Tree Signatures and Unordered XML Pattern Matching

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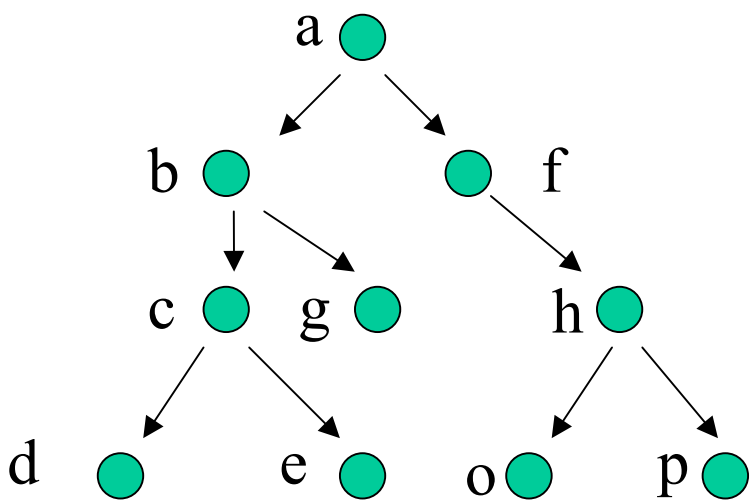
Overview of the talk

- objectives and the approach
- trees and sequences
- tree signatures and their properties
- experimental query evaluation
- future research directions

Objectives and the approach

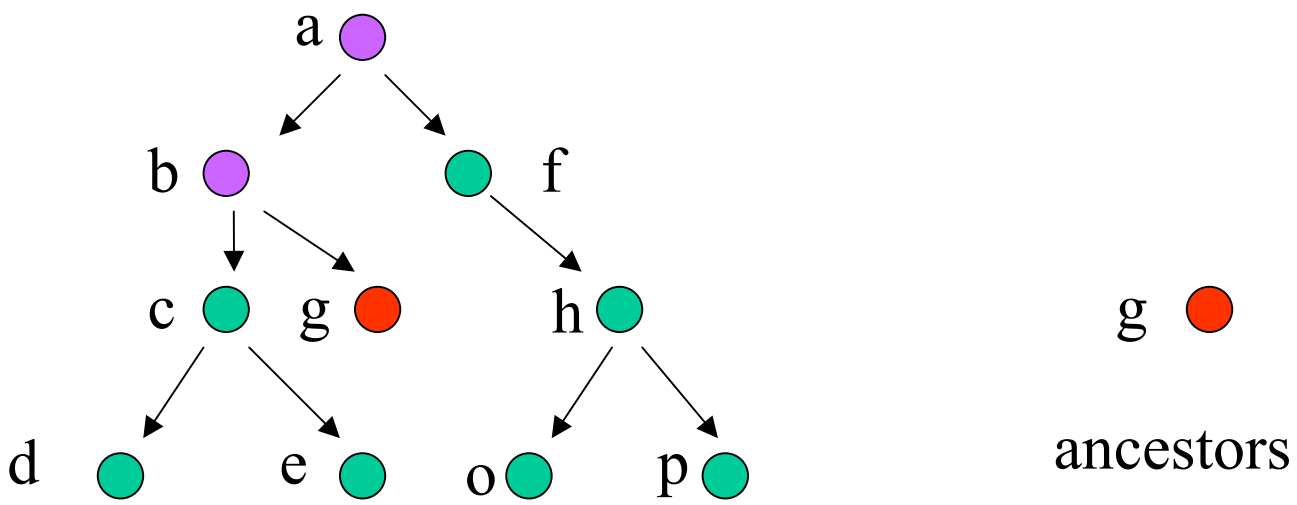
- Accelerate execution of queries on XML data, formulated by languages such as XPath and XQuery.
- Signature file approach.
- Create bases for other types of structured data processing.

XML data abstraction



Ordered labeled trees

Search problems -navigation



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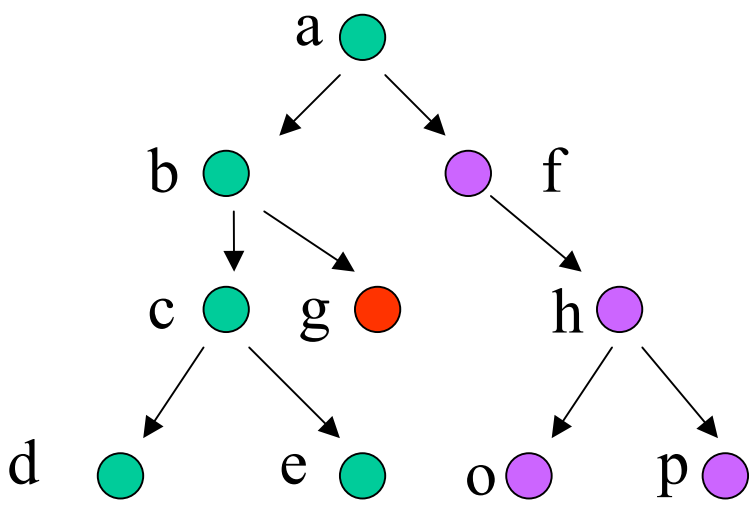
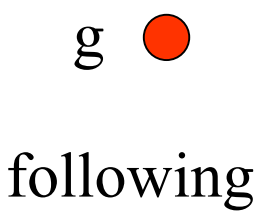
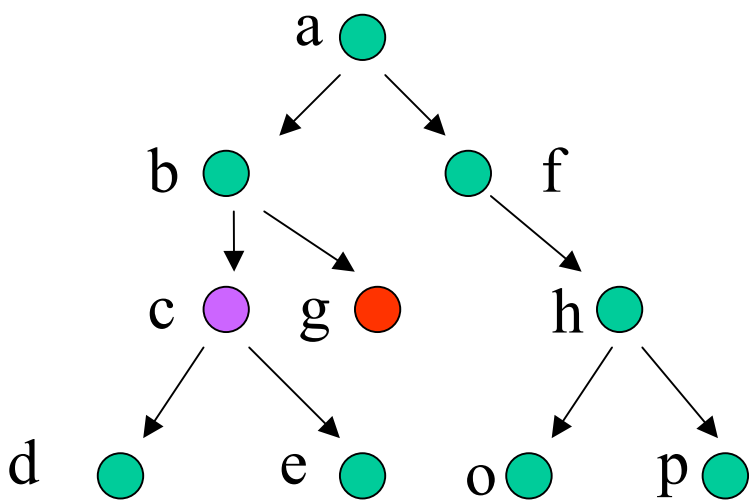


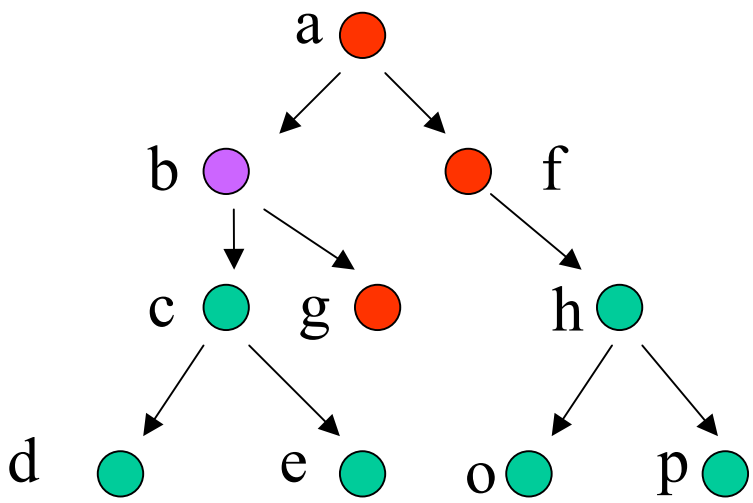


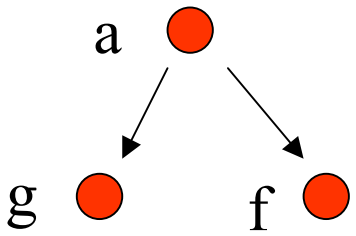
Search problems - navigation



left sibling

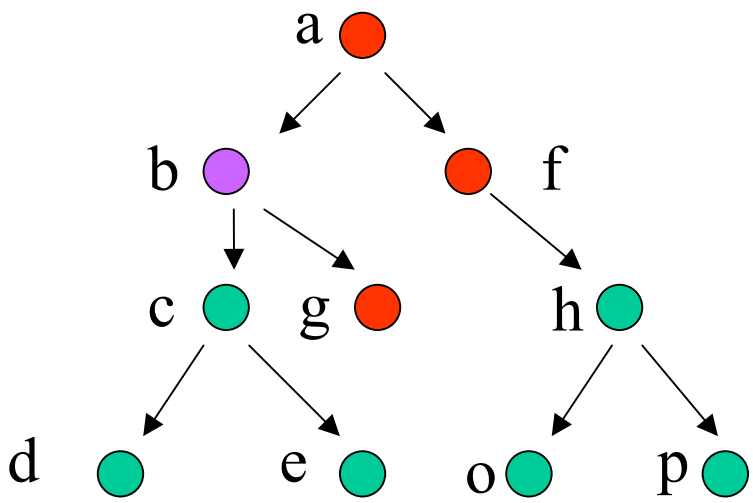
Search problems – tree pattern matching

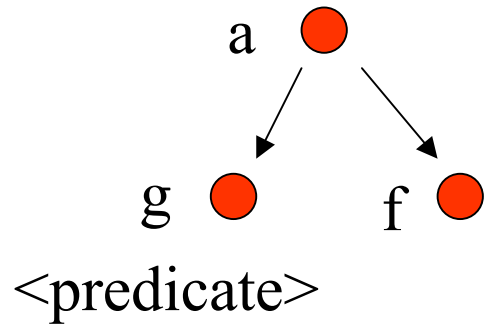




Query tree

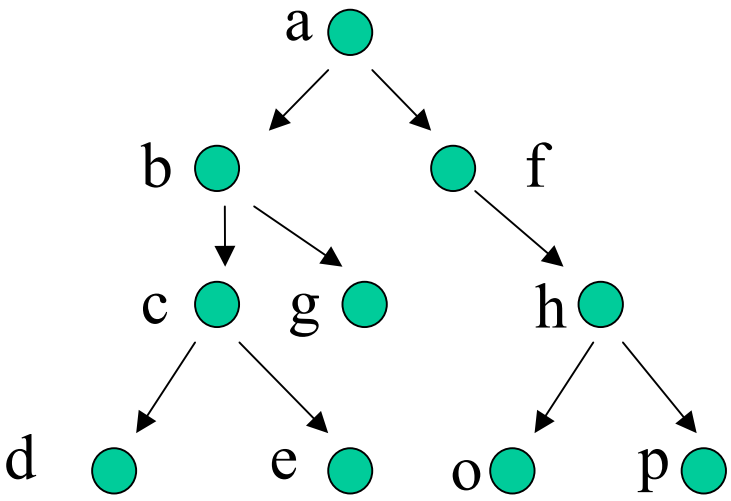
Search problems – tree pattern matching





Query tree

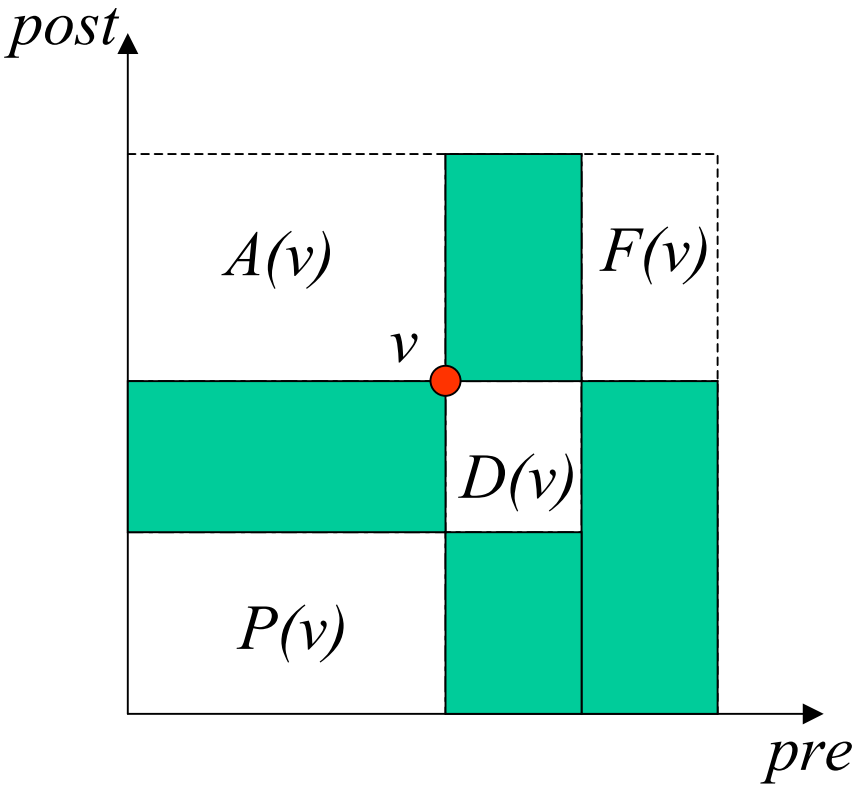
Trees and sequences



pre:	a	b	c	d	e	g	f	h	o	p
post:	d	e	c	g	b	o	p	h	f	a
rank:	1	2	3	4	5	6	7	8	9	10

Properties of *pre*/*post* ranks

$level(v) = pre(v) - post(v) + size(v) = |A(v)|$



$size(v) = |D(v)|$

$pre(v) = |A(v)| + |P(v)| + 1$

$post(v) = |D(v)| + |P(v)| + 1$

- empty space

String operations

string: $x = x_1, \ldots, x_n$

strictly increasing sequence: $1 = i_1 < i_2 < \ldots < i_k \check{} \; n$

subsequence of x: $x_{i1}, x_{i2}, \ldots, x_{ik}$

given strings x and y,
l.c.s. is the longest string that is a subsequence of both x and y,
e.g. **art** is l.c.s of **a**lgo**r**i**t**hm and p**ar**achu**t**e

string x is *sequence included* in string y if their l.c.s. is x,
e.g. **art** is sequence included in p**ar**achu**t**e

Ordered tree inclusion

Given:

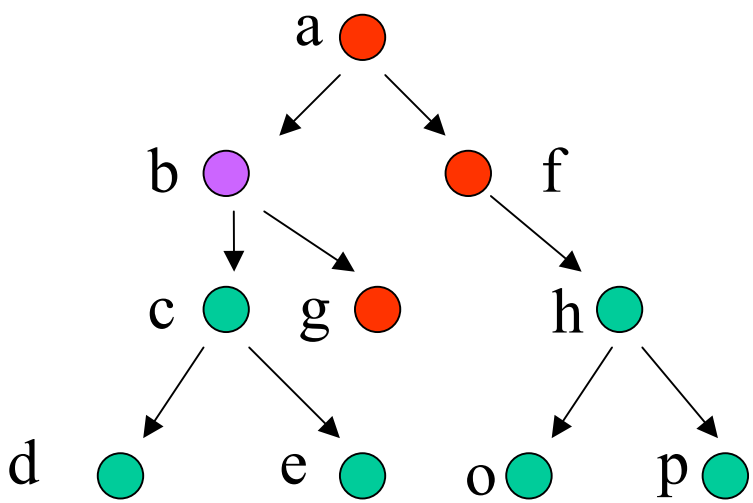
- data tree D
- query tree Q

Tree Q is included in D if

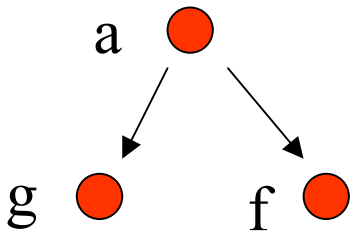
- $pre(Q)$ is sequence included in $pre(D)$, and
- $post(Q)$ is sequence included in $post(D)$.

Tree inclusion – example (true)

Data tree



Query tree



pre: **a** b c d e **g** **f** h o p

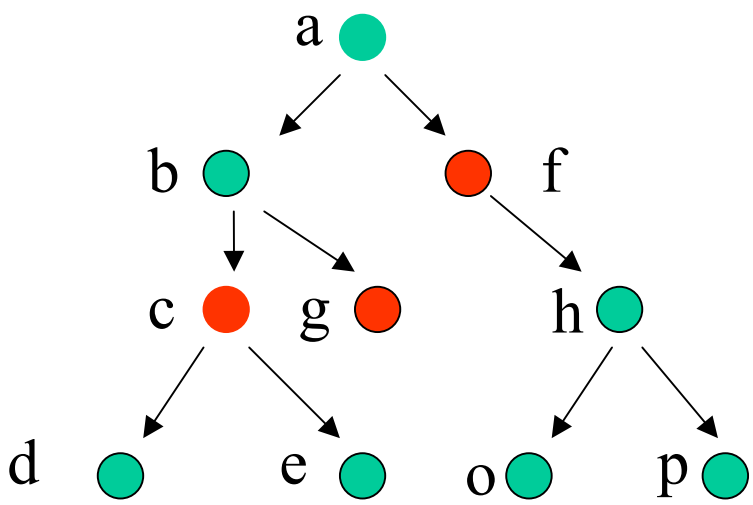
post: d e c **g** b o p h **f** **a**

pre: a g f

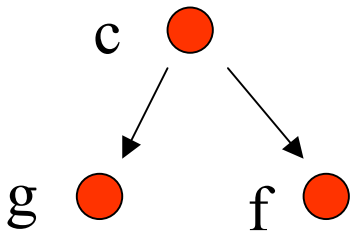
post: g f a

Tree inclusion – example (false)

Data tree



Query tree



pre: a b **c** d e **g** **f** h o p

post: d e c **g** b o p h **f** a

pre: c g f

post: g f c

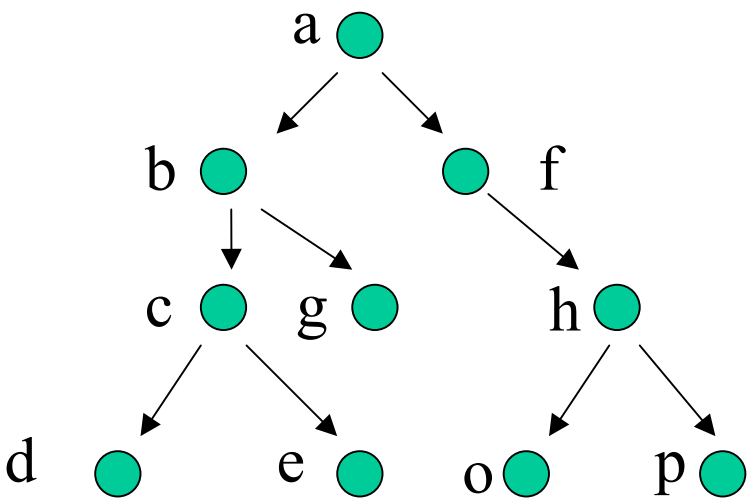
Tree signatures

Let T be an ordered labeled tree. The signature of T is a sequence,

$$sig(T) = \langle t_1, post(t_1); t_2, post(t_2); \ldots; t_m, post(t_m) \rangle$$

of $m = |T|$ entries, where t_i is a name of the node with $pre(t_i) = i$. The $post(t_i)$ is the postorder value of the node named t_i and the preorder value i.

Tree signature - example



A P A ? D

<a,10; b,5; c,3; d,1; e,2; g,4; f,9; h,8; o,6; p,7>

A ? D F

Extended signatures

The extended signature of T is a sequence

$$sig(T) = \langle t_1, post(t_1), ff(t_1), fa(t_1); \ldots ; t_m, post(t_m), ff(t_m), fa(t_m)\rangle$$

where: $ff(t_i)$ – pointer to (index or the preorder of) the first following, for not existing, $ff(t_i) = m+1$;

$fa(t_i)$ – pointer to (index or the preorder of) the first ancestor, for not existing, $fa(t_i) = 0$.

Analytic properties of signatures

- **descendants** $\mathrm{D}(t_i) = \{t_j \mid i < j < ff(t_i)\}$,
  $|\mathrm{D}(t_i)| = ff(t_i) - i - 1$; i.e. $size(t_i)$

- **following** $\mathrm{F}(t_i) = \{t_j \mid ff(t_i) = j = m\}$,
  $|\mathrm{F}(t_i)| = m + 1 - ff(t_i)$;

- **ancestors** $\mathrm{A}(t_i) = \{t_j \mid j < i \wedge post(t_j) > post(t_i)\}$,
  $|\mathrm{A}(t_i)| = ff(t_i) - post(t_i) - 1$; i.e. $level(t_i)$

- **preceding** $\mathrm{P}(t_i) = \{t_j \mid j < i \wedge post(t_j) < post(t_i)\}$,
  $|\mathrm{P}(t_i)| = i + post(t_i) - ff(t_i)$.

Other useful expressions

leaf detection $|\mathrm{D}(t_i)| = 0 \Rightarrow ff(t_i) = i + 1$ or $post(t_{i+1}) > post(t_i)$;

path slicing $t_i \cup \mathrm{A}(t_i) \mid t_i$ is a leaf;

inclusion test if $j < i < ff(t_j)$, t_i is in a sub-tree rooted at t_j;

siblings $[ff(t_i) - post(t_i) = ff(t_j) - post(t_j)] \wedge fa(t_i) = fa(t_j)$;

lowest common ancestor $t_k \in \{t_i \cup \mathrm{A}(t_i) \cap t_j \cup \mathrm{A}(t_j)\} \mid max(pre(t_k)$

XPath navigation

Using the analytic properties, the following XPath axes:

- **Child**
- **Descendant**
- **Parent**
- **Following**
- **Preceding**
- **Following-sibling**
- **Preceding-sibling**

can easily by determined in an obvious way.

Sub-signature

$$sub\_sig_S(T) = \langle\, t_{s1}, post(t_{s1});\ t_{s2}, post(t_{s2});\ \ldots\ ;t_{sk}, post(t_{sk}) \rangle$$

is a sub-sequence of $sig(T)$, defined by the ordered set $S = \{s_1, s_2, \ldots, s_k\}$ of indexes (preorder values) in $sig(T)$, such that $1 = s_1 < s_2 < \ldots < s_k = m$.

Ordered query tree

Given a query tree *Q* and an XML data tree *D*, the tree inclusion of *Q* in *D* is identified by a total mapping from nodes in *Q* to some nodes in *D*, such that the ancestor-descendant and the sibling structural relationships between nodes in *Q* are satisfied by the corresponding nodes in *D*.

We implicitly consider a *week inclusion* of *Q* in *D*:

parent-child relationships in *Q* are satisfied by **ancestor-descendant** relationships in *D*.

Evaluation

- Let Q and D be ordered labeled trees
- Suppose the data tree D and the query tree Q specified by signatures:

$$sig(D) = \langle d_1, post(d_1); d_2, post(d_2); \ldots ; d_m, post(d_m)\rangle$$
$$sig(Q) = \langle q_1, post(q_1); q_2, post(q_2); \ldots ; q_n, post(q_n)\rangle$$

- Tree Q is included in tree D if:

  on the level of node names, $sig(Q)$ is sequence-included in $sig(D)$ determining $sub\_sig_S(D)$ through the ordered set of indexes $S = \{s_1, s_2, \ldots, s_n\} \mid q_1 = d_{s1}, q_2 = d_{s2}, \ldots, q_n = d_{sn}$;

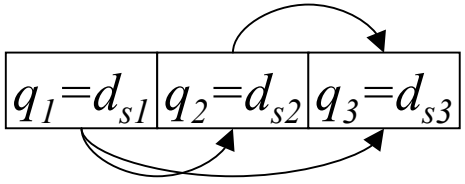
and (depending on the signature)

Using short signatures

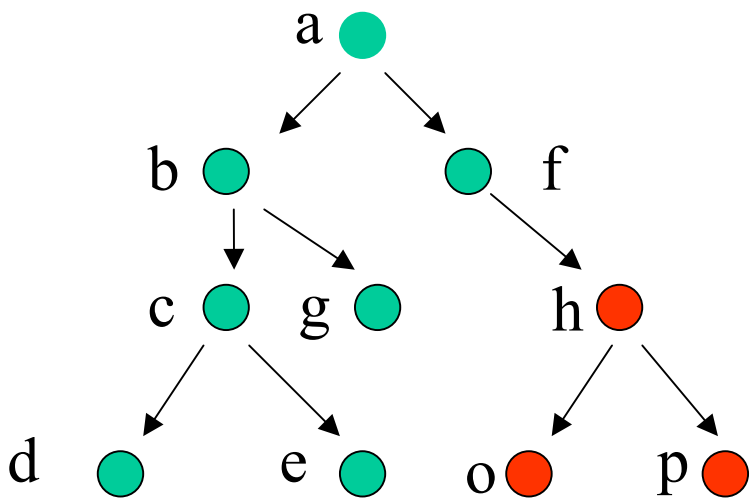
for all pairs of entries i and j in $sig(Q)$ and $sub\_sig_S(D)$

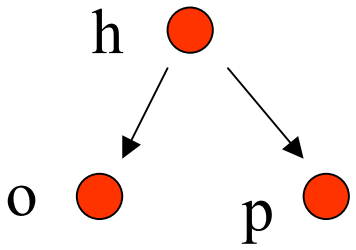
(i,j = 1, 2, ... $|Q|$ - 1 and i+j = |Q|),

$post(q_{i+j}) > post(q_i)$ implies $post(d_{s(i+j)}) > post(d_{si})$ and
$post(q_{i+j}) < post(q_i)$ implies $post(d_{s(i+j)}) < post(d_{si})$



Example - true

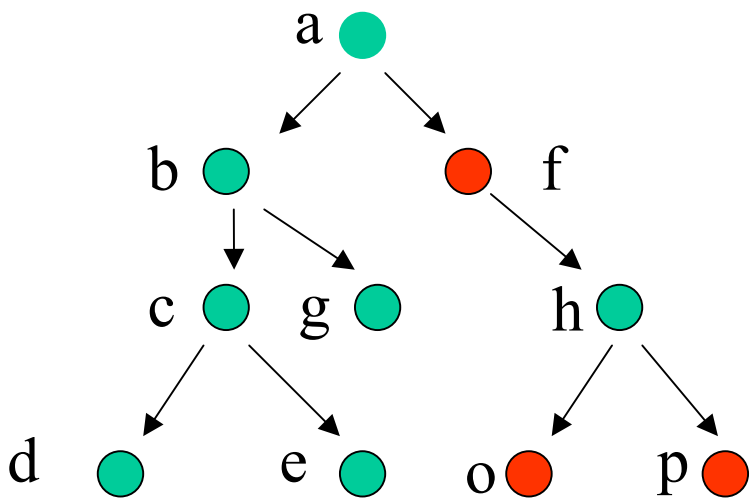


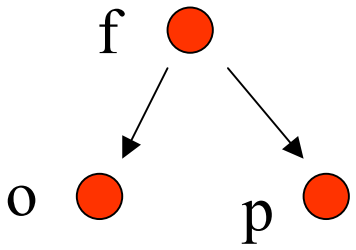


<h,3;o,1;p,2>

<a,10;b,5;c,3;d,1; e,2; g,4; f,9; ***h****,8;* ***o****,6;* ***p****,7>* $\Rightarrow$ *<h,8;o,6;p,7>*

Example - true

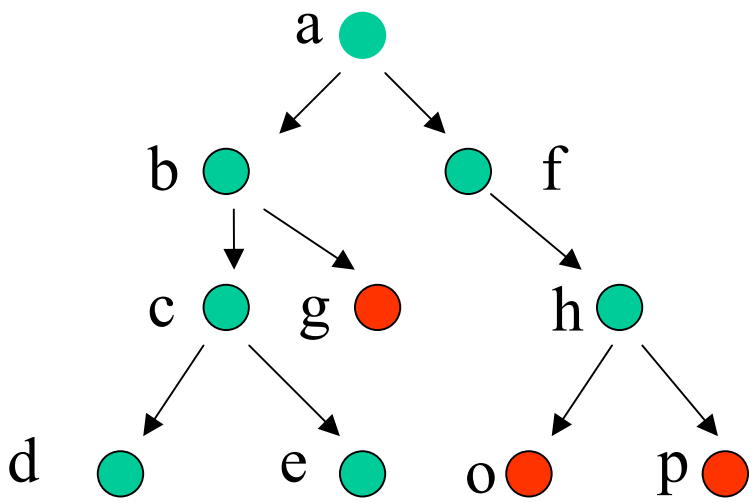


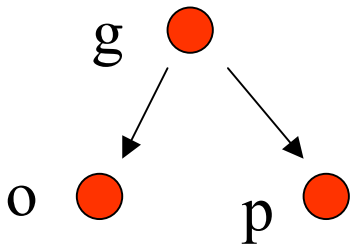


<f,3;o,1;p,2>

<a,10;b,5;c,3;d,1; e,2; g,4; ***f****,9; h,8;* ***o****,6;* ***p****,7> ⇒ <f,9;o,6;p,7>*

Example - false



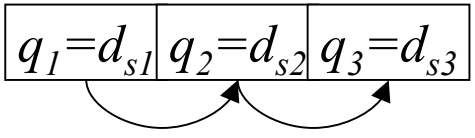


<g,3;o,1;p,2>

<a,10;b,5;c,3;d,1; e,2; ***g****,4; f,9; h,8;* ***o****,6;* ***p****,7>* ⇒ *<g,4;o,6;p,7>*

Using extended signatures

for $i = 1, 2, \ldots |Q| - 1$, if $post(q_i) < post(q_{i+1})$ (leaf node) then $ff(d_{si}) = s_{i+1}$, otherwise $ff(d_{si}) > s_{ff(qi)-1}$.



Query processing

- XQuery example:

```
for $a in // people
where
        $a/name/first="John" and
         $a/name/last="Smith"
return $a/address
```

An execution plan with content indexes

- let R_1 = *ContentIndexSearch*(last = "Smith");
- let R_2 = *ContentIndexSearch*({first = "John");
- let R_3 = *Parent*(R_1 , name);
- let R_4 = *Parent*(R_2, name);
- let R_5 = *Intersect*(R_3,R_4);
- let R_6 = *Parent*(R_5, people);
- let R_7 = *Child*(R_6, address);

Performance evaluation

query template:

```
for $a in //⟨e_name⟩
where ⟨pred($a)⟩
return
        ⟨result⟩ $a/⟨e_1⟩ ... $a/⟨e_n⟩ ⟨/result⟩
```

⟨e_name⟩	name selectivity,
⟨pred($a)⟩	content selectivity,
⟨e_n⟩	number of navigation steps (n).

Query type notation

name selectivity

content selectivity

number of iteration steps

Q N C n

{1,2}

{H(igh), M(edium), L(ow)}

Execution plan for signatures

- let R_1 = *ContentIndexSearch*(<pred>);
- let R_2 = *Parent*(R_1, <e_name>);
- let R_3 = *Child*(R_2, <e_1>);
- let R_4 = *Child*(R_2, <e_2>).

Execution plan for MPMGJN

Multi Predicate MerGe JoiN:

- let R_1 = *ContentIndexSearch*(<pred>);
- let R_2 = *ElementIndexSearch*(<e_name>);
- let R_3 = *ContainingParent*(R_2, R_1);
- let R_4 = *ElementIndexSearch*(<e_1>);
- let R_5 = *ContainedChild*(R_4, R_3);
- let R_6 = *ElementIndexSearch*({ <e_2>);
- let R_7 = *ContainedChild*(R_6, R_3).

Results for DBLP

query	signature	join	retrieved el.
QHH1	80	466	1
QHM1	320	738	1
QHL1	538	742	1
QMH1	88	724	1
QMM1	334	832	9
QML1	550	882	60
QLH1	95	740	38
QLM1	410	1421	1065
QLL1	1389	1282	13 805

Results for DBLP (cont.)

query	signature	join	retrieved el.
QHH2	90	763	1
QHM2	352	942	1
QHL2	582	966	1
QMH2	130	822	1
QMM2	376	1327	9
QML2	602	1220	60
QLH2	142	1159	38
QLM2	450	1664	1065
QLL2	2041	1589	13 805

Unordered query tree

Given a query tree *Q* and an XML data tree *D*, the tree inclusion of *Q* in *D* is identified by a total mapping from nodes in *Q* to some nodes in *D*, such that the ancestor-descendant structural relationships between nodes in *Q* are satisfied by the corresponding nodes in *D* – the sibling relationships are not considered.

We implicitly consider a *week inclusion* of *Q* in *D*:

parent-child relationships in *Q* are satisfied by **ancestor-descendant** relationships in *D*.

Evaluation

- Let D be an ordered and Q an unordered labeled trees
- Suppose the data tree D and the query tree Q specified by signatures:

$$sig(D) = \langle d_1, post(d_1); d_2, post(d_2); \ldots ; d_m, post(d_m) \rangle$$

$$sig(Q) = \langle q_1, post(q_1); q_2, post(q_2); \ldots ; q_n, post(q_n) \rangle$$

Evaluation (cont)

- on the level of node names, an ordered set of indexes $S=\{s_1, s_2, \ldots, s_n\}$ exists, such that $1= s_i = n$ and $d_{si} = q_i$, for $i=1, \ldots, n;$
- for all pairs of entries i and j,

  $i,j = 1, 2, \ldots, |Q|-1$ and $i+j = |Q|$:

  if $post(q_{i+j}) < post(q_i)$ then

  $post(d_{s(i+j)}) < post(d_{s(i)})$ and $s_{i+1} > s_i$

Approaches

- **permutation**: consider all and only such alternatives of Q, satisfying the ancestor-descendent relationships;
- **decomposition**:

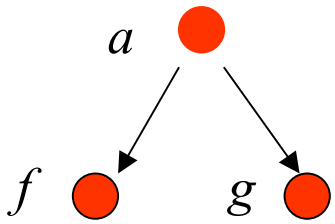
  - decompose the query into a set of paths

  - determine inclusions of the paths

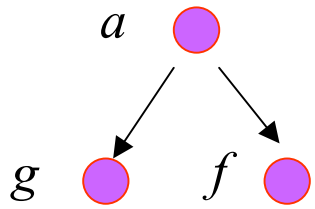
  - find structural consistent alternatives

Example

Query tree

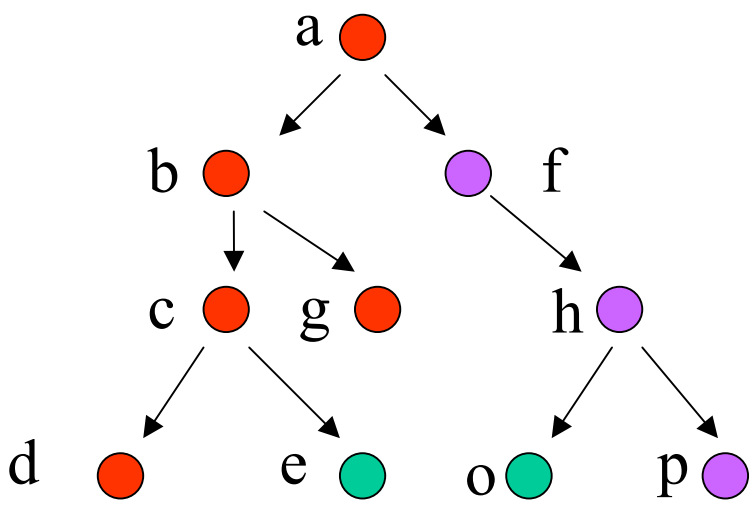


Query permutation



Path Decomposition:

Structurally consistent paths



P1: a,b,c,d
P2: a,b,g
P3: f,h,p

Only P1 and P2 are structurally consistent

Future directions

- **ranking** of results and **similarity** search
- **unordered** query trees
- **searching for structures** of a set (bag) of nodes
- **searching for nodes** (data) structured in a specific way
- any combination of the above