Reasoning about XML Constraints based on XML-to-relational mappings

Matthias Niewerth Thomas Schwentick

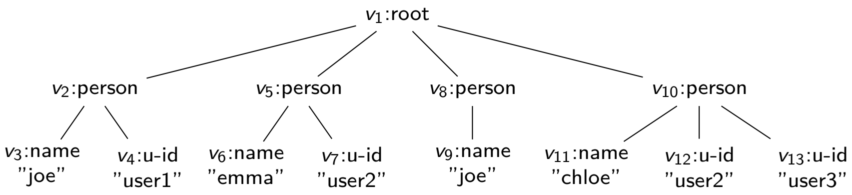
Problem Description

Foundations
of
XML

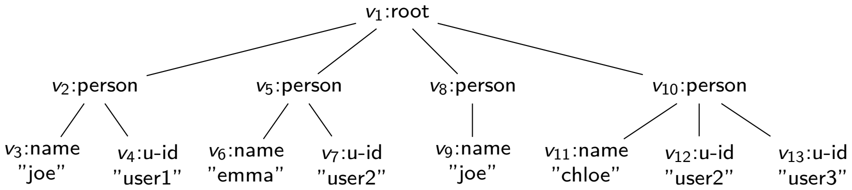
Project Tasks

- Develop a rich modelling language for XML constraints.
- Find an optimal trade-off between structure and data.

Example


v1:root
v2:person
v5:person
v8:person
v10:person
v3:name "joe"
v4:u-id "user1"
v6:name "emma"
v7:u-id "user2"
v9:name "joe"
v11:name "chloe"
v12:u-id "user2"
v13:u-id "user3"

Example

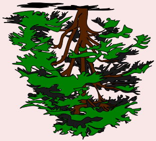


How to express that . . .

- . . . u-ids are unique?
- . . . every person has only one name?
- . . . every u-id has at most one associated name?

Contents

Definition



$\longrightarrow$

a	b	c

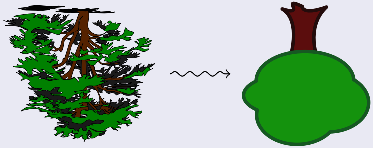
Existing Work

- XFDs
- Hierachical Constraints
- XML Schema Constraints

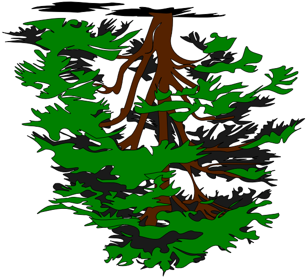
Reasoning

- Model-Checking
- Implication Problem

Tree Chase



XML-to-relational Constraints



mapping →

a	b	c	d	e	f

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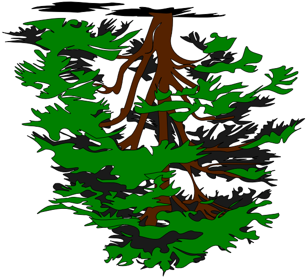

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Definition: XML-to-rel. Constraint

- mapping $m : \mathcal{T} \to \mathcal{R}$
- relational constraint σ

$$t \models (m, \sigma) \;\Leftrightarrow\; m(t) \models \sigma$$

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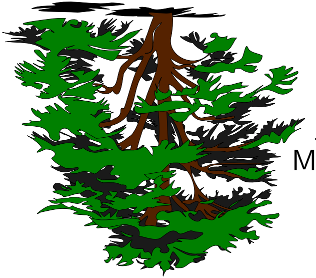

mapping $\longrightarrow$ MSO,FO,XPath

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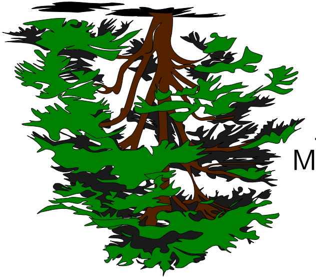

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Semantical Restriction

Mappings should be invariant under renamings of datavalues.

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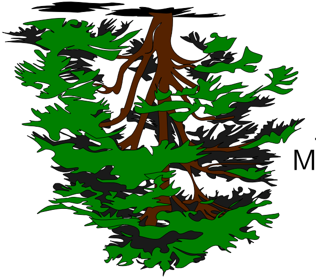

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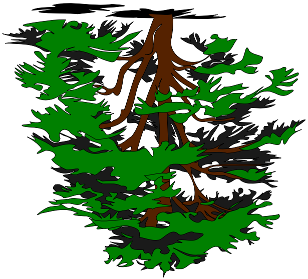

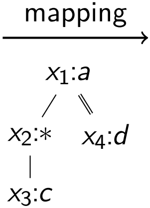

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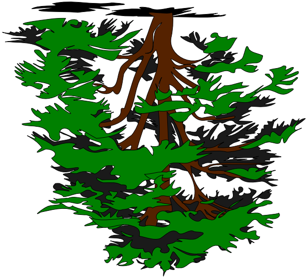

mapping →

$x_1{:}a$

$x_2{:}*$ $x_4{:}d$

$x_3{:}c$

x_1	$x_1.@$	x_2	$x_2.@$	x_3	$x_3.@$	x_4	$x_4.@$

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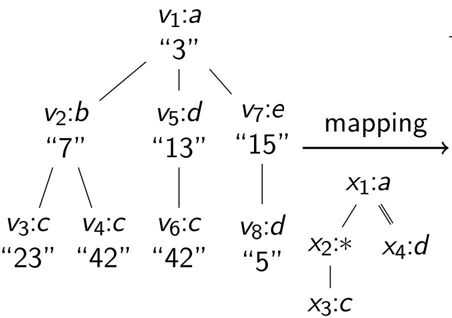

x_1	$x_1.@$	x_2	$x_2.@$	x_3	$x_3.@$	x_4	$x_4.@$

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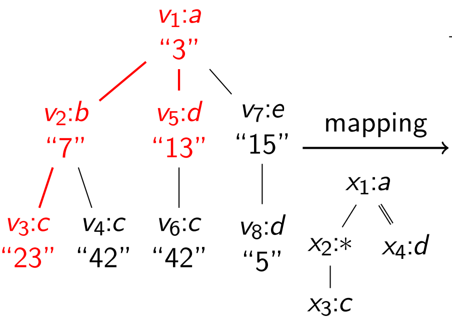

x_1	$x_1.@$	x_2	$x_2.@$	x_3	$x_3.@$	x_4	$x_4.@$
v_1	3	v_2	7	v_3	23	v_5	13

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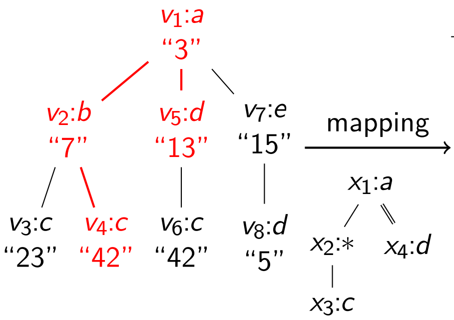

x_1	$x_1.@$	x_2	$x_2.@$	x_3	$x_3.@$	x_4	$x_4.@$
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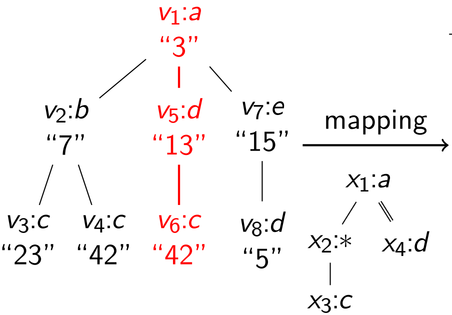

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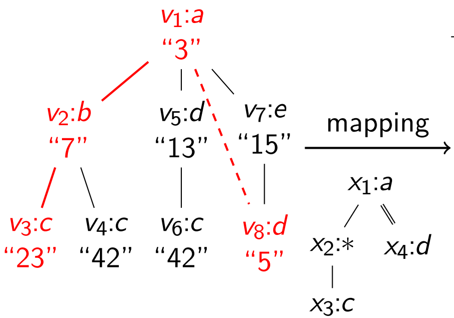

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v_1	3	v_2	7	v_3	23	v_8	5

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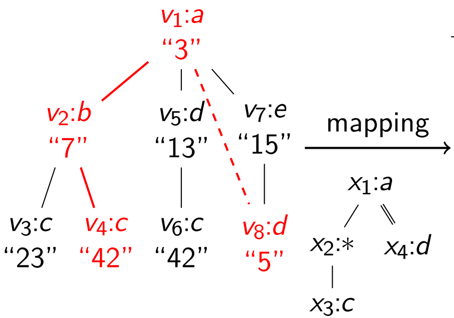

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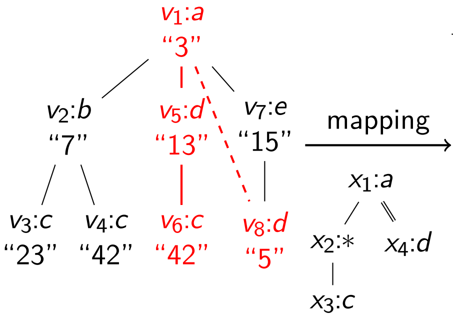

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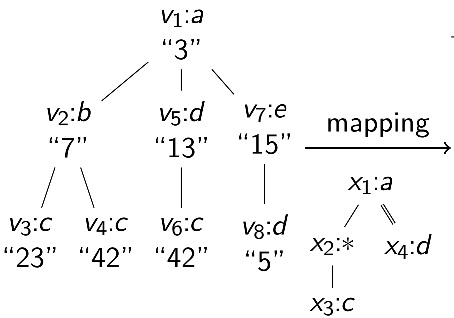

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v_1	3	v_2	7	v_3	23	v_5	13
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Functional Dependencies:

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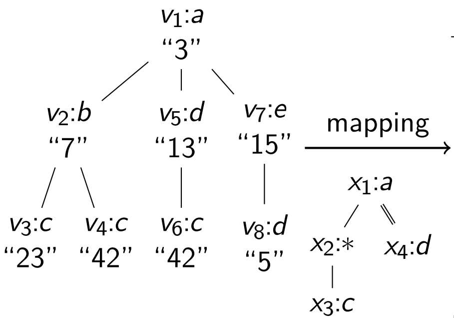

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v_1	3	v_2	7	v_3	23	v_5	13
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- $x_2.@ \rightarrow x_2$

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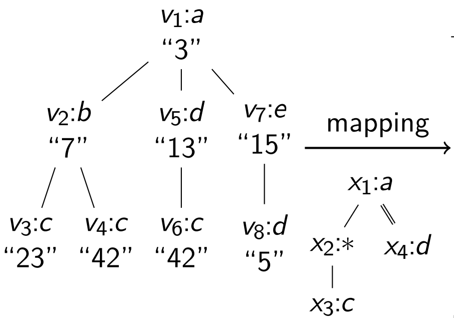

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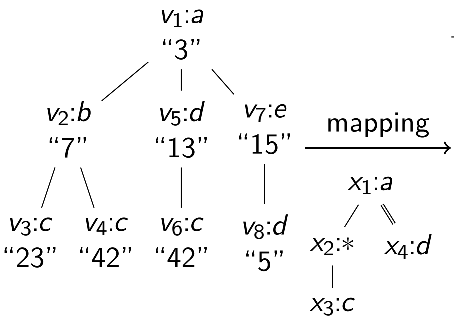

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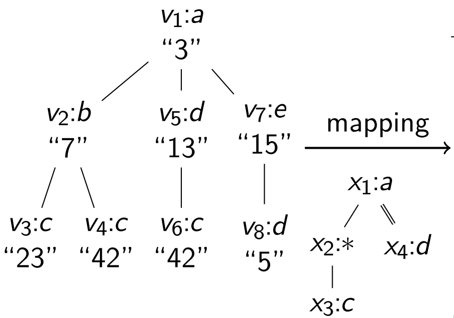

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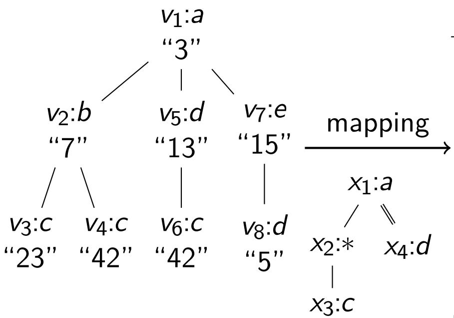

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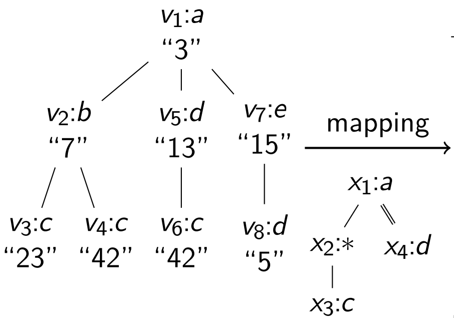
- $x_2, x_3.@ \rightarrow x_3$

XML-to-relational Constraints



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Functional Dependencies:

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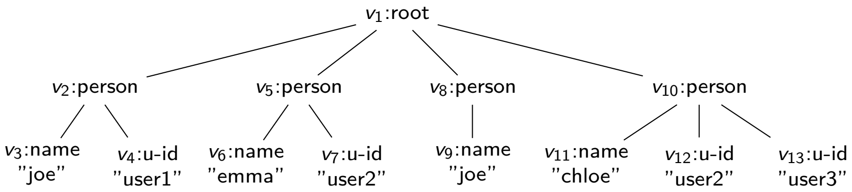
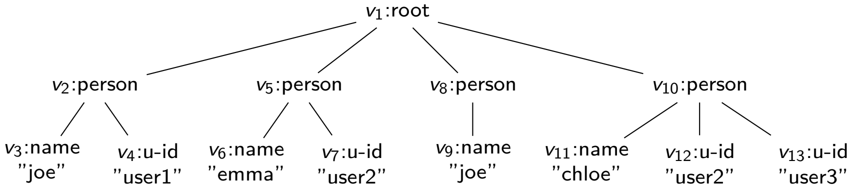
- $x_3.@ \to x_3$ ✗
- $x_2, x_3.@ \to x_3$ ✓

Example


v1:root
v2:person
v5:person
v8:person
v10:person
v3:name "joe"
v4:u-id "user1"
v6:name "emma"
v7:u-id "user2"
v9:name "joe"
v11:name "chloe"
v12:u-id "user2"
v13:u-id "user3"

Example



How to express that ...

- ... u-ids are unique?
- ... every person has only one name (node)?
- ... every u-id has at most one associated name (data value)?

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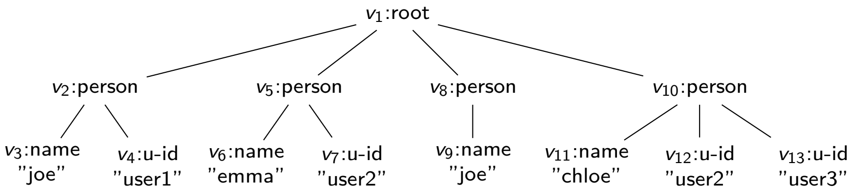
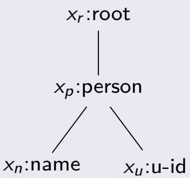


Pattern/Mapping



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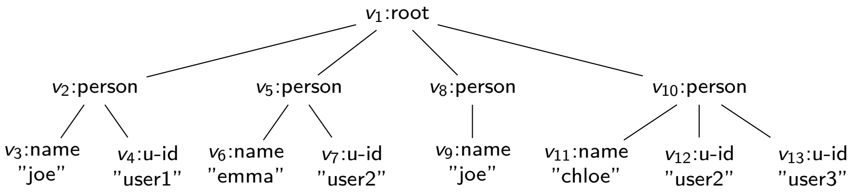
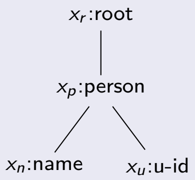


Pattern/Mapping



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- ... every person has only one name (node)?

- ... every u-id has at most one associated name (data value)?

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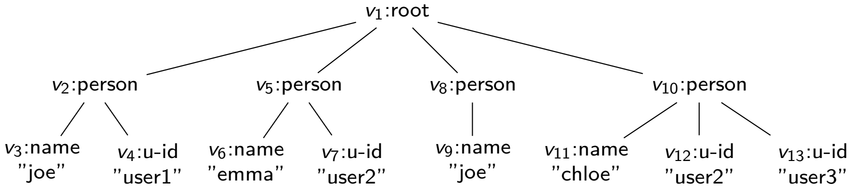

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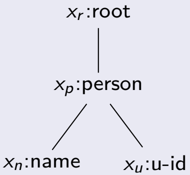

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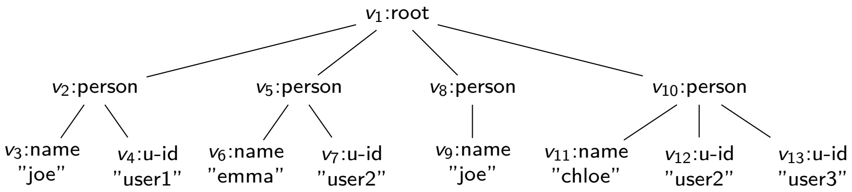

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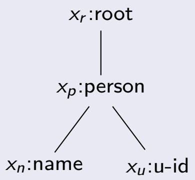

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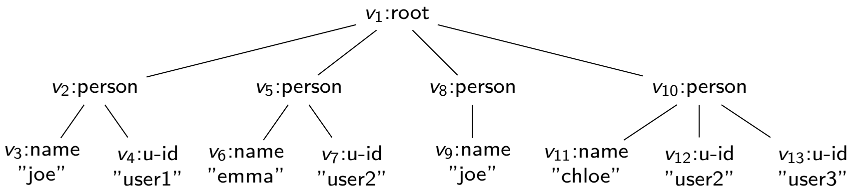

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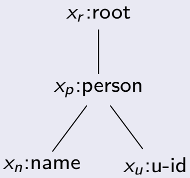

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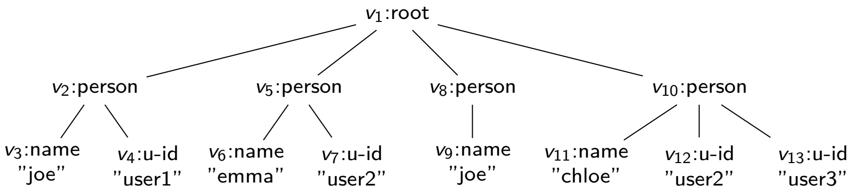

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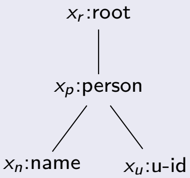

Relation

x_r	x_p	x_n	$x_n.@$	x_u	$x_u.@$
v_1	v_2	v_3	joe	v_4	user1
v_1	v_5	v_6	emma	v_7	user2
v_1	v_{10}	v_{11}	chloe	v_{12}	user2
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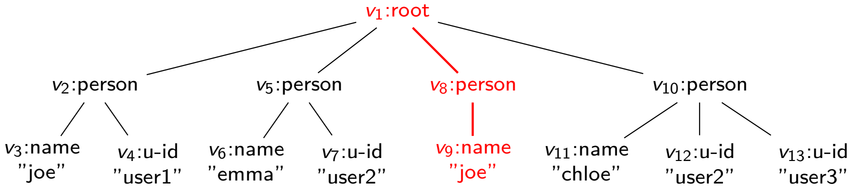

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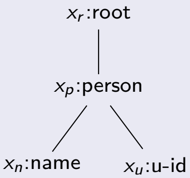

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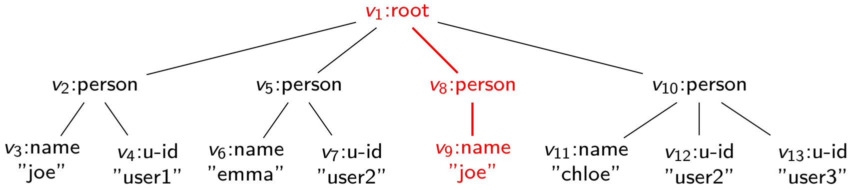

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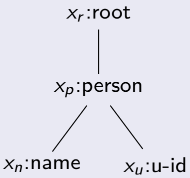

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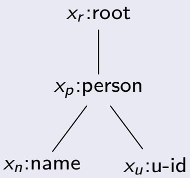
Incomplete/Missing Data

Semantics

Pattern/Mapping



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v_1	v_8	v_9	joe	$\perp$	$\perp$
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- "Complete Data Semantics":
  One tuple for every complete embedding of the tree pattern

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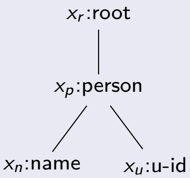

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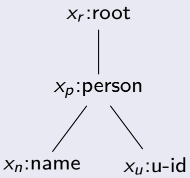

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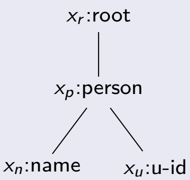

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Functional Dependencies vs. Key Constraints

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Informal Definition

A key constraint uniquely identifies a real-world entity.

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In XML documents real-world entities correspond to nodes.

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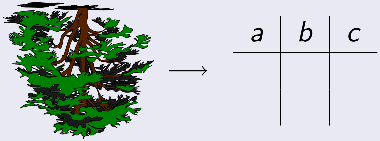
In XML documents real-world entities correspond to nodes.

Formal Definition: XKFD

An XML Key Functional Dependency (XKFD) is an FD $(m, A \rightarrow b)$, where b refers to a node.

Contents

Definition



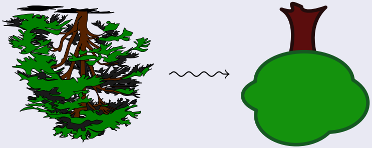
Existing Work

- XFDs
- Hierachical Constraints
- XML Schema Constraints

Reasoning

- Model-Checking
- Implication Problem

Tree Chase



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Definition [Arenas, Fan, Libkin 2002]

An XML Database is in XML Normal Form, if all FDs are XKFDs.

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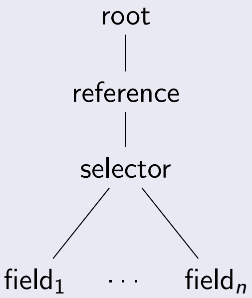

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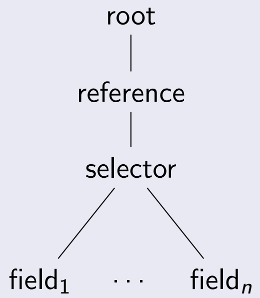

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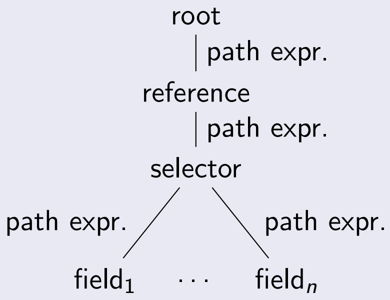

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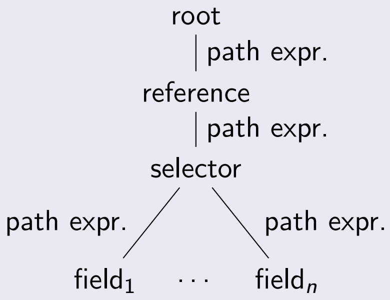

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- All hierachical key constraints are XKFDs.
- Path Expressions instead of simple paths
- Can be expressed with tree patterns if Linear XPath is used.

Contents

Definition

→

a	b	c

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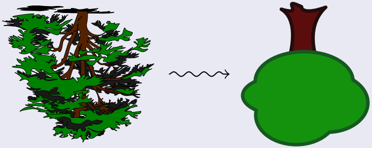

Algorithmic Problems

Model Checking Problem: MC($\mathcal{M}, \mathcal{C}$)

Given: XML tree t,
XML-to-rel constraint $(m, \sigma) \in \mathcal{M} \times \mathcal{C}$

Question: Does $t \models (m, \sigma)$ hold?

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Theorem

MC(TP[/, //, $*$], FD) can be solved in PTIME

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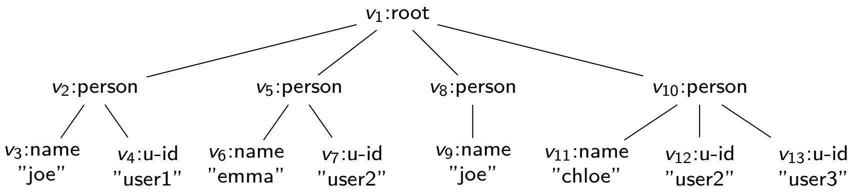

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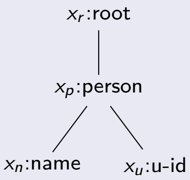

Functional Dependency

- U-IDs are unique: $x_u.@ \to x_u$

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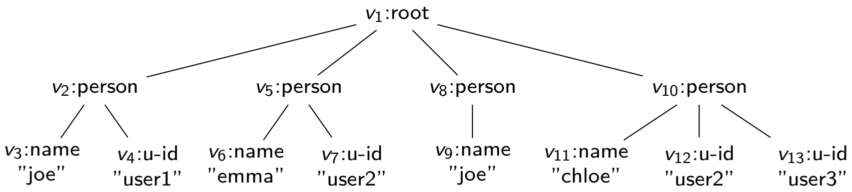

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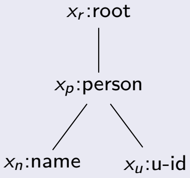

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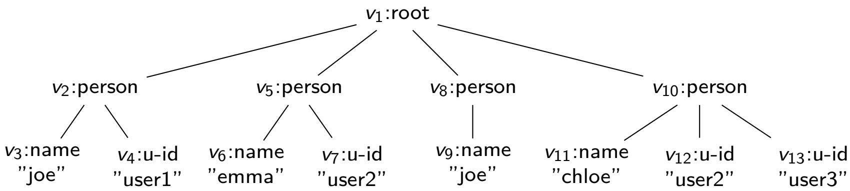

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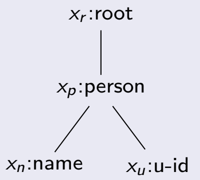

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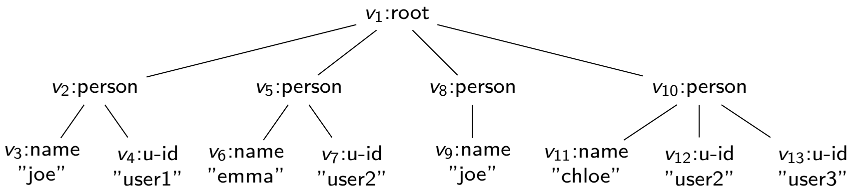
Too Large

Model Checking



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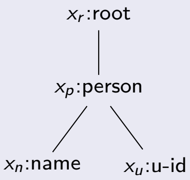

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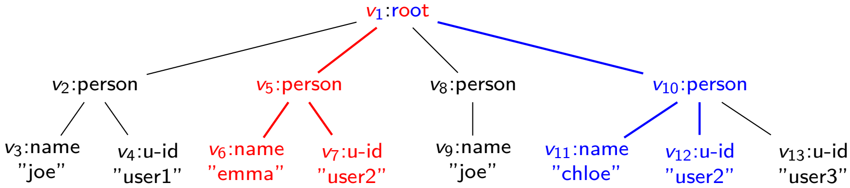

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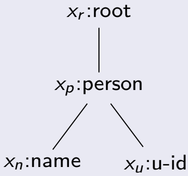

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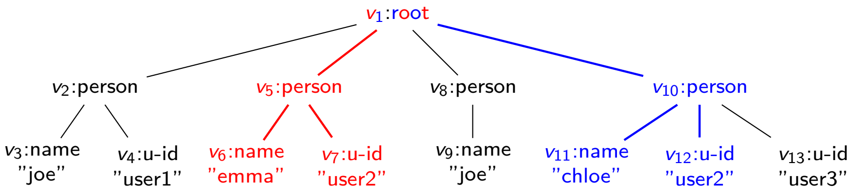
- Compute Witness Pairs using dynamic programming

Model Checking



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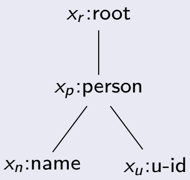

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Complexity

Combined Complexity: $\in$ DTIME($|t|^2|p|$)
Data Complexity: LOGSPACE

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Problem: IMP($\mathcal{M}, \mathcal{C}, \mathcal{S}$)

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Question: Does $(m_1, \sigma_1), \ldots, (m_n, \sigma_n) \models_S (m, \sigma)$ hold?

Theorem

IMP(TP$[/, //, *]$, FD, finite alphabet) is undecidable.

The Implication Problem

Problem: IMP($\mathcal{M}, \mathcal{C}, \mathcal{S}$)

Given: XML-to-rel. constaints
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Theorem

IMP(MSO, XKFD, MSO) is decidable.

MSO formulas have no access to data values!

The Implication Problem

Theorem

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The Implication Problem

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IMP(MSO, XKFD, MSO) is decidable.

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- A counterexample to an XKFD needs at most linearly many important data values, which occur more than once.
- Encode important data values in the labels.
- MSO (without data values) is decidable on trees.

Results

Results

	TP[/]	TP[/, ∗]	TP[/, //]	TP[/, //, ∗]
FD	$\in$ P	$\in$ P	co-NP	co-NP-hard

Results

Results

	TP[/]	TP[/, ∗]	TP[/, //]	TP[/, //, ∗]
XKFD	$\in$ P	$\in$ P	co-NP	co-NP
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Results

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Schema means:

- finite alphabet for lower bounds
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Results

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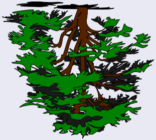
Lower Bounds:

- reductions

Contents

Definition



$\longrightarrow$

a	b	c

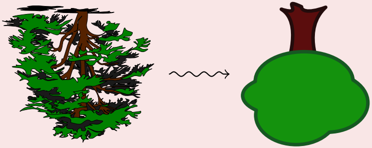
Existing Work

- XFDs
- Hierachical Constraints
- XML Schema Constraints

Reasoning

- Model-Checking
- Implication Problem

Tree Chase



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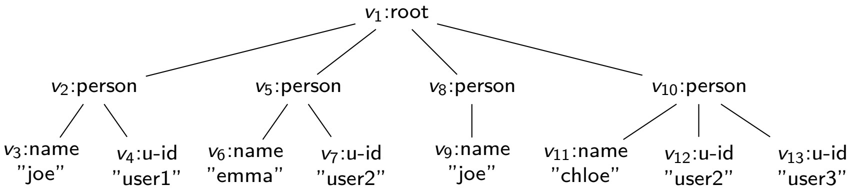

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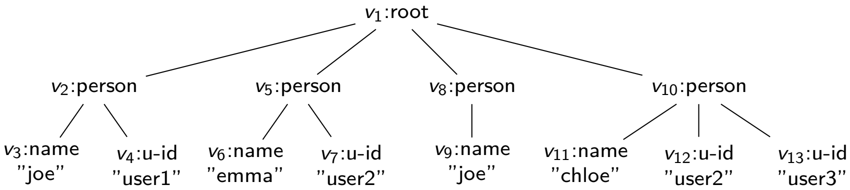

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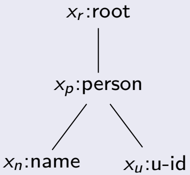

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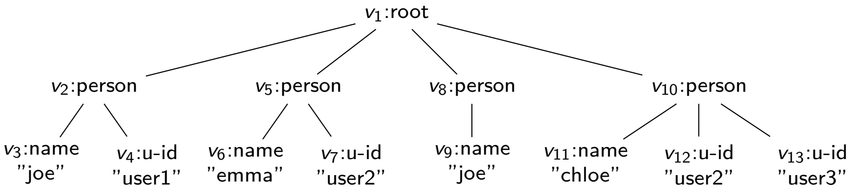

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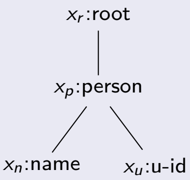

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$\Sigma \models \sigma$?

Our Tree Chase

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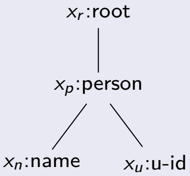

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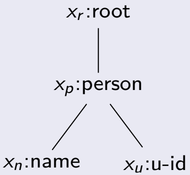

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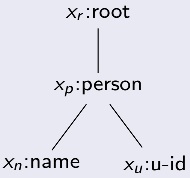

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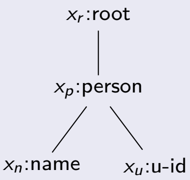

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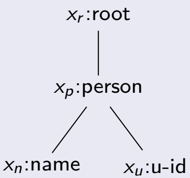

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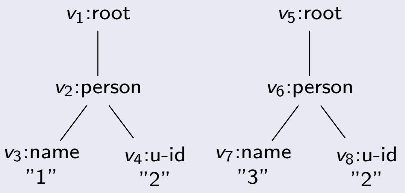

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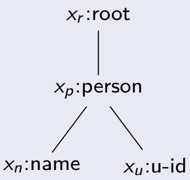

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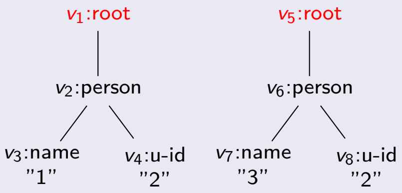

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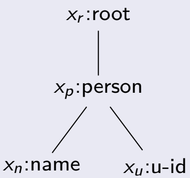

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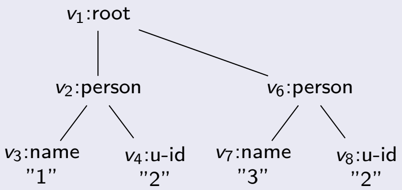

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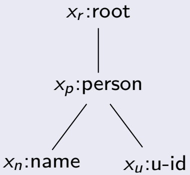

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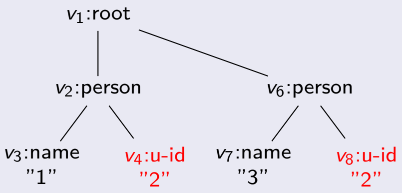

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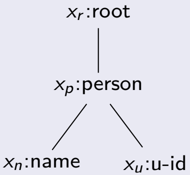

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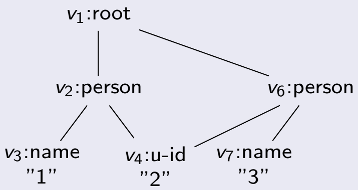

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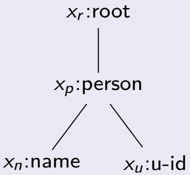

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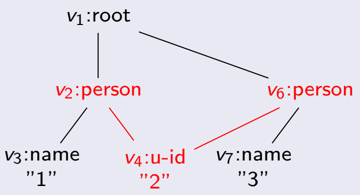

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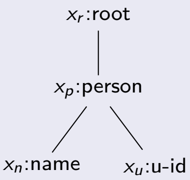

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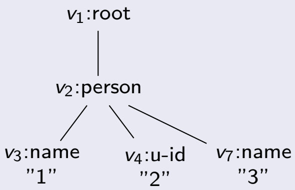

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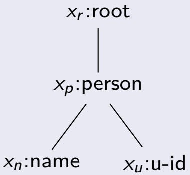

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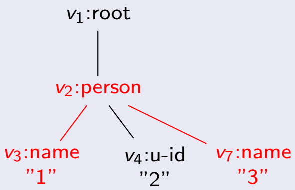

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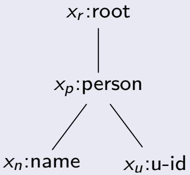

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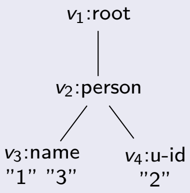

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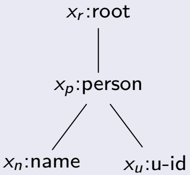

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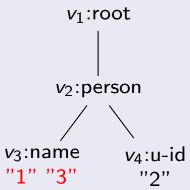

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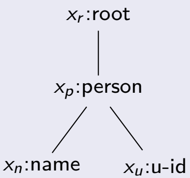

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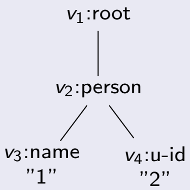

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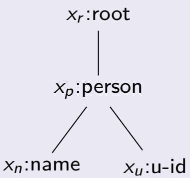

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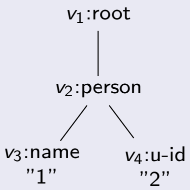

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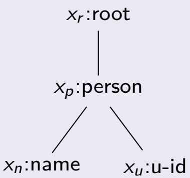

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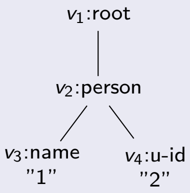

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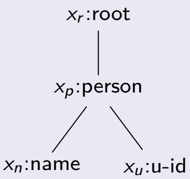

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Further Work

- Solve missing complexities
- Incomplete Data
- More general schemas
- Connections to XML Data Exchange