Optimizing Scoring Functions and Indexes for Proximity Search in Type-annotated Corpora

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(In fewer words)

Ranking and Indexing for Semantic Search

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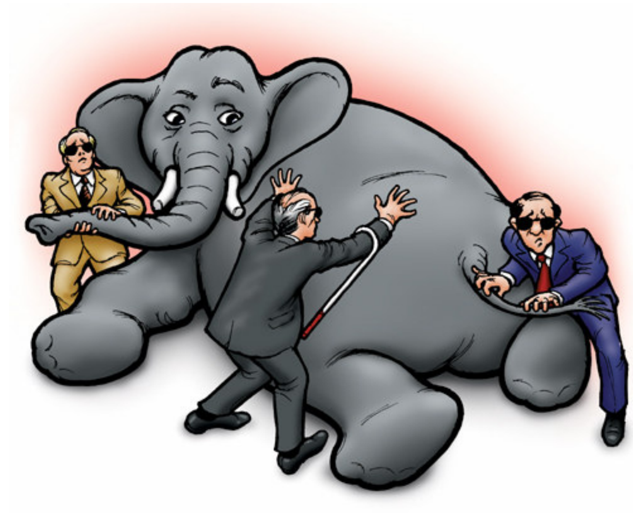
Working notion of semantic search

- Exploiting in conjunction
  - “Strings with meaning” – entities and relations
  - “Uninterpreted strings” – as in IR
- This paper
  - Only “is-a” relation
  - Token match
  - Token proximity
- Can approximate many info needs

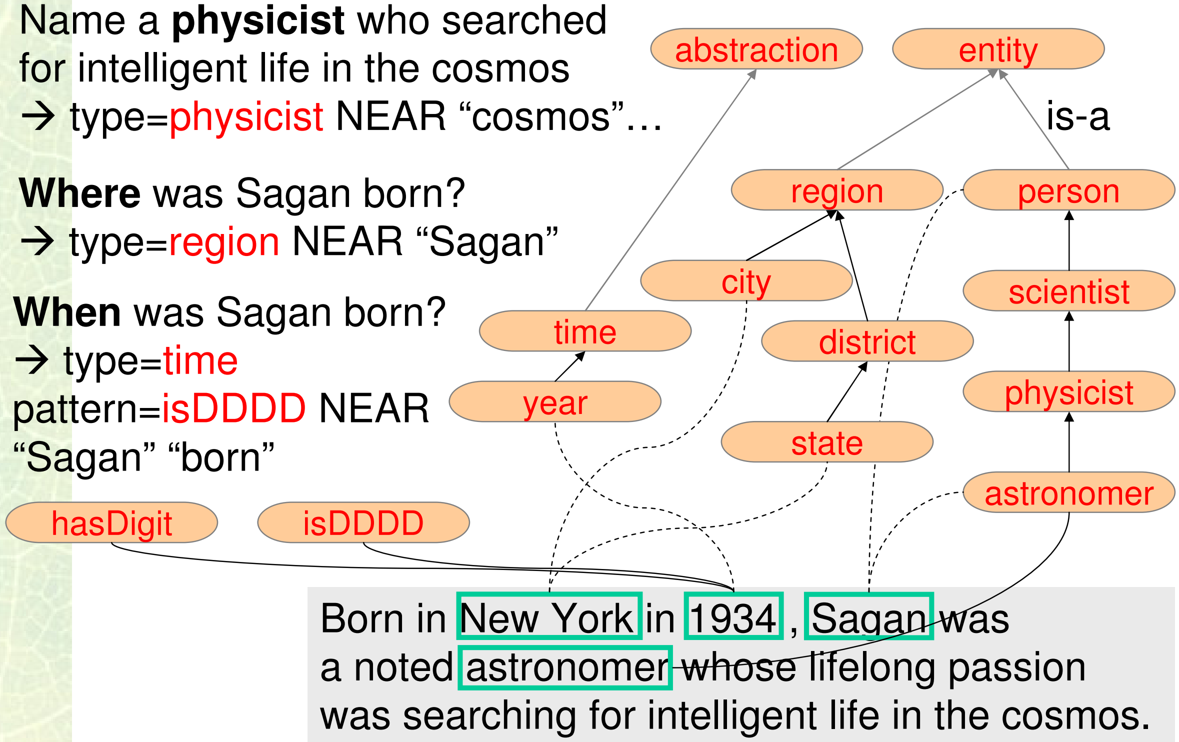


Type-annotated corpus and query e.g.

Name a **physicist** who searched for intelligent life in the cosmos
→ type=physicist NEAR “cosmos”…

Where was Sagan born?
→ type=region NEAR “Sagan”

When was Sagan born?
→ type=time pattern=isDDDD NEAR “Sagan” “born”



The query class we address

- Find a token span *w* (in context) such that
  - *w* is a mention of entity *e*
    - "Carl Sagan" or "Sagan" is a mention of the concept of that specific physicist
  - *e* is an instance of **atype** *a* given in the query
    - Which *a*=physicist …
  - *w* is "NEAR" a set of **selector** strings
    - "searched", "intelligent", "life", "cosmos"
- All uncertain/imprecise; we focus on #3
- Yet surprisingly powerful: correct answer within top 3—4 *w*'s for TREC QA benchmark

Contribution 1: What is "NEAR"?

- XQuery and XPath full text support
  - (distance at most|window) 10 words [ordered] – hard proximity clause, not learnt
  - ftcontains … with thesaurus at … relationship "narrower terms" at most ℓ levels
- No implementation combining "narrower terms" and "soft" proximity ranking
- Search engines favor proximity in proprietary ways

A learning framework for proximity

Contribution 2: Indexing annotations

- type=person NEAR theory relativity → type in {physicist, politician, cricketer,…} NEAR theory relativity
  - Large fanout at query time, impractical
- Complex annotation indexes tend to be large
  - Binding Engine (WWW 2005): 10x index size blowup with only a handful of entity types
  - Our target: 18000 atypes today, more later
- Workload-driven index and query optimization
  - Exploit skew in query atype workload

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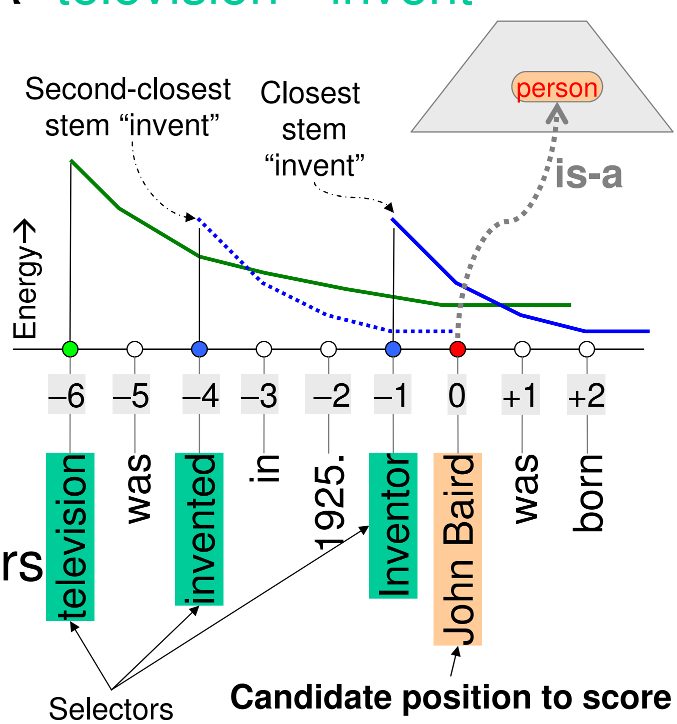
Part-1: Learning to score token spans

- type=person NEAR "television" "invent*"
- Rarity of selectors
- Distance from candidate position to selectors
- Many occurrences of one selector
  - Closest is good
- Combining scores from many selectors
  - Sum is good



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Learning the shape of the decay function

- For simplicity assume left-right symmetry
- Parameters $(\beta_1,\ldots,\beta_W)$, W=max gap window
- Candidate position characterized by a feature vector $f = (f[1],\ldots,f[W])$
  - If there is a matched selector s at distance j and
  - This is the closest occurrence of s
  - Then set $f[j]$ to *energy*(s), … else 0
- Score of candidate position is $\beta \cdot f$
- If we like candidate u less than v ("$u \prec v$")
  - We want $\beta \cdot f_u \le \beta \cdot f_v$
  - Assess a penalty proportional to $\exp(\beta \cdot f_u - \beta \cdot f_v)$

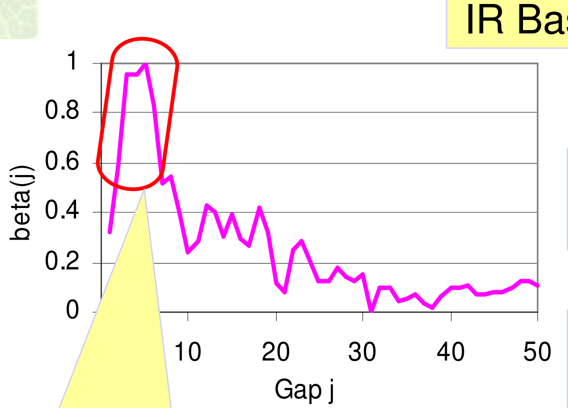
Learning decay function—results

$$\min_{\beta} \sum_{j=1}^{W} (\beta_j - \beta_{j+1})^2 + C \sum_{u \prec v} \exp(\beta \cdot f_u - \beta \cdot f_v)$$

Discourage adjacent βs from differing a lot

Penalize violations of preference order

IR Baseline



Train	Test	MRR
IR	2000	0.16
2001	2000	**0.29**

TREC year

Roughly unimodal around gap = 4 and 5

Mean reciprocal rank: Average over questions, reciprocal of the first rank where an answer token was found (large good)

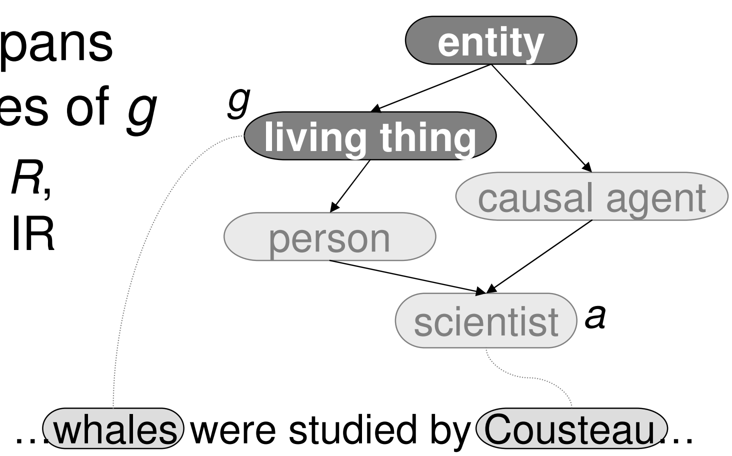
Part-2: Workload-driven indexing

- Type hierarchies are large and deep
  - 18000 internal and 80000 leaf types in WordNet
- Runtime atype expansion time-intensive
  - Even WordNet knows 650 scientists, 860 cities…
- Index each token as all generalizations
  - Sagan → physicist, scientist, person, living thing
  - Large index space bloat
- Index a subset of atypes

Corpus/Index	Gbytes
Original corpus	5.72
Gzipped corpus	1.33
Stem index	0.91
Full type index	4.30

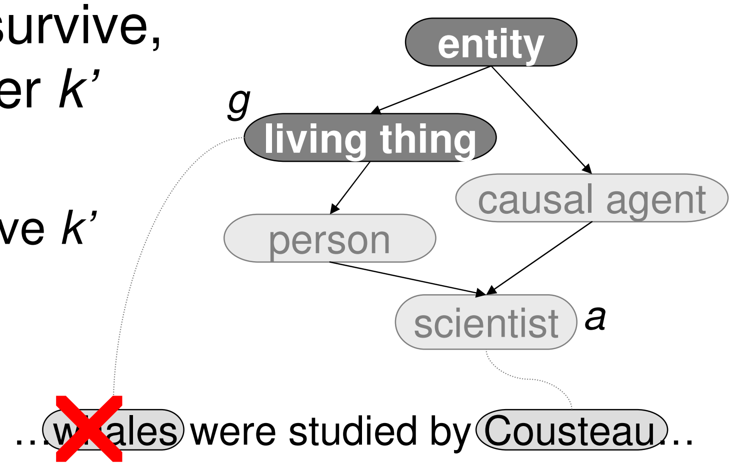
Pre-generalize (and post-filter)

- Full set of "atypes" (answer types) is A
- Index only a "registered" subset R of A
- Say query has atype a; want k answers
- Find a's "best" generalization $g \in R$
- Get best k' > k spans that are instances of g
  - Given index on R, this is standard IR (see paper)



(Pre-generalize and) post-filter

- Fetch each high-scoring span *w*
- Check if *w* is-a *a*
  - Fast compact "forward index" (doc,offset)→token
  - Fast small "reachability index", common in XML
- If fewer than *k* survive, restart with larger *k'*
  - Expensive
  - Pick conservative *k'*



Estimates needed by optimizer

- If we index token ancestors in *R* as against ancestors in all of *A*, how much index space will we save?
  - Cannot afford to try out and see for many *R*s
- If query atype *a* is not found in *R* and we must generalize to *g*, what will be the bloat factor in query processing time?
  - Need to average over a representative workload

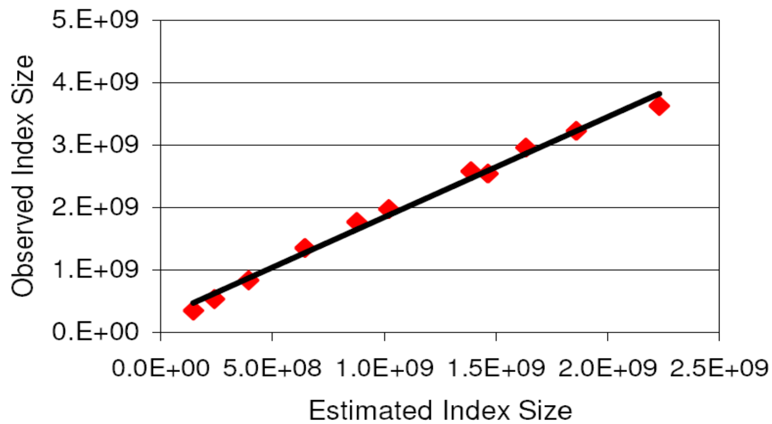
Index space estimate given R

- Each token occurrence leads to one posting entry
- Assume index compression is a constant factor
- Then total estimated index size is proportional to

$$\sum_{r \in R} corpusCount(r)$$

Number of tokens in corpus that connect up to *r*

- Surprisingly accurate!



Processing time bloat for one query

- If $R=A$, query takes time approximated by

$$t_{\text{scan}}\, corpusCount(a)$$

Time to score one candidate position while scanning postings

Number of occurrences of descendants of type *a*

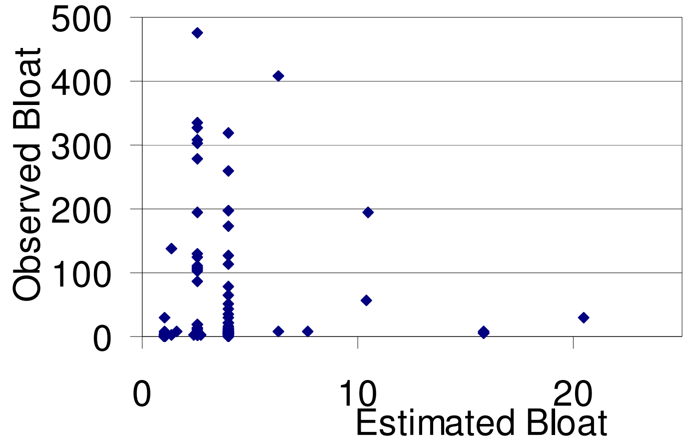
- If *a* cannot be found in *R*, the price paid for generalization to *g* consists of
  - Scanning more posting entries: $t_{\text{scan}}\, corpusCount(g)$
  - Post-filtering *k'* responses: $k'\, t_{\text{filter}}$
- Therefore, overall bloat factor is

$$queryBloat(a, R) = \frac{t_{\text{scan}} corpusCount(g) + k'\, t_{\text{filter}}}{t_{\text{scan}} corpusCount(a)}$$

Time to check if answer is instance of *a* as well

Query time bloat—results

- Observed bloat fit not as good as index space estimate



- While observed::estimated ratio for one query is noisy, average over many queries is much better

Expected bloat over many queries

Prob of new query having atype *a*

$$\sum_{a \in A} queryProb(a)\ queryBloat(a, R)$$

Already estimated

- Maximum likelihood estimate

$$queryProb_{\mathrm{Train}}(a) = \frac{queryCount_{\mathrm{Train}}(a)}{\sum_{a' \in A} queryCount_{\mathrm{Train}}(a')}$$

- Many *a*'s get zero training probability
→ Optimizer does not register *g* close to *a*
- Low-prob atypes appear in test → huge bloat
- Collectively matter a lot (heavy-tailed distrib)

Smoothing low-probability atypes

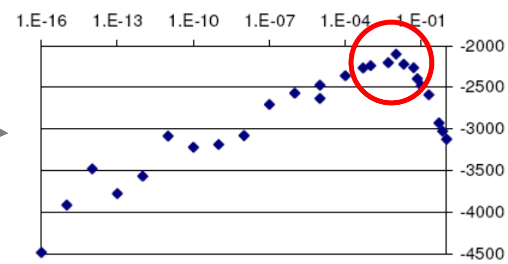
- Lidstone smoothing:

$$queryProb_{\text{Train}}(a) = \frac{queryCount_{\text{Train}}(a) + \ell}{\sum_{a' \in A}\left(queryCount_{\text{Train}}(a') + \ell\right)}$$

- Smoothing param ℓ fit by maximizing log-likelihood of held-out data:

$$\sum_{a \in \text{HeldOut}} queryCount_{\text{HeldOut}}(a) \log(queryProb_{\text{Train}}(a))$$

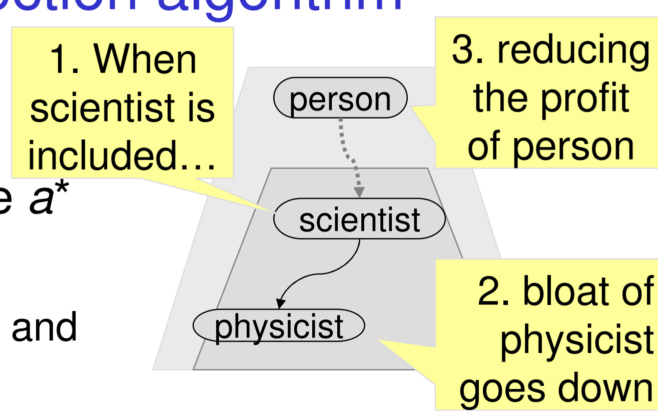
- Clear range of good fits for ℓ

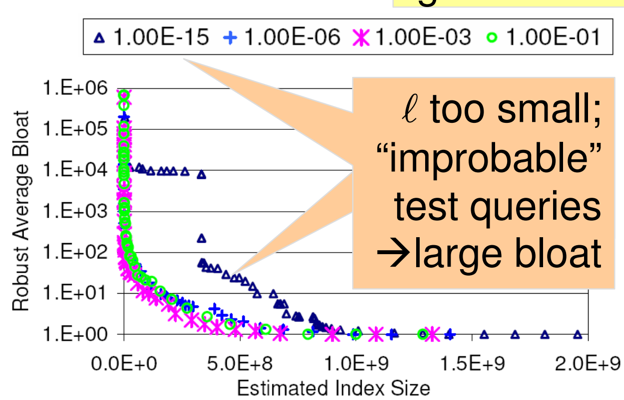


Smoothing param $\ell \rightarrow$

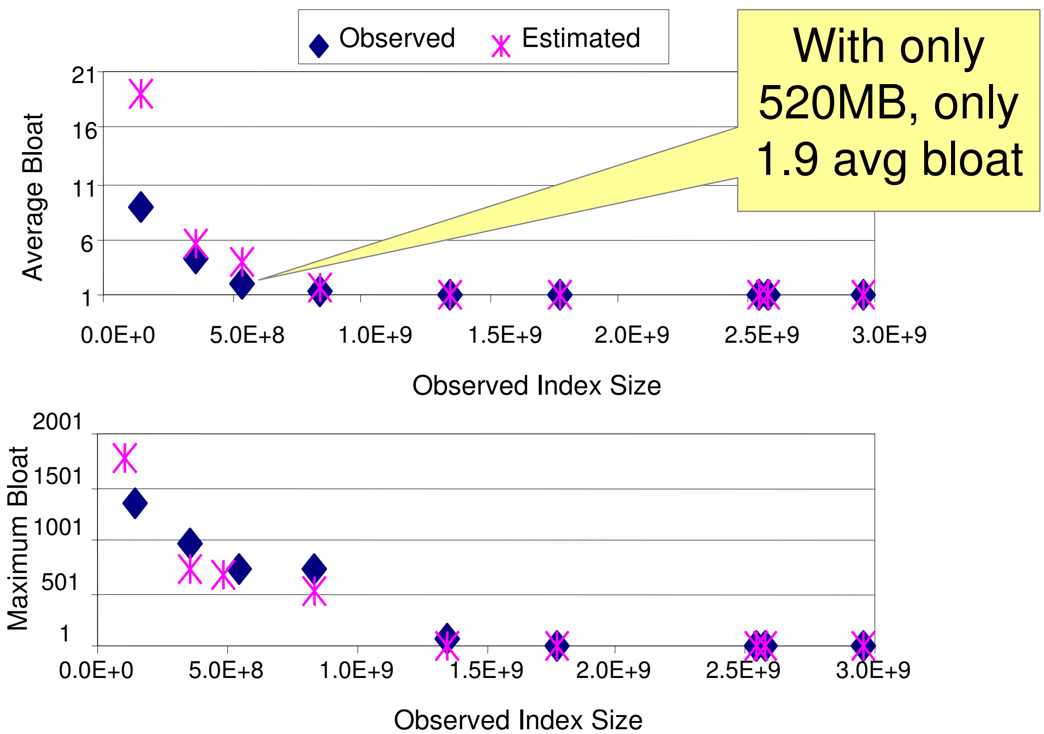
The R selection algorithm

- $R \leftarrow$ roots of A
- Greedily add the "most profitable" atype a^*
- Profit = ratio of
  - reduction in bloat of a^* and its descendants to
  - increase in index space
- Downward and upward traversals and updates
- Gives a tradeoff between index space and query bloat





Optimized space-time tradeoff



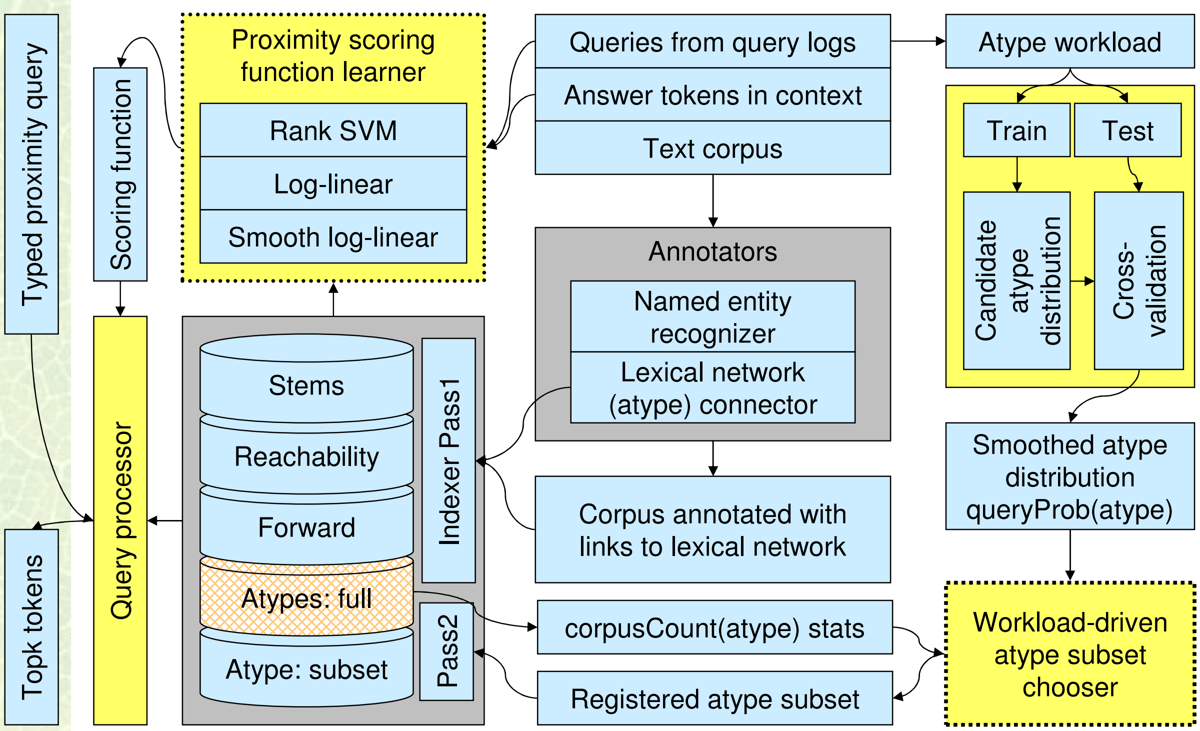
Optimized index sizes

Corpus/Index	Gbytes
Original corpus	5.72
Gzipped corpus	1.33
Stem index	0.91
Full type index	4.30
Reachability index	0.01
Forward index	1.16
Atype subset index	0.52

Summary

- Working prototype around Lucene and UIMA
  - Annotators attach tokens to type taxonomy
  - Query atype workload help compact index
  - Ranking function learnt from preference data
  - NL queries translated into atype+selectors
- Ongoing work
  - Indexing and searching relations other than is-a
  - More general notions of graph proximity
- Email soumen@cse.iitb.ac.in for code access

The big picture



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