Introduction to Deep Processing Techniques for NLP

LING 571 — Deep Processing Techniques for NLP

September 26, 2018

Ryan Georgi

Roadmap

- **Motivation**
- Language and Intelligence
- Knowledge of Language
- Course Overview
- Intro to Syntax and Parsing

Motivation: Applications

- Applications of Speech and Language Processing
  - Call Routing
  - Information Retrieval
  - Question Answering
  - Machine Translation
  - Dialog Systems
  - Spell– and Grammar– Checking
  - Sentiment Analysis
  - Information Extraction
  - …

Building on Many Fields

- **Linguistics**: *Morphology, phonology, syntax, semantics…*
- **Psychology**: *Reasoning, mental representations*
- **Formal Logic**
- **Philosophy (of Language)**
- **Theory of Computation**: *Automata theory*
- **Artificial Intelligence**: *Search, Reasoning, Knowledge Representation, Machine Learning, Pattern Matching*
- **Probability**

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Operationalizing Intelligence: The Turing Test (1950)

- Two contestants: Human vs. Computer
  - **Judge**: human
  - **Test**: interact via text questions
  - **Question**: Can judge tell which contestant is human?
- ***Crucially***:
  - Posits that passing requires language use and understanding

Limitations of the Turing Test

- ELIZA (Weizenbaum, 1966) [Try it Online]
  - Simulates Rogerian therapist:

```
User: You are like my father in some ways
ELIZA: WHAT RESEMBLANCE DO YOU SEE
USER: You are not very aggressive
ELIZA: WHAT MAKES YOU THINK I AM NOT AGGRESSIVE
```

  - Passes the Test! (Sort of)
  - Simple pattern matching technique

Turing Test Revisited:

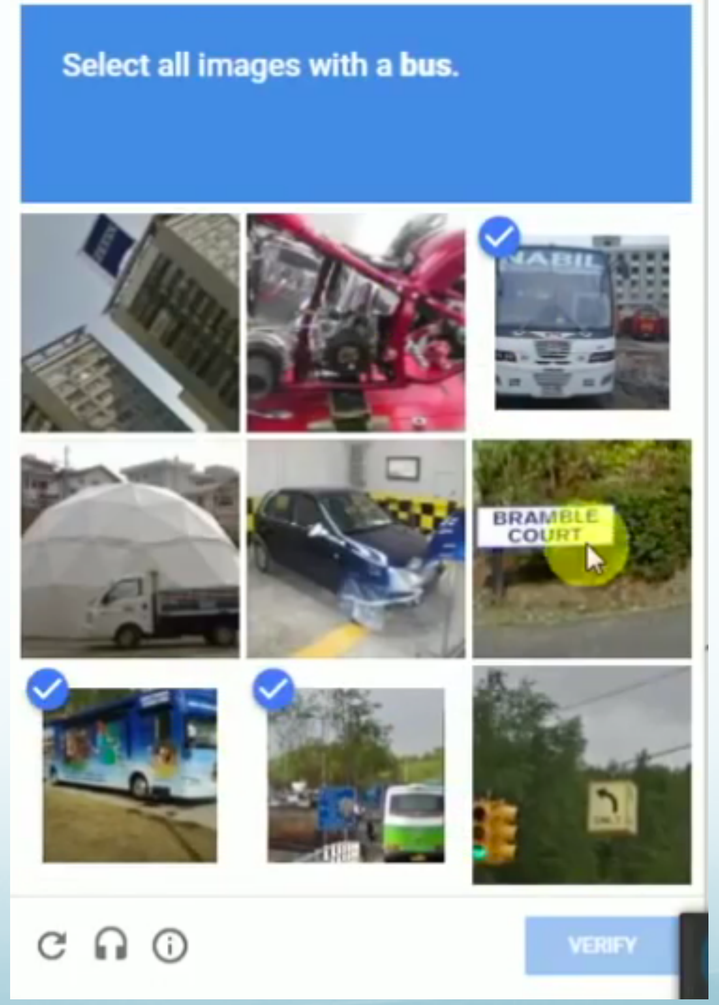
"On the web, no one knows you're a…"

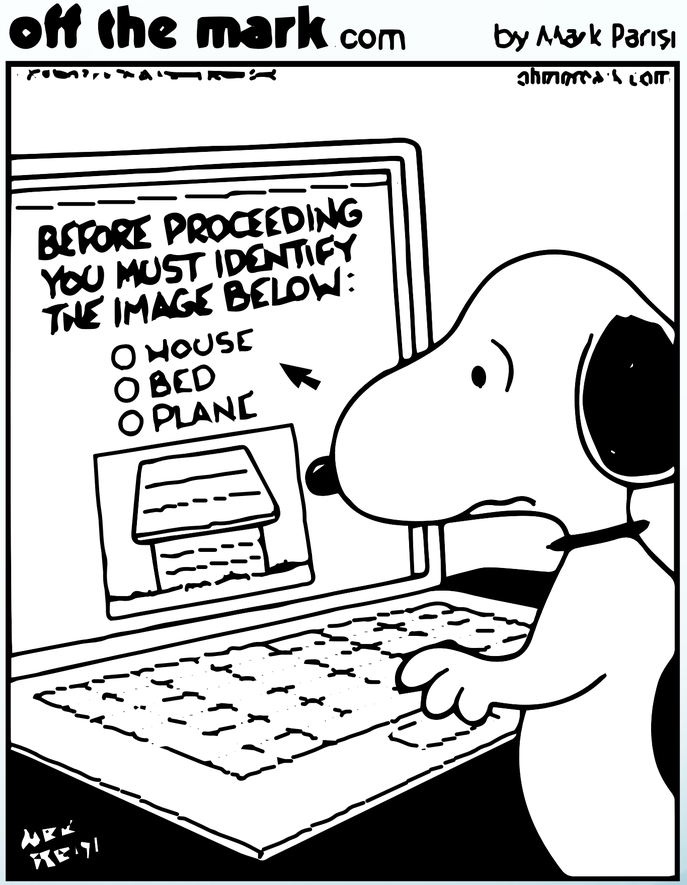
- **Problem**: "Bots":
  - Automated agents overrun services
  - Challenge: Prove you're human
- **Test**: Something a human can do, but a bot can't.
- **Solution:** CAPTCHAs
  - **C**ompletely **A**utomated **P**ublic **T**uring test to tell **C**omputers and **H**umans **A**part *(Von Ahn et al., 2003)*
  - Initially: Distorted images, driven by perception
  - Long-term: Inspires "arms race"

Turing Test Revisited:

"On the web, no one knows you're a…"

- Current Incarnation
  - Still perception-based
  - But also requires on world knowledge
  - "What is a bus?"
    - Assumes that the user has extrinsic, **shared** world knowledge





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Knowledge of Language

- NLP vs. Data Processing
- POSIX command "wc"
  - Counts total number of bytes, words, and lines in text file
  - bytes and lines → data processing
  - words → *what do we mean by "word"?*

Knowledge of Language

- What does HAL (of *2001, A Space Odyssey*) need to know to converse?

***Dave**: Open the pod bay doors, HAL.*
***HAL**: I'm sorry, Dave. I'm afraid I can't do that.*

Knowledge of Language

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- **Phonetics & Phonology** (Ling 450/550)
  - Sounds of a language, acoustics
  - Legal sound sequences in words

Knowledge of Language

- What does HAL (of *2001, A Space Odyssey*) need to know to converse?

***Dave**: Open the pod bay doors, HAL.*
***HAL**: I'm sorry, Dave. I'm afraid I can't do that.*

- **Morphology** (Ling 570)
  - Recognize, produce variation in word forms
  - Singular vs. plural: `Door + sg → "door"` `Door + pl → "doors"`
  - Verb inflection: `be + 1st Person + sg + present → "am"`

Knowledge of Language

- What does HAL (of *2001, A Space Odyssey*) need to know to converse?

***Dave**: Open the pod bay doors, HAL.*
***HAL**: I'm sorry, Dave. I'm afraid I can't do that.*

- **Part-of-speech Tagging** (Ling 570)
  - Identify word use in sentence
  - Bay (Noun) — Not verb, adjective

Knowledge of Language

- What does HAL (of *2001, A Space Odyssey*) need to know to converse?

***Dave**: Open the pod bay doors, HAL.*
***HAL**: I'm sorry, Dave. I'm afraid I can't do that.*

- **Syntax**
  - (566: Analysis, 570: Chunking, 571: Parsing)
  - Order and group words in sentence
    - cf. *"*"I'm I do, sorry that afraid Dave I can't"*

Knowledge of Language

- What does HAL (of *2001, A Space Odyssey*) need to know to converse?

***Dave**: Open the pod bay doors, HAL.*
***HAL**: I'm sorry, Dave. I'm afraid I can't do that.*

- **Semantics** (Word Meaning)
  - Individual (lexical) + Combined (Compositional)
  - 'Open' : AGENT **cause** THEME **to become** *open*;
    - 'pod bay doors' → doors to the 'pod bay' → the bay which houses the pods.

Knowledge of Language

- What does HAL (of *2001, A Space Odyssey*) need to know to converse?

***Dave**: Open the pod bay doors, HAL.*
***HAL**: I'm sorry, Dave. I'm afraid I can't do that.*

- **Pragmatics/Discourse/Dialogue** (Ling 571)
  - Interpret utterances in context
  - Speech as acts (request vs. statement)
  - Reference resolution: `"I"=[HAL]; "that"=[open…doors]`
  - Politeness: "***I'm sorry***, ***I'm afraid I can't***…"

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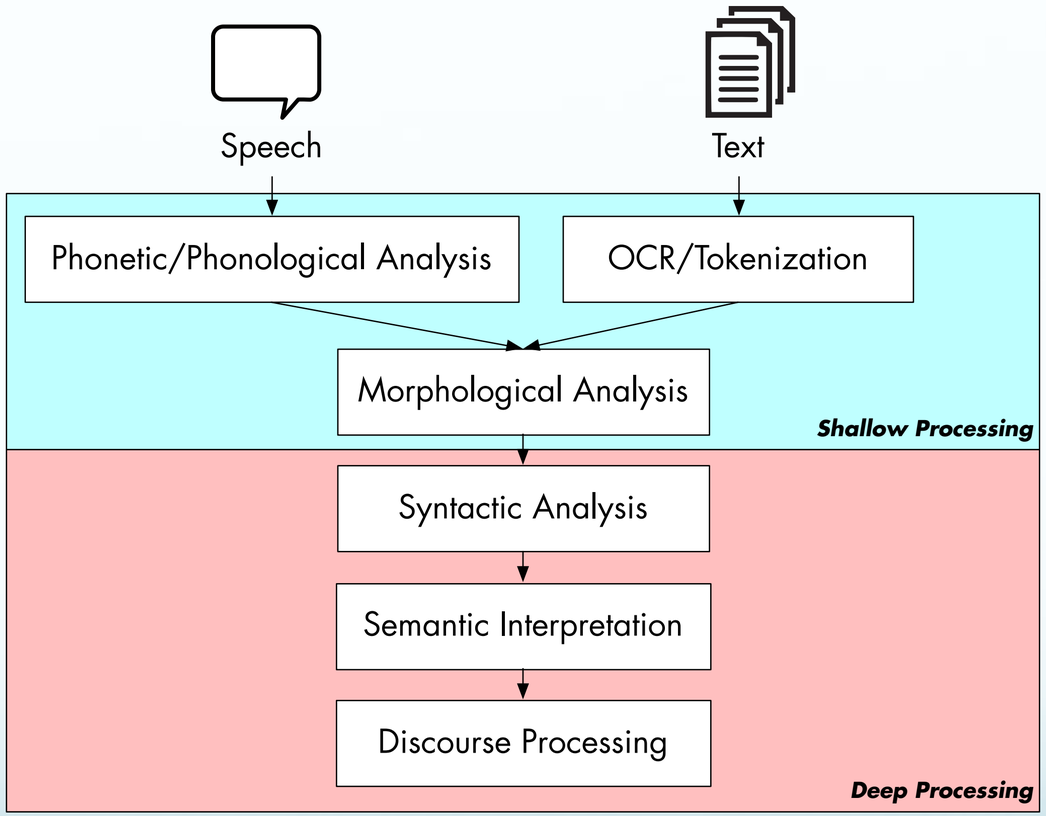
Course Overview: Shallow vs. Deep Processing

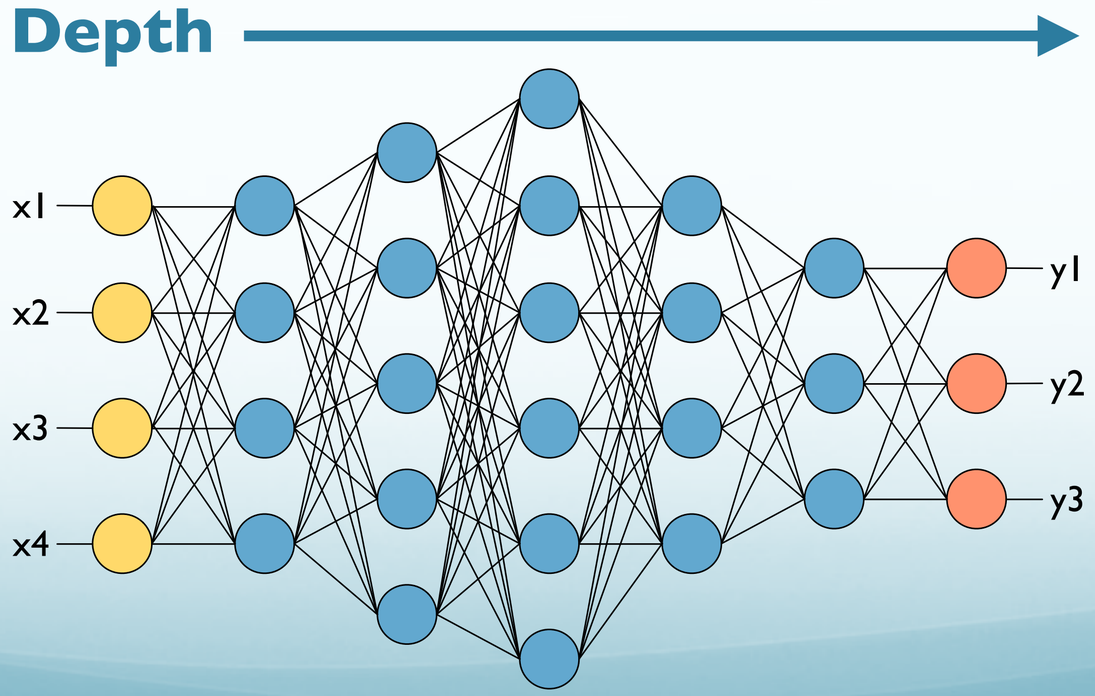
- Shallow processing (LING 570)
  - ***Less elaborate*** linguistic representations
    - Usually relies on surface forms (e.g. words)
  - Examples: HMM POS-tagging; FST morphology
- Deep processing (LING 571)
  - Relies on ***more elaborate*** linguistic representations
    - Deep syntactic analysis (Parsing)
    - Rich spoken language understanding (NLU)

Language Processing Pipeline



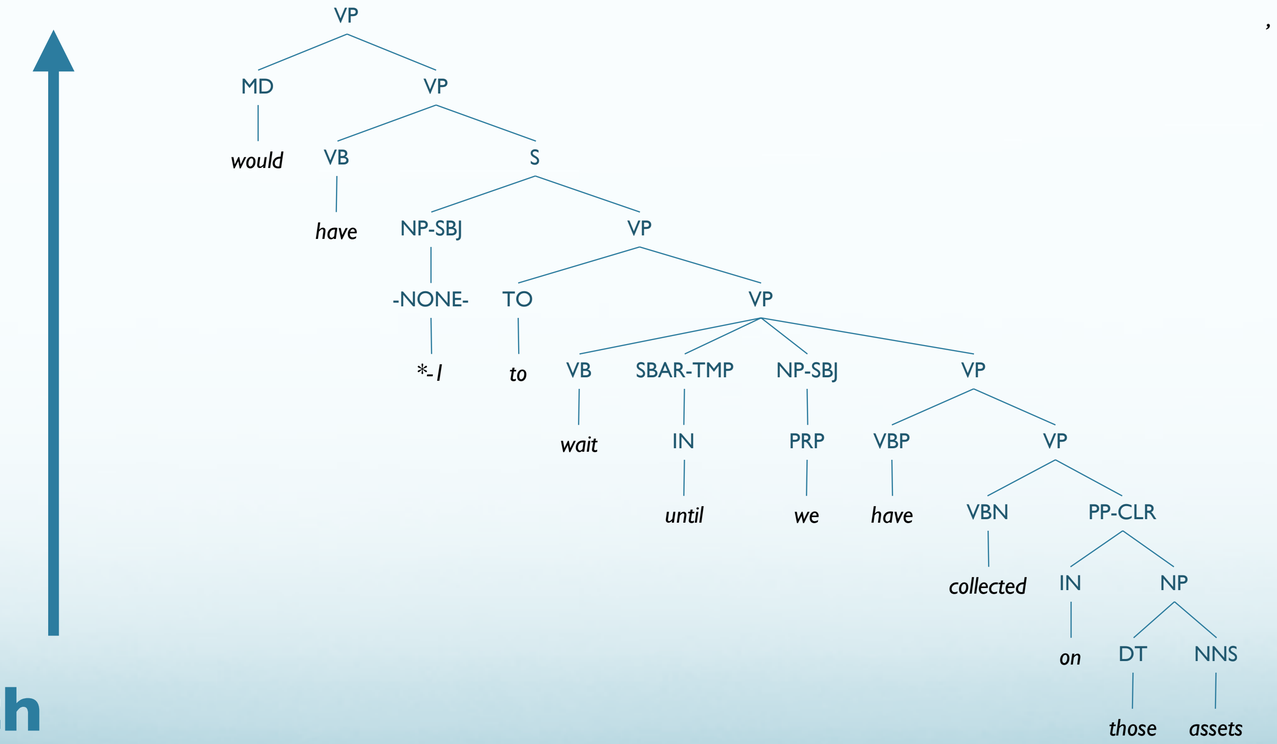
A Note On "Depth"

- "Deep" can be a tricky word these days in NLP
- "Deep Learning" ← "Deep Neural Networks"
  - Refers to depth of network architecture:



A Note On "Depth"

- "Deep Processing" ← "Depth" of Analysis (Amt. of Abstraction)
  - Depth of parse graph (tree) is one representation



Depth

A Note On "Depth"

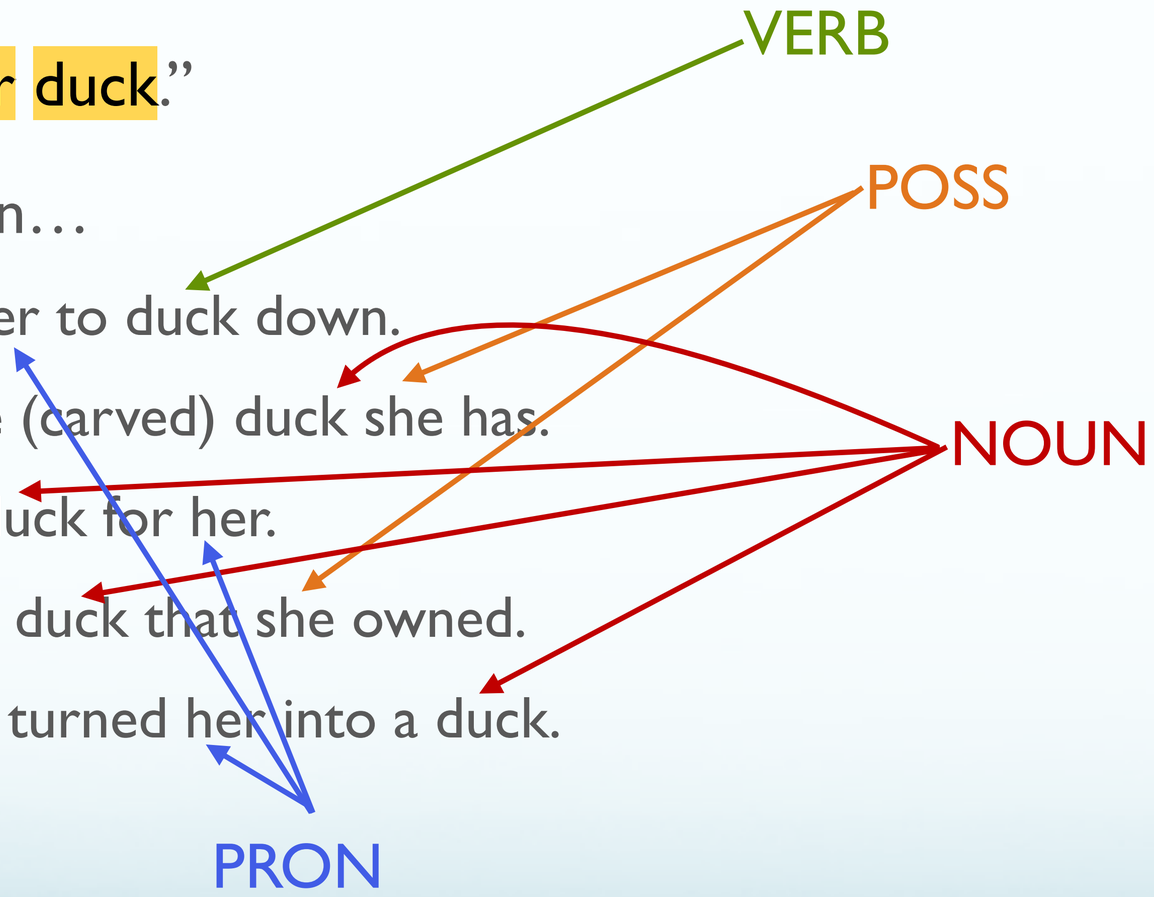
- Depth of NN ⇏ Depth of Analysis
- NNs are general function approximators
  - can be used for "shallow" analysis:
    - POS tagging, chunking, etc.
  - Can ***also*** be used for "deep" analysis:
    - Semantic role labeling
    - Parsing
- In both paradigms, graph depth aids, but ⇏ abstraction

Cross-cutting Themes

- **Ambiguity**
  - How can we select from among alternative analyses?
- **Evaluation**
  - How well does this approach perform:
    - On a standard data set?
    - As part of a system implementation?
- **Multilinguality**
  - Can we apply the same approach to other languages?
  - How much must it be modified to do so?

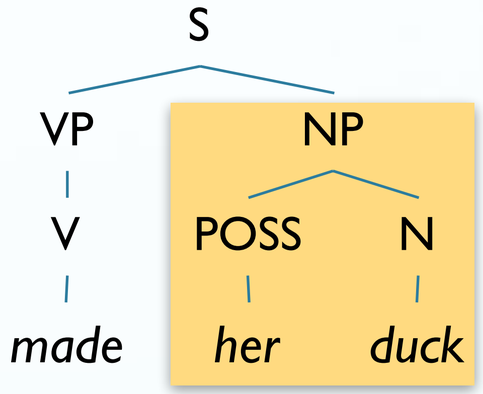
Ambiguity: POS

- "I made her duck."
- Could mean…
  - I caused her to duck down.
  - I made the (carved) duck she has.
  - I cooked duck for her.
  - I cooked a duck that she owned.
  - I magically turned her into a duck.

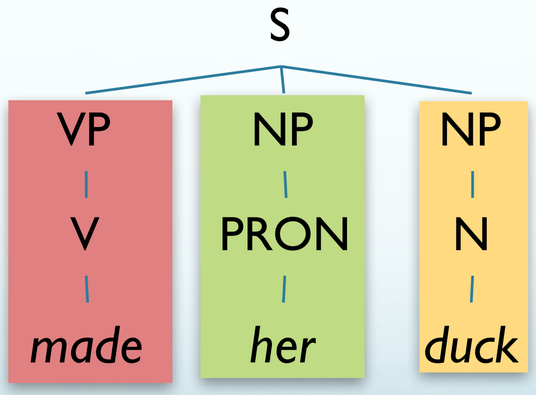


Ambiguity: Syntax

- "I made her duck."
- Could mean…
  - I made the (carved) duck she has



  - I cooked a duck for her



Ambiguity: Semantics

"I made her duck."

I caused her to duck down	***made*** = [AG] **cause** [TH] [to_do_sth]
I cooked duck for her	***made*** = [AG] **cook** [TH] for [REC]
I cooked the duck she owned	***made*** = [AG] **cook** [TH]
I made the (carved) duck she has	***made*** = [AG] **sculpted** [TH] ***duck*** = **duck-shaped-figurine**
I magically turned her into a duck	***made*** = [AG] **transformed** [TH] ***duck*** = **animal**

Ambiguity

- Pervasive in language
- Not a bug, a feature!
- *"I believe we should all pay our tax bill with a smile. I tried—but they wanted cash."*
- What would language be like without ambiguity?

Ambiguity

- Challenging for computational systems
- Issue we will return to again and again in class.

Syntax Crash Course

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Roadmap

- Sentence Structure
  - More than a bag of words
- Representation
  - Context-free Grammars
    - Formal Definition

Applications

- Shallow techniques useful, but limited
- Deeper analysis supports:
  - Grammar checking — and teaching
  - Question-answering
  - Information extraction
  - Dialogue understanding

Grammar and NLP

- Grammar in NLP is **NOT** prescriptive high school grammar
  - Explicit rules
  - "Don't split infinitives!" etc.
- Grammar in NLP:
  - How to capture structural knowledge of language as a native speaker would have
  - Largely implicit
  - Learned early, naturally

More than a Bag of Words

- Sentences are structured
- Choice of structure can impact:
  - Meaning:
    - *Dog bites man.* **vs.** *Man bites dog.*
  - Acceptability:
    - **Dog man bites*

Constituency

- Constituents: basic units of sentences
  - Word or group of words that act as a single unit syntactically
- Phrases:
  - Noun Phrase (NP)
  - Verb Phrase (VP)
  - Prepositional Phrase (PP)
  - …
- Single unit: type determined by "head"
  - e.g. **N** heads NP

Representing Sentence Structure

- Captures constituent structure
  - Basic units
    - Phrases
- Subcategorization
  - Argument structure
    - Components expected by verbs
- Hierarchical

Representation: Context-free Grammars

- CFGs: 4-tuple
  - A set of terminal symbols: Σ
  - A set of nonterminal symbols: N
  - A set of productions P:
    - of the form $A \rightarrow \alpha$
    - Where A is the non-terminal and $\alpha \in \{\Sigma \cup N\}^*$
  - A start symbol $S \in N$

Representation: Context-free Grammars

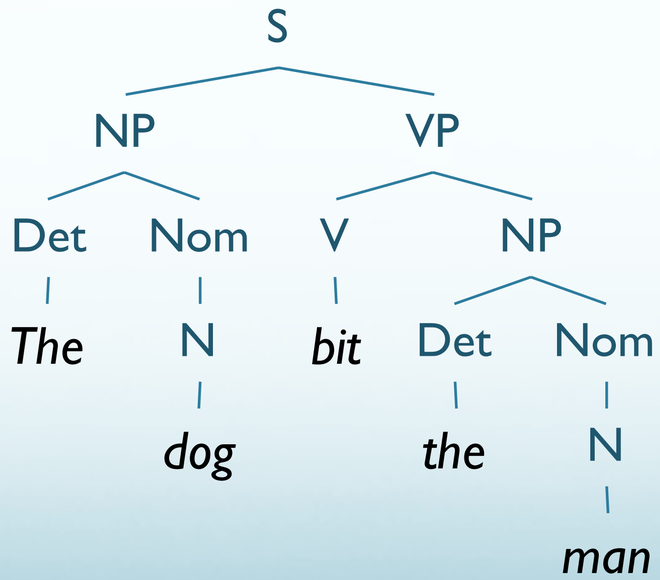
- Altogether a grammar defines a language L
  - $\mathrm{L} = W \mid w$ in Σ^* and $\mathrm{S} \Rightarrow^* w$
    - The language L consists of all sets of words in which:
    - $S \Rightarrow^* w$ means S *derives* w by some sequence of productions

CFG Components

- Terminals:
  - Only appear as leaves of parse tree (hence the name)
  - Right-hand side of productions (RHS)
  - Words of the language
    - *cat, dog, is, the, bark, chase…*
- Non-terminals
  - Do not appear as leaves of parse tree
  - Appear on left or right side of productions
  - Constituents of language
    - NP, VP, S[entence], etc…

Representation: Context-free Grammars

- Partial example:
  - Σ: *the, cat, dog, bit, bites, man*
  - N: NP, VP, Nom, Det, V, N, Adj
  - P: S→{NP VP; NP→Det Nom; Nom→N Nom|N; VP→V NP; N→*cat*; N→*dog*; N→*man*; Det→*the*; V→*bit*; V→*bites*
  - S

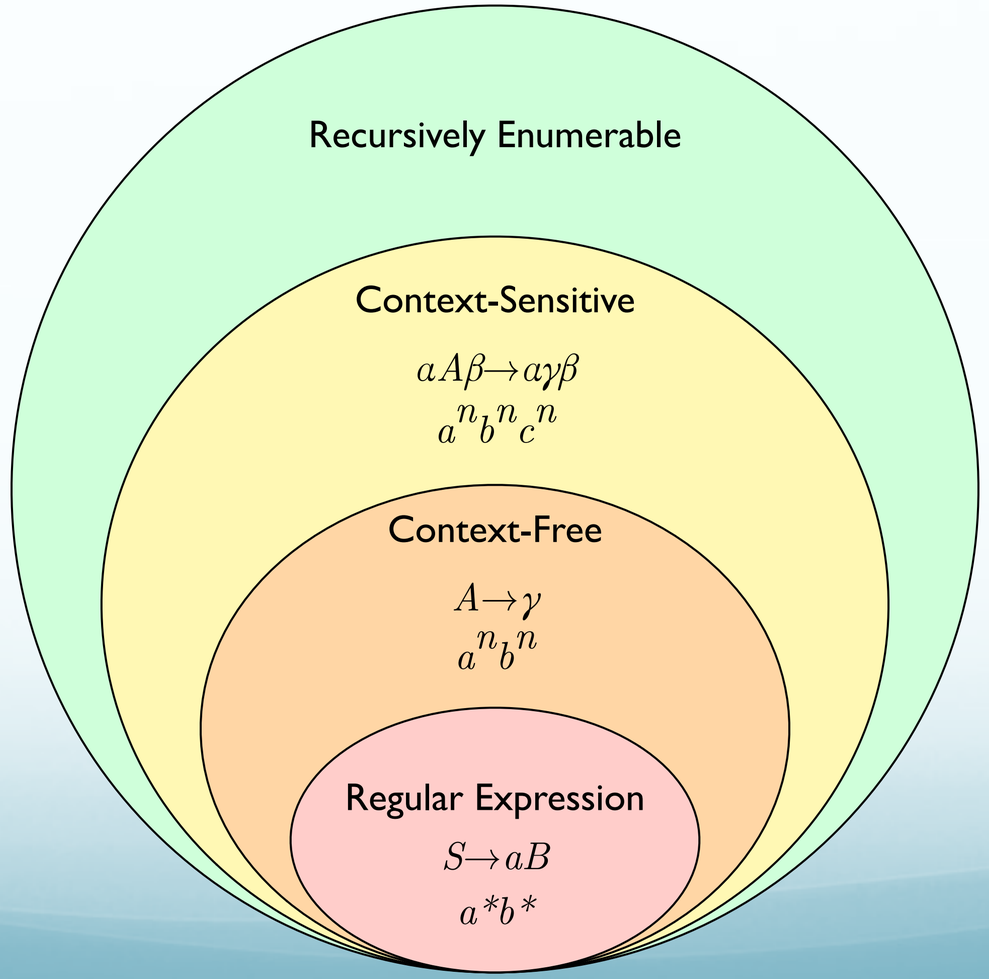


Parsing Goals

- Acceptance
  - Legal string in language?
    - Formally: rigid
    - Practically: degrees of acceptability
- Analysis
  - What structure produced the string
    - Produce one (or all) parses for the string
- Will develop techniques to produce analyses of sentences
  - Rigidly accept (with analysis) or reject
  - Produce varying degrees of acceptability

Sentence-level Knowledge: Syntax

- Different models of language that specify the ***expressive power*** of a formal language



Chomsky Hierarchy

Representing Sentence Structure

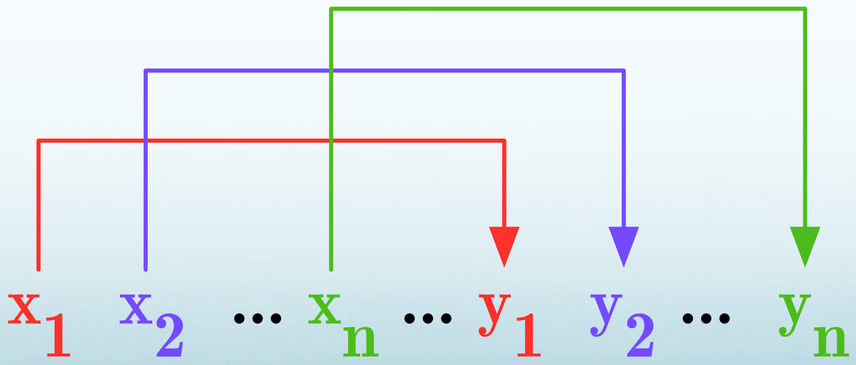
- Why not just Finite State Models (Regular Expressions)?
  - Cannot describe some grammatical phenomena
  - Inadequate expressiveness to capture generalization

Representing Sentence Structure: Center Embedding

- **Finite State:** $A \rightarrow w; A \rightarrow w^{*}B$
- **Context-Free:** $A \Rightarrow \alpha A \beta$
  - Allows recursion:
    - The luggage arrived
    - The luggage that the passengers checked arrived
    - The luggage that the passengers whom the storm delayed checked arrived

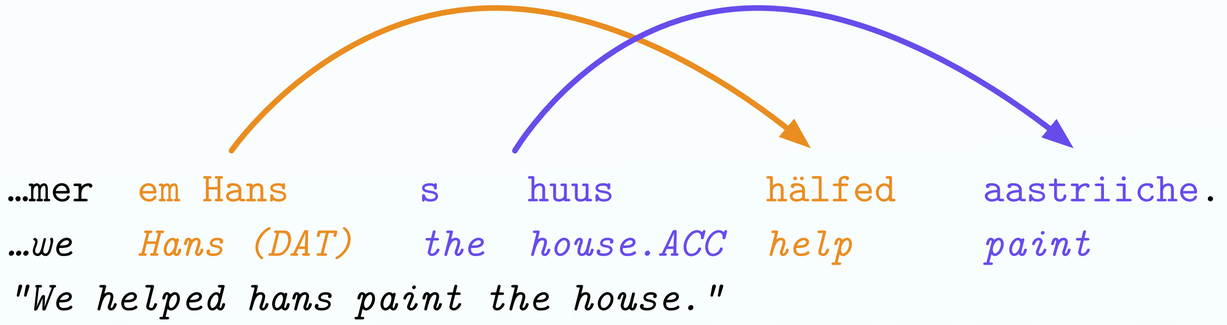
Is Context-Free Enough?

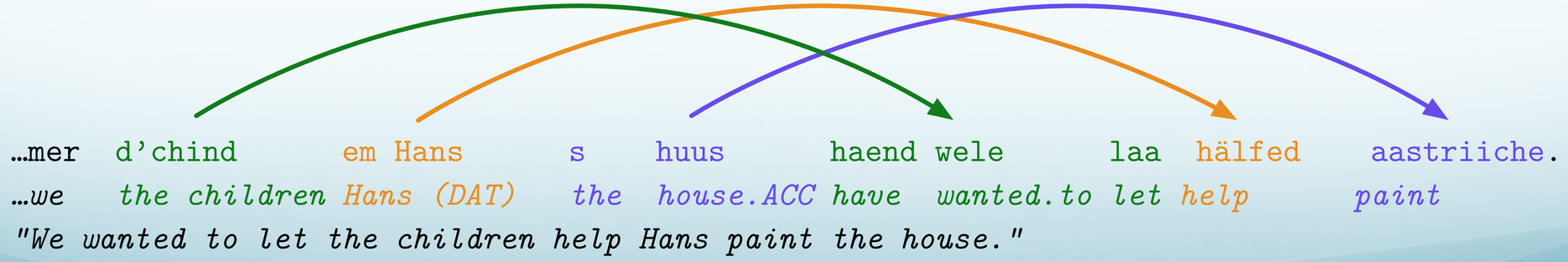
- Natural language not finite state
- …but do we need context-sensitivity?
  - Many articles have attempted to demonstrate we do
  - …many have failed.
- Solid proof for Swiss German: ***Cross-Serial Dependencies*** (Shieber, 1985)
  - $a^i b^j c^i d^j$



Context-Sensitive Example

- Verbs and their arguments must be ordered ***cross-serially***
  - Arguments and verbs must match





Questions so far?

HW#1 & Getting Started

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Department Cluster

- Assignments are **required** to run on department cluster
  - If you don't have a cluster account, request on ASAP!
    - Link to account request form on Canvas or below:
    - vervet.ling.washington.edu/db/accountrequest-form.php
- You are not required to develop on the cluster, but code must run on it
- ***Reminder:*** *All but most simple tasks must be run via Condor*

Condor

- Parallel computing management system
- All homework will be run via condor
- See documentation on CLMS wiki for:
  - Construction of condor scripts
  - Link also on Canvas syllabus page under "Resources"

Programming

- For most assignments, we will be using NLTK in Python.
- For assignments where NLTK is not required, you ***may*** choose to use a different programming language.

NLTK

- **N**atural **L**anguage **T**ool**K**it (NLTK)
  - Large, integrated, fairly comprehensive
    - Stemmers
    - Taggers
    - Parsers
    - Semantic analysis
    - Corpus samples
    - …& More
  - Extensively documented
  - Pedagogically Oriented
    - Implementations Strive for Clarity
    - …sometimes at the expense of efficiency.

NLTK

- nltk.org
  - Online book
  - Demos of software
  - How-Tos for specific components
  - API information, etc.

Python & NLTK

- NLTK is installed on the Cluster
  - Use Python 3.4+ with NLTK
  - **N.B.:** Python 2.7 is default
    - Use: **`python3.4`** to run, not **`python`**
- Data is also installed:
  - /corpora/nltk/nltk-data
- Written in Python
  - Some introductions at:
    - **python.org**, **docs.python.org**

Python & NLTK

- Interactive mode allows experimentation, introspection:

```
patas$ python3
>>> import nltk
>>> dir(nltk)
['AbstractLazySequence', 'AffixTagger', 'AlignedSent',
'Alignment', 'AnnotationTask', 'ApplicationExpression',
'Assignment', 'BigramAssocMeasures', 'BigramCollocationFinder',
'BigramTagger', ‘BinaryMaxentFeatureEncoding’,…
>>> help(nltk.AffixTagger)
```

Turning In Homework

- Will be using Canvas' file submission mechanism
  - Quick how to at: https://community.canvaslms.com/docs/DOC-10663-421254353
- Homeworks due on **Friday** nights (except for HW #1!)
  - **11:00 PM, Pacific Time**
- Each assignment will include:
  - `readme.{txt|pdf}`
  - `hwX.tar.gz`
    - Where "X" is the assignment number
    - **`tar -cvzf hwX.tar.gz <hw_path>`**

HW #1

- Read in sentences and corresponding grammar
- Use NLTK to parse those sentences
- Goals:
  - Set up software environment for rest of course
  - Get familiar with NLTK
  - Work with parsers and CFGs

HW #1: Useful Tools

- Loading data:
  - **`nltk.data.load(resource_url)`**
    - Reads in and processes formatted CFG/FCFG/treebank/etc
    - Returns a grammar from CFG
    - **examples:**

```
nltk.data.load('grammars/sample_grammars/toy.cfg')
nltk.data.load('file://' + my_grammar_path)
```

- Tokenization:
  - **`nltk.word_tokenize(mystring)`**
    - Returns array of tokens in string

HW #1: Useful Tools

- Parsing:
  - **`parser = nltk.parse.EarleyChartParser(grammar)`**
    - Returns parser based on the grammar
  - **`parser.parse(token_list)`**
    - Returns iterator of parses:

```
>>> for item in parser.parse(tokens):
>>>     print(item)

(S (NP (Det the) (N dog)) (VP (V chased) (NP (Det the) (N cat))))
```