Introduction to Information Retrieval

http://informationretrieval.org

IIR 3: Dictionaries and tolerant retrieval

Hinrich Schütze

Institute for Natural Language Processing, University of Stuttgart

2011-10-25

Overview

Outline

Type/token distinction

- Token – an instance of a word or term occurring in a document
- Type – an equivalence class of tokens
- *In June, the dog likes to chase the cat in the barn.*
- 12 word tokens, 9 word types

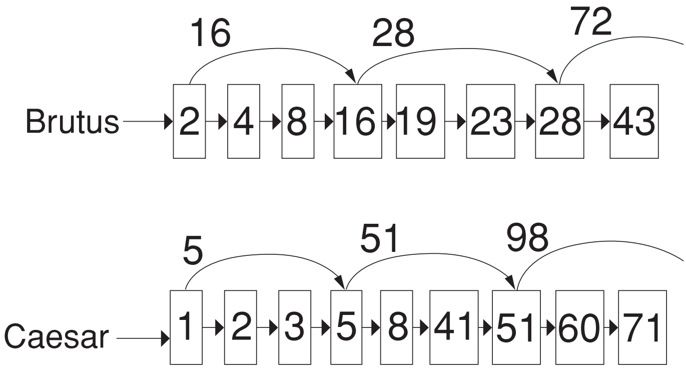
Problems in tokenization

- What are the delimiters? Space? Apostrophe? Hyphen?
- For each of these: sometimes they delimit, sometimes they don't.
- No whitespace in many languages! (e.g., Chinese)
- No whitespace in Dutch, German, Swedish compounds (*Lebensversicherungsgesellschaftsangestellter*)

Problems with equivalence classing

- A term is an equivalence class of tokens.
- How do we define equivalence classes?
- Numbers (3/20/91 vs. 20/3/91)
- Case folding
- Stemming, Porter stemmer
- Morphological analysis: inflectional vs. derivational
- Equivalence classing problems in other languages
  - More complex morphology than in English
  - Finnish: a single verb may have 12,000 different forms
  - Accents, umlauts

Skip pointers



Positional indexes

- Postings lists in a nonpositional index: each posting is just a docID
- Postings lists in a positional index: each posting is a docID and a list of positions
- Example query: *"to_1 be_2 or_3 not_4 to_5 be_6"*

TO, 993427:

$\langle$ 1: $\langle$7, 18, 33, 72, 86, 231$\rangle$;
2: $\langle$1, 17, 74, 222, 255$\rangle$;
4: $\langle$8, 16, 190, 429, 433$\rangle$;
5: $\langle$363, 367$\rangle$;
7: $\langle$13, 23, 191$\rangle$; ... $\rangle$

BE, 178239:

$\langle$ 1: $\langle$17, 25$\rangle$;
4: $\langle$17, 191, 291, 430, 434$\rangle$;
5: $\langle$14, 19, 101$\rangle$; ... $\rangle$

Document 4 is a match!

Positional indexes

- With a positional index, we can answer phrase queries.
- With a positional index, we can answer proximity queries.

Take-away

Take-away

- Tolerant retrieval: What to do if there is no exact match between query term and document term

Take-away

- Tolerant retrieval: What to do if there is no exact match between query term and document term
- Wildcard queries

Take-away

- Tolerant retrieval: What to do if there is no exact match between query term and document term
- Wildcard queries
- Spelling correction

Outline

Inverted index

For each term t, we store a list of all documents that contain t.

BRUTUS $\longrightarrow$ | 1 | 2 | 4 | 11 | 31 | 45 | 173 | 174 |

CAESAR $\longrightarrow$ | 1 | 2 | 4 | 5 | 6 | 16 | 57 | 132 | ... |

CALPURNIA $\longrightarrow$ | 2 | 31 | 54 | 101 |

⋮

dictionary **postings**

Inverted index

For each term *t*, we store a list of all documents that contain *t*.

BRUTUS	$\longrightarrow$	1 | 2 | 4 | 11 | 31 | 45 | 173 | 174
CAESAR	$\longrightarrow$	1 | 2 | 4 | 5 | 6 | 16 | 57 | 132 | ...
CALPURNIA	$\longrightarrow$	2 | 31 | 54 | 101
⋮		
dictionary		**postings**

Dictionaries

- The dictionary is the data structure for storing the term vocabulary.

Dictionaries

- The dictionary is the data structure for storing the term vocabulary.
- Term vocabulary: the data

Dictionaries

- The dictionary is the data structure for storing the term vocabulary.
- Term vocabulary: the data
- Dictionary: the data structure for storing the term vocabulary

Dictionary as array of fixed-width entries

- For each term, we need to store a couple of items:

Dictionary as array of fixed-width entries

- For each term, we need to store a couple of items:
  - document frequency

Dictionary as array of fixed-width entries

- For each term, we need to store a couple of items:
  - document frequency
  - pointer to postings list

Dictionary as array of fixed-width entries

- For each term, we need to store a couple of items:
  - document frequency
  - pointer to postings list
  - ...

Dictionary as array of fixed-width entries

- For each term, we need to store a couple of items:
  - document frequency
  - pointer to postings list
  - ...
- Assume for the time being that we can store this information in a fixed-length entry.

Dictionary as array of fixed-width entries

- For each term, we need to store a couple of items:
  - document frequency
  - pointer to postings list
  - ...
- Assume for the time being that we can store this information in a fixed-length entry.
- Assume that we store these entries in an array.

Dictionary as array of fixed-width entries

	term	document frequency	pointer to postings list
	a	656,265	$\longrightarrow$
	aachen	65	$\longrightarrow$
	...	...	...
	zulu	221	$\longrightarrow$
space needed:	20 bytes	4 bytes	4 bytes

How do we look up a query term q_i in this array at query time? That is: which data structure do we use to locate the entry (row) in the array where q_i is stored?

Data structures for looking up term

- Two main classes of data structures: hashes and trees

Data structures for looking up term

- Two main classes of data structures: hashes and trees
- Some IR systems use hashes, some use trees.

Data structures for looking up term

- Two main classes of data structures: hashes and trees
- Some IR systems use hashes, some use trees.
- Criteria for when to use hashes vs. trees:

Data structures for looking up term

- Two main classes of data structures: hashes and trees
- Some IR systems use hashes, some use trees.
- Criteria for when to use hashes vs. trees:
  - Is there a fixed number of terms or will it keep growing?

Data structures for looking up term

- Two main classes of data structures: hashes and trees
- Some IR systems use hashes, some use trees.
- Criteria for when to use hashes vs. trees:
  - Is there a fixed number of terms or will it keep growing?
  - What are the relative frequencies with which various keys will be accessed?

Data structures for looking up term

- Two main classes of data structures: hashes and trees
- Some IR systems use hashes, some use trees.
- Criteria for when to use hashes vs. trees:
  - Is there a fixed number of terms or will it keep growing?
  - What are the relative frequencies with which various keys will be accessed?
  - How many terms are we likely to have?

Hashes

- Each vocabulary term is hashed into an integer.

Hashes

- Each vocabulary term is hashed into an integer.
- Try to avoid collisions

Hashes

- Each vocabulary term is hashed into an integer.
- Try to avoid collisions
- At query time, do the following: hash query term, resolve collisions, locate entry in fixed-width array

Hashes

- Each vocabulary term is hashed into an integer.
- Try to avoid collisions
- At query time, do the following: hash query term, resolve collisions, locate entry in fixed-width array
- Pros: Lookup in a hash is faster than lookup in a tree.

Hashes

- Each vocabulary term is hashed into an integer.
- Try to avoid collisions
- At query time, do the following: hash query term, resolve collisions, locate entry in fixed-width array
- Pros: Lookup in a hash is faster than lookup in a tree.
    - Lookup time is constant.

Hashes

- Each vocabulary term is hashed into an integer.
- Try to avoid collisions
- At query time, do the following: hash query term, resolve collisions, locate entry in fixed-width array
- Pros: Lookup in a hash is faster than lookup in a tree.
  - Lookup time is constant.
- Cons

Hashes

- Each vocabulary term is hashed into an integer.
- Try to avoid collisions
- At query time, do the following: hash query term, resolve collisions, locate entry in fixed-width array
- Pros: Lookup in a hash is faster than lookup in a tree.
  - Lookup time is constant.
- Cons
  - no way to find minor variants (*resume* vs. *résumé*)

Hashes

- Each vocabulary term is hashed into an integer.
- Try to avoid collisions
- At query time, do the following: hash query term, resolve collisions, locate entry in fixed-width array
- Pros: Lookup in a hash is faster than lookup in a tree.
  - Lookup time is constant.
- Cons
  - no way to find minor variants (*resume* vs. *résumé*)
  - no prefix search (all terms starting with *automat*)

Hashes

- Each vocabulary term is hashed into an integer.
- Try to avoid collisions
- At query time, do the following: hash query term, resolve collisions, locate entry in fixed-width array
- Pros: Lookup in a hash is faster than lookup in a tree.
  - Lookup time is constant.
- Cons
  - no way to find minor variants (*resume* vs. *résumé*)
  - no prefix search (all terms starting with *automat*)
  - need to rehash everything periodically if vocabulary keeps growing

Trees

- Trees solve the prefix problem (find all terms starting with *automat*).

Trees

- Trees solve the prefix problem (find all terms starting with *automat*).
- Simplest tree: binary tree

Trees

- Trees solve the prefix problem (find all terms starting with *automat*).
- Simplest tree: binary tree
- Search is slightly slower than in hashes: $O(\log M)$, where M is the size of the vocabulary.

Trees

- Trees solve the prefix problem (find all terms starting with *automat*).
- Simplest tree: binary tree
- Search is slightly slower than in hashes: $O(\log M)$, where M is the size of the vocabulary.
- $O(\log M)$ only holds for balanced trees.

Trees

- Trees solve the prefix problem (find all terms starting with *automat*).
- Simplest tree: binary tree
- Search is slightly slower than in hashes: $O(\log M)$, where M is the size of the vocabulary.
- $O(\log M)$ only holds for balanced trees.
- Rebalancing binary trees is expensive.

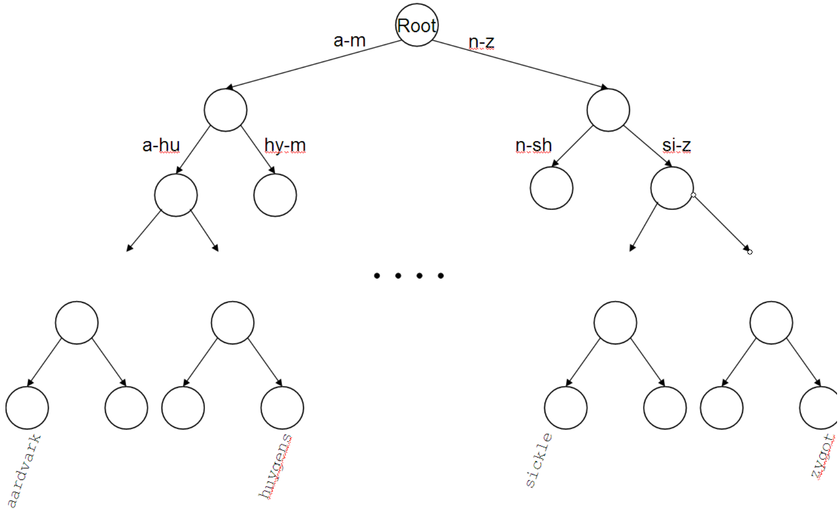
Trees

- Trees solve the prefix problem (find all terms starting with *automat*).
- Simplest tree: binary tree
- Search is slightly slower than in hashes: $O(\log M)$, where M is the size of the vocabulary.
- $O(\log M)$ only holds for balanced trees.
- Rebalancing binary trees is expensive.
- B-trees mitigate the rebalancing problem.

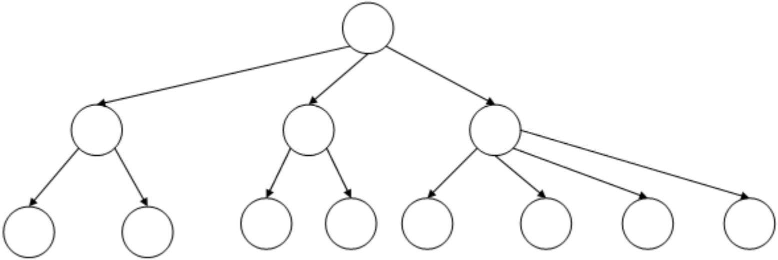
Trees

- Trees solve the prefix problem (find all terms starting with *automat*).
- Simplest tree: binary tree
- Search is slightly slower than in hashes: $O(\log M)$, where M is the size of the vocabulary.
- $O(\log M)$ only holds for balanced trees.
- Rebalancing binary trees is expensive.
- B-trees mitigate the rebalancing problem.
- B-tree definition: every internal node has a number of children in the interval $[a, b]$ where a, b are appropriate positive integers, e.g., $[2, 4]$.

Binary tree



B-tree



Outline

Wildcard queries

- mon*: find all docs containing any term beginning with *mon*

Wildcard queries

- mon*: find all docs containing any term beginning with *mon*
- Easy with B-tree dictionary: retrieve all terms t in the range: mon $\leq t <$ moo

Wildcard queries

- mon*: find all docs containing any term beginning with *mon*
- Easy with B-tree dictionary: retrieve all terms t in the range: mon $\leq t <$ moo
- *mon: find all docs containing any term ending with *mon*

Wildcard queries

- mon*: find all docs containing any term beginning with *mon*
- Easy with B-tree dictionary: retrieve all terms t in the range: mon $\leq t <$ moo
- *mon: find all docs containing any term ending with *mon*
    - Maintain an additional tree for terms *backwards*

Wildcard queries

- mon*: find all docs containing any term beginning with *mon*
- Easy with B-tree dictionary: retrieve all terms t in the range: mon $\leq t <$ moo
- *mon: find all docs containing any term ending with *mon*
  - Maintain an additional tree for terms *backwards*
  - Then retrieve all terms t in the range: nom $\leq t <$ non

Wildcard queries

- mon*: find all docs containing any term beginning with *mon*
- Easy with B-tree dictionary: retrieve all terms t in the range: mon $\leq t <$ moo
- *mon: find all docs containing any term ending with *mon*
  - Maintain an additional tree for terms *backwards*
  - Then retrieve all terms t in the range: nom $\leq t <$ non
- Result: A set of terms that are matches for wildcard query

Wildcard queries

- mon*: find all docs containing any term beginning with *mon*
- Easy with B-tree dictionary: retrieve all terms t in the range: mon $\leq t <$ moo
- *mon: find all docs containing any term ending with *mon*
  - Maintain an additional tree for terms *backwards*
  - Then retrieve all terms t in the range: nom $\leq t <$ non
- Result: A set of terms that are matches for wildcard query
- Then retrieve documents that contain any of these terms

How to handle * in the middle of a term

- Example: m*nchen

How to handle * in the middle of a term

- Example: m*nchen
- We could look up m* and *nchen in the B-tree and intersect the two term sets.

How to handle * in the middle of a term

- Example: m*nchen
- We could look up m* and *nchen in the B-tree and intersect the two term sets.
- Expensive

How to handle * in the middle of a term

- Example: m*nchen
- We could look up m* and *nchen in the B-tree and intersect the two term sets.
- Expensive
- Alternative: permuterm index

How to handle * in the middle of a term

- Example: m*nchen
- We could look up m* and *nchen in the B-tree and intersect the two term sets.
- Expensive
- Alternative: permuterm index
- Basic idea: Rotate every wildcard query, so that the * occurs at the end.

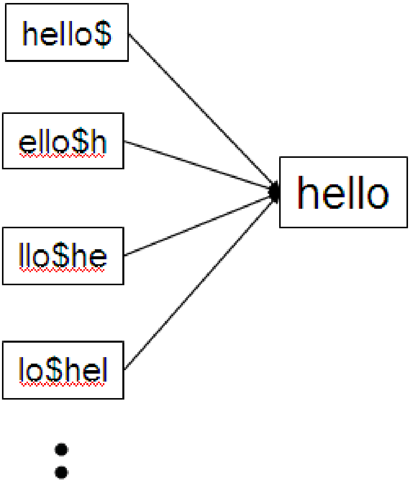
How to handle * in the middle of a term

- Example: m*nchen
- We could look up m* and *nchen in the B-tree and intersect the two term sets.
- Expensive
- Alternative: permuterm index
- Basic idea: Rotate every wildcard query, so that the * occurs at the end.
- Store each of these rotations in the dictionary, say, in a B-tree

Permuterm index

- For term HELLO: add *hello$*, *ello$h*, *llo$he*, *lo$hel*, *o$hell*, and *$hello* to the B-tree where $ is a special symbol

Permuterm → term mapping



Permuterm index

- For HELLO, we've stored: *hello$*, *ello$h*, *llo$he*, *lo$hel*, and *o$hell*

Permuterm index

- For HELLO, we've stored: *hello$*, *ello$h*, *llo$he*, *lo$hel*, and *o$hell*
- Queries

Permuterm index

- For HELLO, we've stored: *hello$*, *ello$h*, *llo$he*, *lo$hel*, and *o$hell*
- Queries
  - For X, look up X$

Permuterm index

- For HELLO, we've stored: *hello$*, *ello$h*, *llo$he*, *lo$hel*, and *o$hell*
- Queries
  - For X, look up X$
  - For X*, look up $X*

Permuterm index

- For HELLO, we've stored: *hello$*, *ello$h*, *llo$he*, *lo$hel*, and *o$hell*
- Queries
  - For X, look up X$
  - For X*, look up $X*
  - For *X, look up X$*

Permuterm index

- For HELLO, we've stored: *hello$*, *ello$h*, *llo$he*, *lo$hel*, and *o$hell*
- Queries
  - For X, look up X$
  - For X*, look up $X*
  - For *X, look up X$*
  - For *X*, look up X*

Permuterm index

- For HELLO, we've stored: *hello$*, *ello$h*, *llo$he*, *lo$hel*, and *o$hell*
- Queries
  - For X, look up X$
  - For X*, look up $X*
  - For *X, look up X$*
  - For *X*, look up X*
  - For X*Y, look up Y$X*

Permuterm index

- For HELLO, we've stored: *hello$*, *ello$h*, *llo$he*, *lo$hel*, and *o$hell*
- Queries
  - For X, look up X$
  - For X*, look up $X*
  - For *X, look up X$*
  - For *X*, look up X*
  - For X*Y, look up Y$X*
  - Example: For hel*o, look up o$hel*

Permuterm index

- For HELLO, we've stored: *hello$*, *ello$h*, *llo$he*, *lo$hel*, and *o$hell*
- Queries
  - For X, look up X$
  - For X*, look up $X*
  - For *X, look up X$*
  - For *X*, look up X*
  - For X*Y, look up Y$X*
  - Example: For hel*o, look up o$hel*
- Permuterm index would better be called a permuterm tree.

Permuterm index

- For HELLO, we've stored: *hello$*, *ello$h*, *llo$he*, *lo$hel*, and *o$hell*
- Queries
  - For X, look up X$
  - For X*, look up $X*
  - For *X, look up X$*
  - For *X*, look up X*
  - For X*Y, look up Y$X*
  - Example: For hel*o, look up o$hel*
- Permuterm index would better be called a permuterm tree.
- But permuterm index is the more common name.

Processing a lookup in the permuterm index

- Rotate query wildcard to the right

Processing a lookup in the permuterm index

- Rotate query wildcard to the right
- Use B-tree lookup as before

Processing a lookup in the permuterm index

- Rotate query wildcard to the right
- Use B-tree lookup as before
- Problem: Permuterm more than quadruples the size of the dictionary compared to a regular B-tree. (empirical number)

k-gram indexes

- More space-efficient than permuterm index

k-gram indexes

- More space-efficient than permuterm index
- Enumerate all character *k*-grams (sequence of *k* characters) occurring in a term

k-gram indexes

- More space-efficient than permuterm index
- Enumerate all character k-grams (sequence of k characters) occurring in a term
- 2-grams are called bigrams.

k-gram indexes

- More space-efficient than permuterm index
- Enumerate all character *k*-grams (sequence of *k* characters) occurring in a term
- 2-grams are called bigrams.
- Example: from *April is the cruelest month* we get the bigrams: *$a ap pr ri il l$ $i is s$ $t th he e$ $c cr ru ue el le es st t$ $m mo on nt h$*

k-gram indexes

- More space-efficient than permuterm index
- Enumerate all character *k*-grams (sequence of *k* characters) occurring in a term
- 2-grams are called bigrams.
- Example: from *April is the cruelest month* we get the bigrams: *$a ap pr ri il l$ $i is s$ $t th he e$ $c cr ru ue el le es st t$ $m mo on nt h$*
- $ is a special word boundary symbol, as before.

k-gram indexes

- More space-efficient than permuterm index
- Enumerate all character *k*-grams (sequence of *k* characters) occurring in a term
- 2-grams are called bigrams.
- Example: from *April is the cruelest month* we get the bigrams: *$a ap pr ri il l$ $i is s$ $t th he e$ $c cr ru ue el le es st t$ $m mo on nt h$*
- $ is a special word boundary symbol, as before.
- Maintain an inverted index from bigrams to the terms that contain the bigram

Postings list in a 3-gram inverted index

k-gram (bigram, trigram, ...) indexes

- Note that we now have two different types of inverted indexes

k-gram (bigram, trigram, . . .) indexes

- Note that we now have two different types of inverted indexes
- The term-document inverted index for finding documents based on a query consisting of terms

k-gram (bigram, trigram, . . .) indexes

- Note that we now have two different types of inverted indexes
- The term-document inverted index for finding documents based on a query consisting of terms
- The *k*-gram index for finding terms based on a query consisting of *k*-grams

Processing wildcarded terms in a bigram index

- Query mon* can now be run as:
  $m AND mo AND on

Processing wildcarded terms in a bigram index

- Query mon* can now be run as:
  $m AND mo AND on
- Gets us all terms with the prefix *mon* . . .

Processing wildcarded terms in a bigram index

- Query mon* can now be run as:
  $m AND mo AND on
- Gets us all terms with the prefix *mon* . . .
- . . . but also many "false positives" like MOON.

Processing wildcarded terms in a bigram index

- Query mon* can now be run as:
  $m AND mo AND on
- Gets us all terms with the prefix *mon* . . .
- . . . but also many "false positives" like MOON.
- We must postfilter these terms against query.

Processing wildcarded terms in a bigram index

- Query mon* can now be run as:
  $m AND mo AND on
- Gets us all terms with the prefix *mon* . . .
- . . . but also many "false positives" like MOON.
- We must postfilter these terms against query.
- Surviving terms are then looked up in the term-document inverted index.

Processing wildcarded terms in a bigram index

- Query mon* can now be run as:
  \$m AND mo AND on
- Gets us all terms with the prefix *mon* . . .
- . . . but also many "false positives" like MOON.
- We must postfilter these terms against query.
- Surviving terms are then looked up in the term-document inverted index.
- *k*-gram index vs. permuterm index

Processing wildcarded terms in a bigram index

- Query mon* can now be run as:
  $m AND mo AND on
- Gets us all terms with the prefix *mon* ...
- ...but also many "false positives" like MOON.
- We must postfilter these terms against query.
- Surviving terms are then looked up in the term-document inverted index.
- *k*-gram index vs. permuterm index
  - *k*-gram index is more space efficient.

Processing wildcarded terms in a bigram index

- Query mon* can now be run as:
  $m AND mo AND on
- Gets us all terms with the prefix *mon* . . .
- . . . but also many "false positives" like MOON.
- We must postfilter these terms against query.
- Surviving terms are then looked up in the term-document inverted index.
- *k*-gram index vs. permuterm index
  - *k*-gram index is more space efficient.
  - Permuterm index doesn't require postfiltering.

Exercise

Exercise

- Google has very limited support for wildcard queries.

Exercise

- Google has very limited support for wildcard queries.
- For example, this query doesn't work very well on Google: [gen* universit*]

Exercise

- Google has very limited support for wildcard queries.
- For example, this query doesn't work very well on Google: [gen* universit*]
  - Intention: you are looking for the University of Geneva, but don't know which accents to use for the French words for university and Geneva.

Exercise

- Google has very limited support for wildcard queries.
- For example, this query doesn't work very well on Google: [gen* universit*]
  - Intention: you are looking for the University of Geneva, but don't know which accents to use for the French words for university and Geneva.
- According to Google search basics, 2010-04-29: "Note that the * operator works only on whole words, not parts of words."

Exercise

- Google has very limited support for wildcard queries.
- For example, this query doesn't work very well on Google: [gen* universit*]
    - Intention: you are looking for the University of Geneva, but don't know which accents to use for the French words for university and Geneva.
- According to Google search basics, 2010-04-29: "Note that the * operator works only on whole words, not parts of words."
- But this is not entirely true. Try [pythag*] and [m*nchen]

Exercise

- Google has very limited support for wildcard queries.
- For example, this query doesn't work very well on Google: [gen* universit*]
  - Intention: you are looking for the University of Geneva, but don't know which accents to use for the French words for university and Geneva.
- According to Google search basics, 2010-04-29: "Note that the * operator works only on whole words, not parts of words."
- But this is not entirely true. Try [pythag*] and [m*nchen]
- Exercise: Why doesn't Google fully support wildcard queries?

Processing wildcard queries in the term-document index

Processing wildcard queries in the term-document index

- Problem 1: we must potentially execute a large number of Boolean queries.

Processing wildcard queries in the term-document index

- Problem 1: we must potentially execute a large number of Boolean queries.
- Most straightforward semantics: Conjunction of disjunctions

Processing wildcard queries in the term-document index

- Problem 1: we must potentially execute a large number of Boolean queries.
- Most straightforward semantics: Conjunction of disjunctions
- For [gen* universit*]: geneva university OR geneva université OR genève university OR genève université OR general universities OR . . .

Processing wildcard queries in the term-document index

- Problem 1: we must potentially execute a large number of Boolean queries.
- Most straightforward semantics: Conjunction of disjunctions
- For [gen* universit*]: geneva university OR geneva université OR genève university OR genève université OR general universities OR . . .
- Very expensive

Processing wildcard queries in the term-document index

- Problem 1: we must potentially execute a large number of Boolean queries.
- Most straightforward semantics: Conjunction of disjunctions
- For [gen* universit*]: geneva university OR geneva université OR genève university OR genève université OR general universities OR ...
- Very expensive
- Problem 2: Users hate to type.

Processing wildcard queries in the term-document index

- Problem 1: we must potentially execute a large number of Boolean queries.
- Most straightforward semantics: Conjunction of disjunctions
- For [gen* universit*]: geneva university OR geneva université OR genève university OR genève université OR general universities OR . . .
- Very expensive
- Problem 2: Users hate to type.
- If abbreviated queries like [pyth* theo*] for [pythagoras' theorem] are allowed, users will use them a lot.

Processing wildcard queries in the term-document index

- Problem 1: we must potentially execute a large number of Boolean queries.
- Most straightforward semantics: Conjunction of disjunctions
- For [gen* universit*]: geneva university OR geneva université OR genève university OR genève université OR general universities OR . . .
- Very expensive
- Problem 2: Users hate to type.
- If abbreviated queries like [pyth* theo*] for [pythagoras' theorem] are allowed, users will use them a lot.
- This would significantly increase the cost of answering queries.

Processing wildcard queries in the term-document index

- Problem 1: we must potentially execute a large number of Boolean queries.
- Most straightforward semantics: Conjunction of disjunctions
- For [gen* universit*]: geneva university OR geneva université OR genève university OR genève université OR general universities OR ...
- Very expensive
- Problem 2: Users hate to type.
- If abbreviated queries like [pyth* theo*] for [pythagoras' theorem] are allowed, users will use them a lot.
- This would significantly increase the cost of answering queries.
- Somewhat alleviated by Google Suggest

Outline

Spelling correction

Spelling correction

- Two principal uses

Spelling correction

- Two principal uses
  - Correcting documents being indexed

Spelling correction

- Two principal uses
  - Correcting documents being indexed
  - Correcting user queries

Spelling correction

- Two principal uses
  - Correcting documents being indexed
  - Correcting user queries
- Two different methods for spelling correction

Spelling correction

- Two principal uses
  - Correcting documents being indexed
  - Correcting user queries
- Two different methods for spelling correction
- Isolated word spelling correction

Spelling correction

- Two principal uses
  - Correcting documents being indexed
  - Correcting user queries
- Two different methods for spelling correction
- Isolated word spelling correction
  - Check each word on its own for misspelling

Spelling correction

- Two principal uses
  - Correcting documents being indexed
  - Correcting user queries
- Two different methods for spelling correction
- Isolated word spelling correction
  - Check each word on its own for misspelling
  - Will not catch typos resulting in correctly spelled words, e.g., *an asteroid that fell form the sky*

Spelling correction

- Two principal uses
  - Correcting documents being indexed
  - Correcting user queries
- Two different methods for spelling correction
- Isolated word spelling correction
  - Check each word on its own for misspelling
  - Will not catch typos resulting in correctly spelled words, e.g., *an asteroid that fell form the sky*
- Context-sensitive spelling correction

Spelling correction

- Two principal uses
  - Correcting documents being indexed
  - Correcting user queries
- Two different methods for spelling correction
- Isolated word spelling correction
  - Check each word on its own for misspelling
  - Will not catch typos resulting in correctly spelled words, e.g., *an asteroid that fell form the sky*
- Context-sensitive spelling correction
  - Look at surrounding words

Spelling correction

- Two principal uses
  - Correcting documents being indexed
  - Correcting user queries
- Two different methods for spelling correction
- Isolated word spelling correction
  - Check each word on its own for misspelling
  - Will not catch typos resulting in correctly spelled words, e.g., *an asteroid that fell form the sky*
- Context-sensitive spelling correction
  - Look at surrounding words
  - Can correct *form*/*from* error above

Correcting documents

Correcting documents

- We're not interested in interactive spelling correction of documents (e.g., MS Word) in this class.

Correcting documents

- We're not interested in interactive spelling correction of documents (e.g., MS Word) in this class.
- In IR, we use document correction primarily for OCR'ed documents. (OCR = optical character recognition)

Correcting documents

- We're not interested in interactive spelling correction of documents (e.g., MS Word) in this class.
- In IR, we use document correction primarily for OCR'ed documents. (OCR = optical character recognition)
- The general philosophy in IR is: don't change the documents.

Correcting queries

Correcting queries

- First: isolated word spelling correction

Correcting queries

- First: isolated word spelling correction
- Premise 1: There is a list of “correct words” from which the correct spellings come.

Correcting queries

- First: isolated word spelling correction
- Premise 1: There is a list of "correct words" from which the correct spellings come.
- Premise 2: We have a way of computing the distance between a misspelled word and a correct word.

Correcting queries

- First: isolated word spelling correction
- Premise 1: There is a list of “correct words” from which the correct spellings come.
- Premise 2: We have a way of computing the distance between a misspelled word and a correct word.
- Simple spelling correction algorithm: return the “correct” word that has the smallest distance to the misspelled word.

Correcting queries

- First: isolated word spelling correction
- Premise 1: There is a list of "correct words" from which the correct spellings come.
- Premise 2: We have a way of computing the distance between a misspelled word and a correct word.
- Simple spelling correction algorithm: return the "correct" word that has the smallest distance to the misspelled word.
- Example: *informaton* → *information*

Correcting queries

- First: isolated word spelling correction
- Premise 1: There is a list of "correct words" from which the correct spellings come.
- Premise 2: We have a way of computing the distance between a misspelled word and a correct word.
- Simple spelling correction algorithm: return the "correct" word that has the smallest distance to the misspelled word.
- Example: *informaton* → *information*
- For the list of correct words, we can use the vocabulary of all words that occur in our collection.

Correcting queries

- First: isolated word spelling correction
- Premise 1: There is a list of "correct words" from which the correct spellings come.
- Premise 2: We have a way of computing the distance between a misspelled word and a correct word.
- Simple spelling correction algorithm: return the "correct" word that has the smallest distance to the misspelled word.
- Example: *informaton* → *information*
- For the list of correct words, we can use the vocabulary of all words that occur in our collection.
- Why is this problematic?

Alternatives to using the term vocabulary

Alternatives to using the term vocabulary

- A standard dictionary (Webster's, OED etc.)

Alternatives to using the term vocabulary

- A standard dictionary (Webster's, OED etc.)
- An industry-specific dictionary (for specialized IR systems)

Alternatives to using the term vocabulary

- A standard dictionary (Webster's, OED etc.)
- An industry-specific dictionary (for specialized IR systems)
- The term vocabulary of the collection, appropriately weighted

Distance between misspelled word and "correct" word

Distance between misspelled word and “correct” word

- We will study several alternatives.

Distance between misspelled word and "correct" word

- We will study several alternatives.
- Edit distance and Levenshtein distance

Distance between misspelled word and "correct" word

- We will study several alternatives.
- Edit distance and Levenshtein distance
- Weighted edit distance

Distance between misspelled word and "correct" word

- We will study several alternatives.
- Edit distance and Levenshtein distance
- Weighted edit distance
- k-gram overlap

Edit distance

Edit distance

- The edit distance between string s_1 and string s_2 is the minimum number of basic operations that convert s_1 to s_2.

Edit distance

- The edit distance between string s_1 and string s_2 is the minimum number of basic operations that convert s_1 to s_2.
- Levenshtein distance: The admissible basic operations are insert, delete, and replace

Edit distance

- The edit distance between string s_1 and string s_2 is the minimum number of basic operations that convert s_1 to s_2.
- Levenshtein distance: The admissible basic operations are insert, delete, and replace
- Levenshtein distance *dog*-*do*: 1

Edit distance

- The edit distance between string s_1 and string s_2 is the minimum number of basic operations that convert s_1 to s_2.
- Levenshtein distance: The admissible basic operations are insert, delete, and replace
- Levenshtein distance *dog*-*do*: 1
- Levenshtein distance *cat*-*cart*: 1

Edit distance

- The edit distance between string s_1 and string s_2 is the minimum number of basic operations that convert s_1 to s_2.
- Levenshtein distance: The admissible basic operations are insert, delete, and replace
- Levenshtein distance *dog*-*do*: 1
- Levenshtein distance *cat*-*cart*: 1
- Levenshtein distance *cat*-*cut*: 1

Edit distance

- The edit distance between string s_1 and string s_2 is the minimum number of basic operations that convert s_1 to s_2.
- Levenshtein distance: The admissible basic operations are insert, delete, and replace
- Levenshtein distance *dog*-*do*: 1
- Levenshtein distance *cat*-*cart*: 1
- Levenshtein distance *cat*-*cut*: 1
- Levenshtein distance *cat*-*act*: 2

Edit distance

- The edit distance between string s_1 and string s_2 is the minimum number of basic operations that convert s_1 to s_2.
- Levenshtein distance: The admissible basic operations are insert, delete, and replace
- Levenshtein distance *dog*-*do*: 1
- Levenshtein distance *cat*-*cart*: 1
- Levenshtein distance *cat*-*cut*: 1
- Levenshtein distance *cat*-*act*: 2
- Damerau-Levenshtein distance *cat*-*act*: 1

Edit distance

- The edit distance between string s_1 and string s_2 is the minimum number of basic operations that convert s_1 to s_2.
- Levenshtein distance: The admissible basic operations are insert, delete, and replace
- Levenshtein distance *dog*-*do*: 1
- Levenshtein distance *cat*-*cart*: 1
- Levenshtein distance *cat*-*cut*: 1
- Levenshtein distance *cat*-*act*: 2
- Damerau-Levenshtein distance *cat*-*act*: 1
- Damerau-Levenshtein includes transposition as a fourth possible operation.

Levenshtein distance: Computation

		f	a	s	t
	0	1	2	3	4
c	1	1	2	3	4
a	2	2	1	2	3
t	3	3	2	2	2
s	4	4	3	2	3

Levenshtein distance: Algorithm

```
LevenshteinDistance(s1, s2)
for i ← 0 to |s1|
do m[i, 0] = i
for j ← 0 to |s2|
do m[0, j] = j
for i ← 1 to |s1|
do for j ← 1 to |s2|
    do if s1[i] = s2[j]
          then m[i, j] = min{m[i-1, j]+1, m[i, j-1]+1, m[i-1, j-1]}
          else m[i, j] = min{m[i-1, j]+1, m[i, j-1]+1, m[i-1, j-1]+1}
return m[|s1|, |s2|]
```

Operations: insert (cost 1), delete (cost 1), replace (cost 1), copy (cost 0)

Levenshtein distance: Algorithm

```
LevenshteinDistance(s1, s2)
for i ← 0 to |s1|
do m[i, 0] = i
for j ← 0 to |s2|
do m[0, j] = j
for i ← 1 to |s1|
do for j ← 1 to |s2|
    do if s1[i] = s2[j]
          then m[i, j] = min{m[i-1, j]+1, m[i, j-1]+1, m[i-1, j-1]}
          else  m[i, j] = min{m[i-1, j]+1, m[i, j-1]+1, m[i-1, j-1]+1}
return m[|s1|, |s2|]
```

Operations: insert (cost 1), delete (cost 1), replace (cost 1), copy (cost 0)

Levenshtein distance: Algorithm

```
LevenshteinDistance(s1, s2)
for i ← 0 to |s1|
do m[i, 0] = i
for j ← 0 to |s2|
do m[0, j] = j
for i ← 1 to |s1|
do for j ← 1 to |s2|
    do if s1[i] = s2[j]
          then m[i, j] = min{m[i-1, j]+1, m[i, j-1]+1, m[i-1, j-1]}
          else  m[i, j] = min{m[i-1, j]+1, m[i, j-1]+1, m[i-1, j-1]+1}
return m[|s1|, |s2|]
```

Operations: insert (cost 1), delete (cost 1), replace (cost 1), copy (cost 0)

Levenshtein distance: Algorithm

LevenshteinDistance(s_1, s_2)

for $i \leftarrow 0$ **to** $|s_1|$
do $m[i, 0] = i$
for $j \leftarrow 0$ **to** $|s_2|$
do $m[0, j] = j$
for $i \leftarrow 1$ **to** $|s_1|$
do for $j \leftarrow 1$ **to** $|s_2|$
  do if $s_1[i] = s_2[j]$
    then $m[i, j] = \min\{m[i\text{-}1, j]+1, m[i, j\text{-}1]+1, m[i\text{-}1, j\text{-}1]\}$
    else $m[i, j] = \min\{m[i\text{-}1, j]+1, m[i, j\text{-}1]+1, m[i\text{-}1, j\text{-}1]+1\}$
return $m[|s_1|, |s_2|]$

Operations: insert (cost 1), delete (cost 1), replace (cost 1), copy (cost 0)

Levenshtein distance: Algorithm

$\text{LEVENSHTEINDISTANCE}(s_1, s_2)$

for $i \leftarrow 0$ **to** $|s_1|$
do $m[i, 0] = i$
for $j \leftarrow 0$ **to** $|s_2|$
do $m[0, j] = j$
for $i \leftarrow 1$ **to** $|s_1|$
do for $j \leftarrow 1$ **to** $|s_2|$
  do if $s_1[i] = s_2[j]$
    then $m[i, j] = \min\{m[i\text{-}1, j]+1, m[i, j\text{-}1]+1, m[i\text{-}1, j\text{-}1]\}$
    else $m[i, j] = \min\{m[i\text{-}1, j]+1, m[i, j\text{-}1]+1, m[i\text{-}1, j\text{-}1]+1\}$
return $m[|s_1|, |s_2|]$

Operations: insert (cost 1), delete (cost 1), replace (cost 1), copy (cost 0)

Levenshtein distance: Example

		f		a		s		t	
	0	**1**	**1**	**2**	**2**	**3**	**3**	**4**	**4**
c	**1**	*1*	*2*	**2**	3	**3**	4	**4**	5
	1	*2*	*1*	**2**	**2**	**3**	**3**	**4**	**4**
a	**2**	**2**	**2**	*1*	*3*	*3*	*4*	4	5
	2	3	**2**	*3*	*1*	*2*	*2*	**3**	**3**
t	**3**	**3**	**3**	3	**2**	*2*	*3*	*2*	*4*
	3	4	**3**	4	**2**	*3*	*2*	*3*	*2*
s	**4**	**4**	**4**	4	**3**	**2**	3	*3*	*3*
	4	5	**4**	5	**3**	4	**2**	*3*	*3*

Each cell of Levenshtein matrix

cost of getting here from my upper left neighbor (copy or replace)	cost of getting here from my upper neighbor (delete)
cost of getting here from my left neighbor (insert)	the minimum of the three possible "movements"; the cheapest way of getting here

Levenshtein distance: Example

			f		a		s		t	
		0	**1**	**1**	**2**	**2**	**3**	**3**	**4**	**4**
c		**1**	*1*	*2*	**2**	3	**3**	4	**4**	5
		1	*2*	*1*	**2**	**2**	**3**	**3**	**4**	**4**
a		**2**	**2**	**2**	*1*	*3*	*3*	*4*	4	5
		2	3	**2**	*3*	*1*	*2*	*2*	**3**	**3**
t		**3**	**3**	**3**	3	**2**	*2*	*3*	*2*	*4*
		3	4	**3**	4	**2**	*3*	*2*	*3*	*2*
s		**4**	**4**	**4**	4	**3**	**2**	3	*3*	*3*
		4	5	**4**	5	**3**	4	**2**	*3*	*3*

Dynamic programming (Cormen et al.)

Dynamic programming (Cormen et al.)

- Optimal substructure: The optimal solution to the problem contains within it subsolutions, i.e., optimal solutions to subproblems.

Dynamic programming (Cormen et al.)

- Optimal substructure: The optimal solution to the problem contains within it subsolutions, i.e., optimal solutions to subproblems.
- Overlapping subsolutions: The subsolutions overlap. These subsolutions are computed over and over again when computing the global optimal solution in a brute-force algorithm.

Dynamic programming (Cormen et al.)

- Optimal substructure: The optimal solution to the problem contains within it subsolutions, i.e., optimal solutions to subproblems.
- Overlapping subsolutions: The subsolutions overlap. These subsolutions are computed over and over again when computing the global optimal solution in a brute-force algorithm.
- Subproblem in the case of edit distance: what is the edit distance of two prefixes

Dynamic programming (Cormen et al.)

- Optimal substructure: The optimal solution to the problem contains within it subsolutions, i.e., optimal solutions to subproblems.
- Overlapping subsolutions: The subsolutions overlap. These subsolutions are computed over and over again when computing the global optimal solution in a brute-force algorithm.
- Subproblem in the case of edit distance: what is the edit distance of two prefixes
- Overlapping subsolutions: We need most distances of prefixes 3 times – this corresponds to moving right, diagonally, down.

Weighted edit distance

Weighted edit distance

- As above, but weight of an operation depends on the characters involved.

Weighted edit distance

- As above, but weight of an operation depends on the characters involved.
- Meant to capture keyboard errors, e.g., *m* more likely to be mistyped as *n* than as *q*.

Weighted edit distance

- As above, but weight of an operation depends on the characters involved.
- Meant to capture keyboard errors, e.g., *m* more likely to be mistyped as *n* than as *q*.
- Therefore, replacing *m* by *n* is a smaller edit distance than by *q*.

Weighted edit distance

- As above, but weight of an operation depends on the characters involved.
- Meant to capture keyboard errors, e.g., m more likely to be mistyped as n than as q.
- Therefore, replacing m by n is a smaller edit distance than by q.
- We now require a weight matrix as input.

Weighted edit distance

- As above, but weight of an operation depends on the characters involved.
- Meant to capture keyboard errors, e.g., *m* more likely to be mistyped as *n* than as *q*.
- Therefore, replacing *m* by *n* is a smaller edit distance than by *q*.
- We now require a weight matrix as input.
- Modify dynamic programming to handle weights

Using edit distance for spelling correction

Using edit distance for spelling correction

- Given query, first enumerate all character sequences within a preset (possibly weighted) edit distance

Using edit distance for spelling correction

- Given query, first enumerate all character sequences within a preset (possibly weighted) edit distance
- Intersect this set with our list of "correct" words

Using edit distance for spelling correction

- Given query, first enumerate all character sequences within a preset (possibly weighted) edit distance
- Intersect this set with our list of “correct” words
- Then suggest terms in the intersection to the user.

Using edit distance for spelling correction

- Given query, first enumerate all character sequences within a preset (possibly weighted) edit distance
- Intersect this set with our list of "correct" words
- Then suggest terms in the intersection to the user.
- $\rightarrow$ exercise in a few slides

Exercise

1. Compute Levenshtein distance matrix for OSLO – SNOW
2. What are the Levenshtein editing operations that transform *cat* into *catcat*?

		s	n	o	w
	0	1 1	2 2	3 3	4 4
o	1 1				
s	2 2				
l	3 3				
o	4 4				

		s	n	o	w
	0	**1** **1**	**2** **2**	**3** **3**	**4** **4**
o	**1** **1**	1 2 2 ?			
s	**2** **2**				
l	**3** **3**				
o	**4** **4**				

		s	n	o	w
	0	1 1	2 2	3 3	4 4
o	1 1	1 2 2 1			
s	2 2				
l	3 3				
o	4 4				

			s		n		o		w	
		0	**1**	**1**	**2**	**2**	**3**	**3**	**4**	**4**
o		**1**	**1**	2	2	3				
		1	2	**1**	2	?				
s		**2**								
		2								
l		**3**								
		3								
o		**4**								
		4								

		s	n	o	w
	0	1 1	2 2	3 3	4 4
o	1 1	1 2 2 1	2 3 2 2		
s	2 2				
l	3 3				
o	4 4				

			s		n		o		w	
		0	**1**	**1**	**2**	**2**	**3**	**3**	**4**	**4**
o		**1**	**1**	2	**2**	3	2	4		
		1	2	**1**	**2**	**2**	3	?		
s		**2**								
		2								
l		**3**								
		3								
o		**4**								
		4								

		s	n	o	w
	 0	 1 1	 2 2	 3 3	 4 4
o	1 1	1 2 2 1	2 3 2 2	2 4 3 2	
s	2 2				
l	3 3				
o	4 4				

			s		n		o		w	
		0	**1**	**1**	**2**	**2**	**3**	**3**	**4**	**4**
o		**1**	**1**	2	**2**	3	**2**	4	4	5
		1	2	**1**	**2**	**2**	3	**2**	3	?
s		**2**								
		2								
l		**3**								
		3								
o		**4**								
		4								

		s	n	o	w
	 0	 **1** **1**	 **2** **2**	 **3** **3**	 **4** **4**
o	**1** **1**	**1** 2 2 **1**	**2** 3 **2** **2**	**2** 4 3 **2**	4 5 **3** **3**
s	**2** **2**				
l	**3** **3**				
o	**4** **4**				

			s		n		o		w	
		0	**1**	**1**	**2**	**2**	**3**	**3**	**4**	**4**
o		**1**	**1**	2	**2**	3	**2**	4	4	5
		1	2	**1**	**2**	**2**	3	**2**	**3**	**3**
s		**2**	1	2						
		2	3	?						
l		**3**								
		3								
o		**4**								
		4								

		s	n	o	w
	0	**1** **1**	**2** **2**	**3** **3**	**4** **4**
o	**1** **1**	**1** 2 2 **1**	**2** 3 **2** **2**	**2** 4 3 **2**	4 5 **3** **3**
s	**2** **2**	**1** 2 3 **1**			
l	**3** **3**				
o	**4** **4**				

			s		n		o		w	
		0	**1**	**1**	**2**	**2**	**3**	**3**	**4**	**4**
o		**1**	**1**	2	**2**	3	**2**	4	4	5
		1	2	**1**	**2**	**2**	3	**2**	**3**	**3**
s		**2**	**1**	2	2	3				
		2	3	**1**	2	?				
l		**3**								
		3								
o		**4**								
		4								

			s		n		o		w	
		0	**1**	**1**	**2**	**2**	**3**	**3**	**4**	**4**
o		**1**	**1**	2	**2**	3	**2**	4	4	5
		1	2	**1**	**2**	**2**	3	**2**	**3**	**3**
s		**2**	**1**	2	**2**	3				
		2	3	**1**	**2**	**2**				
l		**3**								
		3								
o		**4**								
		4								

			s		n		o		w	
		0	**1**	**1**	**2**	**2**	**3**	**3**	**4**	**4**
o		**1**	**1**	2	**2**	3	**2**	4	4	5
		1	2	**1**	**2**	**2**	3	**2**	**3**	**3**
s		**2**	**1**	2	**2**	3	3	3		
		2	3	**1**	**2**	**2**	3	?		
l		**3**								
		3								
o		**4**								
		4								

		s	n	o	w
	0	**1** **1**	**2** **2**	**3** **3**	**4** **4**
o	**1** **1**	**1** 2 2 **1**	**2** 3 **2** **2**	**2** 4 3 **2**	4 5 **3** **3**
s	**2** **2**	**1** 2 3 **1**	**2** 3 **2** **2**	**3** **3** **3** **3**	
l	**3** **3**				
o	**4** **4**				

		s	n	o	w
	 0	 **1** **1**	 **2** **2**	 **3** **3**	 **4** **4**
o	**1** **1**	**1** 2 2 **1**	**2** 3 **2** **2**	**2** 4 3 **2**	4 5 **3** **3**
s	**2** **2**	**1** 2 3 **1**	**2** 3 **2** **2**	**3** **3** **3** **3**	3 4 4 ?
l	**3** **3**				
o	**4** **4**				

			s		n		o		w	
		0	**1**	**1**	**2**	**2**	**3**	**3**	**4**	**4**
o		**1**	**1**	2	**2**	3	**2**	4	4	5
		1	2	**1**	**2**	**2**	3	**2**	**3**	**3**
s		**2**	**1**	2	**2**	3	**3**	**3**	**3**	4
		2	3	**1**	**2**	**2**	**3**	**3**	4	**3**
l		**3**								
		3								
o		**4**								
		4								

			s		n		o		w	
		0	**1**	**1**	**2**	**2**	**3**	**3**	**4**	**4**
o		**1**	**1**	2	**2**	3	**2**	4	4	5
		1	2	**1**	**2**	**2**	3	**2**	**3**	**3**
s		**2**	**1**	2	**2**	3	**3**	**3**	**3**	4
		2	3	**1**	**2**	**2**	**3**	**3**	4	**3**
l		**3**	3	2						
		3	4	?						
o		**4**								
		4								

		s	n	o	w
	0	**1** **1**	**2** **2**	**3** **3**	**4** **4**
o	**1** **1**	**1** 2 2 **1**	**2** 3 **2** **2**	**2** 4 3 **2**	4 5 **3** **3**
s	**2** **2**	**1** 2 3 **1**	**2** 3 **2** **2**	**3** **3** **3** **3**	**3** 4 4 **3**
l	**3** **3**	3 **2** 4 **2**			
o	**4** **4**				

		s	n	o	w
	 0	 **1** **1**	 **2** **2**	 **3** **3**	 **4** **4**
o	**1** **1**	**1** 2 2 **1**	**2** 3 **2** **2**	**2** 4 3 **2**	4 5 **3** **3**
s	**2** **2**	**1** 2 3 **1**	**2** 3 **2** **2**	**3** **3** **3** **3**	**3** 4 4 **3**
l	**3** **3**	3 **2** 4 **2**	2 3 3 ?		
o	**4** **4**				

		s	n	o	w
	 0	 **1** **1**	 **2** **2**	 **3** **3**	 **4** **4**
o	**1** **1**	**1** 2 2 **1**	**2** 3 **2** **2**	**2** 4 3 **2**	4 5 **3** **3**
s	**2** **2**	**1** 2 3 **1**	**2** 3 **2** **2**	**3** **3** **3** **3**	**3** 4 4 **3**
l	**3** **3**	3 **2** 4 **2**	**2** 3 3 **2**		
o	**4** **4**				

		s	n	o	w
	0	**1** **1**	**2** **2**	**3** **3**	**4** **4**
o	**1** **1**	**1** 2 2 **1**	**2** 3 **2** **2**	**2** 4 3 **2**	4 5 **3** **3**
s	**2** **2**	**1** 2 3 **1**	**2** 3 **2** **2**	**3** **3** **3** **3**	**3** 4 4 **3**
l	**3** **3**	3 **2** 4 **2**	**2** 3 3 **2**	3 4 3 ?	
o	**4** **4**				

		s	n	o	w
	 0	 **1** **1**	 **2** **2**	 **3** **3**	 **4** **4**
o	**1** **1**	**1** 2 2 **1**	**2** 3 **2** **2**	**2** 4 3 **2**	4 5 **3** **3**
s	**2** **2**	**1** 2 3 **1**	**2** 3 **2** **2**	**3** **3** **3** **3**	**3** 4 4 **3**
l	**3** **3**	3 **2** 4 **2**	**2** 3 3 **2**	**3** 4 **3** **3**	
o	**4** **4**				

			s		n		o		w	
		0	**1**	**1**	**2**	**2**	**3**	**3**	**4**	**4**
o		**1**	**1**	2	**2**	3	**2**	4	4	5
		1	2	**1**	**2**	**2**	3	**2**	**3**	**3**
s		**2**	**1**	2	**2**	3	**3**	**3**	**3**	4
		2	3	**1**	**2**	**2**	**3**	**3**	4	**3**
l		**3**	3	**2**	**2**	3	**3**	4	4	4
		3	4	**2**	3	**2**	**3**	**3**	4	?
o		**4**								
		4								

			s		n		o		w	
		0	**1**	**1**	**2**	**2**	**3**	**3**	**4**	**4**
o		**1**	**1**	2	**2**	3	**2**	4	4	5
		1	2	**1**	**2**	**2**	3	**2**	**3**	**3**
s		**2**	**1**	2	**2**	3	**3**	**3**	**3**	4
		2	3	**1**	**2**	**2**	**3**	**3**	4	**3**
l		**3**	3	**2**	**2**	3	**3**	4	**4**	**4**
		3	4	**2**	3	**2**	**3**	**3**	**4**	**4**
o		**4**								
		4								

		s	n	o	w
	 0	 **1** **1**	 **2** **2**	 **3** **3**	 **4** **4**
o	**1** **1**	**1** 2 2 **1**	**2** 3 **2** **2**	**2** 4 3 **2**	4 5 **3** **3**
s	**2** **2**	**1** 2 3 **1**	**2** 3 **2** **2**	**3** **3** **3** **3**	**3** 4 4 **3**
l	**3** **3**	3 **2** 4 **2**	**2** 3 3 **2**	**3** 4 **3** **3**	**4** **4** **4** **4**
o	**4** **4**	4 3 5 ?			

			s		n		o		w	
		0	**1**	**1**	**2**	**2**	**3**	**3**	**4**	**4**
o		**1**	**1**	2	**2**	3	**2**	4	4	5
		1	2	**1**	**2**	**2**	3	**2**	**3**	**3**
s		**2**	**1**	2	**2**	3	**3**	**3**	**3**	4
		2	3	**1**	**2**	**2**	**3**	**3**	4	**3**
l		**3**	3	**2**	**2**	3	**3**	4	**4**	**4**
		3	4	**2**	3	**2**	**3**	**3**	**4**	**4**
o		**4**	4	**3**						
		4	5	**3**						

		s	n	o	w
	0	**1** **1**	**2** **2**	**3** **3**	**4** **4**
o	**1** **1**	**1** 2 2 **1**	**2** 3 **2** **2**	**2** 4 3 **2**	4 5 **3** **3**
s	**2** **2**	**1** 2 3 **1**	**2** 3 **2** **2**	**3** **3** **3** **3**	**3** 4 4 **3**
l	**3** **3**	3 **2** 4 **2**	**2** 3 3 **2**	**3** 4 **3** **3**	**4** **4** **4** **4**
o	**4** **4**	4 **3** 5 **3**	3 3 4 ?		

			s		n		o		w	
		0	**1**	**1**	**2**	**2**	**3**	**3**	**4**	**4**
o		**1**	**1**	2	**2**	3	**2**	4	4	5
		1	2	**1**	**2**	**2**	3	**2**	**3**	**3**
s		**2**	**1**	2	**2**	3	**3**	**3**	**3**	4
		2	3	**1**	**2**	**2**	**3**	**3**	4	**3**
l		**3**	3	**2**	**2**	3	**3**	4	**4**	**4**
		3	4	**2**	3	**2**	**3**	**3**	**4**	**4**
o		**4**	4	**3**	**3**	**3**				
		4	5	**3**	4	**3**				

			s		n		o		w	
		0	**1**	**1**	**2**	**2**	**3**	**3**	**4**	**4**
o		**1**	**1**	2	**2**	3	**2**	4	4	5
		1	2	**1**	**2**	**2**	3	**2**	**3**	**3**
s		**2**	**1**	2	**2**	3	**3**	**3**	**3**	4
		2	3	**1**	**2**	**2**	**3**	**3**	4	**3**
l		**3**	3	**2**	**2**	3	**3**	4	**4**	**4**
		3	4	**2**	3	**2**	**3**	**3**	**4**	**4**
o		**4**	4	**3**	**3**	**3**	2	4		
		4	5	**3**	4	**3**	4	?		

			s		n		o		w	
		0	**1**	**1**	**2**	**2**	**3**	**3**	**4**	**4**
o		**1**	**1**	2	**2**	3	**2**	4	4	5
		1	2	**1**	**2**	**2**	3	**2**	**3**	**3**
s		**2**	**1**	2	**2**	3	**3**	**3**	**3**	4
		2	3	**1**	**2**	**2**	**3**	**3**	4	**3**
l		**3**	3	**2**	**2**	3	**3**	4	**4**	**4**
		3	4	**2**	3	**2**	**3**	**3**	**4**	**4**
o		**4**	4	**3**	**3**	**3**	**2**	4		
		4	5	**3**	4	**3**	4	**2**		

			s		n		o		w	
		0	**1**	**1**	**2**	**2**	**3**	**3**	**4**	**4**
o		**1**	**1**	2	**2**	3	**2**	4	4	5
		1	2	**1**	**2**	**2**	3	**2**	**3**	**3**
s		**2**	**1**	2	**2**	3	**3**	**3**	**3**	4
		2	3	**1**	**2**	**2**	**3**	**3**	4	**3**
l		**3**	3	**2**	**2**	3	**3**	4	**4**	**4**
		3	4	**2**	3	**2**	**3**	**3**	**4**	**4**
o		**4**	4	**3**	**3**	**3**	**2**	4	4	5
		4	5	**3**	4	**3**	4	**2**	3	?

			s		n		o		w	
		0	**1**	**1**	**2**	**2**	**3**	**3**	**4**	**4**
o		**1**	**1**	2	**2**	3	**2**	4	4	5
		1	2	**1**	**2**	**2**	3	**2**	**3**	**3**
s		**2**	**1**	2	**2**	3	**3**	**3**	**3**	4
		2	3	**1**	**2**	**2**	**3**	**3**	4	**3**
l		**3**	3	**2**	**2**	3	**3**	4	**4**	**4**
		3	4	**2**	3	**2**	**3**	**3**	**4**	**4**
o		**4**	4	**3**	**3**	**3**	**2**	4	4	5
		4	5	**3**	4	**3**	4	**2**	**3**	**3**

			s		n		o		w	
		0	**1**	**1**	**2**	**2**	**3**	**3**	**4**	**4**
o		**1**	**1**	2	**2**	3	**2**	4	4	5
		1	2	**1**	**2**	**2**	3	**2**	**3**	**3**
s		**2**	**1**	2	**2**	3	**3**	**3**	**3**	4
		2	3	**1**	**2**	**2**	**3**	**3**	4	**3**
l		**3**	3	**2**	**2**	3	**3**	4	**4**	**4**
		3	4	**2**	3	**2**	**3**	**3**	**4**	**4**
o		**4**	4	**3**	**3**	**3**	**2**	4	4	5
		4	5	**3**	4	**3**	4	**2**	**3**	**3**

			s		n		o		w	
		0	**1**	**1**	**2**	**2**	**3**	**3**	**4**	**4**
o		**1**	**1**	2	**2**	3	**2**	4	4	5
		1	2	**1**	**2**	**2**	3	**2**	**3**	**3**
s		**2**	**1**	2	**2**	3	**3**	**3**	**3**	4
		2	3	**1**	**2**	**2**	**3**	**3**	4	**3**
l		**3**	3	**2**	**2**	3	**3**	4	**4**	**4**
		3	4	**2**	3	**2**	**3**	**3**	**4**	**4**
o		**4**	4	**3**	**3**	**3**	**2**	4	4	5
		4	5	**3**	4	**3**	4	**2**	**3**	**3**

How do I read out the editing operations that transform OSLO into SNOW?

			s		n		o		w	
		0	**1**	**1**	**2**	**2**	**3**	**3**	**4**	**4**
o		**1**	**1**	2	**2**	3	**2**	4	4	5
		1	2	**1**	**2**	**2**	3	**2**	**3**	**3**
s		**2**	**1**	2	**2**	3	**3**	**3**	**3**	4
		2	3	**1**	**2**	**2**	**3**	**3**	4	**3**
l		**3**	3	**2**	**2**	3	**3**	4	**4**	**4**
		3	4	**2**	3	**2**	**3**	**3**	**4**	**4**
o		**4**	4	**3**	**3**	**3**	**2**	4	4	5
		4	5	**3**	4	**3**	4	**2**	**3**	**3**

cost	operation	input	output
1	insert	*	w

			s		n		o		w	
		0	**1**	**1**	**2**	**2**	**3**	**3**	**4**	**4**
o		**1**	**1**	2	**2**	3	**2**	4	4	5
		1	2	**1**	**2**	**2**	3	**2**	**3**	**3**
s		**2**	**1**	2	**2**	3	**3**	**3**	**3**	4
		2	3	**1**	**2**	**2**	**3**	**3**	4	**3**
l		**3**	3	**2**	**2**	3	**3**	4	**4**	**4**
		3	4	**2**	3	**2**	**3**	**3**	**4**	**4**
o		**4**	4	**3**	**3**	**3**	**2**	4	4	5
		4	5	**3**	4	**3**	4	**2**	**3**	**3**

cost	operation	input	output
0	(copy)	o	o
1	insert	*	w

			s		n		o		w	
		0	1	1	2	2	3	3	4	4
o		1	1	2	2	3	2	4	4	5
		1	2	1	2	2	3	2	3	3
s		2	1	2	2	3	3	3	3	4
		2	3	1	2	2	3	3	4	3
l		3	3	2	2	3	3	4	4	4
		3	4	2	3	2	3	3	4	4
o		4	4	3	3	3	2	4	4	5
		4	5	3	4	3	4	2	3	3

cost	operation	input	output
1	replace	l	n
0	(copy)	o	o
1	insert	*	w

		s	n	o	w
	0	**1** **1**	**2** **2**	**3** **3**	**4** **4**
o	**1** **1**	**1** 2 2 **1**	**2** 3 **2** **2**	**2** 4 3 **2**	4 5 **3** **3**
s	**2** **2**	**1** 2 3 **1**	**2** 3 **2** **2**	**3** **3** **3** **3**	**3** 4 4 **3**
l	**3** **3**	3 **2** 4 **2**	**2** 3 3 **2**	**3** 4 **3** **3**	**4** **4** **4** **4**
o	**4** **4**	4 **3** 5 **3**	**3** **3** 4 **3**	**2** 4 4 **2**	4 5 **3** **3**

cost	operation	input	output
0	(copy)	s	s
1	replace	l	n
0	(copy)	o	o
1	insert	*	w

			s		n		o		w	
		0	1	1	2	2	3	3	4	4
o		1	1	2	2	3	2	4	4	5
		1	2	1	2	2	3	2	3	3
s		2	1	2	2	3	3	3	3	4
		2	3	1	2	2	3	3	4	3
l		3	3	2	2	3	3	4	4	4
		3	4	2	3	2	3	3	4	4
o		4	4	3	3	3	2	4	4	5
		4	5	3	4	3	4	2	3	3

cost	operation	input	output
1	delete	o	*
0	(copy)	s	s
1	replace	l	n
0	(copy)	o	o
1	insert	*	w

		c	a	t	c	a	t
	0	**1** **1**	**2** **2**	**3** **3**	**4** **4**	**5** **5**	**6** **6**
c	**1** **1**	**0** 2 2 **0**	2 3 **1** **1**	3 4 **2** **2**	**3** 5 **3** **3**	5 6 **4** **4**	6 7 **5** **5**
a	**2** **2**	2 **1** 3 **1**	**0** 2 2 **0**	2 3 **1** **1**	3 4 **2** **2**	**3** 5 **3** **3**	5 6 **4** **4**
t	**3** **3**	3 **2** 4 **2**	2 **1** 3 **1**	**0** 2 2 **0**	2 3 **1** **1**	3 4 **2** **2**	**3** 5 **3** **3**

		c	a	t	c	a	t
	0	1 1	2 2	3 3	4 4	5 5	6 6
c	1 1	0 2 2 0	2 3 1 1	3 4 2 2	3 5 3 3	5 6 4 4	6 7 5 5
a	2 2	2 1 3 1	0 2 2 0	2 3 1 1	3 4 2 2	3 5 3 3	5 6 4 4
t	3 3	3 2 4 2	2 1 3 1	0 2 2 0	2 3 1 1	3 4 2 2	3 5 3 3

cost	operation	input	output
1	insert	*	c
1	insert	*	a
1	insert	*	t
0	(copy)	c	c
0	(copy)	a	a
0	(copy)	t	t

		c	a	t	c	a	t
	0	1 1	2 2	3 3	4 4	5 5	6 6
c	1 1	0 2 2 0	2 3 1 1	3 4 2 2	3 5 3 3	5 6 4 4	6 7 5 5
a	2 2	2 1 3 1	0 2 2 0	2 3 1 1	3 4 2 2	3 5 3 3	5 6 4 4
t	3 3	3 2 4 2	2 1 3 1	0 2 2 0	2 3 1 1	3 4 2 2	3 5 3 3

cost	operation	input	output
0	(copy)	c	c
1	insert	*	a
1	insert	*	t
1	insert	*	c
0	(copy)	a	a
0	(copy)	t	t

		c	a	t	c	a	t
	0	1 1	2 2	3 3	4 4	5 5	6 6
c	1 1	0 2 2 0	2 3 1 1	3 4 2 2	3 5 3 3	5 6 4 4	6 7 5 5
a	2 2	2 1 3 1	0 2 2 0	2 3 1 1	3 4 2 2	3 5 3 3	5 6 4 4
t	3 3	3 2 4 2	2 1 3 1	0 2 2 0	2 3 1 1	3 4 2 2	3 5 3 3

cost	operation	input	output
0	(copy)	c	c
0	(copy)	a	a
1	insert	*	t
1	insert	*	c
1	insert	*	a
0	(copy)	t	t

		c	a	t	c	a	t
	0	1 1	2 2	3 3	4 4	5 5	6 6
c	1 1	0 2 2 0	2 3 1 1	3 4 2 2	3 5 3 3	5 6 4 4	6 7 5 5
a	2 2	2 1 3 1	0 2 2 0	2 3 1 1	3 4 2 2	3 5 3 3	5 6 4 4
t	3 3	3 2 4 2	2 1 3 1	0 2 2 0	2 3 1 1	3 4 2 2	3 5 3 3

cost	operation	input	output
0	(copy)	c	c
0	(copy)	a	a
0	(copy)	t	t
1	insert	*	c
1	insert	*	a
1	insert	*	t

Outline

Spelling correction

Spelling correction

- Now that we can compute edit distance: how to use it for isolated word spelling correction – this is the last slide in this section.

Spelling correction

- Now that we can compute edit distance: how to use it for isolated word spelling correction – this is the last slide in this section.
- k-gram indexes for isolated word spelling correction.

Spelling correction

- Now that we can compute edit distance: how to use it for isolated word spelling correction – this is the last slide in this section.
- *k*-gram indexes for isolated word spelling correction.
- Context-sensitive spelling correction

Spelling correction

- Now that we can compute edit distance: how to use it for isolated word spelling correction – this is the last slide in this section.
- *k*-gram indexes for isolated word spelling correction.
- Context-sensitive spelling correction
- General issues

k-gram indexes for spelling correction

k-gram indexes for spelling correction

- Enumerate all k-grams in the query term

k-gram indexes for spelling correction

- Enumerate all *k*-grams in the query term
- Example: bigram index, misspelled word *bordroom*

k-gram indexes for spelling correction

- Enumerate all *k*-grams in the query term
- Example: bigram index, misspelled word *bordroom*
- Bigrams: *bo, or, rd, dr, ro, oo, om*

k-gram indexes for spelling correction

- Enumerate all *k*-grams in the query term
- Example: bigram index, misspelled word *bordroom*
- Bigrams: *bo, or, rd, dr, ro, oo, om*
- Use the *k*-gram index to retrieve "correct" words that match query term *k*-grams

k-gram indexes for spelling correction

- Enumerate all *k*-grams in the query term
- Example: bigram index, misspelled word *bordroom*
- Bigrams: *bo, or, rd, dr, ro, oo, om*
- Use the *k*-gram index to retrieve "correct" words that match query term *k*-grams
- Threshold by number of matching *k*-grams

k-gram indexes for spelling correction

- Enumerate all *k*-grams in the query term
- Example: bigram index, misspelled word *bordroom*
- Bigrams: *bo, or, rd, dr, ro, oo, om*
- Use the *k*-gram index to retrieve "correct" words that match query term *k*-grams
- Threshold by number of matching *k*-grams
- E.g., only vocabulary terms that differ by at most 3 *k*-grams

k-gram indexes for spelling correction: *bordroom*

BO → aboard → about → boardroom → border

OR → border → lord → morbid → sordid

RD → aboard → ardent → boardroom → border

Context-sensitive spelling correction

Context-sensitive spelling correction

- Our example was: *an asteroid that fell form the sky*

Context-sensitive spelling correction

- Our example was: *an asteroid that fell form the sky*
- How can we correct *form* here?

Context-sensitive spelling correction

- Our example was: *an asteroid that fell form the sky*
- How can we correct *form* here?
- One idea: hit-based spelling correction

Context-sensitive spelling correction

- Our example was: *an asteroid that fell form the sky*
- How can we correct *form* here?
- One idea: hit-based spelling correction
  - Retrieve "correct" terms close to each query term

Context-sensitive spelling correction

- Our example was: *an asteroid that fell form the sky*
- How can we correct *form* here?
- One idea: hit-based spelling correction
  - Retrieve "correct" terms close to each query term
  - for *flew form munich*: *flea* for *flew*, *from* for *form*, *munch* for *munich*

Context-sensitive spelling correction

- Our example was: *an asteroid that fell form the sky*
- How can we correct *form* here?
- One idea: hit-based spelling correction
  - Retrieve "correct" terms close to each query term
  - for *flew form munich*: *flea* for *flew*, *from* for *form*, *munch* for *munich*
  - Now try all possible resulting phrases as queries with one word "fixed" at a time

Context-sensitive spelling correction

- Our example was: *an asteroid that fell form the sky*
- How can we correct *form* here?
- One idea: hit-based spelling correction
  - Retrieve "correct" terms close to each query term
  - for *flew form munich*: *flea* for *flew*, *from* for *form*, *munch* for *munich*
  - Now try all possible resulting phrases as queries with one word "fixed" at a time
  - Try query *"flea form munich"*

Context-sensitive spelling correction

- Our example was: *an asteroid that fell form the sky*
- How can we correct *form* here?
- One idea: hit-based spelling correction
  - Retrieve "correct" terms close to each query term
  - for *flew form munich*: *flea* for *flew*, *from* for *form*, *munch* for *munich*
  - Now try all possible resulting phrases as queries with one word "fixed" at a time
  - Try query *"flea form munich"*
  - Try query *"flew from munich"*

Context-sensitive spelling correction

- Our example was: *an asteroid that fell form the sky*
- How can we correct *form* here?
- One idea: hit-based spelling correction
  - Retrieve "correct" terms close to each query term
  - for *flew form munich*: *flea* for *flew*, *from* for *form*, *munch* for *munich*
  - Now try all possible resulting phrases as queries with one word "fixed" at a time
  - Try query *"flea form munich"*
  - Try query *"flew from munich"*
  - Try query *"flew form munch"*

Context-sensitive spelling correction

- Our example was: *an asteroid that fell form the sky*
- How can we correct *form* here?
- One idea: hit-based spelling correction
  - Retrieve "correct" terms close to each query term
  - for *flew form munich*: *flea* for *flew*, *from* for *form*, *munch* for *munich*
  - Now try all possible resulting phrases as queries with one word "fixed" at a time
  - Try query *"flea form munich"*
  - Try query *"flew from munich"*
  - Try query *"flew form munch"*
  - The correct query *"flew from munich"* has the most hits.

Context-sensitive spelling correction

- Our example was: *an asteroid that fell form the sky*
- How can we correct *form* here?
- One idea: hit-based spelling correction
  - Retrieve "correct" terms close to each query term
  - for *flew form munich*: *flea* for *flew*, *from* for *form*, *munch* for *munich*
  - Now try all possible resulting phrases as queries with one word "fixed" at a time
  - Try query *"flea form munich"*
  - Try query *"flew from munich"*
  - Try query *"flew form munch"*
  - The correct query *"flew from munich"* has the most hits.
- Suppose we have 7 alternatives for *flew*, 20 for *form* and 3 for *munich*, how many "corrected" phrases will we enumerate?

Context-sensitive spelling correction

Context-sensitive spelling correction

- The "hit-based" algorithm we just outlined is not very efficient.

Context-sensitive spelling correction

- The “hit-based” algorithm we just outlined is not very efficient.
- More efficient alternative: look at “collection” of queries, not documents

General issues in spelling correction

General issues in spelling correction

- User interface

General issues in spelling correction

- User interface
  - automatic vs. suggested correction

General issues in spelling correction

- User interface
  - automatic vs. suggested correction
  - *Did you mean* only works for one suggestion.

General issues in spelling correction

- User interface
  - automatic vs. suggested correction
  - *Did you mean* only works for one suggestion.
  - What about multiple possible corrections?

General issues in spelling correction

- User interface
  - automatic vs. suggested correction
  - *Did you mean* only works for one suggestion.
  - What about multiple possible corrections?
  - Tradeoff: simple vs. powerful UI

General issues in spelling correction

- User interface
  - automatic vs. suggested correction
  - *Did you mean* only works for one suggestion.
  - What about multiple possible corrections?
  - Tradeoff: simple vs. powerful UI
- Cost

General issues in spelling correction

- User interface
  - automatic vs. suggested correction
  - *Did you mean* only works for one suggestion.
  - What about multiple possible corrections?
  - Tradeoff: simple vs. powerful UI
- Cost
  - Spelling correction is potentially expensive.

General issues in spelling correction

- User interface
  - automatic vs. suggested correction
  - *Did you mean* only works for one suggestion.
  - What about multiple possible corrections?
  - Tradeoff: simple vs. powerful UI
- Cost
  - Spelling correction is potentially expensive.
  - Avoid running on every query?

General issues in spelling correction

- User interface
  - automatic vs. suggested correction
  - *Did you mean* only works for one suggestion.
  - What about multiple possible corrections?
  - Tradeoff: simple vs. powerful UI
- Cost
  - Spelling correction is potentially expensive.
  - Avoid running on every query?
  - Maybe just on queries that match few documents.

General issues in spelling correction

- User interface
  - automatic vs. suggested correction
  - *Did you mean* only works for one suggestion.
  - What about multiple possible corrections?
  - Tradeoff: simple vs. powerful UI
- Cost
  - Spelling correction is potentially expensive.
  - Avoid running on every query?
  - Maybe just on queries that match few documents.
  - Guess: Spelling correction of major search engines is efficient enough to be run on every query.

Exercise: Understand Peter Norvig's spelling corrector

```
import re, collections
def words(text): return re.findall('[a-z]+', text.lower())
def train(features):
    model = collections.defaultdict(lambda: 1)
    for f in features:
        model[f] += 1
    return model
NWORDS = train(words(file('big.txt').read()))
alphabet = 'abcdefghijklmnopqrstuvwxyz'
def edits1(word):
   splits     = [(word[:i], word[i:]) for i in range(len(word) + 1)]
   deletes    = [a + b[1:] for a, b in splits if b]
   transposes = [a + b[1] + b[0] + b[2:] for a, b in splits if len(b) gt 1]
   replaces   = [a + c + b[1:] for a, b in splits for c in alphabet if b]
   inserts    = [a + c + b     for a, b in splits for c in alphabet]
   return set(deletes + transposes + replaces + inserts)
def known_edits2(word):
    return set(e2 for e1 in edits1(word) for e2 in edits1(e1) if e2 in NWORDS)
def known(words): return set(w for w in words if w in NWORDS)
def correct(word):
    candidates = known([word]) or known(edits1(word)) or known_edits2(word) or [word]
    return max(candidates, key=NWORDS.get)
```

Outline

Soundex

Soundex

- Soundex is the basis for finding phonetic (as opposed to orthographic) alternatives.

Soundex

- Soundex is the basis for finding phonetic (as opposed to orthographic) alternatives.
- Example: *chebyshev* / *tchebyscheff*

Soundex

- Soundex is the basis for finding phonetic (as opposed to orthographic) alternatives.
- Example: *chebyshev* / *tchebyscheff*
- Algorithm:

Soundex

- Soundex is the basis for finding phonetic (as opposed to orthographic) alternatives.
- Example: *chebyshev* / *tchebyscheff*
- Algorithm:
  - Turn every token to be indexed into a 4-character reduced form

Soundex

- Soundex is the basis for finding phonetic (as opposed to orthographic) alternatives.
- Example: *chebyshev* / *tchebyscheff*
- Algorithm:
  - Turn every token to be indexed into a 4-character reduced form
  - Do the same with query terms

Soundex

- Soundex is the basis for finding phonetic (as opposed to orthographic) alternatives.
- Example: *chebyshev* / *tchebyscheff*
- Algorithm:
  - Turn every token to be indexed into a 4-character reduced form
  - Do the same with query terms
  - Build and search an index on the reduced forms

Soundex algorithm

1. Retain the first letter of the term.
2. Change all occurrences of the following letters to '0' (zero): A, E, I, O, U, H, W, Y
3. Change letters to digits as follows:
   - B, F, P, V to 1
   - C, G, J, K, Q, S, X, Z to 2
   - D,T to 3
   - L to 4
   - M, N to 5
   - R to 6
4. Repeatedly remove one out of each pair of consecutive identical digits
5. Remove all zeros from the resulting string; pad the resulting string with trailing zeros and return the first four positions, which will consist of a letter followed by three digits

Example: Soundex of *HERMAN*

Example: Soundex of *HERMAN*

- Retain H

Example: Soundex of *HERMAN*

- Retain H
- *ERMAN* → *0RM0N*

Example: Soundex of *HERMAN*

- Retain H
- *ERMAN* $\rightarrow$ *0RM0N*
- *0RM0N* $\rightarrow$ *06505*

Example: Soundex of *HERMAN*

- Retain H
- *ERMAN* $\rightarrow$ *0RM0N*
- *0RM0N* $\rightarrow$ *06505*
- *06505* $\rightarrow$ *06505*

Example: Soundex of *HERMAN*

- Retain H
- *ERMAN* → *0RM0N*
- *0RM0N* → *06505*
- *06505* → *06505*
- *06505* → *655*

Example: Soundex of *HERMAN*

- Retain H
- *ERMAN* → *0RM0N*
- *0RM0N* → *06505*
- *06505* → *06505*
- *06505* → *655*
- Return *H655*

Example: Soundex of *HERMAN*

- Retain H
- *ERMAN* $\rightarrow$ *0RM0N*
- *0RM0N* $\rightarrow$ *06505*
- *06505* $\rightarrow$ *06505*
- *06505* $\rightarrow$ *655*
- Return *H655*
- Note: *HERMANN* will generate the same code

How useful is Soundex?

How useful is Soundex?

- Not very – for information retrieval

How useful is Soundex?

- Not very – for information retrieval
- Ok for “high recall” tasks in other applications (e.g., Interpol)

How useful is Soundex?

- Not very – for information retrieval
- Ok for "high recall" tasks in other applications (e.g., Interpol)
- Zobel and Dart (1996) suggest better alternatives for phonetic matching in IR.

Exercise

- Compute Soundex code of your last name

Take-away

- Tolerant retrieval: What to do if there is no exact match between query term and document term
- Wildcard queries
- Spelling correction

Resources

- Chapter 3 of IIR
- Resources at `http://ifnlp.org/ir`
  - trie vs hash vs ternary tree
  - Soundex demo
  - Edit distance demo
  - Peter Norvig's spelling corrector
  - Google: wild card search, spelling correction gone wrong, a misspelling that is more frequent that the correct spelling