WHENEVER I LEARN A NEW SKILL I CONCOCT ELABORATE FANTASY SCENARIOS WHERE IT LETS ME SAVE THE DAY.
OH NO! THE KILLER MUST HAVE FOLLOWED HER ON VACATION!
BUT TO FIND THEM WE'D HAVE TO SEARCH THROUGH 200 MB OF EMAILS LOOKING FOR SOMETHING FORMATTED LIKE AN ADDRESS!
IT'S HOPELESS!
EVERYBODY STAND BACK.
I KNOW REGULAR EXPRESSIONS.
PERL!
TAP TAP

https://xkcd.com/208/

CS 1671 / CS 2071 / ISSP 2071
Human Language Technologies

Session 4: Words, tokens and preprocessing

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January 26, 2026

University of Pittsburgh | School of Computing and Information

Course logistics: quiz

- First in-class quiz is **this Wed Jan 28**
  - Covers readings from all the sessions up to that point
  - Looking over the reading is a great way to prepare
  - Session 4: J+M 2-2.6, 2.8, 2.10
  - Can cover content assigned in reading that is not discussed in class
  - Content from other sessions will not be included
- ~4 questions
- Conceptual, not programming
- Lowest quiz score in the course will be dropped
- Quizzes are 15% of your course grade total

Course logistics: quiz

- In class on Canvas, 10 minutes to complete it (1-1:10pm)
- Allowed resources
  - Textbook
  - Your notes (on a computer or physical)
  - Course slides and website
- Resources not allowed
  - Generative AI
  - Internet searches

Course logistics

- Homework 1 will be released soon (tomorrow or Wed). Will be **due Feb 12**
- Please remind me of your name before asking or answering a question

PyLing

Pitt Python Linguistics Group

- Computational linguistics group on campus
- Practice NLP skills related to this class with fun tutorials and guest speakers (with food, too!)
- Next meeting is **Wed Jan 28, 6-7:15pm at CL 2818** (linguistics department conference room)
    - Meeting topic: text analysis of NLP conference proceedings (how much are dominated by LLMs? What other areas are prevalent?)
- Contact Na-Rae Han, naraehan@pitt.edu to get on their mailing list

Overview: Words, tokens and preprocessing

- Words and corpora
- Morphemes
- Tokenization and subword tokenization
- Regular expressions
- Other text preprocessing
- Coding activity: preprocessing Airbnb listings

NLP terminology: words and corpora

How many words in this phrase?

they lay back on the San Francisco grass and looked at the stars and their

- How many?
  - 15 tokens (or 14 if you count "San Francisco" as one)
  - 13 types (or 12) (or 11?)
- **Type**: a unique word in the vocabulary
- **Token**: an instance of a word type in running text
- **Lemma**: same stem, part of speech, rough word sense
  - cat and cats = same lemma
- **Wordform**: the full inflected surface form
  - cat and cats = different wordforms

Slide adapted from Jurafsky & Martin

How many words in a corpus?

Corpus: a (machine-readable) collection of texts

N = number of tokens

V = vocabulary = set of types, $|V|$ is size of vocabulary

	Tokens = N	Types = |V|
Switchboard phone conversations	2.4 million	20 thousand
Shakespeare	884,000	31 thousand
COCA	440 million	2 million
Google N-grams	1 trillion	13+ million

Slide adapted from Jurafsky & Martin

Corpora vary along dimensions like

- Texts don't appear out of nowhere!
- **Language**: 7097 languages in the world
- **Variety**, like African American Language varieties.
  - AAE Twitter posts might include forms like "*iont*" (*I don't*)
- **Code switching**, e.g., Spanish/English, Hindi/English:

  Por primera vez veo a @username actually being helpful! It was beautiful:)

  [For the first time I get to see @username actually being helpful! it was beautiful:)]

  dost tha or ra- hega ... dont wory ... but dherya rakhe

  [“he was and will remain a friend ... don’t worry ... but have faith”]

- **Genre:** newswire, fiction, scientific articles, Wikipedia
- **Author Demographics**: writer's age, gender, ethnicity, SES
- Corpus datasheets [Bender & Friedman 2018, Gebru+ 2020] ask about this information

Slide adapted from Jurafsky & Martin

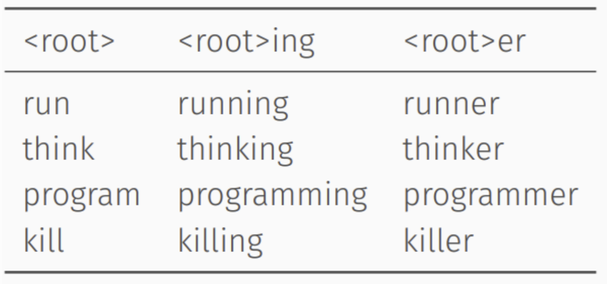
Morphemes

Morphemes

- Morphemes: small meaningful units that make up words
  - Roots: The core meaning-bearing units
  - Affixes: Parts that adhere to roots

un-think-able; kitten-s

- Affixes can add grammatical meaning (inflections, 2nd column) or modify semantic meaning (derivations, 3rd column)



<root>	<root>ing	<root>er
run	running	runner
think	thinking	thinker
program	programming	programmer
kill	killing	killer

Slide adapted from Jurafsky & Martin, David Mortensen

Dealing with complex morphology is necessary for many languages

- e.g., the Turkish word:
  Uygarlastiramadiklarimizdanmissinizcasina
  '(behaving) as if you are among those whom we could not civilize'

  Uygar 'civilized' + las 'become'
  + tir 'cause' + ama 'not able'
  + dik 'past' + lar 'plural'
  + imiz '1pl' + dan 'abl'
  + mis 'past' + siniz '2pl' + casina 'as if'

Slide adapted from Jurafsky & Martin

Tokenization

Why tokenize?

- Using a deterministic series of tokens means systems can be compared equally
  - Systems agree on the length of a string
- Eliminates the problem of unknown words

Space-based tokenization

- A very simple way to tokenize
- For languages that use space characters between words
  - Arabic, Cyrillic, Greek, Latin, etc., based writing systems
- Segment off a token between instances of spaces

Issues in Tokenization

- Can't just blindly remove punctuation:
  - m.p.h., Ph.D., AT&T, cap’n
  - prices ($45.55)
  - dates (01/02/06)
  - URLs (http://www.pitt.edu)
  - hashtags (#nlproc)
  - email addresses (someone@cs.colorado.edu)
- Clitic: a word that doesn't stand on its own
  - "are" in we're, French "je" in j'ai, "le" in l'honneur
- When should multiword expressions (MWE) be words?
  - New York, rock ’n’ roll

Slide adapted from Jurafsky & Martin

Tokenization in languages without spaces between words

- Many languages (like Chinese, Japanese, Thai) don't use spaces to separate words!
- How do we decide where the token boundaries should be?

Word tokenization in Chinese

- Chinese words are composed of characters called "hanzi" (or sometimes just "zi")
- Each one represents a meaning unit called a morpheme
- Each word has on average 2.4 of them.
- But deciding what counts as a word is complex and not agreed upon.

How to do word tokenization in Chinese?

姚明进入总决赛 “Yao Ming reaches the finals”

3 words?

姚明	进入	总决赛
YaoMing	reaches	finals

5 words?

姚	明	进入	总	决赛
Yao	Ming	reaches	overall	finals

7 characters? (don't use words at all):

姚	明	进	入	总	决	赛
Yao	Ming	enter	enter	overall	decision	game

Slide adapted from Jurafsky & Martin

Word tokenization / segmentation

- In Chinese NLP it's common to just treat each character (zi) as a token.
  - So the **segmentation** step is very simple
- In other languages (like Thai and Japanese), more complex word segmentation is required.
  - The standard algorithms are neural sequence models trained by supervised machine learning.

Slide adapted from Jurafsky & Martin

Subword tokenization & BPE

Another option for text tokenization

- **Use the data** to tell us how to tokenize.
- **Subword tokenization** (because tokens can be parts of words as well as whole words)
- Many modern neural NLP systems (like LLMs) use this to handle unknown words
    - Algorithms include Byte Pair Encoding (BPE), WordPiece, etc
- 2 parts:
    - A token learner that takes a raw training corpus and induces a vocabulary (a set of tokens).
    - A token segmenter that takes a raw test sentence and tokenizes it according to that vocabulary

Slide adapted from Jurafsky & Martin

Byte Pair Encoding (BPE) token learner

Iteratively merge frequent neighboring tokens to create longer tokens.

Start with all characters
Repeat:

- Choose most frequent neighboring pair ('A', 'B')
- Add a new merged symbol ('AB') to the vocabulary
- Replace every 'A' 'B' in the corpus with 'AB'.

Until *k* merges

Vocabulary

[A, B, C, D, E]

[A, B, C, D, E, AB]

[A, B, C, D, E, AB, CAB]

Corpus

A B D C A B E C A B

AB D C AB E C AB

AB D CAB E CAB

Slide adapted from Jurafsky & Martin

BPE token learner

Original (very fascinating🙄) corpus:

low low low low low lowest lowest newer newer newer newer newer newer wider wider wider new new

Split on whitespace, add end-of-word tokens _

corpus	
5	l o w _
2	l o w e s t _
6	n e w e r _
3	w i d e r _
2	n e w _

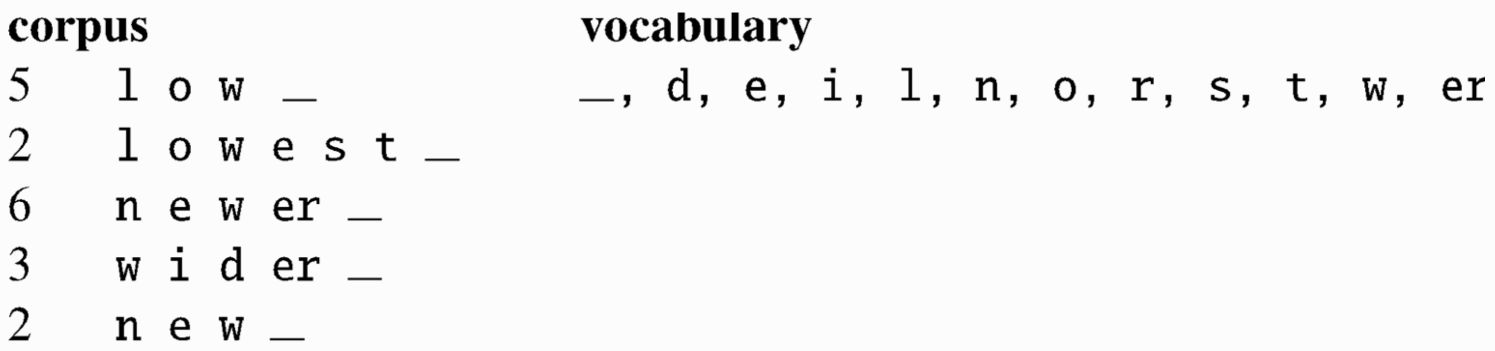
vocabulary

_, d, e, i, l, n, o, r, s, t, w

Slide adapted from Jurafsky & Martin

BPE token learner

- Merge e r to er



corpus		vocabulary
5	l o w _	_, d, e, i, l, n, o, r, s, t, w, er
2	l o w e s t _	
6	n e w er _	
3	w i d er _	
2	n e w _	

- Merge er _ to er_
- Merge n e to ne

Slide adapted from Jurafsky & Martin

BPE token learner

The next merges are:

Merge	**Current Vocabulary**
(ne, w)	_, d, e, i, l, n, o, r, s, t, w, er, er_, ne, new
(l, o)	_, d, e, i, l, n, o, r, s, t, w, er, er_, ne, new, lo
(lo, w)	_, d, e, i, l, n, o, r, s, t, w, er, er_, ne, new, lo, low
(new, er_)	_, d, e, i, l, n, o, r, s, t, w, er, er_, ne, new, lo, low, newer_
(low, _)	_, d, e, i, l, n, o, r, s, t, w, er, er_, ne, new, lo, low, newer_, low_

Slide adapted from Jurafsky & Martin

BPE token segmenter algorithm

- On the test data, run each merge learned from the training data:
    - Greedily, in the order we learned them
- So merge every e r to er, then merge er _ to er_, etc.
- Result:
    - Test set "n e w e r _" would be tokenized as a full word
    - Test set "l o w e r _" would be two tokens: "low er_"

Regular expressions (regex)

Regular expressions

- A formal language for specifying text strings
- How can we search for any of these?
  - woodchuck
  - woodchucks
  - Woodchuck
  - Woodchucks

Slide adapted from Jurafsky & Martin

Regular expressions: Disjunctions (OR)

- Letters inside square brackets []

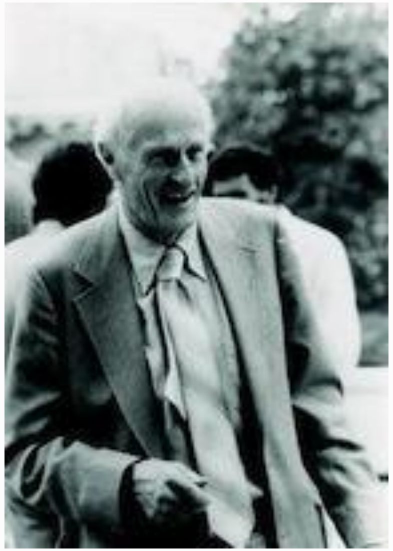
Pattern	Matches
`[wW]oodchuck`	Woodchuck, woodchuck
`[1234567890]`	Any digit

- Ranges `[A-Z] [a-z] [0-9]`
- Negations `[^A-Z]`
  - Carat means negation only when first in []
- Sequence disjunctions with pipe |
  - `groundhog|woodchuck`

Slide adapted from Jurafsky & Martin

Regular expression wildcards: *+.

Pattern	Matches	
`oo*h`	0 or more of previous char	oh ooh oooh ooooh
`o+h`	1 or more of previous char	oh ooh oooh ooooh
`beg.n`	Any char	begin begun begun beg3n


Stephen C Kleene

Regular expression example

- Find all instances of the word “the” in a text.

```
the
```

- Misses capitalized examples

```
[tT]he
```

- Incorrectly returns "other" or "theology"

```
[^a-zA-Z][tT]he[^a-zA-Z]
```

Slide adapted from Jurafsky & Martin

Simple Application: ELIZA

- Early NLP system that imitated a Rogerian psychotherapist [Weizenbaum 1966]
- Uses pattern matching to match phrases

```
“I need X”
```

- and translates them into, e.g.

```
“What would it mean to you if you got X?
```

Simple Application: ELIZA

Men are all alike.
IN WHAT WAY

They're always bugging us about something or other.
CAN YOU THINK OF A SPECIFIC EXAMPLE

Well, my boyfriend made me come here.
YOUR BOYFRIEND MADE YOU COME HERE

He says I'm depressed much of the time.
I AM SORRY TO HEAR YOU ARE DEPRESSED

Slide adapted from Jurafsky & Martin

How ELIZA works

```
.* I’M (depressed|sad) .* → I AM SORRY TO HEAR YOU ARE \1

.* all .* → IN WHAT WAY?

.* always .* → CAN YOU THINK OF A SPECIFIC EXAMPLE?/
```

Slide adapted from Jurafsky & Martin

Regular expressions summary

- Regular expressions play a surprisingly large role in NLP
  - Sophisticated sequences of regular expressions are often the first model for any text processing text
- For hard tasks, we use machine learning classifiers
  - But regular expressions are still used for pre-processing, or used to extract features for the classifiers

Slide adapted from Jurafsky & Martin

Other text preprocessing (normalization)

Case folding (lowercasing)

- Applications like information retrieval: reduce all letters to lowercase
  - Since users tend to use lowercase
  - Possible exception: upper case in mid-sentence?
    - e.g., *General Motors*
    - *Fed* vs. *fed*
    - *SAIL* vs. *sail*
- For sentiment analysis, MT, information extraction
  - Case is helpful (*US* versus *us* is important)

Lemmatization and stemming

Lemmatization: reducing words to their **lemmas**: their shared root, dictionary headword form:

- *am, are, is → be*
- *car, cars, car's, cars' → car*
- Spanish quiero (‘I want’), quieres (‘you want’)
  → querer ‘want'
- *He is reading detective stories*
  → *He be read detective story*

Stemming: reducing words to their “stems”, chopping off affixes crudely. You aren’t left with true words, but is fast to run.

- *This was an accurate, complete copy of the map*
  → *Thi was an accur complet copi of the map*

Slide adapted from Jurafsky & Martin

Stopword removal

- Do we want to keep "function words" like *the*, *of*, *and*, *I*, *you*, etc?
- Sometimes no (information retrieval)
- Sometimes yes (authorship attribution)

Conclusion: Words, tokens, and preprocessing

- Word types are unique words
- Morphemes are the smallest meaning-bearing units within words
- Unicode represent characters for many languages and scripts in code points, which can be encoded into bytes with UTF-8
- Tokenization: splitting texts into sequences of words
  - Subword tokenization finds tokens based on frequencies of sequences of characters in data
- Regular expressions match flexible sequences of characters
- Lemmatization: normalizing words to their dictionary roots
- Stopwords are function words like “the”, “a”, “and”, “of”, etc that are often ignored in NLP applications

Coding activity:
Preprocessing Airbnb listings

Load in-class notebook

1. Go to this nbgitpuller link (also available on course website)
2. Log in with your Pitt username if necessary
3. Start a server with **TEACH – 6 CPUs, 48 GB**
4. Load custom environment at **/ix1/cs1671-2026s/class_env**
5. This should pull the cs1671_spring2026_jupyterhub folder into your JupyterLab
6. Open **session4_preprocessing.ipynb**