CS3245

Information Retrieval

Lecture 3: Postings lists and Choosing terms

3

Last Time: Basic IR system structure

- Basic inverted indexes:
  - In memory dictionary and on disk postings

BRUTUS	⟶	1	2	4	11	31	45	173	174	
CAESAR	⟶	1	2	4	5	6	16	57	132	...
CALPURNIA	⟶	2	31	54	101					

  - Key characteristic: Sorted order for postings
- Boolean query processing
  - Intersection by linear time “merging”
  - Simple optimizations by expected size
- Overview of course topics

Today: Zoom In on Postings Data Structure and How to Define Terms

- Postings
  - Faster merges: skip lists
  - Positional postings and phrase queries

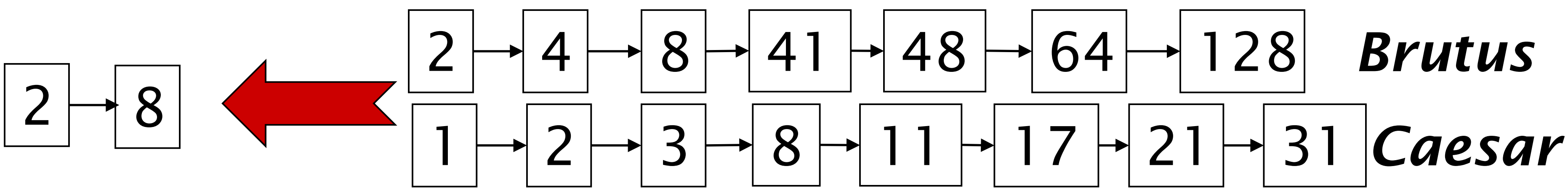
- Preprocessing to form the term vocabulary
  - Documents
  - Tokenization
  - What *terms* do we put in the index?

FASTER POSTINGS MERGES: SKIP POINTERS / SKIP LISTS

Blanks on slides, you may want to fill in

Recall basic merge

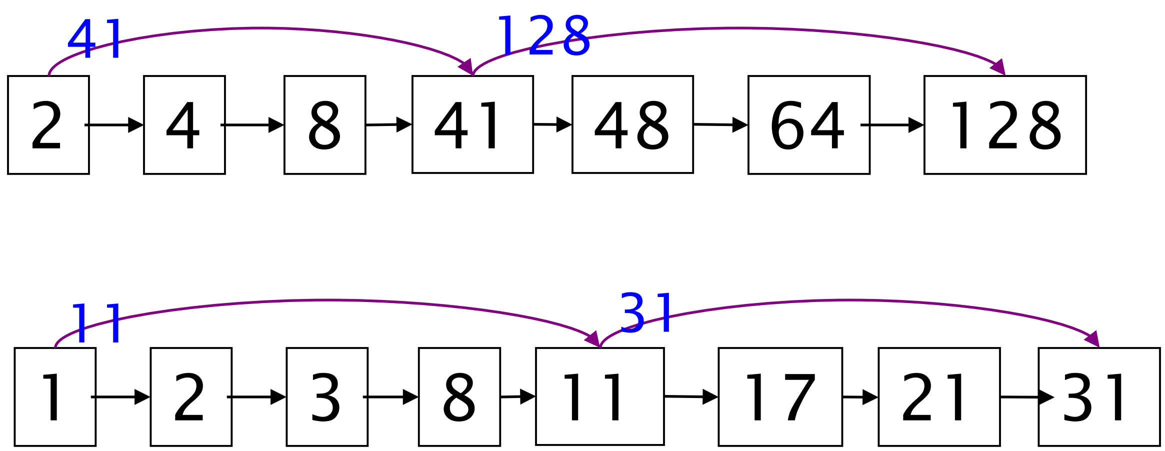
- Walk through the two postings simultaneously, in time linear in the total number of postings entries



If the list lengths are *m* and *n*, the merge takes O(*m*+*n*) operations.

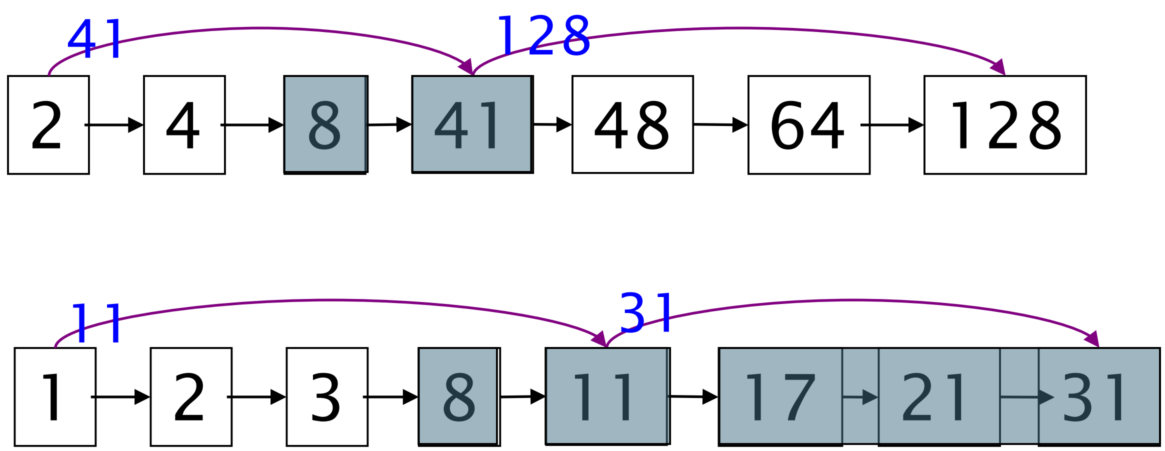
Can we do better?

Adding skip pointers to postings



- Done at indexing time.
- To skip postings that will not figure in the search results.
- How to do it? And where do we place skip pointers?

Query processing with skip pointers



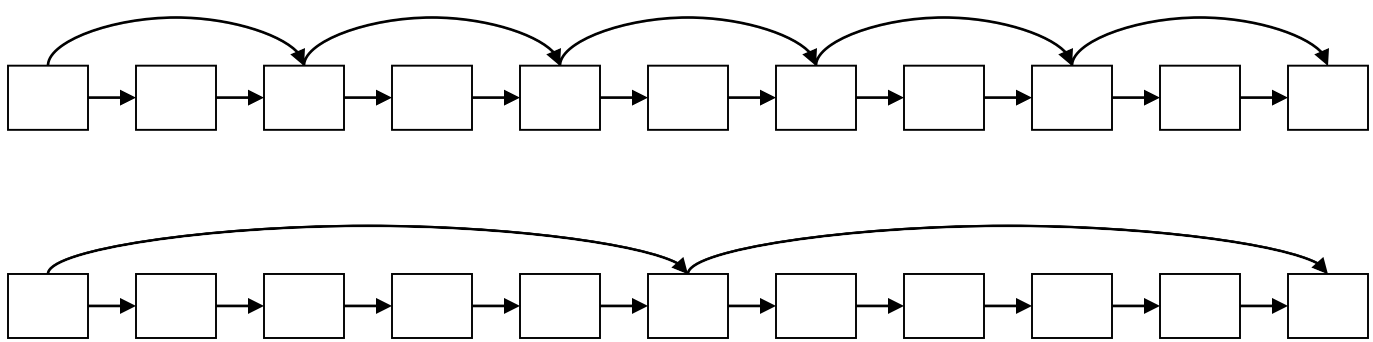
Suppose we've stepped through the lists until we process **8** on each list. We match it and advance.

We then have **41** and **11** on the lower. **11** is smaller.

But the skip successor of **11** on the lower list is **31**, so we can skip ahead past the intervening postings.

Where do we place skips?

- Tradeoff:
  - More skips $\rightarrow$ shorter skip spans $\Rightarrow$ more likely to skip. But lots of comparisons to skip pointers.
  - Fewer skips $\rightarrow$ few pointer comparison, but then long skip spans $\Rightarrow$ few successful skips.



Placing skips

- Simple heuristic: for postings of length *L*, use $\sqrt{L}$ evenly-spaced skip pointers.
  - This ignores the distribution of query terms.
  - Easy if the index is relatively static; harder if *L* keeps changing because of updates.

- This definitely used to help; with modern hardware it may not (Bahle et al. 2002) unless memory-based
  - The I/O cost of loading a bigger postings list can outweigh the gains from quicker in-memory merging!

PHRASE QUERIES AND POSITIONAL INDICES

Phrase queries

- Want to be able to answer queries such as ***"stanford university"*** – as a phrase
- Thus the sentence *"I went to university at Stanford"* is not a match.
  - The concept of phrase queries has proven easily understood by users; one of the few "advanced search" ideas that works (for users; they "get it")
  - Many more queries are *implicit phrase queries*
- For this, it no longer suffices to store only

<*term* : *docs*> entries

A first attempt: Biword indexes

- Index every consecutive pair of terms in the text as a phrase: bigram model using words
- For example the text "Friends, Romans, Countrymen" would generate the biwords
  - ***friends romans***
  - ***romans countrymen***
- Each of these biwords is now a dictionary term
- Two-word phrase query-processing is now immediate.

Longer phrase queries

- Longer phrases be processed as a Boolean query on biwords:

  stanford university palo alto →

  stanford university *AND* ***university palo*** *AND* ***palo alto***

Without the docs, we cannot verify that the docs matching the above Boolean query do contain the phrase.

Can have false positives, why?

Extended biwords

- Parse the indexed text and perform part-of-speech-tagging (POST).
- Bucket the terms into (say) Nouns (N) and articles /prepositions (X).
- Call any string of terms of the form NX*N an extended biword.
  - Each extended biword is now a term in the dictionary.
- Example: ***catcher in the rye***

  N X X N
- Query processing: parse it into N’s and X’s
  - Segment query into enhanced biwords
  - Look up in index: ***catcher rye***

Issues for biword indexes

- False positives, as noted before
- Index blowup due to bigger dictionary
  - Infeasible for more than biwords, big even for them

- Biword indexes are not the standard solution (for all biwords) but can be part of a compound strategy

Solution 2: Positional indexes

- In the postings, store, for each ***term*** the position(s) in which tokens of it appear:

<***term****,* number of docs containing ***term***;

doc1: position1, position2 … ;

doc2: position1, position2 … ;

etc.>

Positional index example

<***be***: 993427;
1: 7, 18, 33, 72, 86, 231;
2: 3, 149;
4: 17, 191, 291, 430, 434;
5: 363, 367, …>

Quick check:
Which of docs 1,2,4,5 could contain "***to be or not to be***"?

- For phrase queries, we use a merge algorithm recursively at the document level
- Now need to deal with more than just equality

Processing a phrase query

- Extract inverted index entries for each distinct term: ***to, be, or, not.***
- Merge their *doc:position* lists to enumerate all positions with "***to be or not to be***".
  - ***to***:
    - *2*:1,17,74,222,551; *4*:8,16,190,429,433; *7*:13,23,191; ...
  - ***be***:
    - *1*:17,19; *4*:17,191,291,430,434; *5*:14,19,101; ...
- Same general method for proximity searches

Proximity queries

- LIMIT! /3 STATUTE /3 FEDERAL /2 TORT
  - Again, here, /*k* means "within *k* words of".

- Clearly, positional indexes can be used for such queries; biword indexes cannot.

Positional index size

- We can compress position values/offsets, later in index compression
- Nevertheless, a positional index expands postings storage *substantially*
- Nevertheless, a positional index is now standardly used because of the power and usefulness of phrase and proximity queries … whether used explicitly or implicitly in a ranking retrieval system.

Positional index size

- Need an entry for each occurrence, not just once per document
- Index size depends on average document size **Why?**
  - Average web page has < 1000 terms
  - SEC filings, books, even some epic poems … easily 100,000 terms
- Consider a term with frequency 0.1%

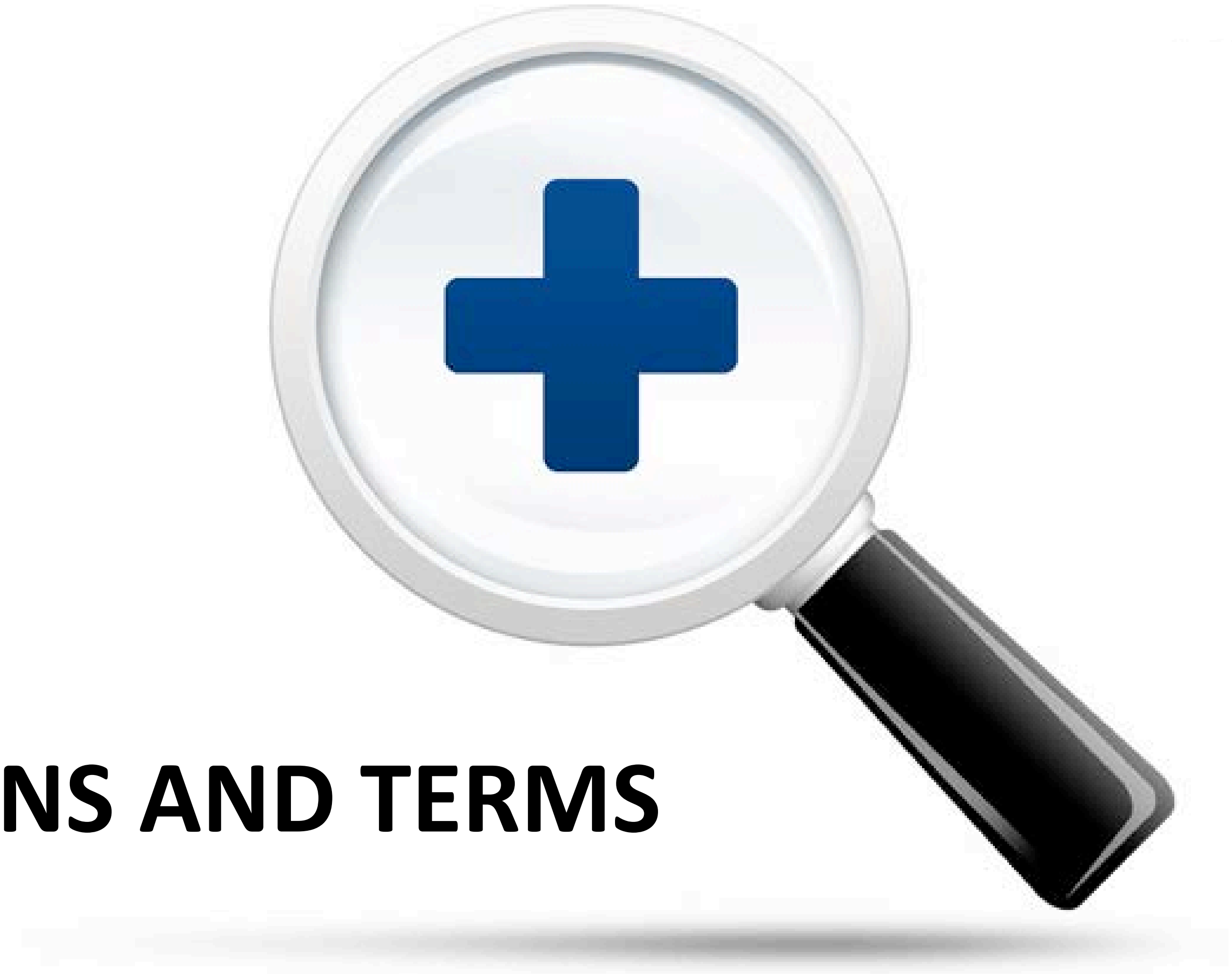
Document size	Postings	Positional postings
1000	1	1
100,000	1	100

Rules of thumb

- A positional index is 2–4x larger as a non-positional index
- Positional index size is ~35–50% of the volume of original text
- Caveat: all of this holds for "English-like" languages

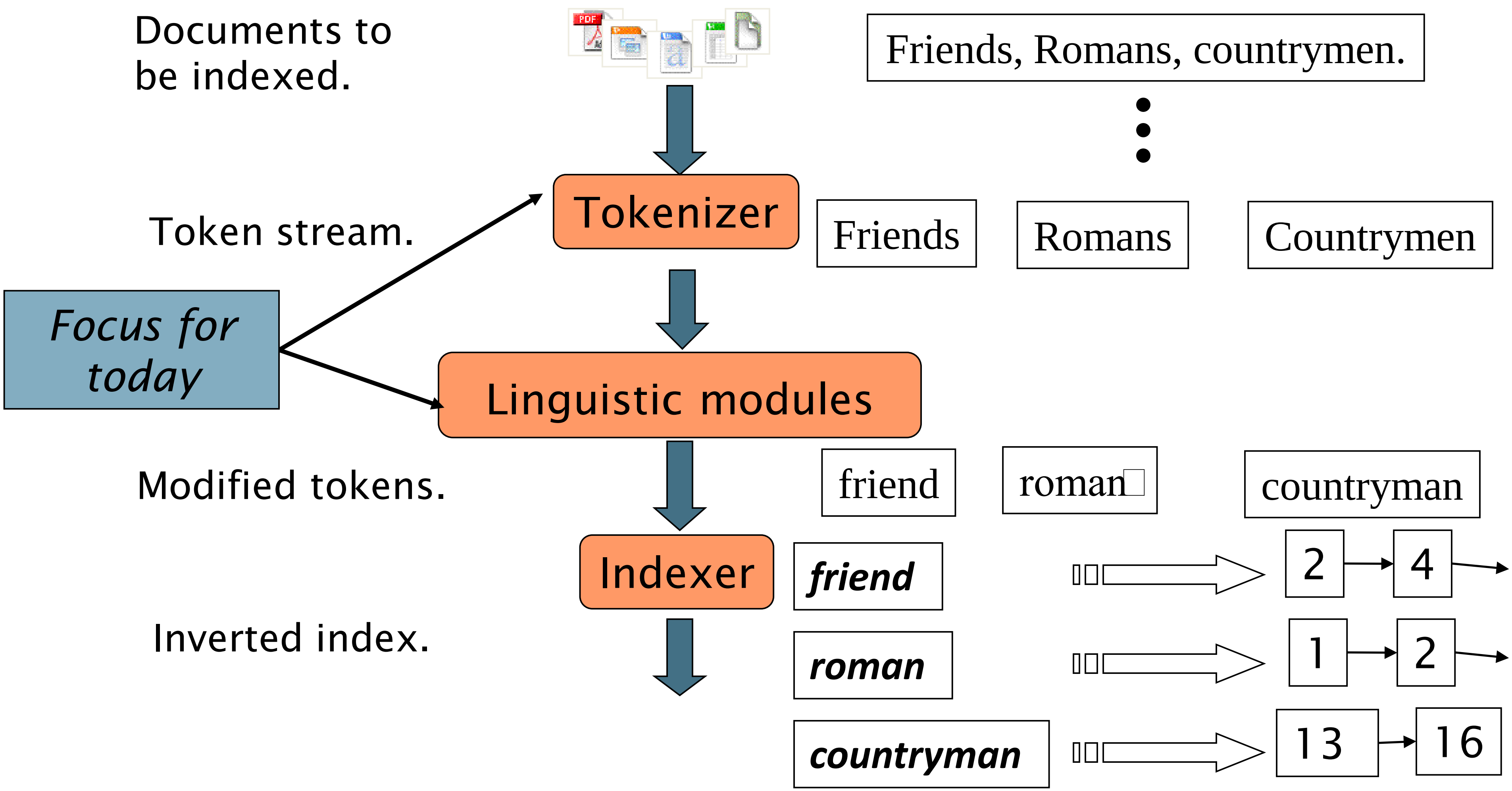
Combining biword and positional indices

- These two approaches can be profitably combined
  - For particular oft-queried phrases ("Michael Jackson", "Britney Spears"), it is inefficient to keep on merging positional postings lists
    - Even more so for phrases like "The Who"
- Williams et al. (2004) evaluate a more sophisticated mixed indexing scheme
  - Added a next word index, recording words that follow a given word
  - A typical web query mixture was executed in ¼ of the time of using just a positional index
  - Required 26% more space over just having a positional index



TOKENS AND TERMS

Recap: Inverted index construction



First step: extracting the text

- What format is it in?
  - PDF / Word / Excel / HTML?
- What language is used?
- What character set is used?

- Beyond the scope of this course, but most of the time are done heuristically, or assumed to be non-issues with help from vendor libraries

Complications: Format / Language

- Collection may have docs in different languages
  - A single index may have to contain terms of several languages.
- Even single documents may have multiple languages / formats
  - French email with a German PDF attachment
  - Crazy lecturer's homework assignment

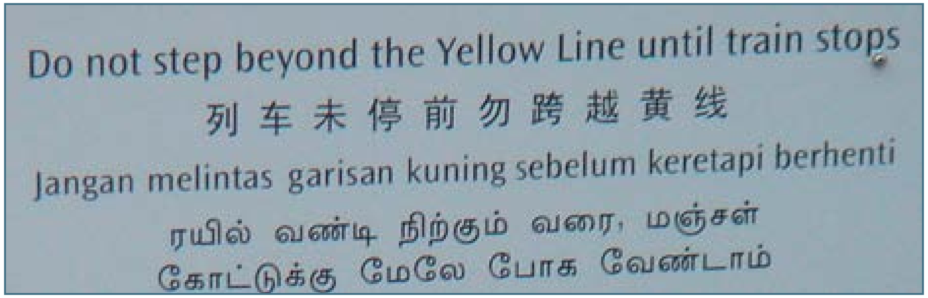


Photo Credits: Wikipedia commons

Blanks on slides, you may want to fill in

Indexing Granularity

- What should the unit document be?
  - A file?
  - An email? (Perhaps one of many in a mailbox / thread)
  - An email with 5 attachments?
  - A group of files (PPT or LaTeX as HTML pages)

Collection? Set of documents? A document? Section of a document? Paragraph? Sentence? Word?

- Too coarse grained

- Too fine grained

Need to decide based on projected use of the IR engine

Tokenization

- Input: "***Friends, Romans and Countrymen***"
- Output: Tokens
  - ***Friends***
  - ***Romans***
  - ***Countrymen***
- A token is an instance of a sequence of characters grouped together as a useful semantic unit
- Each token is a candidate for an index entry, after further processing
- But what are valid tokens to emit?

(English) Tokenization: Issues in Handling Apostrophe, Hyphens and Spaces

- ***Finland's capital*** → ***Finland***? ***Finlands***? ***Finland's***?
- ***Aren't*** → ***Aren*** and ***t***? ***Are*** and ***n't***? ***Are*** and ***not***?
- ***Hewlett-Packard*** → ***Hewlett*** and ***Packard***?
  - ***state-of-the-art***: break up hyphenated sequence.
  - ***co-education***
  - ***lowercase***, ***lower-case***, ***lower case***: all acceptable forms
- ***San Francisco***: one token or two?
  - How did you decide it is one token?
- What about ***Los Angeles-San Francisco***?

Numbers, dates and other dangerous things

- ***3/20/13*** ***Mar. 12, 2013*** ***20/3/13***
- ***55 B.C.***
- ***B-52***
- ***My PGP key is 324a3df234cb23e***
- ***(800) 234-2333***
  - Often have embedded spaces, punctuation
  - Older IR systems may not index numbers
    - But often very useful: think about things like looking up error codes / product codes on the web
  - IR systems often opt to index "meta-data" separately
    - Creation date, format, etc.

Tokenization: language issues

- French
  - ***L'ensemble*** → one token or two?
    - ***L*** ? ***L'*** ? ***Le*** ?
    - Want ***l'ensemble*** to match with ***un ensemble***
      - Until at least 2003, it didn't on Google
        - Internationalization!
- German noun compounds are not segmented
  - ***Lebensversicherungsgesellschaftsangestellter***
    life insurance company employee
  - German retrieval systems benefit greatly from a **compound splitter** module, which can give a 15% performance boost

Tokenization: language issues

- Chinese and Japanese have no spaces between words:
  - 莎拉波娃现在居住在美国东南部的佛罗里达。
    Shā lā bō wá xiànzài jūzhù zài měiguó dōngnán bù de fóluólǐdá
  - Not always guaranteed a unique tokenization
- Japanese intermingles multiple writing systems
  - Dates / amounts in multiple formats

Fōchun gohyaku-sha wa jōhō fusoku no tame jikan ata gozyu man-doru (yaku rokusen man-en)

フォーチュン500社は情報不足のため時間あた$500K(約6,000万円)

Katakana Hiragana Kanji Romaji

  - End-user often express queries entirely in Hiragana!

Tokenization: language issues

- Arabic (or Hebrew) is written right to left, but certain items (e.g., numbers) are written left to right
- Words are separated, but letter forms within a word form complex ligatures

fi → ﬁ
fl → ﬂ

Example of a ligature in modern English

استقلت الجزائر في سنة 1962 بعد 132 عاما من الاحتلال الفرنسي.

French occupation | years | 132 | after | 1962 | independence | Algeria | achieved

"Algeria achieved its independence in 1962 after 132 years of French occupation"

← → ← → ← start

With Unicode, the surface presentation is complex (left to the renderer to solve), but the stored form is in linear order

Unicode in XKCD

Collaborative editing can quickly become a textual rap battle fought with increasingly convoluted invocations of U+202a to U+202e. #geekout

http://xkcd.com/1137/

Stop words

- With a stop list, we exclude the most common words from the dictionary. Intuition:
  - They have little semantic content: *the, a, and, to, be*
- But the trend is away from doing this:
  - Good compression techniques means the space for including stopwords in a system is very small
  - Good query optimization techniques mean you pay little at query time for including stop words.
  - You need them for:
    - Phrase queries: "King of Denmark"
    - Various song titles, etc.: "Let it be", "To be or not to be"
    - "Relational" queries: "flights to London"

Normalization to terms

- We need to "normalize" words in indexed text as well as query words into the same form
  - We want to match ***U.S.A.*** and ***USA***
- Result is terms: a term is a (normalized) word type, which is an entry in our IR system dictionary
- Often, we implicitly define equivalence classes of terms by, e.g.,
  - deleting periods to form a term
    - ***U.S.A., USA*** ▸ ***USA***
  - deleting hyphens to form a term
    - ***anti-discriminatory, antidiscriminatory*** ▸ ***antidiscriminatory***

Normalization: other languages

- Accents: e.g., French ***résumé*** vs. ***resume*.**
- Umlauts: e.g., German: ***Tuebingen*** vs. ***Tübingen***
- Most important criterion:
  - How are your users like to write their queries for these words?
  - Even in languages that have accents, users often may not type them
  - Thus, often best to normalize to a de-accented term
    - ***Tuebingen, Tübingen, Tubingen* ▸ *Tubingen***

Normalization: other languages

- Normalization of things like date forms
  - ***7月30日 vs. 7/30***
  - use of kana (alphabet) vs. Kanji (Chinese chars) in JP
- Tokenization and normalization often depends on the language and so is intertwined with language detection

Morgen will ich in MIT …

Is this the German "mit"?

- Crucial: Need to "normalize" indexed text as well as query terms into the same form

Case folding

- Reduce all letters to lower case
  - exception: upper case in mid-sentence?
    - e.g., ***General Motors***
    - ***Fed*** vs. ***fed***
    - ***SAIL*** vs. ***sail***
  - Often best to lowercase everything, since users' queries most often written this way
- (old) Google example:
  - Query ***C.A.T.***
  - #1 result is for "cat" (well, Lolcats) *not* Caterpillar Inc.
  - Still works for video

Normalization to terms

- An alternative to equivalence classing is to do asymmetric expansion
- An example of where this may be useful
  - Enter: ***window*** Search: ***window, windows***
  - Enter: ***windows*** Search: ***Windows, windows, window***
  - Enter: ***Windows*** Search: ***Windows***
- Potentially more powerful, but often less efficient

Thesauri and soundex

- Do we handle synonyms and homonyms?
  - E.g., by hand-constructed equivalence classes
    - ***car*** = ***automobile*** ***color*** = ***colour***
  - We can rewrite to form equivalence class terms
    - When the document contains ***automobile***, index it under ***car-automobile*** (and vice-versa)
  - Or we can expand a query
    - When the query contains ***automobile***, look under ***car*** as well
- What about spelling mistakes?
  - One approach is soundex (next week), which forms equivalence classes of words based on phonetic heuristics

Lemmatization

- Reduce inflectional/variant forms to base form
- E.g.,
  - *am, are, is* $\rightarrow$ *be*
  - *car, cars, car's, cars'* $\rightarrow$ *car*
- *the boy's cars are different colors* $\rightarrow$ *the boy car be different color*
- Lemmatization implies doing "proper" reduction to dictionary form

Stemming

- Reduce terms to their “roots” before indexing
- “Stemming” suggest crude affix chopping
  - language dependent
  - e.g., ***automate(s), automatic, automation*** all reduced to ***automat***.

for example compressed and compression are both accepted as equivalent to compress.

→

for exampl compress and compress ar both accept as equival to compress

Porter’s algorithm

- Most common algorithm for stemming English
  - Experiments suggest it’s at least as good as other stemming options
- Conventions + 5 phases of reductions
  - phases applied sequentially
  - each phase consists of a set of commands
  - sample convention: *Of the rules in a compound command, select the one that applies to the longest suffix.*

Typical rules in Porter

- *sses → ss*
- *ies → i*
- *ational → ate*
- *tional → tion*

Late phase rules in Porter check the length of the resulting word:

- *(m>1) EMENT →* “ ”
  - *replacement → replac*
  - *cement → cement*

Other stemmers

- Other stemmers exist, e.g., Lovins stemmer

  http://www.comp.lancs.ac.uk/computing/research/stemming/general/lovins.htm

  - Single-pass, longest suffix removal (about 250 rules)
- Lemmatizer – Full morphological analysis to return (dictionary) base form of word
  - At most modest benefits for retrieval
- Do stemming and other normalizations help?
  - English: very mixed results. Helps recall for some queries but harms precision on others
    - E.g., operating system ⇒ oper sys
  - Definitely useful for Spanish, German, Finnish, …
    - 30% performance gains for Finnish!

Language-specificity

- Many of the above features embody transformations that are
  - Language-specific, and often
  - Application-specific
- These are "plug-in" addenda to the indexing process
- Both open source and commercial plug-ins are available for handling them

- Shows the intertwining of NLP with IR
  Plug: take our NLP course next sem!

Summary

Zoomed in on three issues:

1. Postings: Skip lists

2. Phrase and Proximity Handling
   - Biword Indices
   - Positional Indices

3. What is a term?
   - Normalization
   - Stemming
   - Lemmatization
   - Language specific issues

Resources for today's lecture

- IIR 2
- MG 3.6, 4.3; MIR 7.2

- Skip Lists theory: Pugh (1990)
  - Multilevel skip lists give same O(log n) efficiency as trees
- H.E. Williams, J. Zobel, and D. Bahle. 2004. "Fast Phrase Querying with Combined Indexes", ACM Transactions on Information Systems.
  - http://www.seg.rmit.edu.au/research/research.php?author=4
- D. Bahle, H. Williams, and J. Zobel. 2002. Efficient phrase querying with an auxiliary index. SIGIR, pp. 215-221.
- Porter's stemmer: http://www.tartarus.org/~martin/PorterStemmer/
- Stemming and Lemmatization in NLTK