Text Search for Fine-grained Semi-structured Data

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Acknowledgments	
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Two extreme search paradigms

Searching a RDBMS

- Complex data model: tables, rows, columns, data types
- Expressive, powerful query language
- Need to know schema to query
- Answer = unordered set of rows
- Ranking: afterthought

Information Retrieval

- Collection = set of documents, document = sequence of terms
- Terms and phrases present or absent
- No (nontrivial) schema to learn
- Answer = sequence of documents
- Ranking: central to IR

Convergence?

SQL→XML search

- Trees, reference links
- Labeled edges
- Nodes may contain
  - Structured data
  - Free text fields

  Data vs. document
- Query involves node data and edge labels
  - Partial knowledge of schema ok
- Answer = set of paths

Web search←IR

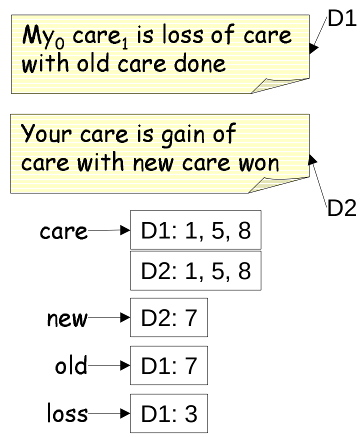
- Documents are nodes in a graph
- Hyperlink edges have important but unspecified semantics
  - Google, HITS
- Query language remains primitive
  - No data types
  - No use of tag-tree
- Answer = URL list

Outline of this tutorial

- Review of text indexing and information retrieval (IR)
- Support for text search and similarity join in relational databases with text columns
- Text search features in major XML query languages (and what's missing)
- A graph model for semi-structured data with "free-form" text in nodes
- Proximity search formulations and techniques; how to rank responses
- Folding in user feedback
- Trends and research problems

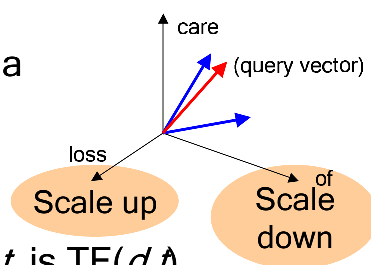
Text indexing basics

- "Inverted index" maps from term to document IDs
- Term offset info enables phrase and proximity ("near") searches
- Document boundary and limitations of "near" queries
- Can extend inverted index to map terms to
  - Table names, column names
  - Primary keys, RIDs
  - XML DOM node IDs



Information retrieval basics

- Stopwords and stemming
- Each term *t* in lexicon gets a dimension in vector space
- Documents and the query are vectors in term space
- Component of *d* along axis *t* is TF(d,t)
  - Absolute term count or scaled by max term count
- Downplay frequent terms: IDF(t) = $\log(1+|D|/|D_t|)$
  - Better model: document vector *d* has component TF(d,t) IDF(t) for term *t*
- Query is like another "document"; documents ranked by cosine similarity with query



Map

		Data model	
		Relational	XML-like
IR support	None	SQL, Datalog	XML-QL, Xquery
	Schema	WHIRL	ELIXIR, XIRQL
	No schema	DBXplorer, BANKS, DISCOVER	EasyAsk, Mercado, DataSpot, BANKS

- "None" = nothing more than string equality, containment (substring), and perhaps lexicographic ordering
- "Schema": Extensions to query languages, user needs to know data schema, IR-like ranking schemes, no implicit joins
- "No schema": Keyword queries, implicit joins

WHIRL (Cohen 1998)

place(univ,state) and job(univ,dept)

- Ranked retrieval from a RDBMS:
  - select univ from job where dept ~ 'Civil'
- Ranked similarity join on text columns:
  - select state, dept from place, job
    where place.univ ~ job.univ
- Limit answer to best *k* matches only
- Avoid evaluating full Cartesian product
  - "Iceberg" query
- Useful for data cleaning and integration

WHIRL scoring function

A where-clause in WHIRL is a

- Boolean predicate as in SQL (age=35)
  - Score for such clauses are 0/1
- Similarity predicate (job ~ 'Web design')
  - Score = cosine(job, 'Web design')
- Conjunction or disjunction of clauses
  - Sub-clause scores interpreted as probabilities
  - $\text{score}(B_1 \wedge \ldots \wedge B_m;\ \theta) = \Pi_{1 \le i \le m}\ \text{score}(B_i, \theta)$
  - $\text{score}(B_1 \vee \ldots \vee B_m;\ \theta) = 1 - \Pi_{1 \le i \le m}(1 - \text{score}(B_i, \theta))$

Query execution strategy

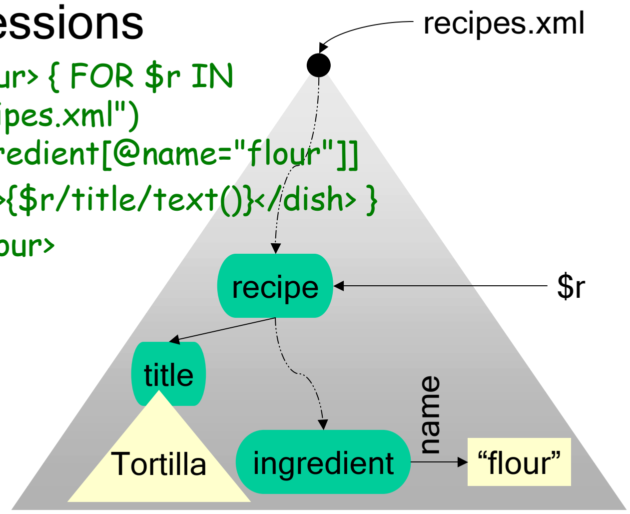
select state, dept from place, job
where place.univ ~ job.univ

- Start with place(U1,S) and job(U2,D) where U1, U2, S and D are "free"
  - Any binding of these variables to constants is associated with a score
- Greedily extend the current bindings for maximum gain in score
- Backtrack to find more solutions

XQuery

- Quilt + Lorel + YATL + XML-QL
- Path expressions

```
<dishes_with_flour> { FOR $r IN
   document("recipes.xml")
   //recipe[//ingredient[@name="flour"]]
   RETURN <dish>{$r/title/text()}</dish> }
</dishes_with_flour>
```



Early text support in XQuery

- Title of books containing some para mentioning both "sailing" and "windsurfing"

```
FOR $b IN document("bib.xml")//book
WHERE SOME $p IN $b//paragraph SATISFIES
   (contains($p,"sailing") AND
     contains($p,"windsurfing"))
RETURN $b/title
```

- Title and text of documents containing at least three occurrences of "stocks"

```
FOR  $a IN view("text_table") WHERE
   numMatches($a/text_document,"stocks") > 3
RETURN
   <text>{$a/text_title}{$a/text_document}</>
```

Tutorial outline

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- Review of text indexing and information retrieval
- Support for text search and similarity join in relational databases with text columns (WHIRL)
- Adding IR-like text search features to XML query languages (Chinenyanga et al. Führ et al. 2001)

ELIXIR: Adding IR to XQuery

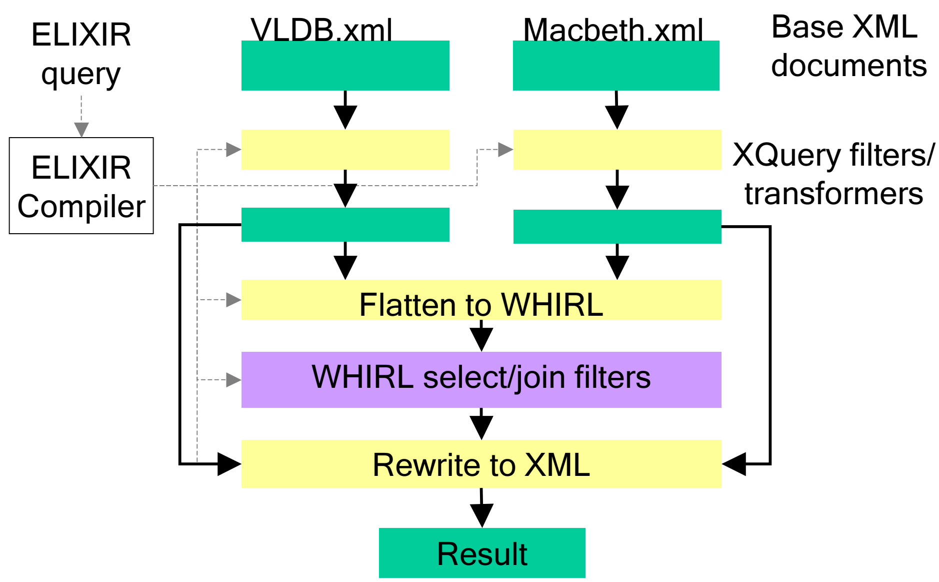
- Ranked select

```
for $t in document("db.xml")/items/(book|cd)
where $t/text() ~ "Ukrainian recipe"
return <dish>$t</dish>
```

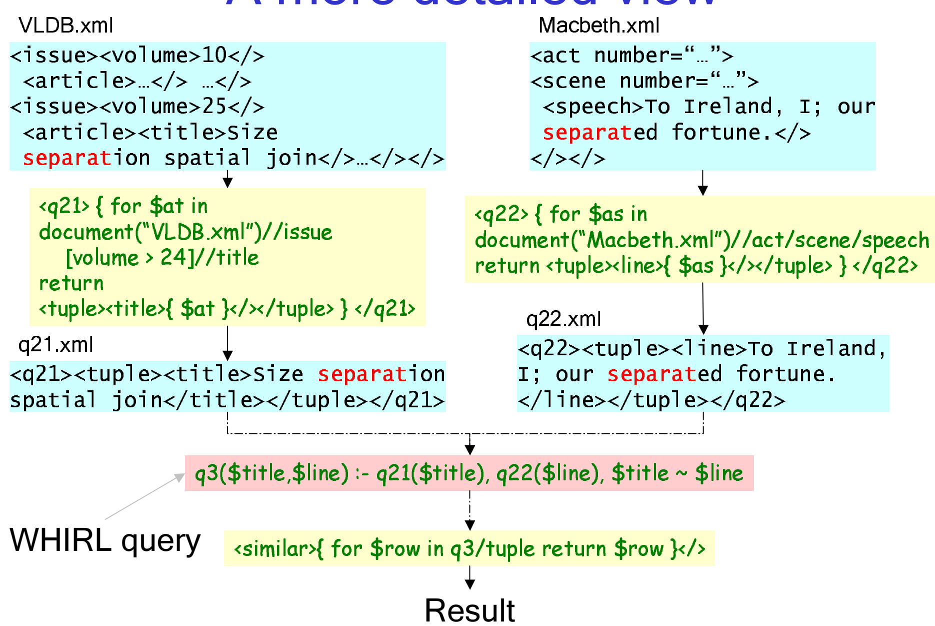
- Ranked similarity join: find titles in recent VLDB proceedings similar to speeches in Macbeth

```
for $vi in
        document("vldb.xml")/issue[@volume>24],
    $si in document("macbeth.xml")//speech
where $vi//article/title ~ $si
return <similar><title>$vi//article/title</>
                    <speech>$si</></similar>
```

How ELIXIR works



A more detailed view



Observations

- SQL/XQuery + IR-like result ranking
- Schema knowledge remains essential
  - "Free-form" text vs. tagged, typed field
  - Element hierarchy, element names, IDREFs
- Typical Web search is two words long
  - End-users don't type SQL or XQuery
  - Possible remedy: HTML form access
  - Limitation: restricted views and queries

Using proximity without schema

- General, detailed representation: XML
- Lowest common representation
  - Collection, document, terms
  - Document = node, hyperlink = edge
- Middle ground
  - Graph with text (or structured data) in nodes
  - Links: element, subpart, IDREF, foreign keys
  - All links hint at unspecified notion of proximity

Exploit structure where available, but do not impose structure by fiat

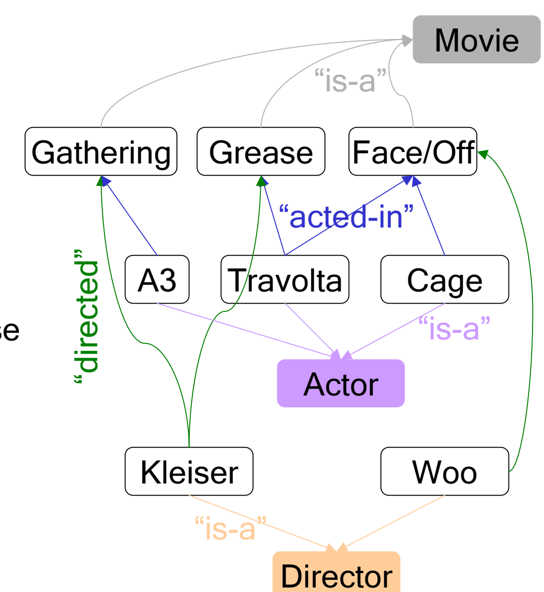
Two paradigms of proximity search

- A single node as query response
  - Find node that matches query terms…
  - …or is "near" nodes matching query terms

  (Goldman et al., 1998)
- A connected subgraph as query response
  - Single node may not match all keywords
  - No natural "page boundary"

Single-node response examples

- Travolta, Cage
  - Actor, Face/Off
- Travolta, Cage, Movie
  - Face/Off
- Kleiser, Movie
  - Gathering, Grease
- Kleiser, Woo, Actor
  - Travolta



Basic search strategy

- Node subset A activated because they match query keyword(s)
- Look for node near nodes that are activated
- Goodness of response node depends
  - Directly on degree of activation
  - Inversely on distance from activated node(s)

Ranking a single node response

- Activated node set *A*
- Rank node *r* in "response set" *R* based on proximity to nodes *a* in *A*
  - Nodes have relevance ρ_R and ρ_A in [0,1]
  - Edge costs are "specified by the system"
- $d(a,r)$ = cost of shortest path from *a* to *r*
- Bond between *a* and *r* $b(a,r) = \frac{\rho_A(a)\rho_R(r)}{d(a,r)^t}$
- Parameter *t* tunes relative emphasis on distance and relevance score
- Several ad-hoc choices

Scoring single response nodes

- Additive

$$\text{score}(r) = \sum_{a \in A} b(a,r)$$

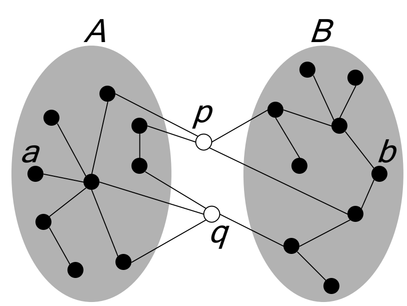
- Belief

$$\text{score}(r) = 1 - \prod_{a \in A} \left(1 - b(a,r)\right)$$

- Goal: list a limited number of find nodes with the largest scores
- Performance issues
  - Assume the graph is in memory?
  - Precompute all-pairs shortest path ($|V|^3$)?
  - Prune unpromising candidates?

Hub indexing

- Decompose APSP problem using sparse vertex cuts
  - $|A|+|B|$ shortest paths to p
  - $|A|+|B|$ shortest paths to q
  - $d(p,q)$
- To find $d(a,b)$ compare
  - $d(a \rightarrow p \rightarrow b)$ not through q
  - $d(a \rightarrow q \rightarrow b)$ not through p
  - $d(a \rightarrow p \rightarrow q \rightarrow b)$
  - $d(a \rightarrow q \rightarrow p \rightarrow b)$
- Greatest savings when |A|≈|B|
- Heuristics to find cuts, e.g. large-degree nodes



Connected subgraph as response

- Single node may not match all keywords
- No natural "page boundary"
- Two scenarios
  - Keyword search on relational data
    - Keywords spread among normalized relations
  - Keyword search on XML-like or Web data
    - Keywords spread among DOM nodes and subtrees

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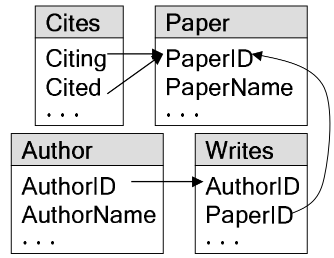
- Adding IR-like text search features to XML query languages
- A graph model for relational data with "free-form" text search and implicit joins
- Generalizing to graph models for XML

Keyword search on relational data

- Tuple = node
- Some columns have text
- Foreign key constraints = edges in schema graph→
- Query = set of terms
- No natural notion of a document
  - Normalization
  - Join may be needed to generate results
  - Cycles may exist in schema graph: 'Cites'



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A1	P1
A2	P2
A3	P2

AuthorID	AuthorName
A1	Chaudhuri
A2	Sudarshan
A3	Hulgeri

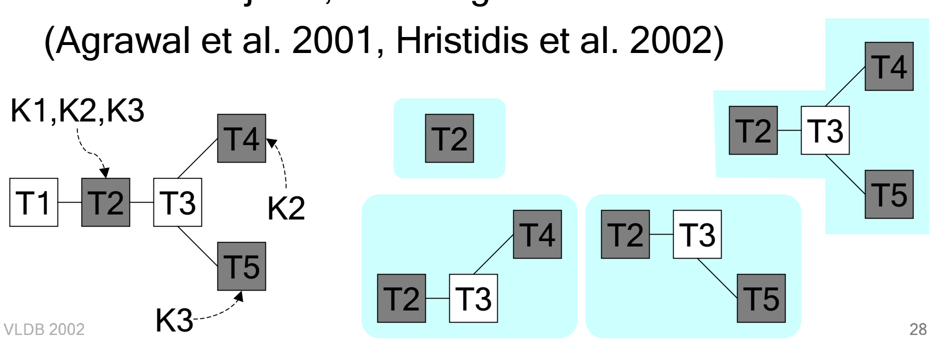
Citing	Cited
P2	P1

PaperID	PaperName
P1	DBXplorer
P2	BANKS

DBXplorer and DISCOVER

- Enumerate subsets of relations in schema graph which, when joined, may contain rows which have *all* keywords in the query
  - "Join trees" derived from schema graph
- Output SQL query for each join tree
- Generate joins, checking rows for matches

(Agrawal et al. 2001, Hristidis et al. 2002)



Discussion

- Exploits relational schema information to contain search
- Pushes final extraction of joined tuples into RDBMS
- Faster than dealing with full data graph directly

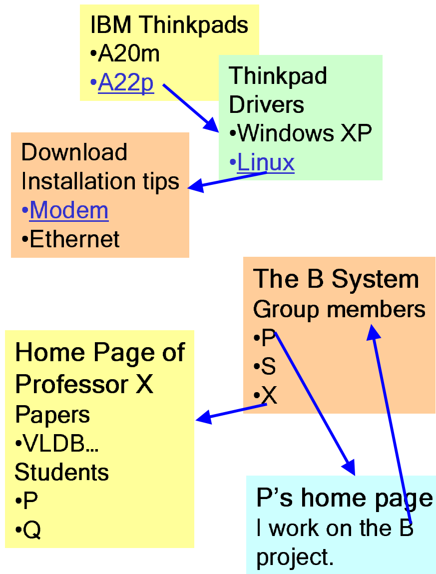
- Coarse-grained ranking based on schema tree
- Does not model proximity or (dis) similarity of individual tuples
- No recipe for data with less regular (e.g. XML) or ill-defined schema

Generalized graph proximity

- General data graph
  - Nodes have text, can be scored against query
  - Edge weights express dissimilarity
- Query is a set of keywords as before
- Response is a connected subgraph of the database
- Each response graph is scored using
  - Node weights which reflect match, maximize
  - Edge weights which reflect lack of proximity, minimize

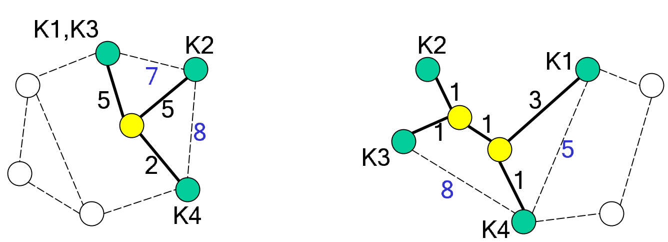
Motivation from Web search

- "Linux modem driver for a Thinkpad A22p"
  - Hyperlink path matches query collectively
  - Conjunction query would fail
- Projects where X and P work together
  - Conjunction may retrieve wrong page
- General notion of graph proximity



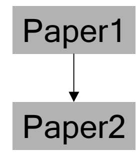
"Information unit" (Lee et al., 2001)

- Generalizes join trees to arbitrary graph data
- Connected subgraph of data without cycles
- Includes at least one node containing each query keyword
- Edge weights represent price to pay to connect all keyword-matching nodes together
- May have to include non-matching nodes

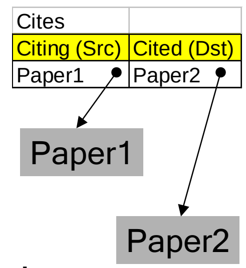


Setting edge weights

- Edges are generally directed
  - Foreign to primary key in relational data
  - Containing to contained element in XML
  - IDREFs have clear source and target



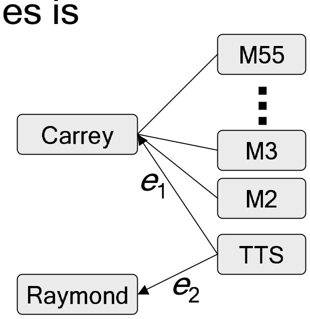
- Consider the RDMS scenario
- Forward edge weight for edge (u,v)
  - u, v are tuples in tables $R(u)$, $R(v)$
  - Weight $s(R(u),R(v))$ between tables
    - Configured heuristically based on semantics
    - $w_F(u,v)=s(R(u),R(v))$ all such tuple pairs u, v



- Proximity search must traverse edges in *both* directions … what should $w_B(u,v)$ be?

Backward edge weights

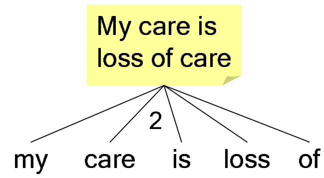
- "Distance" between a pair of nodes is asymmetric in general
  - Ted Raymond acted only in The Truman Show, which is 1 of 55 movies for Jim Carrey
  - $w(e_1)$ should be larger than $w(e_2)$ (think "resistance" on the edge)

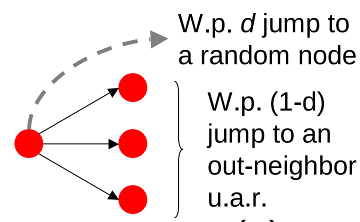


- For every edge (u,v) that exists, $w_B(u,v)=s(R(v),R(u))\ .\ \mathrm{IN}_v(u)$
  - $\mathrm{IN}_v(u)$ is the #edges from $R(v)$ to u
- $w(u,v) = \min\{w_F(u,v),\ w_B(u,v)\}$
- More general edge weight models possible, e.g., R→S→T relation path-based weights

Node weight = relevance + prestige

- Relevance w.r.t. keyword(s)
  - 0/1: node contains term or it does not
  - Cosine score in [0,1] as in IR
  - Uniform model: a node for each keyword (e.g. DataSpot)
- Popularity or prestige
  - E.g. "mohan transaction"
  - Indegree
  - PageRank





$$p(v) = \frac{d}{N} + (1-d)\sum_{u \to v} \frac{p(u)}{\text{OutDegree}(u)}$$

Trading off node and edge weights

- A high-scoring answer *A* should have
  - Large node weight
  - Small edge weight
- Weights must be normalized to extreme values
- N(*v*)=node weight of *v*
- Overall NodeScore = $\frac{\sum_{v \in A} \log\left(1 + N(v)/N_{\max}\right)}{\#\text{nodes}}$
- Overall EdgeScore = $\frac{1}{1 + \sum_{e \in A} \log\left(1 + w(e)/w_{\min}\right)}$
- Overall score = EdgeScore $\times$ NodeScore$^{\lambda}$
  - λ tunes relative contribution of nodes and edges
- Ad-hoc, but guided by heuristic choices in IR

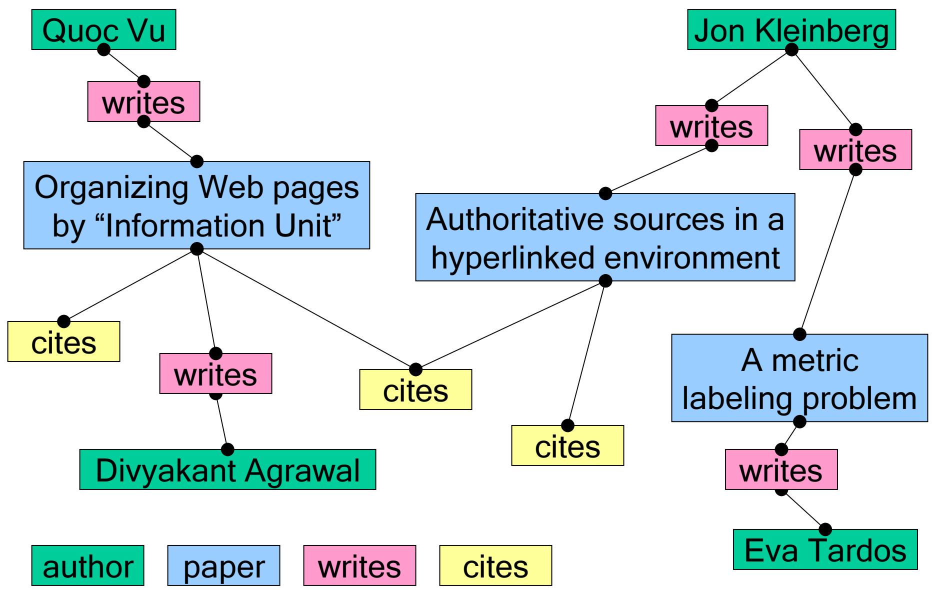
Data structures for search

- Answer = tree with at least one leaf containing each keyword in query
  - Group Steiner tree problem, NP-hard
- Query term t found in source nodes S_t
- Single-source-shortest-path SSSP iterator
  - Initialize with a source (near-) node
  - Consider edges backwards
  - getNext() returns next nearest node
- For each iterator, each visited node v maintains for each t a set $v.R_t$ of nodes in S_t which have reached v

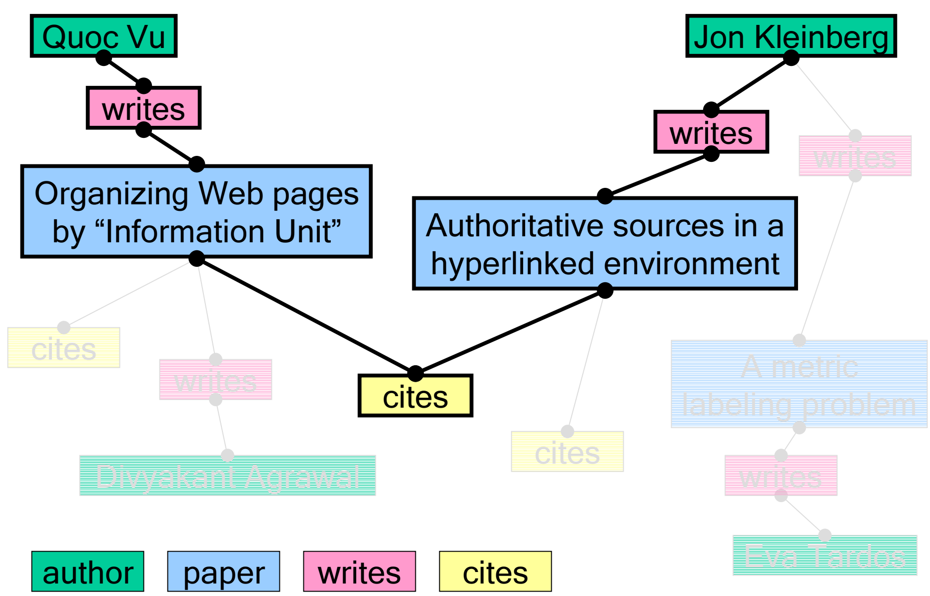
Generic expanding search

- Near node sets S_t with $S = \cup_t S_t$
- For all source nodes $\sigma \in S$
  - create a SSSP iterator with source σ
- While more results required
  - Get next iterator and its next-nearest node v
  - Let t be the term for the iterator's source s
  - crossProduct = $\{s\} \times \Pi_{t' \neq t} v.R_{t'}$
  - For each tuple of nodes in crossProduct
    - Create an answer tree rooted at v with paths to each source node in the tuple
  - Add s to $v.R_t$

Search example (“Vu Kleinberg”)



First response

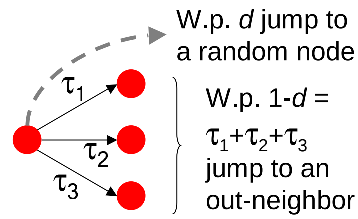


Folding in user feedback

- As in IR systems, results may be imperfect
  - Unlike SQL or XQuery, no exact control over matching, ranking and answer graph form
  - Ad-hoc choices for node and edge weights
- Per-user and/or per-session
  - By graph/path/node type, e.g. “want author *citing* author,” not “author *coauthoring with* author”
- Across users
  - Modifying edge costs to favor nodes (or node types) liked by users

Random walk formulations

- Generalize PageRank to treat outlinks differently
  - $\tau(u,v)$ is the “conductance” of edge $u \rightarrow v$
- $p(v)$ is a function of $\tau(u,v)$ for all in-neighbors u of v
  - $p_{guess}(v)$ … at convergence
  - $p_{user}(v)$ … user feedback



$$p(v) = \frac{d}{N} + \sum_{u \rightarrow v} p(u)\ \tau(u,v)$$

$$\frac{\partial p(v)}{\partial \tau(u,v)} = p(u)$$

Gradient ascent/descent:

- For each $u \rightarrow v$, set (with learning rate η):
  $$\tau(u,v) \leftarrow \tau(u,v) + \eta\ \mathrm{sgn}\left(p_{user}(v) - p_{guess}(v)\right) \frac{p(u)}{\sum_{u' \rightarrow v} p(u')}$$
- Re-iterate to convergence

Prototypes and products

- DTL DataSpot → Mercado Intuifind www.mercado.com/
- EasyAsk www.easyask.com/
- ELIXIR www.smi.ucd.ie/elixir/
- XIRQL ls6-www.informatik.uni-dortmund.de/ir/projects/hyrex/
- Microsoft DBXplorer
- BANKS www.cse.iitb.ac.in/banks/

Summary

- Confluence of structured and free-format, keyword-based search
  - Extend SQL, XQuery, Web search, IR
  - Many useful applications: product catalogs, software libraries, Web search
- Key idiom: proximity in a graph representation of textual data
  - Implicit joins on foreign keys
  - Proximity via IDREF and other links
- Several working systems
- Not enough consensus on clean models

Open problems

- Simple, clean principles for setting weights
  - Node/edge scoring ad-hoc
  - Contrast with classification and distillation
- Iceberg queries
  - Incremental answer generation heuristics do not capture bicriteria nature of cost
- Aggregation: how to express / execute
- User interaction and query refinement
- Advanced applications
  - Web query, multipage knowledge extraction
  - Linguistic connections through WordNet

Selected references

- R. Goldman, N. Shivakumar, S. Venkatasubramanian, H. Garcia-Molina. Proximity search in databases. VLDB 1998, pages 26–37.
- S. Dar, G. Entin, S. Geva, E. Palmon. DTL's DataSpot: Database exploration using plain language. VLDB 1998, pages 645–649
- W. Cohen. WHIRL: A word-based information representation language. Artificial Intelligence 118(1–2), pages 163–196, 2000.
- D. Florescu, D. Kossmann, I. Manolescu. Integrating keyword search into XML query processing. Computer Networks 33(1–6), pages 119–135, 2000
- H. Chang, D. Cohn, A. McCallum. Creating customized authority lists. ICML 2000

Selected references

- T. Chinenyanga and N. Kushmerick. Expressive retrieval from XML documents, SIGIR 2001, pages 163–171
- N. Fuhr and K. Großjohann. XIRQL: A Query Language for Information Retrieval in XML Documents. SIGIR 2001, pages 172–180
- A. Hulgeri, G. Bhalotia, C. Nakhe, S. Chakrabarti, S. Sudarshan: Keyword Search in Databases. IEEE Data Engineering Bulletin 24(3): 22-32, 2001
- S. Agrawal, S. Chaudhuri, and G. Das. DBXplorer: A system for keyword-based search over relational databases. ICDE 2002.