XML and Databases

Lecture 8
Streaming Evaluation: how much memory do you need?

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CSE@UNSW -- Semester 1, 2010

Small XPath Quiz

Can you give an expression that returns the last / first occurrence of each distinct price element?

<price>3</price>
<price>1</price>
<price>3</price>
<price>1</price>
<price>3</price>
<price>4</price>
<price>1</price>
<price>7</price>

Should return	Should return
<price>3</price>	<price>3</price>
<price>4</price>	<price>1</price>
<price>1</price>	<price>4</price>
<price>7</price>	<price>7</price>

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<price>1</price>
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<price>3</price>
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<price>1</price>
<price>7</price>

Should return	Should return
<price>3</price>	<price>3</price>
<price>4</price>	<price>1</price>
<price>1</price>	<price>4</price>
<price>7</price>	<price>7</price>

What's the result for this query: `/descendant::price[.=preceding::price][2]`

Small XPath Quiz

Can you give an expression that returns the last / first occurrence of each distinct price element?

<price>3.0</price>
<price>1</price>
<price>3.00</price>
<price>1</price>
<price>3</price>
<price>4</price>
<price>1.000</price>
<price>7</price>

Should return	Should return
<price>3</price>	<price>3.0</price>
<price>4</price>	<price>1</price>
<price>1.000</price>	<price>4</price>
<price>7</price>	<price>7</price>

What if we mean *number-distinctness* (not strings)?

Small XPath Quiz

Can you give an expression that returns the smallest (last) price element?

<price>3</price>
<price>1</price>
<price>3</price>
<price>1</price>
<price>3</price>
<price>4</price>
<price>1</price>
<price>7</price>

Should return

<price>1</price>

Small XPath Quiz

Can you give an expression that returns the smallest (last) price element?

<price>3.0</price>
<price>1</price>
<price>3.00</price>
<price>1</price>
<price>3</price>
<price>4</price>
<price>1.000</price>
<price>7</price>

Should return

<price>1.000</price>

Recall

→ Koch's CVT-algorithm for full XPath 1.0
→ Evaluation of Simple Paths //a/b/c
→ Arbitrary Queries over //, /, *

Outline

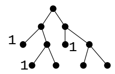
1. Automaton Approach
2. Parallel Evaluation of Multiple Queries
3. Sizes of Automata
4. How to deal with Filters
5. Existing Systems for Streaming XPath Evaluation

Recall: Koch's CVT-algorithm for full XPath 1.0

Question Which subsets of nodes need to appear in the CVTs?

Answer (1) Compute *top-down* for filter-less query-part the exact node set, until a filter appears. (2) Build CVT (*bu*) for the respective sets.

Example `//*[sum(preceding::*/@a)>sum(following::*/@a)]`



(1) simply use Core-XPath algorithm here to compute in *linear time* the correct node set.

(2) Now build Context-Value-Tables for this node set only, going *bottom-up* through the filter.

1	1	11
2	2	11
3	3	11
4	4	11
5	5	11
6	6	11
7	7	11
8	8	11
9	9	11
10	10	11
11	11	11

Recall: Koch's CVT-algorithm for full XPath 1.0

Question Which subsets of nodes need to appear in the CVTs?

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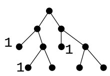
Example `//*[sum(preceding::*/@a)>sum(following::*/@a)]`



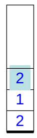
(1) simply use Core-XPath algorithm here to compute in *linear time* the correct node set.

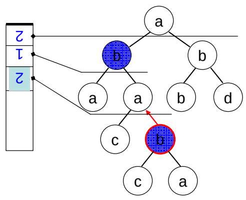
Context-Value Tables

1	1	11	-	-	-	-	-	-	false
2	2	11	-	7-11	-	8.a	-	1	false
3	3	11	-	4-11	-	5.a,8.a	-	2	false
4	4	11	3	7-11	3.a	8.a	1	1	false
5	5	11	3	6-11	3.a	8.a	1	1	false
6	6	11	3,5	7-11	3.a,5.a	8.a	2	1	true
7	7	11	2-6	-	3.a,5.a	-	2	0	true
8	8	11	2-6	9-11	3.a,5.a	-	2	0	true
9	9	11	2-6,8	-	3.a,5.a,8.a	-	3	0	true
10	10	11	2-6,8	11	3.a,5.a,8.a	-	3	0	true
11	11	11	2-6,8,10	-	3.a,5.a,8.a	-	3	0	true

Recall: Top-Down Evaluation of *Simple Paths*

→ evaluate in *one single pre-order traversal* (using a **stack**)





//a/b =Q

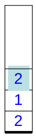
query match position: p = 2

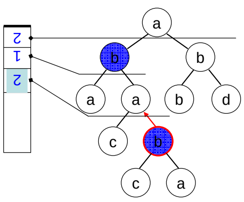
[endElement(b)] p = pop() = 2

[startElement(a)]
[startElement(b)] *result node*
[startElement(a)]
[endElement(a)]
[startElement(a)]
[startElement(c)]
[endElement(c)]
[startElement(b)] *result node*
[startElement(c)] push(1)
[endElement(c)] p = pop() = 1
[startElement(a)] push(1)
[endElement(a)] p = pop() = 1

Recall: Top-Down Evaluation of *Simple Paths*

→ evaluate in *one single pre-order traversal* (using a **stack**)





//a/b =Q

query match position: p = 2

Streaming Algorithm!

→ No need to store the document!!
Can evaluate on SAX event stream.

Simple Path //a_1/a_2/a_3/ . . . /a_n

TIME **one pass** through document tree.
SPACE *stack of query positions*.
height is bounded by depth of document tree.

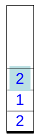
BUT

Need **output buffers**, if subtrees of match nodes should be printed!

Recall: Top-Down Evaluation of *Simple Paths*

→ evaluate in *one single pre-order traversal* (using a **stack**)

If we print **node-IDs**, then no output buffers are needed!



//a/b =Q

query match position: p = 2

→ True Streaming, with memory need proportional to height.

Streaming Algorithm!

→ No need to store the document!!
Can evaluate on SAX event stream.

Simple Path //a_1/a_2/a_3/ . . . /a_n

TIME **one pass** through document tree.
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Recall: Top-Down Evaluation of *Simple Paths*

→ evaluate in *one single pre-order traversal* (using a **stack**)

If we print **node-IDs**, then no output buffers are needed!

➔ any good implementation of this algorithm should work for documents with *depth up to a couple of millions*, and
NO restriction on document size!

`//a/b` =Q

query match position: p = 2

2
1
2

Streaming Algorithm!

➔ No need to store the document!! Can evaluate on SAX event stream.

Simple Path `//a_1/a_2/a_3/ . . . /a_n`

TIME **one pass** through document tree.
SPACE *stack of query positions*.
height is bounded by depth of document tree.

1 Byte/pos is enough for small queries!

Arbitrary *Slash+Slashslash*

→ evaluate in *one single pre-order traversal* (using a **stack)**

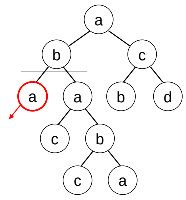
Arbitrary queries with `/,//,*`

multiple `//`'s

`//a/b//c`

query match position: p = 3

3
2



no match
stay in p=3!

…
[startElement(a)] push(3)
[endElement(a)] p = pop() = 3

Arbitrary *Slash+Slashslash*

→ evaluate in *one single pre-order traversal* (using a **stack**)

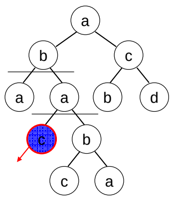
Arbitrary queries with `/,//,*`

multiple `//`'s

`//a/b//c`

query match position: p = 3

3
3
2



no match
stay in p=3!

…
[startElement(a)] push(3)
[endElement(a)] p = pop() = 3
[startElement(a)] push(3)
[startElement(c)] push(3)

Result node!
Mark it, and stay in p=3.

Arbitrary *Slash+Slashslash*

→ evaluate in *one single pre-order traversal* (using a **stack**)

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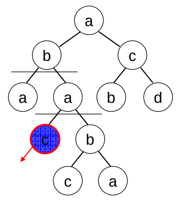
3
2



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[startElement(a)] push(3)
[endElement(a)] p = pop() = 3
[startElement(a)] push(3)
[startElement(c)] push(3)

Result node!
Mark it, and stay in p=3.

Output Node-ID *Start copying to Output Buffer*

Arbitrary *Slash+Slashslash*

→ evaluate in *one single pre-order traversal* (using a **stack**)

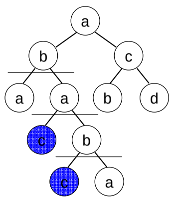
Arbitrary queries with `/,//,*`

multiple `//`'s

`//a/b//c`

query match position: p = 3

3
3
3
2



no match
stay in p=3!

…
[startElement(a)] push(3)
[endElement(a)] p = pop() = 3
[startElement(a)] push(3)
[startElement(c)] push(3)
[endElement(c)] p = pop() = 3
[startElement(b)] push(3)
[startElement(c)] push(3)
…

Arbitrary *Slash+Slashslash*

→ evaluate in *one single pre-order traversal* (using a **stack**)

Arbitrary queries with `/,//,*`

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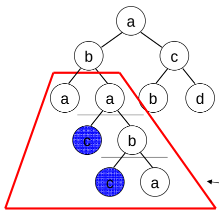
`//a/b//c`

query match position: p = 3

3
3
3
2



Stay at position 3,
for the *complete subtree*!

Never go back to pos. 1 or pos. 2!

Arbitrary *Slash+Slashslash*

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Arbitrary queries with `/,//,*`

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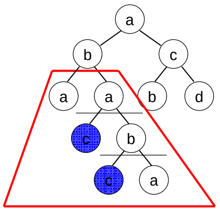
3
3
2



Optimizations (for Output Buffers)

(1) If *inside a matched subtree*, record position (or range within buffer), instead of creating a new output buffer.

(2) If *subtree is finished* (we are not inside a match), then we can write its buffer out and can start with empty buffer again.
[Worst Case:
root node selected. size of doc. Needed.]

Arbitrary *Slash+Slashslash*

→ evaluate in *one single pre-order traversal* (using a **stack)**

Arbitrary queries with `/,//,*`

multiple `//`'s

`//a/b//c`

query match position: p = 3

3
3
3
2

`//a/b//c/d/*/e//f/g//h`

➔ **Same as before**

jump back within `/`-sequence.
AT MOST to the beginning of the last `//`.

Use KMP within `/`-sequence.

For `*`'s: build several KMP-tables.

Arbitrary *Slash+Slashslash*

→ evaluate in *one single pre-order traversal* (using a **stack)**

Arbitrary queries with `/,//,*`

multiple `//`'s

`//a/b//c`

query match position: p = 3

3
3
3
2

`//a/b//c/d/*/e//f/g//h`

If Node-IDs are printed, then no output buffers are needed.

Then:
Memory proportional to height.
Should run for arbitrary large docs!

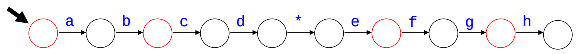
Query Problem is solved!

Leave optimizations of

`>cat file.xml [1.2.7,1.3,1.3.1.1, …]`

To OS/UNIX hackers.. ☺

1. Automaton Approach



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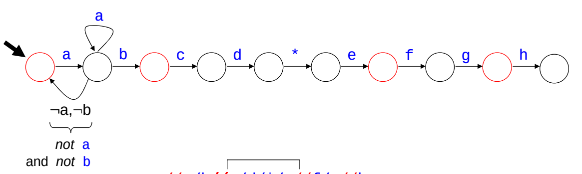
Recall

Deterministic Automaton runs in

→ ***linear time*** and
→ ***constant space***

(plus *stack of states*, if we run on paths of a tree)

1. Automaton Approach



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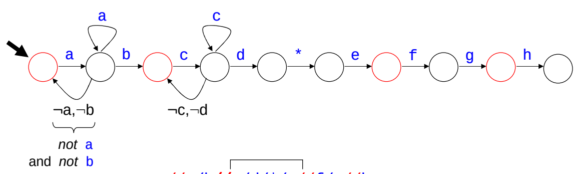

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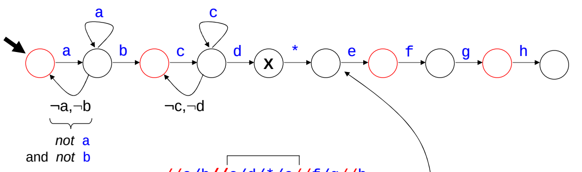


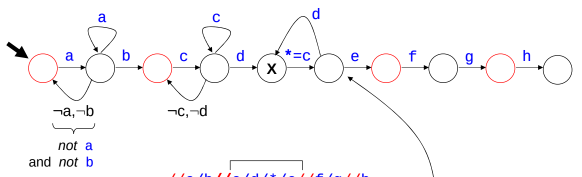
//a/b//c/d/*/e//f/g//h

Problem
If it is NOT an e here, then what to do??

E.g.,
a b c d c d

We should be in state **X**!

1. Automaton Approach



//a/b//c/d/*/e//f/g//h

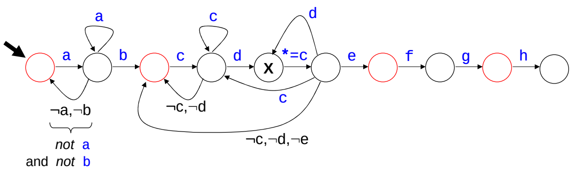
Problem
If it is NOT an e here, then what to do??

➔ Need to know what the * was!!

E.g.,
a b c d c d

We should be in state **X**!

1. Automaton Approach

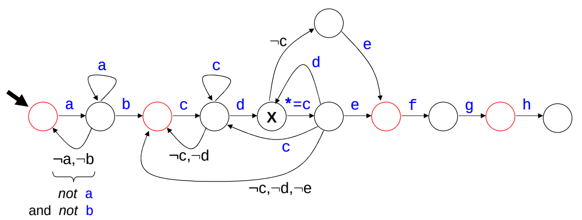


//a/b//c/d/*/e//f/g//h

*=? Which other letters need to be considered?

c d x y

≠c ≠e



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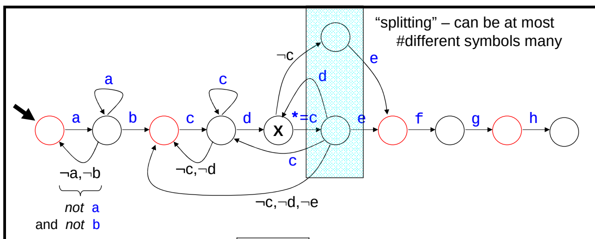
≠c ≠e

→ for x≠c, not important what x is
→ only x=c / x≠c matters



“splitting” – can be at most #different symbols many

//a/b//c/d/*/e//f/g//h

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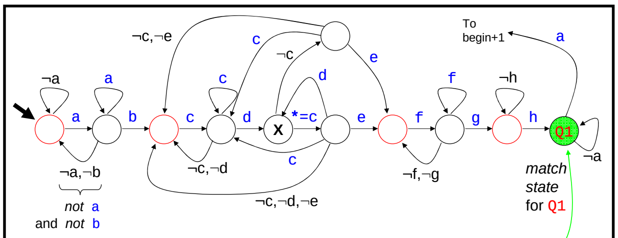

Q1 = //a/b//c/d/*/e//f/g//h

*=? Which other letters need to be considered?

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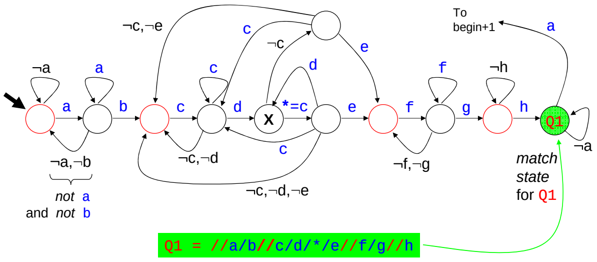
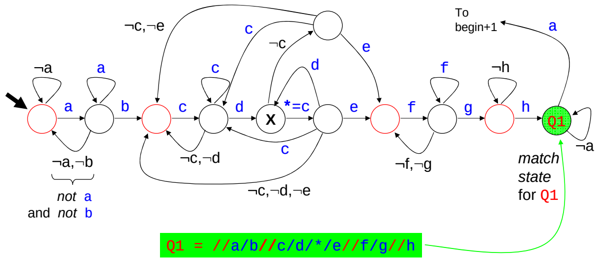


Advantage of automata:
→ can be *combined* to evaluate MANY queries "in parallel".

31



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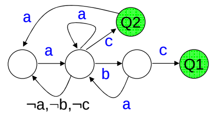
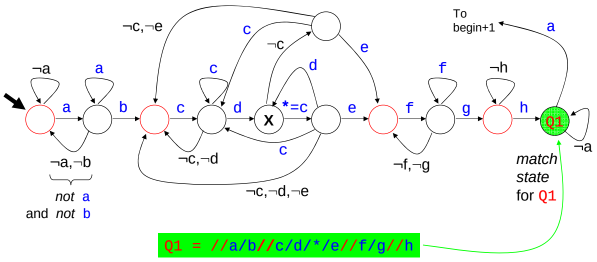
Q1=//a/b/c
Q2=//a/c



32



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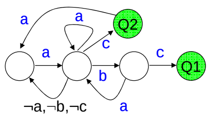
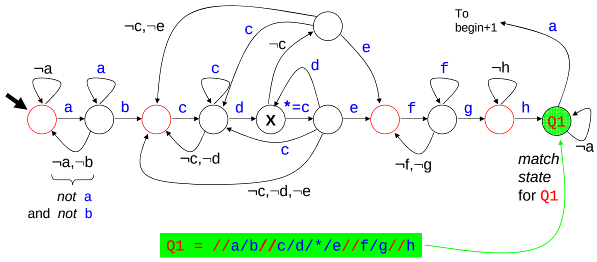


Questions

1. Which transition is WRONG?

33



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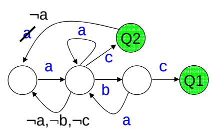
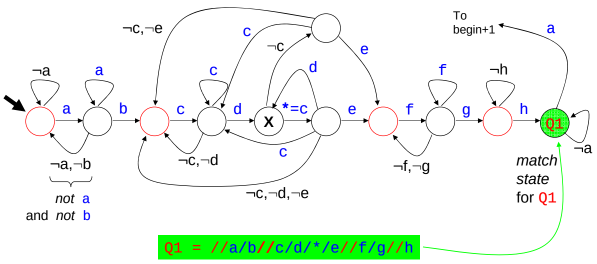


Questions

1. Which transition is WRONG?
2. How many transitions are missing?

34



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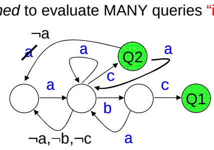

Questions

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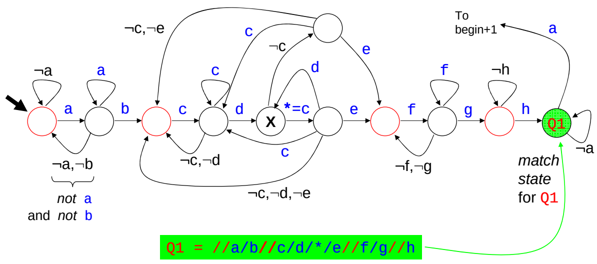
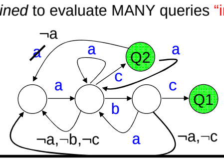


Advantage of automata:
→ can be *combined* to evaluate MANY queries "in parallel".

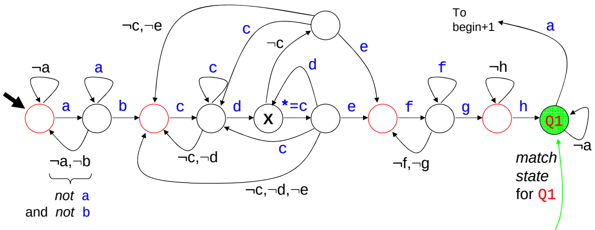
Q1=//a/b/c
Q2=//a/c



Questions

1. Which transition is WRONG?
2. How many transitions are missing?

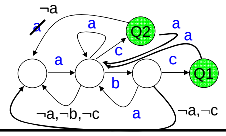
36



Q1 = //a/b//c/d/*/e//f/g//h

Advantage of automata:
→ can be *combined* to evaluate MANY queries "in parallel".

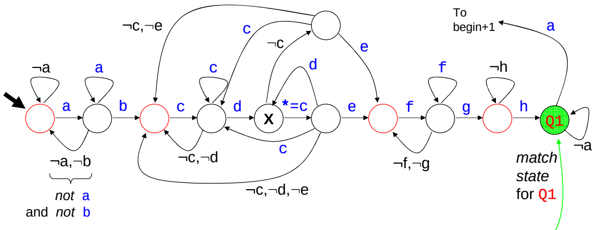
Q1=//a/b/c
Q2=//a/c



Questions

1. Which transition is WRONG?
2. How many transitions are missing?

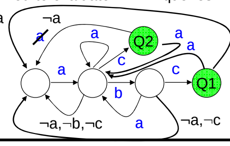
37



Q1 = //a/b//c/d/*/e//f/g//h

Advantage of automata:
→ can be *combined* to evaluate MANY queries "in parallel".

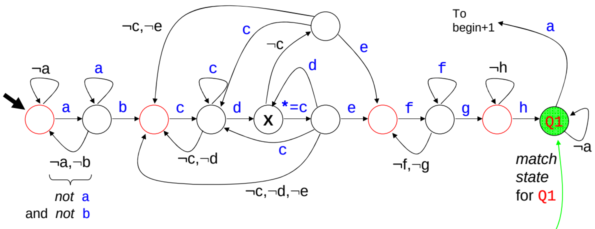
Q1=//a/b/c
Q2=//a/c



Questions

1. Which transition is WRONG?
2. How many transitions are missing?

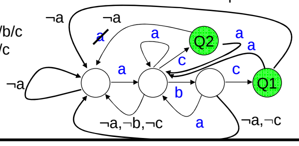
38



Q1 = //a/b//c/d/*/e//f/g//h

Advantage of automata:
→ can be *combined* to evaluate MANY queries "in parallel".

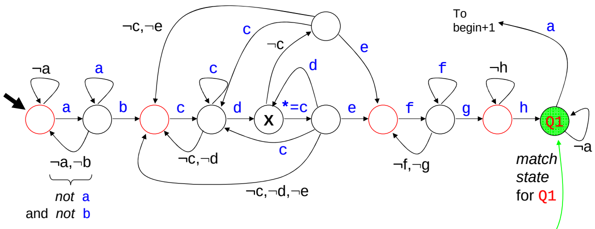
Q1=//a/b/c
Q2=//a/c



Questions

1. Which transition is WRONG?
2. How many transitions are missing?

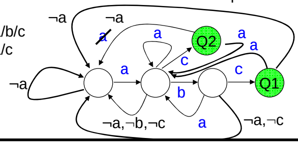
39



Q1 = //a/b//c/d/*/e//f/g//h

Advantage of automata:
→ can be *combined* to evaluate MANY queries "in parallel".

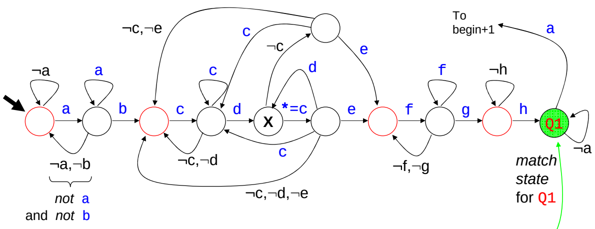
Q1=//a/b/c
Q2=//a/c



Questions

1. Which transition is WRONG?
2. How many transitions are missing?
→ **5**

40

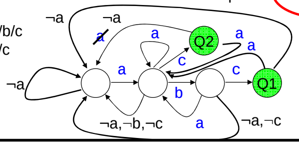


Q1 = //a/b//c/d/*/e//f/g//h

Advantage of automata:
→ can be *combined* to evaluate MANY queries "in parallel".

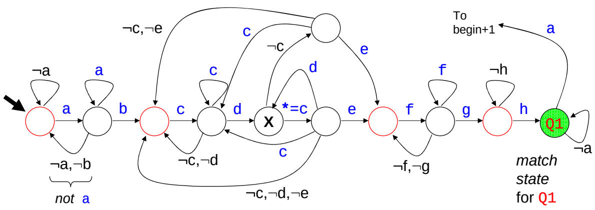
ONE look-up per node!

Q1=//a/b/c
Q2=//a/c



Combined automaton:
SIZE ≤ SIZE(A1) x SIZE(A2)

41



Question

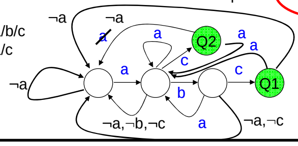
What is SIZE(A1) wrt size of Q1?

Take
(1) SIZE(A) = #states
(2) SIZE(A) = #transitions

Advantage of automata:
→ can be *combined* to evaluate MANY queries "in parallel".

ONE look-up per node!

Q1=//a/b/c
Q2=//a/c



Combined automaton:
SIZE ≤ SIZE(A1) x SIZE(A2)

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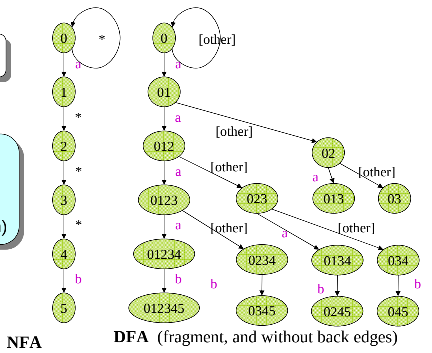
3. The Size of the DFA

//a/*/*/*/b

Size of DFA = exponential in *'s

(not a real concern)



3. The Size of the DFA

Theorem [GMOS'02] The number of states in the DFA for one linear XPath expression P is at most:

$$k+|P|\ k\ s^m$$

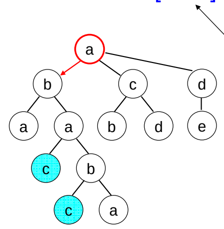
k = number of //

s = size of the alphabet (number of tags)

m = max number of * between two consecutive //

How to deal with filters?

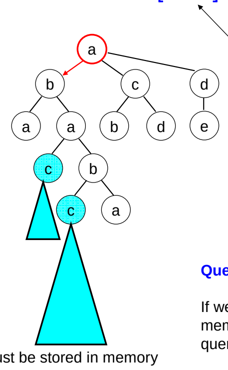
`//a[./d/e]/b//c`



When we meet the c-nodes (in pre order traversal) we do not know yet if the **filter** will evaluate to true.

How to deal with filters?

`//a[./d/e]/b//c`



When we meet the c-nodes (in pre order traversal) we do not know yet if the **filter** will evaluate to true.

➔ We have to use *buffers*, as before.

However, now buffers may be **deleted** without being used.

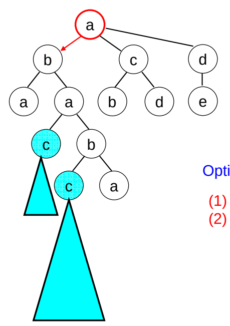
Question

If we output node ID's, then how much memory is needed in the worst case for queries with filters?

Must be stored in memory

How to deal with filters?

`//a[./d/e]/b//c`



➔ Size of largest documents that can be streamed in this way depends on
- #filters,
- sizes of (pre) selected trees,
- quality of (1), (2), etc..

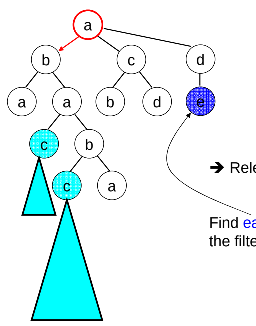
Optimizations

(1) Store potential match trees as DAGs
(2) Release potential match trees as early as possible!

Must be stored in memory

How to deal with filters?

`//a[./d/e]/b//c`



➔ Size of largest documents that can be streamed in this way depends on
- #filters,
- sizes of (pre) selected trees,
- quality of (1), (2), etc..

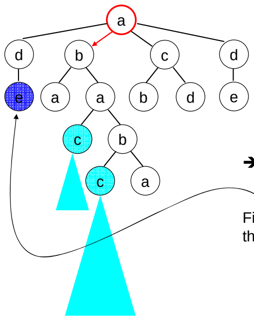
➔ Release potential match trees *as early as possible*!

Find earliest point at which we know the filter is true.

Must be stored in memory

How to deal with filters?

`//a[./d/e]/b//c`



➔ Size of largest documents that can be streamed in this way depends on
- #filters,
- sizes of (pre) selected trees,
- quality of (1), (2), etc..

➔ Release potential match trees *as early as possible*!

Find earliest point at which we know the filter is true.

No need to store. Stream! ☺

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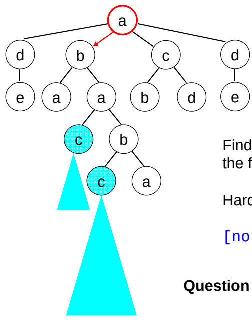
How to deal with filters?

`//a[./d/e]/b//c`



➔ Size of largest documents that can be streamed in this way depends on
- #filters,
- sizes of (pre) selected trees,
- quality of (1), (2), etc..

Find earliest point at which we know the filter is true.

Harder for *Boolean combinations*:

`[not(./d/e) and (./c/d or //b/c)]`

Question where is the earliest point for this filter?

No need to store. Stream! ☺

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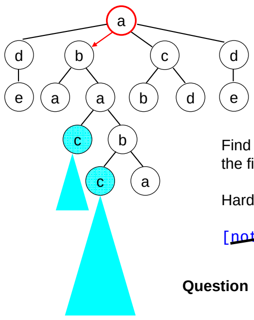
How to deal with filters?

`//a[./d/e]/b//c`



➔ Size of largest documents that can be streamed in this way depends on
- #filters,
- sizes of (pre) selected trees,
- quality of (1), (2), etc..

Find earliest point at which we know the filter is true.

Harder for *Boolean combinations*:

[~~not(./d/e)~~ and (./c/d or //b/c)]

Question where is the earliest point for this filter?
→ and now?

No need to store. Stream! ☺

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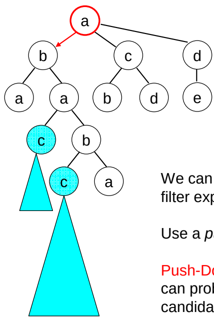
How to deal with filters?

`//a[./d/e]/b//c`



➔ Size of largest documents that can be streamed in this way depends on
- #filters,
- sizes of (pre) selected trees,
- quality of (1), (2), etc..

We can also construct automata for filter expressions!

Use a *push-down* for potential candidates.

Push-Down Automaton
can probably be designed so that it pops/outputs candidates *as early as possible*.

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How to deal with filters?

`//a[./d/e]/b//c`

Another Idea

Use **2-pass algorithm**: first (bottom-up) phase to mark subtrees with filter information.
Second (top-down) phase to determine match nodes.

Why is this interesting?

→ Fast main memory evaluation
→ Use disk as intermediate store (stream twice)

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5. Streaming XPath Algorithms

- XFilter and YFilter [Altinel and Franklin 00] [Diao et al 02]
- X-scan [Ives, Levy, and Weld 00]
- XMLTK [Avila-Campillo et al 02]
- XTrie [Chan et al 02]
- SPEX [Olteanu, Kiesling, and Bry 03]
- Lazy DFAs [Green et al 03]
- The XPush Machine [Gupta and Suciu 03]
- XSQ [Peng and Chawathe 03]
- TurboXPath [Josifovski, Fontoura, and Barta 04]
- …

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5. Streaming XPath Algorithms

Some following slides are by T. Amagasa and M Onizuka (Japan)
See http://www.dasfaa07.ait.ac.th/DASFAA2007_tutorial3_1.pdf

Most of the following slides are by Dan Suciu (the above slides are Actually also based on Suciu's slides ☺)
See
http://www.cs.washington.edu/homes/suciu/talk-spire2002.ppt

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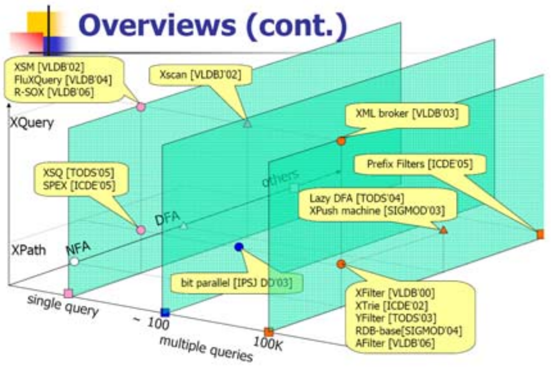
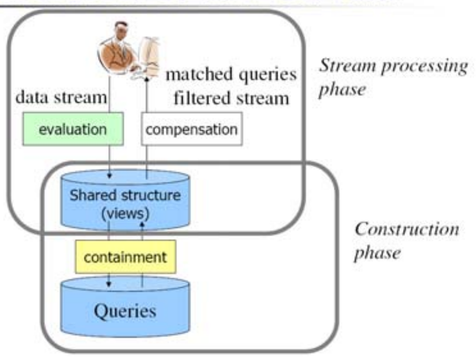
Duality -> XML databases -> XML streams

Overviews (cont.)

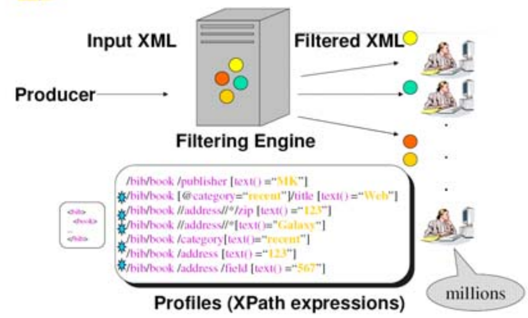


Overview of XML stream



Duality -> XML databases -> XML streams

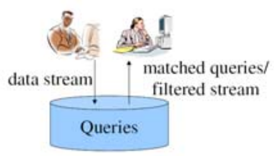
SDI: Selective Dissemination of Information



Duality -> XML databases -> XML streams

XML stream applications

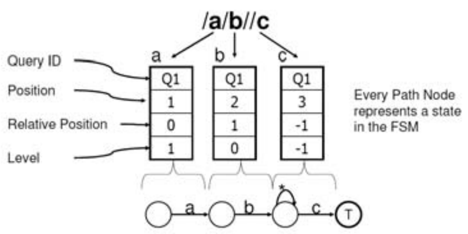
- SDI system/alert system
  stock, real estates, news feeds, flight departure/arrival
- Incremental transformation
  XTim [WWW'05], XPath maintenance [SIGMOD'05]



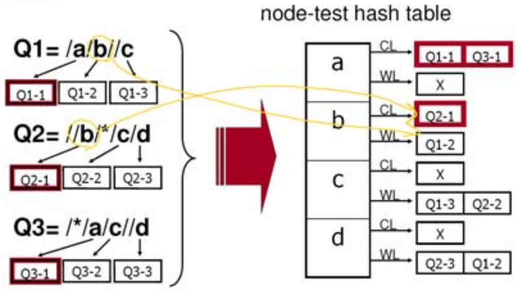
Duality -> XML databases -> XML streams

XFilter (cont.)
NFA, view class: //tag

Decomposing XPath Query

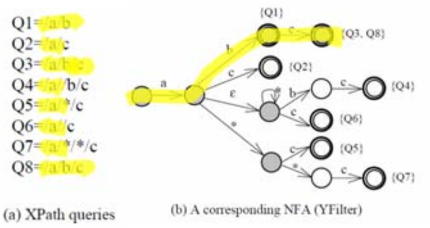


XFilter (cont.)
NFA, view class: //tag



YFilter
NFA, view class: XP{/,//,*}

- prefix sharing
- Predicates are processed by labels



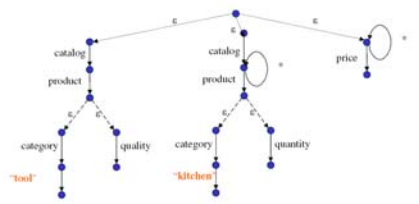
Shared data structure

- Sharing identical structures among query trees
  What to share? node-test, simple path, branch, etc.

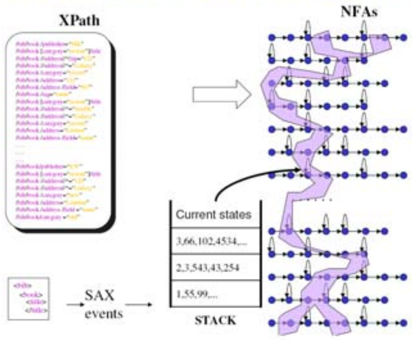
What to share?	View class	Algorithms
node-test	//tag	XFilter [VLDB'00]
simple sub-path	//tag1/…/tagN	XTrie [ICDE'02]
simple path	XP{/,//,*}	YFilter [TODS'03], Lazy DFA [TODS'04], Prefix Filters [ICDE'05], AFilter [VLDB'06]
branch	XP{[],/,//,*}	XPush machine [SIGMOD'03]
…	…	…

XPath Processing with FA
-- From XPath (XP{[],/,//,*) to NFA --

/catalog/product[category="tools"]/quantity
/catalog//product[category="kitchen"]/quality
//price



NFA-based XPE Processing



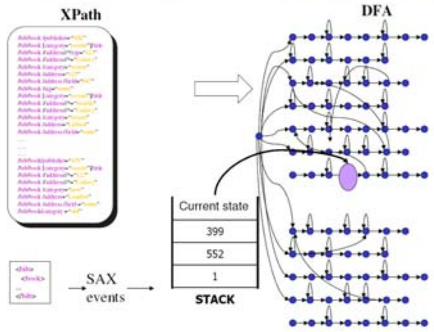
Basic NFA Evaluation

Properties:
- ☺ Space = linear
- ☹ Throughput = decreases linearly

Systems:
- XFilter [Altinel&Franklin'99], YFilter.
- XTrie [Chan et al.'02]

Duality -> XML databases -> XML streams

DFA-based XPE Processing



Basic DFA Evaluation

Properties:
☺ Throughput = constant !
☹ Space = GOOD QUESTION

System:

- XML Toolkit [University of Washington]
  http://xmltk.sourceforge.net

The Size of the DFA

Theorem [GMOS'02] The number of states in the DFA for one linear XPath expression P is at most:

$$\boxed{k+|P|\ k\ s^m}$$

k = number of //
s = size of the alphabet (number of tags)
m = max number of * between two consecutive //

Size of DFA: Multiple Expressions

//section//footnote
//table//footnote
//figure//footnote
. . . . .
//abstract//footnote

100 expressions

2^{100} states !!

There is a theorem here too, but it's not useful…

Solution: Compute the DFA Lazily

- Also used in text searching
- But will it work for 10^6 XPath expressions ?
- YES !
- For XPath it is *provably* effective, for two reasons:
  - XML data is not very deep
  - The nesting structure in XML data tends to be predictable

Duality -> XML databases -> XML streams

Lazy DFA
DFA, view class: XP{/,//,*}

Features

- Sharing the process of / and //, * and tag
- DFA-based
- Compute DFA lazily (on demand)
- # of DFA states
  - Independent from # of XPath exprs.
  - Depends on DataGuide size (schema)

Issue

- Predicates: XPush machine [SIGMOD'03]

Lazy DFA and “Simple” DTDs

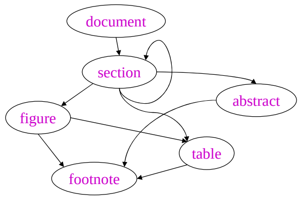
- Document Type Definition (DTD)
  - Part of the XML standard
  - Will be replaced by XML Schema
- Example DTD:

<!ELEMENT document (section*)>
<!ELEMENT section ((section|abstract|table|figure)*)>
<!ELEMENT figure (table?,footnote*)>
. . . . .

Definition A DTD is simple if all cycles are loops

Lazy DFA and “Simple” DTDs

Simple DTD:



XPath expressions

//section//footnote
//table//footnote
//figure//footnote
//abstract//footnote

Eager DFA “remembers” 2^4 sets
Lazy DFA “remembers” only 4 sets

Lazy DFA and “Simple” DTDs

Theorem [GMOS’02] If the XML data has a “simple” DTD, then lazy DFA has at most:

$$\boxed{1+D(1+n)^d}$$

states.

n = max depths of XPath expressions
D = size of the “unfolded” DTD
d = max depths of self-loops in the DTD

Fact of life: “Data-like” XML has simple DTDs

Lazy DFA and Data Guides

- “Non-simple” DTDs are useless for the lazy DFA
- “Everything may contain everything”

<!ELEMENT document (section*)>
<!ELEMENT section ((section|table|figure|abstract|footnote)*)>
<!ELEMENT table ((section|table|figure|abstract|footnote)*)>
<!ELEMENT figure ((section|table|figure|abstract|footnote)*)>
<!ELEMENT abstract ((section|table|figure|abstract|footnote)*)>

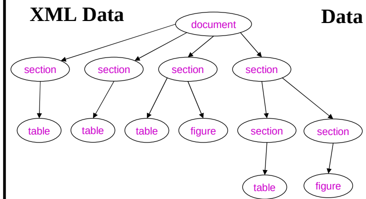
Fact of life: “Text”-like XML has non-simple DTDs

Lazy DFA and Data Guides

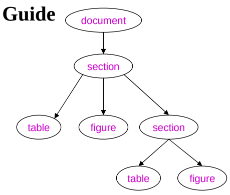
Definition [Goldman&Widom’97]
The data guide for an XML data instance is the Trie of all its root-to-leaf paths

Lazy DFA and Data Guides

XML Data



Data Guide



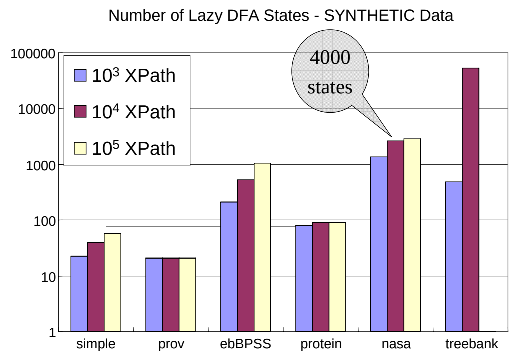
Fact of life: real XML data has “small” data guide [Liefke&S.’00]

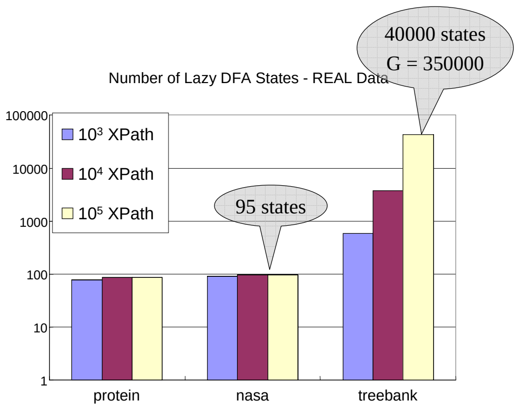
Lazy DFA and “Simple” DTDs

Theorem [GMOS’02] If the XML data has a data guide with G nodes, then the number of states in the lazy DFA is at most:

$\boxed{1+G}$

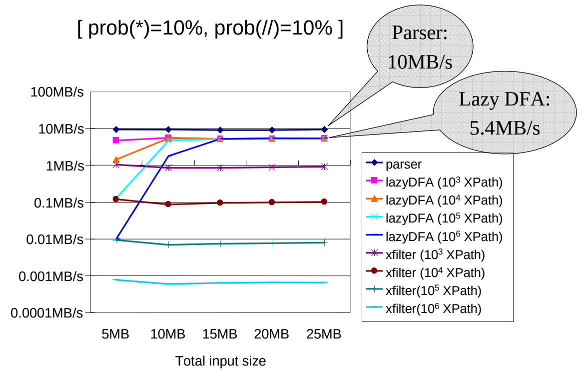
G = number of nodes in the data guide





Throughput for 10^3, 10^4, 10^5, 10^6 XPath expressions

[prob(*)=10%, prob(//)=10%]



END
Lecture 9

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