XPath Whole Query Optimization

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Fast query evaluation over indexed XML documents

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Tree automata

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- Staircase join (used in MonetDB)
- Twig joins
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Tree automata

- Streaming XML queries
- XML typechecking
- XML pattern-matching
- Theoretical work (expressivity or complexity results)

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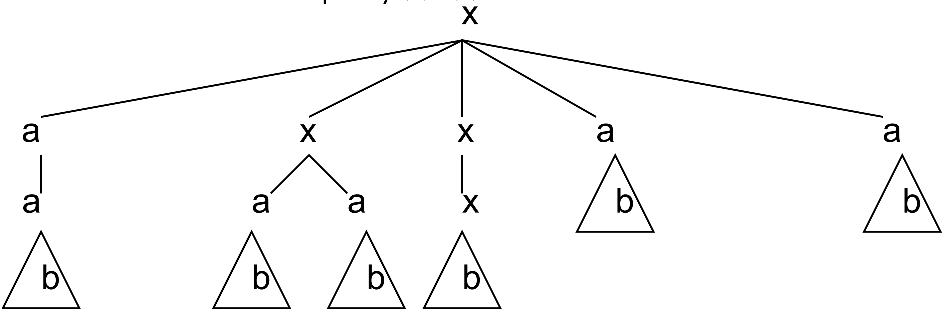
$|Q|$: for each visited node, how much work is needed ?

Consider the XPath query `//a//b` and the document :



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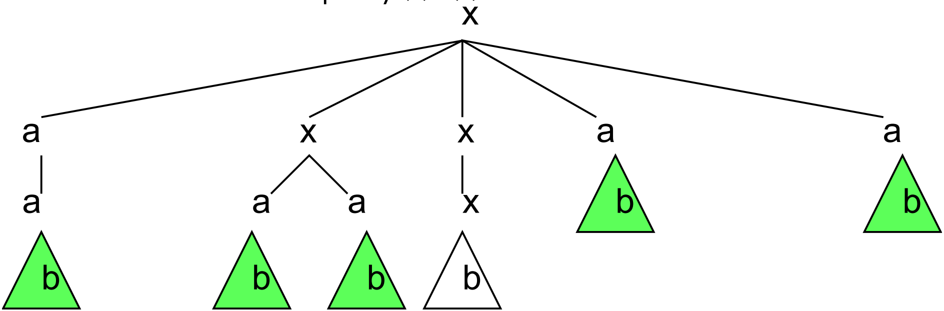

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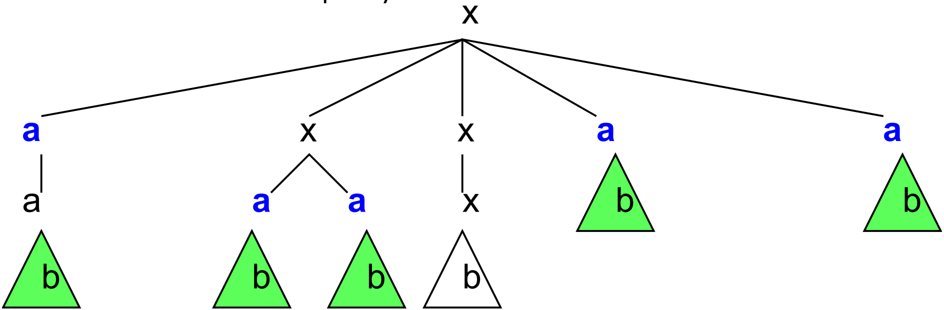

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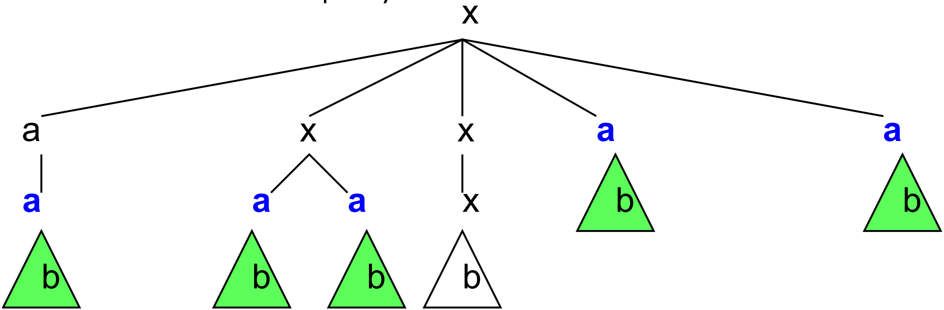

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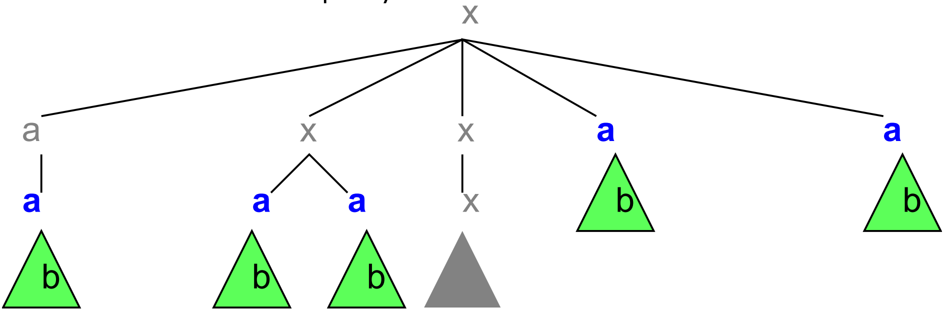

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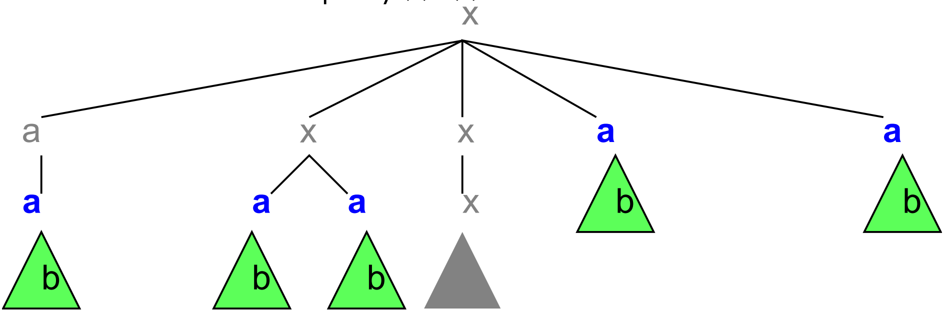

- Does the engine need to know about **these nodes** ?

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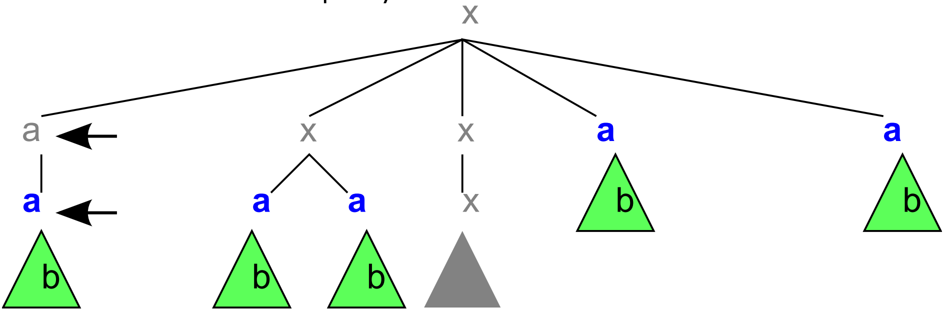

- Does the engine need to know about **these nodes** ?
- How does it choose between to equally good nodes ?

Definition (Binary tree)

Binary trees over Σ : $T(\Sigma)$ smallest set s.t. :

- $\# \in \Sigma$ (leaf symbol)
- $t_1, t_2 \in T(\Sigma) \Rightarrow \forall l \in \Sigma, l(t_1, t_2) \in T(\Sigma)$

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Definition (Set of nodes of a tree t)

Smallest set $\mathrm{Dom}(t) \subseteq \{1, 2\}^*$ such that :

- $\epsilon \in \mathrm{Dom}(t)$
- $t(\epsilon) = l$ if $t \equiv l(t_1, t_2)$
- $t(\epsilon) = \#$ if $t \equiv \#$
- $t(i \cdot \pi) = t_i(\pi)$, if $t \equiv l(t_1, t_2)$

Definition (Selecting Tree Automaton (STA))

$\mathcal{A} = (\Sigma, Q, T, B, S, \delta)$

- Σ input symbols, Q set of states
- T set of top states, B set of bottom-states
- $S \subseteq Q \times \Sigma$ set of selecting configurations
- δ set of transitions : $q, L \rightarrow q_1, q_2$ (where $L \subseteq \Sigma$)

Definition (Run R of an STA $\mathcal{A}$ over t)

A run is a mapping from $\text{Dom}(t)$ to Q generated by δ

Definition (Selected nodes)

For a given run R, the set of selected nodes is

$$\mathcal{A}^R(t) = \{\pi \in \text{Dom}(t) \mid (R(\pi), t(\pi)) \in S\}$$

Example (//a//b)

$$\mathcal{A}_{//\mathtt{a}//\mathtt{b}} = (\underbrace{\{\mathtt{a},\mathtt{b},\mathtt{x}\}}_{\Sigma}, \underbrace{\{q_0,q_1\}}_{Q}, \underbrace{\{q_0\}}_{T}, \underbrace{\{q_0,q_1\}}_{B}, \underbrace{\{(q_1,\mathtt{b})\}}_{S}, \delta)$$

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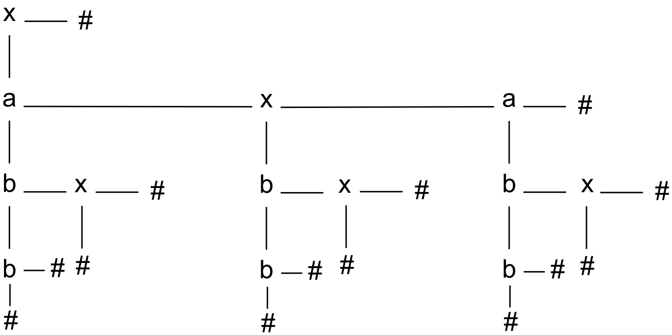

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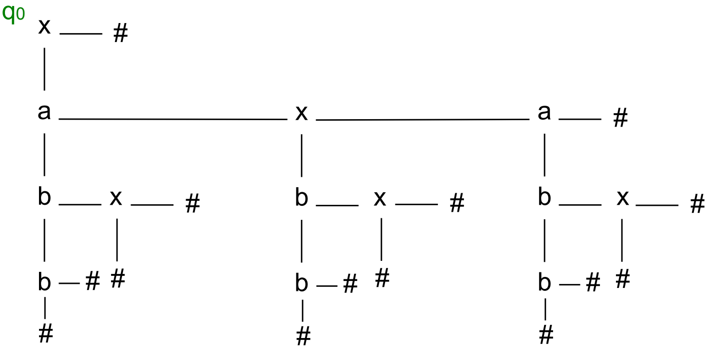

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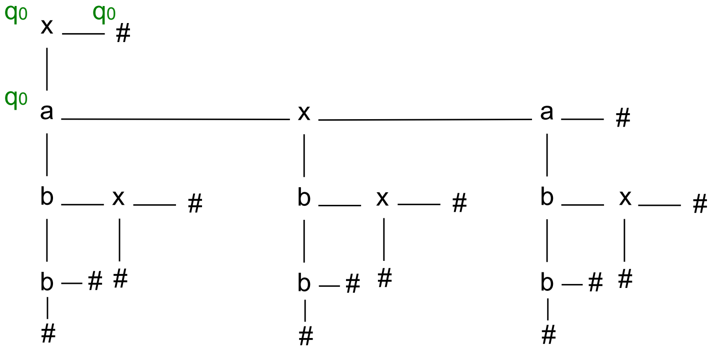

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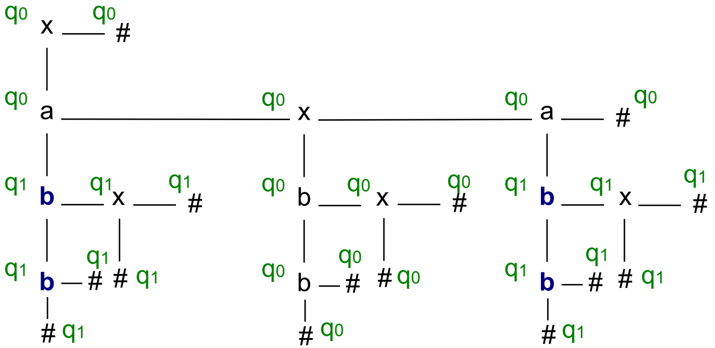

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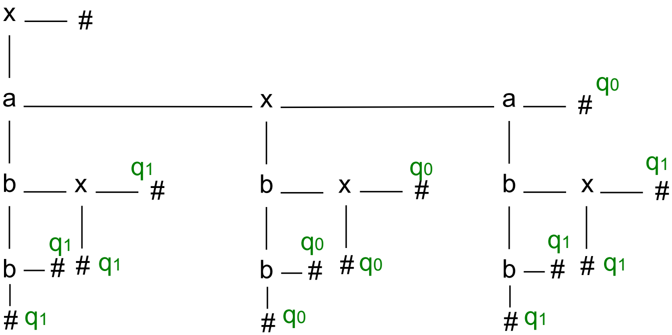

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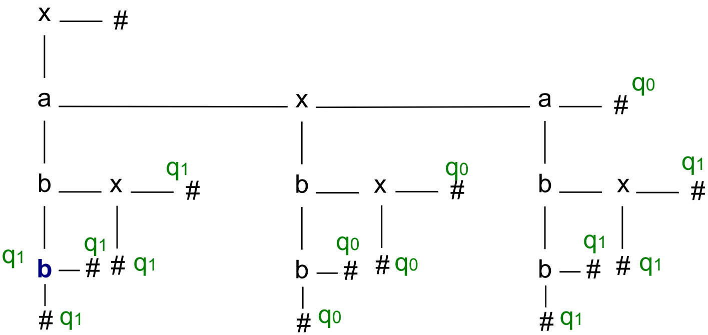

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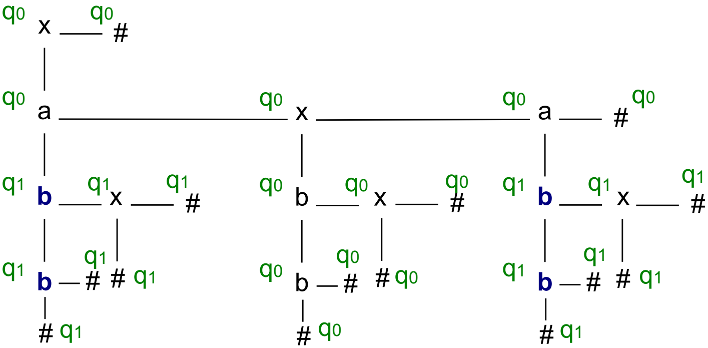

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We write $\mathcal{A}_\top$ the universal recognizer (no selection)

Definition (Equivalence)

$\mathcal{A} \equiv \mathcal{A}'$ if and only if :

- $\mathcal{L}(\mathcal{A}) = \mathcal{L}(\mathcal{A}')$
- $\forall t \in T(\Sigma), \mathcal{A}(t) = \mathcal{A}'(t)$

Definition (Restriction to a state)

Let $\mathcal{A} = (\Sigma, Q, T, B, S, \delta)$. $\mathcal{A}[q] \equiv (\Sigma, Q, \{q\}, B, S, \delta)$.

Main idea :

- An STA $\mathcal{A}$, a tree t and a run R of $\mathcal{A}$ over t

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Definition (Relevant node)

- let $\mathcal{A}$ be an STA, $t \in T(\Sigma)$ and R an accepting run
- let $\pi \in \mathrm{Dom}(t)$ s.t $\pi \cdot i \in \mathrm{Dom}(t), i \in \{1, 2\}$

π is relevant in R iff it is selected or none of the following hold :

- $\mathcal{A}[R(\pi)] \equiv \mathcal{A}[R(\pi \cdot 1)] \equiv \mathcal{A}[R(\pi \cdot 2)]$
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:-(

Checking STA equivalence is hard (EXPTIME-complete)

Non-det. $\Rightarrow$ many runs $\Rightarrow$ different sets of relevant nodes

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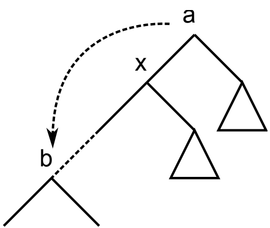

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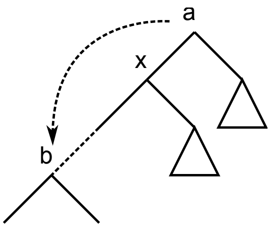

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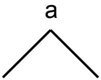

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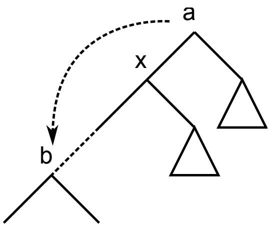

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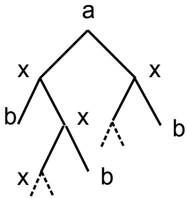

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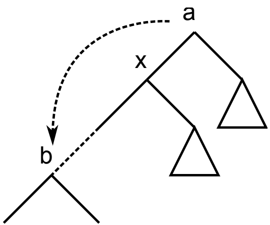

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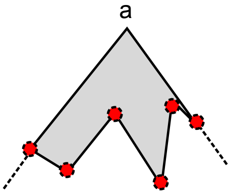
$$\begin{array}{ll} q, L_1 & \to (q_1^1, q_1^2) \\ & \vdots \\ q, L_n & \to (q_n^1, q_n^2) \\ q, \Sigma - \bigcup_{i\in 1..n} L_i & \to (q, q) \end{array}$$



- Defined symmetrically by a state-change in the bottom-up run for a minimal BDSTA
- Automata moves :
  - bottom-most nodes with some label
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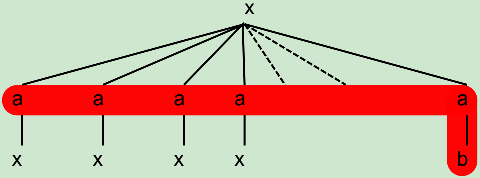
Example

- `//a//b` is TD but not BD
- `//a[.//b]` is BD but not TD
- `//a//b[.//c]` is neither TD nor BD

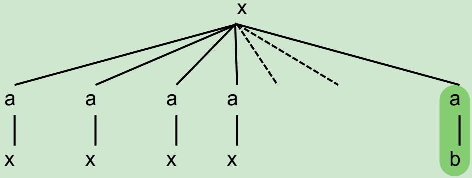
Example (`//a//b`)

`//a//b` is top-down deterministic.



Example (`//a//b`)

`//a//b` is top-down deterministic.However, there is a bottom-up non-deterministic run with less relevant nodes



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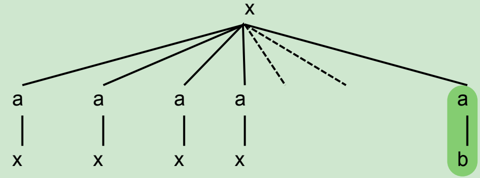
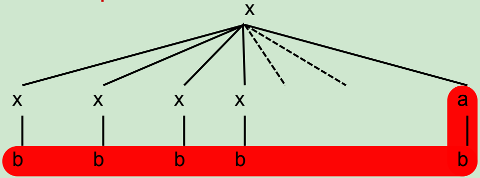


Example (//a[.//b])

//a[.//b] is bottom-up deterministic.



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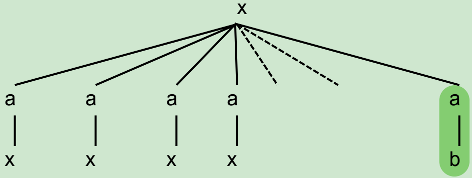

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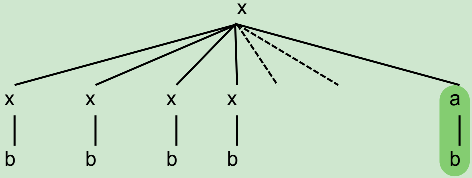

We cannot use STA directly :

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2. we only know how to do things for minimal TD or BD STA

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Definition

Alternating Selecting Tree Automata (ASTA) :

- transitions of the form q, L, τ, ϕ
- τ is either $\rightarrow$ (normal) or $\Rightarrow$ (selecting)
- ϕ is a boolean formula generated by :

$$\phi \quad ::= \quad \top \mid \bot \mid \phi \vee \phi \mid \phi \wedge \phi \mid \neg\phi \mid \downarrow_1 q \mid \downarrow_2 q \quad (q \in Q)$$

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Example (//a//b[c])

$$\mathcal{A}_{//\texttt{a}//\texttt{b(c)}} = (\Sigma, \{q_0, q_1, q_2\}, \{q_0\}, \delta)$$

where δ is :

$$\begin{array}{l|l|l} q_0, \{a\} \rightarrow \downarrow_1 q_1 & q_1, \{b\} \Rightarrow \downarrow_1 q_2 & q_2, \{c\} \rightarrow \top \\ q_0, \Sigma \rightarrow \downarrow_1 q_0 \vee \downarrow_2 q_0 & q_1, \Sigma \rightarrow \downarrow_1 q_1 \vee \downarrow_2 q_1 & q_2, \Sigma \rightarrow \downarrow_2 q_2 \end{array}$$

Allow us to write XPath queries with :

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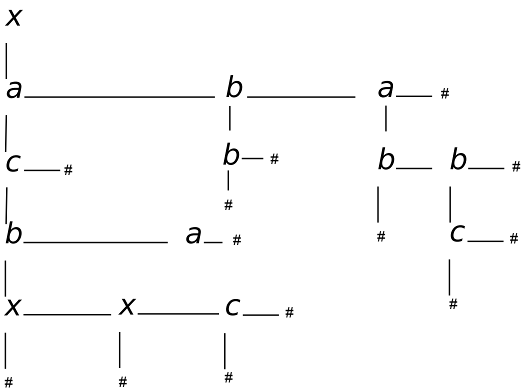
The translation is linear in the size of the query

We can use a textbook evaluation algorithm : $O(|D| \cdot |\mathcal{A}|)$

Example (//a//b[c])

$q_0, \{a\} \rightarrow \downarrow_1 q_1$	$q_1, \{b\} \Rightarrow \downarrow_1 q_2$	$q_2, \{c\} \rightarrow \top$
$q_0, \Sigma \rightarrow \downarrow_1 q_0 \vee \downarrow_2 q_0$	$q_1, \Sigma \rightarrow \downarrow_1 q_1 \vee \downarrow_2 q_1$	$q_2, \Sigma \rightarrow \downarrow_2 q_2$



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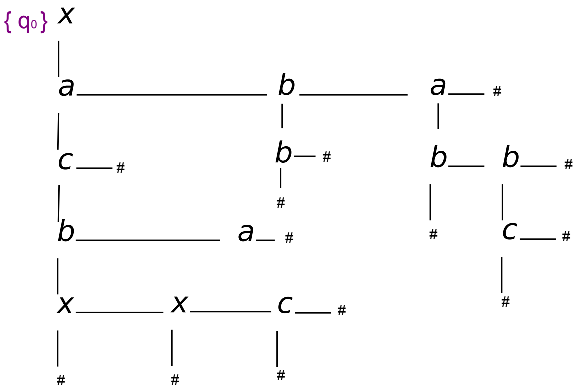

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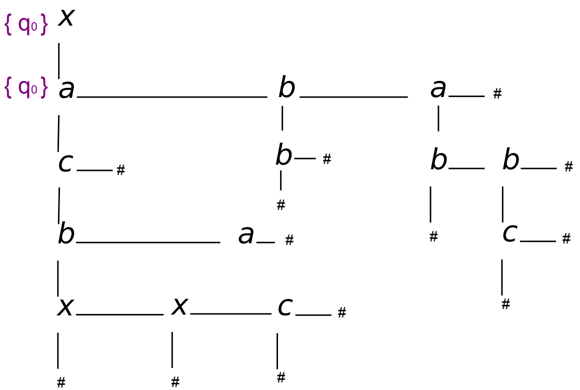

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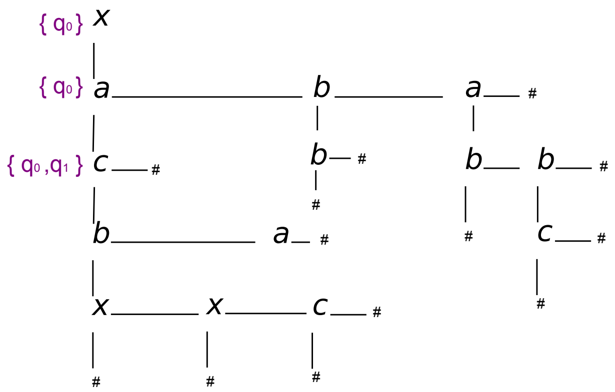

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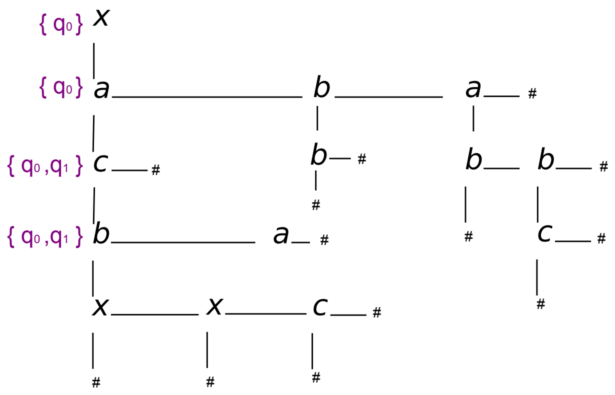

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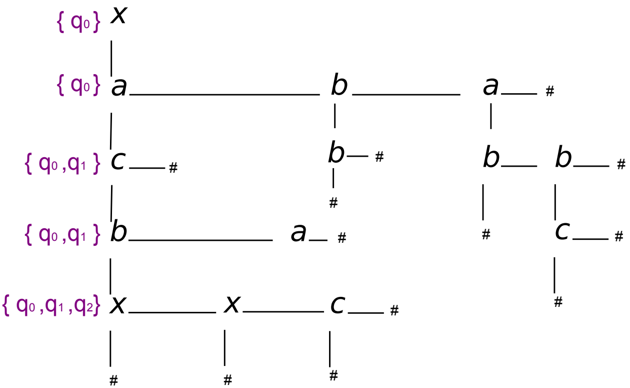

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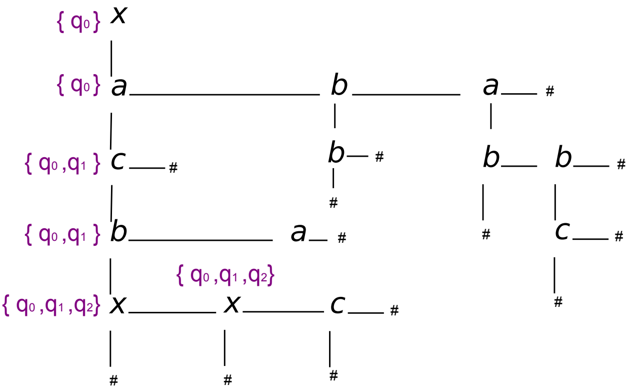

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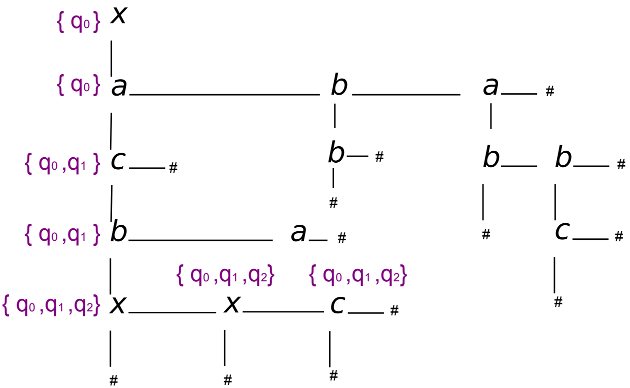

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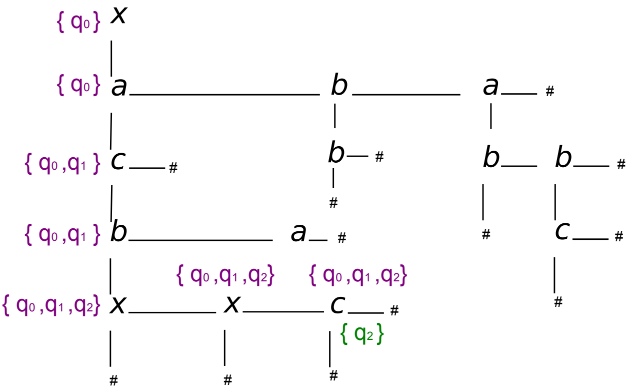

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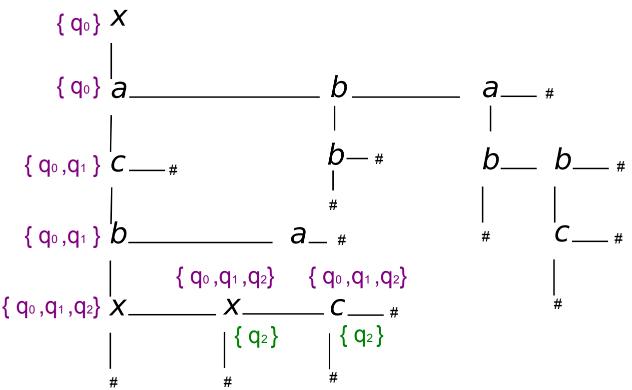

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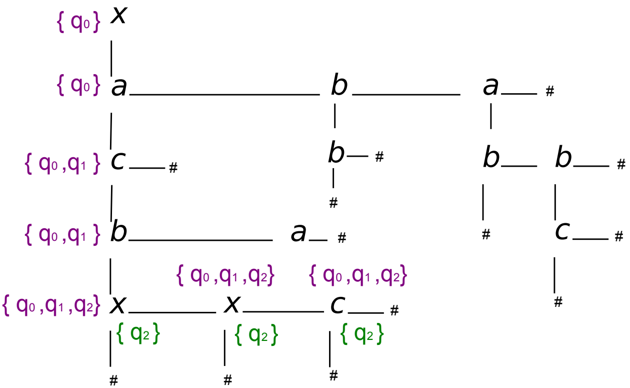

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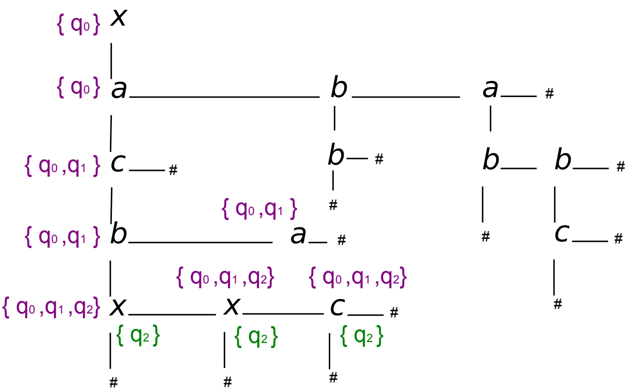

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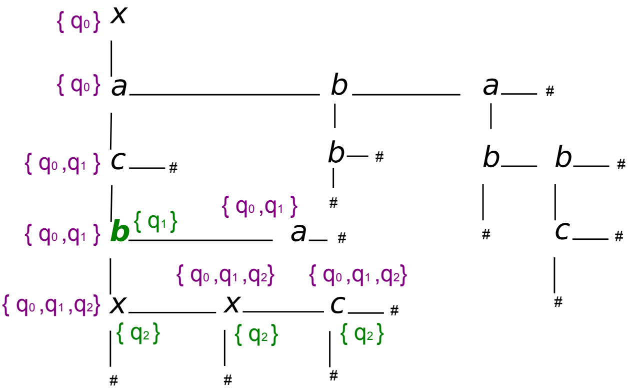

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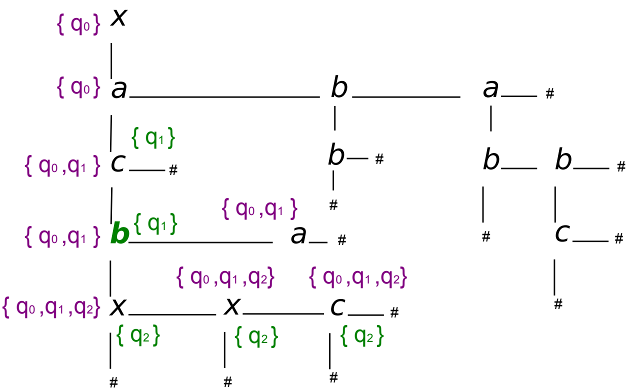
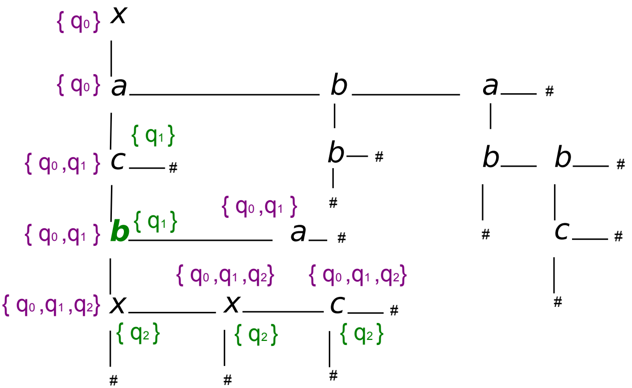


Example (//a//b[c])

$$
\begin{array}{ll|ll|ll}
q_0, \{a\} & \rightarrow \downarrow_1 q_1 & q_1, \{b\} & \Rightarrow \downarrow_1 q_2 & q_2, \{c\} & \rightarrow \top \\
q_0, \Sigma & \rightarrow \downarrow_1 q_0 \vee \downarrow_2 q_0 & q_1, \Sigma & \rightarrow \downarrow_1 q_1 \vee \downarrow_2 q_1 & q_2, \Sigma & \rightarrow \downarrow_2 q_2
\end{array}
$$



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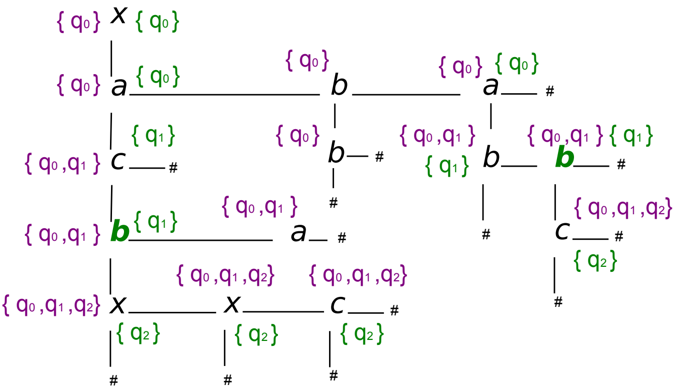

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$$
\begin{array}{ll|ll|ll}
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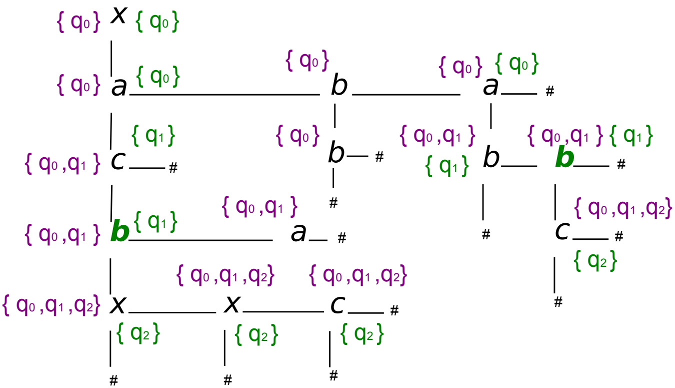

$$
\begin{array}{lll}
Q_0 & = & \{q_0\} \\
Q_1 & = & \{q_0, q_1\} \\
Q_2 & = & \{q_0, q_1, q_2\}
\end{array}
$$

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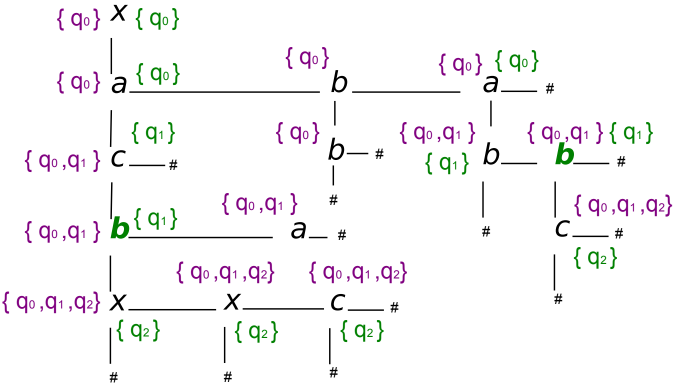

$$Q_0 = \{q_0\}$$
$$Q_1 = \{q_0, q_1\}$$
$$Q_2 = \{q_0, q_1, q_2\}$$

$\mathcal{A}_{\text{approx}}$

$Q_0, \{a\}$	$\rightarrow Q_1, Q_0$
$Q_0, \Sigma - \{a\}$	$\rightarrow Q_0, Q_0$
$Q_1, \{b\}$	$\rightarrow Q_2, Q_0$
$Q_1, \Sigma - \{b\}$	$\rightarrow Q_1, Q_1$
$Q_2, \{c\}$	$\rightarrow Q_1, Q_1$
$Q_2, \{b\}$	$\rightarrow Q_2, Q_2$
$Q_2, \Sigma - \{b, c\}$	$\rightarrow Q_1, Q_2$

Example (`//a//b[c]`)

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\begin{array}{lll|lll|lll}
q_0, \{a\} & \rightarrow & \downarrow_1 q_1 & q_1, \{b\} & \Rightarrow & \downarrow_1 q_2 & q_2, \{c\} & \rightarrow & \top \\
q_0, \Sigma & \rightarrow & \downarrow_1 q_0 \vee \downarrow_2 q_0 & q_1, \Sigma & \rightarrow & \downarrow_1 q_1 \vee \downarrow_2 q_1 & q_2, \Sigma & \rightarrow & \downarrow_2 q_2
\end{array}
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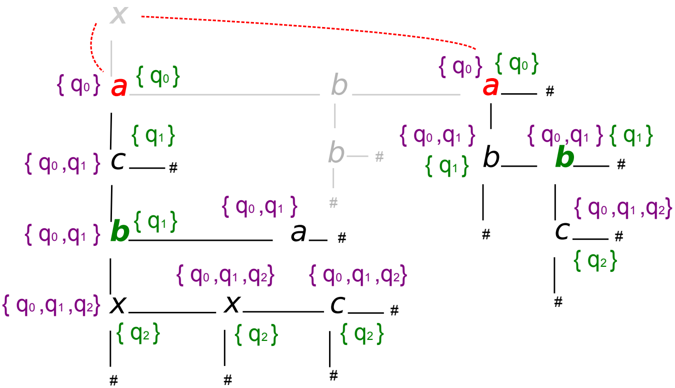

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$\mathcal{A}_{\text{approx}}$

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\begin{array}{ll}
Q_0, \{a\} & \rightarrow Q_1, Q_0 \\
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Q_1, \{b\} & \rightarrow Q_2, Q_0 \\
Q_1, \Sigma - \{b\} & \rightarrow Q_1, Q_1 \\
Q_2, \{c\} & \rightarrow Q_1, Q_1 \\
Q_2, \{b\} & \rightarrow Q_2, Q_2 \\
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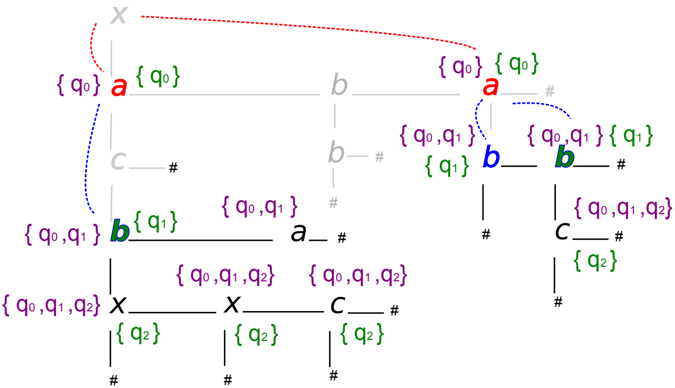

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$\mathcal{A}_{\text{approx}}$

$Q_0, \{a\} \rightarrow Q_1, Q_0$

$Q_0, \Sigma - \{a\} \rightarrow Q_0, Q_0$

$Q_1, \{b\} \rightarrow Q_2, Q_0$

$Q_1, \Sigma - \{b\} \rightarrow Q_1, Q_1$

$Q_2, \{c\} \rightarrow Q_1, Q_1$

$Q_2, \{b\} \rightarrow Q_2, Q_2$

$Q_2, \Sigma - \{b, c\} \rightarrow Q_1, Q_2$

Example (`//a//b[c]`)

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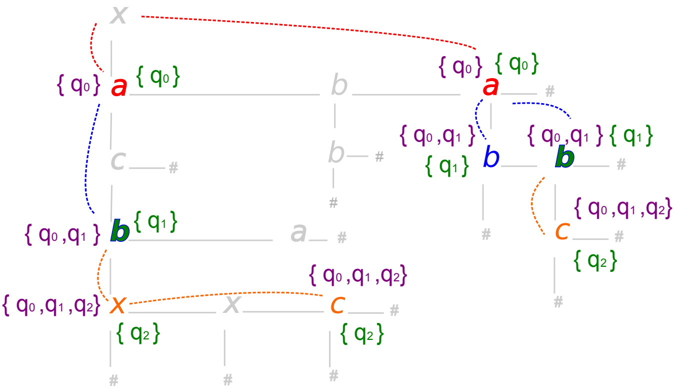
\begin{array}{ll|ll|ll}
q_0,\{a\} \rightarrow \downarrow_1 q_1 & & q_1,\{b\} \Rightarrow \downarrow_1 q_2 & & q_2,\{c\} \rightarrow \top & \\
q_0,\Sigma \rightarrow \downarrow_1 q_0 \vee \downarrow_2 q_0 & & q_1,\Sigma \rightarrow \downarrow_1 q_1 \vee \downarrow_2 q_1 & & q_2,\Sigma \rightarrow \downarrow_2 q_2 &
\end{array}
$$



$$
\begin{array}{lcl}
Q_0 & = & \{q_0\} \\
Q_1 & = & \{q_0, q_1\} \\
Q_2 & = & \{q_0, q_1, q_2\}
\end{array}
$$

$\mathcal{A}_{\text{approx}}$

$$
\begin{array}{ll}
Q_0, \{a\} & \rightarrow Q_1, Q_0 \\
Q_0, \Sigma - \{a\} & \rightarrow Q_0, Q_0 \\
Q_1, \{b\} & \rightarrow Q_2, Q_0 \\
Q_1, \Sigma - \{b\} & \rightarrow Q_1, Q_1 \\
Q_2, \{c\} & \rightarrow Q_1, Q_1 \\
Q_2, \{b\} & \rightarrow Q_2, Q_2 \\
Q_2, \Sigma - \{b, c\} & \rightarrow Q_1, Q_2
\end{array}
$$

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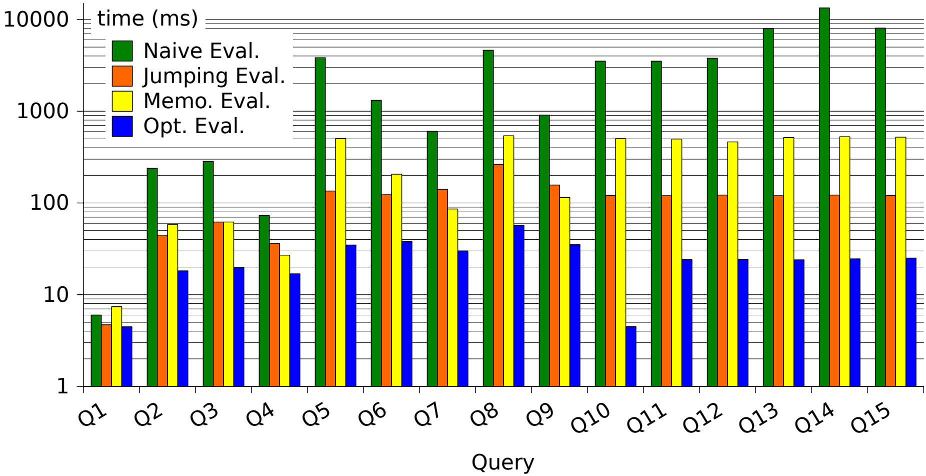
Result-sets that allow $O(1)$ duplicate-free sorted insert ($|Q|$)



Q1-Q10 taken from XPathMark

Q5-Q15 contain //

Factored computations :

Q10 : `/site[ .//keyword ]` touches two nodes, return 1 node

Q11 : `/site//keyword` touches 73071 nodes, returns 73070

Q12 : `/site[.//keyword]//keyword` touches 73071 nodes

Q15 : `/site[ .//*//* ]//keyword` touches 73074 nodes

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Reliance to syntactic changes

`//a[ .//b or .//c ]//d` and `//a[ .//c or .//b ]//d` executed the same way (same nodes are touched)

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Future work

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- Can we characterize the average complexity ?