

Foundations of XML Types: Tree Grammars

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Which Data Model for XML?

Trees: a natural answer

- They cannot model all XML structures (limitation: IDREFs)
- Nevertheless, throughout this session, we will focus on trees which are:
 - finite,
 - ordered (limitation: attributes),
 - labeled from a finite alphabet of symbols (limitation: values),
 - of unbounded depth and arity.

Tree Languages

A Tree Language

- is a set of trees
- can be specified by a tree grammar

Example

```
Person   = person[Name, Gender, Children?]  
Name     = name[String]  
Gender   = gender[Male | Female]  
Male     = male[]  
Female   = female[]  
Children = children[Person+]
```

Terminology

- Person is a type variable (non-terminal) and person is a terminal
- A tree grammar defines a set of trees

Tree Grammars: a Syntactic Definition

Given

- An alphabet Σ
- A set of type variables ranged by X

Definition

- A tree grammar is a pair (E, X)
- E is a set of definitions of the form $\{X_1 = T_1; \dots; X_n = T_n\}$
- X is the starting type variable
- Each T is a tree type expression:

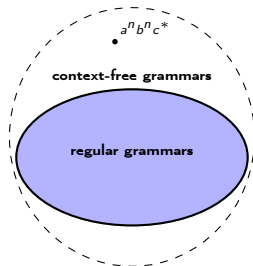
$T ::=$	$I[T]$	$I \in \Sigma$ with <i>content model</i> T
	$()$	empty sequence
	T_1, T_2	concatenation
	$T_1 \mid T_2$	choice
	X	reference

- Usual operators $(?, +, *)$ are *syntactic sugars*

Recursion and Computability Frontier

A Syntactic Restriction

- Every recursive use of a type variable X which is not guarded (behind a label) must be in tail
- Examples (shortcut: a stands for $a[()]$):
 - ✗ $\{X = a, X, b\}$
 - ✗ $\{X = a, Y, b; Y = X\}$
 - ✓ $\{X = a, c[X], b\}$
 - ✓ $\{X = a, Y; Y = b, X \mid ()\}$



With the restriction: *regular* tree grammars

- Decidable operations (e.g.: inclusion)
- A robust and well characterized class

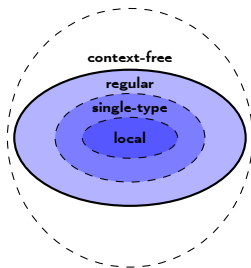
Without the restriction: *context-free* tree grammars

- Inclusion is undecidable [Hopcroft et al., 2000]
- Checking whether a context-free grammar is regular is undecidable

Classes of Tree Grammars

3 sub-classes of particular interest

- Defined by additional restrictions
 - Increasing expressive power
 - Correspond to XML type languages
1. *Local* tree grammars: DTD
 2. *Single-type* tree grammars: XML Schema
 3. *Regular* tree grammars



Local Tree Grammars: DTDs

Restriction

- Recall: each element name is associated with a regular expression
- For each $a[T_1]$ and $a[T_2]$ occurring in E , *content models* are identical:
 $T_1 = T_2$

Construction of Validators

- Simple principle: a word automaton is associated with each terminal
- Validation (matching) in linear time
- You know how to construct a word automaton from a regular expression...

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 - ✗ $a (bc \mid bb)$ (matched reg. exp. part cannot be determined without look ahead of the next symbol)
 - ✓ $ab (c \mid b)$

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Local Tree Grammars: DTDs

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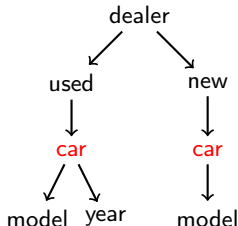
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- For any deterministic expression, we can build a deterministic automaton in linear time [Brüggemann-Klein, 1993] (see Glushkov automata)
- Alternatively (and equivalently), we can use a derivative operator with a stack and even implement *streaming* DTD validation... Remember!

Weaknesses of DTDs

- An element name cannot have different *content models* in different contexts
- Example: a DTD cannot recognize only:



- Corollary: union of two DTDs may not be a DTD
- Class is not closed under composition (e.g. : union, complementation)

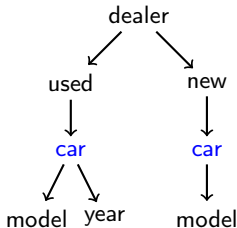
Single-Type Tree Grammars: XML Schemas... to the Rescue!

Restriction

- For each $a[T_1]$ and $a[T_2]$ occurring **under the same parent** in E , *content models* are identical: $T_1 = T_2$

$$\mathcal{L}_{\text{dtd}} \subset \mathcal{L}_{\text{xmlschema}}$$

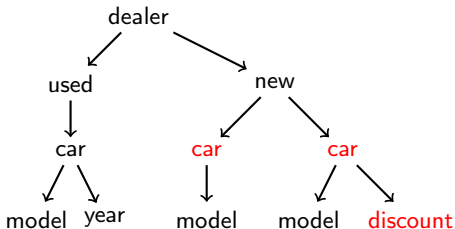
- \mathcal{L}_{dtd} : *content model* depends on the label of the parent
- $\mathcal{L}_{\text{xmlschema}}$: may depend on the label of any ancestor
- Strict inclusion, example of a *single-type* (and not *local*) grammar:



Dealer = dealer [Used, New]
Used = used [UsedCar]
New = new [NewCar]
UsedCar = car [Model, Year]
NewCar = car [Model]
...

XML Schemas also have Weaknesses

- “At least one car has a discount” is not *single-type*:



- Corollary: the class still not closed under union (although XML Schema specification is quite long)...

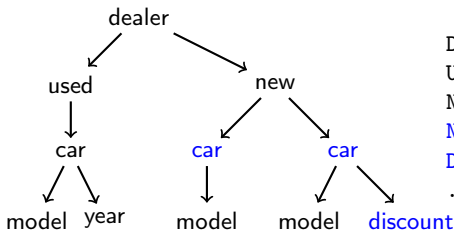
Regular Tree Grammars

No additional restriction

- A simple and powerful class
- In the XML world, it corresponds to Relax NG (see relaxng.org)

$$\mathcal{L}_{\text{xmlschema}} \subset \mathcal{L}_r$$

- $\mathcal{L}_{\text{xmlschema}}$: *content model* may depend on the label of any ancestor
- \mathcal{L}_r : *content model* may also depend on ancestor's siblings for instance
- Strict inclusion:



Dealer = dealer[Used, New]
Used = used[UsedCar]
New = new[NewCar, DNewCar]
NewCar = car[Model]
DNewCar = car[Model, Discount]
...

What do you think of this Tree Grammar?

```
Person = MPerson | FPerson
MPerson = person[Name,gender[Male], FSpouse?, Children?]
FPerson = person[Name,gender[Female],MSpouse?, Children?]
Male    = male[]
Female  = female[]
FSpouse = spouse[Name, gender[Female]]
MSpouse = spouse[Name, gender[Male]]
Children= children[Person+]
Name    = name[String]
```

1. Is it local (DTD-definable) ?
2. Single-type (XML-Schema definable)?
3. Regular?

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1. Is it local (DTD-definable) ? **No**
2. Single-type (XML-Schema definable)? **No**: two elements of the same name **person** with different *content models* under the same parent **children**
3. Regular?

What do you think of this Tree Grammar?

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1. Is it local (DTD-definable) ? **No**
2. Single-type (XML-Schema definable)? **No**: two elements of the same name **person** with different *content models* under the same parent **children**
3. Regular? **Yes!** (all recursive uses of type variables are guarded)

Tree Grammars: Conclusion

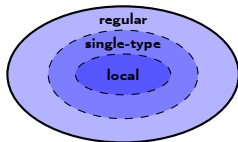
Sample Questions

- Are valid documents against type X also valid against type X'? (type inclusion, backward compability)
- Does a type X defines a non-empty set of trees? (consistency)
- Can I build the union, intersection, difference... of types X and Y and express the result with my favorite XML type language?

If we can answer for regular grammars then we can for local/single-type too!

Regular Tree Grammars

- A simply defined class
- High expressive power
- Robust (closed under set-theoretic operations)
- and well-characterized (e.g. tree automata...)





Brüggemann-Klein, A. (1993).

Regular expressions into finite automata.

Theor. Comput. Sci., 120(2):197–213.



Hopcroft, J. E., Motwani, R., Rotwani, and Ullman, J. D. (2000).

Introduction to Automata Theory, Languages and Computability.

Addison-Wesley Longman Publishing Co., Inc., Boston, MA, USA.