AALBORG UNIVERSITY

Document Modeling, Indexing & Matching
– Content Based

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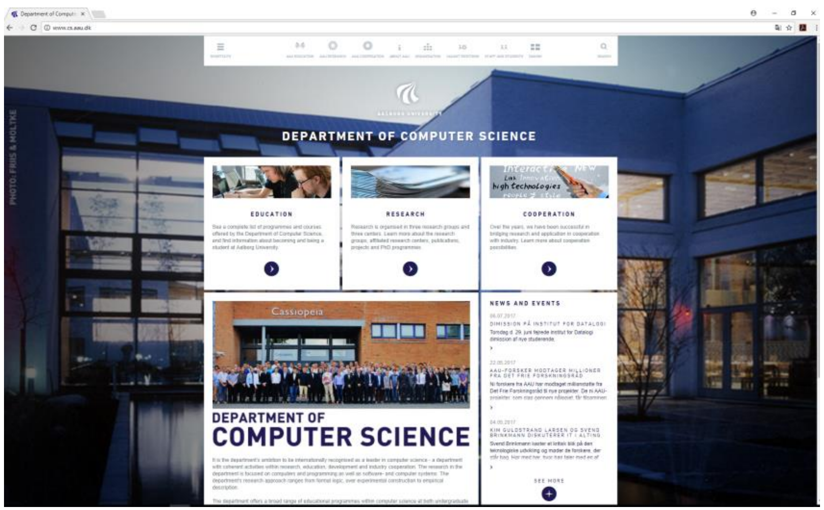
Based (heavily) on Stanford slides by Christopher Manning & Pandu Nayak and on the 'Introduction to Information Retrieval ' book (Chap. 1,2) by Christopher Manning, Prabhakar Raghavan & Hinrich Schütze.

Outline

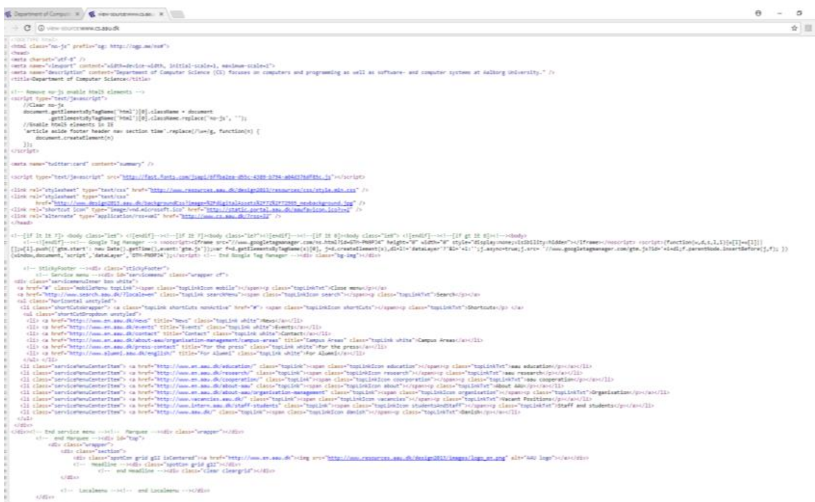
- Web search basics (short review)
- Document pre-processing / feature construction
- Index construction – the “Inverted index”
- Boolean query processing model
    - standard
    - Phrase
    - Positional

http://www.cs.aau.dk/en/welcome/

User's view



Browser/crawler's view



Content-based Information Retrieval

Input: Document collection (aka. Corpus)

Goal: Retrieve documents or text with information content that is relevant to user's information need.

Three aspects:

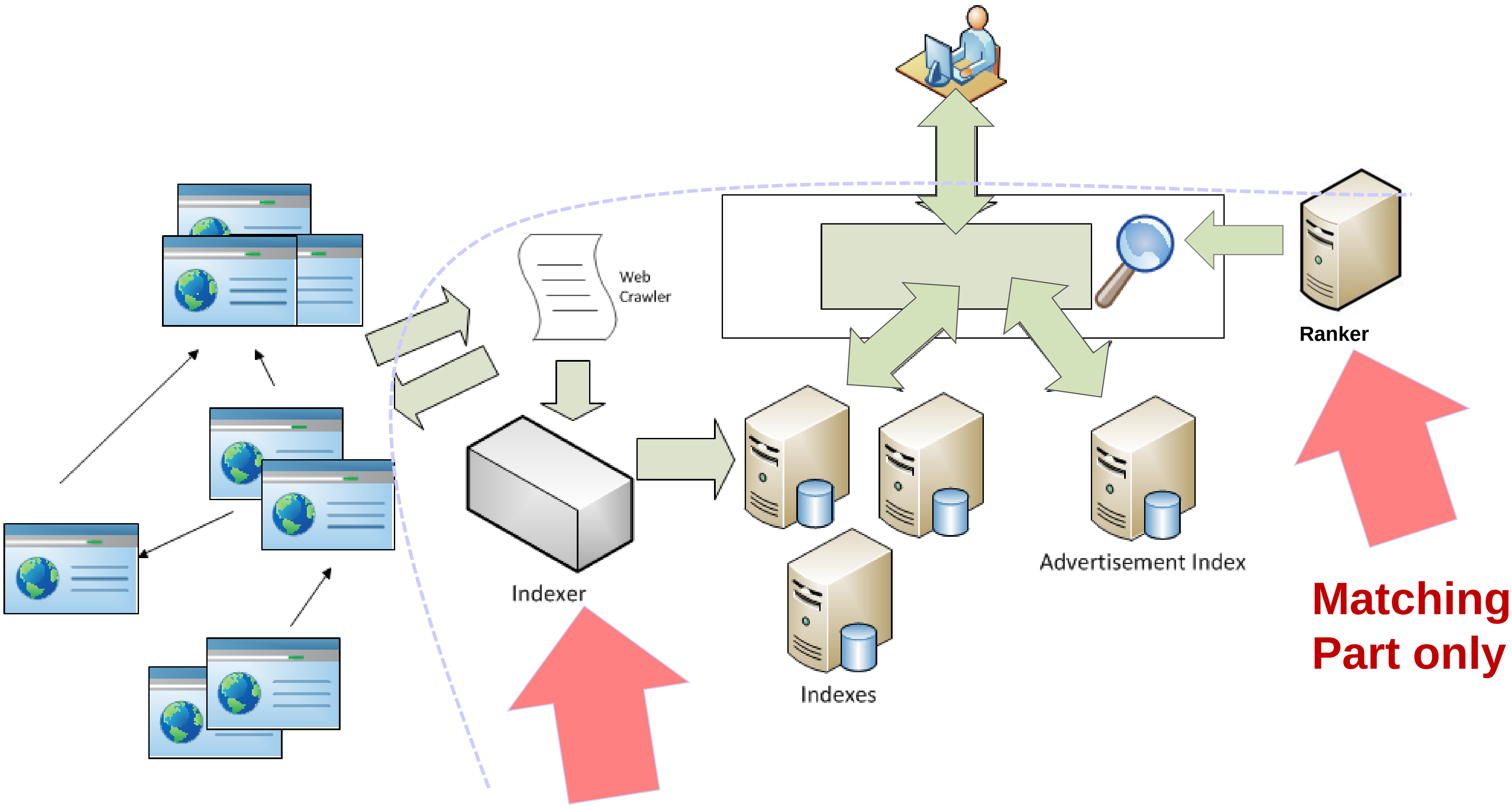
- Document representation (feature construction)
- Processing the corpus (indexing)
- Processing the queries (matching & ranking)

Information needs:

- Web search
- E-mail search
- Searching your laptop
- Corporate knowledge bases
- Legal, health, etc. information retrieval
- …

Notice: not including quality/authoritativeness yet!

Search Engine Architecture



Document Representation

Web documents consist of different formats

- Text, graphics, audio and video
- Represented by intelligently selected features
- We will focus on unstructured text

Text reduced to a list of “keywords” (bag-of-words)

- Simplistic representation of a document
- Yet, the most common representation in Information Retrieval

Basic Representation & Indexing

The department's ambition is to be recognized

Tokenizer

Token stream

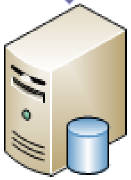
The	departments	ambition	is	to	be	recognized

(Linguistic) feature constructor modules

Document features

depart	ambit	recogn

Indexer



depart	→	3	17	34		
ambit	→	1	3	9	15	91
recogn	→	11	15			

Tokenization

Input: Document

The department's ambition is to be recognized

Output: Tokens

The	departments	ambition	is	to	be	recognized

Def: A token is an instance of a sequence of characters from input document that are grouped together as a useful semantic unit (e.g., separated by spaces, tabs, new-line, and other special characters)

Resulting tokens are passed on to further (linguistic) feature construction

Tokenizer: Complications

Parsing a document

- What format is it in
  - html/pdf/word/…?
  - Multiple formats in same documents (e.g., attachments)
- What language is it?
  - Multiple languages in same document?
  - Left-to-right (English), Right to left (Arabic)
- What character set is used?
  - UTF-8, UTF-16, ANSI, Unicode,…?

Tokenizer: Complications (cont.)

- Apostrophes
  - department's ⇒ department AND s? departments? department's?
- Hyphens
  - Hewlett-Packard ⇒ HewlettPackard? Hewlett Packard? Hewlett-Packard?
  - lowercase, lower-case, lower case?
- Aalborg East ⇒ one token or two?
- Numbers - Date/Time/Phone…
  - Sep. 3, 2014, 03-09-2014, 9/3/14…?
- Compounds
  - Lebensversicherungsgesellschaftsangestellter (german)
  - Atombombeprøvesprængning (danish)
- No white spaces between words (East Asian)
  - 部門的志向是國際公認 (The departments ambition is to be recognized internationally???)
- Etc.

Normalization

- Maps class of equivalent tokens into same term
  e.g., U.S.A, USA, United States of America $\Rightarrow$ USA
- Normalization of words in indexed text MUST be the same as normalization of query
- Which form? Well, what is the preferred form among your users when they write their queries!

Stop words

With a stop list, you exclude the *most common* words.
Intuition:

- They have little semantic content: *the, a, and, to, be*
  (may skew quality search)
- There are a lot of them: ~30% of postings for top 30 words
  (slows down the search, take up a lot of space)

On the other hand, you may need them for:

- Phrase queries: “King of Denmark”
- “Relational” queries: “flights to London”
- Etc.

English stopwords list
(http://www.ranks.nl/stopwords)

a
about
above
after
again
against
all
am
an
and
any
are
aren't
as
at
be
because
been
before
being
below
between
both
but
by
can't
cannot
could
couldn't
did
didn't
do
does
doesn't
doing
don't
down
during
each
few
for
from
further
had
hadn't
has
hasn't
have
haven't
having
he
he'd
he'll
he's
her
here
here's
hers
herself
him
himself
his
how
how's
i
i'd
i'll
i'm
i've
if
in
into
is
isn't
it
it's
its
itself
let's
me
more
most
mustn't
my
myself
no
nor
not
of
off
on
once
only
or
other
ought
our
ours
ourselves
out
over
own
same
shan't
she
she'd
she'll
she's
should
shouldn't
so
some
such
than
that
that's
the
their
theirs
them
themselves
then
there
there's
these
they
they'd
they'll
they're
they've
this
those
through
to
too
under
until
up
very
was
wasn't
we
we'd
we'll
we're
we've
were
weren't
what
what's
when
when's
where
where's
which
while
who
who's
whom
why
why's
with
won't
would
wouldn't
you
you'd
you'll
you're
you've
your
yours
yourself
yourselves

Danish stopwords list
(http://www.ranks.nl/stopwords/danish)

af
alle
andet
andre
at
begge
da
de
den
denne
der
deres
det
dette
dig
din
dog
du
ej
eller
en
end
ene
eneste
enhver
et
fem
fire
flere
fleste
for
fordi
forrige
fra
få
før
god
han
hans
har
hendes
her
hun
hvad
hvem
hver
hvilken
hvis
hvor
hvordan
hvorfor
hvornår
i
ikke
ind
ingen
intet
jeg
jeres
kan
kom
kommer
lav
lidt
lille
man
mand
mange
med
meget
men
mens
mere
mig
ned
ni
nogen
noget
ny
nyt
nær
næste
næsten
og
op
otte
over
på
se
seks
ses
som
stor
store
syv
ti
til
to
tre
ud
var

Example – Stopword removal

Case folding

Reduce all letters to lower case

- exception: upper case in mid-sentence?
  - e.g., Aalborg University
  - Denmark vs denmark
- Often best to lower case everything, since users will use lowercase regardless of 'correct' capitalization…

Anecdotic Google example: [believed to be fixed in 2011… but]

- Query C.A.T.
- #1 result in my browser is Wikipedia article for "cats" not Caterpillar Inc.

Thesauri and soundex

Do we handle synonyms and homonyms?

- E.g., by hand-constructed equivalence classes
  - ***car* = *automobile*   *color* = *colour***
- We can rewrite to form equivalence-class terms
  - When the document contains ***automobile***, index it under ***car-automobile*** (and vice-versa)
- Or we can expand a query
  - When the query contains ***automobile***, look under ***car*** as well

Do we handle spelling mistakes?

- One approach is Soundex, which forms equivalence classes of words based on phonetic heuristics

Stemming (to the "root")

A given word may occur in a variety of syntactic forms, such as plurals, past tense, or gerund forms:

- Connect, connector, connection, connections, connected, connecting, connects, preconnection and postconnection

A stem is what is left after its affixes (prefixes and suffixes) are removed

- ed, s, or, ed, ing and ion are suffixes
- pre and post are prefixes
- connect is the stem of connector, connection, etc.

The use of stems will improve retrieval performance

- Users rarely specify the exact forms of the word they are looking for
- Stemming reduces the size of the index
- However, researchers have conflicting opinions on quality from the use of stems (In particular English; better for Spanish, German, Finnish,…)
- Increases recall but harms precision

Porter's Stemming Algorithm

- The most popular algorithm for stemming English text
  - Designed by Martin Porter in1980
  - Results suggest it's at least as good as other stemming options

Conventions + 5 phases of reductions

- phases applied sequentially
- each phase consists of a set of commands
- sample convention: *Of the rules in a compound command, select the one that applies to the longest suffix.*

Typical rules in Porter

- *sses* $\rightarrow$ *ss*
- *ies* $\rightarrow$ *i*
- *ational* $\rightarrow$ *ate*
- *tional* $\rightarrow$ *tion*

word sensitive rules:

- *(m>1) EMENT* $\rightarrow$

examples:

  - *replacement* $\rightarrow$ *replac*
  - *cement* $\rightarrow$ *cement*

Example – Porter Stemming

(http://textanalysisonline.com/nltk-porter-stemmer)

TextAnalysisOnline

Text Analysis Result -- NLTK Porter Stemmer

Original Text

The departments ambition is to be recognized internationally as a leading computer science environment. It is a department with many coherent activities within research, education, technology, development and co-operation with the surrounding society and research dissemination within the computer science area.

Analysis Result

The depart ambit is to be recogn intern as a lead comput scienc environment. It is a depart with mani coher activ within research , educ , technolog , develop and co-oper with the surround societi and research dissemin within the comput scienc area .

mashape Consume API @ 2014 Text Analysis Online

Other stemmers

Other stemmers exist, e.g.:

- Lovins stemmer
- Paice/Husk stemmer
- Snowball

Full morphological linguistic analysis (lemmatization)

- Closely related to stemming
- Stemmer operates on a single word *without* knowledge of the context, whereas lemmatization may use context
- Stemmers easier to implement and run faster
- No significant benefit for retrieval accuracy (in general)

Good open source and commercial “plug-in”s are available

Basic Representation & Indexing

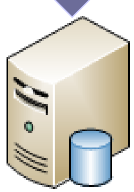
Tokenizer

Token stream

(Linguistic) feature constructor modules

Document features

Indexer



+Doc retrieval (and ranking)

The department's ambition is to be recognized

The	departments	ambition	is	to	be	recognized

depart	ambit	recogn

depart → 3 → 17 → 34

ambit → 1 → 3 → 9 → 15 → 91

recogn → 11 → 15

Indexing

Term Vector

- Corpus contains many documents
- Vocabulary = all distinct words in these documents

Doc

the research in the department has computers, programming, as well as software and computer systems as its field.

Binary

Term	1/0.
⋮	0
and	1
⋮	0
as	1
⋮	0
computer(s)	1
⋮	0
department	1
⋮	0
field	1
⋮	

-or-

Frequency

Term	Freq.
⋮	0
and	1
⋮	0
as	3
⋮	0
computer(s)	2
⋮	0
department	2
⋮	0
field	1
⋮	

This lecture

Next lecture

Binary Term-Document Matrix

Term	Term ID	Doc1	Doc2	Doc3
depart	t1	1	1	0
activ	t2	0	1	0
play	t3	0	0	0
recogn	t4	1	1	1
area	t5	1	0	0
lead	t6	1	0	1
hous	t7	0	1	0

- **A 0/1 term vector for each document (*typically very large and sparse*)**
- **A 0/1 incidence vector for each term (*typically very large and sparse*)**
- **Variations – to follow**

The Boolean Query Model: Example

Simple model based on **set theory** and **Boolean algebra**

Queries specified as Boolean expressions

To answer query "*depart* $\wedge$ *recogn* $\wedge$ $\neg$*hous*" perform bitwise AND on incidence vectors

d1	d2	d3
1	1	0
1	1	1
1	0	1
1	0	0

Term	Term ID	Doc1	Doc2	Doc3
depart	t1	1	1	0
activ	t2	0	1	0
play	t3	0	0	0
recogn	t4	1	1	1
area	t5	1	0	0
lead	t6	1	0	1
hous	t7	0	1	0

Back of envelope computation!

Let's say that we have

- 1M documents
- 500K distinct terms among these documents
- 1K words in each document

- Term-document matrix has
  - $1M \times 500K = \frac{1}{2}$Tera 0/1's

Yikes!

  - Only 1G of 1's
- Better representation than term document **matrix**?
  - **Yes, only keeps the 1's and let 0's be implicit!**

Kilo	1,000	
Mega	1,000,000	
Giga	1,000,000,000	RAM
Tera	1,000,000,000,000	HDD
Peta	1,000,000,000,000,000	

The Inverted Index

The key data structure in most modern information retrieval!

Why INVERTED – what does that mean?

Term	Term ID	Doc1	Doc2	Doc3
depart	t1	1	1	0
activ	t2	0	1	0
play	t3	0	0	0
recogn	t4	1	1	1
area	t5	1	0	0
lead	t6	1	0	1
hous	t7	0	1	0

It simply means that:

- **We record 1's in the incidence vector**
  - **i.e, in which documents does a particular term appear.**
- **And NOT the other way, the 1's in the term vector**
  - **i.e., what are the terms that appear in a particular document**

⇒ We do not need to investigate all documents to find matches for a query!!!

Inverted index

Term	Term ID	Doc1	Doc2	Doc3
depart	t1	1	1	0
activ	t2	0	1	0
play	t3	0	0	0
recogn	t4	1	1	1
area	t5	1	0	0
lead	t6	1	0	1
hous	t7	0	1	0

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

- Identify each doc by a **docID**

depart →	1	2	4	11	31	45	173	174
recogn →	1	2	4	5	6	16	57	132
lead →	1	3	54	101				

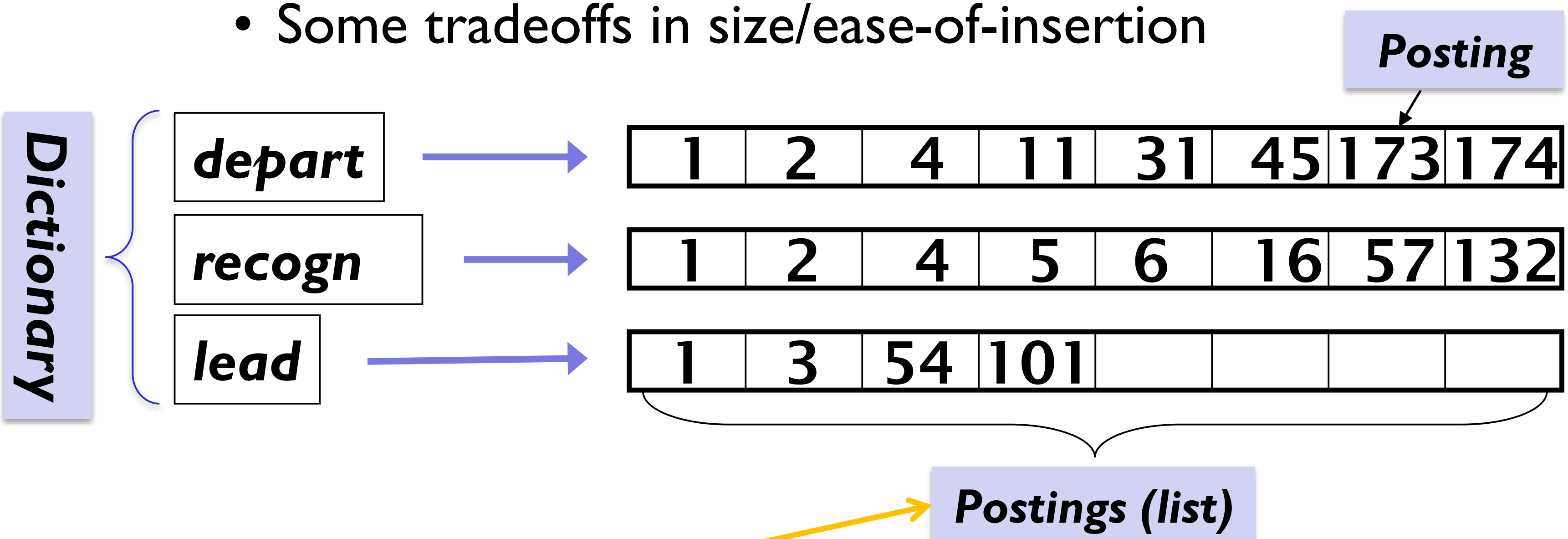
Can we used fixed-size arrays for this? **No, not usually!**

What happens if the term *recogn* is added to document 14?

Inverted index (cont.)

We need variable-size postings lists

- On disk, a continuous run of postings is normal and best
- In memory, can use linked lists or variable length arrays
  - Some tradeoffs in size/ease-of-insertion



Sorted by docID (more later on why)

Inverted Index -- Construction

Index Construction Step 1: Term sequence

- Sequence of (Term, Doc ID) pairs.

Doc 1

The departments ambition is to be recognized internationally as a leading computer science environment.

Doc 2

The research in the department has computers, programming, as well as software and computer systems as its field.

Term	DocID
the	1
departments	1
ambition	1
is	1
to	1
be	1
recognized	1
internationally	1
as	1
a	1
leading	1
computer	1
science	1
environment	1
the	2
research	2
in	2
the	2
department	2
has	2
computers	2
programming	2
as	2
well	2
as	2
software	2
and	2
computer	2
systems	2
as	2
its	2
field	2

Index Construction Step 2: Sort

- Sort by terms
  - and then docID

Core indexing step

Term	DocID
the	1
department	1
ambition	1
is	1
to	1
be	1
recognized	1
internationally	1
as	1
a	1
leading	1
computer	1
science	1
environment	1
the	2
research	2
in	2
the	2
department	2
has	2
computer	2
programming	2
as	2
well	2
as	2
software	2
and	2
computer	2
systems	2
as	2
its	2
field	2

→

Term	DocID
a	1
ambition	1
and	2
as	1
as	2
as	2
as	2
be	1
computer	1
computer	2
computer	2
department	1
department	2
environment	1
field	2
has	2
in	2
internationally	1
is	1
its	2
leading	1
programming	2
recognized	1
research	2
science	1
software	2
systems	2
the	1
the	2
the	2
to	1
well	2

Index Construction Step 3: Dictionary & Postings

- Multiple term entries in a single document are merged.
- Split into Dictionary and Postings
- Doc. frequency information is added. (will discuss later)

Term	DocID
a	1
ambition	1
and	2
as	1
as	2
as	2
as	2
be	1
computer	1
computer	2
computer	2
department	1
department	2
environment	1
field	2
…	…

→

Term	**Doc. Freq.**	**Posting lists**
a	**1**	→ **1**
ambition	**1**	→ **1**
and	**1**	→ **2**
as	**2**	→ **1** → **2**
be	**1**	→ **1**
computer	**2**	→ **1** → **2**
department	**2**	→ **1** → **2**
environment	**1**	→ **1**
field	**1**	→ **2**

Why not $1 \rightarrow 2 \rightarrow 2 \rightarrow 2$
Will discuss later.

Index Construction: Summary

1. Construct term sequence: (Term, Doc ID) pairs
2. Sort (Term, Doc ID) pairs
   - Primary by Term
   - Secondary by Doc ID
3. Construct Dictionary & Postings

A "trivial" MapReduce task!

Doc 1

The departments ambition is to be recognized internationally as a leading computer science environment.

Doc 2

The research in the department has computers, programming, as well as software and computer systems as its field.

Term	Doc. Freq.	Posting lists
a	1	→ 1
ambition	1	→ 1
and	1	→ 2
as	2	→ 1 → 2
be	1	→ 1
computer	2	→ 1 → 2
department	2	→ 1 → 2
environment	1	→ 1
field	1	→ 2

...

Inverted Index – Boolean Query Processing

Boolean queries

- The Boolean retrieval model is being able to ask a query that is a Boolean expression:
  - using *AND*, *OR* and *NOT* to join query terms
    - Views each document as a set of words (aka. "bag of words"
    - Is precise: document matches condition or not.
  - Perhaps the simplest model to build an IR system on
- Primary commercial retrieval tool for 3 decades.
- In many search systems you still use Boolean retrieval:
  - Email, library catalog, Mac OS X Spotlight

Boolean Query Processing: AND

- Process the query
  - aalborg AND engineer — result: {13}
- Locate aalborg and engineer in the dictionary
  - Retrieve postings
- "**Intersect**" the two postings (i.e., intersect the document ids)

Term	Doc. Freq.	Posting lists
aalborg	**4**	→ 1 → 7 → 13 → 54
computer	**5**	→ 1 → 2 → 16 → 32 → 115
department	**3**	→ 1 → 2 → 13
engineer	**5**	→ 12 → 13 → 15 → 116 → 211

If the list lengths are *x* and *y*, the intersection takes O(*x*+*y*) operations.

Crucial: postings sorted by docID.

Boolean score algorithm (Intersecting two postings lists)

```
INTERSECT(p1, p2)
answer ← ⟨ ⟩
while p1 ≠ NIL and p2 ≠ NIL
do if docID(p1) = docID(p2)
      then ADD(answer, docID(p1))
           p1 ← next(p1)
           p2 ← next(p2)
      else if docID(p1) < docID(p2)
             then p1 ← next(p1)
             else p2 ← next(p2)
return answer
```

Boolean Query Processing: OR

- Process the query
  - aalborg OR engineer result: {1,7,12,13,15, 54,116,211}
- Locate aalborg and engineer in the dictionary
  - Retrieve postings
- "**join**" the two postings (i.e., join the document ids)

Term	Doc. Freq.	Posting lists					
aalborg	4	→	1 →	7 →	13 →	54	
computer	5	→	1 →	2 →	16 →	32 →	115
department	3	→	1 →	2 →	13		
engineer	5	→	12 →	13 →	15 →	116 →	211

If the list lengths are x and y, the join takes $O(x+y)$ operations.
Crucial: postings sorted by docID.

Boolean Query Processing: NOT

- Process the query
  - NOTengineer
- Locate engineer in the dictionary
  - Retrieve posting
- Implicit "**complement**" the posting (in principle, now a ***very long*** posting list!)

Term	Doc. Freq.	Posting lists				
aalborg	4	→ 1	→ 7	→ 13	→ 54	
computer	5	→ 1	→ 2	→ 16	→ 32	→ 115
department	3	→ 1	→ 2	→ 13		
engineer	5	→ 12	→ 13	→ 15	→ 116	→ 211

Boolean Query Processing (cont.)

What about an arbitrary Boolean formula?

(aalborg *OR* ***engineer)*** *AND NOT* ***computer***

Can we always merge in "linear" time?

- Linear in what?

Mostly yes! – sum of posting lengths for the query terms

But, *NOT* **can sometimes create problems!**

Boolean Query Processing (cont.)

This is why we kept document freq. in dictionary

Evaluation order:

- Join OR's
- **Sequentially process AND's in order of increasing document-freq**
- Recall, that NOT produces a large implicit posting list (can be efficient, if in combination with AND)

- Example: aalborg AND engineer AND department
  ⇒(department AND aalborg) AND engineer result:{13}
- Example: aalborg AND NOT computer result:{7,13,54}

Term	Doc. Freq.	Posting lists
aalborg	4	→ 1 → 7 → 13 → 54
computer	5	→ 1 → 2 → 16 → 32 → 115
department	3	→ 1 → 2 → 13
engineer	5	→ 12 → 13 → 15 → 116 → 211

Quiz
(from IIR book)

Recommend a query processing order for

(tangerine OR trees) AND
(marmalade OR skies) AND
(kaleidoscope OR eyes)

Which two terms should we process first?

Term	Freq
eyes	213312
kaleidoscope	87009
marmalade	107913
skies	271658
tangerine	46653
trees	316812

Phrase & Proximity Queries

Phrase queries

- We want to be able to answer queries such as ***"aalborg university"*** – as a phrase
- The sentence *"I went to the university in aalborg"* is not a match.
  - 10% of all web queries are phrase queries
  - Many more are implicit phrase queries
    - E.g., person names entered without surrounding " "
  - Proven easy to understand by users; one of the few "advanced search" ideas that actually works
- To accommodate, we need to further expand the inverted index

Solution 1: Biword indexes (aka. bi-grams)

- Index every consecutive pair of terms in the text as a phrase
- For example the text "…software engineer, aalborg university…" would generate the biwords
  - software engineer
  - engineer aalborg
  - aalborg university
- Each of these biwords are now added as dictionary term
- Two-word phrase query-processing is now immediate.
- Longer phrases can be processed by breaking them down
- Example: "software engineer, aalborg university can be broken into the Boolean query on biwords:

  software engineer *AND* engineer aalborg *AND* aalborg university

Can have false positives!

Issues for biword indexes

False positives, as noted before
Index blowup due to bigger dictionary

Pragmatic solution

Keep N-gram phrases for most used phrase queries in index

- demands processing of query logs (web *usage* mining)

Solution 2: Positional indexes

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

  <***term***, doc-freq; *doc1*: pos1, pos2 … ; *doc2*: pos1, pos2 … ; etc.>

- Is "computer engineer" a match? **Yes**

Term	**Doc. Freq.**	**Posting lists**					
aalborg	**4**	→	**1:11,25** →	**7:10,15,29** →	**13:2,7** →	**54:5,7,16**	
computer	**5**	→	**1:5,9** →	**2:31** →	**16:9** →	**32:4** →	**115:19**
department	**3**	→	**1:19** →	**2:3,5,9** →	**13:8**		
engineer	**5**	→	**12:6** →	**13:9,16** →	**32:1,5,86** →	**116:2,6,20** →	**211:2,7**

Positional index example

<***be***: **993427;**

1: 7, 18, 33, 72, 86, 231;

2: 3, 149;

4: 17, 191, 291, 430, 434;

5: 363, 367, …>

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

For phrase queries, we use a intersection algorithm recursively at the document level

But we now need to deal with more than just equality

Processing a phrase query

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

Positional index size

A positional index expands postings storage *substantially*

Rules of thumb (for “English-like” languages)

- 2–4 times as large as a non-positional index
- 35–50% of volume of original text

Phrase & Positional Indexing Combination

- Most expensive phrase queries to evaluate in positional index are those where
  - Individual words are common
  - Phrase is rare
  - Implies intersection of large positional posting lists

- Use phrase index terms for
  - Common phrases ("Michael Jackson", "Britney Spears")
  - Phrases with common individual terms ("The Who")

Learned from query logs

Outline

- Web search basics (short review)
- Document pre-processing / feature construction
- Index construction – the “Inverted index”
- Boolean query processing model
  - standard
  - Phrase
  - Positional