Web Data Models

XPath: Evaluation

Silviu Maniu

UNIVERSITÉ PARIS SUD

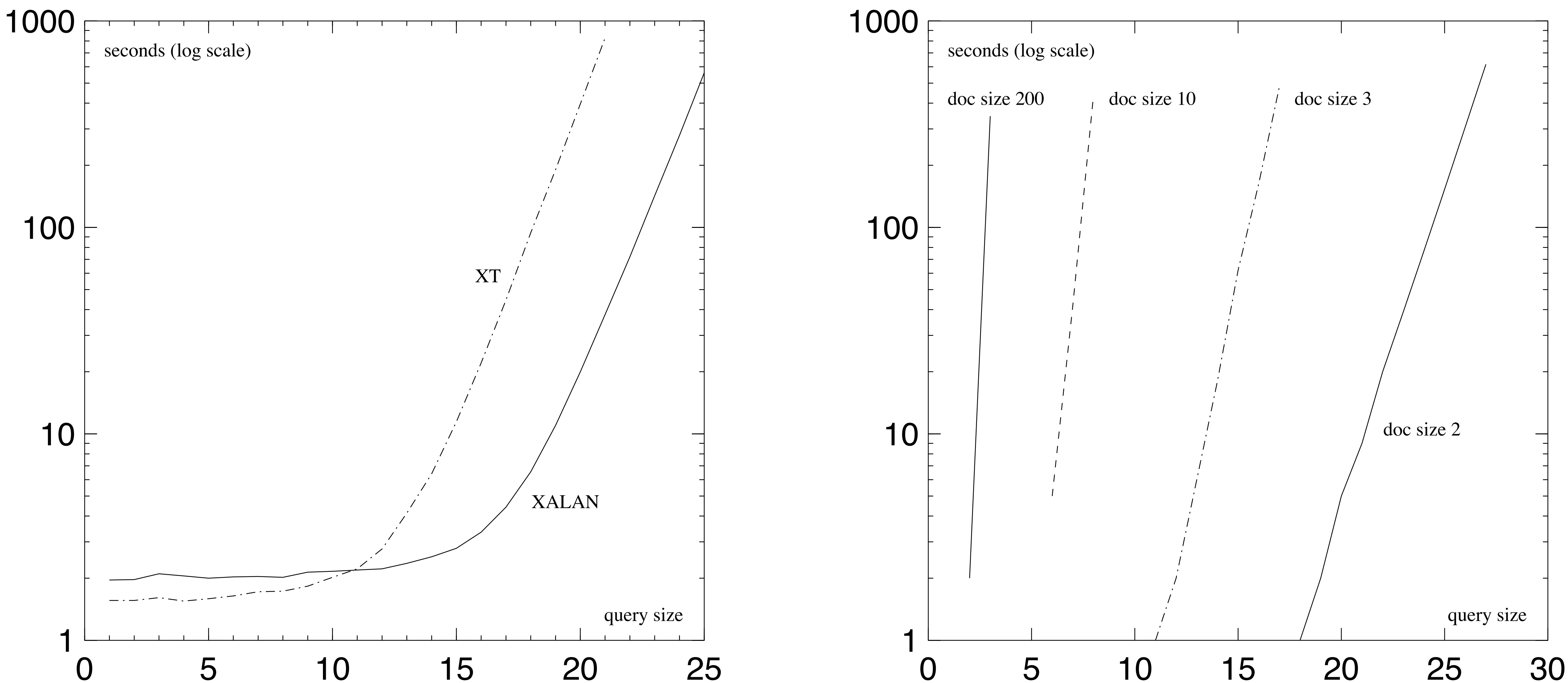
Comprendre le monde, construire l'avenir

université PARIS-SACLAY

XPath: Performance

- XPath is a navigational language — specifies how the XML documents should be traversed
- **Main issue**: big volume of nodes can be extracted via XPath, so efficient processing is still an ongoing challenge

XPath: Performance



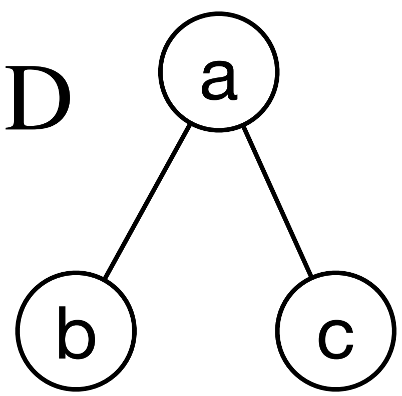
Gottlob, Koch, Pichler “Efficient Algorithms for Processing XPath Queries”, VLDB 2002

XPath: Performance

Why?

$\mathbf{Q}$:= `child::*/parent::*/child::*/parent::*/child::*`

D

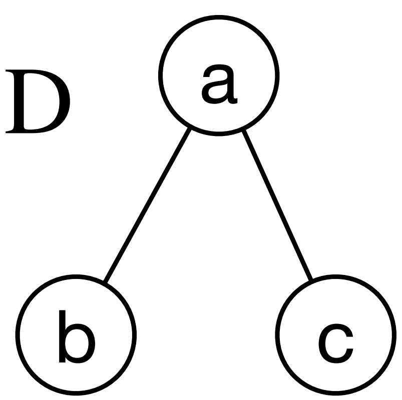


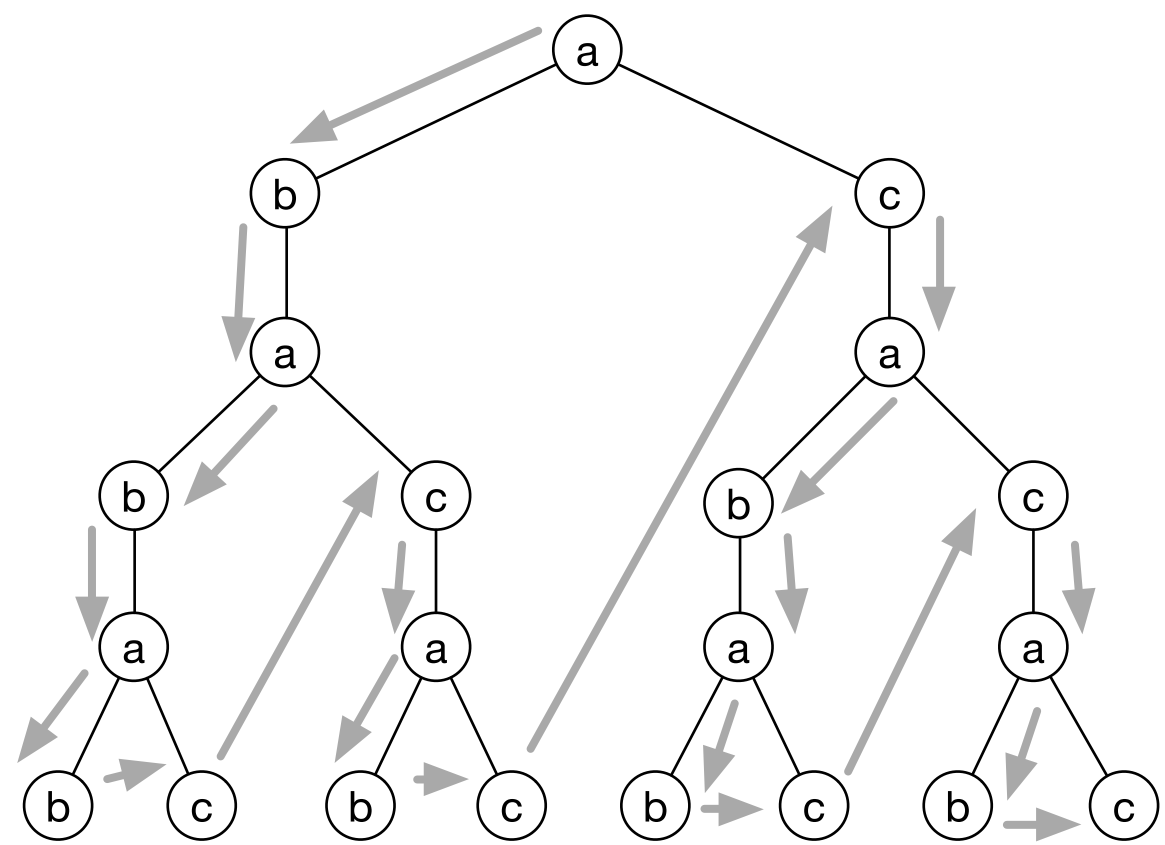
XPath: Performance

Why?

$\mathbf{Q}$:= `child::*/parent::*/child::*/parent::*/child::*`

D





$$O(|D|^{|Q|})$$

XPath: Performance

Why?

```
procedure process-location-step(n_0, Q)
/* n_0 is the context node;
   query Q is a list of location steps */
begin
   node set S := apply Q.first to node n_0;
   if (Q.tail is not empty) then
      for each node n ∈ S do
         process-location-step(n, Q.tail);
end
```

$O(|D|^{|Q|})$

Gottlob, Koch, Pichler “Efficient Algorithms for Processing XPath Queries”, VLDB 2002

Lecture Outline

- evaluating simple paths
- evaluating Core XPath
- evaluating Full XPath

XPath: Simple Paths

- Simple paths are of the form:

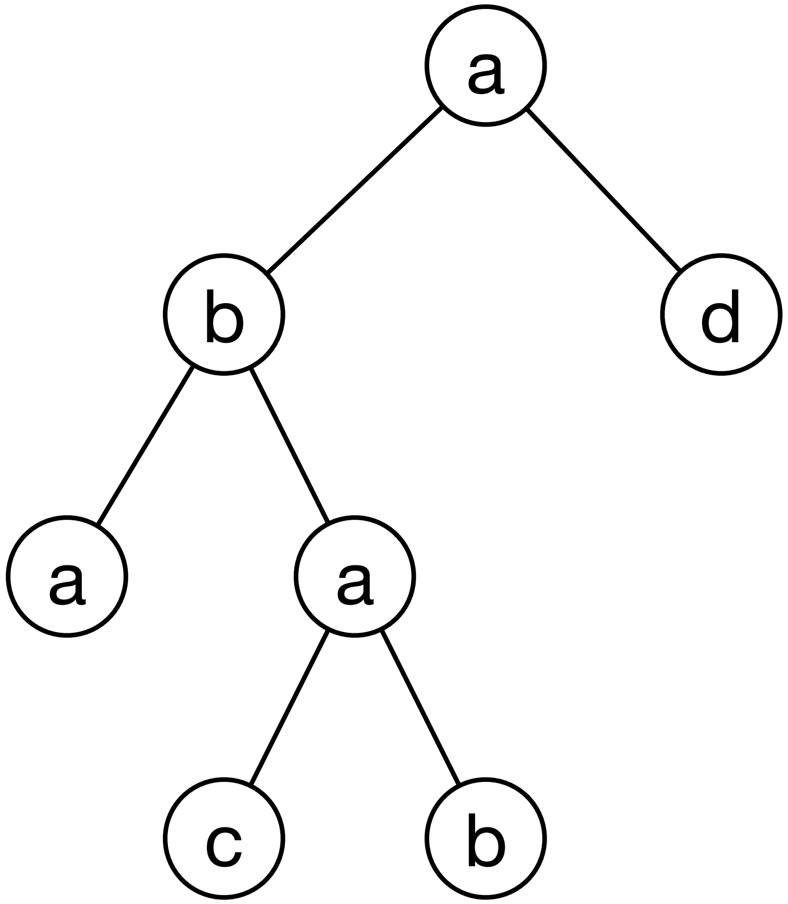
```
//tag_1/tag_2/…/tag_n

//tag_1/tag_2/…/tag_n-1/text()
```

- Can be evaluated in a single pre-order traversal (by using a stack)

XPath: Simple Paths

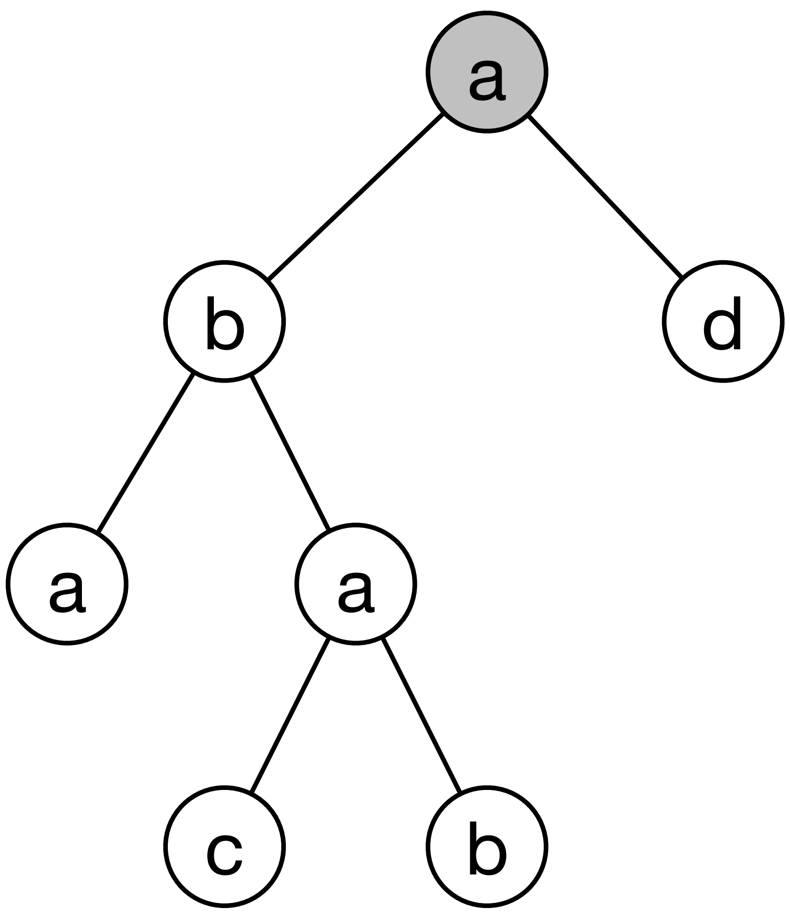
Q: `//a/b`



XPath: Simple Paths

Q: `//a/b`

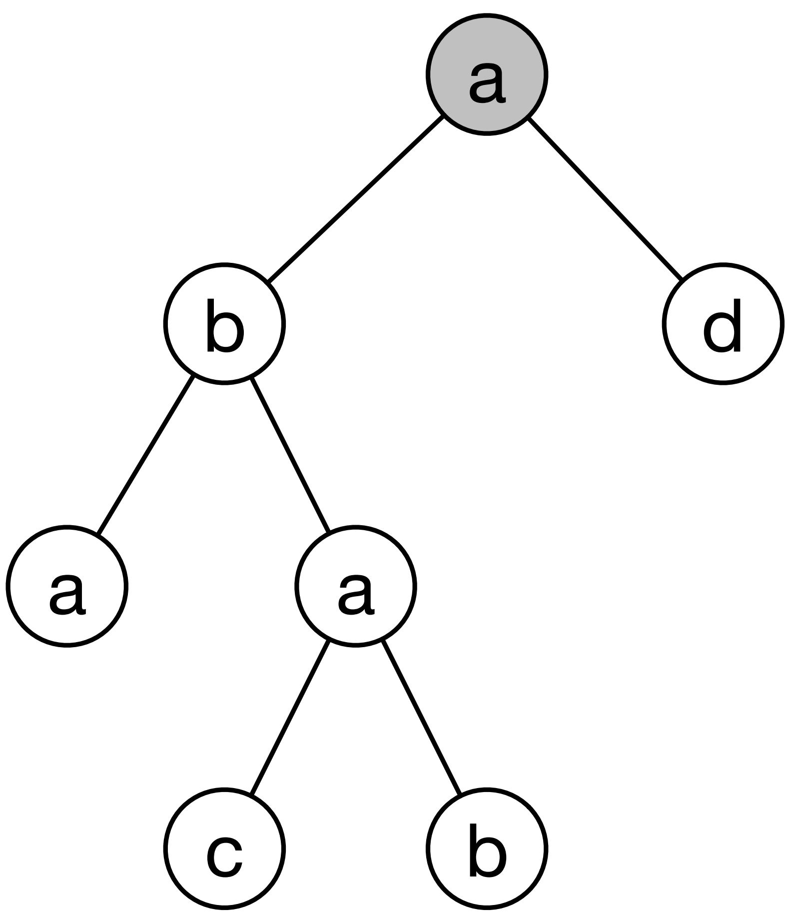
p = 1



XPath: Simple Paths

Q: **//a/b**

p = p+1 = 2



Seq

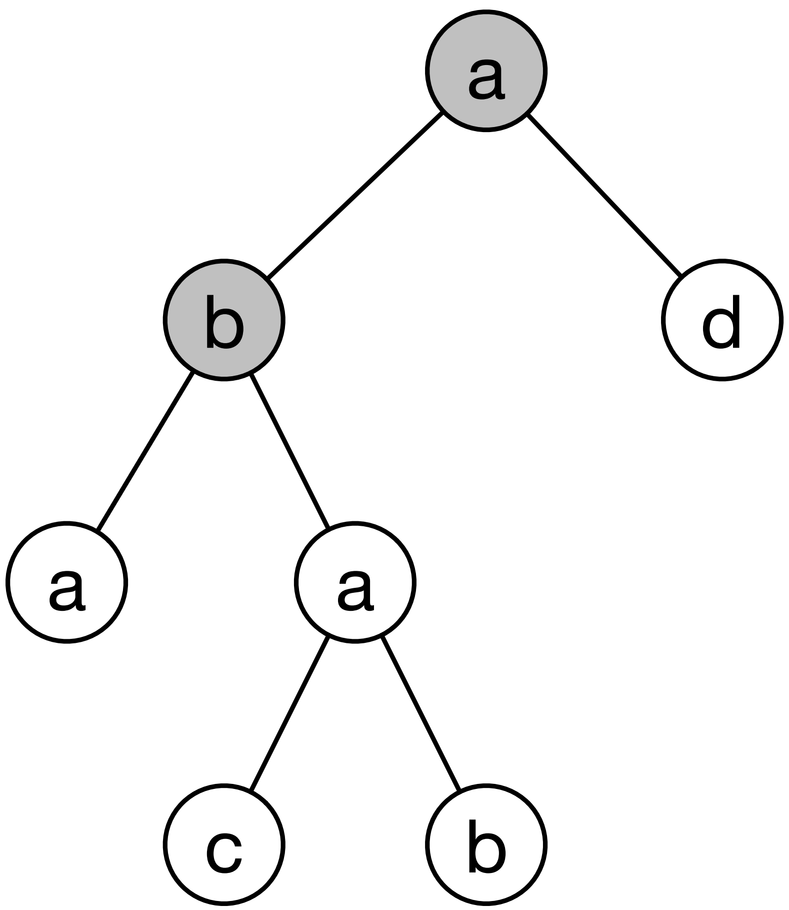
<a>

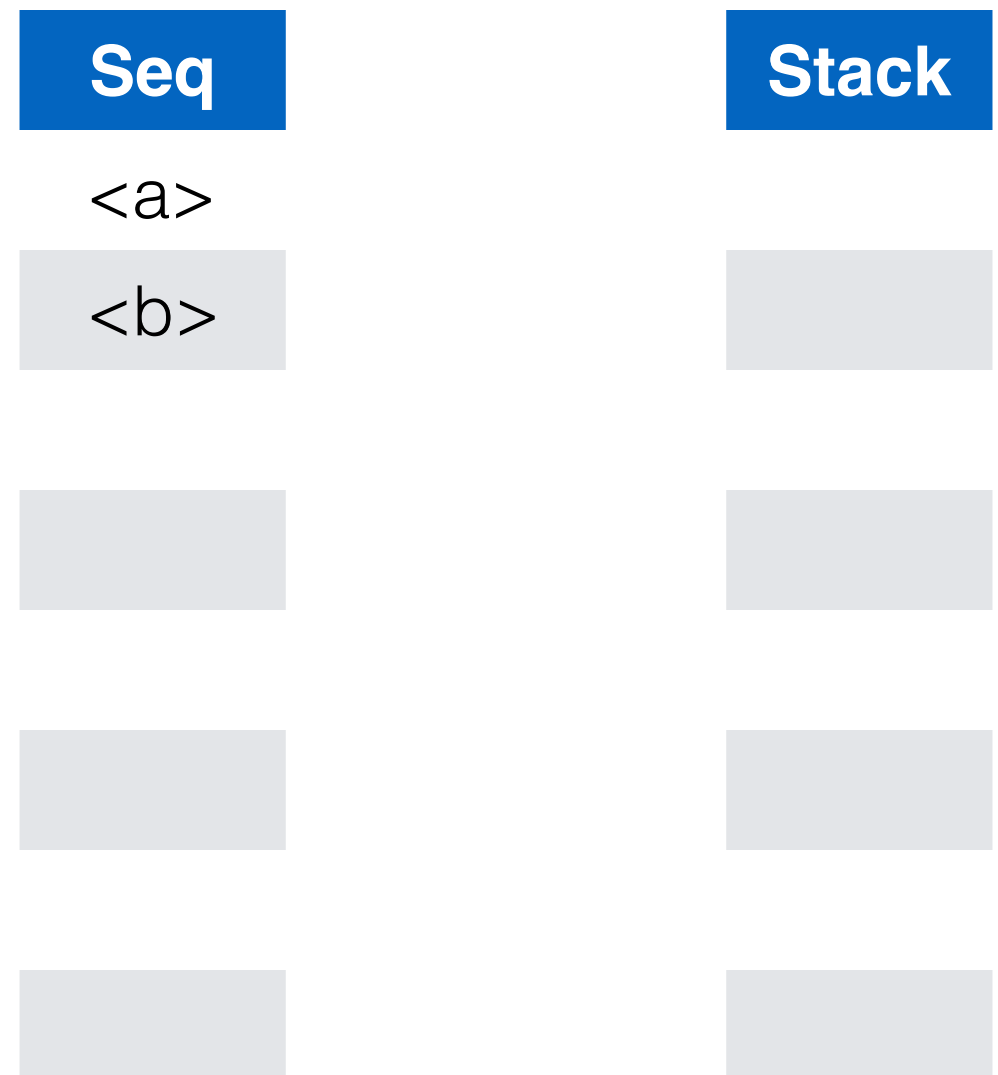
Stack

XPath: Simple Paths

Q: //a/b

p = 2



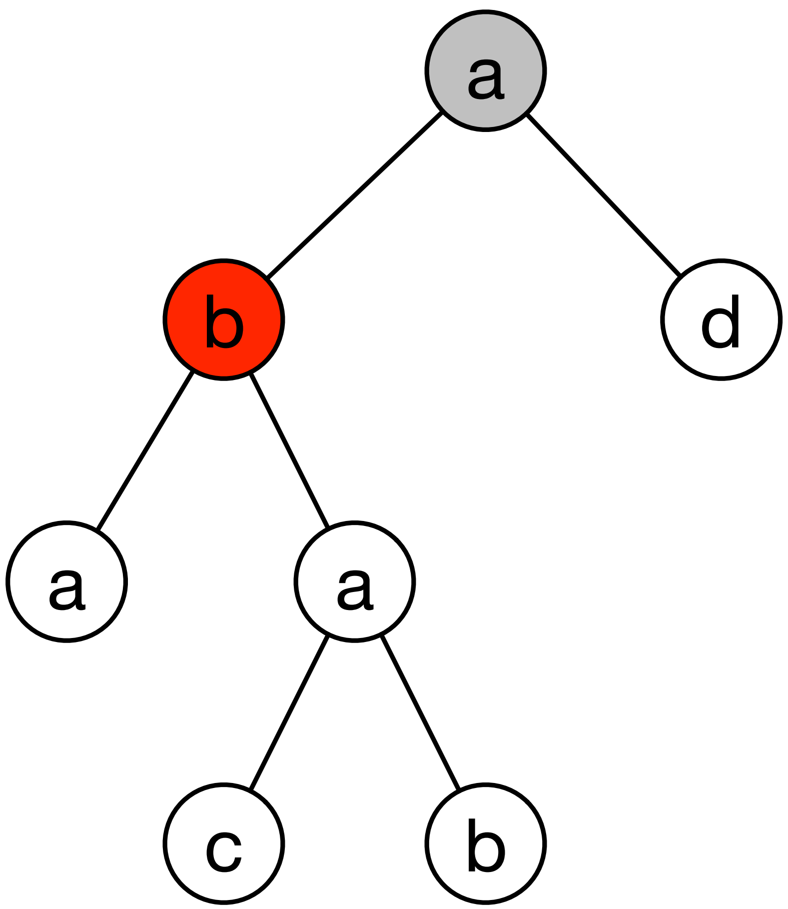


Match!

XPath: Simple Paths

Q: //a/b

p = 1



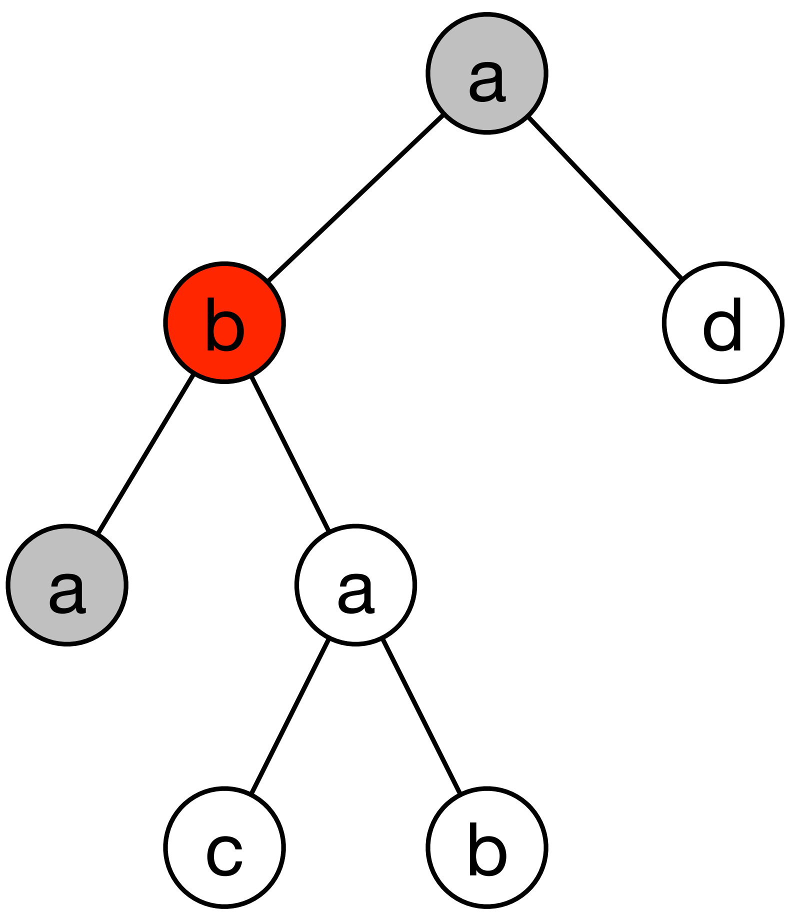
Seq	Stack
<a>	
<b>	
	2

Match!

XPath: Simple Paths

Q: //a/b

p = 1

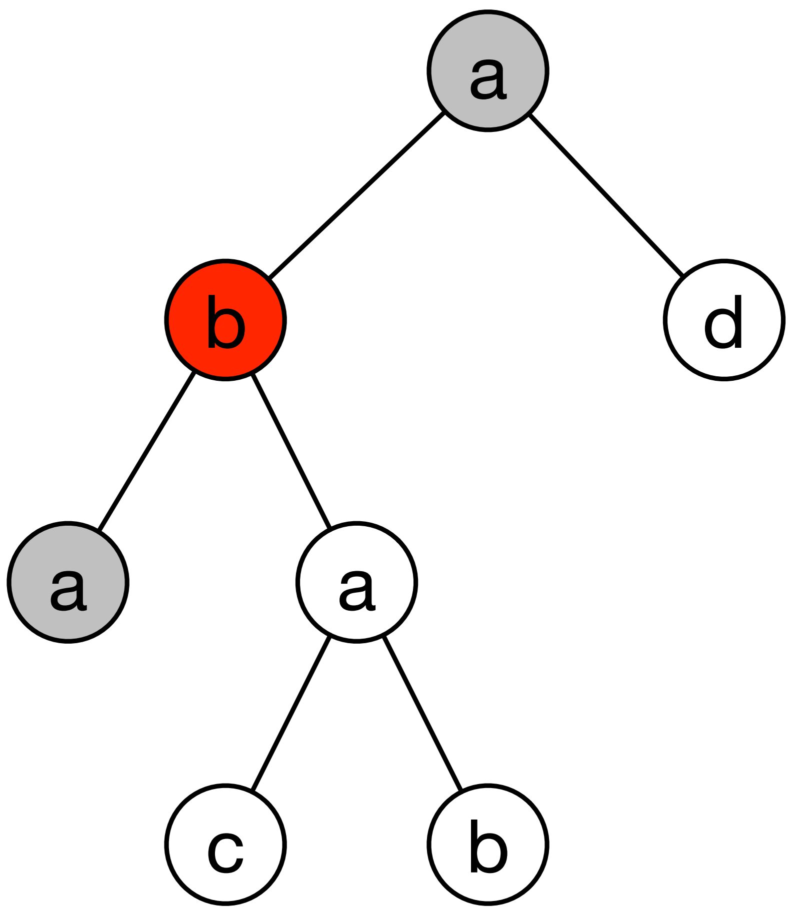


Seq	Stack
<a>	
<b>	
<a>	
	2

XPath: Simple Paths

Q: `//a/b`

p = p+1 = 2

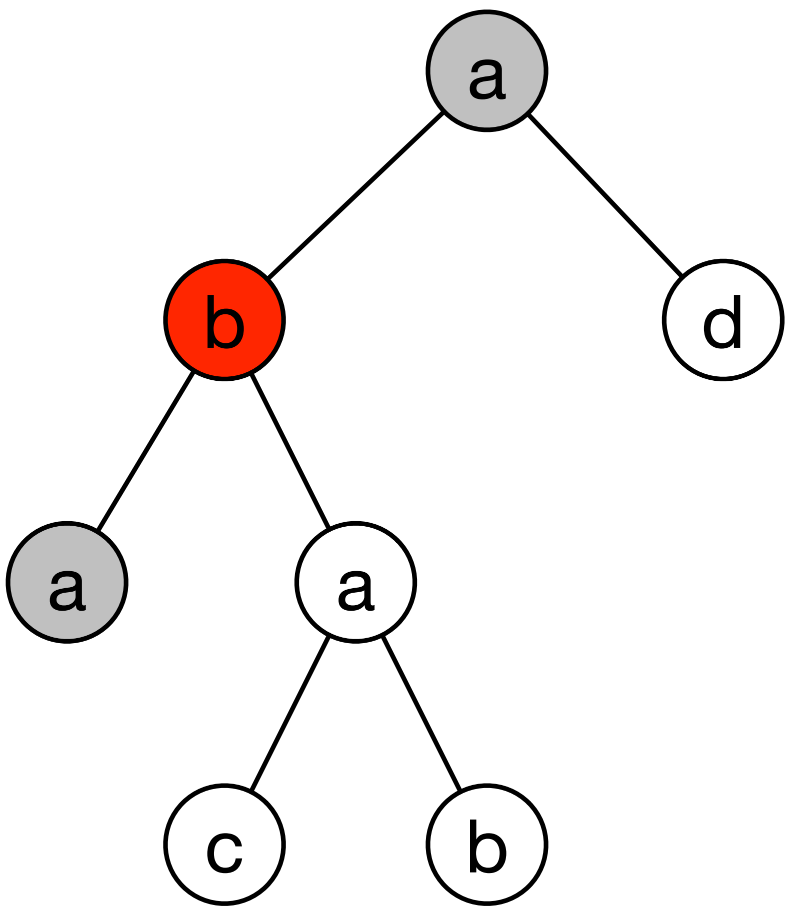


Seq	Stack
<a>	
<b>	
<a>	
	1
	2

XPath: Simple Paths

Q: `//a/b`

p = 2

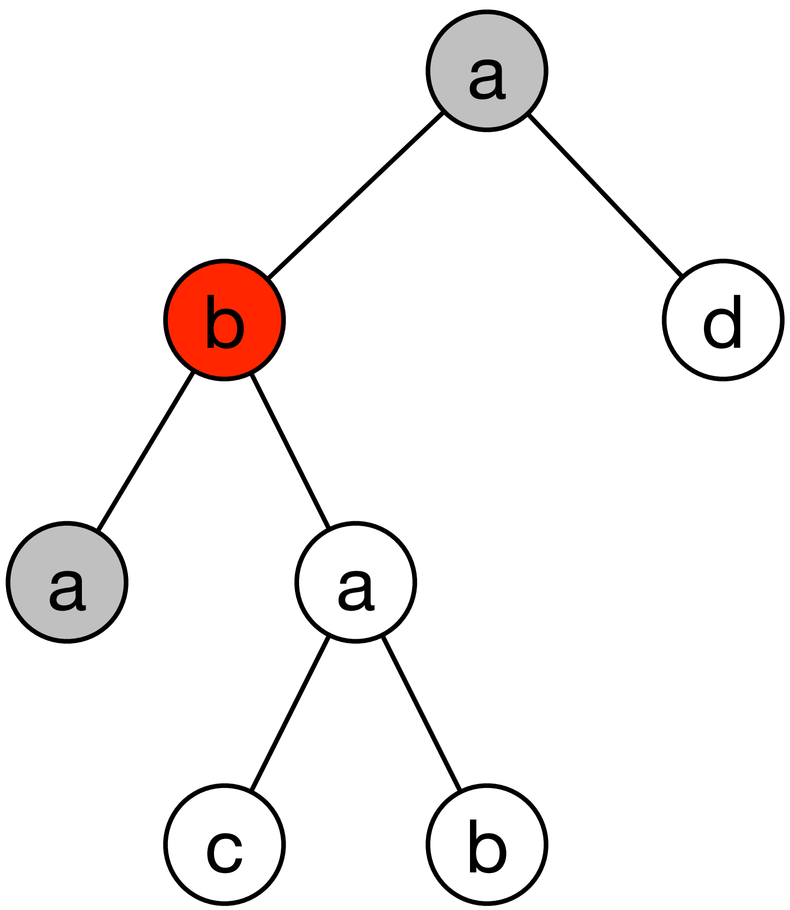


Seq	Stack
<a>	
<b>	
<a>	
	
	1
	2

XPath: Simple Paths

Q: //a/b

p = pop() = 1

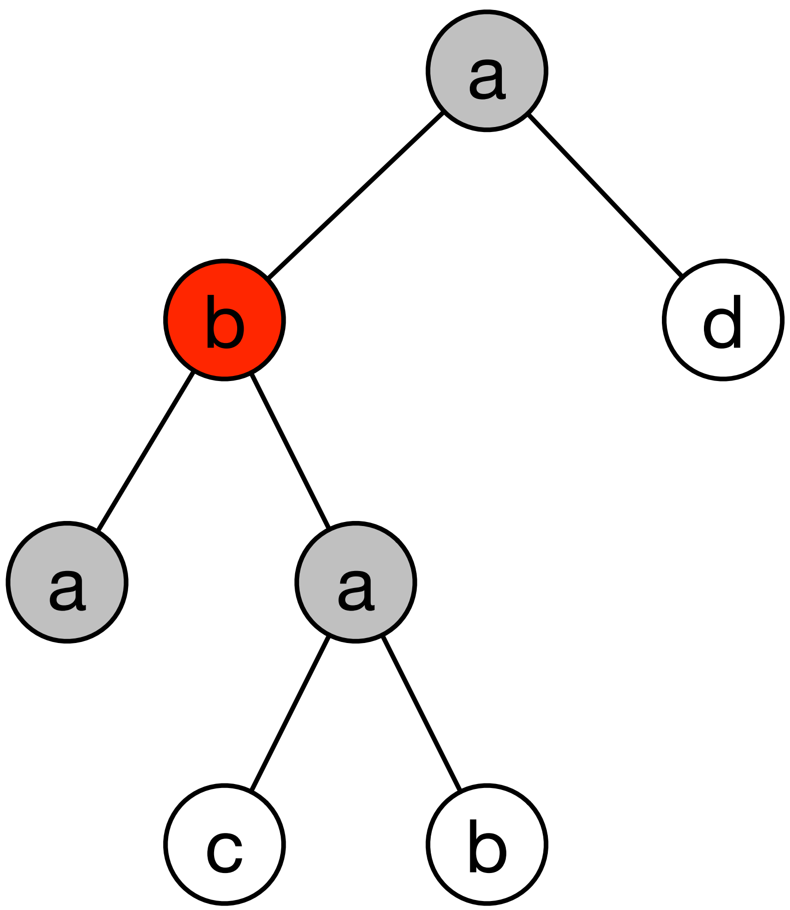


Seq	Stack
<a>	
<b>	
<a>	
	
	2

XPath: Simple Paths

Q: **//a/b**

p = 1

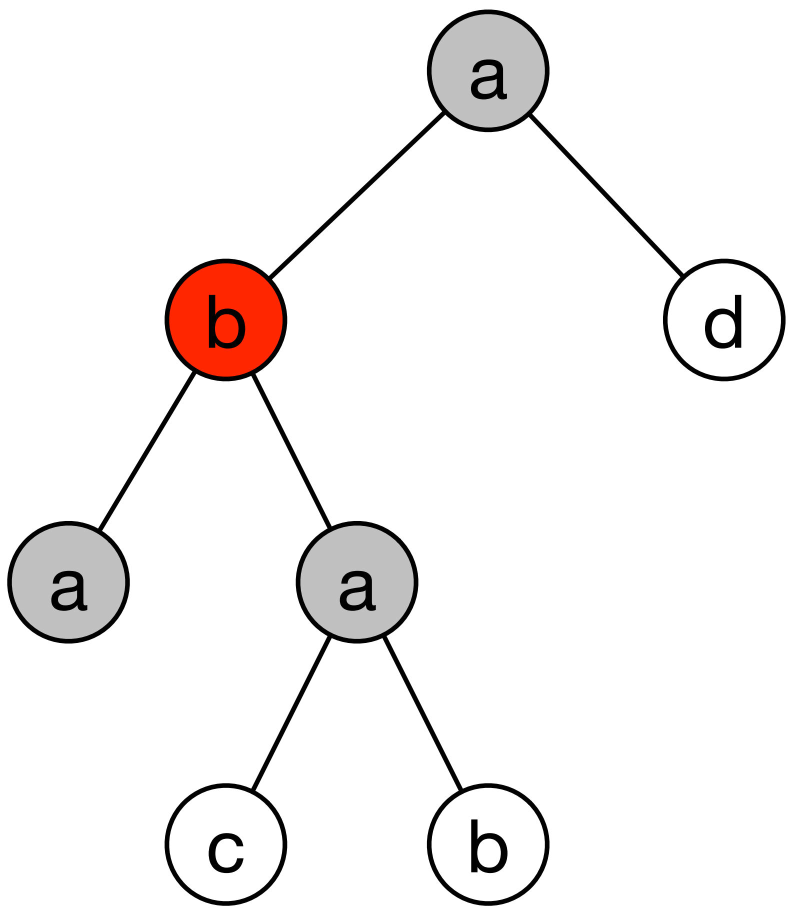


Seq	Stack
<a>	
<b>	
<a>	
	
<a>	
	2

XPath: Simple Paths

Q: //a/b

p = p+1 = 2

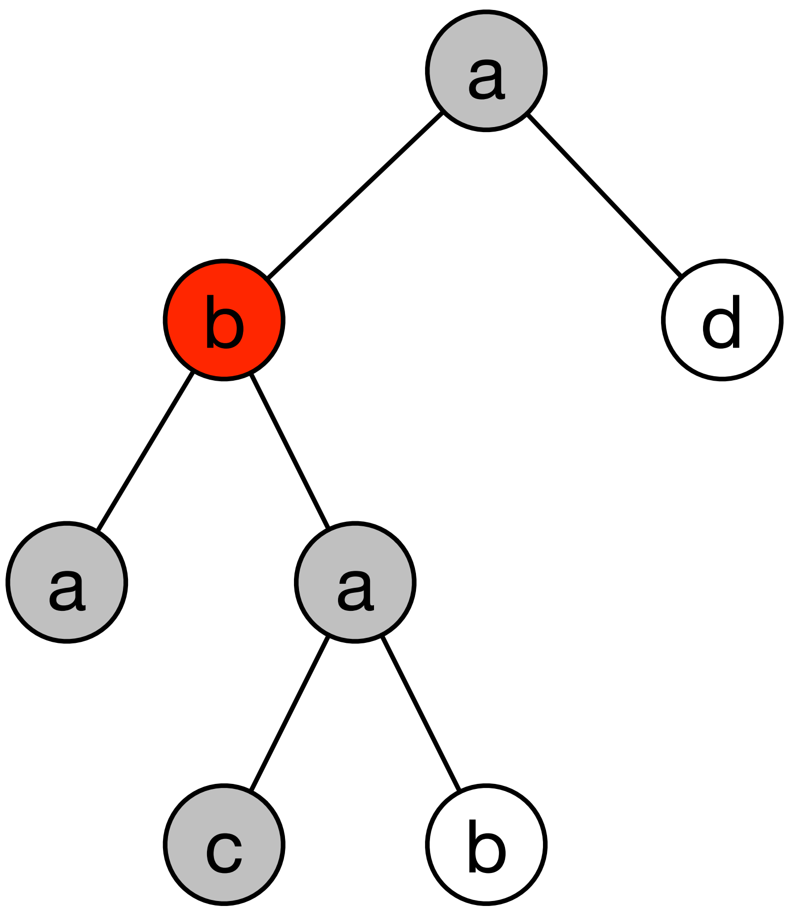


Seq	Stack
<a>	
<b>	
<a>	
	
<a>	
	1
	2

XPath: Simple Paths

Q: //a/b

p = 2

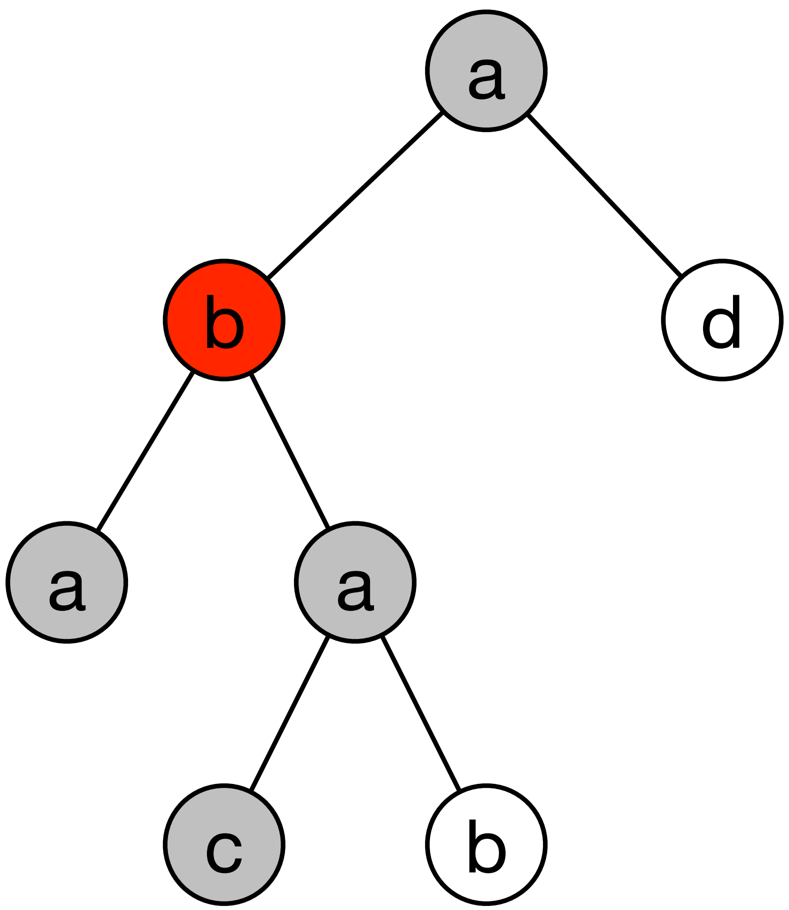


Seq	Stack
<a>	
<b>	
<a>	
	
<a>	
<c>	
	1
	2

XPath: Simple Paths

Q: //a/b

p = pop() = 1

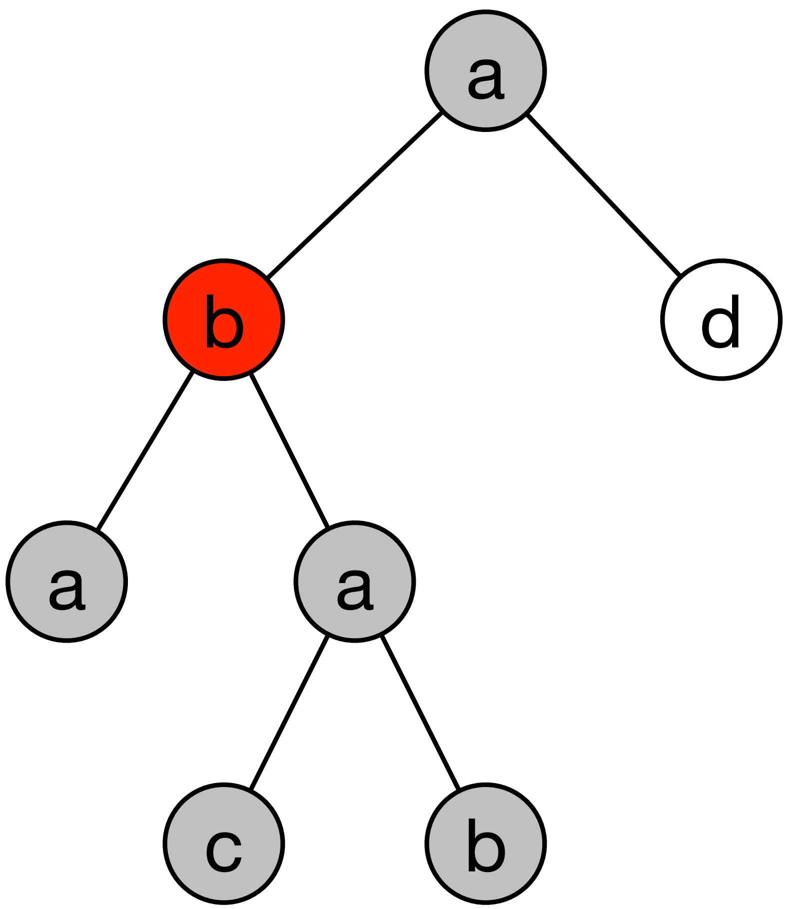


Seq	Stack
<a>	
<b>	
<a>	
	
<a>	
<c>	
</c>	
	2

XPath: Simple Paths

Q: //a/b

p = 2



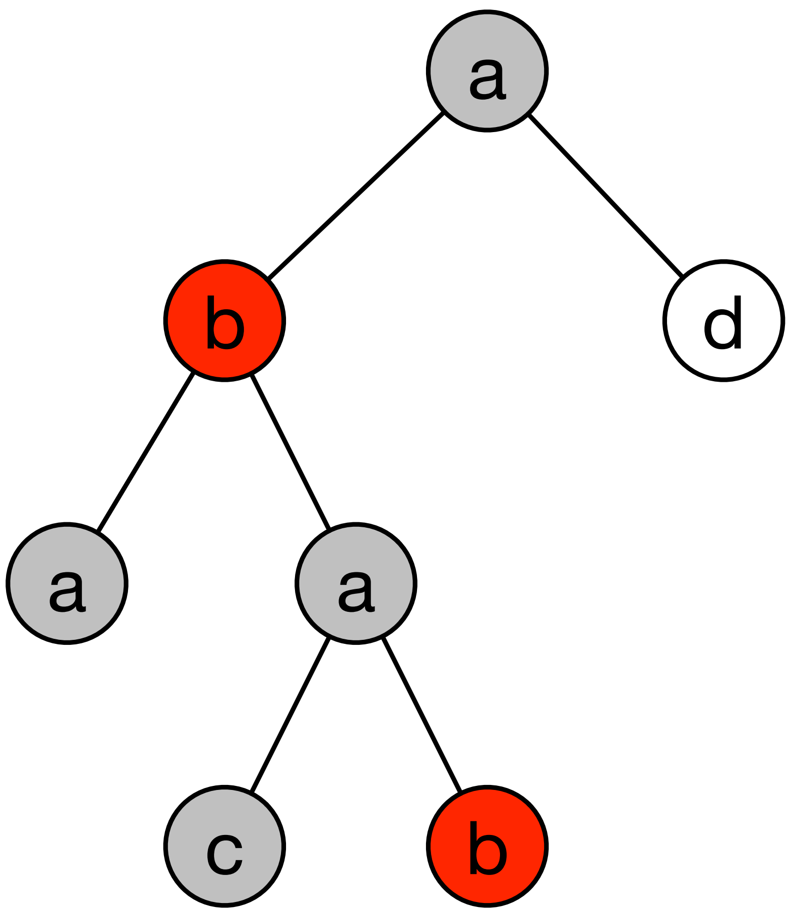
Seq	Stack
<a>	
<b>	
<a>	
	
<a>	
<c>	
</c>	
<b>	2

Match!

XPath: Simple Paths

Q: //a/b

p = 1



Seq	Stack
<a>	
<b>	
<a>	
	
<a>	
<c>	
</c>	
<b>	2

Match!

XPath: Simple Path Evaluation Complexity

- The algorithm is linear in the size of the document $O(|D|)$
- Moreover, it can be implemented as a streaming algorithm
- Simple path evaluation can be implemented on top of SAX (Simple API for XML)

XPath: Simple Path Evaluation In SAX

Algorithm (sketch):

1. **Initialization**: represent *path* query as an array for each step, maintain an array index *i* of the current step in the path, maintain a stack *S* of index positions

2. `startDocument`: empty stack S; i=1

3. `startElement`: if *path[i]* and element match, proceed to next step; otherwise, make a **failure transition**. Push *i* on *S*.

4. `endElement`: Pop old *i* from *S*.

5. `text`: If *path[i]=text*, we found a match. Otherwise, do nothing.

Failure Transitions

Example:

Q: **`//a/b/a/c/`** but we have seen **`//a/b/a/b`**

- postfix of we have seen is prefix of the query!

Q: `//`**`a/b`**`/a/c/`   `//a/b/`**`a/b`**

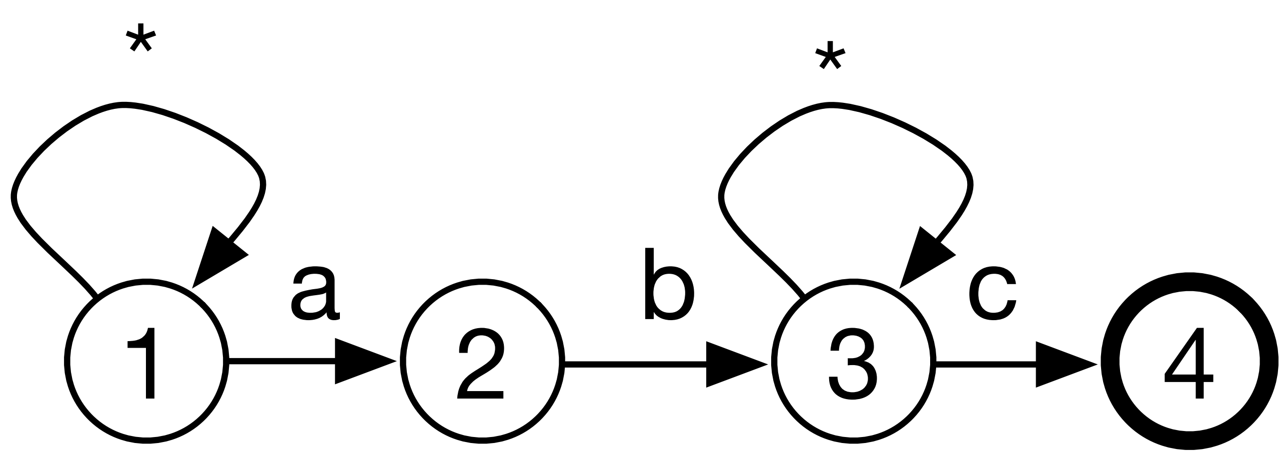
- this can be done via the Knuth-Morris-Pratt algorithm — linear string matching

Evaluation Using Automata

Principle: Use the XPath expression as a regular expression matching the paths of the tree.

Evaluation Using Automata

```
//a/b//c
```



Evaluation Using Automata

- dealing with * transitions is quite tricky
- transforming the NFA into a DFA has exponential blow-up
- good news: do not need to transform into DFA (lazy DFA)

Evaluation Using Automata

- dealing with * transitions is quite tricky
- transforming the NFA into a DFA has exponential blow-up
- good news: do not need to transform into DFA (lazy DFA)

Green, Gupta, Miklau, Onizuka, Suciu. “**Processing XML Streams with Deterministic Automata and Stream Indexes**” ACM TODS 29(4), 2004

XPath: Core XPath

Core XPath contains:

- all 12 axes
- all node tests (only element nodes)
- filters with logical operators: `and`, `or`, `not`

XPath: Bottom-up Evaluation of Core XPath

Set operations on nodes:

Operation	Objective
$\text{axis}(S_1) = S_2$	the node ids corresponding to the axis axis
$\cap(S_1, S_2) = S_3$	intersection of sets; for steps and `and`
$\cup(S_1, S_2) = S_3$	union of sets; for `or`
$-(S_1, S_2) = S_3$	difference of sets; for `not`
$T(\text{label}) = S_1$	set of node ids labelled label

XPath: Bottom-up Evaluation of Core XPath

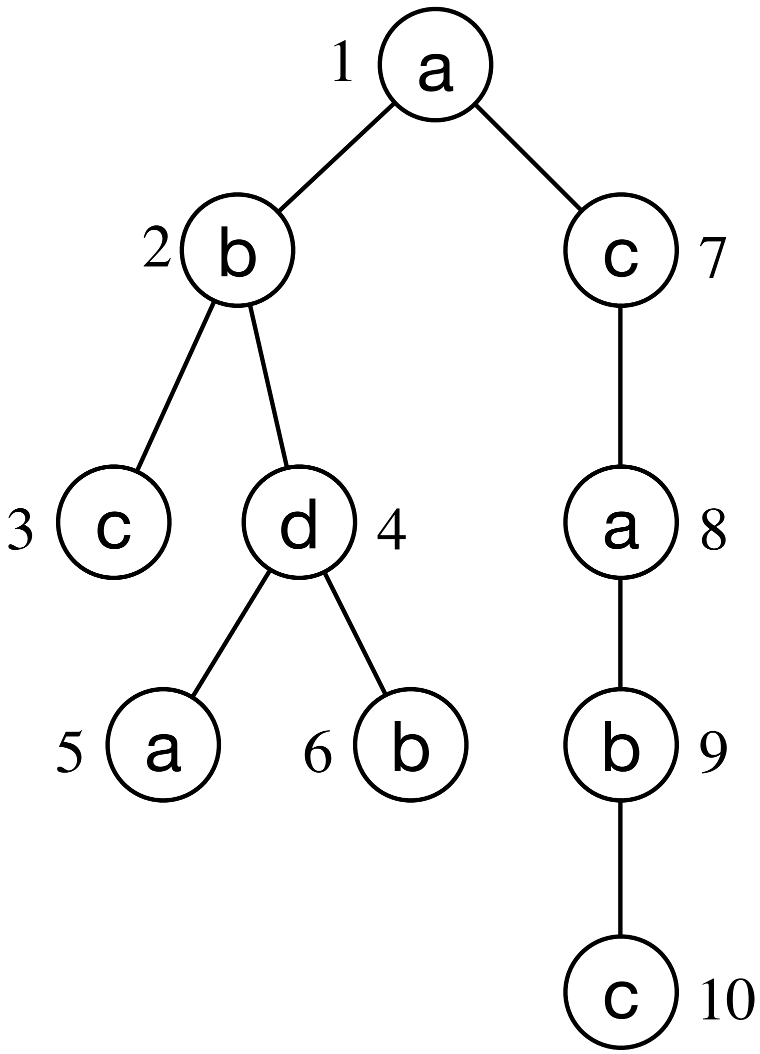
Algorithm (sketch):

1. Transform the query into a tree composed of set operations;

2. Starting at the root (or at the filters); evaluate the set operations bottom-up;

3. The final results are the nodes corresponding to node ids.

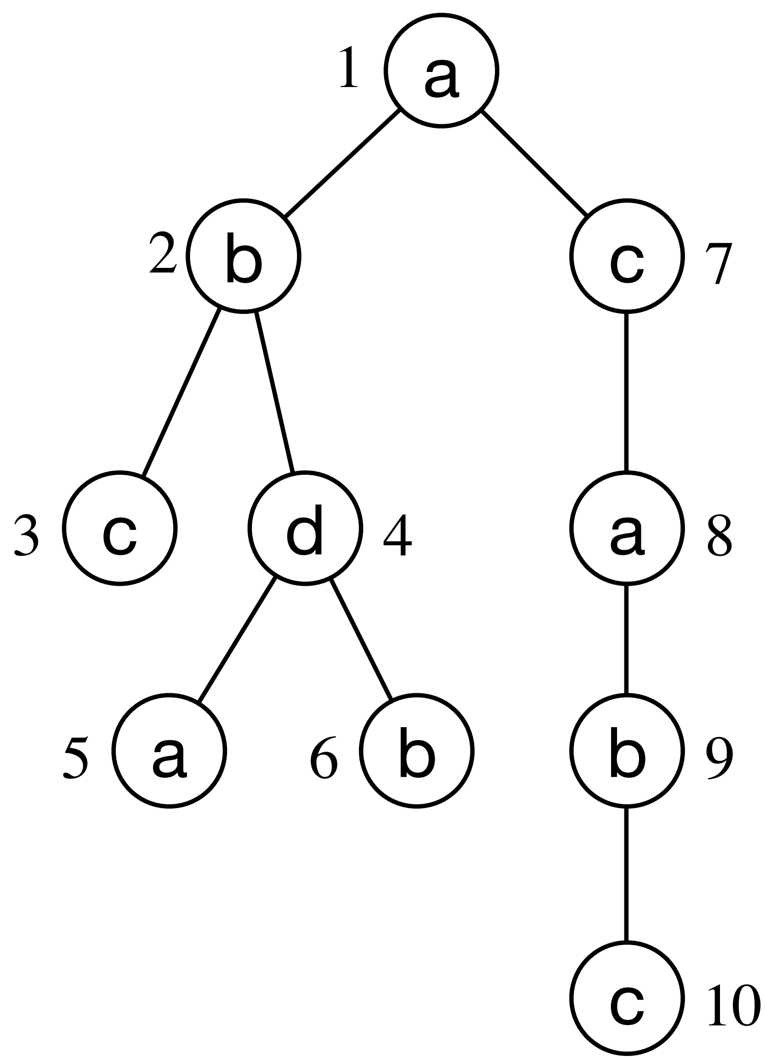
XPath: Bottom-up Evaluation of Core XPath



label	T(label)
a	{1,5,8}
b	{2,6,9}
c	{3,7,10}
d	{4}

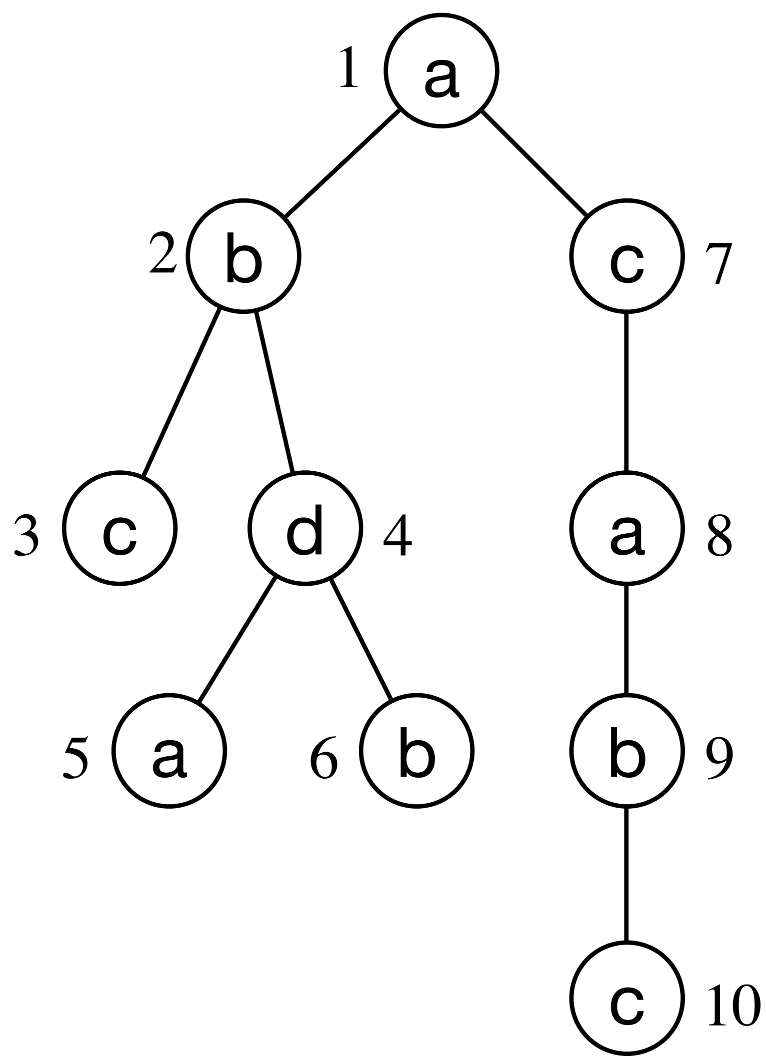
XPath: Bottom-up Evaluation of Core XPath

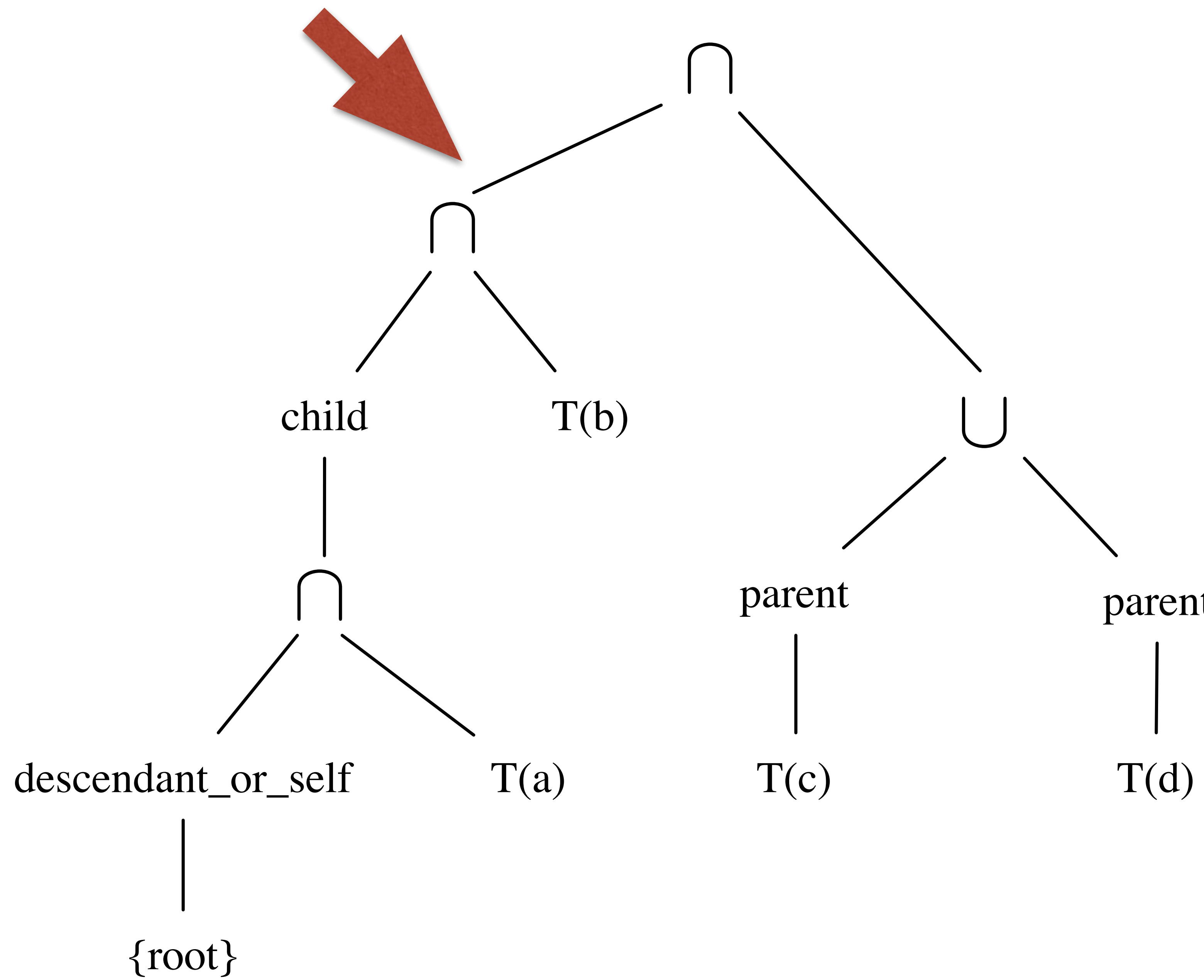
`/descendant_or_self::a/child::b[child::d or child::c]`



XPath: Bottom-up Evaluation of Core XPath

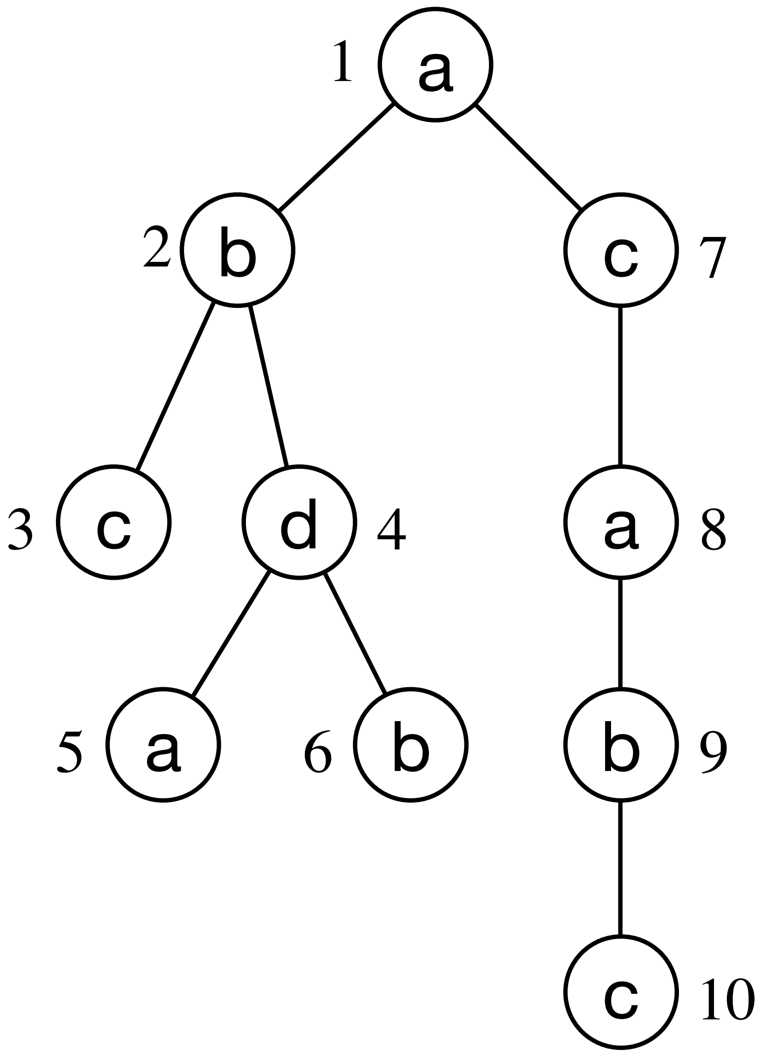
`/descendant_or_self::a/child::b[child::d or child::c]`

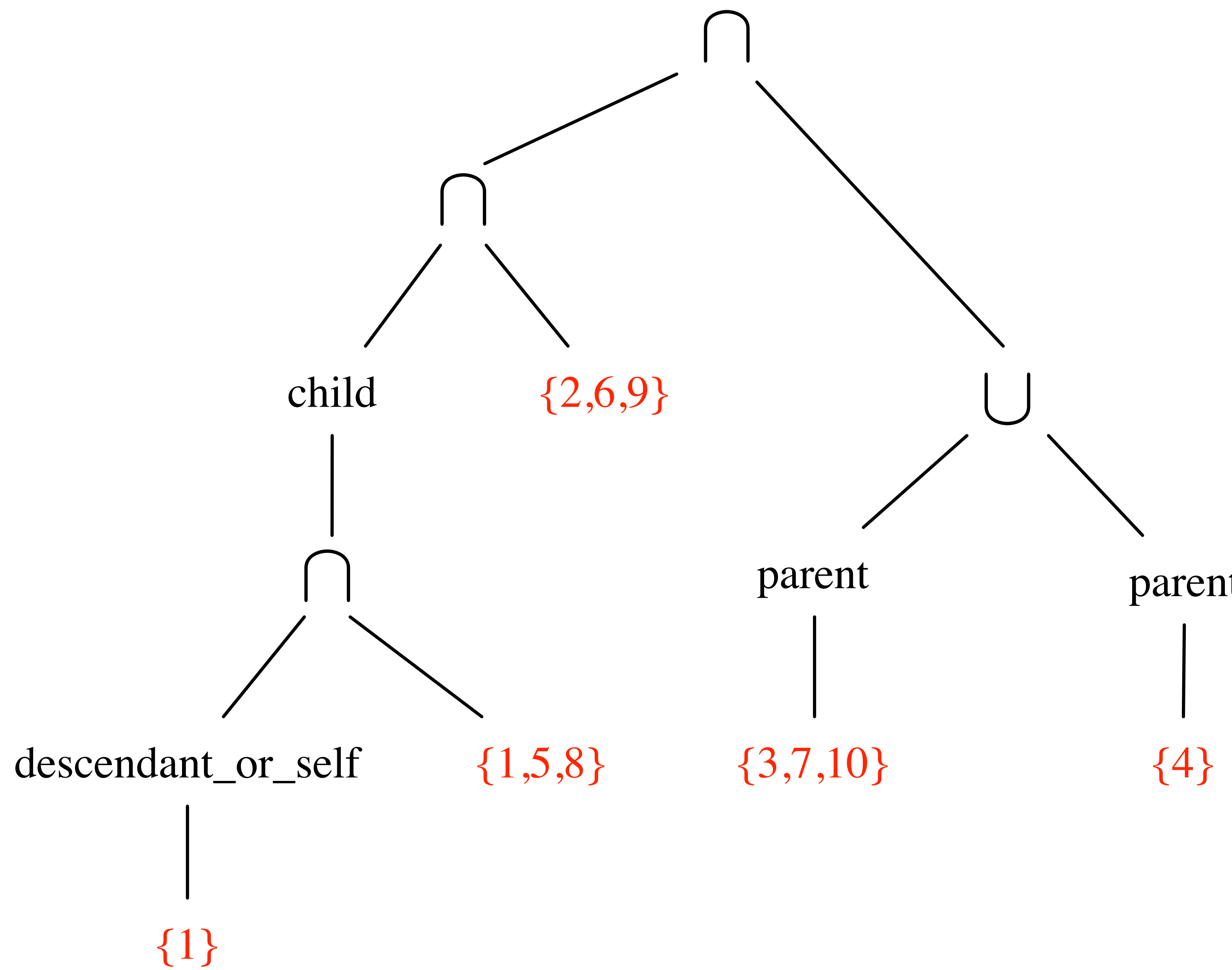




XPath: Bottom-up Evaluation of Core XPath

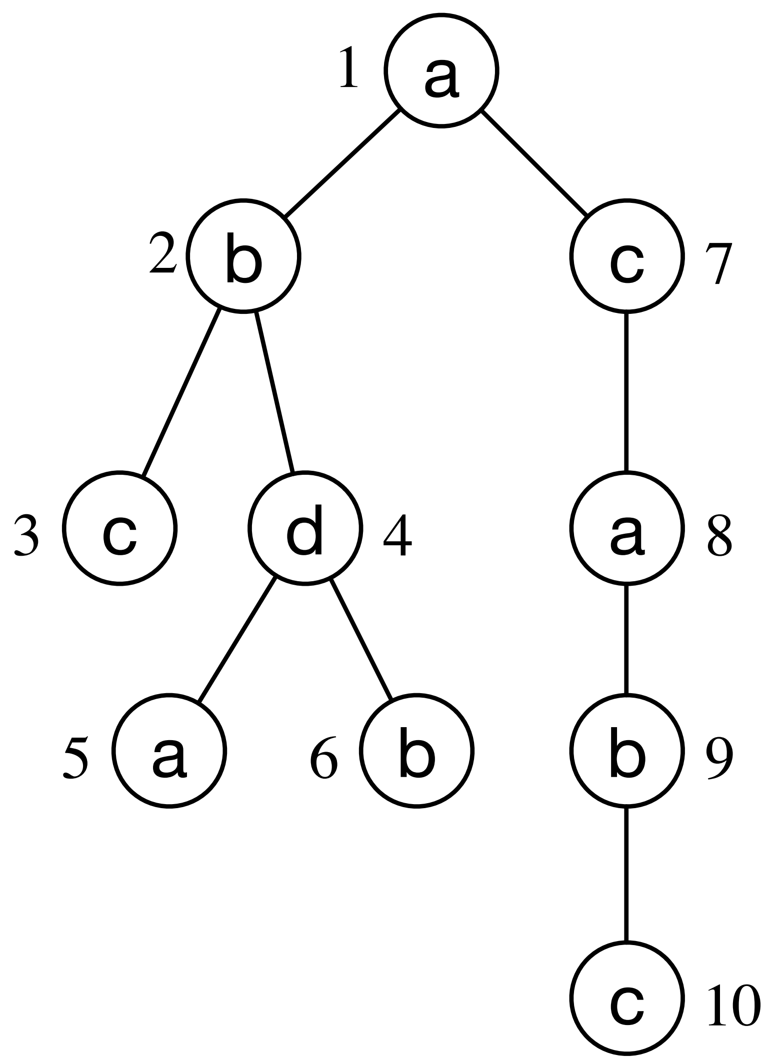
```
/descendant_or_self::a/child::b[child::d or child::c]
```

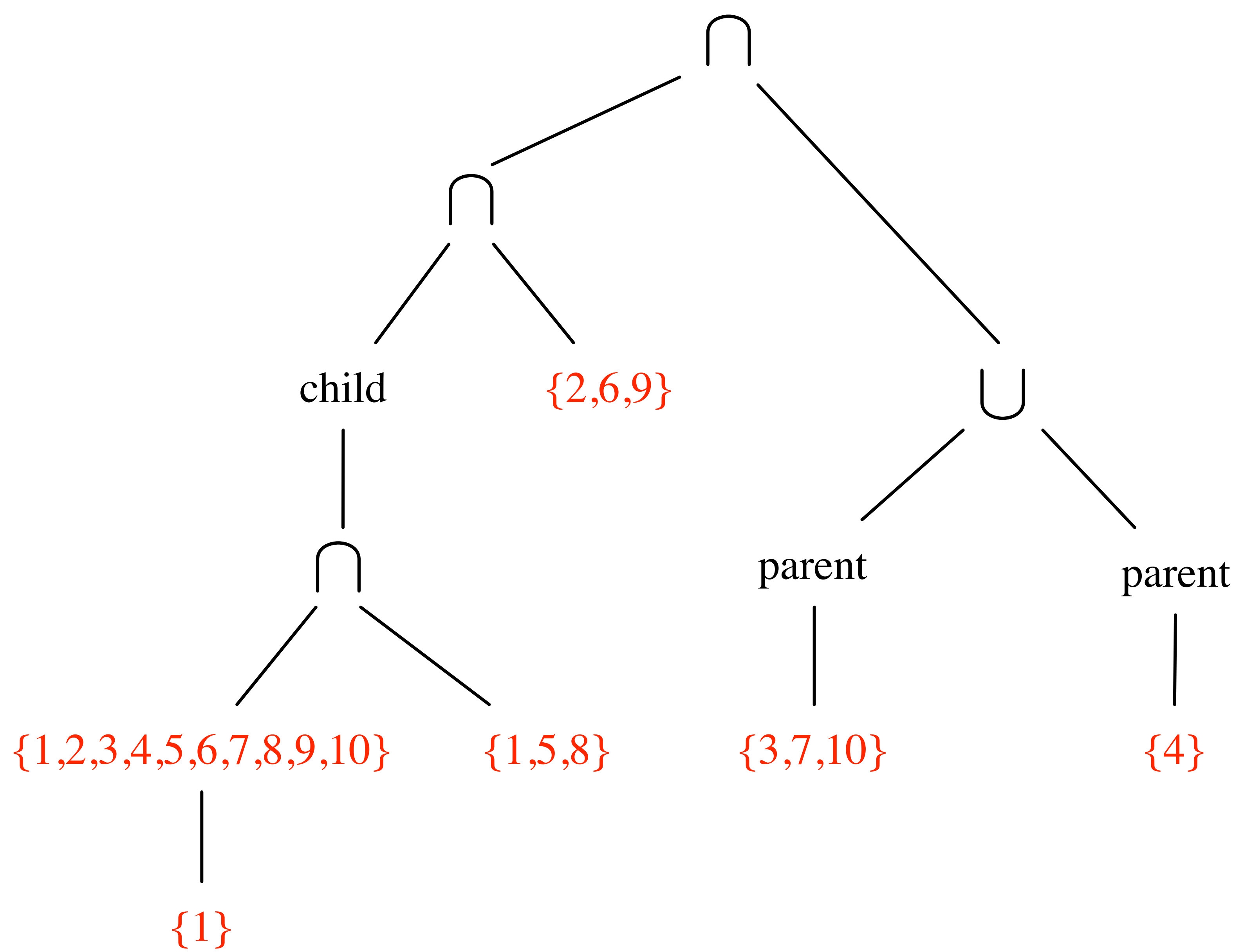




XPath: Bottom-up Evaluation of Core XPath

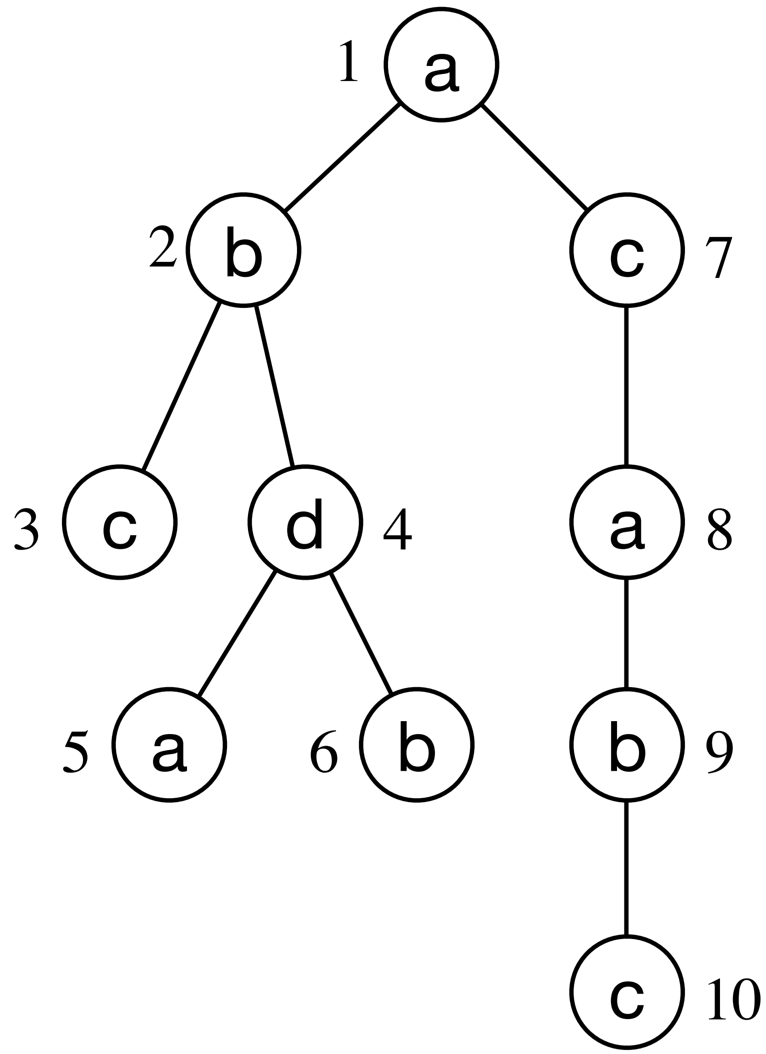
```
/descendant_or_self::a/child::b[child::d or child::c]
```

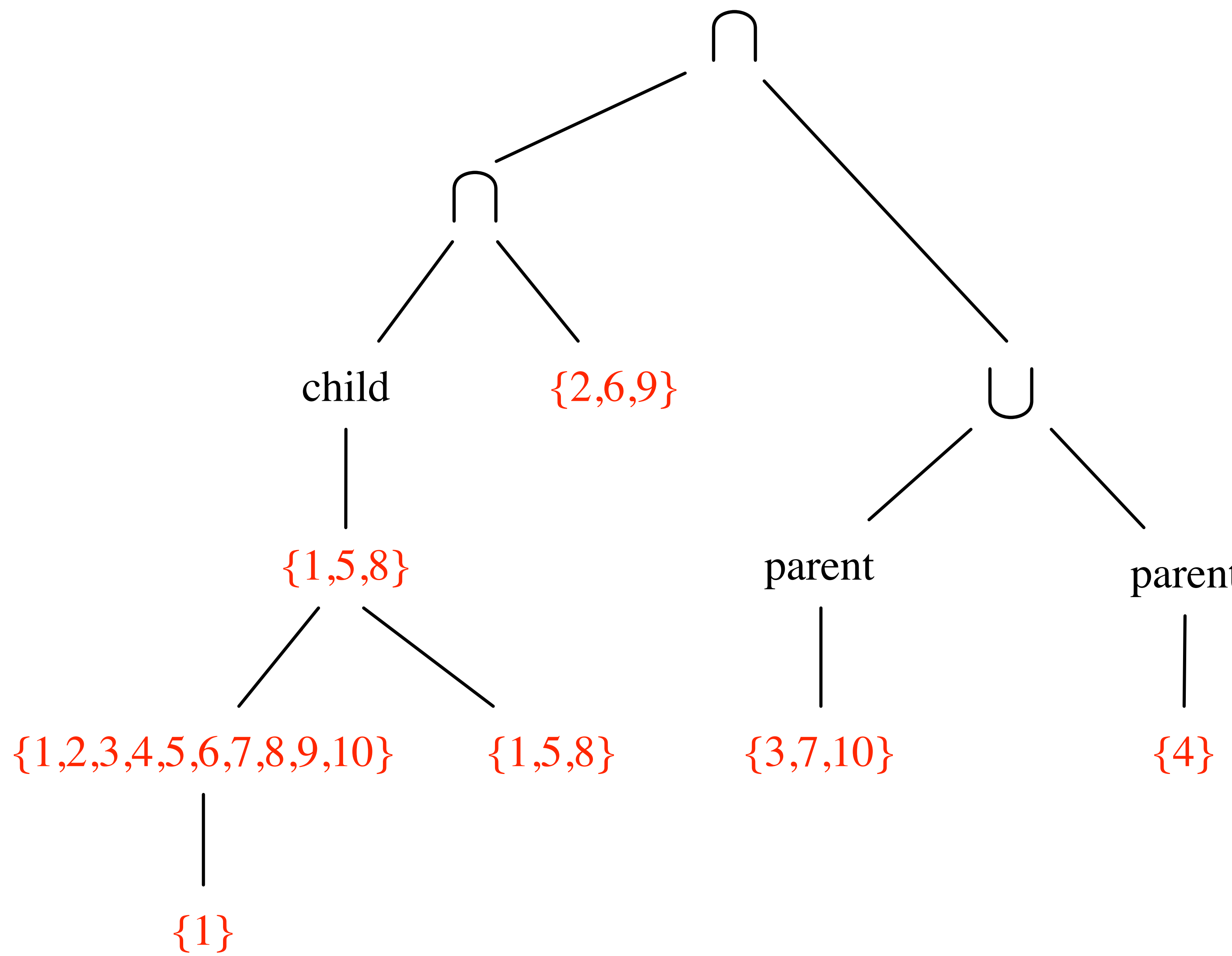




XPath: Bottom-up Evaluation of Core XPath

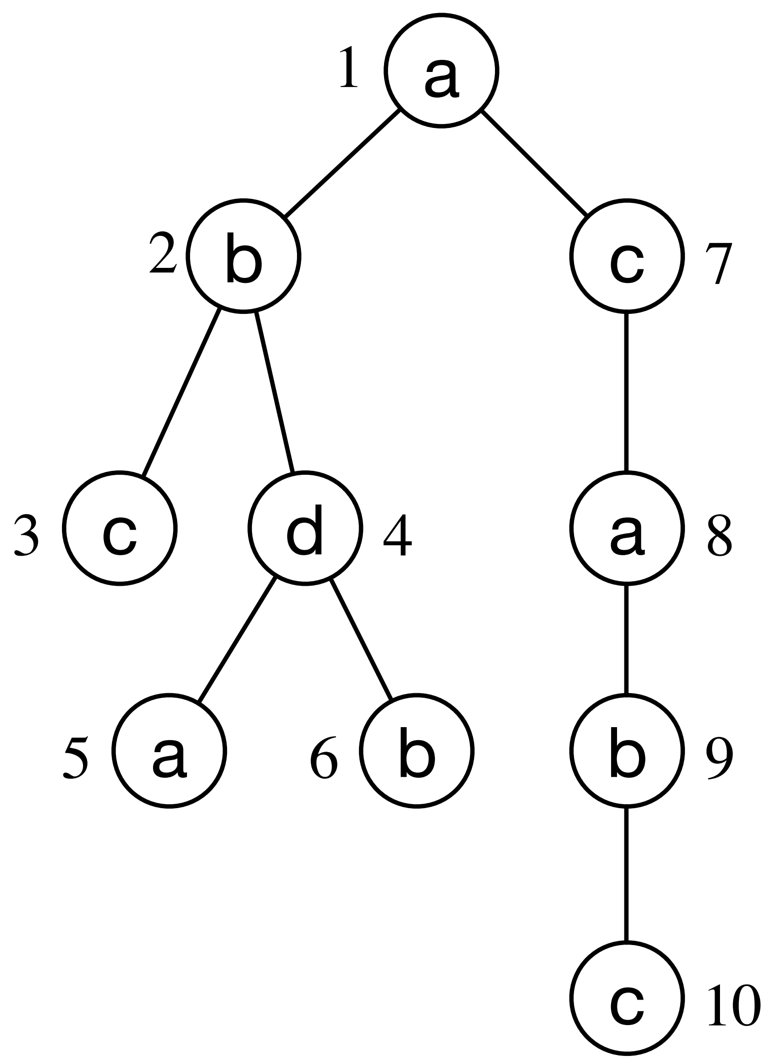
```
/descendant_or_self::a/child::b[child::d or child::c]
```

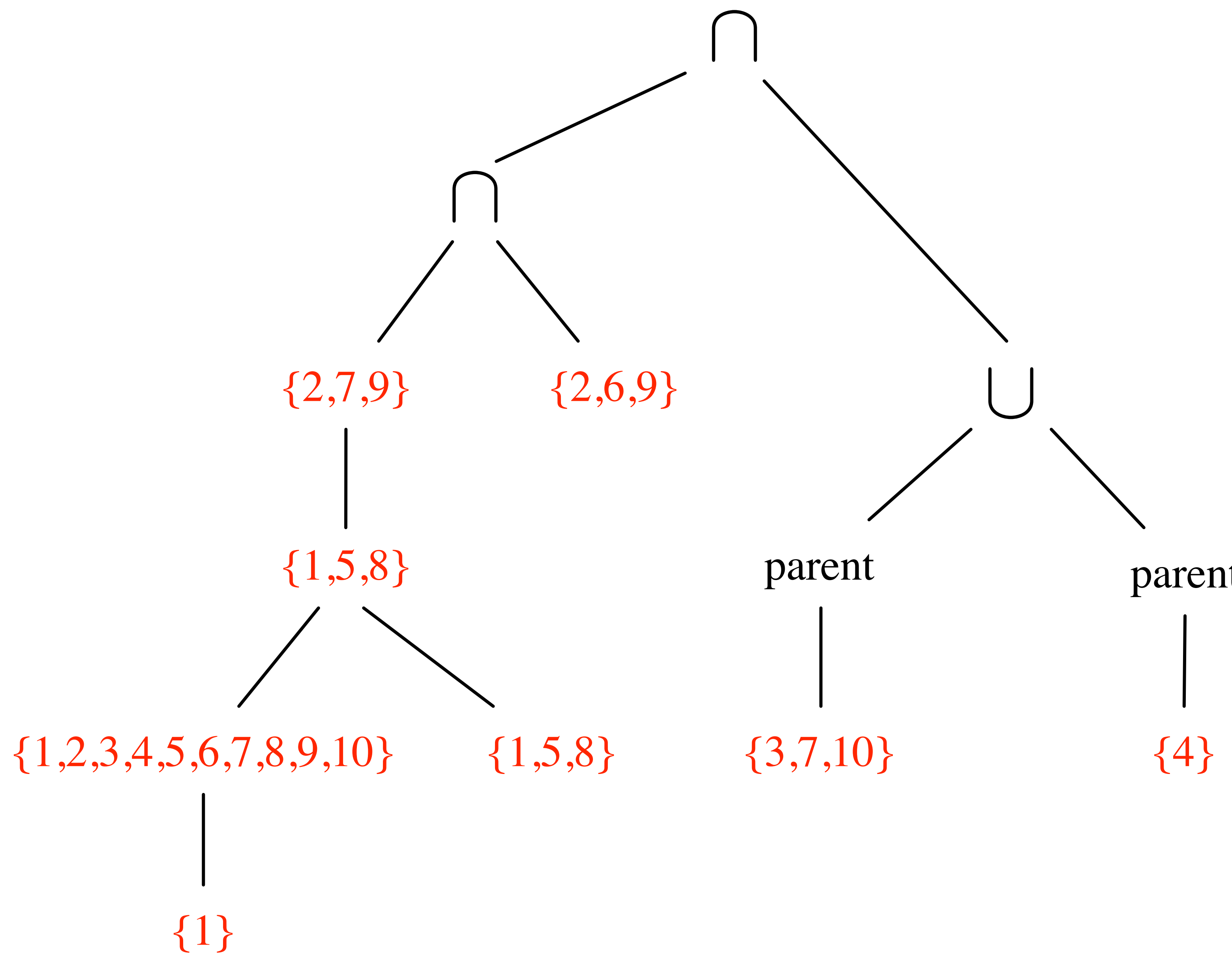




XPath: Bottom-up Evaluation of Core XPath

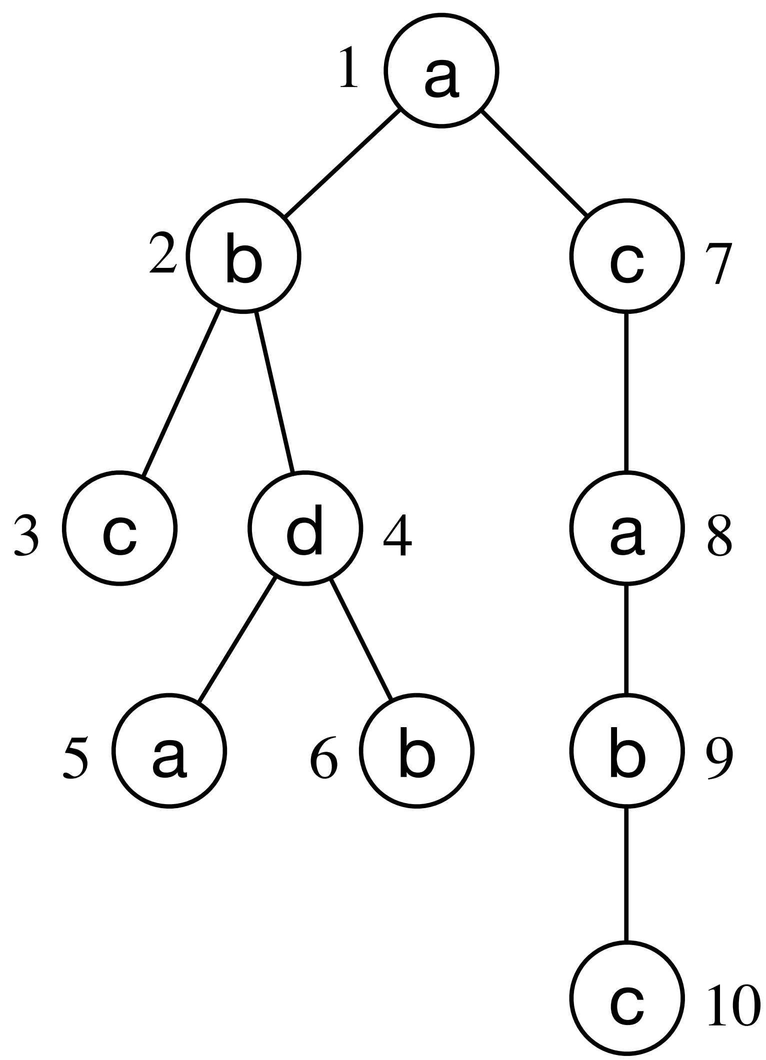
`/descendant_or_self::a/child::b[child::d or child::c]`

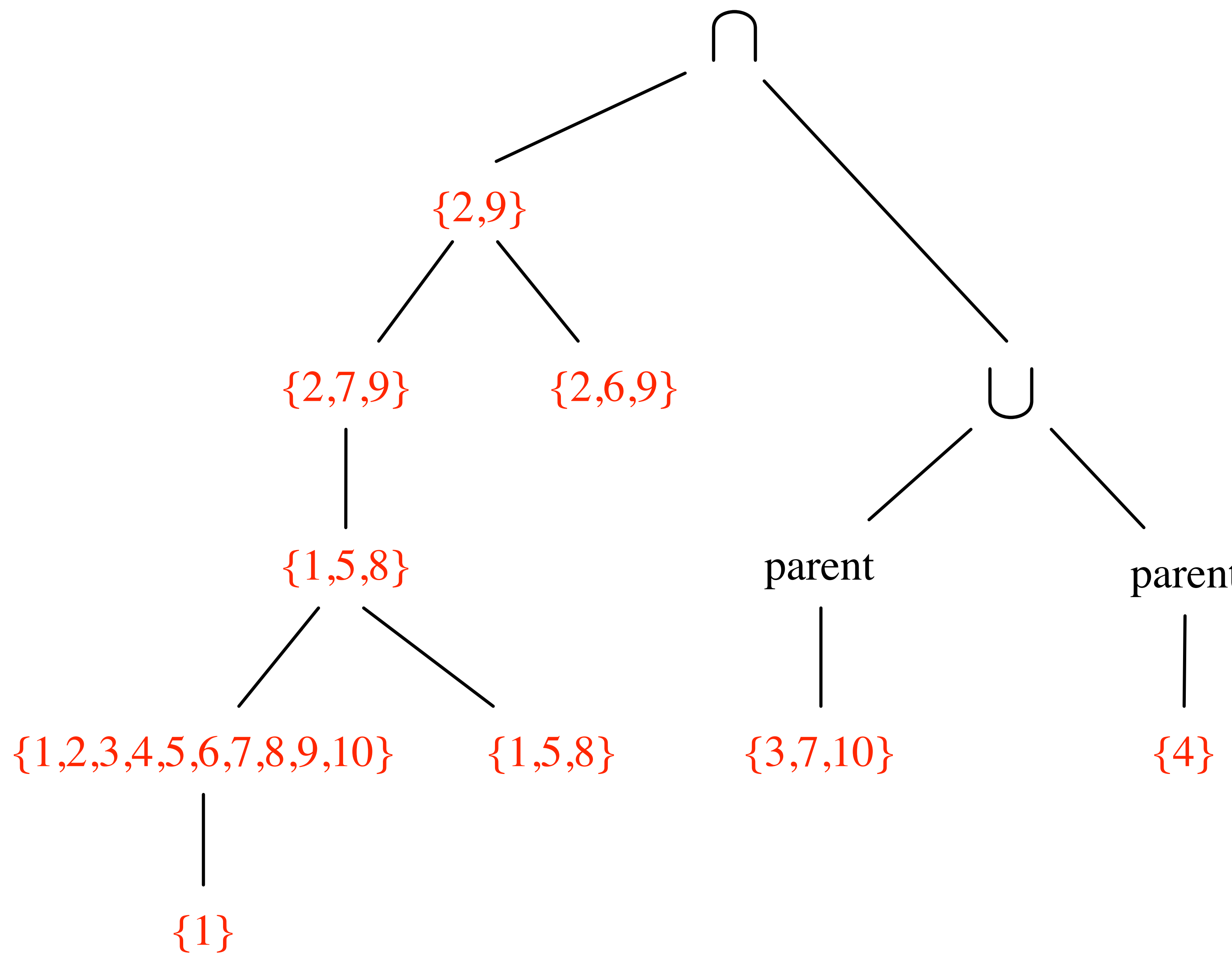




XPath: Bottom-up Evaluation of Core XPath

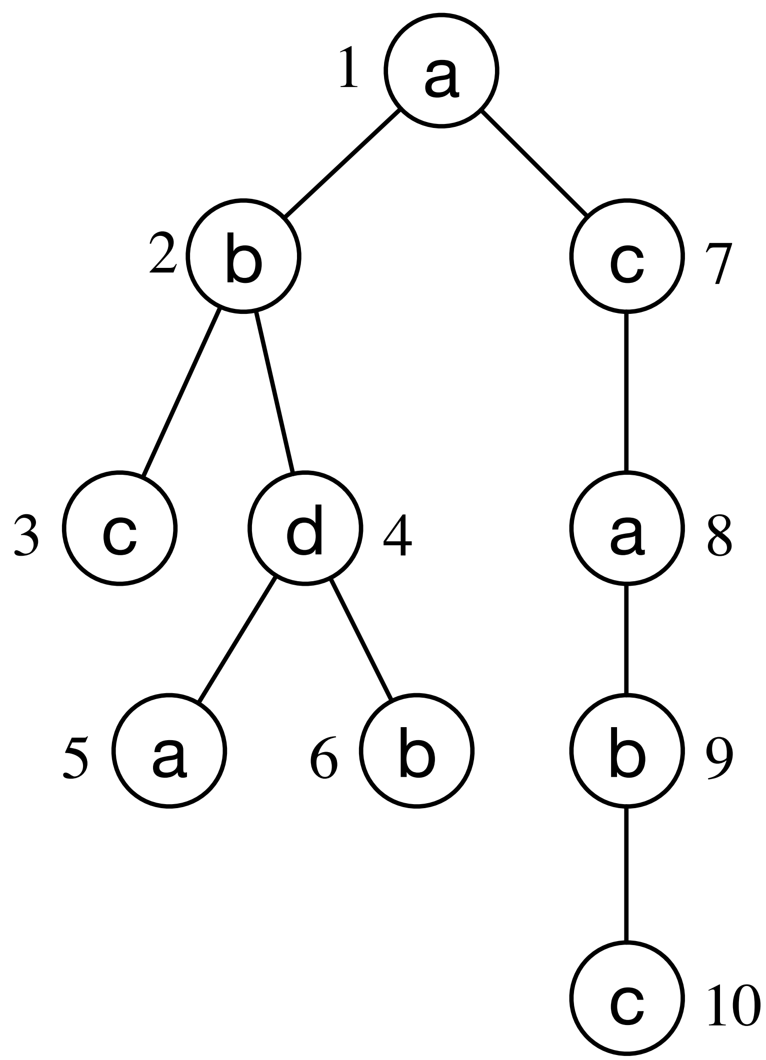
```
/descendant_or_self::a/child::b[child::d or child::c]
```

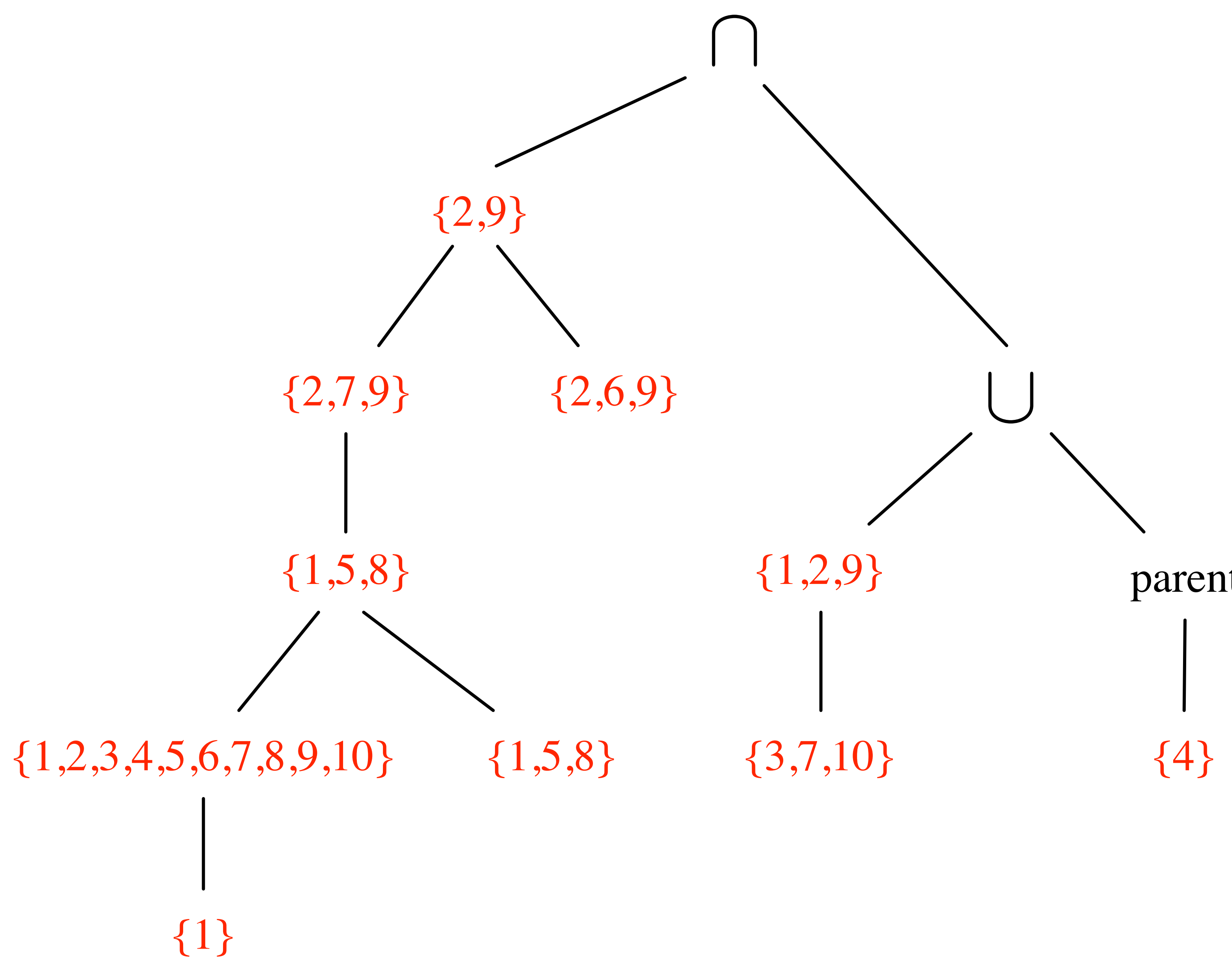




XPath: Bottom-up Evaluation of Core XPath

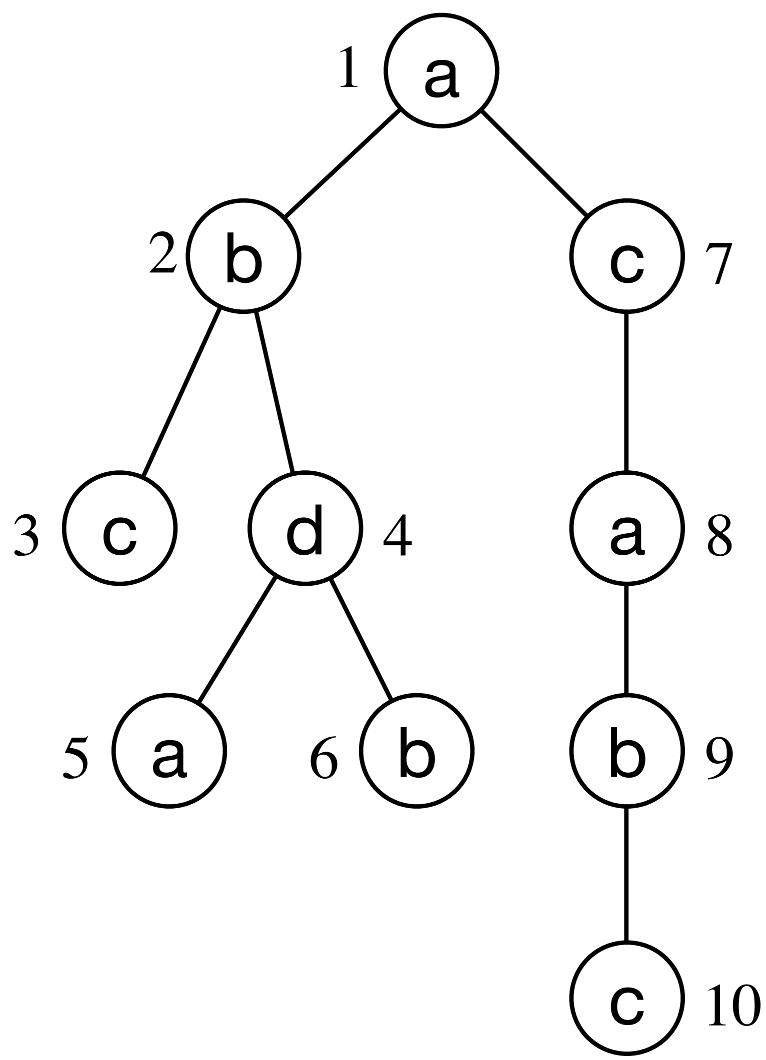
```
/descendant_or_self::a/child::b[child::d or child::c]
```

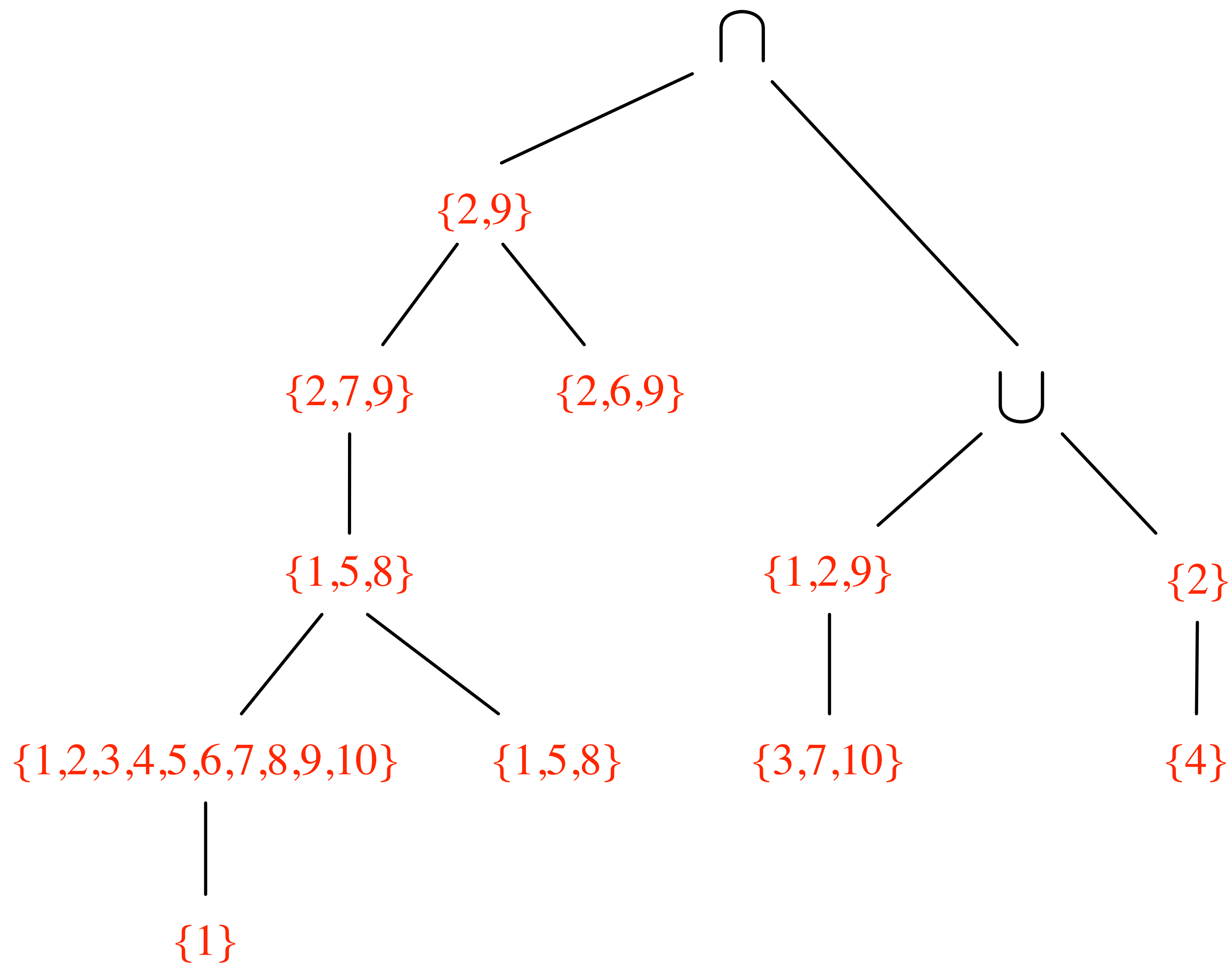




XPath: Bottom-up Evaluation of Core XPath

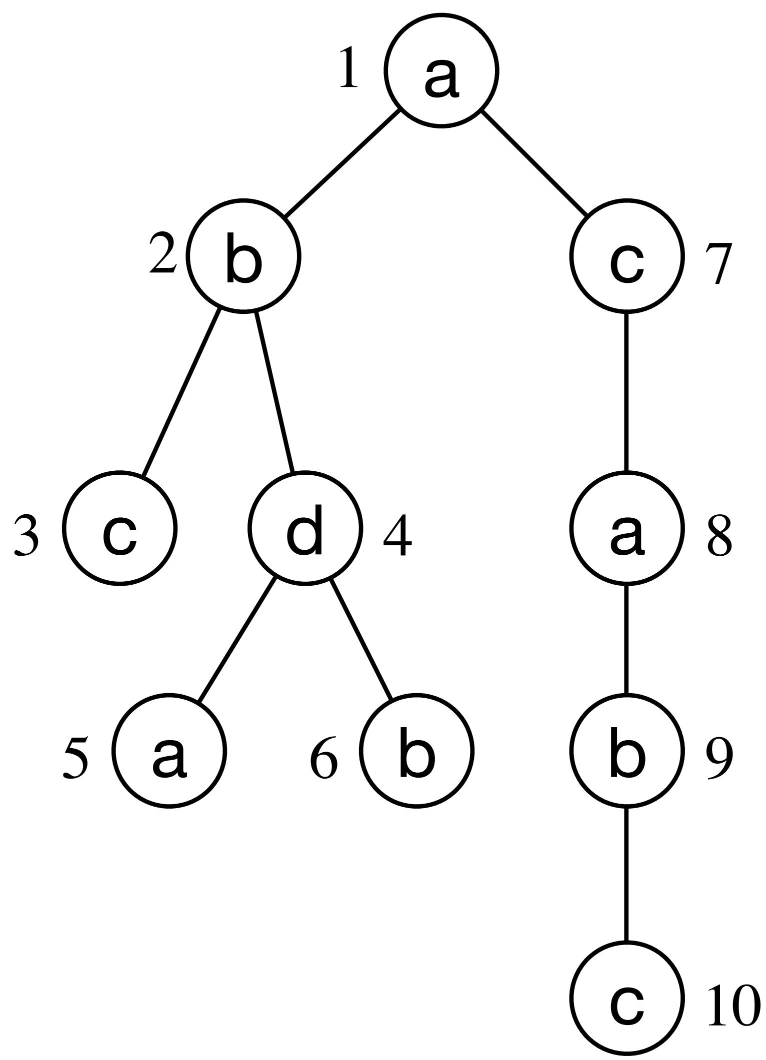
```
/descendant_or_self::a/child::b[child::d or child::c]
```

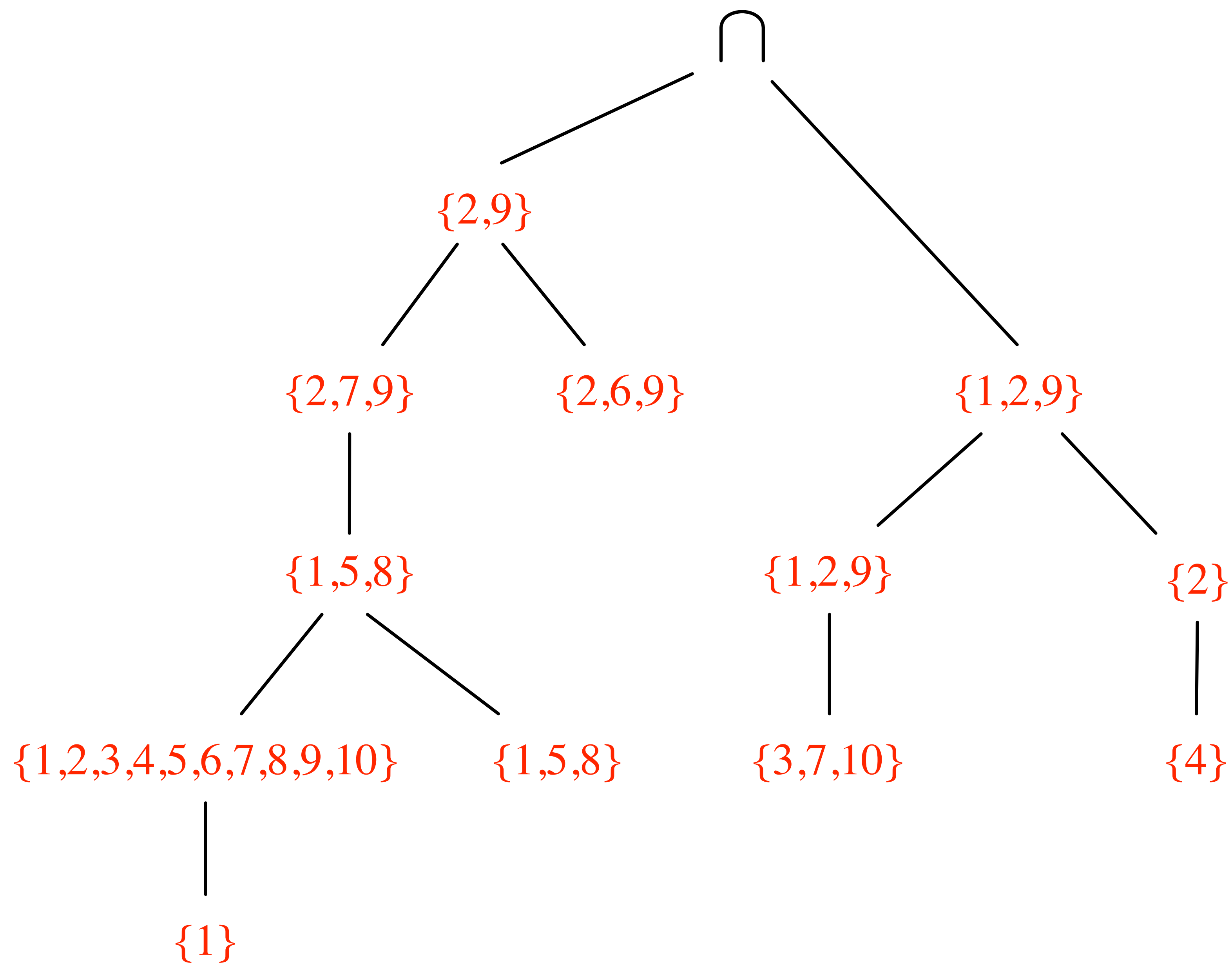




XPath: Bottom-up Evaluation of Core XPath

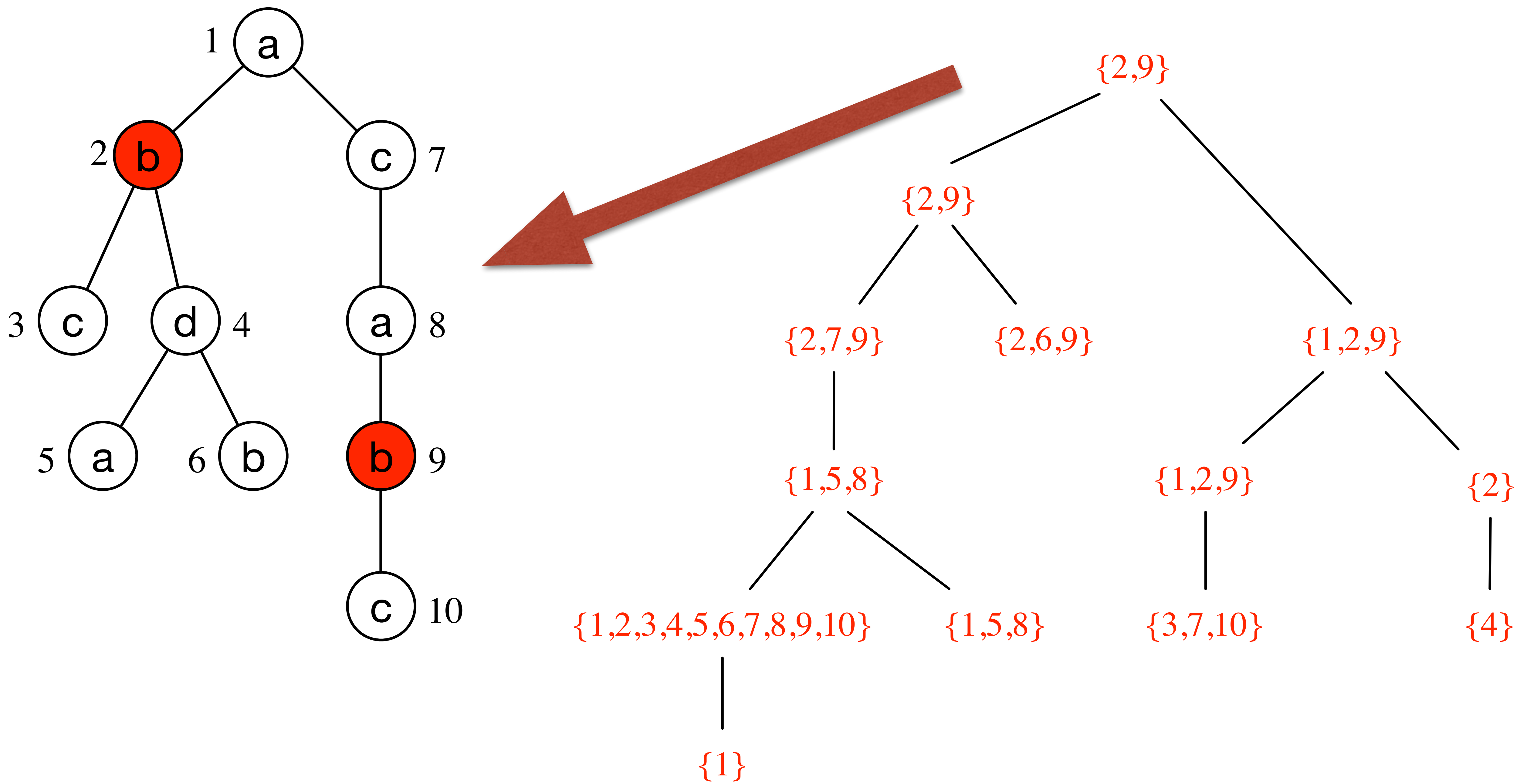
```
/descendant_or_self::a/child::b[child::d or child::c]
```





XPath: Bottom-up Evaluation of Core XPath

/descendant_or_self::a/child::b[child::d or child::c]



XPath: Bottom-up Evaluation of Core XPath

- each set operation and the bookkeeping takes $O(|D|)$ time
- the parse tree is of size $O(|Q|)$
- hence, linear processing:

$$O(|D| \cdot |Q|)$$

XPath: Bottom-up Evaluation of Full XPath

- we can still have polynomial evaluation of full XPath (similar principle as Core XPath)

XPath: Bottom-up Evaluation of Full XPath

Context-value tables:

- each context in XPath can be represented using a context-value table (specifies situations in which a subquery should be evaluated):

$$\text{context} :< x, k, n >$$

- determined by preceding XPath computations —- bottom-up algorithm

XPath: Bottom-up Evaluation of Full XPath

$$\mathcal{E}_\uparrow : \text{Expression} \rightarrow \text{nset} \cup \text{num} \cup \text{str} \cup \text{bool},$$

Expr. E : **Operator Signature**   **Semantics** $\mathcal{E}_\uparrow[\![E]\!]$
location step χ::t : $\rightarrow$ nset $\{\langle x_0, k_0, n_0, \{x \mid x_0 \chi x,\ x \in T(t)\}\rangle \mid\ \langle x_0, k_0, n_0\rangle \in \mathbf{C}\}$
location step $E[e]$ over axis χ: nset $\times$ bool $\rightarrow$ nset $\{\langle x_0, k_0, n_0, \{x \in S \mid \langle x, \text{idx}_\chi(x, S), \lvert S\rvert, \text{true}\rangle \in \mathcal{E}_\uparrow[\![e]\!]\}\rangle$ $\mid \langle x_0, k_0, n_0, S\rangle \in \mathcal{E}_\uparrow[\![E]\!]\}$
location path $/\pi$: nset $\rightarrow$ nset $\mathbf{C} \times \{S \mid \exists k, n : \langle \text{root}, k, n, S\rangle \in \mathcal{E}_\uparrow[\![\pi]\!]\}$
location path π_1/π_2 : nset $\times$ nset $\rightarrow$ nset $\{\langle x, k, n, z\rangle \mid\ 1 \leq k \leq n \leq \lvert\text{dom}\rvert,$ $\langle x, k_1, n_1, Y\rangle \in \mathcal{E}_\uparrow[\![\pi_1]\!],$ $\bigcup_{y \in Y} \langle y, k_2, n_2, z\rangle \in \mathcal{E}_\uparrow[\![\pi_2]\!]\}$
location path $\pi_1 \mid \pi_2$: nset $\times$ nset $\rightarrow$ nset $\mathcal{E}_\uparrow[\![\pi_1]\!] \cup \mathcal{E}_\uparrow[\![\pi_2]\!]$
position() : $\rightarrow$ num $\{\langle x, k, n, k\rangle \mid \langle x, k, n\rangle \in \mathbf{C}\}$
last() : $\rightarrow$ num $\{\langle x, k, n, n\rangle \mid \langle x, k, n\rangle \in \mathbf{C}\}$

XPath: Bottom-up Evaluation of Full XPath

$$\mathcal{E}_{\uparrow} : \text{Expression} \rightarrow \text{nset} \cup \text{num} \cup \text{str} \cup \text{bool},$$

$$\begin{aligned}
&\mathcal{E}_{\uparrow}[\![Op(e_1, \ldots, e_m)]\!] := \\
&\{\langle \vec{c}, \mathcal{F}[\![Op]\!](v_1, \ldots, v_m)\rangle \mid \vec{c} \in \mathbf{C},\ \langle \vec{c}, v_1\rangle \in \mathcal{E}_{\uparrow}[\![e_1]\!],\ \ldots, \\
&\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad \langle \vec{c}, v_m\rangle \in \mathcal{E}_{\uparrow}[\![e_m]\!]\}
\end{aligned}$$

XPath: Bottom-up Evaluation of Full XPath

Context-Value Principle (CVT):

- the size of each of the context-value tables is polynomial
- computing each combination step of the expression is polynomial
- hence, the computation is polynomial

XPath: Bottom-up Evaluation of Full XPath

GOTTLOB EXAMPLE SLIDES

XPath: Bottom-up Evaluation of Full XPath

Space Complexity:

- O(|Q|) relations are created,
- **nset** are bounded by O(|D|^4), **bool** are bounded by O(|D|^3)
- numbers and string computable in XPath are of size O(|D||Q|)

$$O(|D|^4 \cdot |Q|^2)$$

XPath: Bottom-up Evaluation of Full XPath

Time Complexity:

- $O(|Q|)$ computations are needed (parse tree size is linear in the query size),
- $O(|D|^5|Q|)$ for each expression relation

$$O(|D|^5 \cdot |Q|^2)$$

Useful Reading

- Gottlob, Koch, Pichler. "**Efficient Algorithms for Processing XPath Queries**", VLDB 2002.

- Green, Gupta, Miklau, Onizuka, Suciu. "**Processing XML Streams with Deterministic Automata and Stream Indexes**", ACM TODS 29(4), 2004.

- Benedikt, Koch. "**XPath Leashed**", ACM Computing Surveys 41(1), 2009.