he lost his wallet
  - What happened was that John lost his wallet
  - What John did was lose his wallet
  - It was John who lost his wallet
  - What John lost was his wallet

[2] See Martin Hilpert's lectures: https://www.youtube.com/watch?v=PJecXZp_SYw

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Constructions everywhere

- Constructions are patterns whose form or meaning is not strictly predictable from their components:
  - He has whiffled my borogroves completely vorpal again
  - *The knife chopped the carrots into the salad
- Embedded items are coerced:
  - There was cat all over the road
  - She smiled herself an upgrade

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Metaphors

Not just arbitrary idioms and poetry!

- We understand things in terms of metaphor, and use it all the time[3]
- Abstract term = container
  - An argument has a hole, has less substance, does not have content
  - To find something in an argument
- Argument = journey
  - The content of the argument proceeds, path to the core of the argument, the direction has no substance

[3] See *Metaphors we live by* by John Lakoff

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Applications

What does theory have to do with NLP, at all?

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Overall assessment

- We have now already seen some ideas that agree:
  - Statistical learning (“usage based”)
  - Associative learning (“context based”)
  - Shallow processing (no creation of deep structures)

Now: some examples of theory transfer from linguistics to NLP

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Information structure + Generative Grammar

Modeling Information Structure In A Cross-Linguistic Perspective[4]

- Formalized version HPSG + Information structure
- Improve machine translation across multiple languages
- *Information structure facilitates fluency in contiguous speech*

[4] doi: 10.5281/ZENODO.818365

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Construction Grammar + Semantics

Computational construction grammar for visual question answering[5]

- Based on computational construction grammar
- Mapping questions onto their executable semantic representations
- *Constructions succintly capture form-meaning pairs in a domain*

[5] doi: 10.1515/lingvan-2018-0070

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Generative Grammar + Parsing

Head-Driven Statistical Models for Natural Language Parsing[6]

- Actual parsing using a Generative Grammar formalism
- Probabilistic context-free grammars to lexicalized grammars
- Parse tree represented as sequence of decisions corresponding to a head-centered, top-down derivation of the tree
- *UG isn't dead yet*

[6] doi: 10.1162/089120103322753356

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Fluid Construction Grammar + Agent-Based Modelling

Linguistic Assessment Criteria for Explaining Language Change[7]

- … A Case Study on Syncretism in German Definite Articles.
- Evolution of the German definite article paradigm
- Agent-based simulation of communicative interactions (“language games”), implemented with Fluid Construction Grammar
- *CxG can provide explanations for variation & change*

[7] doi: 10.1163/22105832-13030106

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Metaphor + Corpora

Psychologically Motivated Text Mining[8]

- Corpus-based learning of patterns of metaphorical framing
- Detection of the structure of metaphorical associations through clustering
- *Metaphors are useful and detectable empirically*

[8] arXiv: 1609.09019

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More Cognitive Linguistics

Cognitive approach to natural language processing

- Several essays, mostly on semantics in NLP
- *Word association, disambiguation, frequency estimation, stylistic analysis…*

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Thank You!

Implementations are waiting for you.
Next: ???

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