05 – Indexing and Searching Very Large Texts
IA161 Advanced Techniques of Natural Language Processing

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1 Indexing

2 Searching
Searching big text corpora

Corpus:
- positional attributes – word form, lemma, PoS tag, ...
- structures and structure attributes – documents (e.g. with author, id, year, ...), paragraph, sentence
- searching: Manatee/Bonito/Sketch Engine
- http://corpora.fi.muni.cz
- https://app.sketchengine.eu
- SQL unsuitable (independent rows)
Searching big text corpora

- data too big to be stored in memory
- data too big to be search sequentially

⇒ preprocessing needed (indexing, alias corpus compilation)

key decisions are:
  ▶ trade off between compile-time (preprocessing) and run-time
  ▶ trade off between in memory and off-memory processing
Zipf’s law I
Zipf’s law II

- may be simplified to inductive definition:

**Zipf’s law (simplified)**

frequency of the $n$-th element $f_n \approx \frac{1}{n} \cdot f_1$

- $\Rightarrow$ frequency is inversely proportional to the rank according to frequency
- $\Rightarrow$ one needs really large corpora to capture all the variety of many language phenomena
### Zipf’s law III

<table>
<thead>
<tr>
<th>Word</th>
<th>↓ Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>the</td>
<td>174,935,080</td>
</tr>
<tr>
<td>of</td>
<td>88,596,331</td>
</tr>
<tr>
<td>and</td>
<td>80,072,865</td>
</tr>
<tr>
<td>to</td>
<td>77,354,235</td>
</tr>
<tr>
<td>a</td>
<td>59,410,937</td>
</tr>
<tr>
<td>in</td>
<td>54,044,533</td>
</tr>
<tr>
<td>that</td>
<td>34,942,237</td>
</tr>
<tr>
<td>is</td>
<td>34,190,792</td>
</tr>
<tr>
<td>for</td>
<td>27,849,928</td>
</tr>
<tr>
<td>it</td>
<td>24,609,587</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Word</th>
<th>↓ Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td>23,989,001</td>
</tr>
<tr>
<td>on</td>
<td>20,237,809</td>
</tr>
<tr>
<td>with</td>
<td>19,230,246</td>
</tr>
<tr>
<td>as</td>
<td>19,076,719</td>
</tr>
<tr>
<td>be</td>
<td>18,269,437</td>
</tr>
<tr>
<td>was</td>
<td>16,505,649</td>
</tr>
<tr>
<td>this</td>
<td>16,475,525</td>
</tr>
<tr>
<td>you</td>
<td>16,268,767</td>
</tr>
<tr>
<td>are</td>
<td>15,838,329</td>
</tr>
<tr>
<td>by</td>
<td>14,917,197</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Word</th>
<th>↓ Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>not</td>
<td>14,421,888</td>
</tr>
<tr>
<td>or</td>
<td>13,599,707</td>
</tr>
<tr>
<td>have</td>
<td>13,540,277</td>
</tr>
<tr>
<td>at</td>
<td>13,282,835</td>
</tr>
<tr>
<td>he</td>
<td>12,821,501</td>
</tr>
<tr>
<td>from</td>
<td>12,285,435</td>
</tr>
<tr>
<td>but</td>
<td>11,049,177</td>
</tr>
<tr>
<td>we</td>
<td>10,997,497</td>
</tr>
<tr>
<td>they</td>
<td>10,388,785</td>
</tr>
<tr>
<td>an</td>
<td>10,182,791</td>
</tr>
</tbody>
</table>

enTenTen2008, 3.2G tokens
Zipf’s law IV

About 1 billion words is enough to have enough evidence for single word units. But not for multiwords:

<table>
<thead>
<tr>
<th>word</th>
<th>Brown (1M)</th>
<th>BNC (100M)</th>
<th>enTenTen08 (2.7G)</th>
<th>enTenTen15 (15.7G)</th>
</tr>
</thead>
<tbody>
<tr>
<td>carbonation</td>
<td>0</td>
<td>5</td>
<td>429</td>
<td>2,817</td>
</tr>
<tr>
<td>weird phrase</td>
<td>0</td>
<td>0</td>
<td>14</td>
<td>34</td>
</tr>
</tbody>
</table>
Building corpora

1. content definition (what will it be used for? how do I get texts?)
2. obtaining data (e.g. crawling)
3. data cleaning (spam, boilerplate, duplicates)
4. tokenization
5. sentence segmentation
6. further annotation (PoS tagging)
7. corpus indexing and analysis
Building corpora

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Corpus indexing

- text corpus is a database
- standard (=relational) database management systems are not suitable at all
  - text corpus does not have relational nature
- special database management systems needed

⇒ Manatee
Indexing corpora in Manatee

Key data structures for a positional attribute:

- lexicon
  - because operations on numbers are just so much faster than on strings
- corpus text
  - to iterate over positions
- inverted (reversed) index
  - to give fast access to positions for a given value
How to store integer numbers

• given Zipf’s distribution: fixed-length storing very inefficient
• variable-length more complicated but yielding much smaller and quicker indices
• variable-length bit-wise universal Elias’ codes: gamma, delta codes
• cf. Huffman coding
Indexing corpora in Manatee

Structures and operations:

- operations in between: string (str) – number (id) – position (poss)
- lexicon building: ⇒ word-to-id mapping ⇒ operations on numbers, not strings ⇒ id2str, str2id
- inverted index: id2poss
- corpus text: pos2id
- yields transitively also pos2str, str2poss
Searching corpora in Manatee

- key idea: operations on sorted forward-only streams of positions
- FastStream – single position stream
- RangeStream – stream of position pairs (structures: from position, to position)
CQL

- = Corpus Query Language (Christ and Schulze, 1994)
- positions and positional attributes: `[attr="value"]`
- structures and structural attributes: `<str attr="value">`
- example:
  
  `[word="*ing" & tag="V.*"]`
  
  `<doc id="20[5-9].*"`

- established a within `<str/>` query:
  
  `[tag="N.*"]+ within `<s/>

and alternative meet/union query:

  (meet [lemma="take"] [tag="N.*"] -5 +5)
  (union (meet ...) (meet ...))
CQL in Manatee/Bonito

- enhancements and differences to the original CQL syntax
- within <query> and containing <query>
- meet/union (sub)query
- inequality comparisons
- frequency function
within/containing queries

- searching for particles:
  
  `[tag="PR.*"] within [tag="V.*"] [tag="ATO"]? [tag="AJ0"]* [tag="(PR.?|N.*)"] [tag="PR.*"] within <s/>

- searching for a Czech idiom “hnout někomu žlučí” (“to get somebody’s goat”):
  
  word-by-word translated as:
  
  *hnout* “move” [V, infinitive]
  *někomu* “somebody” [N, dative]
  *žlučí* “bile” [N, instrumental].

  `<s/> containing [lemma="hnout"] containing [tag=".*c3.*"] containing [word="žlučí"]`
within/containing queries

- **structure boundaries**: begin: `<str>`, whole structure: `<str/>`, end: `</str>`
- **changes**: within `<str>` not allowed anymore, use within `<str/>`
meet/union queries

- combined with regular query: `<s/>
  containing (meet [lemma="have"] [tag="P.*"] -5 5)
  containing (meet [tag="N.*"] [lemma="blue"])`

- changes: meet/union queries can be used on any position, they can contain labels and no MU keyword is required (and deprecated):
  `(meet 1:[] 2:[]) & 1.tag = 2.tag`
Inequality comparisons

- former comparisons allowed only equality and its negation: [attr="value"] [attr!="value"]
- inequality comparisons implemented: [attr<="value"] [attr>="value"] [attr!<="value"] [attr!>="value"]
- intended usage: [tag="AJ.*"] [tag="NN.*"] within <doc year>="2009">
- sophisticated comparison performed on the attribute value: <doc id="CC20101031B"> matches e.g. BB20101031B, CC20091031B, CC20101030B CC20101031A.
Fixed string comparisons

- normally the CQL values are regular expressions
- sometimes this is not desirable (batch processing needs escaping of metacharacters)
- new == and !== operator introduced for fixed strings comparison
- no escaping needed except for "" and '\'
- examples: ".", "$", " " matches a single dot, dollar sign and tilda, respectively, "\n" matches a backslash followed by the character n,
Frequency function

- a frequency constraint allowed in the global conditions part of CQL:
  1:[tag="PP.*"] 2:[tag="NN.*"] & f(1.word) > 10
Performance evaluation

Table: Query performance evaluation – corpora legend: ◦ BNC (110M tokens), • BiWeC (version with 9.5G tokens), ∗ Czes (1.2G tokens)

<table>
<thead>
<tr>
<th>query</th>
<th># of results</th>
<th>time (m:s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>◦ [lemma=&quot;time&quot;]</td>
<td>179,321</td>
<td>0.07</td>
</tr>
<tr>
<td>◦ [lemma=&quot;t.*&quot;]</td>
<td>14,660,881</td>
<td>3.12</td>
</tr>
<tr>
<td>◦ Ex: particles</td>
<td>1,219,973</td>
<td>33.36</td>
</tr>
<tr>
<td>• Ex: particles</td>
<td>97,671,485</td>
<td>32:26.48</td>
</tr>
<tr>
<td>∗ Ex: idioms</td>
<td>66</td>
<td>1:6.86</td>
</tr>
<tr>
<td>◦ Ex: meet/union</td>
<td>3</td>
<td>8.47</td>
</tr>
<tr>
<td>• Ex: meet/union</td>
<td>1457</td>
<td>7:13.12</td>
</tr>
</tbody>
</table>
CQL query evaluation

Example: 
`[tag="ADJ"] [(word="record" | word="process") & tag="NOUN"] within <doc year="2012"/>`
Conclusions

- special database management systems for processing text corpora needed
- trade-offs between compile-time and run-time, in-memory and off-memory
- CQL
- Manatee