Multimedia Information Extraction and Retrieval

Term Frequency
Inverse Document Frequency

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Introduction
to
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This lecture

- Parametric and field searches
  - Zones in documents
- Scoring documents: zone weighting
  - Index support for scoring
- Term weighting

Parametric search

- Most documents have, in addition to text, some “meta-data” in <u>fields</u> e.g.,
  - Language = French
  - Format = pdf
  - Subject = Physics etc.
  - Date = Feb 2000

Fields

Values

- A parametric search interface allows the user to combine a full-text query with selections on these field values e.g.,
  - language, date range, etc.

Parametric search example

CarFinder.com

Over one million fictional vehicles to choose from!

Choose your search criteria from the drop down menus:

Number of results to display: 50

Make BMW **Model** 5-Series **Category** Any **Year** All

City San Francisco **Color** Any **Price** From $10,100 to $15,000

Search

Reset Filters Reset Sorts

Notice that the output is a (large) table. Various parameters in the table (column headings) may be clicked on to effect a sort.

Make	Model	Year	City	Mileage	Price	Category	Description	Color
BMW	5-Series	1995	San Francisco	16100	11100	Luxury	Never driven in winter conditions. Body work makes it look like new. Keyless entry and security features. This is a bargain.	Silver
BMW	5-Series	1995	San Francisco	16600	11100	Luxury	Great first car for your teen-aged kid. Solid, dependable, affordable with 0% down and owner financing.	Blue
BMW	5-Series	1995	San Francisco	16800	11200	Luxury	Upgraded sound system really rocks. Customized interior features wood grain dash and beige leather seats. Power locks, windows, steering. Price firm.	White
BMW	5-Series	1995	San Francisco	16100	11300	Luxury	Safe choice for a young family: ABS, driver and passenger air bags. Roomy interior with power everything. Low mileage driving kids back and forth to soccer.	Maroon
BMW	5-Series	1995	San Francisco	16300	11400	Luxury	This baby's got it all: power steering, cruise, power locks, power windows, remote entry, leather interior, security alarm, AM/FM/CD/Cassette. Priced to sell!	Brown

Parametric search example

CarFinder.com

Over one million fictional vehicles to choose from!

We can add text search.

Choose your search criteria from the drop down menus:

Number of results to display: 50

Make BMW **Model** 5-Series **Category** Any **Year** 1997

City San Francisco **Color** Any **Price** From $10,100 to $15,000 **Description**

Search

Clear Form

Reset Filters | Reset Sorts

Make	Model	Year	City	Mileage	Price	Category	Description	Color
BMW	5-Series	1997	San Francisco	14300	13100	Luxury	5-speed, heavy-duty suspension, extra wide tires. Well-maintained by mechanic-owner. Cloth seats and upgraded stereo system.	White
BMW	5-Series	1997	San Francisco	14600	13100	Luxury	Is that price for real? You bet it is. Fully loaded with all factory options. Former floor model.	Beige
BMW	5-Series	1997	San Francisco	14900	13100	Luxury	Fun to drive. Manual 5-speed transmission, turbo charger. Garaged all winter and pampered the rest of the year. This is a steal!	Orange
BMW	5-Series	1997	San Francisco	14800	13200	Luxury	Fully loaded, automatic transmission. Power everything. Anti-lock brakes and full safety features. Must test drive. Price firm.	Green
BMW	5-Series	1997	San Francisco	14300	13200	Luxury	Formerly an executive's vehicle. Interior has been professionally maintained, engine factory serviced every 3000 miles. Great gas mileage. Price negotiable.	Maroon
BMW	5-Series	1997	San Francisco	15000	13200	Luxury	Sun roof, air, CD player, driver side air bag. 10% deposit required. Owner financing available. Best offer by end of weekend buys it	Red

Parametric/field search

- In these examples, we select field values
  - Values can be hierarchical, e.g.,
  - Geography: Continent → Country → State → City
- A paradigm for navigating through the document collection, e.g.,
  - "Aerospace companies in Brazil" can be arrived at first by selecting Geography then Line of Business, or vice versa
  - Filter docs in contention and run text searches scoped to subset

Index support for parametric search

- Must be able to support queries of the form
  - Find pdf documents that contain “stanford university”
  - A field selection (on doc format) and a phrase query
- Field selection – use inverted index of field values → docids
  - Organized by field name

Parametric index support

- Optional – provide richer search on field values – e.g., wildcards
  - Find books whose Author field contains ***s*trup***
- Range search – find docs authored between September and December
  - Inverted index doesn't work (as well)
  - Use techniques from database range search (e.g., B-trees as explained before)
- Use query optimization heuristics as usual

Field retrieval

- In some cases, must retrieve field values
  - E.g., ISBN numbers of books by ***s*trup***
- Maintain "forward" index – for each doc, those field values that are "retrievable"
  - Indexing control file specifies which fields are retrievable (and can be updated)
  - Storing primary data here, not just an index

(as opposed to "inverted")

Zones

- A zone is an identified region within a doc
  - E.g., Title, Abstract, Bibliography
  - Generally culled from marked-up input or document metadata (e.g., powerpoint)
- Contents of a zone are free text
  - Not a "finite" vocabulary
- Indexes for each zone - allow queries like
  - ***"sorting"*** in Title AND ***"smith"*** in Bibliography AND ***"recur*"*** in Body
- Not queries like "all papers whose authors cite themselves"

Why?

Zone indexes – simple view

Term	N docs	Tot Freq
ambitious	1	1
be	1	1
brutus	2	2
capitol	1	1
caesar	2	3
did	1	1
enact	1	1
hath	1	1
I	1	2
i'	1	1
it	1	1
julius	1	1
killed	1	2
let	1	1
me	1	1
noble	1	1
so	1	1
the	2	2
told	1	1
you	1	1
was	2	2
with	1	1

Doc #	Freq
2	1
2	1
1	1
2	1
1	1
1	1
2	2
1	1
1	1
2	1
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2	1
2	1

Title

Term	N docs	Tot Freq
ambitious	1	1
be	1	1
brutus	2	2
capitol	1	1
caesar	2	3
did	1	1
enact	1	1
hath	1	1
I	1	2
i'	1	1
it	1	1
julius	1	1
killed	1	2
let	1	1
me	1	1
noble	1	1
so	1	1
the	2	2
told	1	1
you	1	1
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Doc #	Freq
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1	1
2	1
2	1

Author

Term	N docs	Tot Freq
ambitious	1	1
be	1	1
brutus	2	2
capitol	1	1
caesar	2	3
did	1	1
enact	1	1
hath	1	1
I	1	2
i'	1	1
it	1	1
julius	1	1
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1	1
2	1
2	1

Body

etc.

So we have a database now?

- Not really.
- Databases do lots of things we don't need
  - Transactions
  - Recovery (our index is not the system of record; if it breaks, simply reconstruct from the original source)
  - Indeed, we never have to store text in a search engine – only indexes
- We're focusing on optimized indexes for text-oriented queries, not an SQL engine.

Scoring

- Thus far, our queries have all been Boolean
  - Docs either match or not
- Good for expert users with precise understanding of their needs and the corpus
- Applications can consume 1000's of results
- Not good for (the majority of) users with poor Boolean formulation of their needs
- Most users don't want to wade through 1000's of results – cf. use of web search engines

Scoring

- *We wish to return in order the documents most likely to be useful to the searcher*
- How can we rank order the docs in the corpus with respect to a query?
- Assign a score – say in [0,1]
  - for each doc on each query
- Assume a perfect world
  - No spammers
  - Nobody stuffing keywords into a doc to make it match queries ("adversarial IR")

Linear zone combinations

- First generation of scoring methods: use a linear combination of Booleans:
  - E.g.,

Score = 0.6*<“***sorting***“in Title> + 0.3*<“***sorting”*** in Abstract> + 0.05*<“***sorting”*** in Body> + 0.05*<“***sorting”*** in Boldface>

  - Each expression such as <***sorting*** in Title> takes on a value in {0,1}.
  - Then the overall score is in [0,1].

For this example the scores can only take on a finite set of values – what are they?

Linear zone combinations

- In fact, the expressions between <> on the last slide could be *any* Boolean query
- Who generates the Score expression (with weights such as 0.6 etc.)?
  - In uncommon cases – the user, in the UI
  - Most commonly, a query parser that takes the user's Boolean query and runs it on the indexes for each zone

Exercise

- On the query ***bill*** *OR* ***rights*** suppose that we retrieve the following docs from the various zone indexes:

<u>*Author*</u>	***bill***	1 → 2
	rights	
<u>*Title*</u>	***bill***	3 → 5 → 8
	rights	3 → 5 → 9
<u>*Body*</u>	***bill***	1 → 2 → 5 → 9
	rights	3 → 5 → 8 → 9

Compute the score for each doc based on the weightings 0.6,0.3,0.1

General idea

- We are given a weight vector whose components sum up to 1.
  - There is a weight for each zone/field.
- Given a Boolean query, we assign a score to each doc by adding up the weighted contributions of the zones/fields.
- Typically – users want to see the *K* highest-scoring docs.

Index support for zone combinations

- In the simplest version we have a separate inverted index for each zone
- Variant: have a single index with a separate dictionary entry for each term and zone
- E.g.,

bill.author *1* → *2*

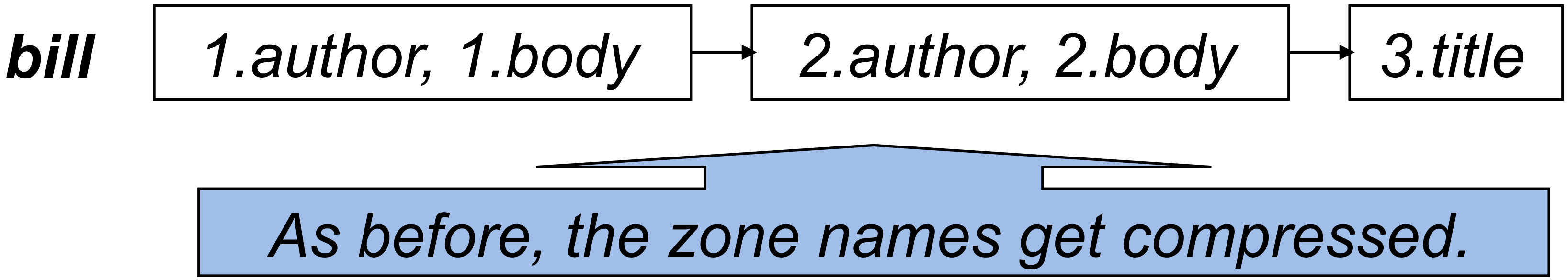
bill.title *3* → *5* → *8*

bill.body *1* → *2* → *5* → *9*

Of course, compress zone names like author/title/body.

Zone combinations index

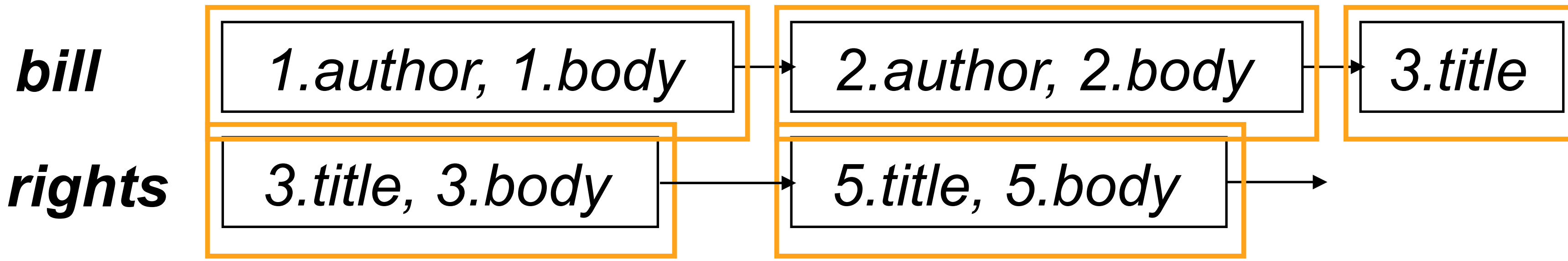
- The above scheme is still wasteful: each term is potentially replicated for each zone
- In a slightly better scheme, we encode the zone in the postings:



- At query time, accumulate contributions to the total score of a document from the various postings, e.g.,

Score accumulation

1	0.7
2	0.7
3	0.4
5	0.4



- As we walk the postings for the query ***bill*** *OR* ***rights***, we accumulate scores for each doc in a linear merge as before.
- Note: we get both ***bill*** and ***rights*** in the Title field of doc 3, but score it no higher.
- Should we give more weight to more hits?

Where do these weights come from?

- Machine learned relevance
- Given
  - A *test corpus*
  - A suite of *test queries*
  - A set of *relevance judgments*
- Learn a set of weights such that relevance judgments matched
- Can be formulated as ordinal regression (see lecture on machine learning)

Full text queries

- We just scored the Boolean query ***bill*** *OR* ***rights***
- Most users more likely to type ***bill rights*** or ***bill of rights***
  - How do we interpret these *full text* queries?
  - No Boolean connectives
  - Of several query terms some may be missing in a doc
  - Only some query terms may occur in the title, etc.

Full text queries

- To use zone combinations for free text queries, we need
  - A way of assigning a score to a pair <free text query, zone>
  - Zero query terms in the zone should mean a zero score
  - More query terms in the zone should mean a higher score
  - Scores don't have to be Boolean
- Will look at some alternatives now

Incidence matrices

- Bag-of-words model
- Document (or a zone in it) is binary vector X in $\{0,1\}^V$
- Query is a vector Y
- Score: Overlap measure:

$$|X \cap Y|$$

	Antony and Cleopatra	Julius Caesar	The Tempest	Hamlet	Othello	Macbeth
Antony	1	1	0	0	0	1
Brutus	1	1	0	1	0	0
Caesar	1	1	0	1	1	1
Calpurnia	0	1	0	0	0	0
Cleopatra	1	0	0	0	0	0
mercy	1	0	1	1	1	1
worser	1	0	1	1	1	0

Example

- On the query ***ides of march***, Shakespeare's *Julius Caesar* has a score of 3
- All other Shakespeare plays have a score of 2 (because they contain ***march***) or 1
- Thus in a rank order, *Julius Caesar* would come out tops

Overlap matching

- What's wrong with the overlap measure?
- It doesn't consider:
  - Term frequency in document
  - Term scarcity in collection (document mention frequency)
    - ***of*** is more common than ***ides*** or ***march***
  - Length of documents
    - (and queries: score not normalized)

Overlap matching

- One can normalize in various ways:
  - Jaccard coefficient:

$$|X \cap Y| / |X \cup Y|$$

  - Cosine measure:

$$|X \cap Y| / \sqrt{|X| \times |Y|}$$

- What documents would score best using Jaccard against a typical query?
- Does the cosine measure fix this problem?

Scoring: density-based

- Thus far: position and overlap of terms in a doc – title, author etc.
- Obvious next idea: If a document talks *more* about a topic, then it is a better match
- This applies even when we only have a single query term.
- Document is relevant if it has a lot of the terms
- This leads to the idea of term weighting.

Term-document count matrices

- Consider the number of occurrences of a term in a document:
  - Bag of words model
  - Document is a vector in $\mathbb{N}^v$: a column below

	Antony and Cleopatra	Julius Caesar	The Tempest	Hamlet	Othello	Macbeth
Antony	157	73	0	0	0	0
Brutus	4	157	0	1	0	0
Caesar	232	227	0	2	1	1
Calpurnia	0	10	0	0	0	0
Cleopatra	57	0	0	0	0	0
mercy	2	0	3	5	5	1
worser	2	0	1	1	1	0

Bag of words view of a doc

- Thus the doc
  - ***John is quicker than Mary*.**

is indistinguishable from the doc

  - ***Mary is quicker than John*.**

Which of the indexes discussed so far distinguish these two docs?

Counts vs. frequencies

- Consider again the ***ides of march*** query.
  - *Julius Caesar* has 5 occurrences of ***ides***
  - No other play has ***ides***
  - ***march*** occurs in over a dozen
  - All the plays contain ***of***
- By this scoring measure, the top-scoring play is likely to be the one with the most ***of***s

Digression: terminology

- WARNING: In a lot of IR literature, "frequency" is used to mean "count"
  - Thus *term frequency* in IR literature is used to mean *number of occurrences* in a doc
  - Not divided by document length (which would actually make it a frequency)
- We will conform to this misnomer
  - In saying term frequency we mean the number of occurrences of a term in a document.

Term frequency *tf*

- Long docs are favored because they're more likely to contain query terms
- Can fix this to some extent by normalizing for document length
- But is raw *tf* the right measure?

Weighting term frequency: *tf*

- What is the relative importance of
  - 0 vs. 1 occurrence of a term in a doc
  - 1 vs. 2 occurrences
  - 2 vs. 3 occurrences …
- Unclear: While it seems that more is better, a lot isn't proportionally better than a few
  - Can just use raw *tf*
  - Another option commonly used in practice:

$$wf_{t,d} = 0 \text{ if } tf_{t,d} = 0,\ 1 + \log tf_{t,d} \text{ otherwise}$$

Score computation

- Score for a query q = sum over terms t in q:

$$= \sum_{t \in q} tf_{t,d}$$

- [Note: 0 if no query terms in document]
- This score can be zone-combined
- Can use *wf* instead of *tf* in the above
- Still doesn't consider term scarcity in collection (***ides*** is rarer than ***of***)

Weighting should depend on the term overall

- Which of these tells you more about a doc?
  - 10 occurrences of *hernia*?
  - 10 occurrences of *the*?
- Would like to attenuate the weight of a common term
  - But what is "common"?
- Suggest looking at collection frequency (*cf*)
  - The total number of occurrences of the term in the entire collection of documents

Document frequency

- But document frequency (*df*) may be better:
- *df* = number of docs in the corpus containing the term

Word	*cf*	*df*
ferrari	10422	17
insurance	10440	3997

- Document/collection frequency weighting is only possible in known (static) collection.
- So how do we make use of *df*?

tf x idf term weights

- tf x idf measure combines:
  - term frequency (*tf*)
    - or *wf*, some measure of term density in a doc
  - inverse document frequency (*idf*)
    - measure of informativeness of a term: its rarity across the whole corpus
    - could just be raw count of number of documents the term occurs in ($idf_i = n/df_i$)
    - but by far the most commonly used version is:

$$idf_i = \log\left(\frac{n}{df_i}\right)$$

- See Kishore Papineni, NAACL 2, 2002 for theoretical justification

Summary: tf x idf (or tf.idf)

- Assign a tf.idf weight to each term *i* in each document *d*

$$w_{i,d} = tf_{i,d} \times \log(n / df_i)$$

What is the wt of a term that occurs in all of the docs?

$tf_{i,d}$ = frequency of term i in document d

n = total number of documents

df_i = the number of documents that contain term i

- Increases with the number of occurrences *within* a doc
- Increases with the rarity of the term *across* the whole corpus

Real-valued term-document matrices

- Function (scaling) of count of a word in a document:
  - Bag of words model
  - Each is a vector in $\mathbb{R}^V$
  - Here log-scaled *tf.idf*

Note can be >1!

	Antony and Cleopatra	Julius Caesar	The Tempest	Hamlet	Othello	Macbeth
Antony	13.1	11.4	0.0	0.0	0.0	0.0
Brutus	3.0	8.3	0.0	1.0	0.0	0.0
Caesar	2.3	2.3	0.0	0.5	0.3	0.3
Calpurnia	0.0	11.2	0.0	0.0	0.0	0.0
Cleopatra	17.7	0.0	0.0	0.0	0.0	0.0
mercy	0.5	0.0	0.7	0.9	0.9	0.3
worser	1.2	0.0	0.6	0.6	0.6	0.0

Documents as vectors

- Each doc *d* can now be viewed as a vector of *wf*×*idf* values, one component for each term
- So we have a vector space
  - terms are axes
  - docs live in this space
  - even with stemming, may have 20,000+ dimensions
- (The corpus of documents gives us a matrix, which we could also view as a vector space in which words live – transposable data)

Recap

- We began by looking at zones in scoring
- Ended up viewing documents as vectors in a vector space
- We will pursue this view next time.