Introduction to Information Retrieval

http://informationretrieval.org

IIR 3: Dictionaries and tolerant retrieval

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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

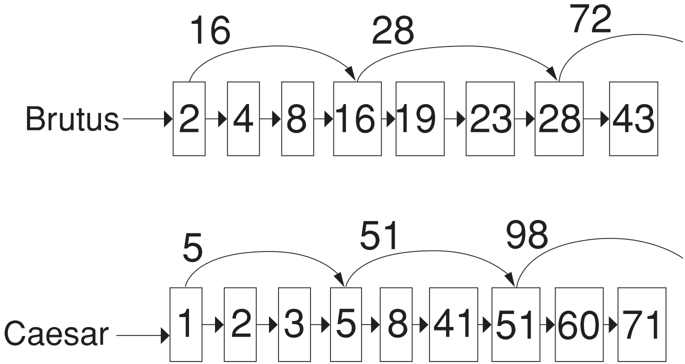
Problems in tokenization

- 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.

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- Spelling correction

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Inverted index

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

Dictionary		Postings								
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**

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- 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?

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  - need to rehash everything periodically if vocabulary keeps growing

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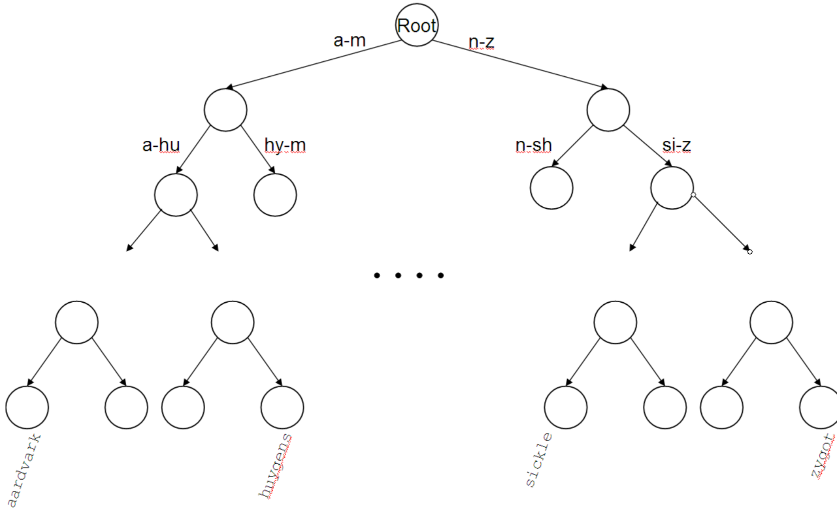
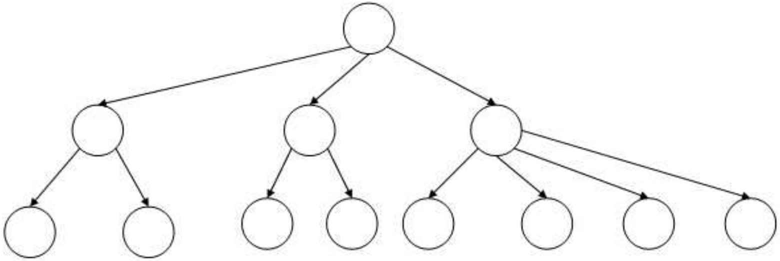
- B-tree definition: every internal node has a number of children in the interval $[a, b]$ where a, b are appropriate positive integers, e.g., $[2, 4]$.

Binary tree



B-tree



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- Then retrieve documents that contain any of these terms

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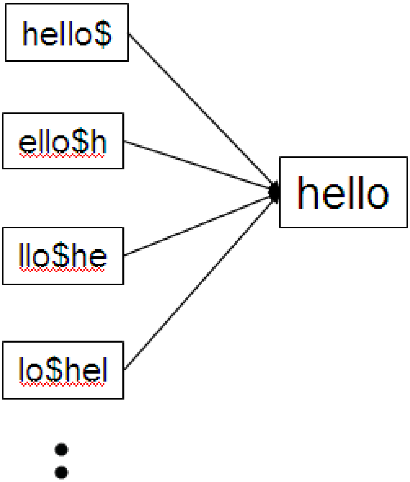
- Basic idea: Rotate every wildcard query, so that the * occurs at the end.
- Store each of these rotations in the dictionary, say, in a B-tree

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



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- But permuterm index is the more common name.

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- Problem: Permuterm more than quadruples the size of the dictionary compared to a regular B-tree. (empirical number)

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- Maintain an inverted index from bigrams to the terms that contain the bigram

Postings list in a 3-gram inverted index

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  - Permuterm index doesn't require postfiltering.

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- Exercise: Why doesn't Google fully support wildcard queries?

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- Somewhat alleviated by Google Suggest

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- Levenshtein distance: The admissible basic operations are insert, delete, and replace

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- 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

$\textsc{LevenshteinDistance}(s_1, s_2)$

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 $m[i,j] = \min\{m[i\text{-}1,j]+1, m[i,j\text{-}1]+1, m[i\text{-}1,j\text{-}1]+1\}$
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Levenshtein distance: Algorithm

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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*

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- 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.

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- 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

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- 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**	**1** 2 2 **1**	2 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	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**	**1** 2 2 **1**	**2** 3 **2** **2**	2 4 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		
		1	2	**1**	**2**	**2**	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**	**1** 2 2 **1**	**2** 3 **2** **2**	**2** 4 3 **2**	4 5 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**	2	**2**	3	**2**	4	4	5
		1	2	**1**	**2**	**2**	3	**2**	**3**	**3**
s		**2**	**1**	2						
		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**	**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 ?		
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		
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 ?	
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**	**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**				
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**	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	**2**	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	**2**	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**	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		
		3	4	**2**	3	**2**	**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**	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	?						

		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**			

			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	?				

		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**		

		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 ?	

		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**	

			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**	**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**

			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	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
1	insert	*	w

		s		n		o		w	
	0	1	1	2	2	3	3	4	4
o	1 1	1 2	2 1	2 2	3 2	2 3	4 2	4 3	5 3
s	2 2	1 3	2 1	2 2	3 2	3 3	3 3	3 4	4 3
l	3 3	3 4	2 2	2 3	3 2	3 3	4 3	4 4	4 4
o	4 4	4 5	3 3	3 4	3 3	2 4	4 2	4 3	5 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	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
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	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
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**	**0**	2	2	3	3	4	**3**	5	5	6	6	7
		1	2	**0**	**1**	**1**	**2**	**2**	**3**	**3**	**4**	**4**	**5**	**5**
a		**2**	2	**1**	**0**	2	2	3	3	4	**3**	5	5	6
		2	3	**1**	2	**0**	**1**	**1**	**2**	**2**	**3**	**3**	**4**	**4**
t		**3**	3	**2**	2	**1**	**0**	2	2	3	3	4	**3**	5
		3	4	**2**	3	**1**	2	**0**	**1**	**1**	**2**	**2**	**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	0	2	2	3	3	4	3	5	5	6	6	7
		1	2	0	1	1	2	2	3	3	4	4	5	5
a		2	2	1	0	2	2	3	3	4	3	5	5	6
		2	3	1	2	0	1	1	2	2	3	3	4	4
t		3	3	2	2	1	0	2	2	3	3	4	3	5
		3	4	2	3	1	2	0	1	1	2	2	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
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1	insert	*	t

Outline

Spelling correction

Spelling correction

- Two principal uses

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  - Correcting documents being indexed

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- The general philosophy in IR is: don't change the documents.

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- Why is this problematic?

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- The term vocabulary of the collection, appropriately weighted

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- 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

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- 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

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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

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  - 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

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  - 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*

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- Retain H

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

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

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- *06505* $\rightarrow$ *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

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- 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://cislmu.org`
  - 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