CS 380: Artificial Intelligence

Lecture 11: Natural-Language Processing

Natural Language Processing:

- Let's start with some classic examples:
  - Eliza (Weizenbaum, 1966)
    - Sample implementation: http://www.masswerk.at/elizabot/
  - SHRDLU (Winograd, 1970)
    - http://hci.stanford.edu/~winograd/shrdlu/
    - https://www.youtube.com/watch?v=QAJz4YKUwqw
    - How did SHRDLU get its name? http://hci.stanford.edu/~winograd/shrdlu/name.html

Natural Language Processing

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Natural Language Processing

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- So, is NLP solved nowadays? (after >40 years?!?)
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- But SHRDLU worked pretty well — can't we just apply the algorithms in SHRDLU to other domains?
  - SHRDLU worked on a "micro-world", which masks most of the hard problems in NLP (ambiguity, metaphor, noncompositionality, etc.)
  - Efforts to scale SHRDLU to larger domains have consistently failed (e.g., CyC)

Natural Language Processing

- There are many possible perspectives for an analysis of language…
  - Linguistics: e.g., general & specific aspects of language
  - Psychology: e.g., developmental learning
  - Computer Science: e.g., grammar & parsing
  - Sociology: e.g., language across cultures
  - Etc.
- Here we focus on NLP from an **agent** perspective: an agent/human communicating with an agent/human

Communication

"Classical" view (pre-1953):
language consists of sentences that are true/false (cf. logic)

"Modern" view (post-1953):
language is a form of action

Wittgenstein (1953) **Philosophical Investigations**
Austin (1962) **How to Do Things with Words**
Searle (1969) **Speech Acts**

Why?

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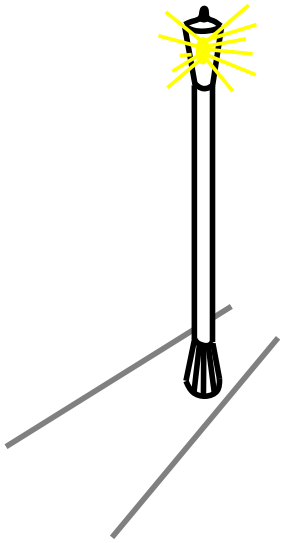
Why?



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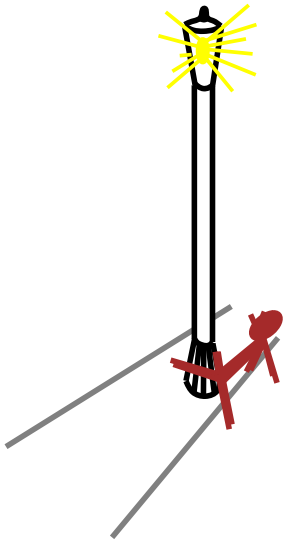

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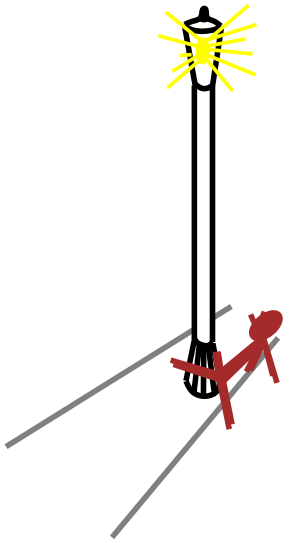
Why?

To change the actions of other agents



Speech acts

Speech acts achieve the speaker's goals:

Inform	"There's a pit in front of you"
Query	"Can you see the gold?"
Command	"Pick it up"
Promise	"I'll share the gold with you"
Acknowledge	"OK"

Speech act planning requires knowledge of

- Situation
- Semantic and syntactic conventions
- Hearer's goals, knowledge base, and rationality

Stages in communication (informing)

Intention	S wants to inform H that P
Generation	S selects words W to express P in context C
Synthesis	S utters words W
Perception	H perceives W' in context C'
Analysis	H infers possible meanings $P_1, \ldots P_n$
Disambiguation	H infers intended meaning P_i
Incorporation	H incorporates P_i into KB

How could this go wrong?

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How could this go wrong?

- Insincerity (S doesn't believe P)
- Speech wreck ignition failure (speech recognition failure ☺)
- Ambiguous utterance
- Differing understanding of current context ($C \neq C'$)

Grammar

Vervet monkeys, antelopes etc. use isolated symbols for sentences

$\Rightarrow$ restricted set of communicable propositions, no generative capacity

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$\Rightarrow$ [illegible]ted set of communicable propositions, no generative capacity

Vervet monkeys are known to elicit predator-specific alarm calls. Three well-documented vervet monkey alarm calls are those for leopard, martial eagle and python. Leopard alarm calls are short tonal calls produced in a series of inhalations and exhalations. Eagle alarm calls are low pitched grunt while python alarm calls are high pitched “chutters”. Different alarm calls seem to evoke different responses to individuals that heard the alarm calls. However, the first reaction of a vervet monkey upon hearing an alarm call is to look at the direction of the caller. Looking at the direction of the caller gives them clues as to why the alarm calls were made and also where the caller is facing reveals the direction of the approaching predator. *[from primatology.net]*

Grammar

Vervet monkeys, antelopes etc. use isolated symbols for sentences

$\Rightarrow$ restricted set of communicable propositions, no generative capacity

(Chomsky (1957): **Syntactic Structures**)

Grammar specifies the compositional structure of complex messages

e.g., speech (linear), text (linear), music (two-dimensional)

A formal language is a set of strings of terminal symbols

Each string in the language can be analyzed/generated by the grammar

The grammar is a set of rewrite rules, e.g.,

$S \rightarrow NP\ VP$

$Article \rightarrow \textbf{\textit{the}} \mid \textbf{\textit{a}} \mid \textbf{\textit{an}} \mid \ldots$

Backus–Naur Form (BNF)

Here S is the sentence symbol, NP and VP are nonterminals

Grammar types

Regular: $nonterminal \rightarrow \boldsymbol{terminal}[nonterminal]$

$S \rightarrow \boldsymbol{a}S$
$S \rightarrow \Lambda$

Context-free: $nonterminal \rightarrow anything$

$S \rightarrow \boldsymbol{a}S\boldsymbol{b}$

Context-sensitive: more nonterminals on right-hand side

$ASB \rightarrow AA\boldsymbol{a}BB$

Recursively enumerable: no constraints

Related to Post systems and Kleene systems of rewrite rules

Natural languages probably context-free, parsable in real time!

Wumpus lexicon

$$
\begin{aligned}
\textit{Noun} &\rightarrow \textbf{\textit{stench}} \mid \textbf{\textit{breeze}} \mid \textbf{\textit{glitter}} \mid \textbf{\textit{nothing}} \\
&\quad \mid \textbf{\textit{wumpus}} \mid \textbf{\textit{pit}} \mid \textbf{\textit{pits}} \mid \textbf{\textit{gold}} \mid \textbf{\textit{east}} \mid \ldots \\
\textit{Verb} &\rightarrow \textbf{\textit{is}} \mid \textbf{\textit{see}} \mid \textbf{\textit{smell}} \mid \textbf{\textit{shoot}} \mid \textbf{\textit{feel}} \mid \textbf{\textit{stinks}} \\
&\quad \mid \textbf{\textit{go}} \mid \textbf{\textit{grab}} \mid \textbf{\textit{carry}} \mid \textbf{\textit{kill}} \mid \textbf{\textit{turn}} \mid \ldots \\
\textit{Adjective} &\rightarrow \textbf{\textit{right}} \mid \textbf{\textit{left}} \mid \textbf{\textit{east}} \mid \textbf{\textit{south}} \mid \textbf{\textit{back}} \mid \textbf{\textit{smelly}} \mid \ldots \\
\textit{Adverb} &\rightarrow \textbf{\textit{here}} \mid \textbf{\textit{there}} \mid \textbf{\textit{nearby}} \mid \textbf{\textit{ahead}} \\
&\quad \mid \textbf{\textit{right}} \mid \textbf{\textit{left}} \mid \textbf{\textit{east}} \mid \textbf{\textit{south}} \mid \textbf{\textit{back}} \mid \ldots \\
\textit{Pronoun} &\rightarrow \textbf{\textit{me}} \mid \textbf{\textit{you}} \mid \textbf{\textit{I}} \mid \textbf{\textit{it}} \mid \ldots \\
\textit{Name} &\rightarrow \textbf{\textit{John}} \mid \textbf{\textit{Mary}} \mid \textbf{\textit{Boston}} \mid \textbf{\textit{UCB}} \mid \textbf{\textit{PAJC}} \mid \ldots \\
\textit{Article} &\rightarrow \textbf{\textit{the}} \mid \textbf{\textit{a}} \mid \textbf{\textit{an}} \mid \ldots \\
\textit{Preposition} &\rightarrow \textbf{\textit{to}} \mid \textbf{\textit{in}} \mid \textbf{\textit{on}} \mid \textbf{\textit{near}} \mid \ldots \\
\textit{Conjunction} &\rightarrow \textbf{\textit{and}} \mid \textbf{\textit{or}} \mid \textbf{\textit{but}} \mid \ldots \\
\textit{Digit} &\rightarrow \textbf{0} \mid \textbf{1} \mid \textbf{2} \mid \textbf{3} \mid \textbf{4} \mid \textbf{5} \mid \textbf{6} \mid \textbf{7} \mid \textbf{8} \mid \textbf{9}
\end{aligned}
$$

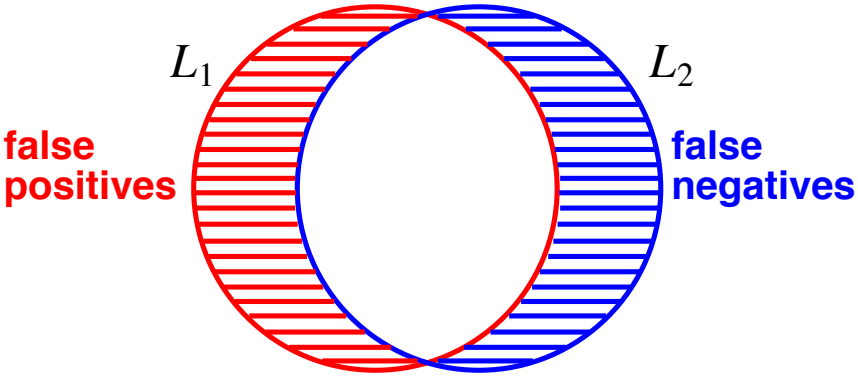
Divided into closed and open classes

Wumpus grammar

S	$\rightarrow$	$NP\ VP$	I + feel a breeze
	|	$S\ Conjunction\ S$	I feel a breeze + and + I smell a wumpus
NP	$\rightarrow$	$Pronoun$	I
	|	$Noun$	pits
	|	$Article\ Noun$	the + wumpus
	|	$Digit\ Digit$	3 4
	|	$NP\ PP$	the wumpus + to the east
	|	$NP\ RelClause$	the wumpus + that is smelly
VP	$\rightarrow$	$Verb$	stinks
	|	$VP\ NP$	feel + a breeze
	|	$VP\ Adjective$	is + smelly
	|	$VP\ PP$	turn + to the east
	|	$VP\ Adverb$	go + ahead
PP	$\rightarrow$	$Preposition\ NP$	to + the east
$RelClause$	$\rightarrow$	$\boldsymbol{that}\ VP$	that + is smelly

Grammaticality judgements

Formal language L_1 may differ from natural language L_2



Adjusting L_1 to agree with L_2 is a learning problem!

* the gold grab the wumpus
* I smell the wumpus the gold
I give the wumpus the gold
* I donate the wumpus the gold

Intersubjective agreement somewhat reliable, independent of semantics!
Real grammars 10–500 pages, insufficient even for "proper" English

Parse trees

Exhibit the grammatical structure of a sentence

I **shoot** **the** **wumpus**

Parse trees

Exhibit the grammatical structure of a sentence

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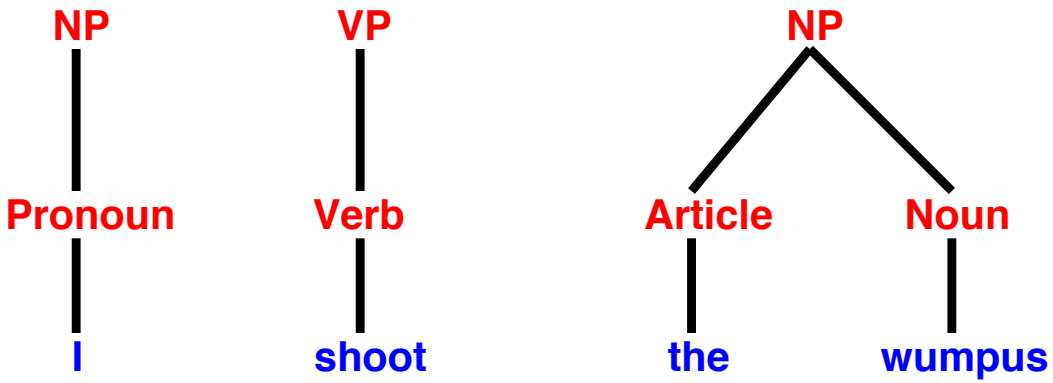

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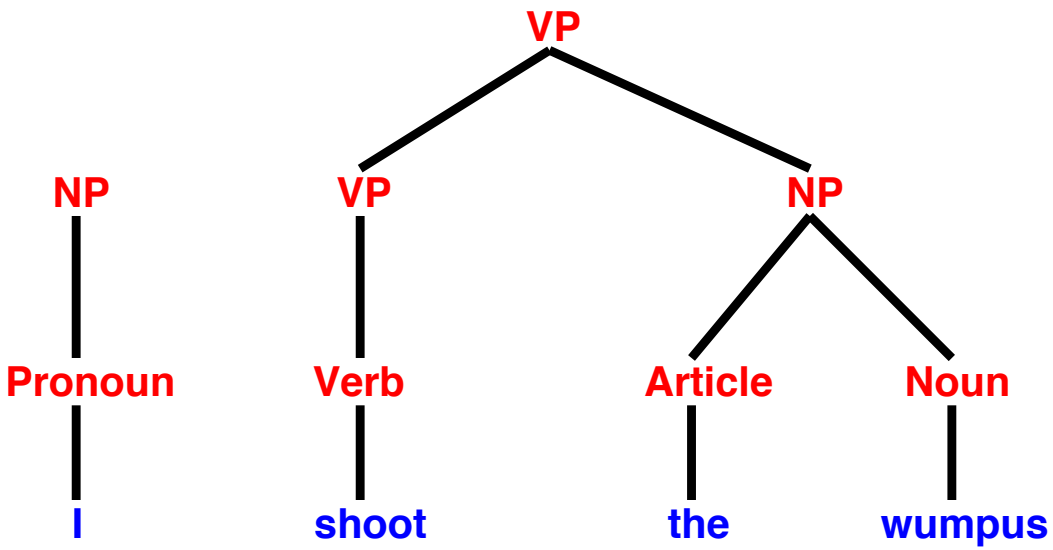

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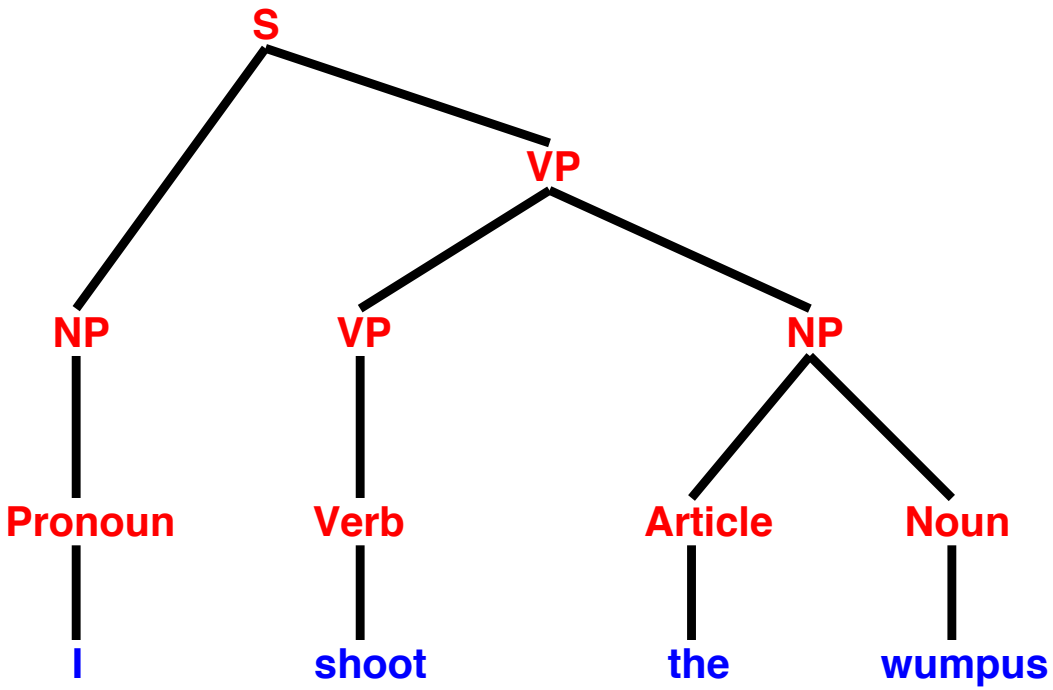

Syntax in NLP

Most view syntactic structure as an essential step towards meaning;

"Mary hit John" $\neq$ "John hit Mary"

"And since I was not informed—as a matter of fact, since I did not know that there were excess funds until we, ourselves, in that checkup after the whole thing blew up, and that was, if you'll remember, that was the incident in which the attorney general came to me and told me that he had seen a memo that indicated that there were no more funds."

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"Wouldn't the sentence 'I want to put a hyphen between the words Fish and And and And and Chips in my Fish-And-Chips sign' have been clearer if quotation marks had been placed before Fish, and between Fish and and, and and and And, and And and and, and and and And, and And and and, and and and Chips, as well as after Chips?"

Logical grammars

BNF notation for grammars too restrictive:

– difficult to add "side conditions" (number agreement, etc.)

– difficult to connect syntax to semantics

Idea: express grammar rules as logic

$X \rightarrow YZ$ becomes $Y(s_1) \wedge Z(s_2) \Rightarrow X(Append(s_1, s_2))$

$X \rightarrow \boldsymbol{word}$ becomes $X([\text{"}\boldsymbol{word}\text{"}])$

$X \rightarrow Y \mid Z$ becomes $Y(s) \Rightarrow X(s) \quad Z(s) \Rightarrow X(s)$

Here, $X(s)$ means that string s **can be interpreted** as an X

Logical grammars contd.

Now it's easy to augment the rules

$$NP(s_1) \wedge EatsBreakfast(Ref(s_1)) \wedge VP(s_2) \Rightarrow NP(Append(s_1, [\text{“}\boldsymbol{who}\text{”}], s_2))$$

$$NP(s_1) \wedge Number(s_1, n) \wedge VP(s_2) \wedge Number(s_2, n) \Rightarrow S(Append(s_1, s_2))$$

Parsing is reduced to logical inference:

ASK(KB, $S([\text{“}\boldsymbol{I}\text{”}\ \text{“}\boldsymbol{am}\text{”}\ \text{“}\boldsymbol{a}\text{”}\ \text{“}\boldsymbol{wumpus}\text{”}])$)

(Can add extra arguments to return the parse structure, semantics)

Generation simply requires a query with uninstantiated variables:

ASK(KB, $S(x)$)

If we add arguments to nonterminals to construct sentence semantics, NLP generation can be done from a given logical sentence:

ASK(KB, $S(x, At(Robot, [1, 1]))$)

Real language

Real human languages provide many problems for NLP:

- ambiguity
- anaphora
- indexicality
- vagueness
- discourse structure
- metonymy
- metaphor
- noncompositionality

Ambiguity

Squad helps dog bite victim

Ambiguity

Squad helps dog bite victim
Helicopter powered by human flies

Ambiguity

Squad helps dog bite victim
Helicopter powered by human flies
American pushes bottle up Germans

Ambiguity

Squad helps dog bite victim
Helicopter powered by human flies
American pushes bottle up Germans
I ate spaghetti with meatballs

Ambiguity

Squad helps dog bite victim

Helicopter powered by human flies

American pushes bottle up Germans

I ate spaghetti with meatballs

salad

Ambiguity

Squad helps dog bite victim

Helicopter powered by human flies

American pushes bottle up Germans

I ate spaghetti with meatballs
salad
abandon

Ambiguity

Squad helps dog bite victim

Helicopter powered by human flies

American pushes bottle up Germans

I ate spaghetti with meatballs
salad
abandon
a fork

Ambiguity

Squad helps dog bite victim

Helicopter powered by human flies

American pushes bottle up Germans

I ate spaghetti with meatballs
salad
abandon
a fork
a friend

Ambiguity

Squad helps dog bite victim
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Ambiguity can be lexical (polysemy), syntactic, semantic, referential

Anaphora

Using pronouns to refer back to entities already introduced in the text

After Mary proposed to John, **they** found a preacher and got married.

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Mary saw a ring through the window and asked John for **it**

Anaphora

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After Mary proposed to John, **they** found a preacher and got married.

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Mary saw a ring through the window and asked John for **it**

Mary threw a rock at the window and broke **it**

Compare: Mary threw a vase at the wall and broke it

Indexicality

Indexical sentences refer to utterance situation (place, time, S/H, etc.)

I am over **here**

Why did **you** do **that**?

Metonymy

Using one noun phrase to stand for another

I've read **Shakespeare**

Chrysler announced record profits

The **ham sandwich** on Table 4 wants another beer

Metaphor

"Non-literal" usage of words and phrases, often systematic:

I've tried killing the process but it won't die. Its parent keeps it alive.

Noncompositionality

Meaning of a phrase = combined meaning of its terms?

Noncompositionality

basketball shoes

Noncompositionality

basketball shoes
baby shoes

Noncompositionality

basketball shoes
baby shoes
alligator shoes

Noncompositionality

basketball shoes
baby shoes
alligator shoes
designer shoes

Noncompositionality

basketball shoes
baby shoes
alligator shoes
designer shoes
brake shoes

Noncompositionality

basketball shoes
baby shoes
alligator shoes
designer shoes
brake shoes

red book

Noncompositionality

basketball shoes
baby shoes
alligator shoes
designer shoes
brake shoes

red book
red pen

Noncompositionality

basketball shoes
baby shoes
alligator shoes
designer shoes
brake shoes

red book
red pen
red hair

Noncompositionality

basketball shoes
baby shoes
alligator shoes
designer shoes
brake shoes

red book
red pen
red hair
red herring

Noncompositionality

basketball shoes
baby shoes
alligator shoes
designer shoes
brake shoes

red book
red pen
red hair
red herring

small moon

Noncompositionality

basketball shoes
baby shoes
alligator shoes
designer shoes
brake shoes

red book
red pen
red hair
red herring

small moon
large molecule

Noncompositionality

basketball shoes
baby shoes
alligator shoes
designer shoes
brake shoes

red book
red pen
red hair
red herring

small moon
large molecule
mere child

Noncompositionality

basketball shoes
baby shoes
alligator shoes
designer shoes
brake shoes

red book
red pen
red hair
red herring

small moon
large molecule
mere child
alleged murderer

Noncompositionality

basketball shoes
baby shoes
alligator shoes
designer shoes
brake shoes

red book
red pen
red hair
red herring

small moon
large molecule
mere child
alleged murderer
real leather

Noncompositionality

basketball shoes
baby shoes
alligator shoes
designer shoes
brake shoes

red book
red pen
red hair
red herring

small moon
large molecule
mere child
alleged murderer
real leather
artificial grass

NLP in the Real World

Jeremy Fowler 
@JFowlerESPN

Follow 

I'm not expecting the Steelers to make a move for cornerback help at the deadline barring unforeseen development. Will likely roll with what they have.

12:19 PM - 30 Oct 2018

Steeler 4 Life @jarvis1104 · Oct 30

Replying to @JFowlerESPN @Alex_Kozora

Sadly this tweet can be sent every year at this time and remain true

7 80

John @jrw412 · Oct 30

Replying to @JFowlerESPN

Huge surprise

1 12

jONh @jonhthagreat · Oct 30

not really, as much as i love the steelers they are probably the most boring team when it comes to making deadline deals

1 1 6

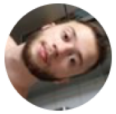
my name jason @jbmorton21 · Oct 30

You're not that great at identifying sarcasm

1 9

jONh @jonhthagreat · Oct 30

lol i didnt even think of sarcasm for some reason 😂



Daniel Cabral Nephas @medanielrose · Oct 30

Replying to @JFowlerESPN @SteelTownUsa

Dude, dont u know words can hurt? U dont have to say it just cuz its true

@BurghSportsRT · Oct 30

Replying to @JFowlerESPN

With all that money they got from bell being out .. didn't take the opportunity of what was given

Michael Perrotti @mperrotti22 · Oct 30

Replying to @JFowlerESPN

NLP in the Real World

- Thinking beyond agents, how you do NLP depends on what task you're trying to accomplish
- Examples
  - Part-of-speech classification (noun/verb/etc.)
  - Classification w.r.t. a taxonomy (e.g., Amazon products)
  - Authorship detection (e.g., Founding Fathers)
  - Language detection (which language is this?)
  - Sentiment analysis (is this positive, negative, other?)
  - Concept extraction, summarization (what is this about?)
  - Machine translation (one language to another)

NLP in the Real World

- Problem: A perfect, unambiguous parsed understanding of a sentence is often elusive.
- In the face of real-world language & ambiguity, how can we handle the explosion of possible grammatical rules?
  - Allow for partial partially-formed parse trees
  - Incorporate probabilistic parsing
  - Use modern techniques (e.g., neural networks) that can better handled “imperfect” language

Coming up…

- These ideas lead us naturally into the next topic, Machine Learning
  - How can agents learn what to do and when to do it?
  - Once they know what to do, how can they improve their behavior over time?