XML and Databases

Lecture 4
DTDs, Schemas, Regular Expressions, Ambiguity

Sebastian Maneth
NICTA and UNSW

CSE@UNSW -- Semester 1, 2009

2

Outline

0. Comments about PRE/POST encoding & about Assignment 3 (map XML to a DB)
1. DTDs
2. Regular Expressions
3. Finite-State Automata / Glushkov Automaton

3

Some XPath Axes

See `http://www.w3.org/TR/xpath#axes`

→ the `following` axis contains all nodes in the same document as the context node that are after the context node in document order, **excluding any descendants** and excluding attribute nodes and namespace nodes

→ the `preceding` axis contains all nodes in the same document as the context node that are before the context node in document order, **excluding any ancestors** and excluding attribute nodes and namespace nodes

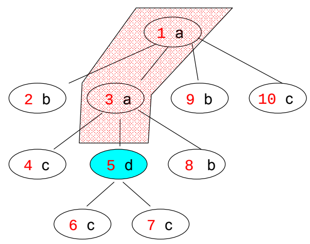
NOTE: The ancestor, descendant, following, preceding and self axes *partition* a document (ignoring attribute and namespace nodes): they **do not overlap** and together they **contain all the nodes in the document**.

4

Some XPath Axes

See `http://www.w3.org/TR/xpath#axes`

`ancestor`(n) = { nodes on the path from n to the root (wo node n)}
`descendant`(n) = { nodes in the subtree rooted at n (wo node n) }
`preceding`(n) = { nodes to the left of n (wo node n) and wo ancestor & descendant}
`following`(n) = { nodes to the right of n (wo node n) and wo ancestor & descendant}



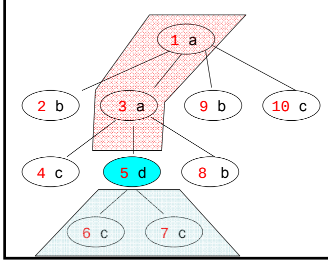
ancestor(5) = { 1, 3 }

5

Some XPath Axes

See `http://www.w3.org/TR/xpath#axes`

`ancestor`(n) = { nodes on the path from n to the root (wo node n)}
`descendant`(n) = { nodes in the subtree rooted at n (wo node n) }
`preceding`(n) = { nodes to the left of n (wo node n) and wo ancestor & descendant}
`following`(n) = { nodes to the right of n (wo node n) and wo ancestor & descendant}



ancestor(5) = { 1, 3 }

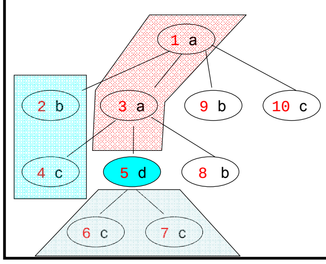
descendant(5) = { 6, 7 }

6

Some XPath Axes

See `http://www.w3.org/TR/xpath#axes`

`ancestor`(n) = { nodes on the path from n to the root (wo node n)}
`descendant`(n) = { nodes in the subtree rooted at n (wo node n) }
`preceding`(n) = { nodes to the left of n (wo node n) and wo ancestor & descendant}
`following`(n) = { nodes to the right of n (wo node n) and wo ancestor & descendant}



ancestor(5) = { 1, 3 }

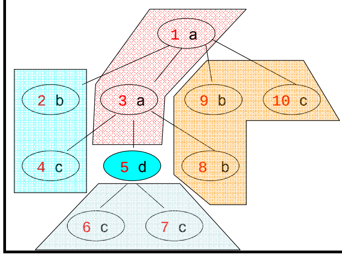
descendant(5) = { 6, 7 }

preceding(5) = { 2, 4 }

Some XPath Axes

See http://www.w3.org/TR/xpath#axes

ancestor(n) = { nodes on the path from n to the root (wo node n)}
descendant(n) = { nodes in the subtree rooted at n (wo node n) }
preceding(n) = { nodes to the left of n (wo node n) and wo ancestor & descendant}
following(n) = { nodes to the right of n (wo node n) and wo ancestor & descendant}



ancestor(5) = { 1, 3 }

descendant(5) = { 6, 7 }

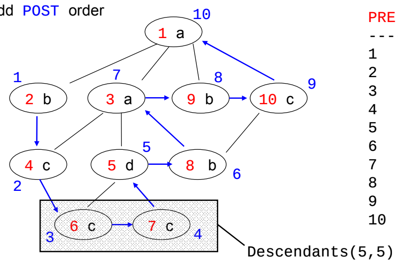
preceding(5) = { 2, 4 }

following(5) = { 8, 9, 10 }

self(5) = { 5 }

Pre/Post Encoding

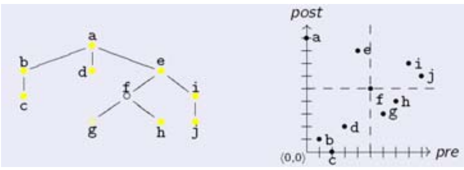
➔ Add POST order

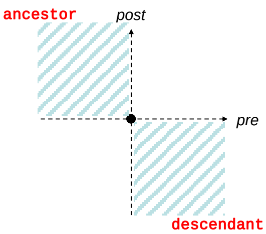


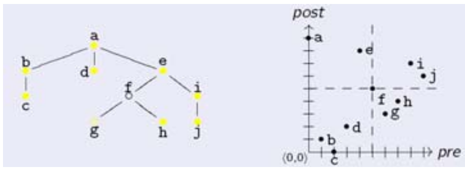
PRE	POST	lab
1	10	a
2	1	b
3	7	a
4	2	c
5	5	d
6	3	c
7	4	c
8	6	b
9	8	b
10	9	c

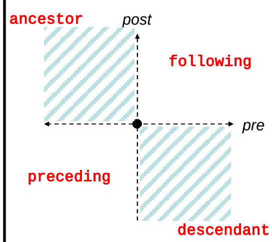
```
Descendants( Pre, Post ) =

  SELECT r1.pre FROM DOCtable r1,
               WHERE r1.pre > Pre
                 AND r1.post < Post
```

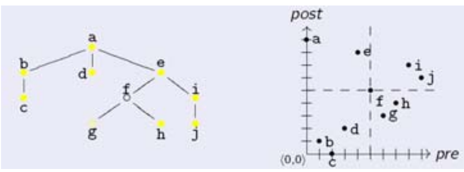
"structural join"

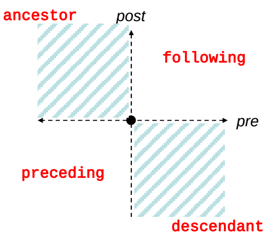




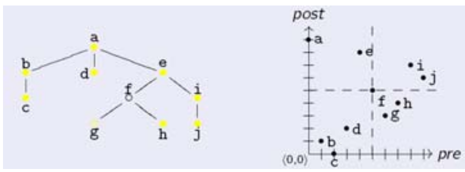


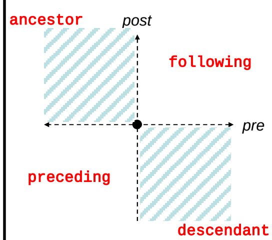






firstChild(pr, po) = ?



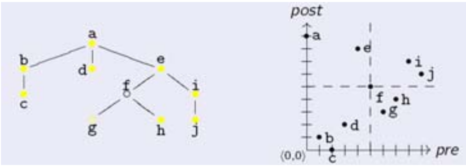


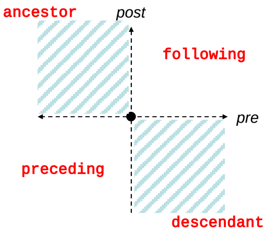
firstChild(pr, po) = left-most node, below and to the right of (pr,po)

or, equivalently

node (pr+1, p) with p < po, if it exists.

13





firstChild(pr, po) = left-most node,
below and to the right of (pr,po)

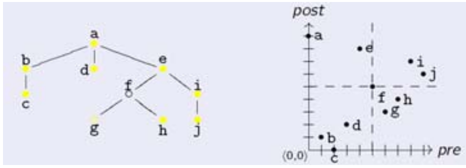
or, equivalently

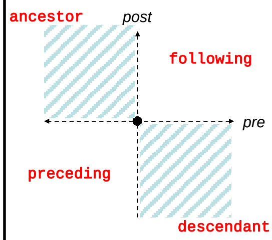
node (pr+1, p) with p < po, if it exists.

lastChild(pr, po) =

node (p, po-1) with p > pr, if it exists.

14

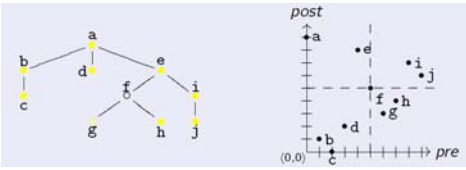


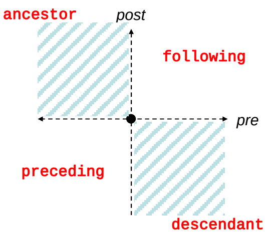


firstChild(pr, po) = left-most node,
below and to the right of (pr,po)

nextSibling(pr, po) =
left-most node,
→ to the right
→ up
such that …?

15





firstChild(pr, po) = left-most node,
below and to the right of (pr,po)

nextSibling(pr, po) =
left-most node (pr2, po2),
→ to the right
→ up
such that there is no node
with post value > po and < po2
to the left.

e.g., **not** c- and d-node
(because b-node is inbetween..)

16

Questions

If you know the **size-of-subtree** at each node, then how can you determine **nextSibling**(pr, po, size)?

If you know the **level** of each node, then how can you determine **parent**(pr, po, level)?
And how **children**(pr, po, level)?

If you do not know size, but know the **level** of a node, then how can you determine size-of-subtree?

If you know pre/post/parent, does that also give you level and size-of-subtree?

firstChild(pr, po) = left-most node,
below and to the right of (pr,po)

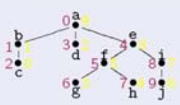
nextSibling(pr, po) =
left-most node (pr2, po2),
→ to the right
→ up
such that there is no node
with post value > po and < po2
to the left.

e.g., **not** c- and d-node
(because b-node is inbetween..)

XPath Accelerator encoding

XML fragment *f* and its skeleton tree

```
<a>
  <b>c</b>
  <!--d-->
  <e><f><g/><?h?></f>
    <i>j</i>
  </e>
</a>
```



Pre/*post* encoding of *f*: table accel

pre	post	par	kind	tag	text
0	9	NULL	elem	a	NULL
1	1	0	elem	b	NULL
2	0	1	text	NULL	c
3	2	0	com	NULL	d
4	8	0	elem	e	NULL
5	5	4	elem	f	NULL
6	3	5	elem	g	NULL
7	4	5	pi	NULL	h
8	7	4	elem	i	NULL
9	6	8	text	NULL	j

18

Assignment 3

Write a program that
→ reads an XML document, and a file with SQL queries
→ sends a PRE/POST/LEVEL encoding to the DB (e.g., MySQL)
→ sends the queries to the DB
→ receives the answers and prints/evaluates them

pre	post	par	kind	tag	text
0	9	NULL	elem	a	NULL
1	1	0	elem	b	NULL
2	0	1	text	NULL	c
3	2	0	com	NULL	d
4	8	0	elem	e	NULL
5	5	4	elem	f	NULL
6	3	5	elem	g	NULL
7	4	5	pi	NULL	h
8	7	4	elem	i	NULL
9	6	8	text	NULL	j

→ Only element/text nodes!

Nice JDBC+MySQL tutorial:
http://www.developer.com/java/data/article.php/3417381

19

Assignment 3

Write a program that
→ reads an XML document, and a file with SQL queries
→ sends a PRE/POST/LEVEL encoding to the DB (e.g., MySQL)
→ sends the queries to the DB
→ receives the answers and prints/evaluates them

pre	post	par	kind	tag	text
0	9	NULL	elem	a	NULL
1	1	0	elem	b	NULL
2	0	1	text	NULL	c
3	2	0	com	NULL	d
4	8	0	elem	e	NULL
5	5	4	elem	f	NULL
6	3	5	elem	g	NULL
7	4	5	pi	NULL	h
8	7	4	elem	i	NULL
9	6	8	text	NULL	j

→ Only element/text nodes!

PLUS **attributes**

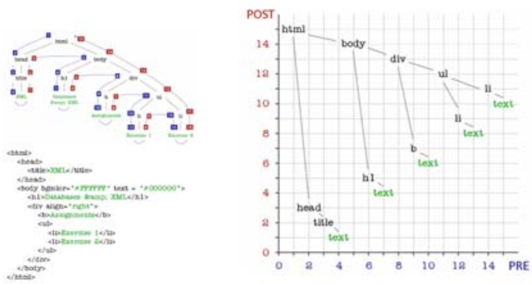
```
<a color="green">
...
</a>
```

Nice JDBC+MySQL tutorial:
http://www.developer.com/java/data/article.php/3417381

20

XML Database – Table Storage

Pre/Post Plane:



21

Assignment 3 Generate (pre,post,tag,text)-table

```
<a>
  <b>Hello World</b>
  <c></c>
</a>
```

```
pre|post |level| tag  | text
-------------------------------
1 |  4  |  1  | "a"  | null
2 |  2  |  2  | "b"  | null
3 |  1  |  3  | null | "Hello World"
4 |  3  |  2  | "c"  | null
```

from the document, generate SQL insert statements

```
INSERT INTO book_tbl (pre,post,tag,text)
VALUE (1, 12, "book", null);
```

22

Assignment 3 Generate (pre,post,tag,text)-table & **(pre,attr,value)-table**

```
<a>
  <b>Hello World</b>
  <c></c>
</a>
```

```
pre|post |level| tag  | text
-------------------------------
1 |  4  |  1  | "a"  | null
2 |  2  |  2  | "b"  | null
3 |  1  |  3  | null | "Hello World"
4 |  3  |  2  | "c"  | null
```

from the document, generate SQL insert statements

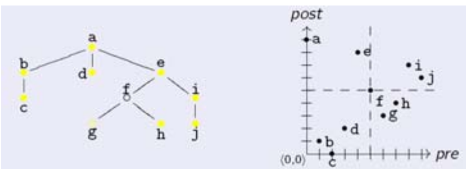
```
INSERT INTO book_tbl (pre,post,tag,text)
VALUE (1, 12, "book", null);
```

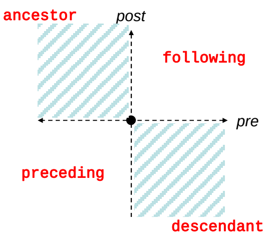
```
<a>
  <b>Hello World</b>
  <c a1="123"></c>
</a>
```

```
pre | attr | value
------------------
  4 |  a1  | "123"
```

```
INSERT INTO book_tbl (pre,post,tag,text)
VALUE (1, 12, "book", null);
```

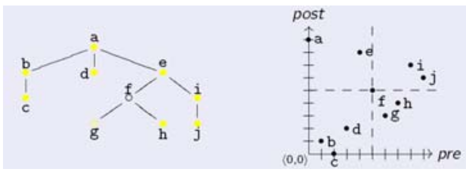
23

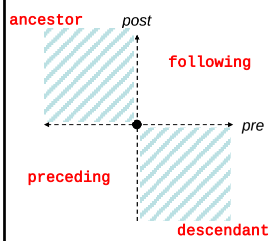




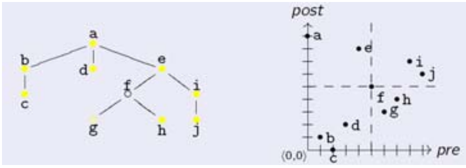
nextSibling(pr, po, LE) =
left-most node (pr2, po2, LE2),
→ to the right
→ up
~~such that there is no node~~
~~with post value > po and < po2~~

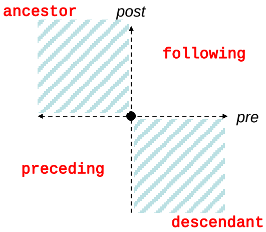
24





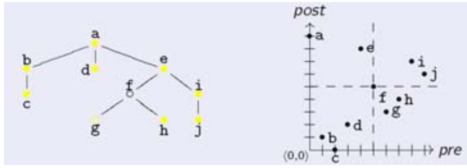
nextSibling(pr, po, LE) =
left-most node (pr2, po2, LE2),
→ to the right
→ up
~~such that there is no node~~
~~with post value > po and < po2~~
↑
if (LE == LE2)





nextSibling(pr, po, LE) =
left-most node (pr2, po2, LE2),
→ to the right
→ up
~~such that there is no node~~
~~with post value > po and < po2~~
if (LE == LE2)

nextSibling(pr, po, pa) = (pr2, po2, pa)
such that pr<pr2 and there is no
(pr3, po3, pa) with pr<pr3<pr2



Using
(pre, SIZE, LEVEL)-encoding:

→ How to compute
all children of a node (p,s,l)?

→ Can you compute the post value
from given (pre, size, level)?

nextSibling(pr, po, LE) =
left-most node (pr2, po2, LE2),
→ to the right
→ up
~~such that there is no node~~
~~with post value > po and < po2~~
if (LE == LE2)

nextSibling(pr, po, pa) = (pr2, po2, pa)
such that pr<pr2 and there is no
(pr3, po3, pa) with pr<pr3<pr2

Later in this course, we will use the PRE/POST encoding again.

→ We will find a systematic way to *map* queries on XML (Xpath)
into XQL queries.

Assignment 5 is about programming this mapping.

Outline - Lectures

1. Introduction to XML, Encodings, Parsers
2. Memory Representations for XML: Space vs Access Speed
3. RDBMS Representation of XML

4. DTDs, Schemas, Regular Expressions, Ambiguity

5. Node Selecting Queries: XPath
6. Efficient XPath Evaluation
7. XPath Properties: backward axes, containment test
8. Streaming Evaluation: how much memory do you need?
9. **XPath Evaluation using RDBMS**
10. XSLT
11. XSLT & XQuery
12. XQuery & Updates

Outline - Assignments

1. Read XML, using DOM parser. Create document statistics.
2. SAX Parse into memory structure: Tree and DAG

3. Map XML into RDBMS → 27. April
4. XPath evaluation → 11. May
5. **XPath into SQL Translation** → 25. May

Lecture 4

DTDs & Reg. Exprs

Today

XML type definition languages

want to specify a certain subset of XML doc's = a "type" of XML documents

Remember
The specification/type definition should be **simple**, so that

→ a *validator* can be built automatically (and efficiently)
→ the *validator* runs efficient on any XML input

(similar demands as for a *parser*)

➔ Type def. language must be SIMPLE!

(similarly: parsers generators use EBNF or smaller subclasses)

O(n^3) parsing

XML Type Definition Languages

DTD (Document Type Definition, W3C)
Originated from SGML. Now part of XML

→DTD may appear at the beginning of an XML document

XML Schema (W3C)
Now at version 1.1
HUGE language, many built-in simple types

→Schemas themselves: written in XML

See the "Schema Primer" at http://www.w3.org/TR/xmlschema-0/

RELAX NG (Oasis)
For tree structure definition, more powerful than DTDs & Schemas

SGML relics

- only a fool does not fear "external general parsed entities"

As an unfortunate heritage from SGML, the header of an XML document may contain a **document type declaration**:

```
<?xml version="1.0"?>
<!DOCTYPE greeting [
  <!ELEMENT greeting (#PCDATA)>
  <!ATTLIST greeting style (big|small) "small">
  <!ENTITY hi "Hello">
]>
<greeting> &hi; world! </greeting>
```

This part can contain:

- DTD (Document Type Definition) information:
  - element type declarations (**ELEMENT**)
  - attribute-list declarations (**ATTLIST**)

  (described later...)
- entity declarations (**ENTITY**) - a simple macro mechanism
- notation declarations (**NOTATION**) - data format specifications

Avoid all these features whenever possible!

Unfortunately, they cannot always be ignored - all XML processors (even non-validating ones) are required to:

- normalize attribute values (prune white-space etc.) ← if the attribute type is not CDATA
- handle internal entity references (e.g. expand `&hi;` in `greeting`)
- insert default attribute values (e.g. insert `style="small"` in `greeting`)

according to the document type declaration, if a such is present.

(also next 4 slides)

SGML relics

- only a fool does not fear "external general parsed entities"

As an unfortunate heritage from SGML, the header of an XML document may contain a **document type declaration**:

```
<?xml version="1.0"?>
<!DOCTYPE greeting [
  <!ELEMENT greeting (#PCDATA)>
  <!ATTLIST greeting style (big|small) "small">
  <!ENTITY hi "Hello">
]>
<greeting> &hi; world! </greeting>
```

This part can contain:

- DTD (Document Type Definition) information:
  - element type declarations (**ELEMENT**)
  - attribute-list declarations (**ATTLIST**)

  (described later...)
- entity declarations (**ENTITY**) - a simple macro mechanism
- notation declarations (**NOTATION**) - data format specifications

Avoid all these features whenever possible!

Unfortunately, they cannot always be ignored - all XML processors (even non-validating ones) are required to:

- normalize attribute values (prune white-space etc.) ← if the attribute type is not CDATA
- handle internal entity references (e.g. expand `&hi;` in `greeting`)
- insert default attribute values (e.g. insert `style="small"` in `greeting`)

according to the document type declaration, if a such is present.

COPYRIGHT © 2000-2003 ANDERS MØLLER & MICHAEL I. SCHWARTZBACH

(also next 4 slides)

Or:
Store DTD in `gr.dtd`, and use:

```
<!DOCTYPE greeting SYSTEM "gr.dtd">
```


Example DTD

A DTD for our recipe collections, `recipes.dtd`:

```
<!ELEMENT collection (description,recipe*)>

<!ELEMENT description ANY>

<!ELEMENT recipe (title,ingredient*,preparation,comment?,nutrition)>

<!ELEMENT title (#PCDATA)>

<!ELEMENT ingredient (ingredient*,preparation)?>
<!ATTLIST ingredient name CDATA #REQUIRED
                     amount CDATA #IMPLIED
                     unit CDATA #IMPLIED>

<!ELEMENT preparation (step*)>

<!ELEMENT step (#PCDATA)>

<!ELEMENT comment (#PCDATA)>

<!ELEMENT nutrition EMPTY>
<!ATTLIST nutrition protein CDATA #REQUIRED
                    carbohydrates CDATA #REQUIRED
                    fat CDATA #REQUIRED
                    calories CDATA #REQUIRED
                    alcohol CDATA #IMPLIED>
```

There are **two** kinds of *recursion* here..

Do you see them?

By inserting:

```
<!DOCTYPE collection SYSTEM "recipes.dtd">
```

in the headers of recipe collection documents, we state that they are intended to conform to `recipes.dtd`.


```
<!ELEMENT collection (description,recipe*)>

<!ELEMENT description ANY>

<!ELEMENT recipe (title,ingredient*,preparation,comment?,nutrition)>

<!ELEMENT title (#PCDATA)>

<!ELEMENT ingredient (ingredient*,preparation)?>
<!ATTLIST ingredient name CDATA #REQUIRED
                     amount CDATA #IMPLIED
                     unit CDATA #IMPLIED>

<!ELEMENT preparation (step*)>

<!ELEMENT step (#PCDATA)>

<!ELEMENT comment (#PCDATA)>

<!ELEMENT nutrition EMPTY>
<!ATTLIST nutrition protein CDATA #REQUIRED
                    carbohydrates CDATA #REQUIRED
                    fat CDATA #REQUIRED
                    calories CDATA #REQUIRED
                    alcohol CDATA #IMPLIED>
```


This grammatical description has some obvious shortcomings:

- we cannot express that, e.g. `protein`, must contain a non-negative number
- `unit` should only be allowed when `amount` is present
- the `comment` element should be allowed to appear anywhere
- nested `ingredient` elements should only be allowed when `amount` is absent

37

- <!DOCTYPE *root-element* [*doctype-declaration*...]>
  determines the name of the root element and contains the document type declarations
- <!ELEMENT *element-name content-model*>
  associates a *content model* to all elements of the given name

  content models:

  - **EMPTY**: no content is allowed
  - **ANY**: any content is allowed
  - **(#PCDATA|*element-name*|...)***: "mixed content", arbitrary sequence of character data and listed elements
  - *deterministic regular expression over element names*: sequence of elements matching the expression
    - choice: (...|...|...)
    - sequence: (...,...,...)
    - optional: ...?
    - zero or more: ...*
    - one or more: ...+
- <!ATTLIST *element-name attr-name attr-type attr-default* ...>
  declares which attributes are allowed or required in which elements

  attribute types:

  - **CDATA**: any value is allowed (the default)
  - **(value|...)**: enumeration of allowed values
  - **ID**, **IDREF**, **IDREFS**: ID attribute values must be unique (contain "element identity"), IDREF attribute values must match some ID (reference to an element)
  - **ENTITY**, **ENTITIES**, **NMTOKEN**, **NMTOKENS**, **NOTATION**: just forget these... (consider them deprecated)

  attribute defaults:

  - **#REQUIRED**: the attribute must be explicitly provided
  - **#IMPLIED**: attribute is optional, no default provided
  - **"value"**: if not explicitly provided, this value inserted by default
  - **#FIXED "value"**: as above, but only this value is allowed

This is a simple subset of SGML DTD.

Validity can be checked by a simple top-down traversal of the XML document (followed by a check of IDREF requirements).

38

Some examples of attribute defs:

(1) Fixed default attribute value

Syntax:
```
<!ATTLIST element-name attribute-name attribute-type #FIXED "value">
```

DTD example:
```
<!ATTLIST sender company CDATA #FIXED "Microsoft">
```

XML example:
```
<sender company="Microsoft">
```

Use if you want an attribute to have a fixed value without allowing the author to change it.

If an author includes another value, the XML parser will return an error.

39

Some examples of attribute defs:

(2) Variable attribute value (with default)

Syntax:
```
<!ATTLIST element-name attribute-name attribute-type "value">
```

DTD example:
```
<!ATTLIST payment type CDATA "check">
```

XML example:
```
<payment type=“check”>
```

Use if you want the attribute to be present with the default value, even if the author did not include it.

40

Some examples of attribute defs:

(2b) Enumerated attribute type

Syntax:
```
<!ATTLIST element-name attribute-name (value_1|value_2|..) “value”>
```

DTD example:
```
<!ATTLIST payment type (cash|check) "cash">
```

XML example:
```
<payment type="check">
or <payment type="cash">
```

Use enumerated attribute values when you want the attribute values to be one of a fixed set of legal values.

41

Some examples of attribute defs:

(3) Required attribute

Syntax:
```
<!ATTLIST element-name attribute_name attribute-type #REQUIRED>
```

DTD example:
```
<!ATTLIST person securityNumber CDATA #REQUIRED>
```

XML example:
```
<person securityNumber=“3141593">
```

↑ **must** be included

Use a required attribute if you don't have an option for a default value, but still want to force the attribute to be present.

If an author forgets a required attribute, the XML parser will return an error.

42

Some examples of attribute defs:

(4) Implied attribute

Syntax:
```
<!ATTLIST element-name attribute_name attribute-type #IMPLIED>
```

DTD example:
```
<!ATTLIST contact fax CDATA #IMPLIED>
```

XML example:
```
<contact fax=“555-667788">
```

↑ **may** be included

Use an implied attribute if you don't want to force the author to include the attribute, and you don't have a default value either.

43

- **<!DOCTYPE *root-element* [*doctype-declaration...*]>**
  determines the name of the root element and contains the document type declarations
- **<!ELEMENT *element-name content-model*>**
  associates a *content model* to all elements of the given name

  content models:
  - **EMPTY**: no content is allowed
  - **ANY**: any content is allowed
  - **(#PCDATA|*element-name*|...)***: "mixed content", arbitrary sequence of character data and listed elements
  - *deterministic regular expression over element names*: sequence of elements matching the expression
    - choice: (...|...|...)
    - sequence: (...,...,...)
    - optional: ...?
    - zero or more: ...*
    - one or more: ...+
- **<!ATTLIST *element-name attr-name attr-type attr-default ...*>**
  declares which attributes are allowed or required in which elements

  attribute types:
  - **CDATA**: any value is allowed (the default)
  - **(value|...)**: enumeration of allowed values
  - **ID**, **IDREF**, **IDREFS**: ID attribute values must be unique (contain "element identity"), IDREF attribute values must match some ID (reference to an element)
  - **ENTITY**, **ENTITIES**, **NMTOKEN**, **NMTOKENS**, **NOTATION**: just forget these... (consider them deprecated)

  attribute defaults:
  - **#REQUIRED**: the attribute must be explicitly provided
  - **#IMPLIED**: attribute is optional, no default provided
  - **"value"**: if not explicitly provided, this value inserted by default
  - **#FIXED "value"**: as above, but only this value is allowed

This is a simple subset of SGML DTD.

Validity can be checked by a simple top-down traversal of the XML document (followed by a check of IDREF requirements).

44

- **<!DOCTYPE *root-element* [*doctype-declaration...*]>**
  determines the name of the root element and contains the document type declarations
- **<!ELEMENT *element-name content-model*>**
  associates a *content model* to all elements of the given name

  content models:
  - **EMPTY**: no content is allowed
  - **ANY**: any content is allowed
  - **(#PCDATA|*element-name*|...)***: "mixed content", arbitrary sequence of character data and listed elements
  - *deterministic regular expression over element names*: sequence of elements matching the expression
    - choice: (...|...|...)
    - sequence: (...,...,...)
    - optional: ...?
    - zero or more: ...*
    - one or more: ...+
- **<!ATTLIST *element-name attr-name attr-type attr-default ...*>**
  declares which attributes are allowed or required in which elements

  attribute types:
  - **CDATA**: any value is allowed (the default)
  - **(value|...)**: enumeration of allowed values
  - **ID**, **IDREF**, **IDREFS**: ID attribute values must be unique (contain "element identity"), IDREF attribute values must match some ID (reference to an element)
  - **ENTITY**, **ENTITIES**, **NMTOKEN**, **NMTOKENS**, **NOTATION**: just forget these... (consider them deprecated)

  attribute defaults:
  - **#REQUIRED**: the attribute must be explicitly provided
  - **#IMPLIED**: attribute is optional, no default provided
  - **"value"**: if not explicitly provided, this value inserted by default
  - **#FIXED "value"**: as above, but only this value is allowed

This is a simple subset of SGML DTD.

How??

Validity can be checked by a simple top-down traversal of the XML document (followed by a check of IDREF requirements).

45

The Definition of Mixed Content

- *Mixed content* is described by a repeatable OR group

  (#PCDATA | *element-name* | …)*

  - Inside the group, no regular expressions – just element names
  - #PCDATA must be first, followed by 0 or more element names that are separated by |
  - The group can be repeated 0 or more times

➔ It should be clear how to check validity of Mixed Content!

46

Most interesting content mode:

Regular Expression

An Address-Book XML Document with an Internal DTD

```
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE addressbook [
  <!ELEMENT addressbook (person*)>
  <!ELEMENT person
     (name, greet?, address*, (fax | tel)*, email*)>
  <!ELEMENT name    (#PCDATA)>
  <!ELEMENT greet   (#PCDATA)>
  <!ELEMENT address    (#PCDATA)>
  <!ELEMENT tel     (#PCDATA)>
  <!ELEMENT fax     (#PCDATA)>
  <!ELEMENT email   (#PCDATA)>
]>
```

The name of the DTD is addressbook

The syntax of a DTD is *not* XML syntax

"Internal" means that the DTD and the XML Document are in the same file

2005

47

Most interesting content mode:

Regular Expression

1. What is a regular expression?
   Given a reg. expr. how can we match a string against it?
2. What is a finite-state automaton?
3. What is a **deterministic** regular expression?
4. What is a 1-unambiguous regular expression?

48

Specifying the Structure (cont'd)

- addr* — to specify 0 or more address lines
- tel | fax — a tel *or* a fax element
- (tel | fax)* — 0 or more repeats of tel or fax
- email* — 0 or more email elements

2005 http://www.cs.huji.ac.il/~dbi 33

Specifying the Structure (cont'd)

- So the whole structure of a person entry is specified by

name, greet?, addr*, (tel | fax)*, email*

- This is known as a regular expression
- Why is it important?

Summary of Regular Expressions

- A — The tag (i.e., element) A occurs
- e1,e2 — The expression e1 followed by e2
- e* — 0 or more occurrences of e
- e? — Optional: 0 or 1 occurrences
- e+ — 1 or more occurrences
- e1 | e2 — either e1 or e2
- (e) — grouping

Regular Expressions are a very useful concept.

→used in EBNF, for defining the syntax of PLs

→used in various unix tools (e.g., `grep`)

→used in `Perl,Tcl`, text editors (like `ed,emacs`, …)

→Old classical concept in CS (Stephen Kleene, 1950's)

How can you **implement** a regular expression?

Input: Reg Expr e, string w
Question: Does w match e?

Example
e = (ab | b)* a* a

w = a b b a a b a

Regular Expressions are a very useful concept.

→used in EBNF, for defining the syntax of PLs

→used in various unix tools (e.g., `grep`)

→used in `Perl,Tcl`, text editors (like `ed,emacs`, …)

→Old classical concept in CS (Stephen Kleene, 1950's)

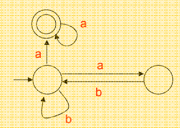
How can you **implement** a regular expression?

Input: Reg Expr e, string w
Question: Does w match e?

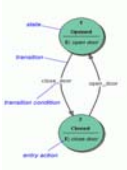
Example
e = (ab | b)* a* a

w = a b b a a b a

→Construct a Finite-State Automaton



Finite-State Automata (FA) even more useful concept!



→they **truly** incarnate *constant memory* computation.

→like Turing Machines, but *read-only* and *one-way* (left-to-right)

→for every Reg Exp there is a FA (and vica versa)

→useful in many, many areas of CS (verification, compilers, learning, hardware, linguistics, UML, etc, etc)

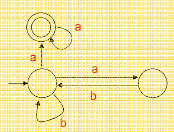
How can you **implement** a regular expression?

Input: Reg Expr e, string w
Question: Does w match e?

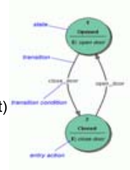
Example
e = (ab | b)* a* a

w = a b b a a b a

→Construct a Finite-State Automaton



Finite-State Automata (FA) even more useful concept!



→they **truly** incarnate *constant memory* computation.

→like Turing Machines, but read-only and one-way (left-to-right)

→for every Reg Exp there is a FA (and vica versa)

→for every FA there is an equivalent *deterministic* FA
(= per letter *at most one* outgoing edge)

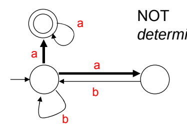
How can you **implement** a regular expression?

Input: Reg Expr e, string w
Question: Does w match e?

Example
e = (ab | b)* a* a

w = a b b a a b a

→Construct a Finite-State Automaton



NOT
deterministic

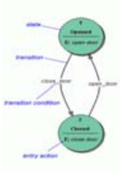
Finite-State Automata (FA) even more useful concept!

→they **truly** incarnate *constant memory* computation.

→like Turing Machines, but read-only and one-way (left-to-right)

→for every Reg Exp there is a FA (and vica versa)

→for every FA there is an equivalent *deterministic* FA
(= per letter *at most one* outgoing edge)



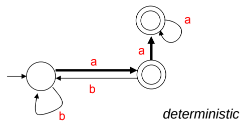
How can you **implement** a regular expression?

Input: Reg Expr e, string w
Question: Does w match e?

Example
e = (ab | b)* a* a

w = a b b a a b a

→Construct a Finite-State Automaton



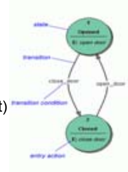
Finite-State Automata (FA) even more useful concept!

→they **truly** incarnate *constant memory* computation.

→like Turing Machines, but read-only and one-way (left-to-right)

→for every Reg Exp there is a FA (and vica versa)

→for every FA there is an equivalent *deterministic* FA
(= per letter *at most one* outgoing edge)

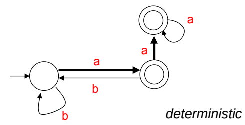


How can you **implement** a regular expression?

Input: Reg Expr e, string w
Question: Does w match e?

deterministic FA: run on w takes
time **linear** in length(w)
and **constant space** (#states, e.g., 3 →)

→Construct a Finite-State Automaton



57

Finite-State Automata (FA)

→ For every FA you can build and equivalent *deterministic* FA ☺
But, could become **exponentially** larger, ☹
sometimes unavoidable (FA is more *succinct*)

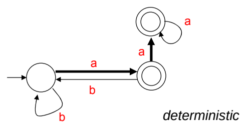
→ For every *deterministic FA* you can build a *minimal unique equivalent* one
Thus, equivalence is decidable! ☺
Very rare! --- E.g., equivalence of EBNF's is NOT decidable.

How can you **implement** a regular expression?

Input: Reg Expr e, string w
Question: Does w match e?

deterministic FA: run on w takes
time **linear** in length(w)
and **constant space** (#states, e.g., 3 →)

→Construct a Finite-State Automaton



58

Why?
Can you find an example?

Finite-State Automata (FA)

→ For every FA you can build and equivalent *deterministic* FA ☺
But, could become **exponentially** larger, ☹
sometimes unavoidable (FA is more *succinct*)

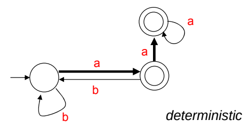
→ For every *deterministic FA* you can build a *minimal unique equivalent* one
Thus, equivalence is decidable! ☺
Very rare! --- E.g., equivalence of EBNF's is NOT decidable.

How can you **implement** a regular expression?

Input: Reg Expr e, string w
Question: Does w match e?

deterministic FA: run on w takes
time **linear** in length(w)
and **constant space** (#states, e.g., 3 →)

→Construct a Finite-State Automaton



59

Finite-State Automata (FA)

→ For every FA you can build and equivalent *deterministic* FA ☺
But, could become **exponentially** larger, ☹
sometimes unavoidable (FA is more *succinct*)

→ For every *deterministic FA* you can build a *minimal unique equivalent* one
Thus, equivalence is decidable! ☺
Very rare! --- E.g., equivalence of EBNF's is NOT decidable.

How can you **implement** a regular expression?

Input: Reg Expr e, string w
Question: Does w match e?

deterministic FA: run on w takes
time **linear** in length(w)

Algorithm

```
FA = BuildFA(e);
DFA = BuildDFA(FA);
```

Size of FA is linear in size(e)=m
Size of DFA is exponential in m

n = length(w) **Total Running time** O(n + 2^m)

60

Finite-State Automata (FA)

→ For every FA you can build and equivalent *deterministic* FA ☺
But, could become **exponentially** larger, ☹
sometimes unavoidable (FA is more *succinct*)

→ For every *deterministic FA* you can build a *minimal unique equivalent* one
Thus, equivalence is decidable! ☺
Very rare! --- E.g., equivalence of EBNF's is NOT decidable.

How can you **implement** a regular expression?

Input: Reg Expr e, string w
Question: Does w match e?

deterministic FA: run on w takes
time **linear** in length(w)

Algorithm

```
FA = BuildFA(e);
DFA = BuildDFA(FA);
```

Size of FA is linear in size(e)=m
Size of DFA is exponential in m

n = length(w) **Total Running time** O(n + 2^m)

→ Other alternative: O(nm)

61

To avoid these expensive running times

W3C simply requires that `FA=BuildFA(e)` must be deterministic already!

Is small! ☺
size is only O(m)

W3C DTD-defin.

How can you **implement** a regular expression?

Input: Reg Expr e, string w
Question: Does w match e?

deterministic FA: run on w takes time **linear** in length(w)

Algorithm

```
FA = BuildFA(e);
DFA = BuildDFA(FA);
```

Size of FA is linear in size(e)=m
Size of DFA is exponential in m

n = length(w) **Total Running time** O(n + 2^m)

→ Other alternative: O(nm)

62

To avoid these expensive running times

W3C simply requires that `FA=BuildFA(e)` must be deterministic already!

Is small! ☺
size is only O(m)

Unfortunately, we will loose some regular expressions (which hence are *not allowed* to appear in a DTD!!)

W3C DTD-defin.

How can you **implement** a regular expression?

Input: Reg Expr e, string w
Question: Does w match e?

deterministic FA: run on w takes time **linear** in length(w)

Algorithm

```
FA = BuildFA(e);
DFA = BuildDFA(FA);
```

Size of FA is linear in size(e)=m
Size of DFA is exponential in m

n = length(w) **Total Running time** O(n + 2^m)

→ Other alternative: O(nm)

63

To avoid these expensive running times

W3C simply requires that `FA=BuildFA(e)` must be deterministic already!

Is small! ☺
size is only O(m)

How does `BuildFA(e)` work?
"**Glushkov automaton**" = "position automaton"
/ more details later, if time permits

How can you **implement** a regular expression?

Input: Reg Expr e, string w
Question: Does w match e?

deterministic FA: run on w takes time **linear** in length(w)

Algorithm

```
FA = BuildFA(e);
DFA = BuildDFA(FA);
```

Size of FA is linear in size(e)=m
Size of DFA is exponential in m

n = length(w) **Total Running time** O(n + 2^m)

→ Other alternative: O(nm)

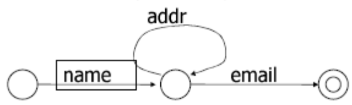
64

Regular Expressions

- Each regular expression determines a corresponding *finite-state automaton*
- Let's start with a simpler example:

name, addr*, email

A double circle denotes an accepting state



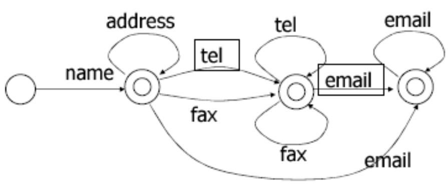
This suggests a simple parsing program

2005 http://www.cs.huji.ac.il/~dbi 40

65

Another Example

name,address*,(tel | fax)*,email*



Adding in the optional greet further complicates things

2005 http://www.cs.huji.ac.il/~dbi 41

66

Deterministic Requirement: Content Models must be Deterministic

- If element-type declarations are deterministic, it is easier to parse XML documents
- W3C XML recommendation requires the Glushkov automaton to be deterministic
- The states of this automaton are the positions of the regular expression (semantic actions)
- The transitions are based on the "follows set"

2005 http://www.cs.huji.ac.il/~dbi 42

67

Deterministic Requirement (cont'd)

- The associated automata are succinct
- A regular language may not have an associated deterministic grammar, e.g.,

<!ELEMENT ndeter

((movie|director)*,movie,(movie|director))>

This is not allowed in a DTD

(a|b)*a(a|b)

68

To summarize

In order to check whether a (large) document
is **valid** wrt to a given DTD ("it validates")
you need to

→ Check if children lists match the given Reg Expr's

This can be done *efficiently*, using **finite-automata**!

To check if a Reg Expr is **allowed in a DTD**
we have to construct a particular finite automaton: the **Glushkov automaton**.

69

To summarize

Next, let us look at some other (minor) issues

→ Unordered lists (permutations)
→ Recursive DTDs

70

Some Things are Hard to Specify

Each employee element should contain name, age and ssn elements in some order

```
<!ELEMENT employee
   ( (name, age, ssn) | (age, ssn, name) |
     (ssn, name, age) | ...
   )>
```

Suppose that there were many more fields!

71

Recursive DTDs

```
<DOCTYPE genealogy [
   <!ELEMENT genealogy (person*)>
   <!ELEMENT person (
               name,
               dateOfBirth,
               person,      -- mother
               person  )>   -- father
   ...
]>
```

What is the problem with this?

A parser does not notice it!

72

Recursive DTDs

```
<DOCTYPE genealogy [
   <!ELEMENT genealogy (person*)>
   <!ELEMENT person (
               name,
               dateOfBirth,
               person,      -- mother
               person  )>   -- father
   ...
]>
```

What is the problem with this?

A parser does not notice it!

Each person should have a father and a mother. This leads to either infinite data or a person that is a descendent of herself.

Recursive DTDs (cont'd)

```
<DOCTYPE genealogy [
   <!ELEMENT genealogy (person*)>
   <!ELEMENT person (
                  name,
                  dateOfBirth,
                  person?,       -- mother
                  person?  )>    -- father
   ...
]>
```

What is now the problem with this?

Recursive DTDs (cont'd)

```
<DOCTYPE genealogy [
   <!ELEMENT genealogy (person*)>
   <!ELEMENT person (
                  name,
                  dateOfBirth,
                  person?,       -- mother
                  person?  )>    -- father
   ...
]>
```

If a person only has a mother, how can you tell that he has a mother and does not have a father?

What is now the problem with this?

Document Type Definitions (DTDs)

- The XML specification restricts regular expressions in DTDs to be deterministic (*1-unambiguous*).
- Unambiguous regular expression: "*each word is witnessed by at most one sequence of positions of symbols in the expression that matches the word*" .[Brüggemann-Klein, Wood 1998]
  - ✓ Ambiguous expression $(a + b)^*aa^*$ —mark with subscripts→ $(a_1 + b_1)^*a_2a_3^*$
  - ✓ For aaa → three witnesses: $a_1a_1a_2$ $a_1a_2a_3$ $a_2a_3a_3$
  - ✓ Unambiguous equivalent expression : $(a + b)^*a$

(this and next 2, from: www.infosys.uni-sb.de/teaching/streams0506/slides/stoyan.mutafchiev.slides.**ppt**

Document Type Definitions (DTDs)

- Is it enough for our purpose if the regular expression is unambiguous ? *No, it is not enough*
- the same unambiguous regular expression:
  $(a + b)^*a$ —mark with subscripts→ $(a_1 + b_1)^*a_2$
- consider : baa
  - ✓ one witness: $b_1a_1a_2$ (unambiguous)
  - ✓ it is not possible to decide b_1a? without looking ahead
- *Without looking beyond that symbol in the input word* [1-unambiguous]

$(a + b)^*a$ ≡ ?
unambiguous — 1-unambiguous

Can you find a 1-unambiguous Reg Exp for $(a + b)^*a$ … not so easy…. ☺

Document Type Definitions (DTDs)

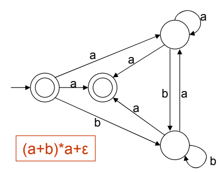
- Is it enough for our purpose if the regular expression is unambiguous ? *No, it is not enough*
- the same unambiguous regular expression:
  $(a + b)^*a$ —mark with subscripts→ $(a_1 + b_1)^*a_2$
- consider : baa
  - ✓ one withness: $b_1a_1a_2$ (unambiguous)
  - ✓ it is not possible to decide b_1a? without looking ahead
- *Without looking beyond that symbol in the input word* [1-unambiguous]

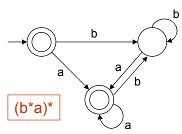
$(a + b)^*a$ ≡ $b^*a(b^*a)^*$
unambiguous — 1-unambiguous

Document Type Definitions (DTDs)

[Brüggemann-Klein, Wood 1998]:

- Can we recognize deterministic regular expressions?
  - ✓ *A regular expression is deterministic (one-unambiguous) iff its Glushkov automaton is deterministic.*
  - ✓ *The Gluschkov automaton can be computed in time quadratic in the size of the regular expression*





Glushkov's automaton

R (E | G) (E X) *

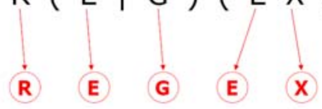
Following slides from: http://www.cs.ut.ee/~varmo/tday-rouge/tammeoja-slides.pdf

10

Glushkov's automaton

- Character in RE = **state** in automaton

R (E | G) (E X) *



11

Glushkov's automaton

- Character in RE = **state** in automaton
  + one state for the beginning of the RE

R (E | G) (E X) *

12

Glushkov's automaton

- Character in RE = **state** in automaton
  + one state for the beginning of the RE
- **Transitions** show which characters/positions can precede each other

R (E | G) (E X) *

R...

13

Glushkov's automaton

- Character in RE = **state** in automaton
  + one state for the beginning of the RE
- **Transitions** show which characters/positions can precede each other

R (E | G) (E X) *

R...

14

Glushkov's automaton

- Character in RE = **state** in automaton
  + one state for the beginning of the RE
- **Transitions** show which characters/positions can precede each other

R (E | G) (E X) *

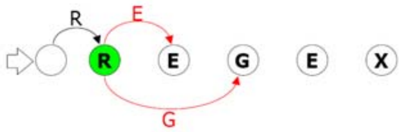
R...

15

Glushkov's automaton

- Character in RE = **state** in automaton
  + one state for the beginning of the RE
- **Transitions** show which characters/positions can precede each other

R (E | G) (E X) *

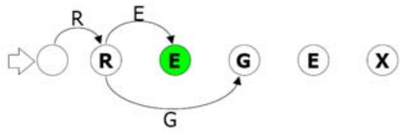


RE...
RG...

Glushkov's automaton

- Character in RE = **state** in automaton
  + one state for the beginning of the RE
- **Transitions** show which characters/positions can precede each other

R (E | G) (E X) *

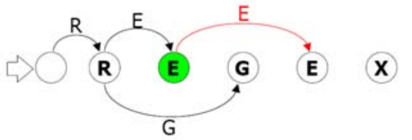


R**E**...

Glushkov's automaton

- Character in RE = **state** in automaton
  + one state for the beginning of the RE
- **Transitions** show which characters/positions can precede each other

R (E | G) (E X) *

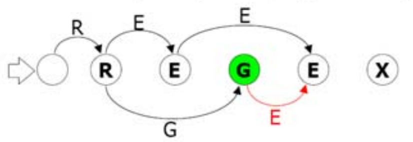


R**E**E...

Glushkov's automaton

- Character in RE = **state** in automaton
  + one state for the beginning of the RE
- **Transitions** show which characters/positions can precede each other

R (E | G) (E X) *

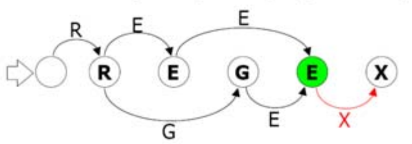


R**G**E...

Glushkov's automaton

- Character in RE = **state** in automaton
  + one state for the beginning of the RE
- **Transitions** show which characters/positions can precede each other

R (E | G) (E X) *

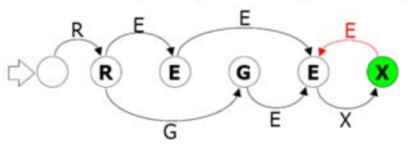


RG**E**X...

Glushkov's automaton

- Character in RE = **state** in automaton
  + one state for the beginning of the RE
- **Transitions** show which characters/positions can precede each other

R (E | G) (E X) *

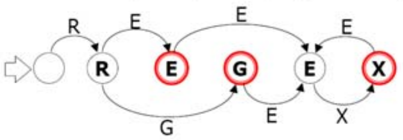


RGE**X**E...

Glushkov's automaton

- Character in RE = **state** in automaton + one state for the beginning of the RE
- **Transitions** show which characters/positions can precede each other

R (E | G) (E X) *

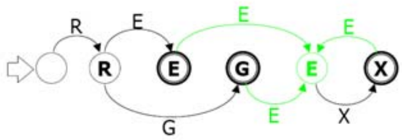


22

Glushkov's automaton

- All labels entering a node are labeled by the same character

for example **after reading character 'E' only states with label 'E' can be active**



25

93

Questions

E = (a_1? a_2? a_3? … a_n?)* 1) Does E contain: w = a_1 a_3 a_2 a_1

2) Construct the Glushkov automaton for E.

3) How many transitions (edges) does this automaton have?

4) Is there a smaller automaton which recognizes the same set of strings?

5) What is the smallest equivalent automaton? (→ merge states)

94

Questions

E = (a_1? a_2? a_3? … a_n?)* 1) Does E contain: w = a_1 a_3 a_2 a_1

2) Construct the Glushkov automaton for E.

3) How many transitions (edges) does this automaton have?

4) Is there a smaller automaton which recognizes the same set of strings?

5) What is the smallest equivalent automaton? (→ merge states)

F = (a_1? a_2? a_3? … a_n? c)*

How many transitions are in the Glushkov automaton for F?

And how many in F's minimal automaton?

Does F contain: v = a_3 a_2 c

95

Question

Why does it take **quadratic time**, to construct the Glushkov automaton for a given regular expression E?

O(n^2), where n is the *length* of the regular expression E.

Given an input string w of length m, it takes us time O(n^2 + m) to check w against E.

Can this be improved for the case the m is small (non-quadratic) with resepect to n?

→ do not want to construct the full automaton, because that is too expensive..

96

END
Lecture 4