XML and Databases

Lecture 5
XML Validation using Automata

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CSE@UNSW -- Semester 1, 2010

Outline

1. Recap: deterministic Reg Expr's
   / Glushkov Automaton

2. Complexity of DTD validation

3. Beyond DTDs: XML Schema and RELAX NG

4. Static Methods, based on Tree Automata

Previous Lecture

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: parser generators use EBNF or smaller subclasses: LL / LR)

↑ 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

Reg Exprs
must be
deterministic
(=1-unambiguous)

same!!

"*Unique*
Particle Attribution"

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 Schemas&DTDs

XML Type Definition Languages

DTD (Document Type Definition)

```
<!DOCTYPE root-element [ doctype declaration …]>
```

```
<!ELEMENT element-name content-model>
```

content-models

- EMTPY
- ANY
- (#PCDATA | elem-name_1 | … | elem-name_n)*
- deterministic Reg Expr over element names

```
<!ATTLIST element-name attr-name attr-type attr-default ..>
```

Types: CDATA, (v1|..), ID, IDREFs
Defaults: #REQUIRED, #IMPLIED, “value”, #FIXED

XML Type Definition Languages

DTD (Document Type Definition)

```
<!DOCTYPE root-element [ doctype declaration …]>
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```
<!ELEMENT element-name content-model>
```

content-models

- EMTPY
- ANY
- (#PCDATA | elem-name_1 | … | elem-name_n)*
- deterministic Reg Expr

Most interesting / challenging aspect of DTDs

```
<!ATTLIST element-name attr-name attr-type attr-default ..>

Types: CDATA, (v1|..), ID, IDREFs
Defaults: #REQUIRED, #IMPLIED, “value”, #FIXED
```

Summary

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 (FAs)**!

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

Glu(e)

Glu(e) must be *deterministic*.

Note If Glu(e) is *deterministic*, then its size (# transitions) is *linear* in size(e)!

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(Glushkov automaton = Glu(e))

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Note If Glu(e) is *deterministic*, then its size (# transitions) is *linear* in size(e)!

Question Can you explain why this is the case?

Summary

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Glu(e) must be *deterministic*.

Note If Glu(e) is *deterministic*, then its size (# transitions) is ~~*linear*~~ in size(e)!

Question Can you explain why this is the case?

not correct:
linear in **size(e) * #letters(e)**

More Notes

(1) From a *deterministic* FA you can**not** obtain a deterministic (= 1-unambiguous) regular expression!!

Example: e = (a | b)* a (a | b) ← NO 1-unambiguous reg exp exists for e

Question
Can you build a **Deterministic Automaton** for the expression e?

More Notes

(1) From a *deterministic* FA you can**not** obtain a deterministic (= 1-unambiguous) regular expression!!

Example: e = (a | b)* a (a | b) ← NO 1-unambiguous reg exp exists for e

Deterministic Automaton for e:
E.g., first nondeterministic FA, then determinize (subset construction)
CAVE: can cause exponential size blow-up!

Other important constructions on Finite Automata:

- → Union (easy)
- → Intersection (product construction)
- → Complementation

Question
Size blow-up for these?

For more details:
See paper by Brüggemann-Klein,
Linked from the course web-page.

More Notes

(1) From a *deterministic* FA you can**not** obtain a deterministic (= 1-unambiguous) regular expression!!

Example: e = (a | b)* a (a | b) ← NO 1-unambiguous reg exp exists for e

(2) Glu(e) is closely related to → Thomson(e) [remove ε-transitions]
and to → Berry/Sethi(e) [same]
and → Brzozowski(e)

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

(Glushkov automaton = Glu(e))

Note If Glu(e) is *deterministic*, then its size is *linear* in **size(e) * #letters(e)**

Glushkov automaton Glu(e)

Each letter-position in the Reg Expr e becomes one state of Glu;
plus, Glu has one extra begin state.

FIRST(e) = all possible begin positions of words matching e

e.g. FIRST(R (E | G) (EX)*) = { R_1 }

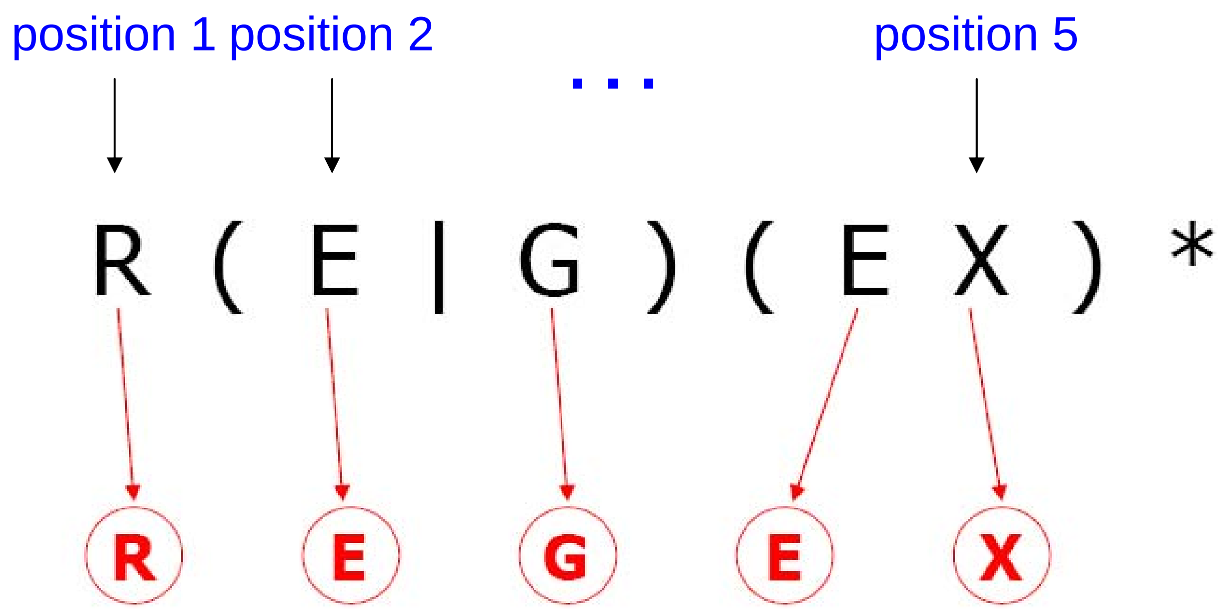
Glushkov's automaton

R (E | G) (E X) *

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

Glushkov's automaton

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



Glushkov's automaton

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

R (E | G) (E X) *

Glushkov's automaton

- Character in RE = **state** in automaton
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- **Transitions** show which characters/positions can precede each other

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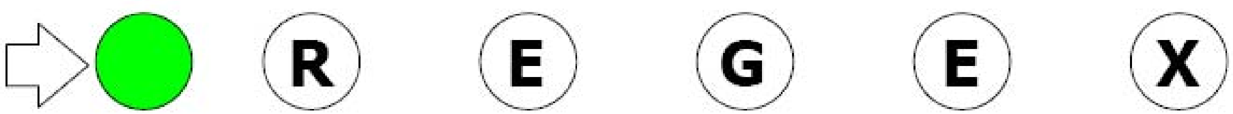

R...

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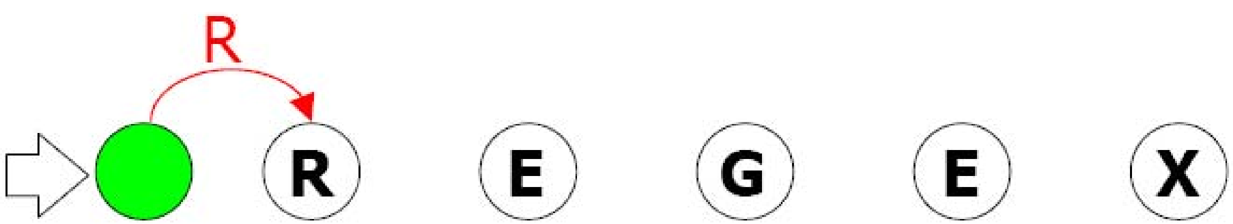

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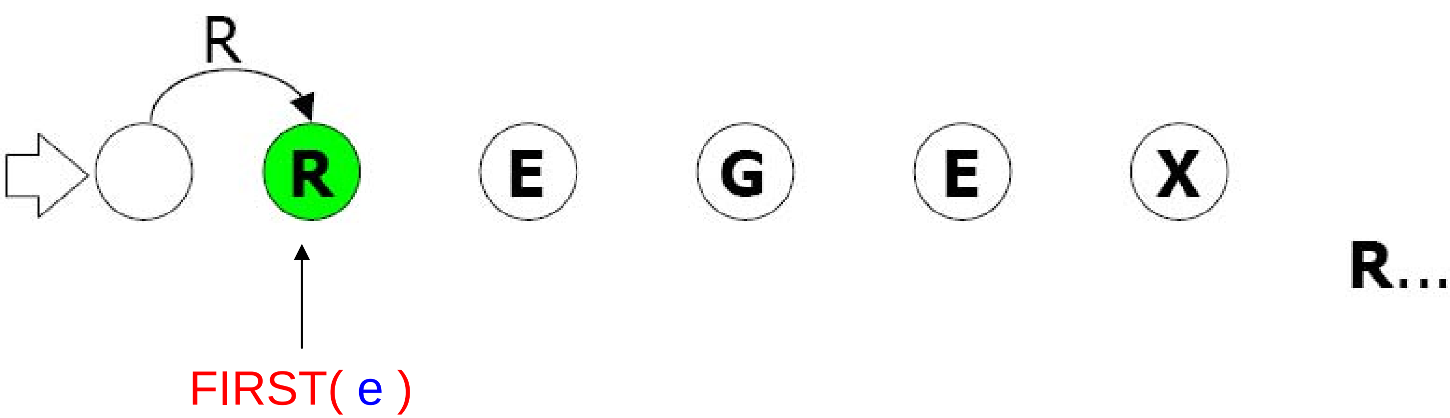

Glushkov automaton G(e)

Each position in the Reg Expr e becomes one state of G;
plus, G has one extra begin state.

FIRST(e) = all possible begin positions of words matching e

e.g. FIRST(R (E | G) (EX)*) = { R_1 }

FOLLOW(e, x) = all possible positions following position x in e

e.g. FOLLOW(R (E | G) (EX)*, R_1) = { E_2, G_3 }

➔ From state "R_1": add E-transition to E_2
G-transition to G_3

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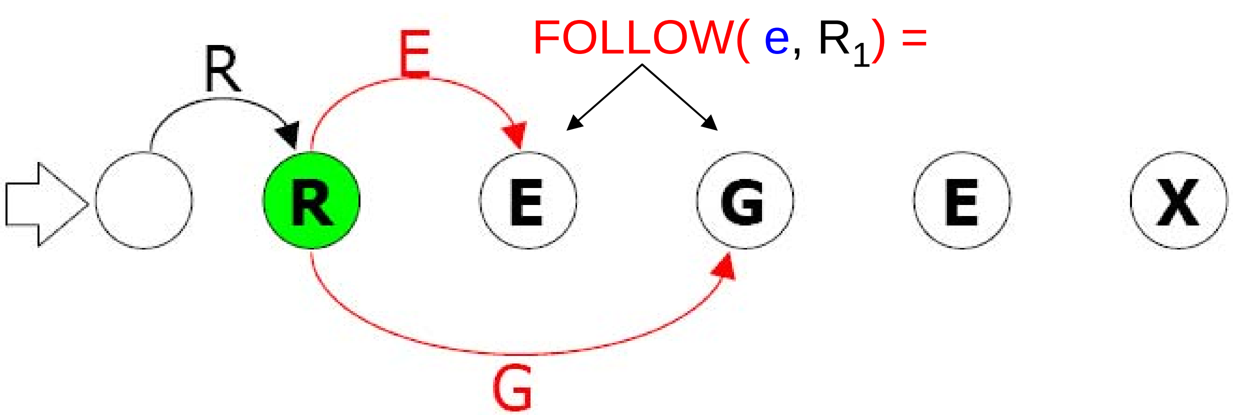

RE...
RG...

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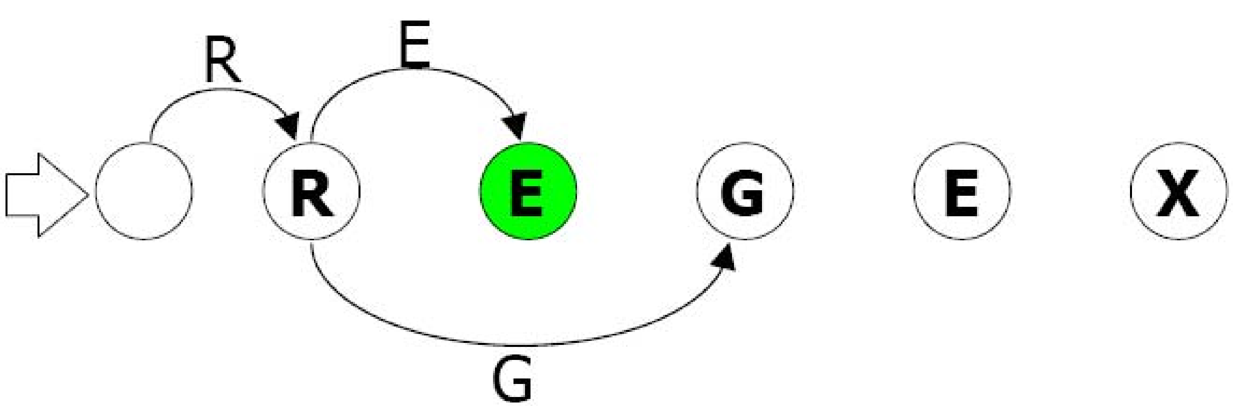

RE...

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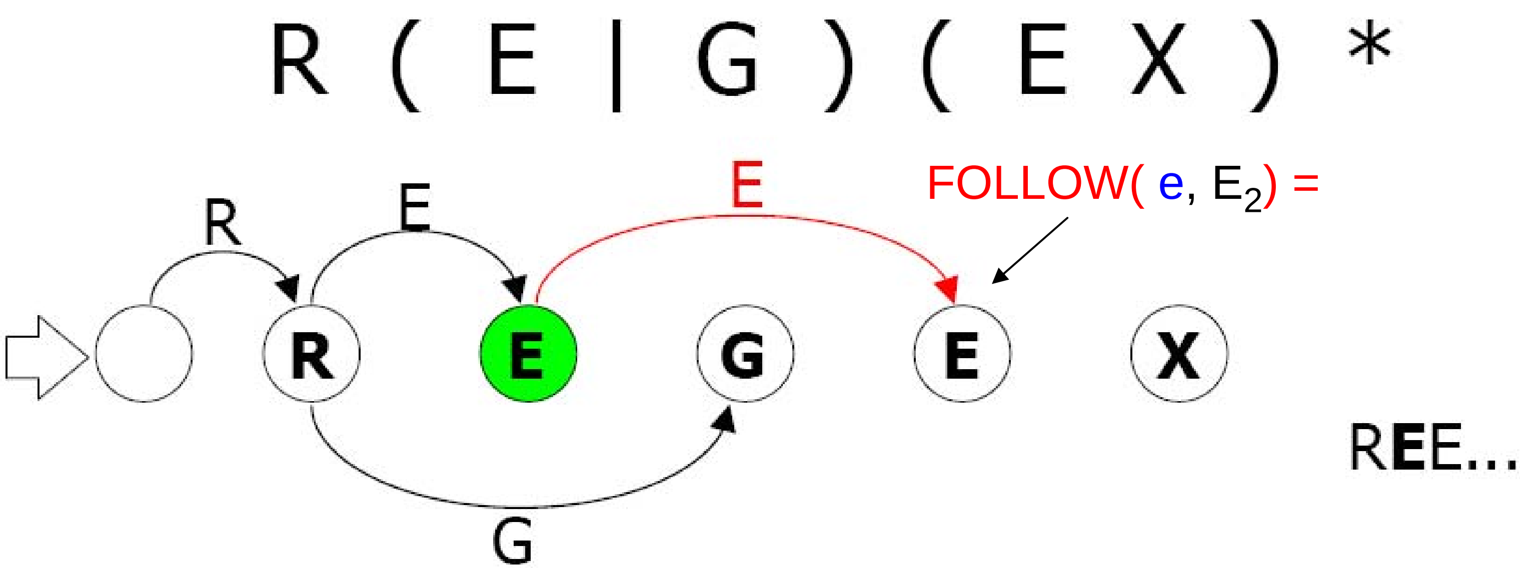

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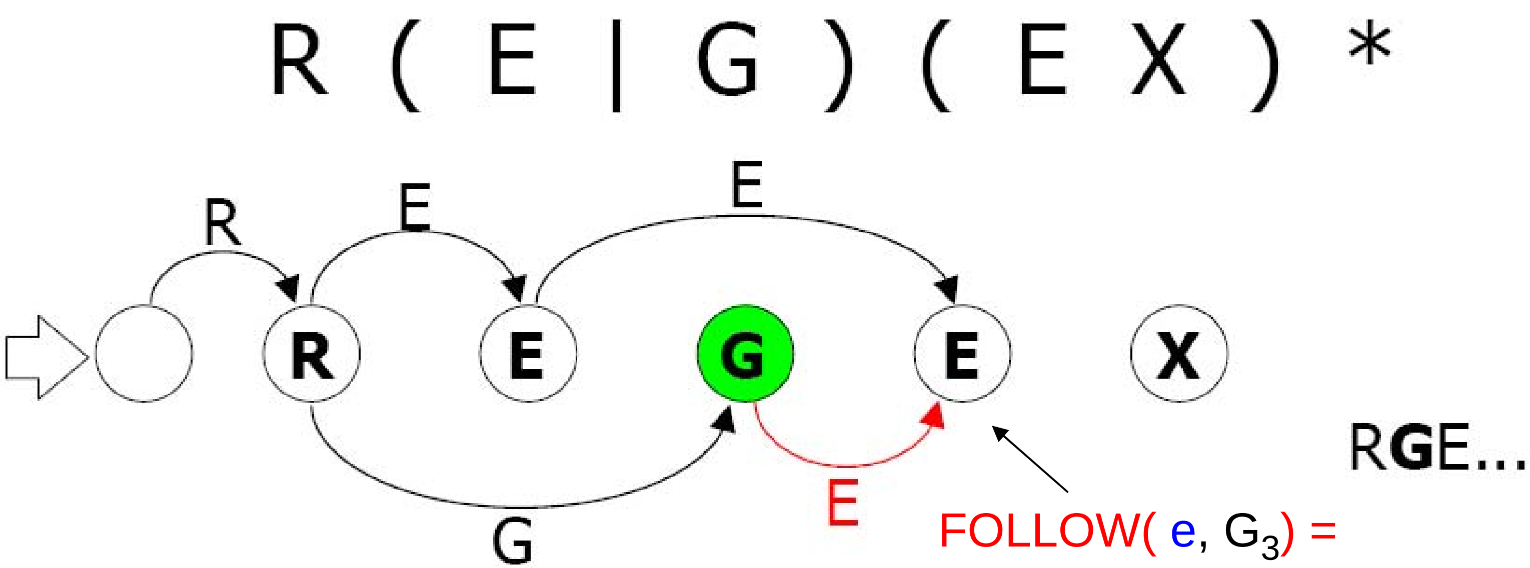

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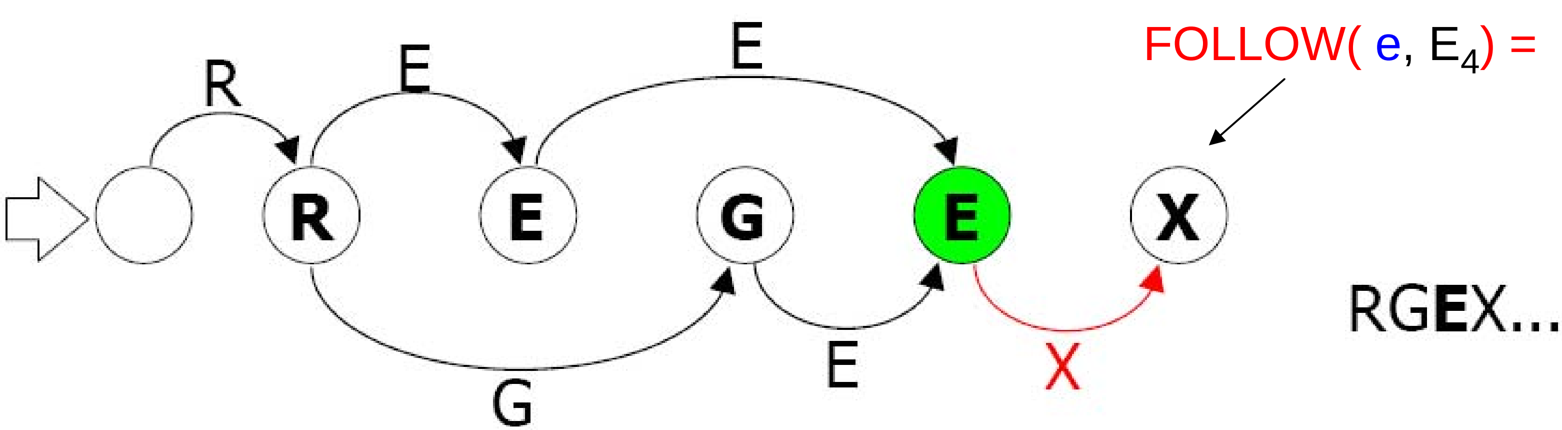

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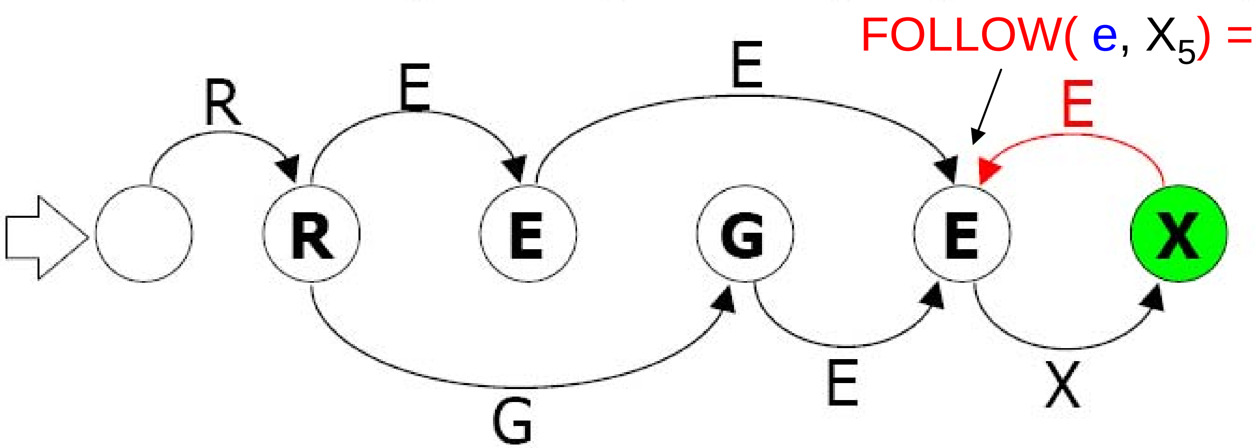

RGE**X**E...

Glushkov automaton G(e)

Each position in the Reg Expr e becomes one state of G;
plus, G has one extra begin state.

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e.g. FIRST(R (E | G) (EX)*) = { R_1 }

FOLLOW(e, x) = all possible positions following position x in e

e.g. FOLLOW(R (E | G) (EX)*, R_1) = { E_2, G_3 }

➔ From state "R_1": add E-transition to E_2
G-transition to G_3

LAST(e) = all possible *end* positions of words matching e

e.g. LAST(R (E | G) (EX)*) = { E_2, G_3, X_5 }

Glushkov's automaton

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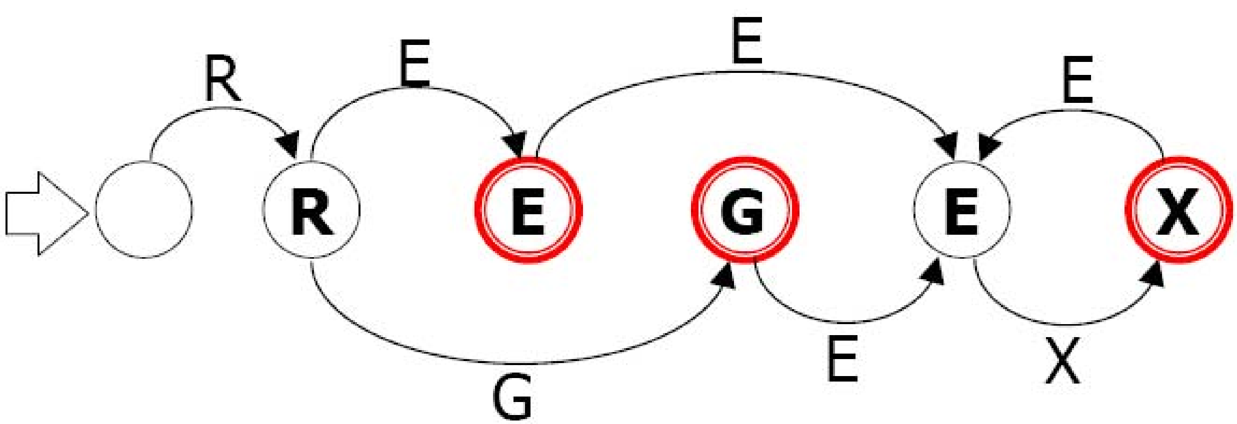

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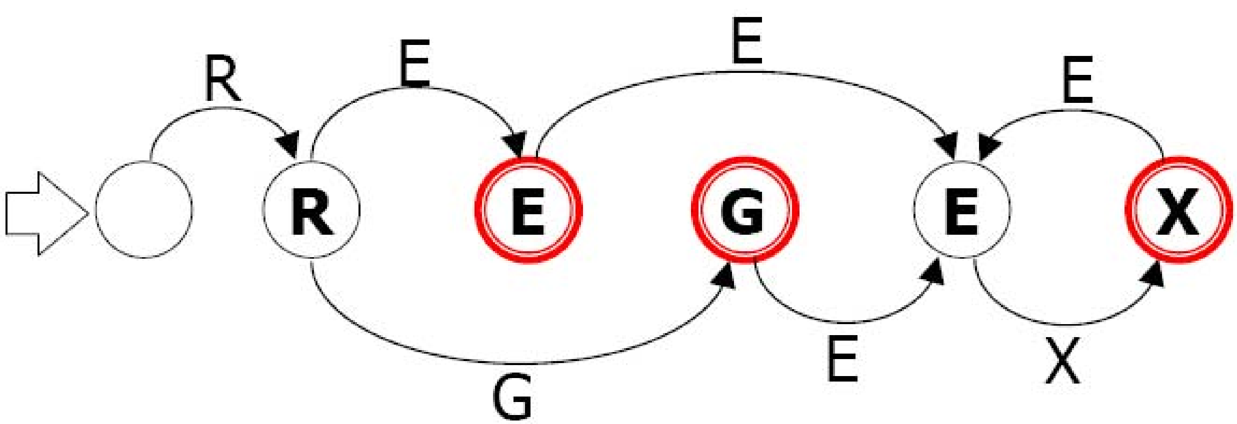


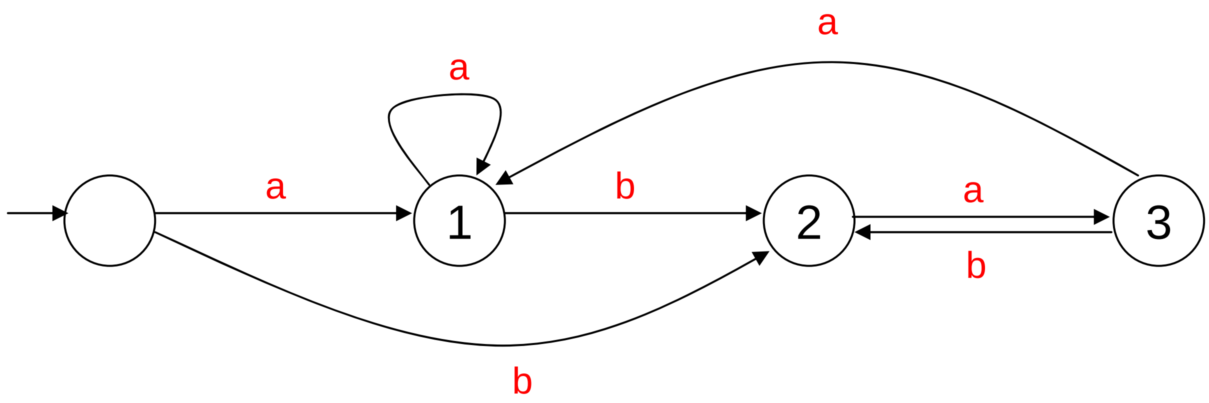
Is this automaton *deterministic* ??

Glushkov automaton G(e)

Another example

(a* | ba)*

This FA
is deterministic.



Which of these is deterministic?

→ (ab) | (ac)
→ a (b | c)
→ a(a | b)*ac

Glushkov automaton G(e)

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e.g. FIRST(R (E | G) (EX)*) = { R_1 }

FOLLOW(e, x) = all possible positions *following* position x in e

LAST(e) = all possible *end* positions of words matching e

Naïve implementation: O(m^3) time, where m = size(e)

(for each position: computing FOLLOW goes through every position
at each step, needs to compute *union* ➔ O(m*m*m)

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Not really needed. Can be improved to O(m^2)

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Naïve implementation: O(m^3) time, where m = size(e)

(for each position: computing FOLLOW goes through every position
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Can be improved to
O(size(e) + size(G(e)))

Not really needed. Can be improved to O(m^2)

Glushkov automaton G(e)

Note If G(e) is *deterministic*, then its size (# transitions) is *quadratic* in size(e)!

Linear in size(e) * #letters(e), if G(e) is deterministic!

➔ O(size(e) * #letters(e))

Can this be improved? → E.g., to O(size(e) * log(#letters(e)) ?
→ Are there known *lower bounds*?

Naïve implementation: O(m^3) time, where m = size(e)

(for each position: computing FOLLOW goes through every position
at each step, needs to compute *union* ➔ O(m*m*m)

O(size(e) + **size(G(e))**) ⇐ Not really needed. Can be improved to O(m^2)

To avoid these expensive running times

DTD requires that `FA=G(e)` must be *deterministic*!

m = size(e)
n = length(w)

Total Running time O(m + n)

If s = #letters(e) is assumed fixed (not part of the input)

Otherwise: O(ms + n)

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)

Unrestricted Reg Expr e →

Algorithm

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

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

Total Running time O(2^m + n)

→ Other alternative: O(mn)

Summary

Deterministic (1-unambiguous) content models give rise to *efficient matching algorithms*.

(they avoid $O(mn)$
or $O(2^m + n)$ complexities)

Disadvantages

→ Hard to know whether given reg expr is OK (deterministic)

→ Det. reg exprs are NOT closed under union. (not so nice.)

Question Can you see why?

Maybe, can find det reg exprs, such that
their union equals (a | b)* a (a | b) ?

Now that we know how the check all the different content-models (in particular det. Reg Expr's) how to build a full validator for a given DTD?

elem-name_1 → RegExpr_1			
elem-name_2 → RegExpr_2		Automata A_1, A_2, …, A_k	
…			
elem-name_k → RegExpr_k			

The Validation Problem
Given a DTD T and a document D, is D valid wrt T?

Top-Down Implementation
→ at element node w. label elem-name_i, run automaton A_i

→ check attribute constraints
→ check ID/IDREF constraints

(Given A_1, A_2, …, A_k)

Total Running time *linear in the sum of size(DTD) * #letters(DTD) and size of document*: O(size(D) * #letters(D) + size(T))

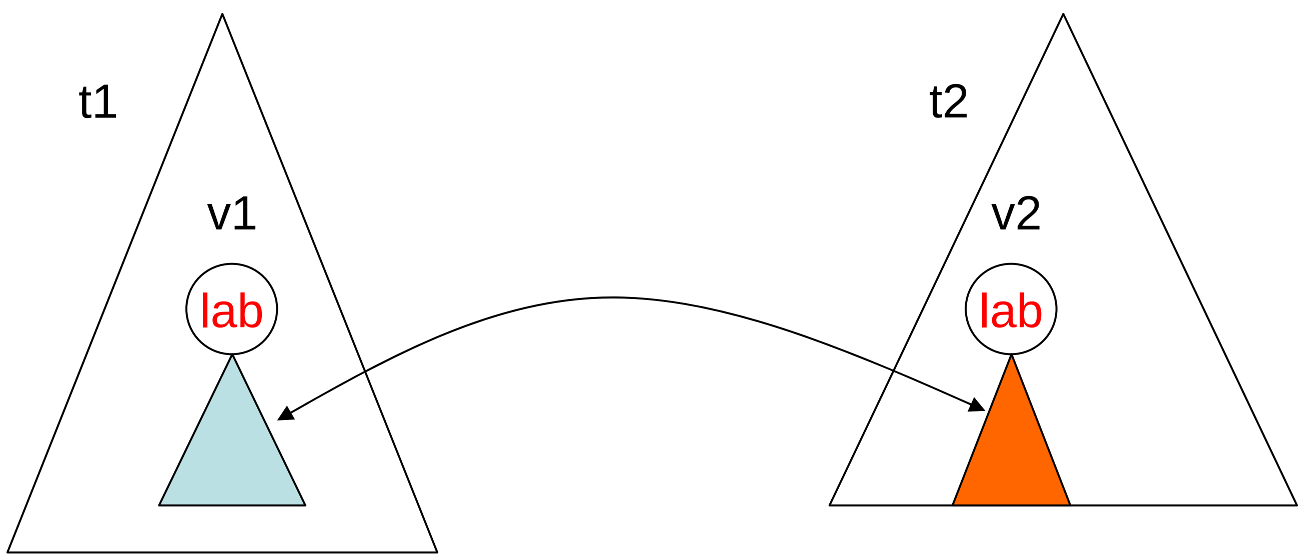
DTDs have the

“**label-guarded subtree exchange**” property:

t1, t2 trees in a DTD language T
v1 node in t1, labeled “lab”
v2 node in t2, labeled “lab”

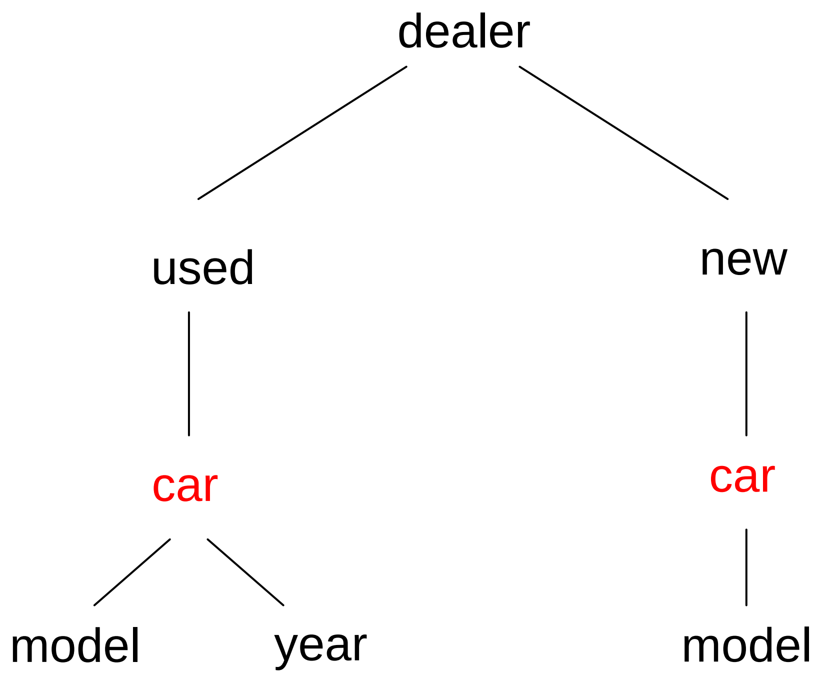
trees obtained by exchanging the subtrees rooted at v1 and v2 are also in T

aka “local”
→ content model only depends on label of parent



Beyond DTDs

Often, the expressive power of DTDs is *not sufficient*.
Problem each element name has precisely one content-model in a DTD.
Would like to distuingish, depending on the context (parent).



car has different structure, in different contexts.

(content model depends on the parent node)

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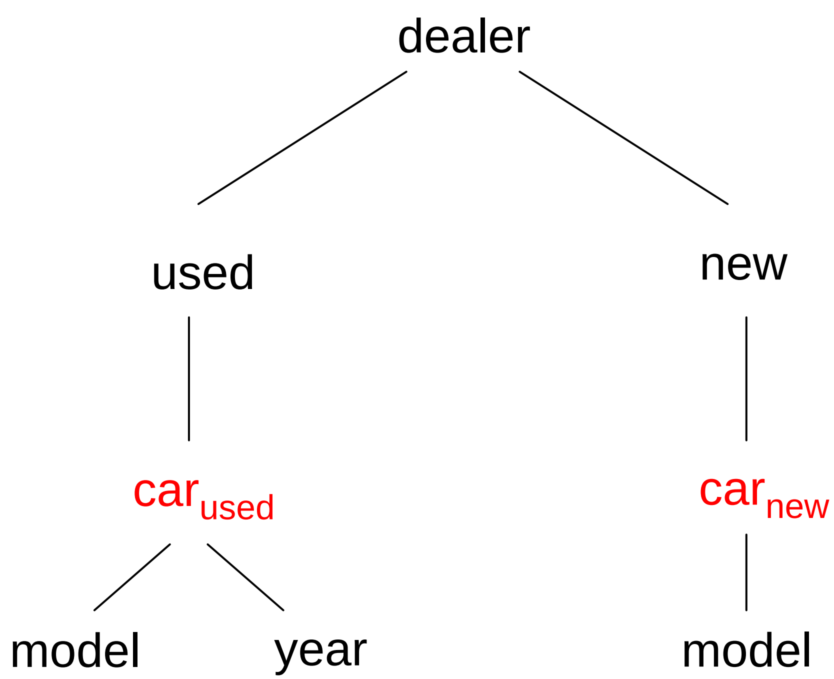
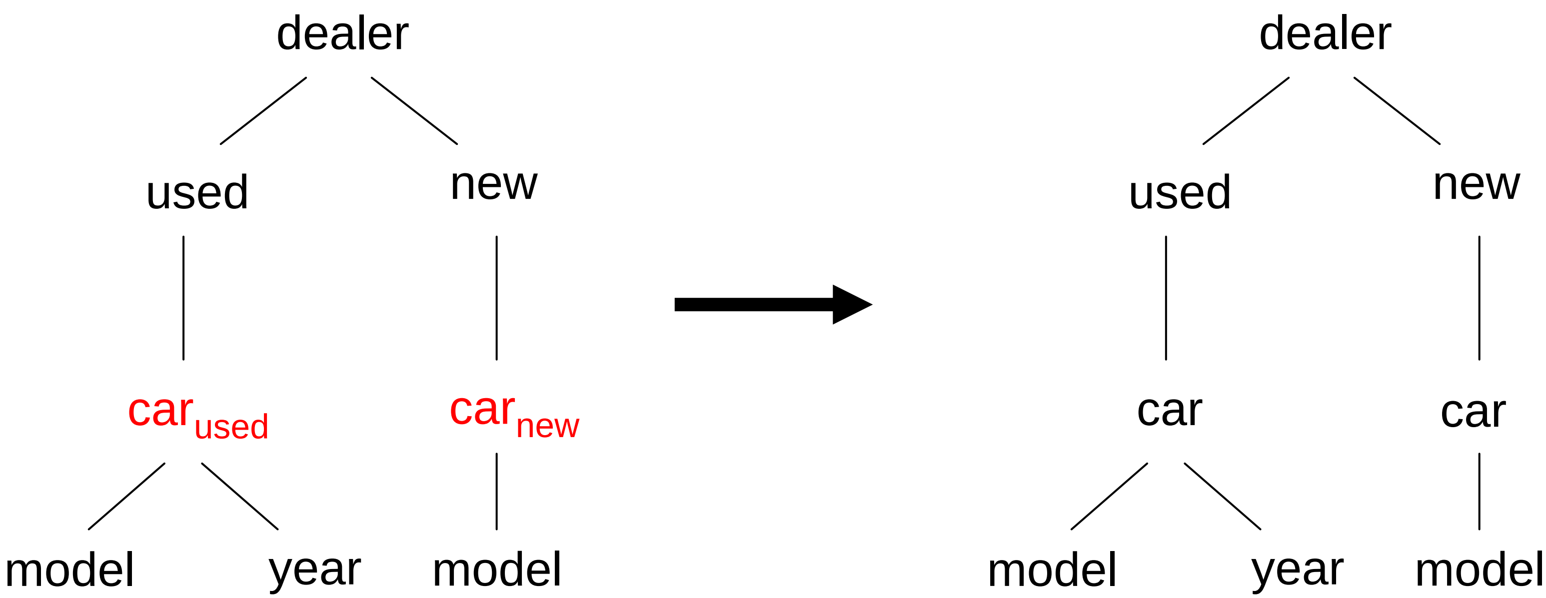


“specialization”

car has different structure, in different contexts.

Specialized DTDs

dealer → used, new
used → $(car_{used})^*$
new → $(car_{new})^*$
car_{used} → model, year
car_{new} → model

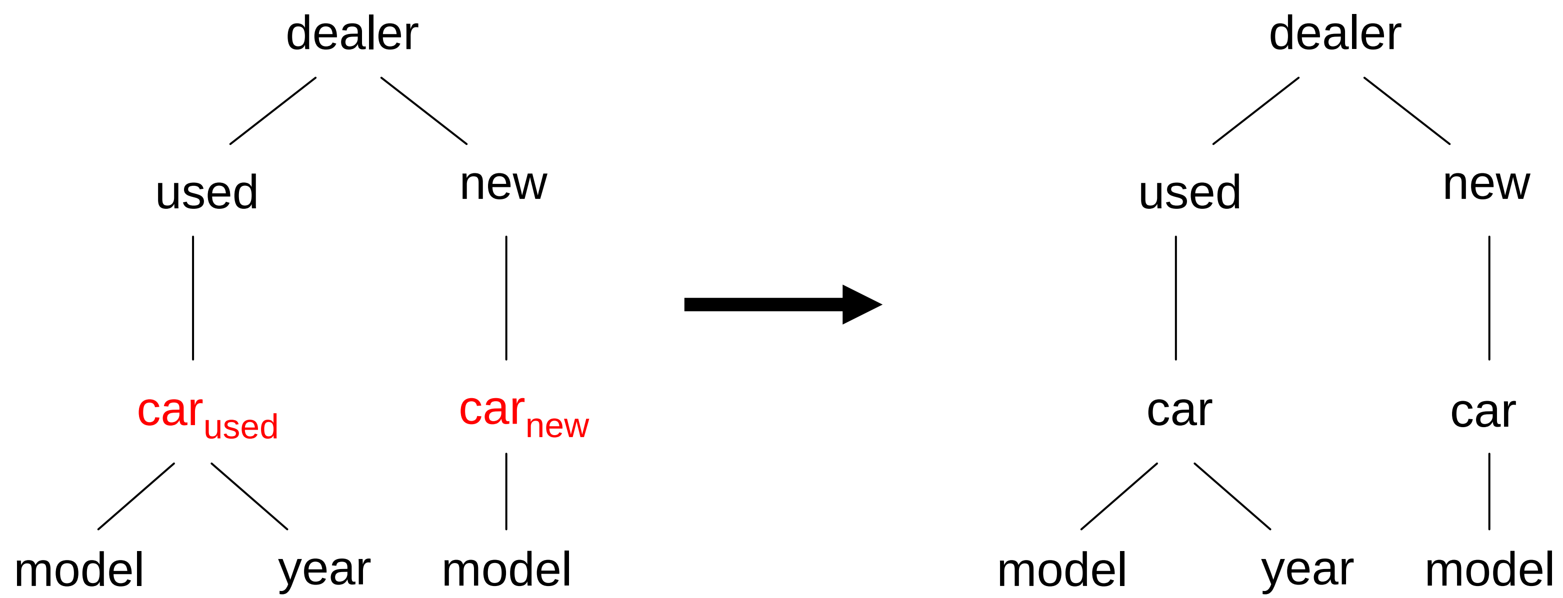


Specialized DTDs

dealer → used, new
used → (car_{used})*
new → (car_{new})*
car_{used} → model, year
car_{new} → model

New notation. Use *capitalized* TYPE Names

Dealer → dealer [Used, New]
Used → used [(Car_{used})*]
New → new [(Car_{new})*]
Car_{used} → car [Model, Year]
Car_{new} → car [Model]



New notation. Use *capitalized* TYPE Names

Dealer → dealer [Used, New]
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Not local

Let us call this new concept a "grammar".

the "*local*" restriction

A grammar G is **local**, if
for any label[RegExpr_1], label[RegExpr_2] present in G
it holds that RegExpr_1 = RegExpr_2.

By definition: Every DTD is a local grammar, and vice versa.

New notation. Use *capitalized* TYPE Names

	Dealer	→	dealer [Used, New]
	Used	→	used [(Car_{used})*]
	New	→	new [(Car_{new})*]
competing	Car_{used}	→	**car** [Model, Year]
	Car_{new}	→	**car** [Model]

Alternatively:

Call two TYPE Names T1 and T2 "competing"
if they have the same element name (but not identical rules)

Classes of Grammars

local no competing TYPE names! (DTDs)

single-type TYPE names in the *same content model* do not compete! (XML Schema's)

regular no restriction. (RELAX NG)

New notation. Use *capitalized* TYPE Names

competing → Car_{used}, Car_{new}

Dealer → dealer [Used, New]
Used → used [(Car_{used})*]
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Car_{used} → **car** [Model, Year]
Car_{new} → **car** [Model]

Question Are there single-type grammars (XML Schemas) which cannot be expressed by local grammars (DTDs).

Classes of Grammars

local no competing TYPE names! (DTDs)

single-type TYPE names in the *same content model* do not compete! (XML Schema's)

regular no restriction. (RELAX NG)

New notation. Use *capitalized* TYPE Names

competing

but are not in same content model!

Person → person [PersonName, Gender, Spouse?, Pet*]
PersonName → name [First, Last]
Pet → pet [Kind, PetName]
PetName → name [#PCDATA]
…

Question Are there single-type grammars (XML Schemas) which cannot be expressed by local grammars (DTDs).
YES!

Classes of Grammars

local no competing TYPE names! (DTDs)

single-type TYPE names in the *same content model* do not compete! (XML Schema's)

regular no restriction. (RELAX NG)

New notation. Use *capitalized* TYPE Names

Dealer → dealer [Used, New]

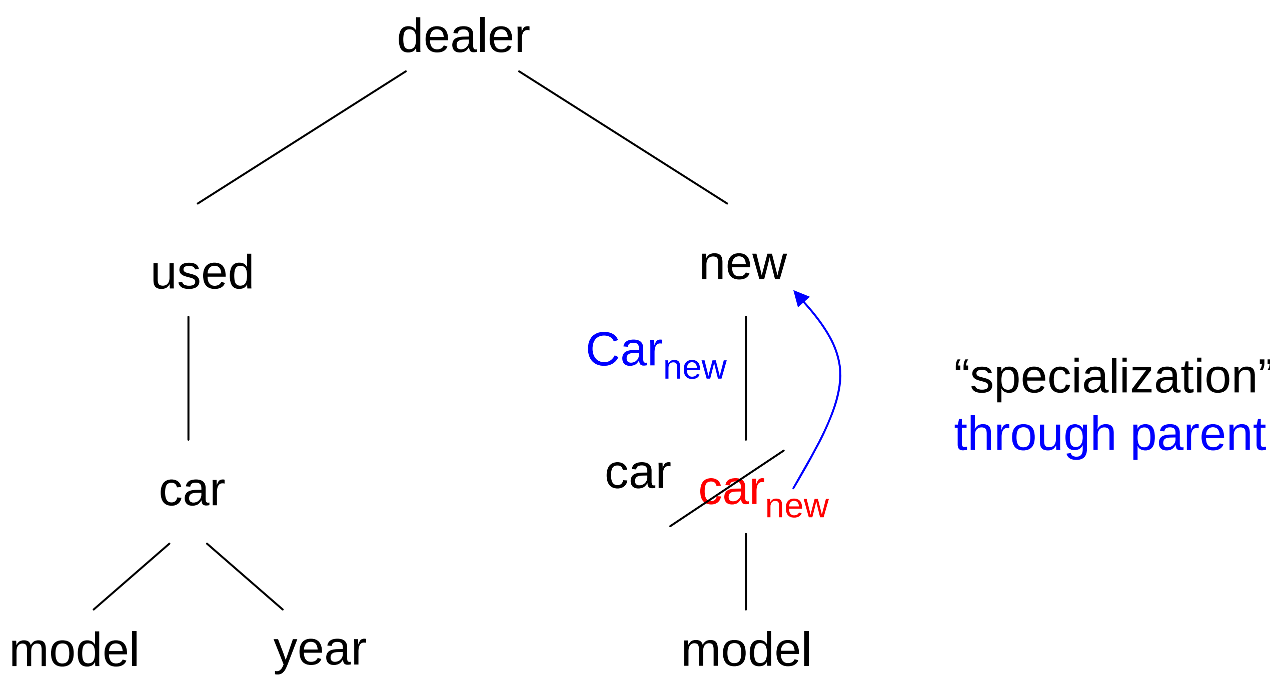
Used → used [(Car_{used})*]

New → new [(Car_{new})*]

competing: Car_{used} → **car** [Model, Year]

Car_{new} → **car** [Model]

Through the use of TYPE Names (nonterminals / states) you can distinguish **deep context**!



New notation. Use *capitalized* TYPE Names

Dealer $\rightarrow$ dealer [Used, New]
Used $\rightarrow$ used [(Car_{used})*]
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competing: Car_{used} $\rightarrow$ **car** [Model, Year]
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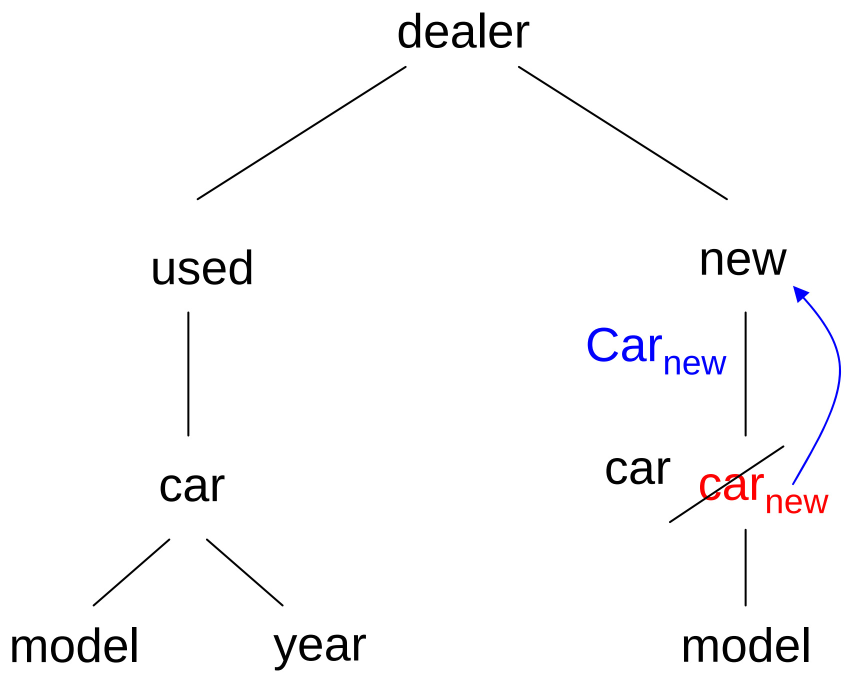
Can we model context that is far away from the specialized node?



"specialization" through parent

New notation. Use *capitalized* TYPE Names

competing →

Dealer → dealer [Used, New]
Used → used [(Car_{used})*]
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Car_{used} → **car** [Model, Year]
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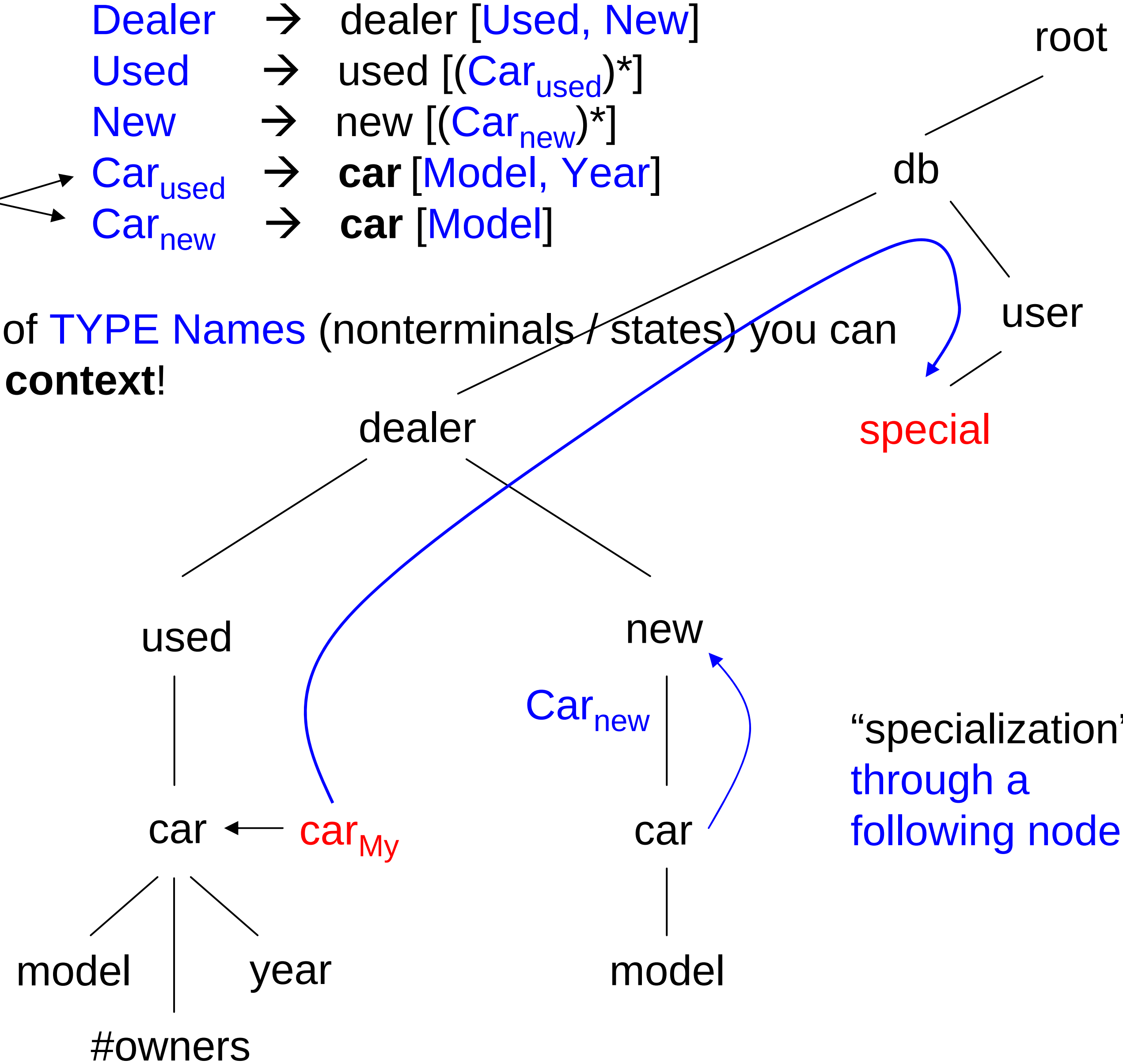
Through the use of TYPE Names (nonterminals / states) you can distinguish **deep context**!



Can we model context that is far away from the specialized node?

Sure!

“specialization” through a following node…

Doc → root [DB | sDB]

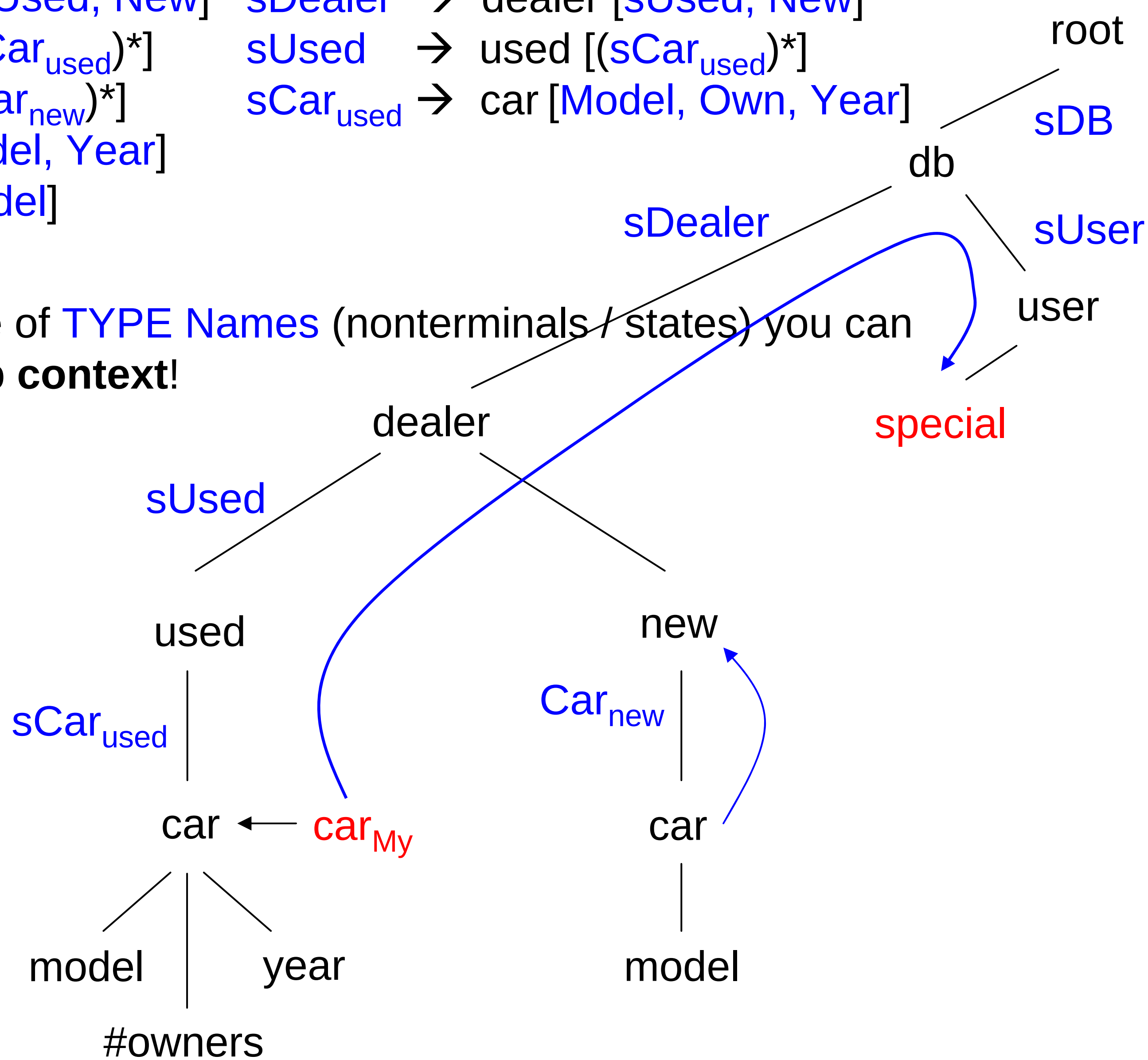
DB → db [Dealer, User]
Dealer → dealer [Used, New]
Used → used [(Car_{used})*]
New → new [(Car_{new})*]
Car_{used} → car [Model, Year]
Car_{new} → car [Model]

sDB → db [sDealer, sUser]
sDealer → dealer [sUsed, New]
sUsed → used [($sCar_{used}$)*]
$sCar_{used}$ → car [Model, Own, Year]

Through the use of TYPE Names (nonterminals / states) you can distinguish **deep context**!

Can we model context that is far away from the specialized node?

Sure!



Doc → root [DB | sDB]

DB → db [Dealer, User]		sDB → db [sDealer, sUser]	
Dealer → dealer [Used, New]		sDealer → dealer [sUsed, New]	
Used → used [(Car_{used})*]		sUsed → used [($sCar_{used}$)*]	
New → new [(Car_{new})*]		$sCar_{used}$ → car [Model, Own, Year]	
Car_{used} → car [Model, Year]			
Car_{new} → car [Model]			

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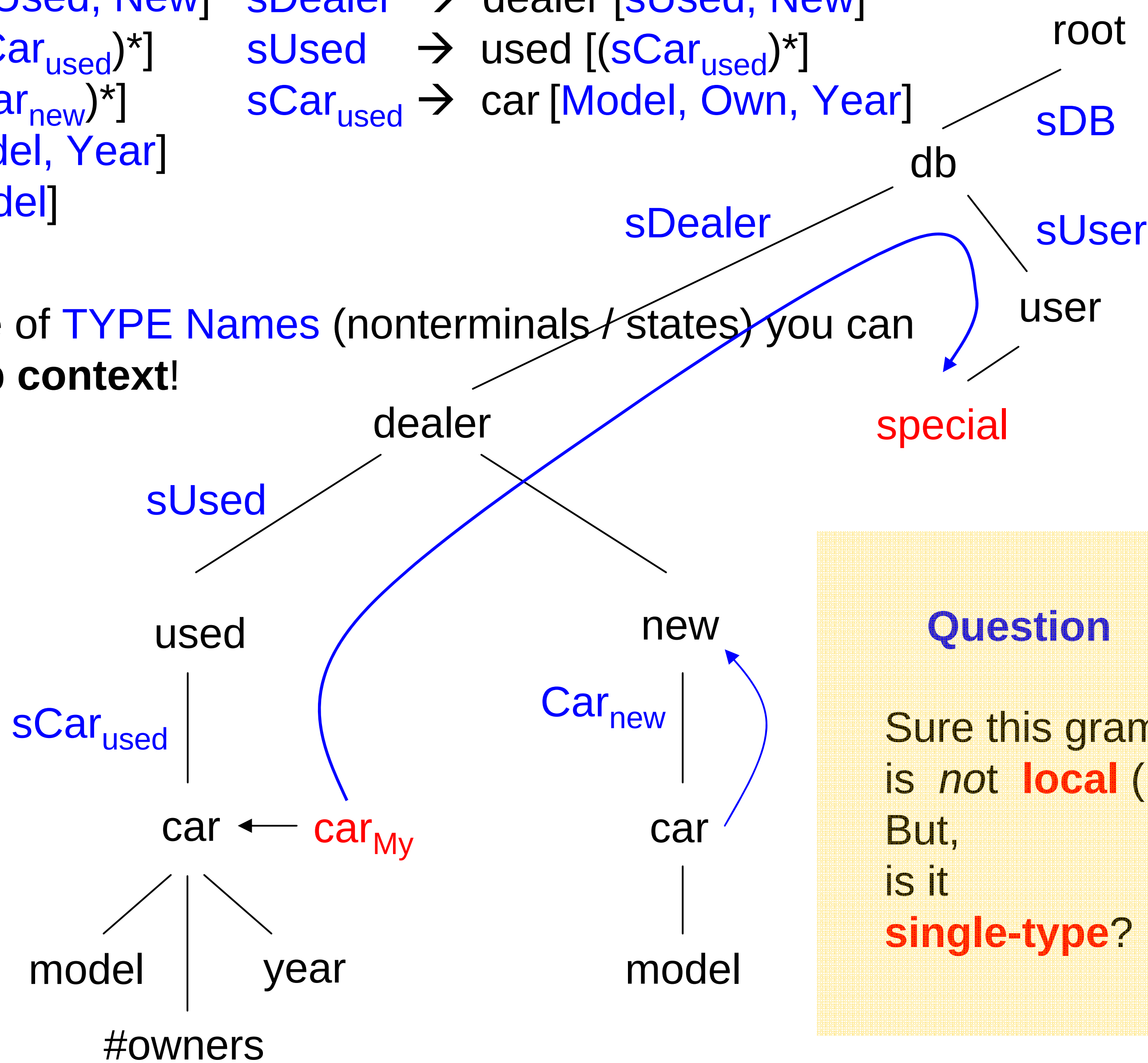
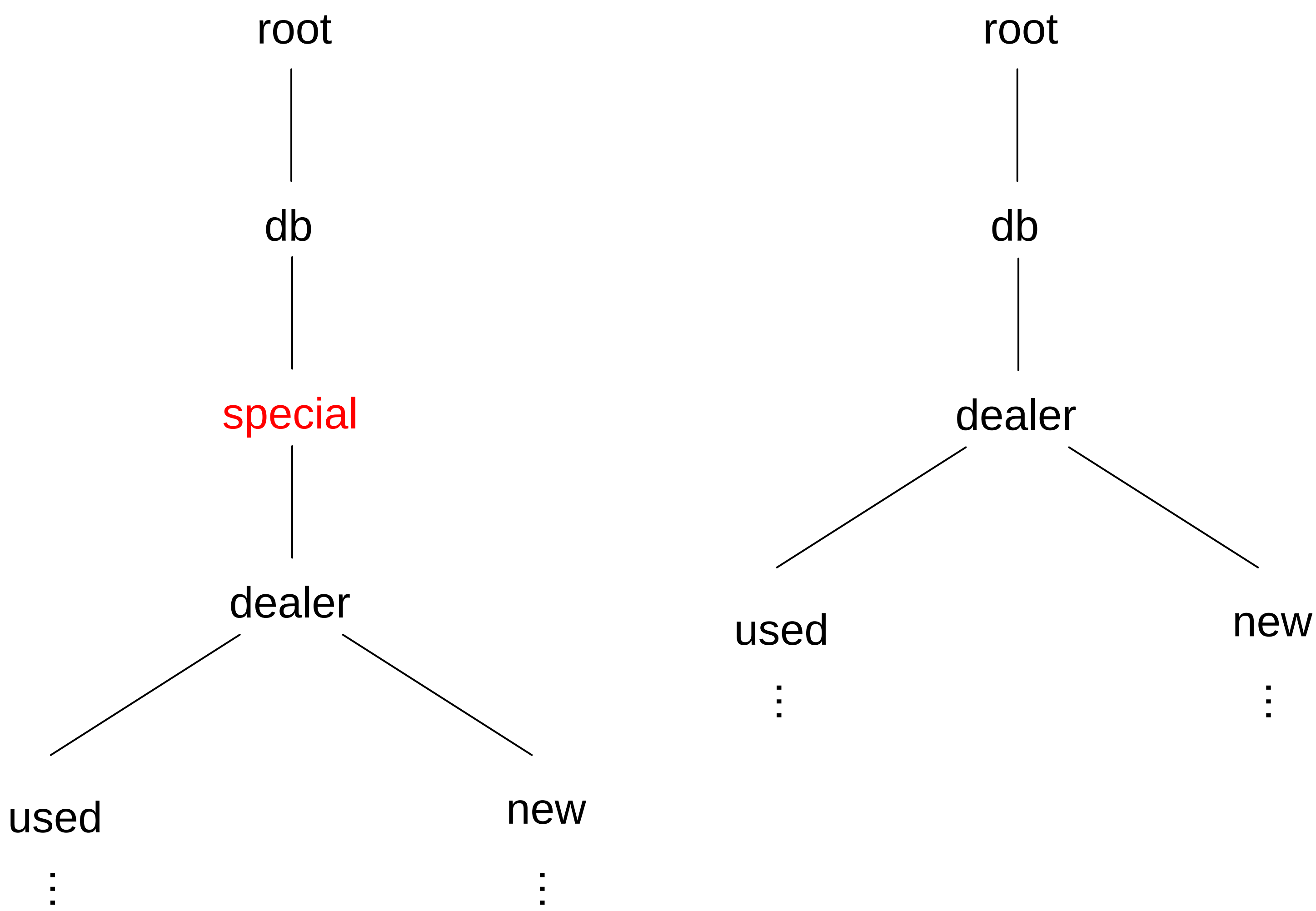


Can we model context that is far away from the specialized node?

Sure!

Question

Sure this grammar is *not* **local** (DTD).
But,
is it
single-type?



Question Is this grammar **single-type**?

Classes XML Type Formalisms

local no competing TYPE names! (**DTDs**)

single-type TYPE names in the *same content model* do not compete! (**XML Schema's**)

regular no restriction… (**RELAX NG**)

Increasing Expressivness
of defining sets of trees ("tree languages")

Questions

Given two DTDs D1 and D2 can we check if
→ all documents valid for D1 are also valid for D2? (DTD inclusion problem)
→ D1 and D2 describe the same set of documents? (DTD equality problem)

Given a Relax NG grammar G, can we check if
→ there exists any document that is valid for G? (emptiness problem)
→ there is a document valid for G *and* valid for G2? (intersection & emptiness)

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→ If we can do it for **regular tree** grammars, then also works for single-type/local!!

All of the checks can be done automatically, for **regular tree** grammars!

↑

equivalent to tree **automata**

Tree Automata: very powerful framework,

→ Have all the good properties of string automata!
→ Yet, they are more expressive!

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Tree Automata: very powerful framework,

→ Have all the good properties of string automata!
→ Yet, they are more expressive!

Note

String automata are **not** sufficient to check DTDs / Schemas!
Even if we only consider well-bracketed strings!

Example 1

c → c[a, c, b]
a → empty
b → empty
c → empty

Example 2

a → a[c, a]
a → a[a, b]
a / b / c → empty

All of the checks can be done automatically, for **regular tree** grammars!

constant memory computation

↑ equivalent to tree **automata**

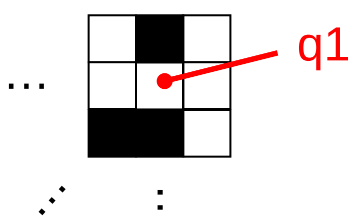
Finite-state automata are important:

→ Think you are in a maze, with only fixed memory and you can only read the maze (cannot mark anything).

wall

Model by finite automaton. In state q1, (to [N|S|E|W], ■) → (q2, [N|S|E|W])
q2, (to [N|S|E|W], □) → (q3, [N|S|E|W])

empty



Can an automaton search the maze?

All of the checks can be done automatically, for **regular tree** grammars!

↑ equivalent to tree **automata**

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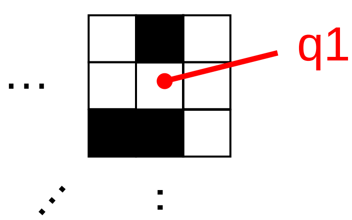
Finite-state automata are important:

→ Think you are in a maze, with only fixed memory and you can only read the maze (cannot mark anything).

Model by finite automaton. In state q1, (to [N|S|E|W], ■ (wall)) → (q2, [N|S|E|W])
q2, (to [N|S|E|W], □ (empty)) → (q3, [N|S|E|W])



Can an automaton search the maze?

No!! → need markers ("pebbles").
How many? 5? 2?

All of the checks can be done automatically, for **regular tree** grammars!

↑

equivalent to tree **automata**

constant memory computation

Finite-state automata are important:

In our context, e.g., for

→ KMP (efficient string matching) [Knuth/Morris/Pratt] generalization using automata. Used, e.g., in `grep`

→ Compression

→ Static analysis of schemas & queries (= "everything you can do *before* running over the actual data")

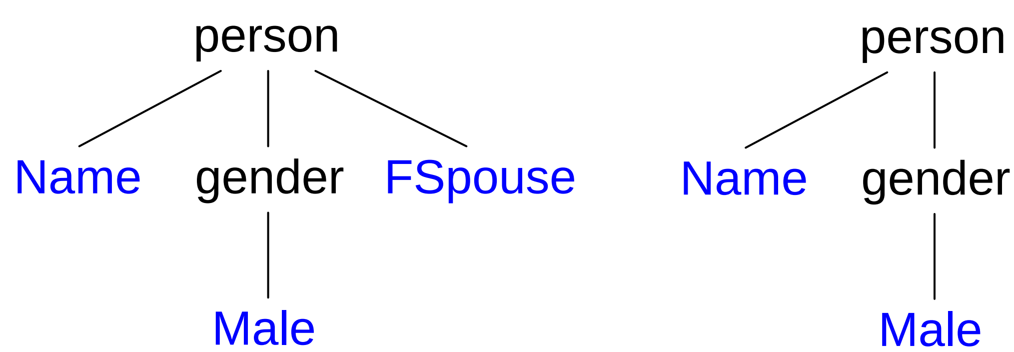
4. Static Methods, based on Tree Automata

Person → MPerson | FPerson
MPerson → person [Name, gender[Male], FSpouse?]
FPerson → person [Name, gender[Female], MSpouse?]

Regular Tree Grammar

Leaves may be labeled by TypeNames

Rules of the form TypeName → Tree



Alternatively, regular tree languages are defined by **Tree Automata**.

state, element-name → state1, state2

conventionally, defined for *binary/ranked* trees.

4. Static Methods, based on Tree Automata

Given grammars D1 and D2 can we check if
→ all documents valid for D1 are also valid for D2? (inclusion problem)
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→ does there exists any document that is valid for D1? (emptiness problem)
→ there is a document valid for D1 *and* valid for D2? (intersection & emptiness)

ALL these checks are possible for ***regular tree grammars****!!*

→ hence, they are also solvable for DTDs / XML Schemas / RELAX NG's

(1) use binary tree encodings
(2) translate XML Type Definition to a Tree Grammar (easy)

Alternatively, regular tree languages are defined by **Tree Automata**.

state, element-name → state1, state2 ← conventionally, defined for *binary/ranked* trees.

4. Static Methods, based on Tree Automata

Given grammars D1 and D2 can we check if
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→ there is a document valid for D1 *and* valid for D2? (intersection & emptiness)

ALL these checks are possible for ***regular tree grammars****!!*

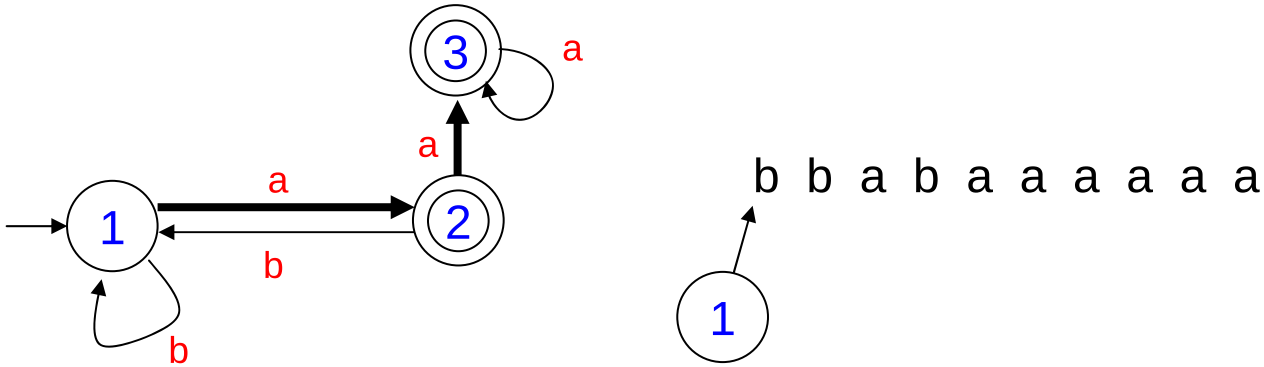
➔ The checks above give rise to
very powerful optimization procedures for XML Databases!

For example:
documents d_1, d_2, …, d_n are valid for your schema “Small_xhtml”.

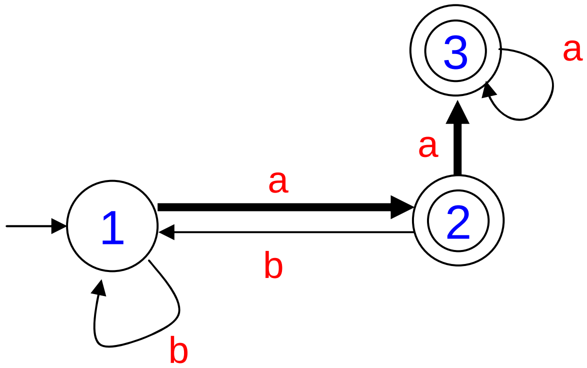
Are they also valid for schema XHTML?

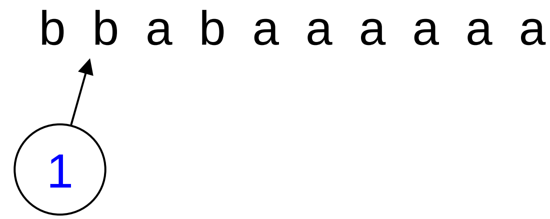
➔ Check *inclusion problem* for Small_html and XHTML!

Automata on words



Automata on words





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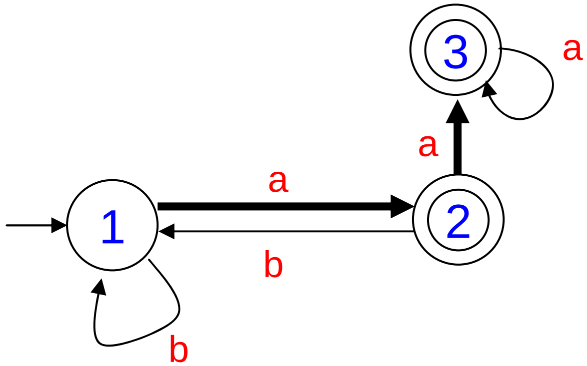
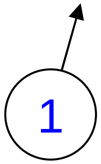


b b a b a a a a a a



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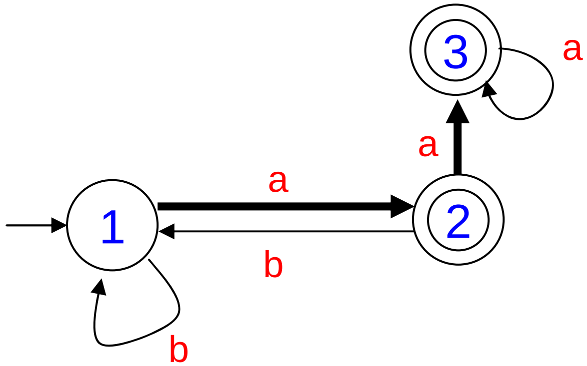

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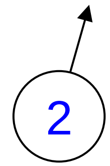

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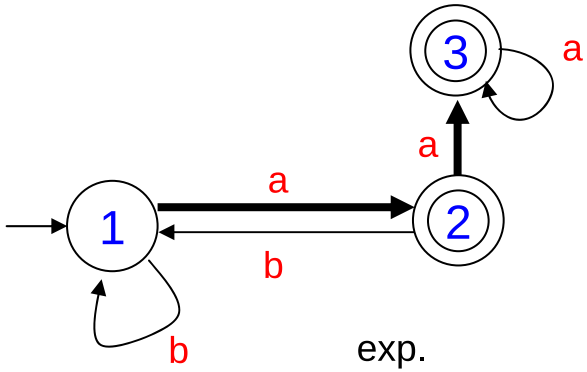
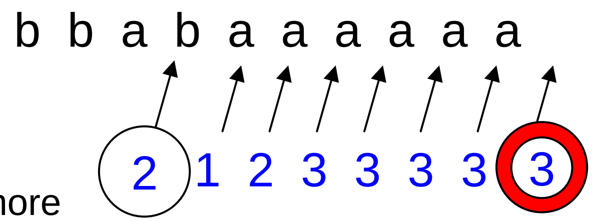




word is accepted by the automaton

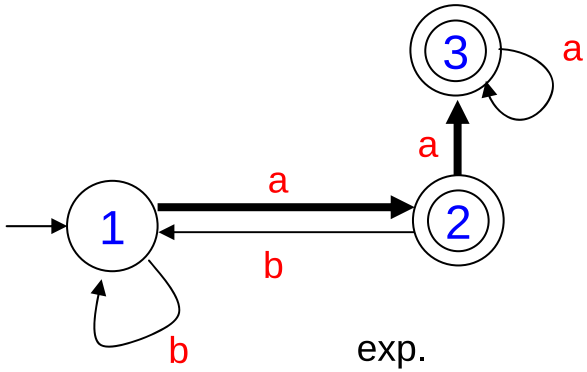
exp. blow-up

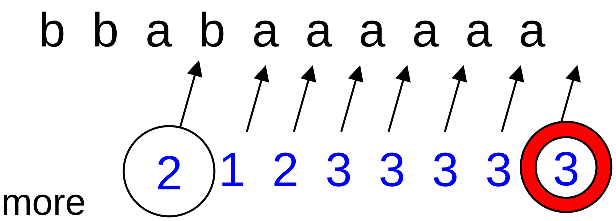
exp. more succinct

Expressiveness deteterministic = nondeterministic

left-to-right = right-to-left

Automata on words





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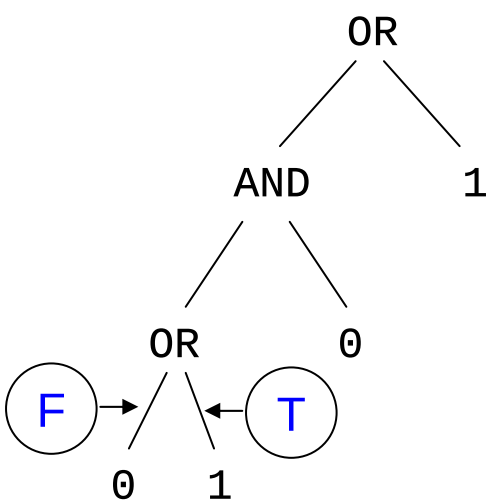
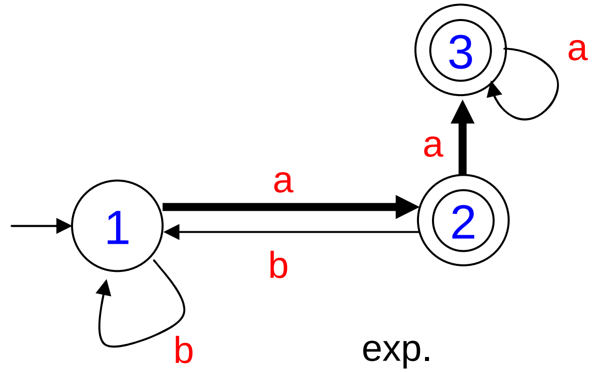
Automata on trees

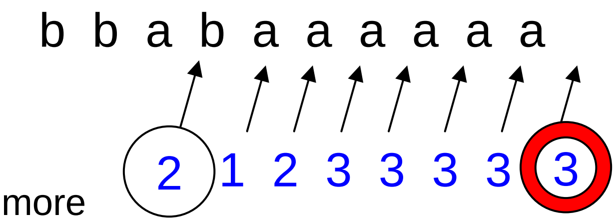
1. *bottom-up* LABEL(state1, state2) → state




```
0()  → F
1()  → T
OR( F, F ) → F
OR( F, T ) → T
...
```

Automata on words





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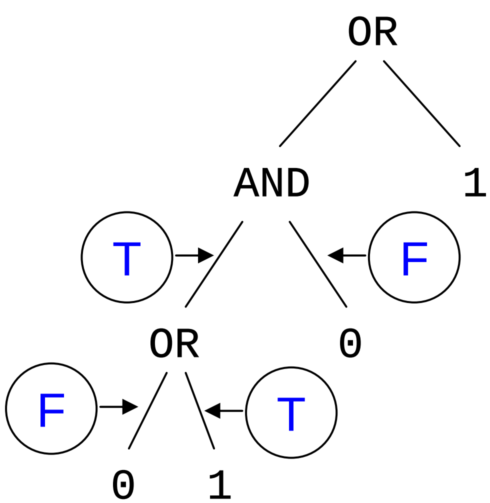

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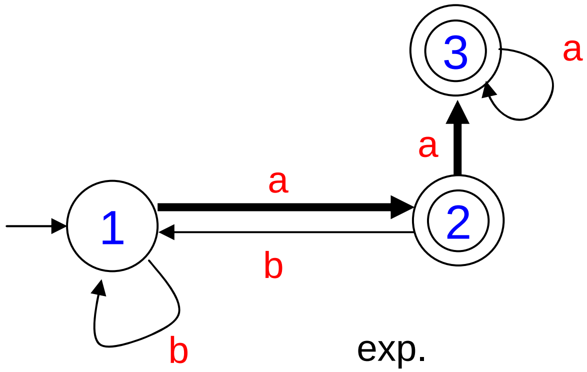
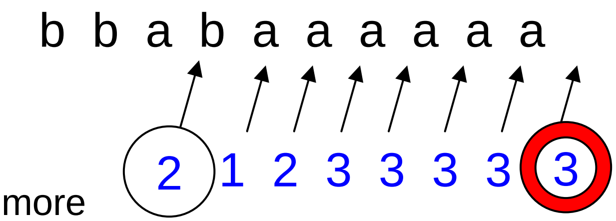
Automata — on words





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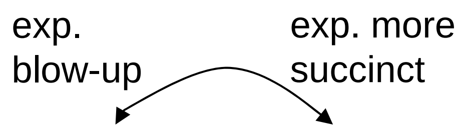

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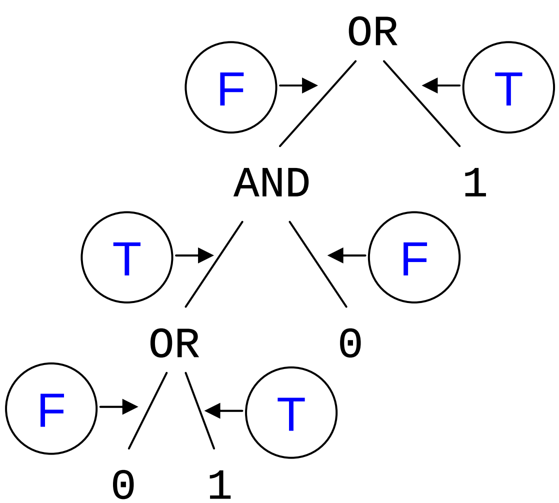

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...
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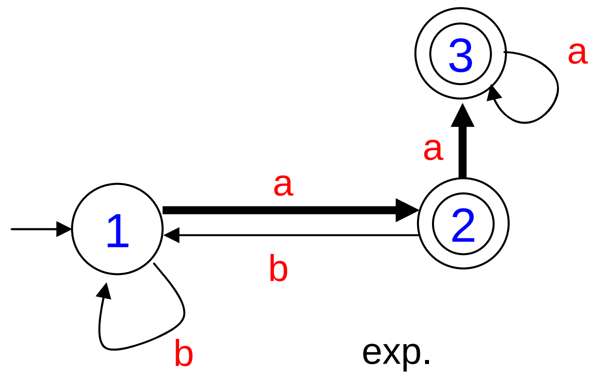
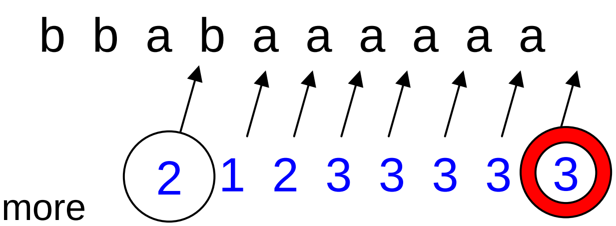
Automata on words





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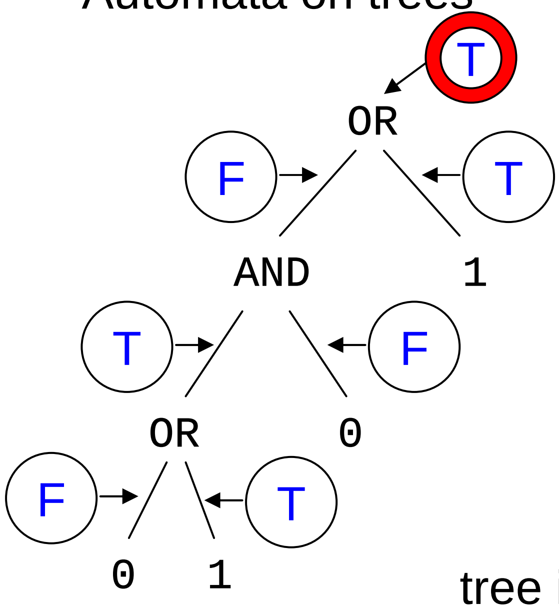

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Accepting States = { T }

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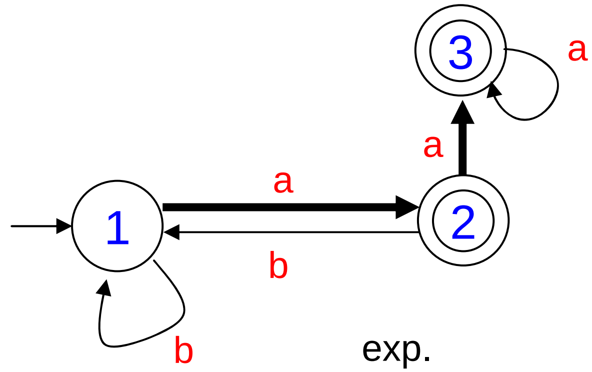
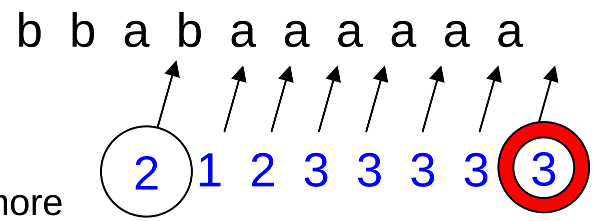
Automata on words





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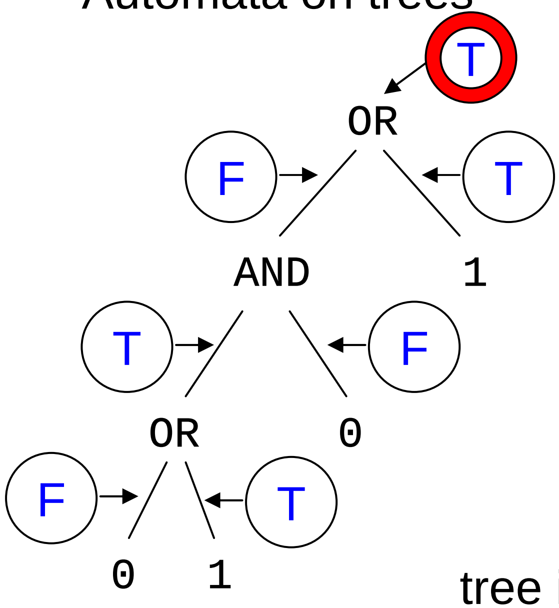
Expressiveness

deteterministic = nondeterministic

left-to-right = right-to-left

Automata on trees



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AND(T, F) → F

Accepting States = { T }

This automaton is *deterministic*.

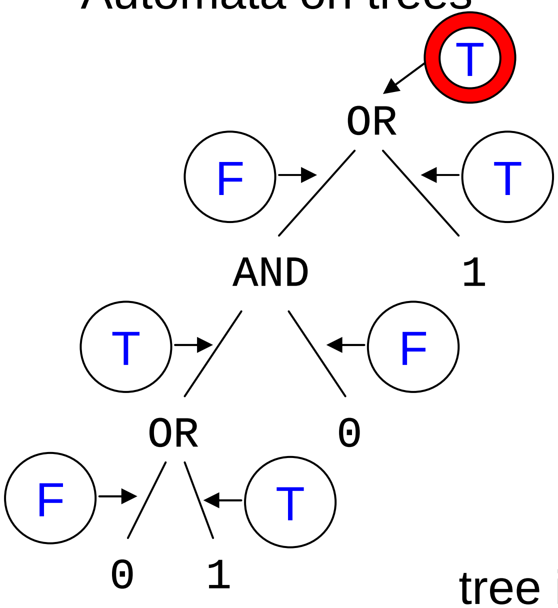
nondeterminism
LABEL(st1, st2) → { st3, … }

tree is accepted by the automaton

Question

How much memory do you need exactly, to run such a bottom-up tree automaton?

Automata on trees



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This automaton is *deterministic*.

nondeterminism
LABEL(st1, st2) → { st3, … }

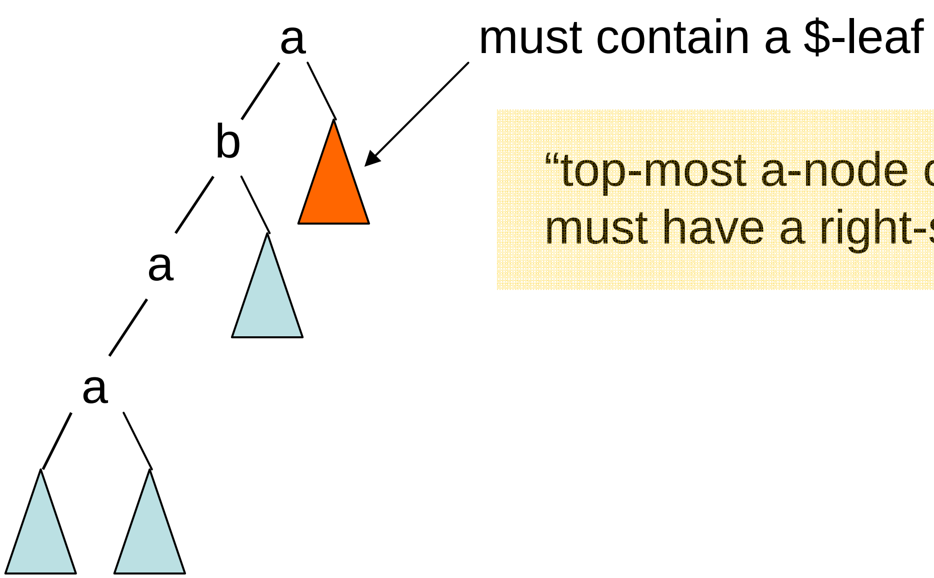
tree is accepted by the automaton

Similarly as for word automata:

> For every nondeterministic bottom-up tree automaton
> there is an equivalent deterministic bottom-up tree automaton.

Again, the construction can cause exponential size blow-up.

2. *top-down* state, LABEL → (state1, state2)



a,b = binary node labels
e,$ = leaf node labels

"top-most a-node on the left-most path
must have a right-subtree which contains a $-node."

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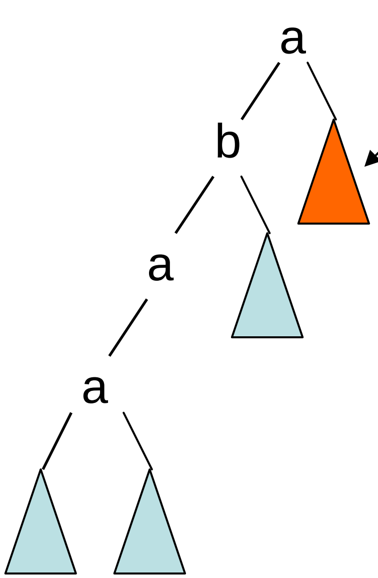


must contain a $-leaf

a,b = binary node labels
e,$ = leaf node labels

"top-most a-node on the left-most path
must have a right-subtree which contains a $-node."

begin, a	→	(any, find$)
begin, b	→	(begin, any)
find$, a/b	→	{ (find$, any), (any, find$) }
find$, $	→	ACC
find$, e	→	REJ
any, a/b	→	(any,any)
any, $/e	→	ACC

nondeterministic

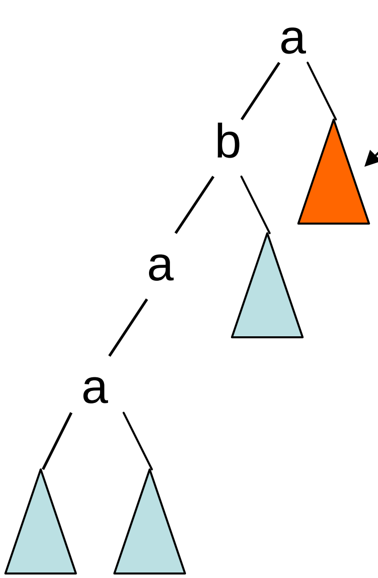
→ accept tree if there exists an accepting run
(= all leaves go to ACC)

For every nondeterministic bottom-up tree automaton
there is an equivalent deterministic bottom-up tree automaton.

Question
Can you find an equivalent *bottom-up* automaton for this example?

---

2. *top-down* state, LABEL → (state1, state2)



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nondeterministic

→ accept tree if there exists an accepting run

For every nondeterministic bottom-up tree automaton
→ there is an equivalent deterministic bottom-up tree automaton, and
→ there is an equivalent nondeterministic *top-down* tree automaton.

➔ Yes! you can… ☺

---

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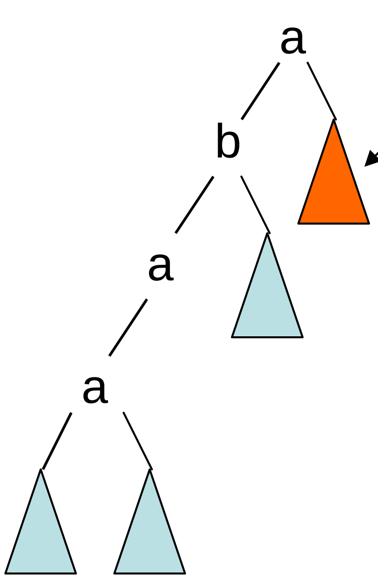

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nondeterministic

→ accept tree if there exists an accepting run

For every nondeterministic bottom-up tree automaton
→ there is an equivalent deterministic bottom-up tree automaton, and
→ there is an equivalent nondeterministic *top-down* tree automaton.

Question
Is there an equivalent deterministic top-down automaton??

---

2. *top-down* state, LABEL → (state1, state2)

a,b = binary node labels
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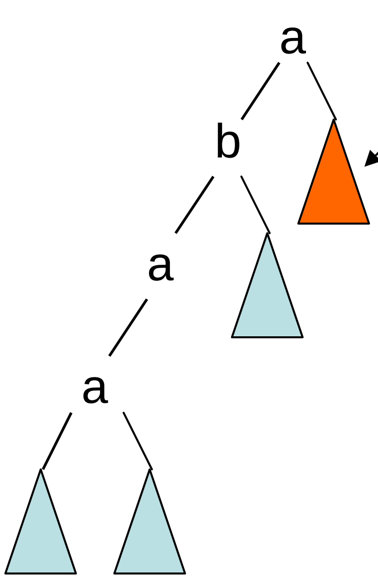

must contain a $-leaf

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any, $/e	→	ACC

nondeterministic

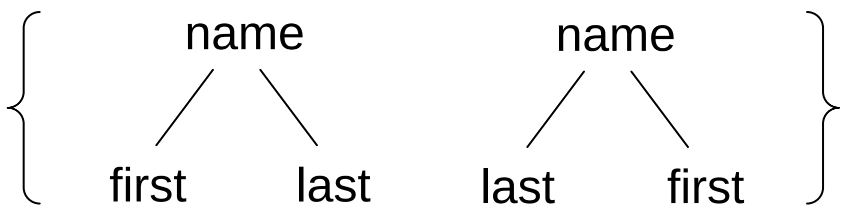
→ accept tree if there exists an accepting run

For every nondeterministic bottom-up tree automaton
→ there is an equivalent deterministic bottom-up tree automaton, and
→ there is an equivalent nondeterministic *top-down* tree automaton.

Question

Is there an equivalent deterministic top-down automaton??

➔ NO! ☹ -- not a good model..



This set of two trees canNOT be recognized
by any determinstic top-down tree automaton!!

Why?

For every nondeterministic bottom-up tree automaton
→ there is an equivalent deterministic bottom-up tree automaton, and
→ there is an equivalent nondeterministic *top-down* tree automaton.

Question
Is there an equivalent deterministic top-down automaton??

➔ NO! ☹ -- not a good model..

Questions

What about **local** tree languages (defined by DTDs).
→ Can they be accepted by deterministic top-down automata?

What about **single-type** tree languages (defined by XML Schema's)
→ Can they be accepted by deterministic top-down automata?

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Questions

What about **local** tree languages (defined by DTDs).
→ Can they be accepted by deterministic top-down automata?

What about **single-type** tree languages (defined by XML Schema's)
→ Can they be accepted by deterministic top-down automata?

Yes!

Hence, there is **no DTD / Schema** for { name[first,last], name[last,first] }

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→ there is an equivalent deterministic bottom-up tree automaton, and
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Question
Is there an equivalent deterministic top-down automaton??

➔ NO! ☹ -- not a good model..

Nevertheless, **XML Schemas** are a subclass of deterministic top-down automata.

Questions
What is the reasoning behind this?
Similarity to restriction to deterministic reg. expressions?

Recall: Deterministic (1-unambiguous) content models give rise to *efficient matching algorithms*.

(they avoid $O(mn)$
$O(2^m + n)$ complexities)

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→ there is an equivalent deterministic bottom-up tree automaton, and
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Question
Is there an equivalent deterministic top-down automaton??

→ NO! ☹ -- not a good model..

Nevertheless, **XML Schemas** are a subclass of deterministic top-down automata.

Questions
What is the reasoning behind this?
Similarity to restriction to deterministic reg. expressions?

In total, given a DTD D, we can build one deterministic top-down automaton of size O(size(D) * #letters(D))

Thus, matching time is inside **O(m^2 + n)**

For every deterministic bottom-up tree automaton
there exists a minimal unique equivalent one!

→ Equivalence is decidable

In fact, YOU have already produced
minimal bottom-up tree automata!

The minimal DAG of a tree t can be seen as the minimal unique
deterministic BU tree automaton that only accepts the tree t.

For every deterministic bottom-up tree automaton
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The minimal DAG of a tree t can be seen as the minimal unique
tree automaton that only accepts the tree t.

Question

Given deterministic BU tree automaton.
How expensive (complexity) to find unique mininmal one?

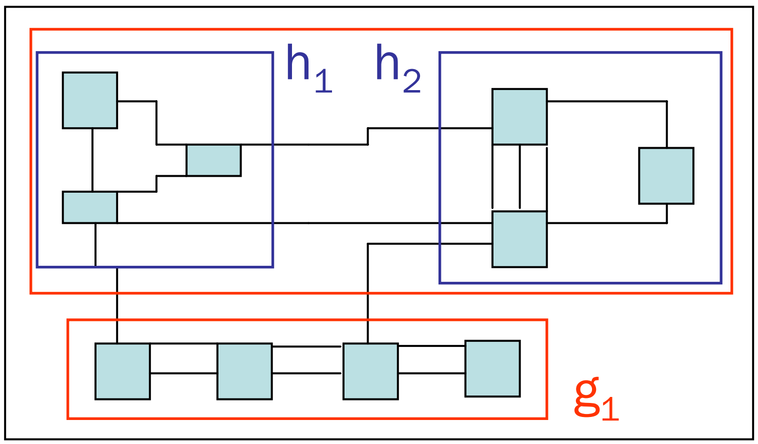
As for DFAs: merge equivalent states
Typically: quadratic running time. → Hopcroft's algorithm, O(n log n)

More generally, once we have partitioned on a block and an input symbol, we need never partition on that block and input symbol again until the block is split and then we need only partition on one of the two subblocks. Since the time needed to partition on a block is proportional to the transitions into the block and since we can always select the half with fewer transitions, the total number of steps in the algorithm is bounded by n log n.

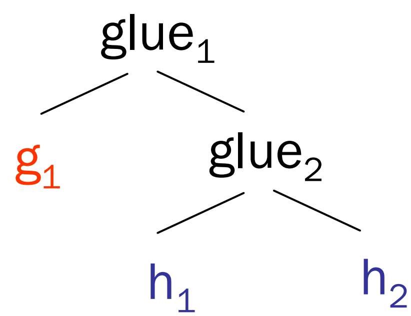
See ftp://db.stanford.edu/pub/cstr/reports/cs/tr/71/190/CS-TR-71-190.pdf

Tree Automata are a very useful concept in CS!

→ Heavily used in verification
"Derive a property of a complex object
from the properties of its constituents…"



$g = glue_1(g_1, glue_2(h_1, h_2))$



→ Do all graphs / chip-layouts produced in this way, have property P?

Use the hierarchical construction history of an object, in order to work on a "parse" tree instead of a complex graph.
From there, use tree automata. ☺

Many NP-complete graph problems become
tractable on "bounded-treewidth " graphs!

XML Tree Automata play crucial rule for

➔ Efficient validators against XML Types

→ Optimizations If doc1 is of TYPE1, then no need to validate against TYPE2, if we know TYPE2 included in TYPE1

- if only “slightly different” then only need to validate “there”
- incremental validation against updates
- etc, etc.

➔ Efficient query evaluators, use richer automata which can select nodes and produce query answers

→ Optimizations If answer of QUERY1 is in cache, then no need to evaluate QUERY2, if “included” in QUERY1.

- if every possible answer set to QUERY1 (of TYPE X) is EMPTY, then no need to evaluate on the real data!

➔ XML Type Checking for Programming Languages

The Future

In 5-10 years from now: ☺

You can write a function in Programming Language X

```
Function foo(XML document D: TYPE1):  TYPE2
{
    traverse D
        & compute output;
    .
    .
    .
    return output
}
```

Compiler (XML Type Checker) will complain, if your function does not compute documents of TYPE2.

➔ If no complaint, then **guaranteed**:
ALL outputs are ALWAYS of correct type!!)

The Future

Experimental PL's
In this direction:
→CDuce
→XDuce

In 5-10 years from now: ☺

You can write a function in Programming Language *X*

```
Function foo(XML document D: TYPE1):  TYPE2
{
    traverse D
        & compute output;
    .
    .
    .
    return output
}
```

Compiler (XML Type Checker) will complain, if your function does not compute documents of TYPE2.

➔ If no complaint, then correct type **guaranteed**.

Compilers will **have** to be able to give *static guarantees* about input/output behaviour of program!

END
Lecture 5