

Linguistics 384: Language and Computers

Topic 4: Writer's aids (Spelling and Grammar Correction)

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Why people care about spelling (cont.)

- ▶ Standard spelling makes it easy to organize words and text:
 - ▶ e.g., Without standard spelling, how would you look up things in a lexicon or thesaurus?
 - ▶ e.g., Optical character recognition software can use knowledge about standard spelling to recognize scanned words even for hardly legible input.
- ▶ Standard spelling makes it possible to provide a single text, which is accessible to a wide range of readers (different backgrounds, speaking different dialects, etc.).
- ▶ Using standard spelling is associated with being well-educated, i.e., is used to make a good impression in social interaction.

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What causes errors?

- ▶ Keyboard mistypings
- ▶ Phonetic errors
- ▶ Knowledge problems

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Who cares about spelling?

*Aoccdnrng to a rscheearch at Cmabrigde
Uinervtisy, it deosn't mttar in waht oredr the ltteers
in a wrod are, the only iprmoentn tihng is taht the
frist and lsat ltter be at the rghit pclae. The rset
can be a toatl mses and you can sitll raed it wouthit
porbelm. Tihs is bcuseae the huamn mnid deos not
raed ervey lteter by istlfe, but the wrod as a wlohe.*

(See <http://www.mrc-cbu.cam.ac.uk/personal/matt.davis/Cmabrigde/> for the story behind this supposed research report.)

*A dtcoor has aimtted the magltheuansr of a
taegeene cceanr pinaet who deid aetfr a haptosil
durg bednlur.*

How are spell checkers used?

- ▶ **interactive spelling checkers** = spell checker detects errors as you type.
 - ▶ It may or may not make suggestions for correction.
 - ▶ Requires a "real-time" response (i.e., must be fast)
 - ▶ It is up to the human to decide if the spell checker is right or wrong.
 - ▶ If there are a list of choices, we may not require 100% accuracy in the corrected word
- ▶ **automatic spelling correctors** = spell checker runs on a whole document, finds errors, and corrects them
 - ▶ A much more difficult task.
 - ▶ A human may or may not proofread the results later.

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Keyboard mistypings

Space bar issues

- ▶ **run-on errors** = two separate words become one
 - ▶ e.g., *the fuzz* becomes *thefuzz*
- ▶ **split errors** = one word becomes two separate items
 - ▶ e.g., *equalization* becomes *equali zation*

Note that the resulting items might still be words!

- ▶ e.g., *a tollway* becomes *atoll way*

Why people care about spelling

- ▶ Misspellings can cause misunderstandings and real-life problems:
 - ▶ For example:
 - ▶ Did you see her god yesterday? It's a big golden retriever.
 - ▶ This will be a fee [free] concert.
 - ▶ 1991 Bell Atlantic & Pacific Bell telephone network outages were partly caused by a typographical error: A 6 in a line of computer code was supposed to be a D. "That one error caused the equipment and software to fail under an avalanche of computer-generated messages." (Wall Street Journal, Nov. 25, 1991)

Detection vs. Correction

- ▶ There are two distinct tasks:
 - ▶ **error detection** = simply find the misspelled words
 - ▶ **error correction** = correct the misspelled words
 - ▶ e.g., It might be easy to tell that *ater* is a misspelled word, but what is the correct word? *water?* *later?* *after?*
- ⇒ Depends on what we want to do with our results as to what we want to do.
Note, though, that detection is a prerequisite for correction.

Keyboard mistypings (cont.)

Keyboard proximity

- ▶ e.g., *Jack* becomes *Hack* since *h* and *j* are next to each other on a typical American keyboard

Physical similarity

- ▶ similarity of shape, e.g., mistaking two physically similar letters when typing up something handwritten
 - ▶ e.g., *tight* for *fight*

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Phonetic errors

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phonetic errors = errors based on the sounds of a language (not necessarily on the letters)

- ▶ **homophones** = two words which sound the same
 - ▶ e.g., *red/read* (past tense), *cite/site/sight*, *they're/their/there*
- ▶ **Spoonerisms** = switching two letters/sounds around
 - ▶ e.g., *It's a tavy grain with biscuit wheels.*

Phonetic errors (cont.)

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- ▶ letter substitution: replacing a letter (or sequence of letters) with a similar-sounding one
 - ▶ e.g., *John cracked his nuckles.* instead of *John cracked his knuckles.*
 - ▶ e.g., *I study sikolagee.*
- ▶ word replacement: replacing one word with some similar-sounding word
 - ▶ e.g., *John battled me on the back.* instead of *John patted me on the back.*

More examples for phonetic errors

- (1) a. death in Venice
b. deaf in Venice
- (2) a. give them an ice bucket
b. give them a nice bucket
- (3) a. the stuffy nose
b. the stuff he knows
- (4) a. the biggest hurdle
b. the biggest turtle
- (5) a. some others
b. some mothers
- (6) a. a Coke and a danish
b. a coconut danish

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Knowledge problems

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- ▶ not knowing a word and guessing its spelling (can be phonetic)
 - ▶ e.g., *sientist*
- ▶ not knowing a rule and guessing it
 - ▶ e.g., Do we double a consonant for *ing* words?
jog → *joging*
joke → *jokking*

What makes spelling correction difficult?

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- ▶ **Tokenization:** What is a word?
- ▶ **Inflection:** How are some words related?
- ▶ **Productivity of language:** How many words are there?

How we handle these issues determines how we build a dictionary.

Tokenization

Intuitively a “word” is simply whatever is between two spaces, but this is not always so clear.

- ▶ contractions = two words combined into one
 - ▶ e.g., *can't*, *he's*, *John's [car]* (vs. *his car*)
- ▶ multi-token words = (arguably) a single word with a space in it
 - ▶ e.g., *New York*, *in spite of*, *deja vu*
- ▶ hyphens (note: can be ambiguous if a hyphen ends a line)
 - ▶ Some are always a single word: *e-mail*, *co-operate*
 - ▶ Others are two words combined into one: *Columbus-based*, *sound-change*
- ▶ Abbreviations: may stand for multiple words
 - ▶ e.g., *etc.* = *et cetera*, *ATM* = *Automated Teller Machine*

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Inflection

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- ▶ A word in English may appear in various guises due to word **inflections** = word endings which are fairly systematic for a given part of speech
 - ▶ plural noun ending: *the boy* + *s* → *the boys*
 - ▶ past tense verb ending: *walk* + *ed* → *walked*
- ▶ This can make spell-checking hard:
 - ▶ There are exceptions to the rules: *mans*, *runned*
 - ▶ There are words which look like they have a given ending, but they don't: *Hans*, *deed*

Productivity

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- ▶ part of speech change: nouns can be verbalized
 - ▶ *emailed* is a common new verb coined after the noun *email*
- ▶ morphological productivity: prefixes and suffixes can be added
 - ▶ e.g., I can speak of *un-email-able* for someone who you can't reach by email.
- ▶ words entering and exiting the lexicon, e.g.:
 - ▶ *thou*, or *spleet 'split'* (*Hamlet III.2.10*) are on their way out
 - ▶ *d'oh* seems to be entering

Techniques used for spell checking

- ▶ Non-word error detection
- ▶ Isolated-word error correction
- ▶ Context-dependent word error detection and correction → grammar correction.

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Non-word error detection

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- ▶ **non-word error detection** is essentially the same thing as **word recognition** = splitting up "words" into true words and non-words.
- ▶ How is non-word error detection done?
 - ▶ using a dictionary (construction and lookup)
 - ▶ n-gram analysis

Dictionary lookup

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Several issues arise when trying to look up a word:

- ▶ Have to make lookup fast by using efficient lookup techniques, such as a hash table.
- ▶ Have to strip off prefixes and suffixes if the word isn't an entry by itself.
 - ▶ *running* → *run*
 - ▶ *nonreligiously* → *religious*

Bigram array

- ▶ Instead, we can define a **bigram array** = information stored in a tabular fashion.
- ▶ An example, for the letters *k*, *l*, *m*, with examples in parentheses

	...	k	l	m	...
⋮					
k		0	1 (<i>tackle</i>)	1 (<i>Hackman</i>)	
l		1 (<i>elk</i>)	1 (<i>hello</i>)	1 (<i>alms</i>)	
m		0	0	1 (<i>hammer</i>)	
⋮					

- ▶ The first letter of the bigram is given by the vertical letters (i.e., down the side), the second by the horizontal ones (i.e., across the top).
- ▶ This is a **non-positional bigram array** = the array 1's and 0's apply for a string found anywhere within a word (beginning, 4th character, ending, etc.).

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Dictionaries

Intuition:

- ▶ Have a complete list of words and check the input words against this list.
- ▶ If it's not in the dictionary, it's not a word.

Two aspects:

- ▶ **Dictionary construction** = build the dictionary (what do you put in it?)
- ▶ **Dictionary lookup** = lookup a potential word in the dictionary (how do you do this quickly?)

N-gram analysis

- ▶ An **n-gram** here is a string of *n* letters.

a	1-gram (unigram)
at	2-gram (bigram)
ate	3-gram (trigram)
late	4-gram
⋮	⋮

- ▶ We can use this n-gram information to define what the possible strings in a language are.
 - ▶ e.g., *po* is a possible English string, whereas *kvt* is not.

Positional bigram array

- ▶ To store information specific to the beginning, the end, or some other position in a word, we can use a **positional bigram array** = the array only applies for a given position in a word.
- ▶ Here's the same array as before, but now only applied to word endings:

	...	k	l	m	...
⋮					
k		0	0	0	
l		1 (<i>elk</i>)	1 (<i>hall</i>)	1 (<i>elm</i>)	
m		0	0	0	
⋮					

Dictionary construction

- ▶ Do we include inflected words? i.e., words with prefixes and suffixes already attached.
 - ▶ Pro: lookup can be faster
 - ▶ Con: takes much more space, doesn't account for new formations (e.g., *google* → *googled*)
- ▶ Want the dictionary to have only the word relevant for the user → **domain-specificity**
 - ▶ e.g., For most people *memoize* is a misspelled word, but in computer science this is a technical term and spelled correctly.
- ▶ Foreign words, hyphenations, derived words, proper nouns, and new words will always be problems for dictionaries since we cannot predict these words until humans have made them words.
- ▶ Dictionary should probably be dialectally consistent.
 - ▶ e.g., include only *color* or *colour* but not both

How do we store and use n-gram information?

- ▶ Store the number of times an n-gram appears (like in Language Identification). But, maybe we just want to know if an n-gram is possible.
- ▶ We could have a list of possible and impossible n-grams (1 = possible, 0 = impossible):

po	1
kvt	0
police	1
asdf	0

- ▶ Any word which has a 0 for any substring is a misspelled word.
- ▶ Problems with such an approach:
 - ▶ Information is repeated (*po* is in *police*)
 - ▶ Requires a lot of computer storage space
 - ▶ Inefficient (slow) when looking up every string

Isolated-word error correction

- ▶ Having discussed how errors can be detected, we want to know how to correct these misspelled words:
 - ▶ The most common method is **isolated-word error correction** = correcting words without taking context into account.
 - ▶ Note: This technique can only handle errors that result in non-words.
- ▶ Knowledge about what is a typical error helps in finding correct word.

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Knowledge about typical errors

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- ▶ word length effects: most misspellings are within two characters in length of original
 - When searching for the correct spelling, we do not usually need to look at words with greater length differences.
- ▶ first-position error effects: the first letter of a word is rarely erroneous
 - When searching for the correct spelling, the process is sped up by being able to look only at words with the same first letter.

Similarity key techniques

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- ▶ Problem: How can we find a list of possible corrections?
- ▶ Solution: Store words in different boxes in a way that puts the similar words together.
- ▶ Example:
 1. Start by storing words by their first letter (first letter effect),
 - ▶ e.g., *punc* starts with the code P.
 2. Then assign numbers to each letter
 - ▶ e.g., 0 for vowels, 1 for b, p, f, v (all bilabials), and so forth, e.g., *punc* → P052
 3. Then throw out all zeros and repeated letters,
 - ▶ e.g., P052 → P52.
 4. Look for real words within the same box,
 - ▶ e.g., *punk* is also in the P52 box.

How is a mistyped word related to the intended?

Types of operations

- ▶ **insertion** = a letter is added to a word
- ▶ **deletion** = a letter is deleted from a word
- ▶ **substitution** = a letter is put in place of another one
- ▶ **transposition** = two adjacent letters are switched

Note that the first two alter the length of the word, whereas the second two maintain the same length.

General properties

- ▶ **single-error misspellings** = only one instance of an error
- ▶ **multi-error misspellings** = multiple instances of errors (harder to identify)

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Isolated-word error correction methods

- ▶ Many different methods are used; we will briefly look at four methods:
 - ▶ rule-based methods
 - ▶ similarity key techniques
 - ▶ minimum edit distance
 - ▶ probabilistic methods
- ▶ The methods play a role in one of the three basic steps:
 1. Detection of an error (discussed above)
 2. Generation of candidate corrections
 - ▶ rule-based methods
 - ▶ similarity key techniques
 3. Ranking of candidate corrections
 - ▶ probabilistic methods
 - ▶ minimum edit distance

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Probabilistic methods

Two main probabilities are taken into account:

- ▶ **transition probabilities** = probability (chance) of going from one letter to the next.
 - ▶ e.g., What is the chance that a will follow p in English? That u will follow q?
- ▶ **confusion probabilities** = probability of one letter being mistaken (substituted) for another (can be derived from a confusion matrix)
 - ▶ e.g., What is the chance that q is confused with p?

Useful to combine probabilistic techniques with dictionary methods

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Minimum edit distance

- ▶ In order to rank possible spelling corrections, it can be useful to calculate the **minimum edit distance** = minimum number of operations it would take to convert one word into another.
- ▶ For example, we can take the following five steps to convert *junk* to *haiku*:
 1. *junk* → *juk* (deletion)
 2. *juk* → *huk* (substitution)
 3. *huk* → *hku* (transposition)
 4. *hku* → *hiku* (insertion)
 5. *hiku* → *haiku* (insertion)
- ▶ But is this the minimal number of steps needed?

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Rule-based methods

One can generate correct spellings by writing rules:

- ▶ Common misspelling rewritten as correct word:
 - ▶ e.g., *hte* → *the*
- ▶ Rules
 - ▶ based on inflections:
 - ▶ e.g., *VcIng* → *VCCing*, where V = letter representing vowel, basically the regular expression [aeiou]
 - C = letter representing consonant, basically [bcd fghjklmnpqrstvwxyz]
 - ▶ based on other common spelling errors (such as keyboard effects or common transpositions):
 - ▶ e.g., *CsC* → *CaC*
 - ▶ e.g., *Cie* → *Cei*

Confusion probabilities

- ▶ For the various reasons discussed above (keyboard layout, phonetic similarity, etc.) people type other letters than the ones they intended.
- ▶ It is impossible to fully investigate all possible error causes and how they interact, but we can learn from watching how often people make errors and where.
- ▶ One way of doing so is to build a **confusion matrix** = a table indicating how often one letter is mistyped for another

		correct				
		...	r	s	t	...
typed	r		n/a	12	22	
	s		14	n/a	15	
	t		11	37	n/a	
	:					

(cf. Kernighan et al 1999)

Computing edit distances

Figuring out the worst case

- ▶ To be able to compute the edit distance of two words at all, we need to ensure there is a finite number of steps.
- ▶ This can be accomplished by
 - ▶ requiring that letters cannot be changed back and forth a potentially infinite number of times, i.e., we
 - ▶ limit the number of changes to the size of the material we are presented with, the two words.
- ▶ Idea: Never deal with a character in either word more than once.
- ▶ Result:
 - ▶ In the worst case, we delete each character in the first word and then insert each character of the second word.
 - ▶ The worst case edit distance for two words is $length(word1) + length(word2)$

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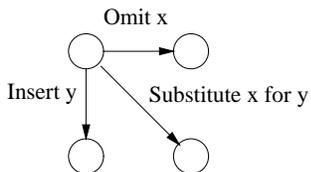
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Computing edit distances

Using a graph to map out the options

- ▶ To calculate minimum edit distance, we set up a **directed, acyclic graph**, a set of nodes (circles) and arcs (arrows).
- ▶ Horizontal arcs correspond to deletions, vertical arcs correspond to insertions, and diagonal arcs correspond to substitutions (and a letter can be “substituted” for itself).



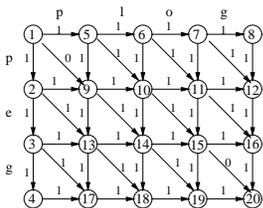
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Computing edit distances

Adding costs to the arcs of the example graph

- ▶ We need to add the costs involved to the arcs.
- ▶ In the simplest case, the cost of deletion, insertion, and substitution is 1 each (and substitution with the same character is free).



- ▶ Instead of assuming the same cost for all operations, in reality one will use different costs, e.g., for the first character or based on the confusion probability.

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Context-dependent word correction

Context-dependent word correction = correcting words based on the surrounding context.

- ▶ This will handle errors which are real words, just not the right one or not in the right form.
- ▶ Essentially a fancier name for a **grammar checker** = a mechanism which tells a user if their grammar is wrong.

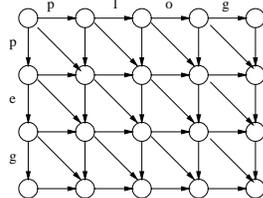
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Computing edit distances

An example graph

- ▶ Say, the user types in *plug*.
- ▶ We want to calculate how far away *peg* is (one of the possible corrections). In other words, we want to calculate the minimum edit distance (or minimum edit cost) from *plug* to *peg*.
- ▶ As the first step, we draw the following directed graph:



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Computing edit distances

How to compute the path with the least cost

We want to find the path from the start (1) to the end (20) with the least cost.

- ▶ The simple but dumb way of doing it:
 - ▶ Follow every path from start (1) to finish (20) and see how many changes we have to make.
 - ▶ But this is very inefficient! There are many different paths to check.

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Grammar correction—what does it correct?

- ▶ Syntactic errors = errors in how words are put together in a sentence: the order or form of words is incorrect, i.e., ungrammatical.
- ▶ **Local** syntactic errors: 1-2 words away
 - ▶ e.g., *The study was conducted mainly **be** John Black.*
 - ▶ A verb is where a preposition should be.
- ▶ **Long-distance** syntactic errors: (roughly) 3 or more words away
 - ▶ e.g., *The **kids** who are most upset by the little totem is going home early.*
 - ▶ Agreement error between subject *kids* and verb *is*

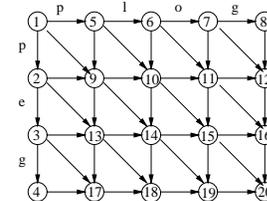
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Computing edit distances

Adding numbers to the example graph

- ▶ The graph is **acyclic** = for any given node, it is impossible to return to that node by following the arcs.
- ▶ We can add identifiers to the states, which allows us to define a **topological order**:



Computing edit distances

The smart way to compute the least cost

- ▶ The smart way to compute the least cost uses **dynamic programming** = a program designed to make use of results computed earlier
 - ▶ We follow the topological ordering.
 - ▶ As we go in order, we calculate the least cost for that node:
 - ▶ We add the cost of an arc to the cost of reaching the node this arc originates from.
 - ▶ We take the minimum of the costs calculated for all arcs pointing to a node and store it for that node.
 - ▶ The key point is that we are storing partial results along the way, instead of recalculating everything, every time we compute a new path.

More on grammar correction

- ▶ Semantic errors = errors where the sentence structure sounds okay, but it doesn't really mean anything.
 - ▶ e.g., *They are leaving in about fifteen **minuets** to go to her house.*
- ⇒ *minuets* and *minutes* are both plural nouns, but only one makes sense here

There are many different ways in which grammar correctors work, two of which we'll focus on:

- ▶ Bigram model (bigrams of words)
- ▶ Rule-based model

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Bigram grammar correctors

We can look at **bigrams** of words, i.e., two words appearing next to each other.

- ▶ **Question:** Given the previous word, what is the probability of the current word?
 - ▶ e.g., given *these*, we have a 5% chance of seeing *reports* and a 0.001% chance of seeing *report* (*these report cards*).
 - ▶ Thus, we will change *report* to *reports*
- ▶ But there's a major problem: we may hardly ever see *these reports*, so we won't know the probability of that bigram.
- ▶ **(Partial) Solution:** use bigrams of **parts of speech**.
 - ▶ e.g., What is the probability of a noun given that the previous word was an adjective?

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Syntax

- ▶ **Syntax** = the study of the way that sentences are constructed from smaller units.
- ▶ There cannot be a "dictionary" for sentences since there is an infinite number of possible sentences:

- (7) The house is large.
- (8) John believes that the house is large.
- (9) Mary says that John believes that the house is large.

There are two basic principles of sentence organization:

- ▶ Linear order
- ▶ Hierarchical structure (Constituency)

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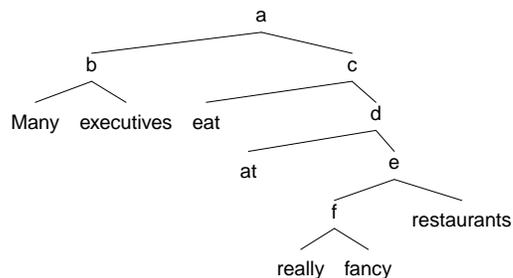
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Hierarchical structure

- ▶ Constituents can appear within other constituents, which can be represented in a bracket form or in a **syntactic tree**.
- ▶ Constituents shown through brackets: `[[[Many executives] [eat [at [[really fancy] restaurants]]]]]`
- ▶ Constituents displayed as a tree:



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Rule-based grammar correctors

We can write regular expressions to target specific error patterns. For example:

- ▶ *To a certain extend, we have achieved our goal.*
 - ▶ Match the pattern *some* or *certain* followed by *extend*, which can be done using the regular expression `some|certain extend`
 - ▶ Change the occurrence of *extend* in the pattern to *extent*.
- ▶ Naber (2003) uses 56 such rules to build a grammar corrector which works nearly as well as that in commercial products.

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Linear order

- ▶ **Linear order** = the order of words in a sentence.
- ▶ A sentence can have different meanings, based on its linear order:

- (10) John loves Mary.
- (11) Mary loves John.

- ▶ Languages vary as to what extent this is true, but linear order in general is used as a guiding principle for organizing words into meaningful sentences.
- ▶ Simple linear order as such is not sufficient to determine sentence organization though. For example, we can't simply say "The verb is the second word in the sentence."

- (12) I **eat** at really fancy restaurants.
- (13) Many executives **eat** at really fancy restaurants.

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Categories

- ▶ We would also like some way to say that
 - ▶ *Many executives*, and
 - ▶ *really fancy restaurants*are the same type of grouping, or constituent, whereas
 - ▶ *at really fancy restaurants* seems to be something else.
- ▶ For this, we will talk about different **categories**
 - ▶ Lexical
 - ▶ Phrasal

Beyond regular expressions

- ▶ But what about correcting the following:
 - ▶ *A baseball teams were successful.*
- ▶ We should change *A* to *Some*, but a simple regular expression doesn't work because we don't know where the word *teams* might show up.
 - ▶ *A wildly overpaid, horrendous baseball teams were successful.* (Five words later; change needed.)
 - ▶ *A player on both my teams was successful.* (Five words later; no change needed.)
- ▶ We need to look at how the sentence is constructed in order to build a better rule.

Constituency

- ▶ What are the "meaningful units" of a sentence like *Many executives eat at really fancy restaurants*?
 - ▶ Many executives
 - ▶ really fancy
 - ▶ really fancy restaurants
 - ▶ at really fancy restaurants
 - ▶ eat at really fancy restaurants
- ▶ We refer to these meaningful groupings as **constituents** of a sentence.

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Lexical categories

Lexical categories are simply word classes, or what you may have heard as **parts of speech**. The main ones are:

- ▶ verbs: *eat, drink, sleep, ...*
- ▶ nouns: *gas, food, lodging, ...*
- ▶ adjectives: *quick, happy, brown, ...*
- ▶ adverbs: *quickly, happily, well, westward*
- ▶ prepositions: *on, in, at, to, into, of, ...*
- ▶ determiners/articles: *a, an, the, this, these, some, much, ...*

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Determining lexical categories

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Closed & Open classes

- ▶ We can add words to some classes, but not to others. This also seems to correlate with whether a word is “meaningful” or just a **function word** = only meaning comes from its usage in a sentence.
- ▶ **Open classes:** new words can be easily added:
 - ▶ verbs
 - ▶ nouns
 - ▶ adjectives
 - ▶ adverbs
- ▶ **Closed classes:** new words cannot be easily added:
 - ▶ prepositions
 - ▶ determiners

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Phrasal categories

- ▶ What about phrases? Can we assign them categories?
- ▶ We can also look at their distribution and see which ones behave in the same way.
 - ▶ The joggers ran through the park.
- ▶ What other phrases can we put in place of *The joggers*?

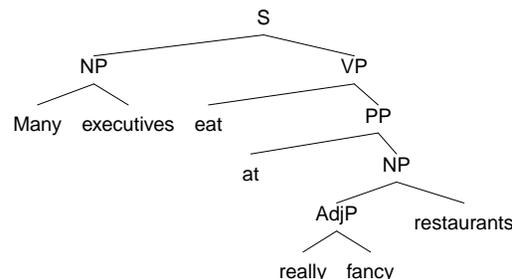
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Phrasal categories (cont.)

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Building a tree

Other phrases work similarly (S = sentence, VP = verb phrase, PP = prepositional phrase, AdjP = adjective phrase):



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Phrase Structure Rules

- ▶ We can give rules for building these phrases. That is, we want a way to say that a determiner and a noun make up a noun phrase, but a verb and an adverb do not.
- ▶ **Phrase structure rules** are a way to build larger constituents from smaller ones.
 - ▶ e.g., $S \rightarrow NP VP$
This says:
 - ▶ A sentence (S) constituent is composed of a noun phrase (NP) constituent and a verb phrase (VP) constituent. (hierarchy)
 - ▶ The NP must precede the VP. (linear order)

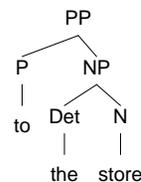
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Some other English rules

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Phrase Structure Rules and Trees

With every phrase structure rule, you can draw a tree for it.



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Phrase Structure Rules in Practice

Try analyzing these sentences and drawing trees for them, based on the phrase structure rules given above.

- ▶ The man in the kitchen drives a truck.
- ▶ That dang cat squeezed some fresh orange juice.
- ▶ The mouse in the corner by the stairs ate the cheese.

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Properties of Phrase Structure Rules

- ▶ **generative** = a schematic strategy that describes a set of sentences completely.
- ▶ potentially (**structurally**) **ambiguous** = have more than one analysis

(14) We need more intelligent leaders.

(15) Paraphrases:

- We need leaders who are more intelligent.
- Intelligent leaders? We need more of them!

- ▶ **hierarchical** = categories have internal structure; they aren't just linearly ordered.
- ▶ **recursive** = property allowing for a rule to be reapplied (within its hierarchical structure).

e.g., NP → NP PP

PP → P NP

The property of recursion means that the set of potential sentences in a language is **infinite**.

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Context-free grammars

A **context-free grammar** (CFG) is essentially a collection of phrase structure rules.

- ▶ It specifies that each rule must have:
 - ▶ a left-hand side (LHS): a single **non-terminal** element = (phrasal and lexical) categories
 - ▶ a right-hand side (RHS): a mixture of non-terminal and terminal elements
terminal elements = actual words
- ▶ A CFG tries to capture a natural language completely.

Why "context-free"? Because these rules make no reference to any context surrounding them. i.e. you can't say "PP → P NP" when there is a verb phrase (VP) to the left.

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Pushdown automata

Pushdown automaton = the computational implementation of a context-free grammar.

It uses a **stack** (its memory device) and has two operations:

- ▶ **push** = put an element onto the top of a stack.
- ▶ **pop** = take the topmost element from the stack.

This has the property of being **Last In First Out (LIFO)**. So, when you have a rule like "PP → P NP", you push NP onto the stack and then push P onto it. If you find a preposition (e.g., *on*), you pop P off of the stack and now you know that the next thing you need is an NP.

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Parsing

So, using these phrase structure (context-free) rules and using something like a pushdown automaton, we can get a computer to **parse** a sentence = assign a structure to a sentence.

Do you parse top-down or bottom-up (or a mixture)?

- ▶ **top-down**: build a tree by starting at the top (i.e. S → NP VP) and working down the tree.
- ▶ **bottom-up**: build a tree by starting with the words at the bottom and working up to the top.

There are many, many parsing techniques out there.

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Writing grammar correction rules

So, with context-free grammars, we can now write some correction rules, which we will just sketch here.

- ▶ *A baseball teams were successful.*

A followed by PLURAL NP: change *A* → *The*

- ▶ *John at the taco.*

The structure of this isolated sentence is NP PP, but that doesn't make up a whole sentence. We need a verb somewhere.

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Is this really how spell checkers work?

As far as we know, yes, but:

- ▶ Many spell checkers are proprietary and the way they work is kept secret; we don't know how they work exactly, which hampers research and thereby progress.
- ▶ Others, such as aspell and ispell, are **open source** spell checkers, meaning that anyone can
 - ▶ contribute to their further development, and
 - ▶ see how they work, which makes it possible to understand exactly what they will and what they won't catch.

(cf. <http://aspell.sourceforge.net/> and <http://fm-g-www.cs.ucla.edu/fm-g-members/geoff/ispell.html>)

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Dangers of spelling and grammar correction

- ▶ The more we depend on spelling correctors, the less we try to correct things on our own. But spell checkers are not 100%
- ▶ A study at the University of Pittsburgh found that students made **more** errors when using a spell checker!

	high SAT scores	low SAT scores
use checker	16 errors	17 errors
no checker	5 errors	12.3 errors

(cf., <http://www.wired.com/news/business/0,1367,58058,00.html>)

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A Poem on the Dangers of Spell Checkers

Michael Livingston

*Eye halve a spelling chequer
It came with my pea sea.
It plainly marques four my revue
Miss steaks eye kin knot sea.
Eye strike a key and type a word
And weight four it two say
Weather eye am wrong oar write
It shows me strait a weigh.
As soon as a mist ache is maid
It nose bee fore two long
And eye can put the error rite
Its rare lea ever wrong.
Eye have run this poem threw it
I am shore your pleased two no
Its letter perfect awl the weigh
My chequer tolled me sew.*

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