A Normal Form for XML Documents

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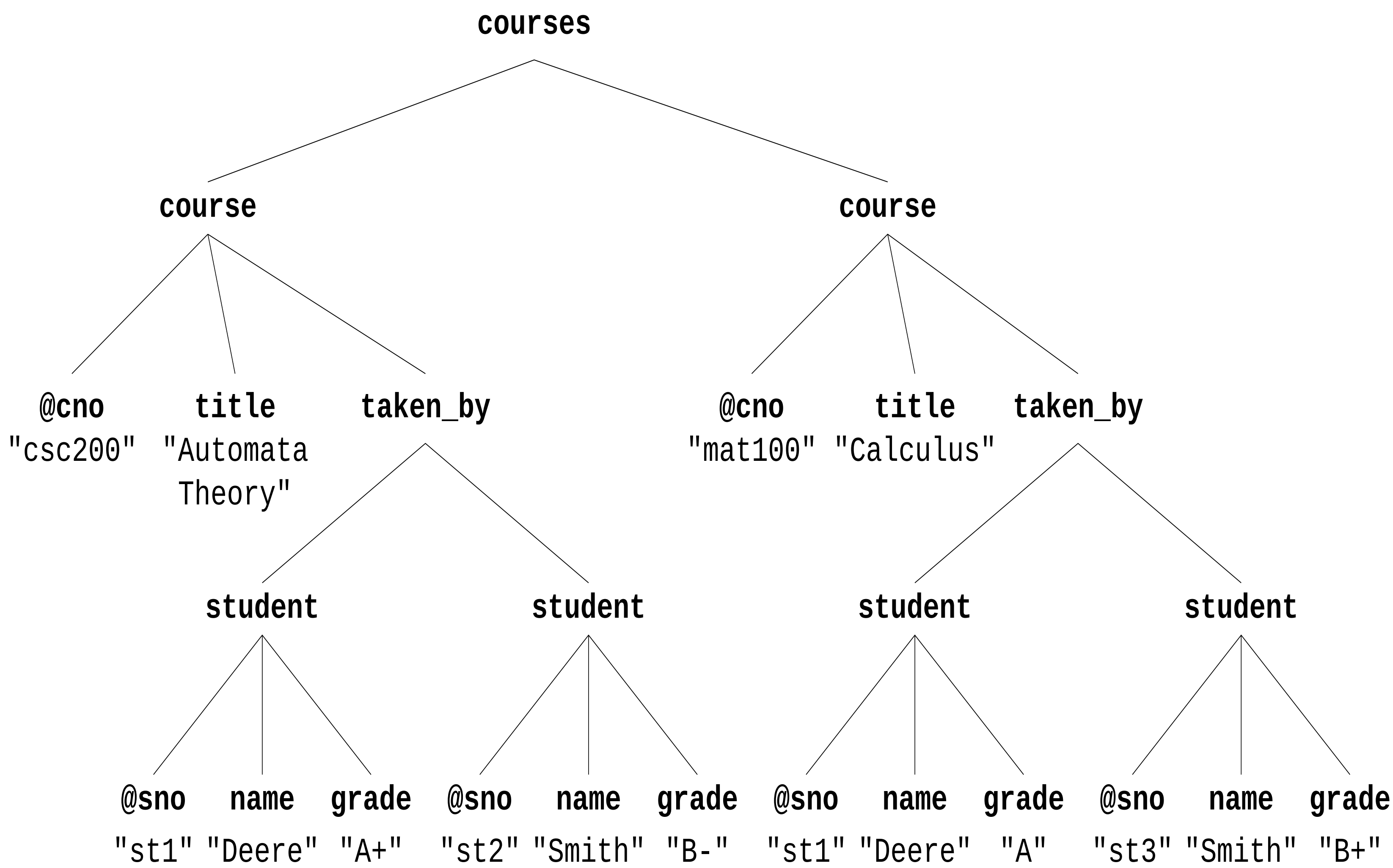
Outline

- Motivation
- Functional dependencies for XML
- A normal form for XML documents
- An algorithm for normalizing XML documents
- Implication problem for functional dependencies
- Ongoing work

XML Data: University Database



DTD: Schema of XML Documents

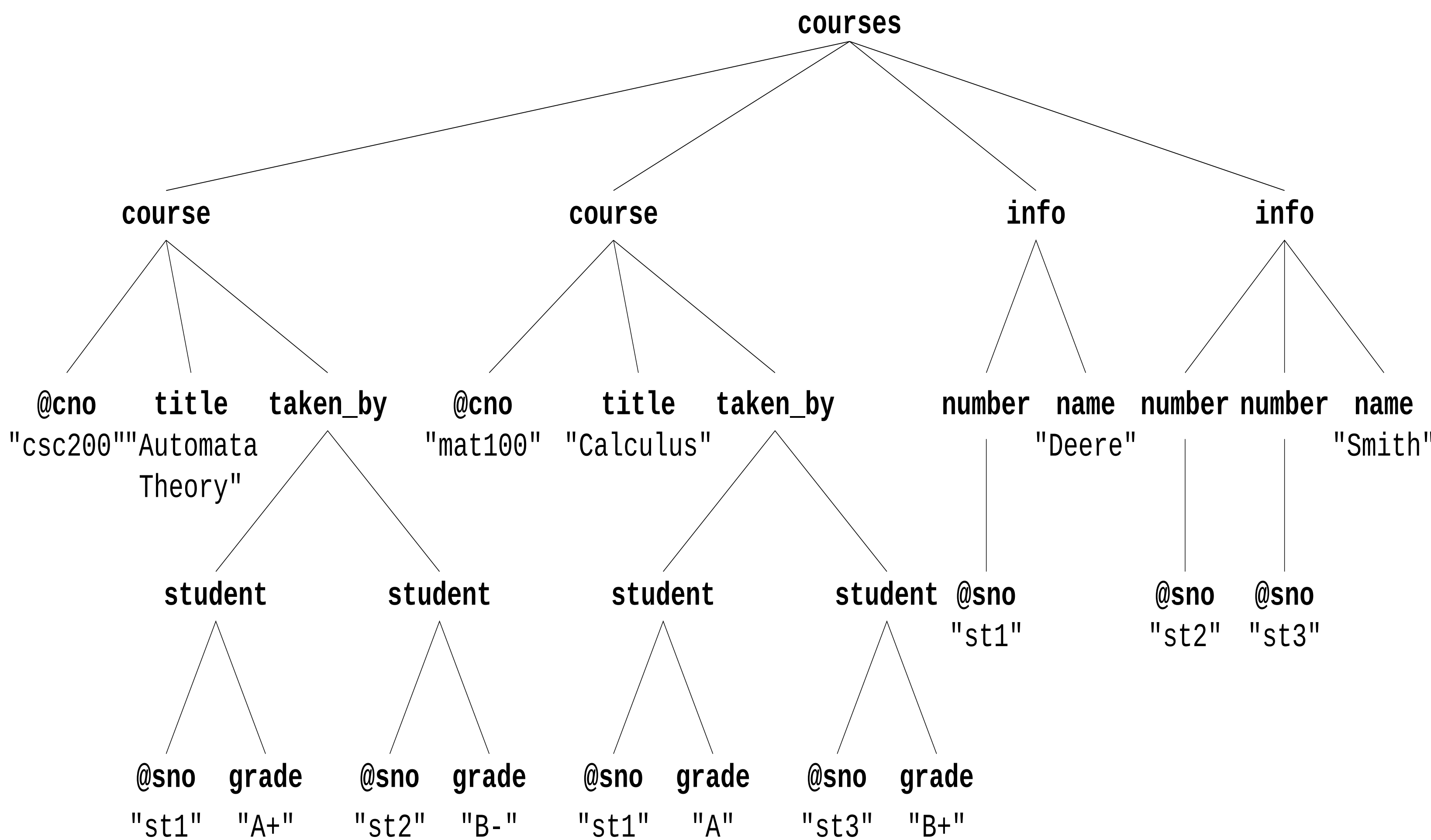
```
<!DOCTYPE courses [
  <!ELEMENT courses (course*)>
  <!ELEMENT course (title, taken_by)>
    <!ATTLIST course
              cno CDATA #REQUIRED>
  <!ELEMENT title (#PCDATA)>
  <!ELEMENT taken_by (student*)>
  <!ELEMENT student (name, grade)>
    <!ATTLIST student
              sno CDATA #REQUIRED>
  <!ELEMENT name (#PCDATA)>
  <!ELEMENT grade (#PCDATA)>
]>
```

Semantic Information

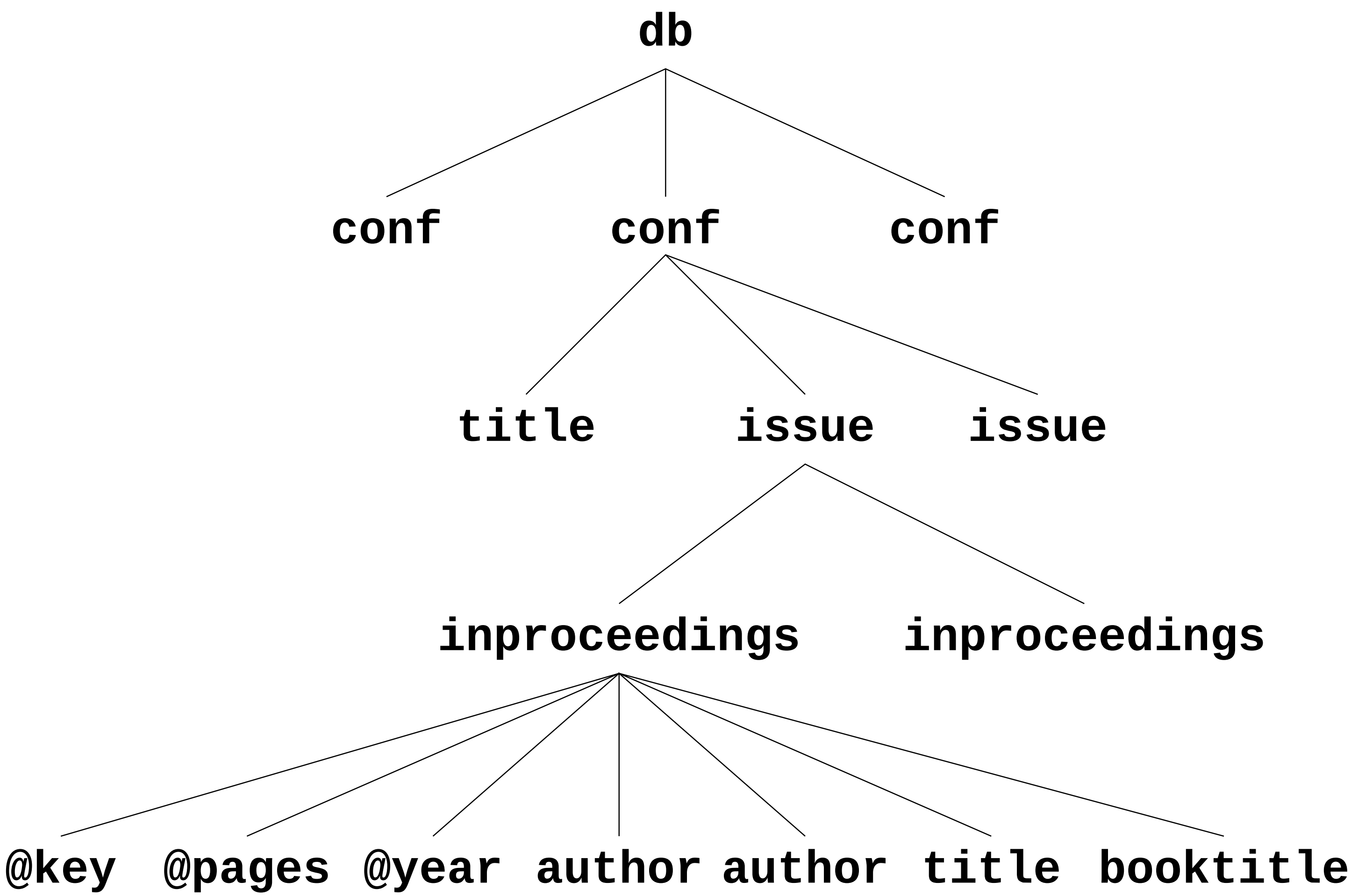
- XML specifications can include semantic information:
  - ◇ Two distinct **`course`** elements cannot have the same **`cno`**
  - ◇ Two distinct **`student`** subelements of the same **`course`** cannot have the same **`sno`**
  - ◇ Two **`student`** elements with the same **`sno`** value must have the same **`name`**

- XML documents can contain redundant information

Our Goal: Schema Refinement



Relational Ideas can be Inadequate: DBLP



Problems to Address

- Definition of a language for expressing functional dependencies
  - ◇ Simple language
  - ◇ Absolute and Relative constraints
  - ◇ The order of children in an XML tree is irrelevant as far as satisfaction of constraints is concerned

- Definition of a normal form for XML documents (XNF)

- Construction of an algorithm for normalizing XML documents
  - ◇ Implication problem for functional dependencies
  - ◇ Testing if a specification is in XNF

Framework: DTDs

We do not consider mixed content, IDs and IDREFs

Notation:

- $Paths(D)$: all paths in a DTD D

  In the university database example:

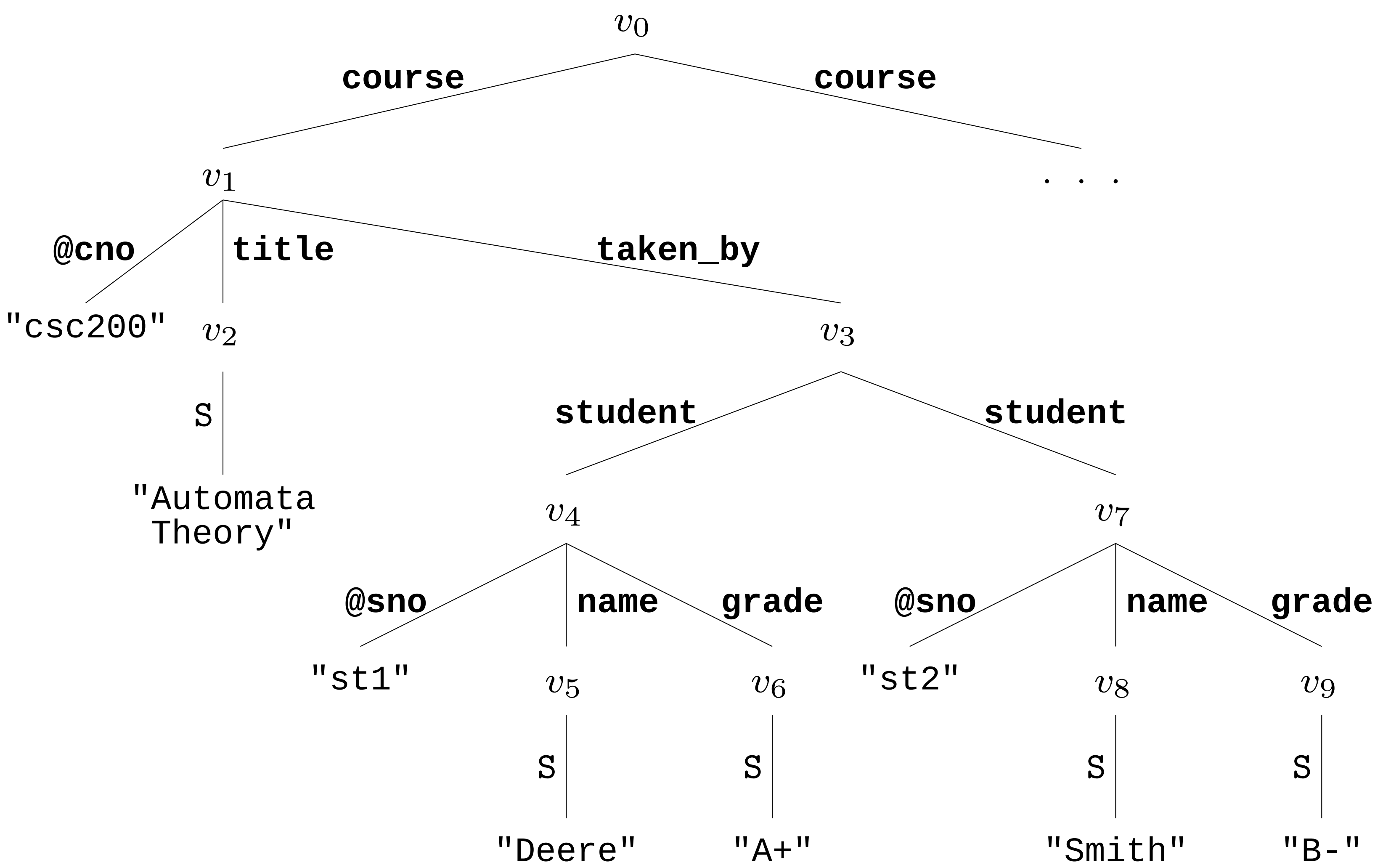
$courses$	$courses.course$
$courses.course.@cno$	$courses.course.title$
$courses.course.title.\mathtt{S}$	$\ldots$

- $EPaths(D)$: all paths that end with an element type

  $courses.course$ is in $EPaths(D)$

  $courses.course.@cno$ is not

Framework: XML Trees



Tree Tuples

A *tree tuple t in a DTD D* is a function from $Paths(D)$ to $Vertices \cup Strings \cup \{\perp\}$

$t(courses) = v_0$

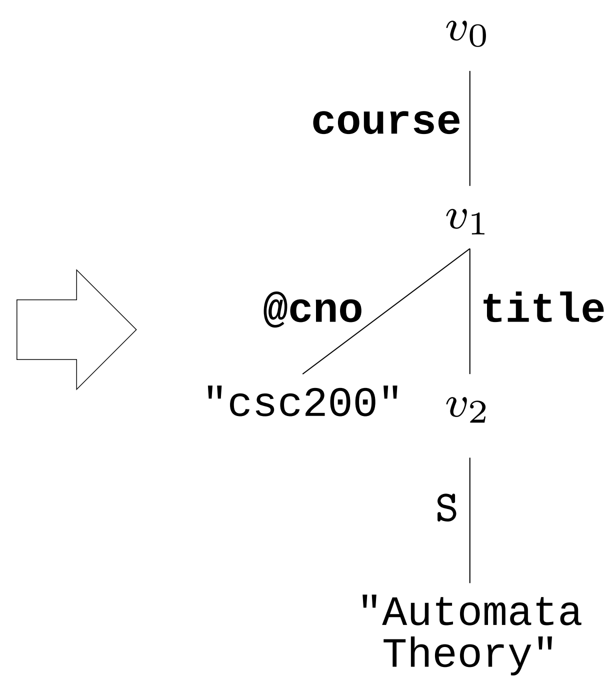
$t(courses.course) = v_1$

$t(courses.course.@cno) = \texttt{csc200}$

$t(courses.course.title) = v_2$

$t(courses.course.title.\texttt{S}) = \texttt{Automata Theory}$

$t(p) = \perp$, for the remaining paths



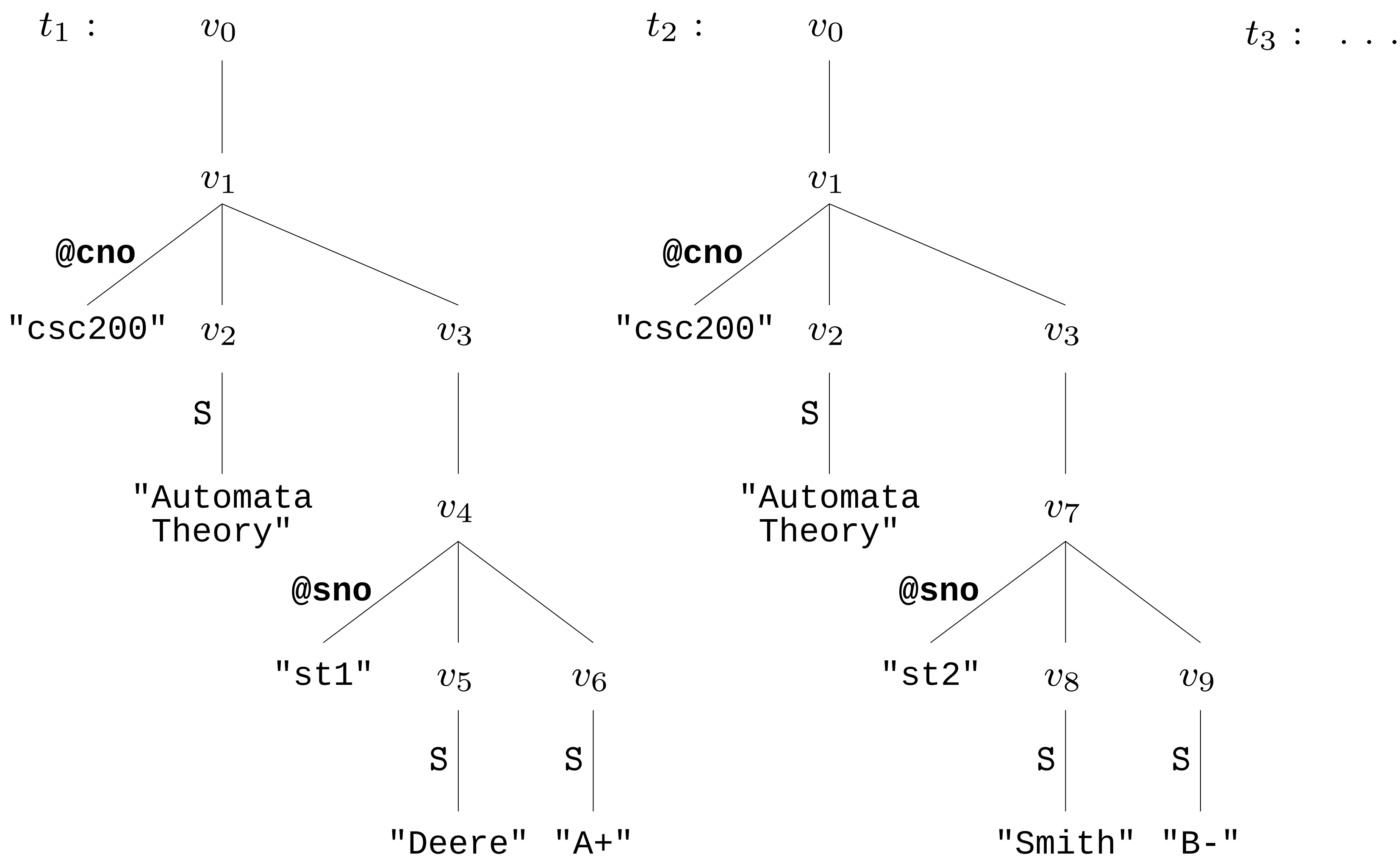
XML tree: Set of Tree Tuples

- An XML tree can be represented as a set of tree tuples, if we consider it as an unordered tree

- We consider tuples containing a maximal amount of information (minimal set of $\perp$ values)

- If T is the XML tree containing information about courses, then $\mathit{Tuples}_D(T) = \{t_1, t_2, t_3, t_4\}$, where ...

Tree Tuples of T



Functional Dependencies for XML

- A *functional dependency over a DTD D* is an expression

$$S_1 \rightarrow S_2$$

where S_1 and S_2 are finite subsets of $Paths(D)$

- $T \models S_1 \rightarrow S_2$ if for every $t_1, t_2 \in Tuples_D(T)$,

$$t_1.S_1 = t_2.S_1 \ \text{ and } \ t_1.S_1 \neq \bot \quad \Longrightarrow \quad t_1.S_2 = t_2.S_2.$$

Back to the University Example

- Two distinct **`course`** elements cannot have the same **`cno`**:

$$courses.course.@cno \rightarrow courses.course$$

- Two distinct **`student`** subelements of the same **`course`** cannot have the same **`sno`**:

$$\{courses.course,\ courses.course.taken\_by.student.@sno\} \rightarrow courses.course.taken\_by.student$$

- Two **`student`** elements with the same **`sno`** value must have the same **`name`**:

$$courses.course.taken\_by.student.@sno \rightarrow courses.course.taken\_by.student.name.\mathtt{S}.$$

XNF: An XML Normal Form

- XML specification: a DTD D and a set of functional dependencies Σ

- (D, Σ) *is in XML Normal Form (XNF)* if:

  for every non-trivial functional dependency $\varphi \in (D, \Sigma)^+$ of the form $S \to p.@l$ or $S \to p.\mathtt{S}$, it is the case that $S \to p$ is in $(D, \Sigma)^+$

- XNF generalizes BCNF and a normal form for nested relations (NNF) when those are coded as XML documents

XNF: Back to the Examples

- University specification is not in XNF:

$$courses.course.taken\_by.student.@sno \rightarrow courses.course.taken\_by.student.name$$

  is not in $(D, \Sigma)^+$.

- DBLP specification is not in XNF:

$$db.conf.issue \rightarrow db.conf.issue.inproceedings.@year \quad \in \quad (D, \Sigma)^+$$

$$db.conf.issue \rightarrow db.conf.issue.inproceedings \quad \notin \quad (D, \Sigma)^+$$

- Proposed solutions are in XNF

Normalizing XML Documents

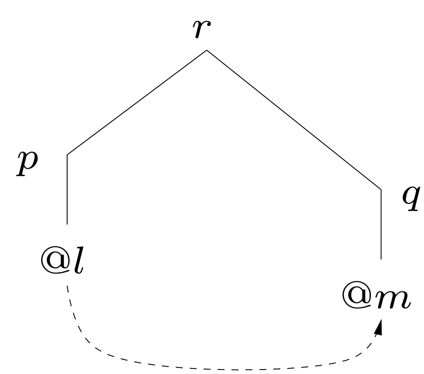
We consider functional dependencies of the form

$$\{q,\ p_1.@l_1,\ \ldots, p_n.@l_n\} \rightarrow p$$

where $n \geq 0$, $q \in EPaths(D)$ and $p \in Paths(D)$

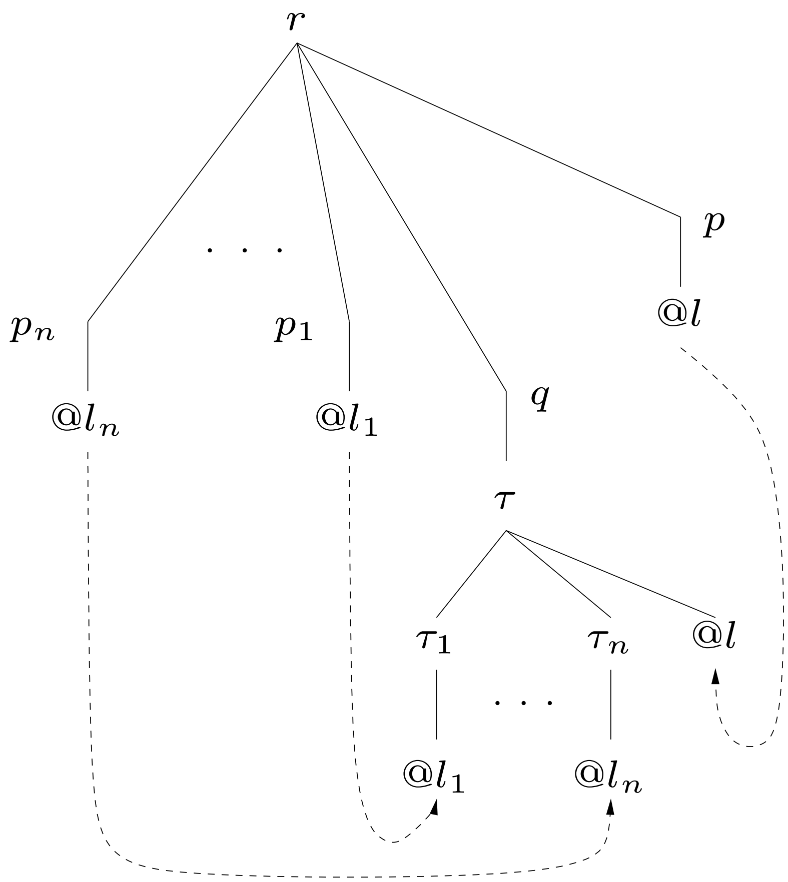
The normalization algorithm applies two transformations until the schema is in XNF:

- **Moving attributes**: if there is an anomalous functional dependency $q \rightarrow p.@l$ in $(D, \Sigma)^+$, then



Normalizing XML Documents

- **Creating new element types**: choose a minimal anomalous functional dependency $\{q,\ p_1.@l_1,\ \ldots, p_n.@l_n\} \rightarrow p.@l$ and



Normalizing XML Documents

- **Theorem** *The decomposition algorithm terminates and outputs a specification in XNF*

- Our transformations do not lose information: there are XQuery queries that translate back and forth two schemas
(a‘ la Hull’s information capacity of schemas)

- It involves implication of functional dependencies

Reasoning about Functional Dependencies

- Typically, regular expressions used in DTDs are rather simple

- *D is a simple DTD* if D contains regular expression of the form $s_1, \ldots, s_n$, where
  - ◇ each s_i is either one of a_i, $a_i?$, a_i^+ or a_i^*
  - ◇ for $i \neq j$, $a_i \neq a_j$

  D can also contain "permutations" of this type of expressions:
  $(course \mid info)^*$

Example: ebXML

Business process specification schema of ebXML:

```
<!ELEMENT ProcessSpecification (Documentation*, SubstitutionSet*, (Include |
    BusinessDocument | ProcessSpecification | Package | BinaryCollaboration |
    BusinessTransaction | MultiPartyCollaboration)*)>
<!ELEMENT Include (Documentation*)>
<!ELEMENT BusinessDocument (ConditionExpression?, Documentation*)>
<!ELEMENT SubstitutionSet (DocumentSubstitution | AttributeSubstitution |
    Documentation)*>
<!ELEMENT BinaryCollaboration (Documentation*, InitiatingRole, RespondingRole,
    (Documentation | Start | Transition | Success | Failure |
    BusinessTransactionActivity | CollaborationActivity | Fork | Join)*)>
<!ELEMENT Transition (ConditionExpression?, Documentation*)>
```

Reasoning about Functional Dependencies

- **Theorem** *For simple DTDs*
  - ◇ *The implication problem for FDs is solvable in quadratic time*
  - ◇ *Testing if a specification is in XNF can be done in cubic time*

- Other results
  - ◇ There is a larger class of DTDs for which these problems are tractable ("small" number of disjunctions)
  - ◇ There is a class of DTDs for which these problems are coNP-complete

Ongoing Work

- Improve the decomposition algorithm in various ways
- Find a complete classification of the complexity of the implication problem for various classes of DTDs
- Construct a more expressive language for functional dependencies (regular expressions)
- Consider other anomalies and other integrity constraints
- Implementation