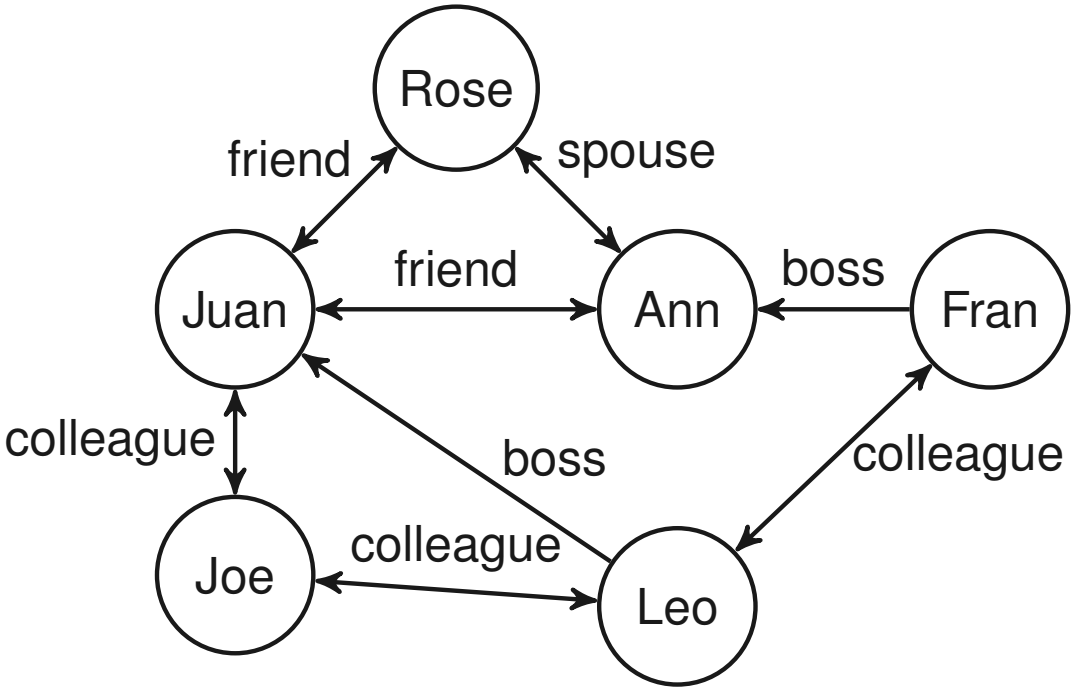
Graph Structured Data is now everywhere



- Facebook, Twitter
- DBPedia (Wikipedia represented as a graph)
- Biological databases, geological databases, social databases...

Semantic Web $\longrightarrow$ Graph Database

Web resources are modeled as nodes of a graph,
edges are relations between resources

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Querying Semantic Web:

SPARQL:

SPARQL Protocol and RDF Query Language

- Standardized query language for RDF
- Query language with strong relational flavor

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SPARQL:

SPARQL Protocol and RDF Query Language

- Standardized query language for RDF
- Query language with strong relational flavor

- Think of Relational Algebra or SQL over graphs (selection, projection, joins, unions, etc...)

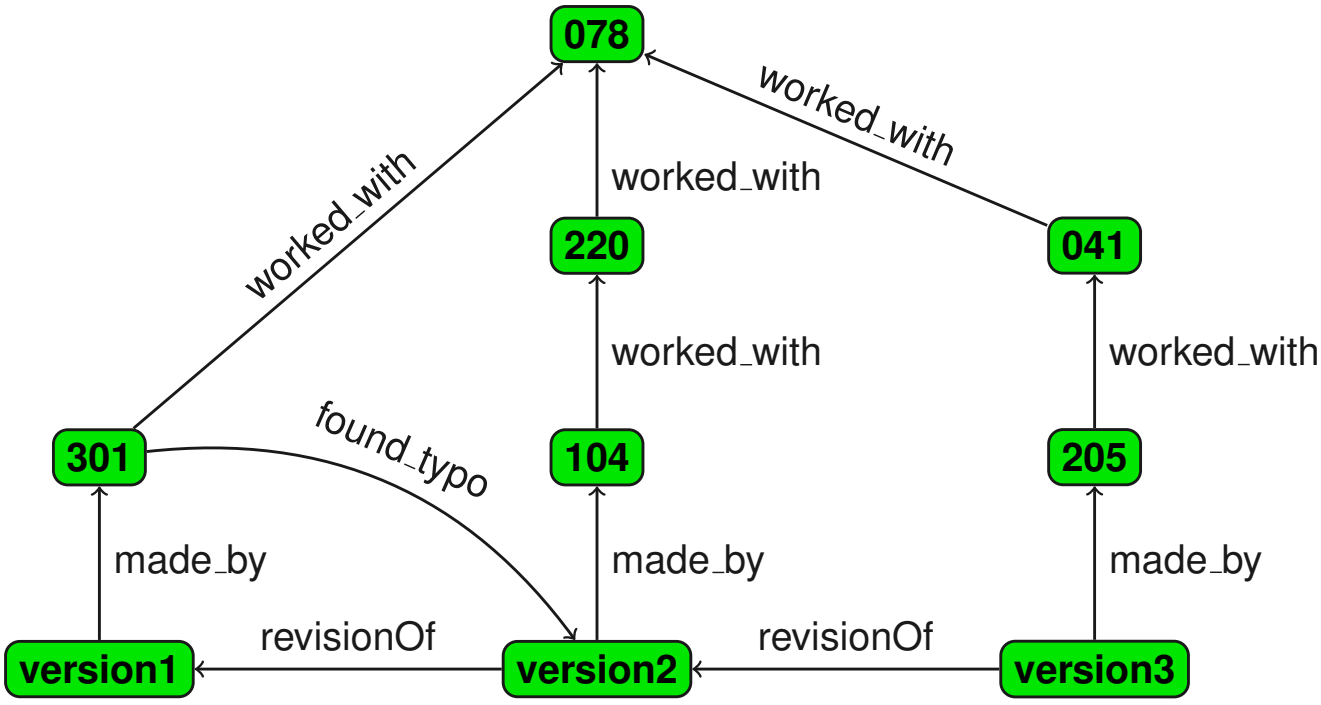
Connectivity Queries: a novel challenge

Talk about paths in graphs

Connectivity Queries: a novel challenge

- In a social network: Am I connected to a superstar?
- Workflows (biological):
  how is the path from process A to process B?
- Maps: shortest path form A to B?

Example: Provenance of a DBPedia Article



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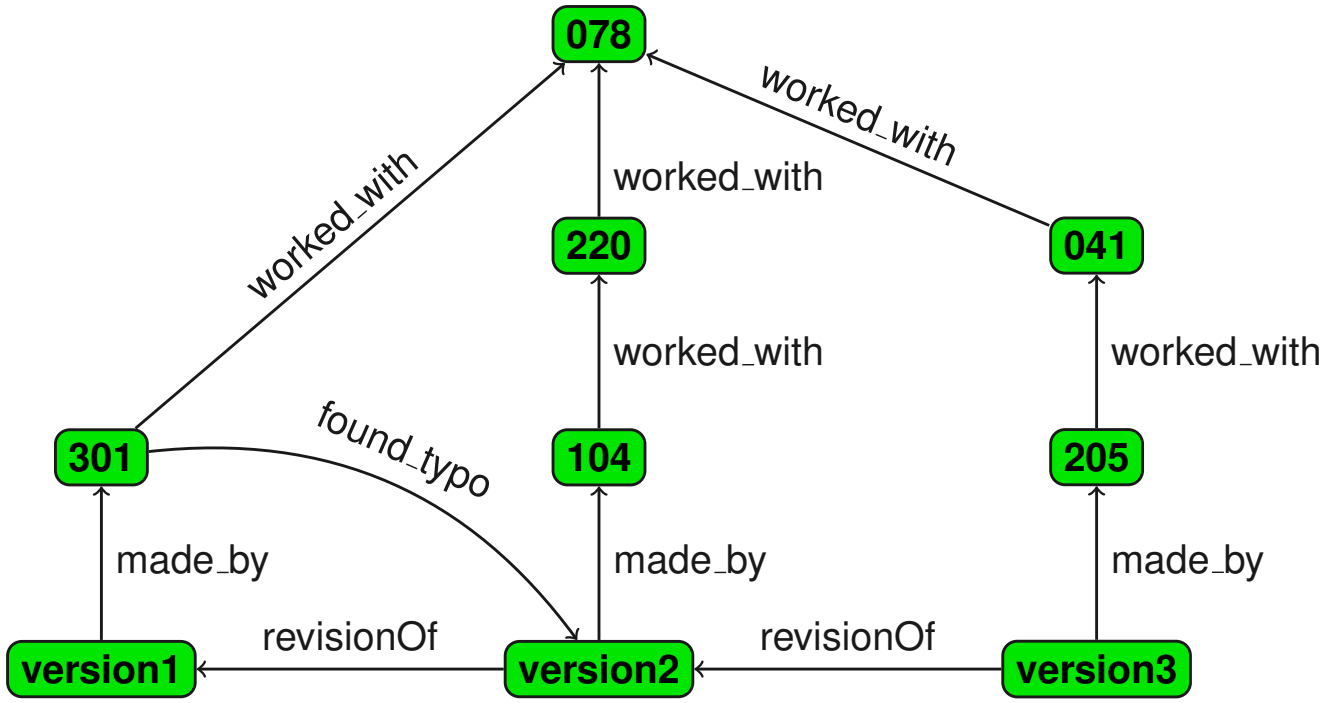

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104, 220, 078

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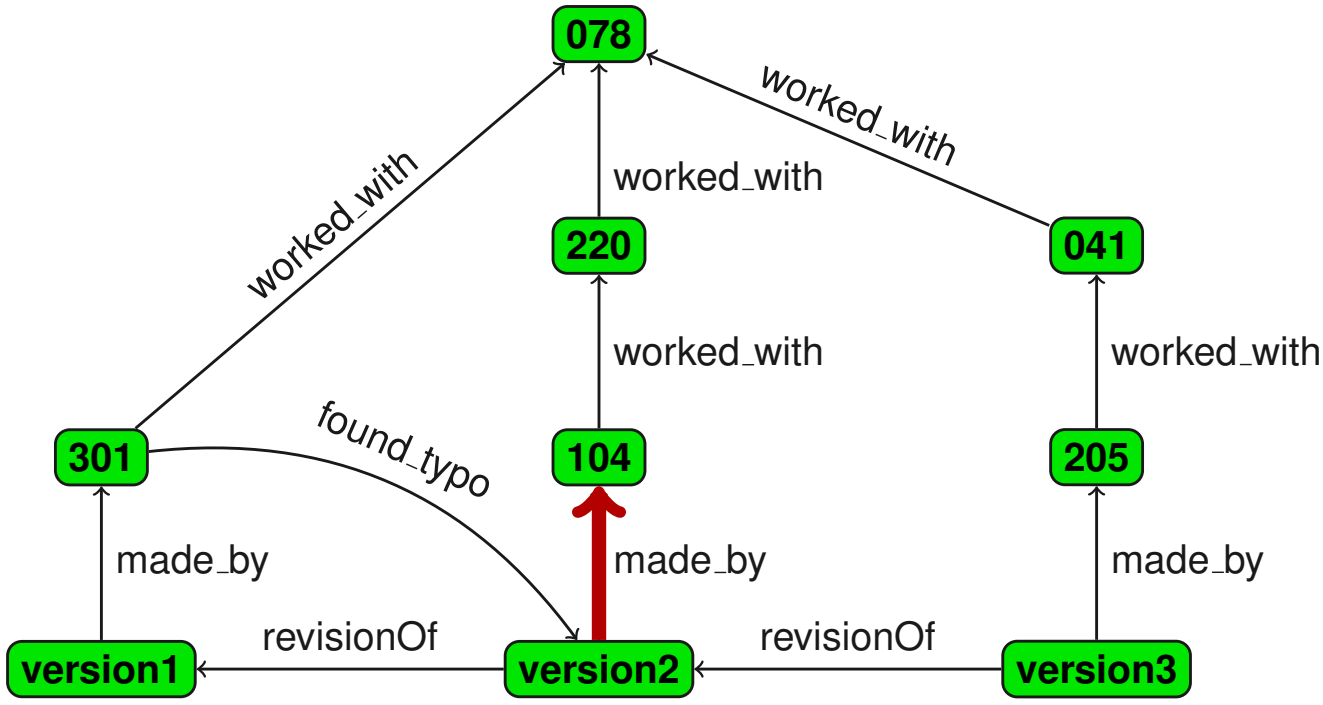

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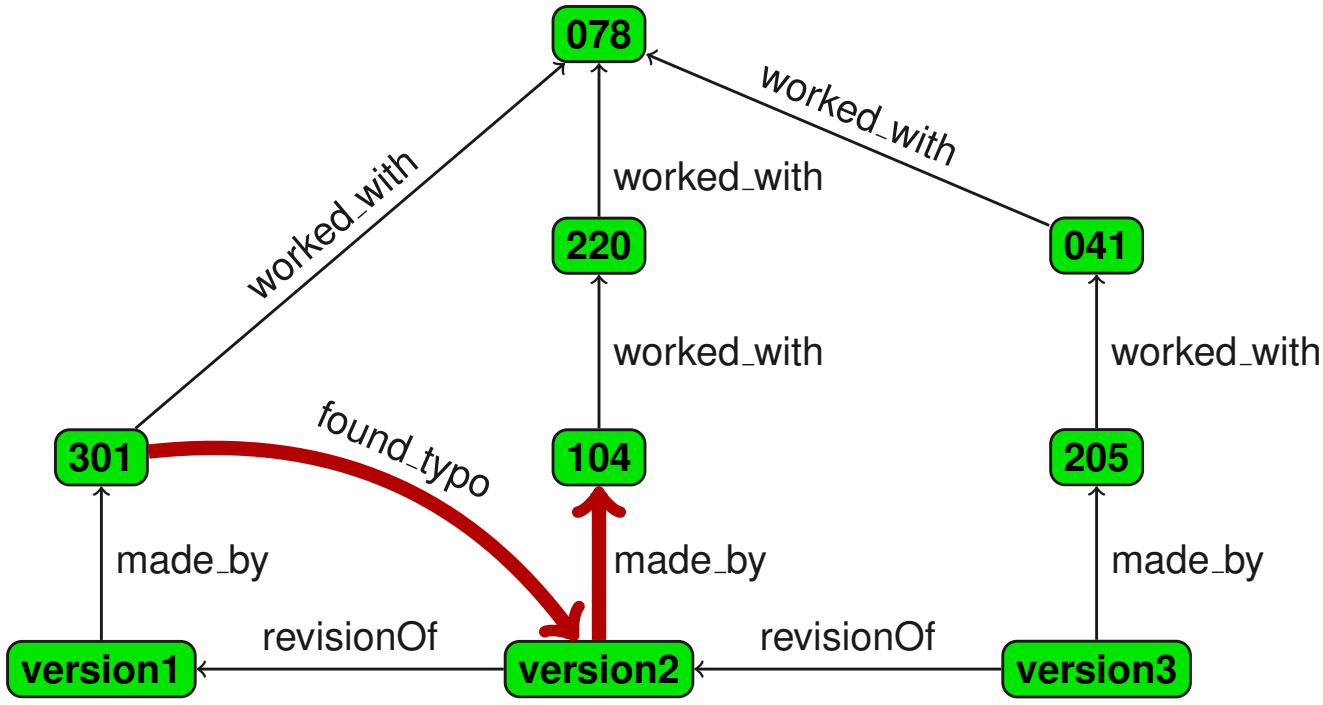

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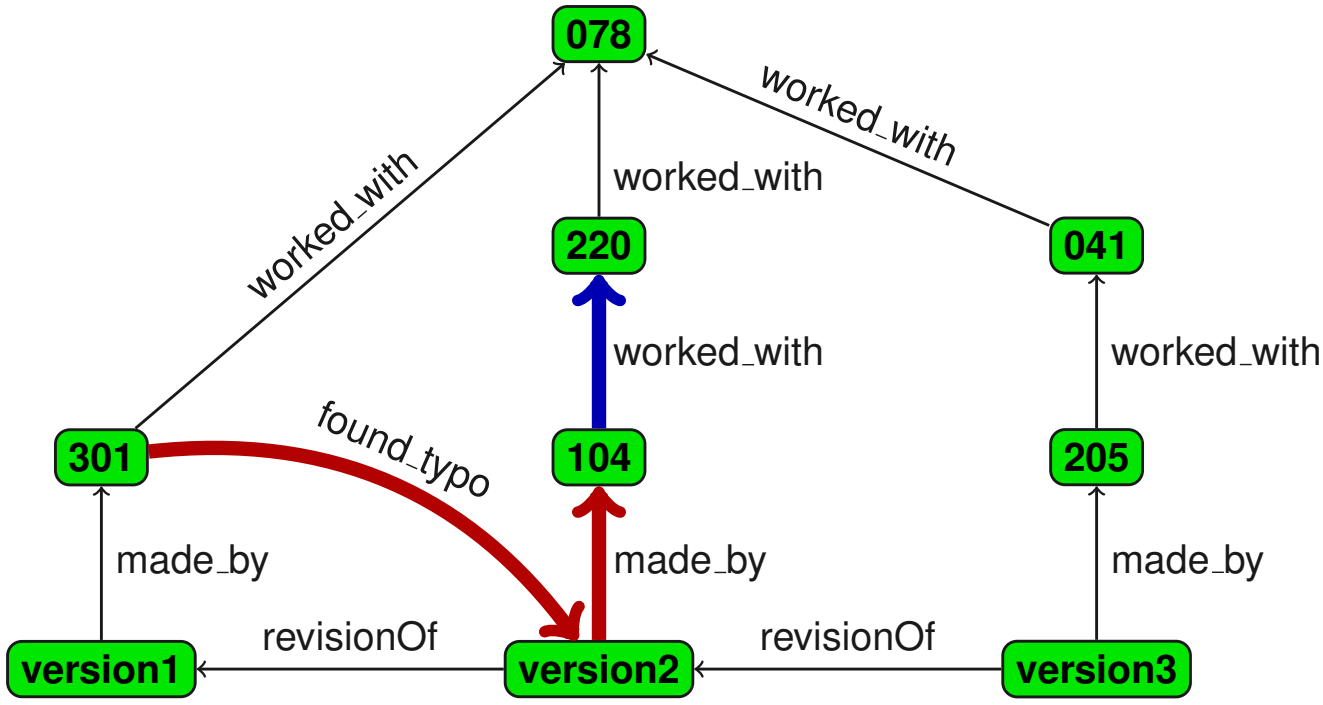

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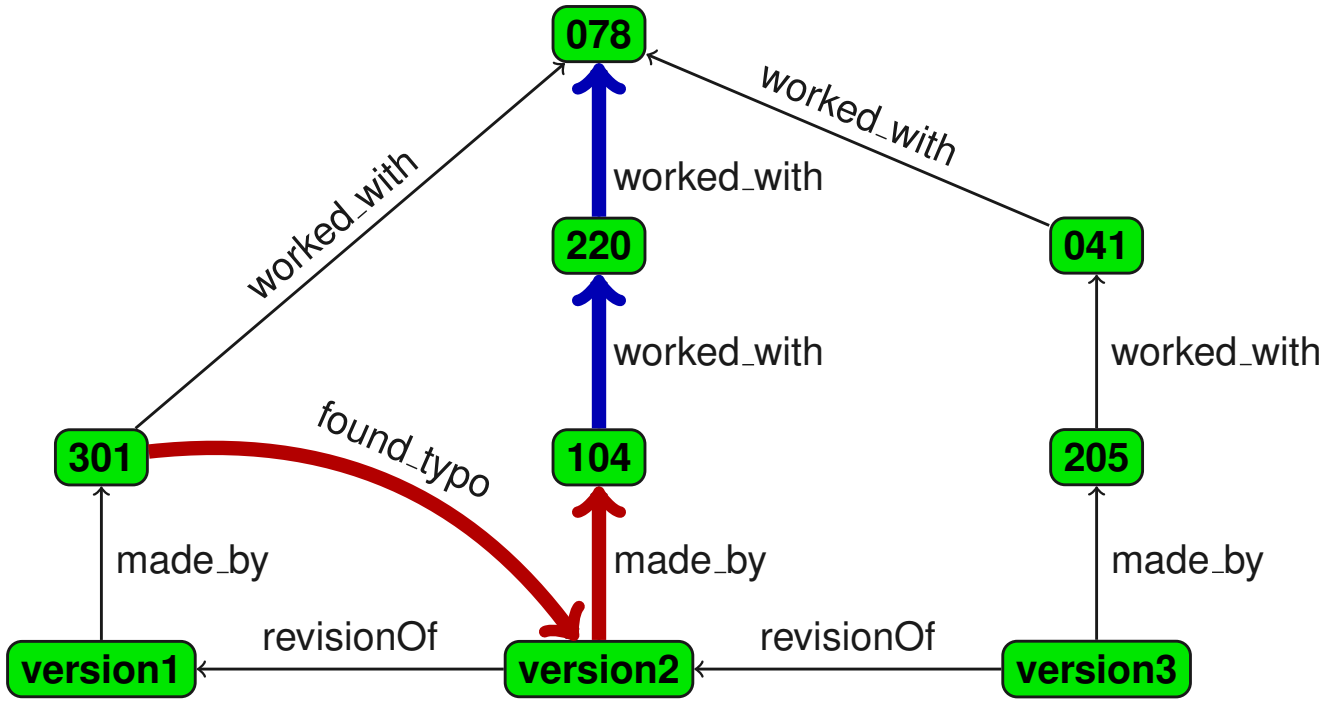

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TriAL for RDF: Adapting Graph Query Languages for RDF Data

Leonid Libkin[1] Juan Reutter[2] Domagoj Vrgoč[2]

[1]University of Edinburgh

[2]PUC Chile

Outline

1. Graph databases
   Most studied connectivity queries

2. Relationship between connectivity and recursion
   An algebra for querying graphs

3. Where to go from here

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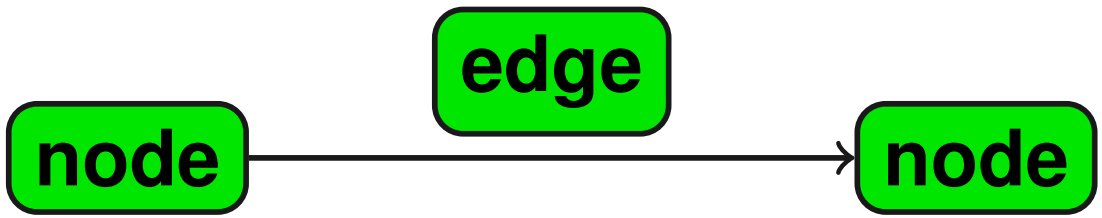
Graph databases (for this talk):

We abstract them as triples:



Graph databases (for this talk):

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A graph database is a collection of triples.

RDF graphs can be represented by relational databases.

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Relational Representation:

Subj.	Prop.	Obj.
version3	revisionOf	version2
version2	revisionOf	version1

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Relational Representation:

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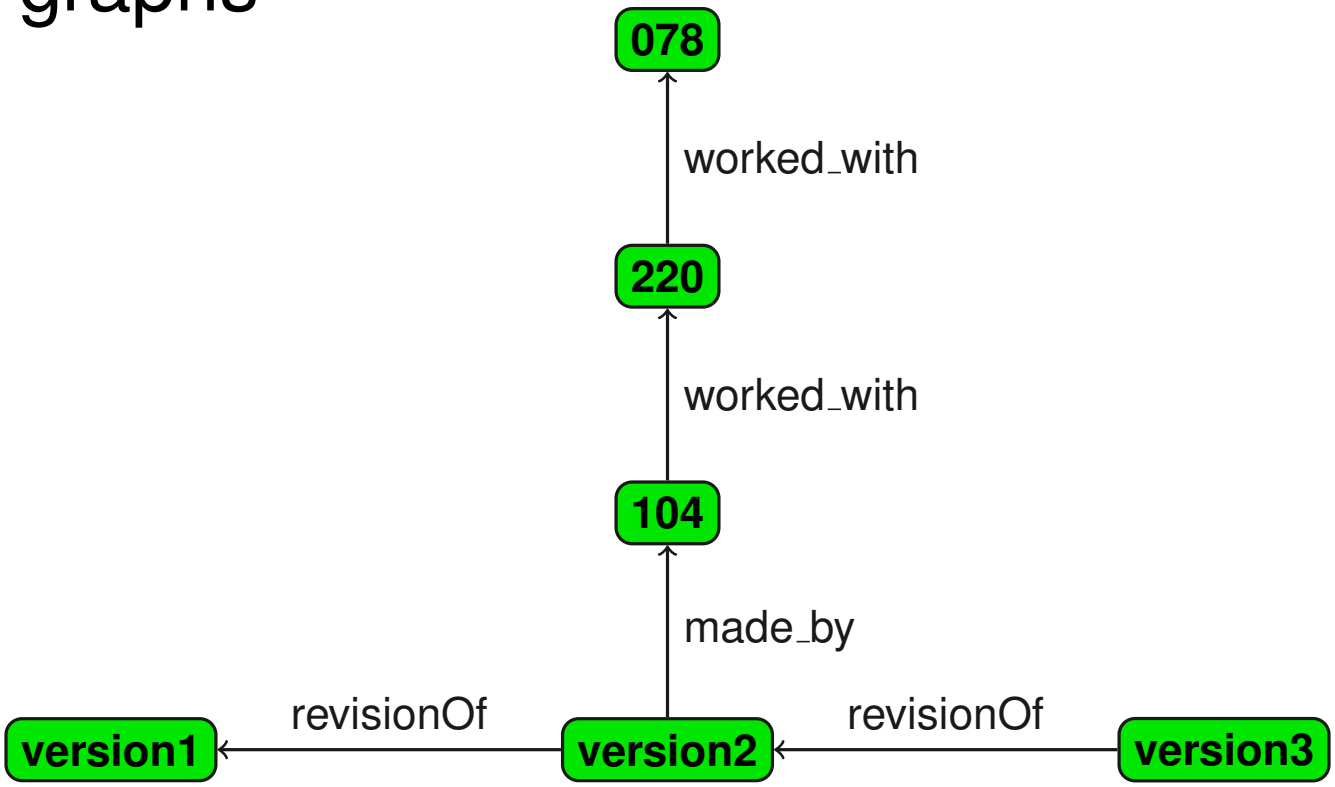
The distinction is in the queries that we want to ask (such as connectivity queries)

Paths in graphs



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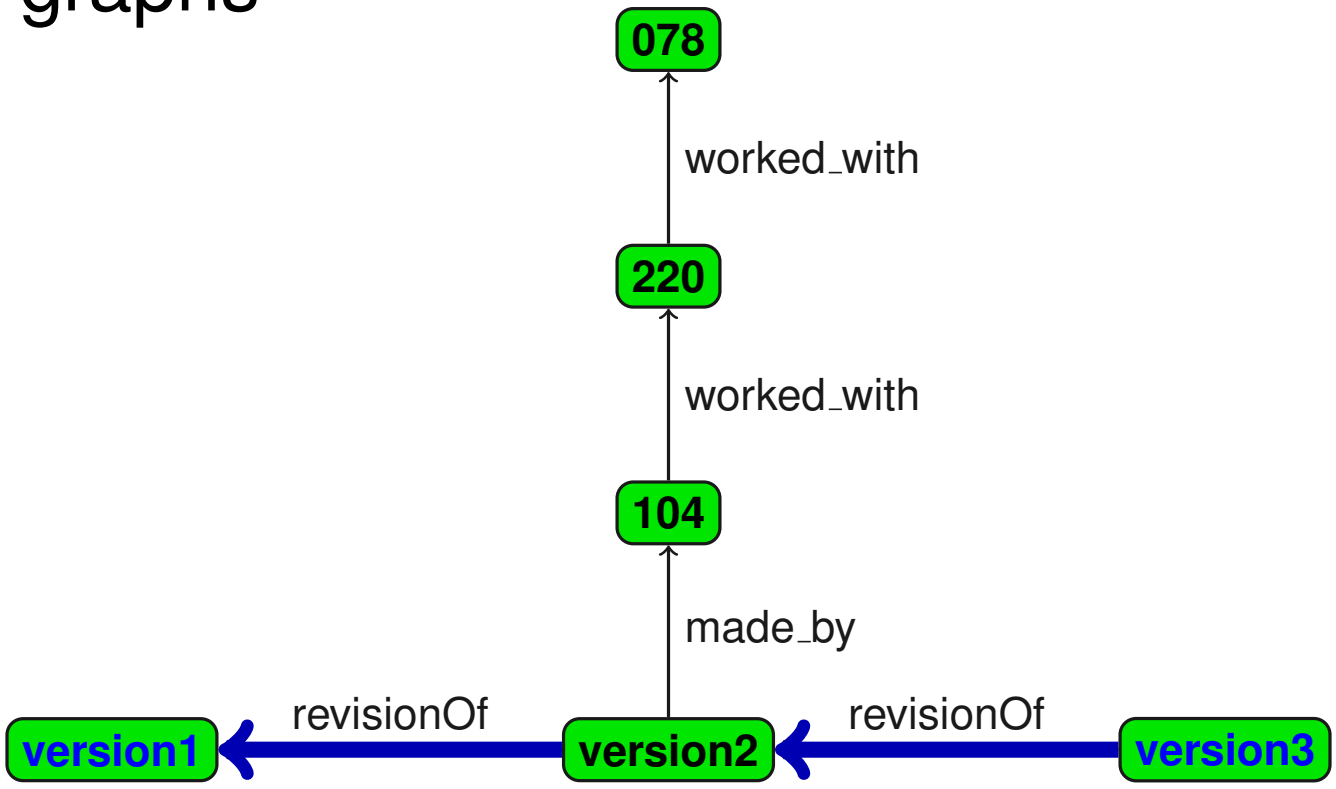

The label of the path is

$$\text{revisionOf} \cdot \text{revisionOf}$$

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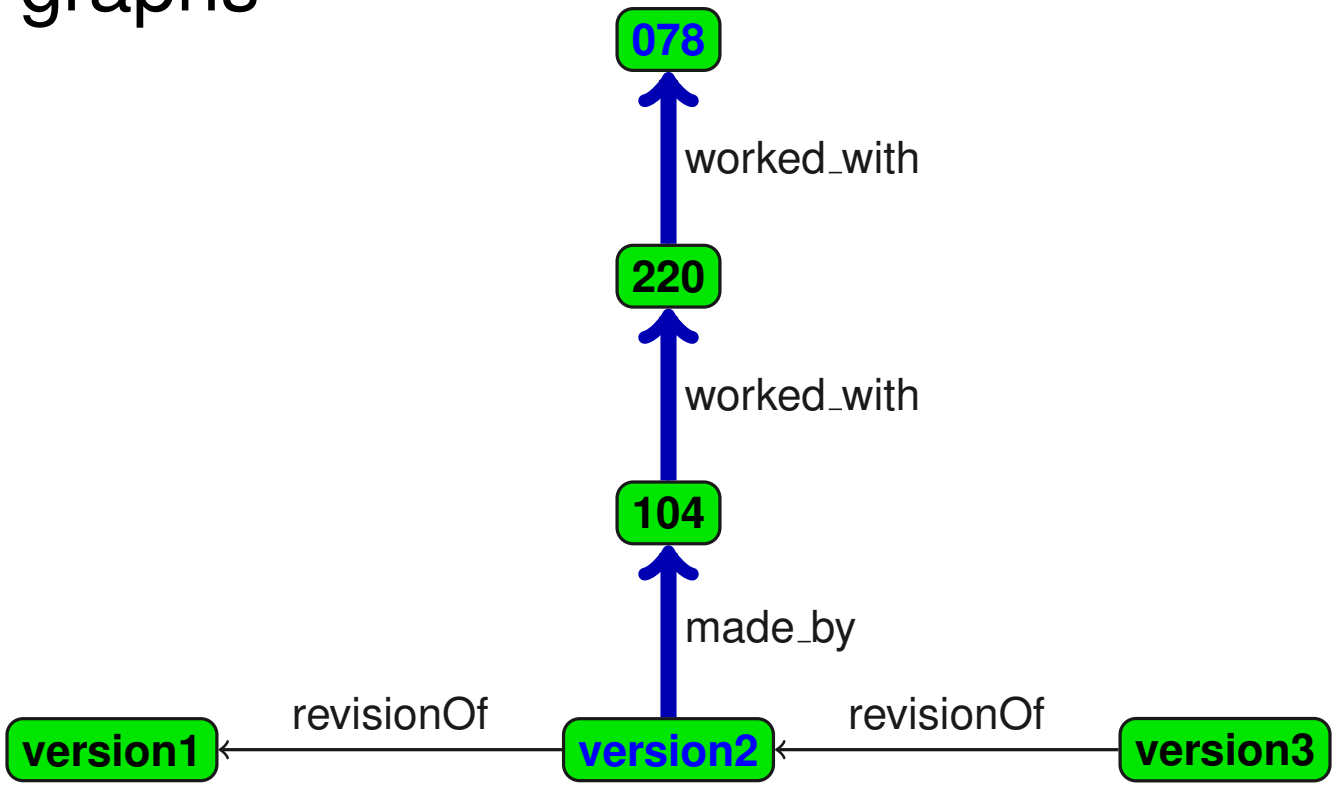

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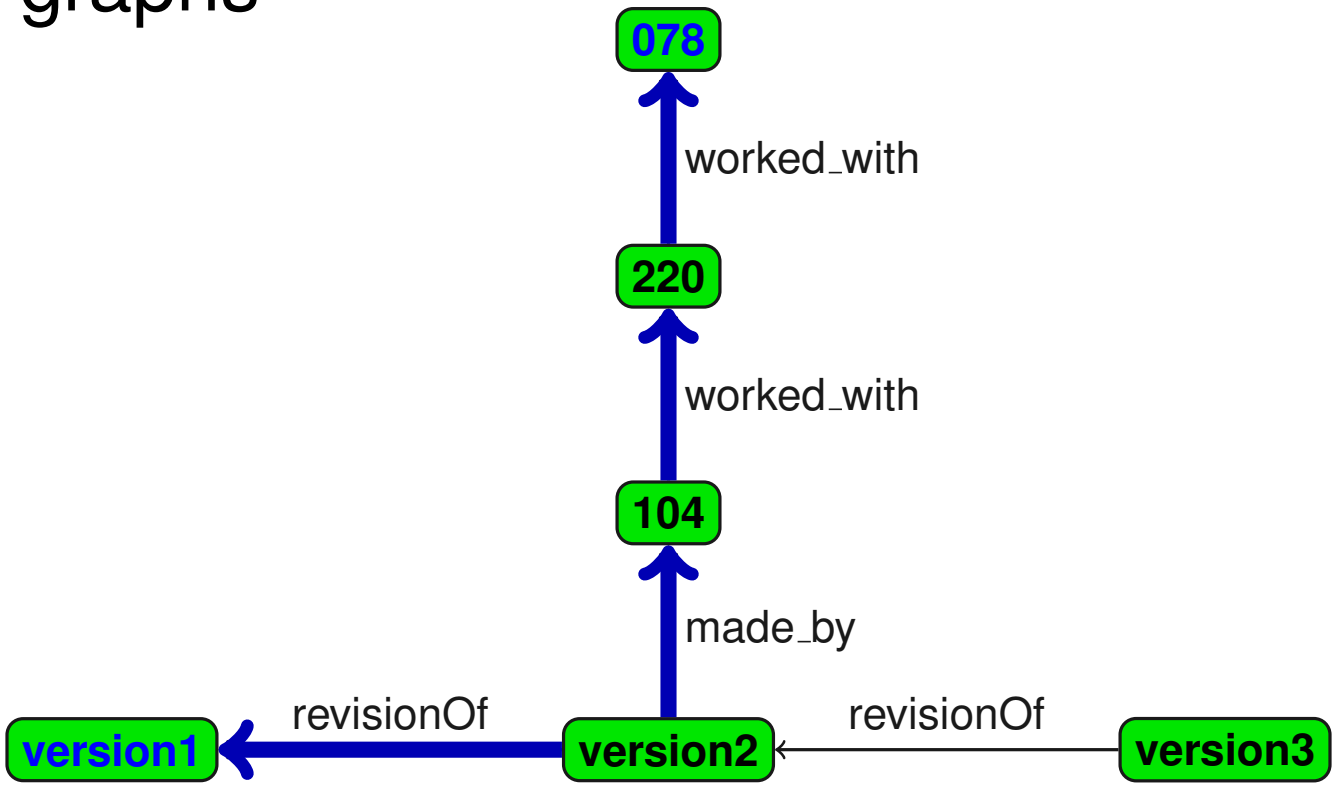
Paths in graphs



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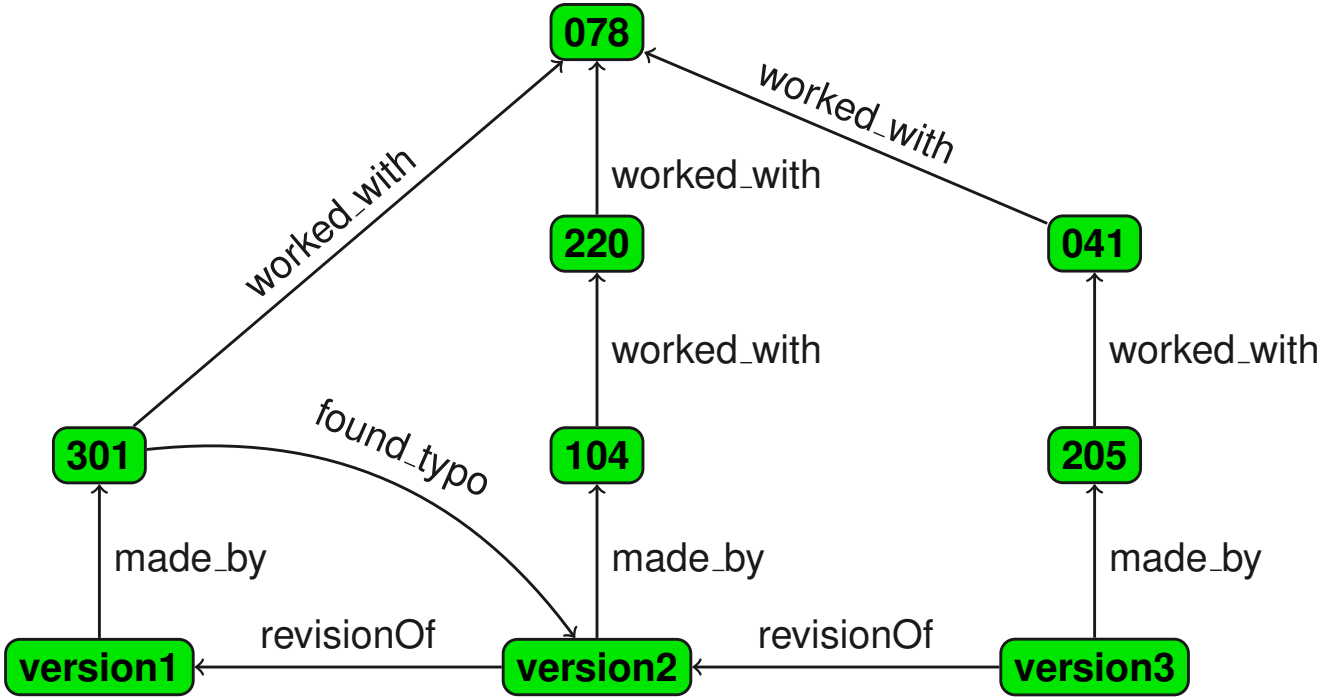
Regular Path Queries



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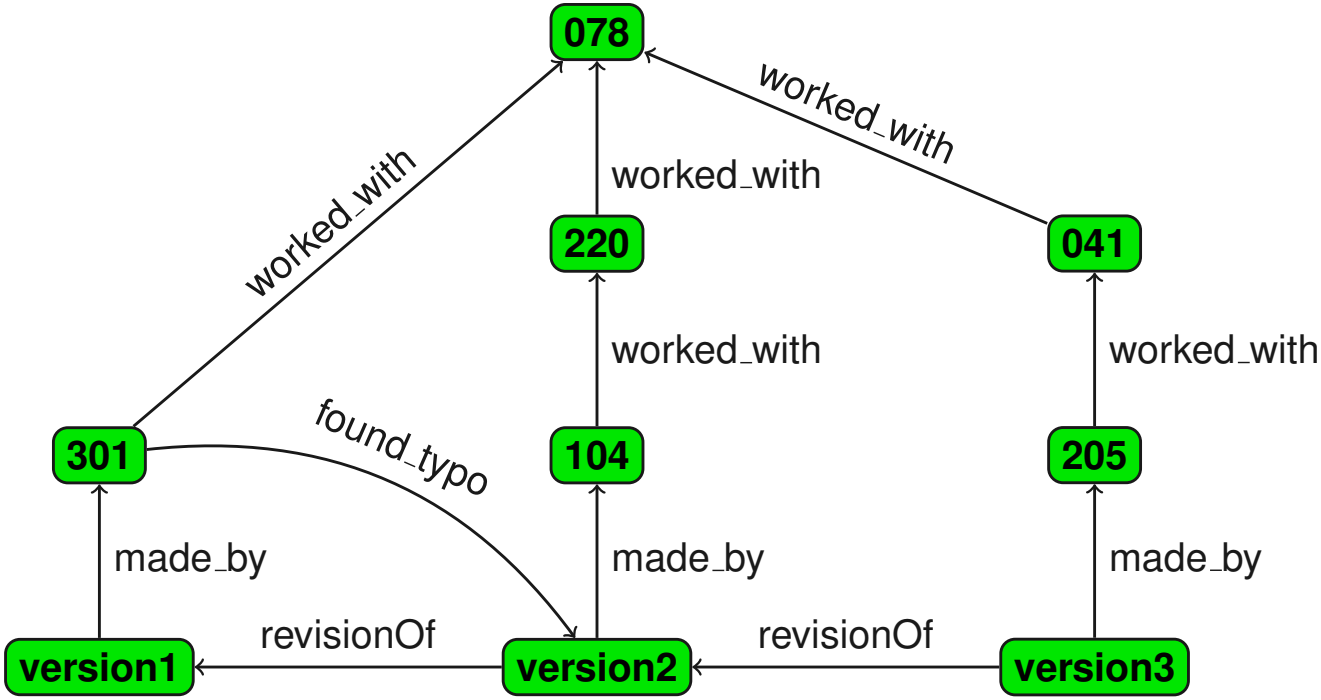
Regular Path Queries



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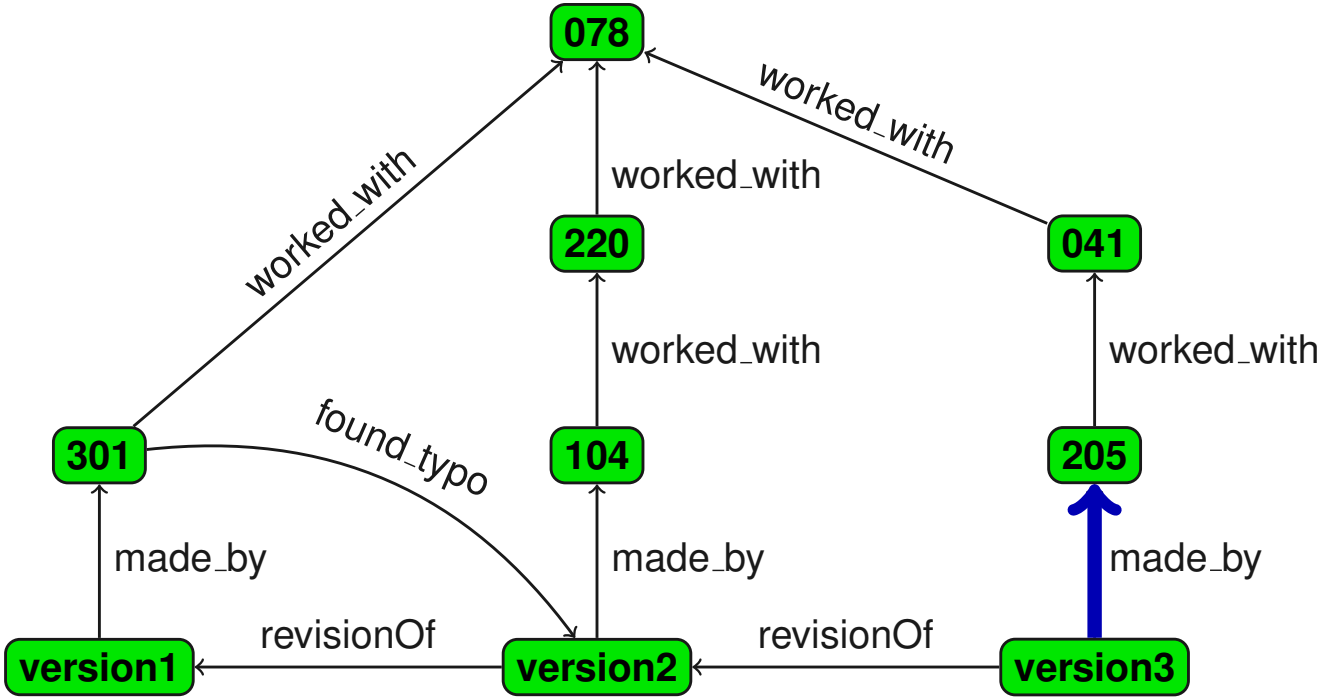

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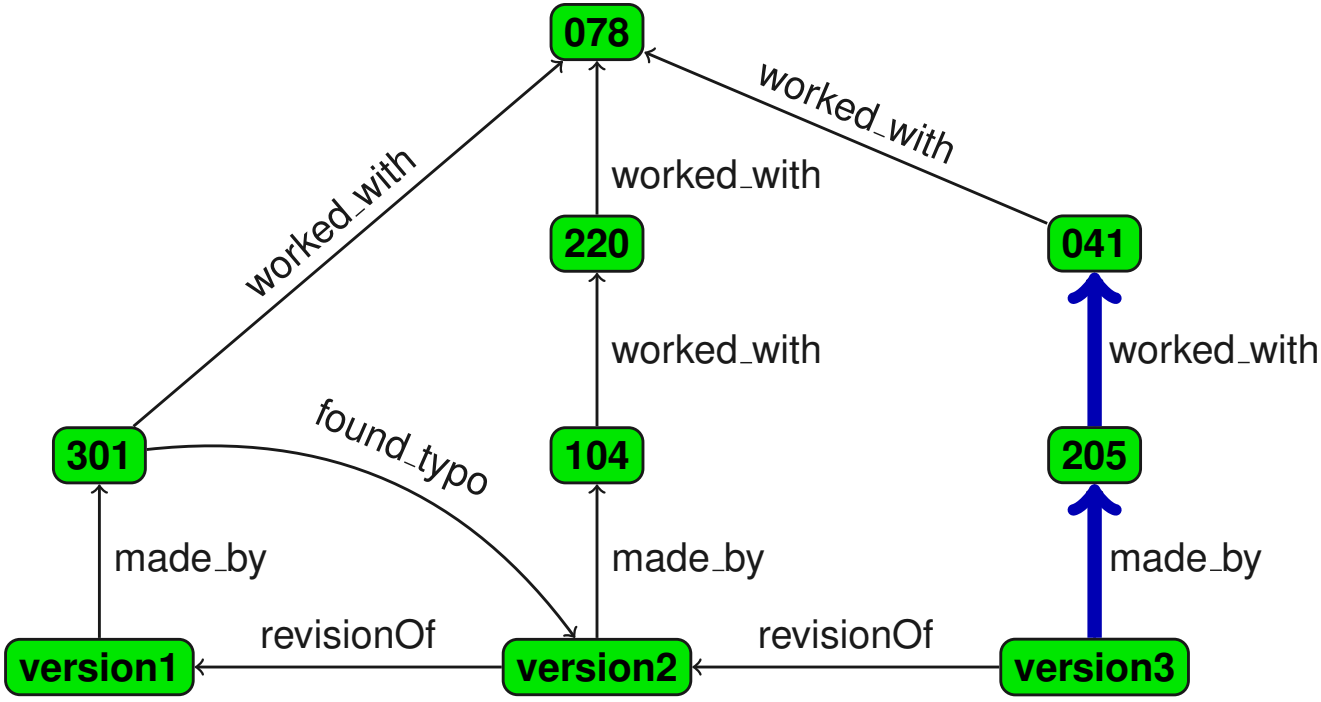

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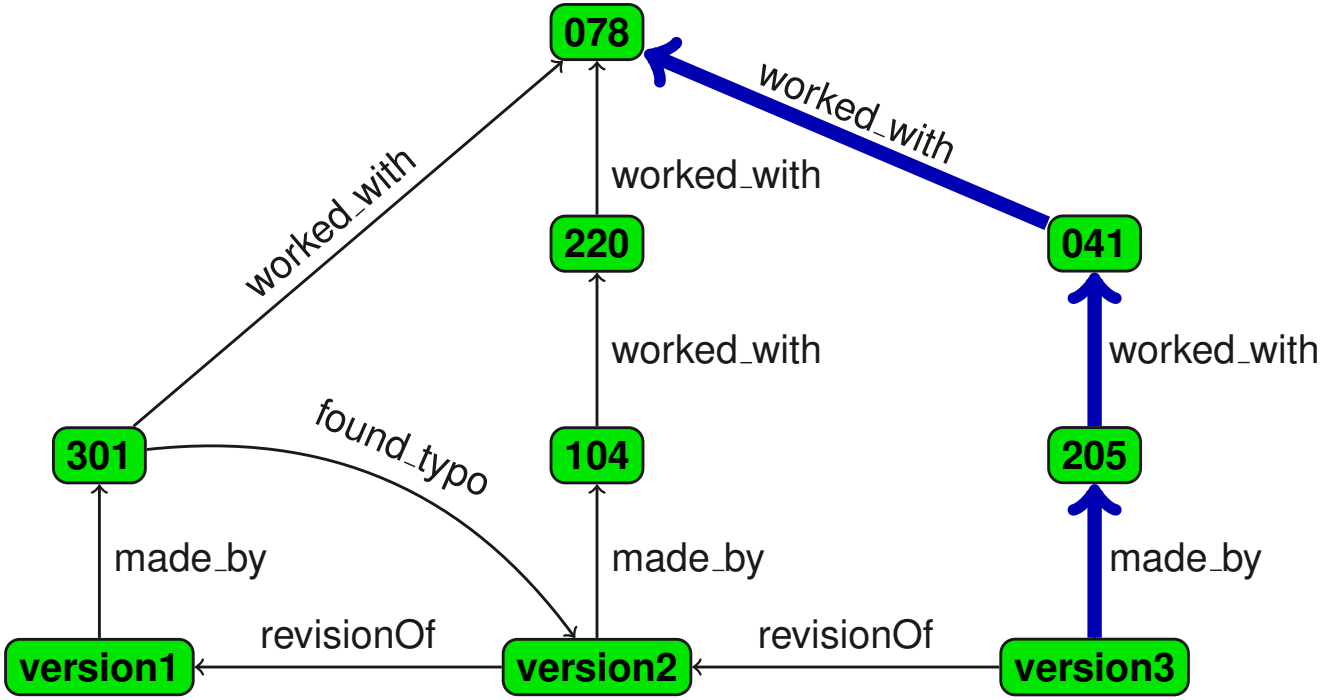

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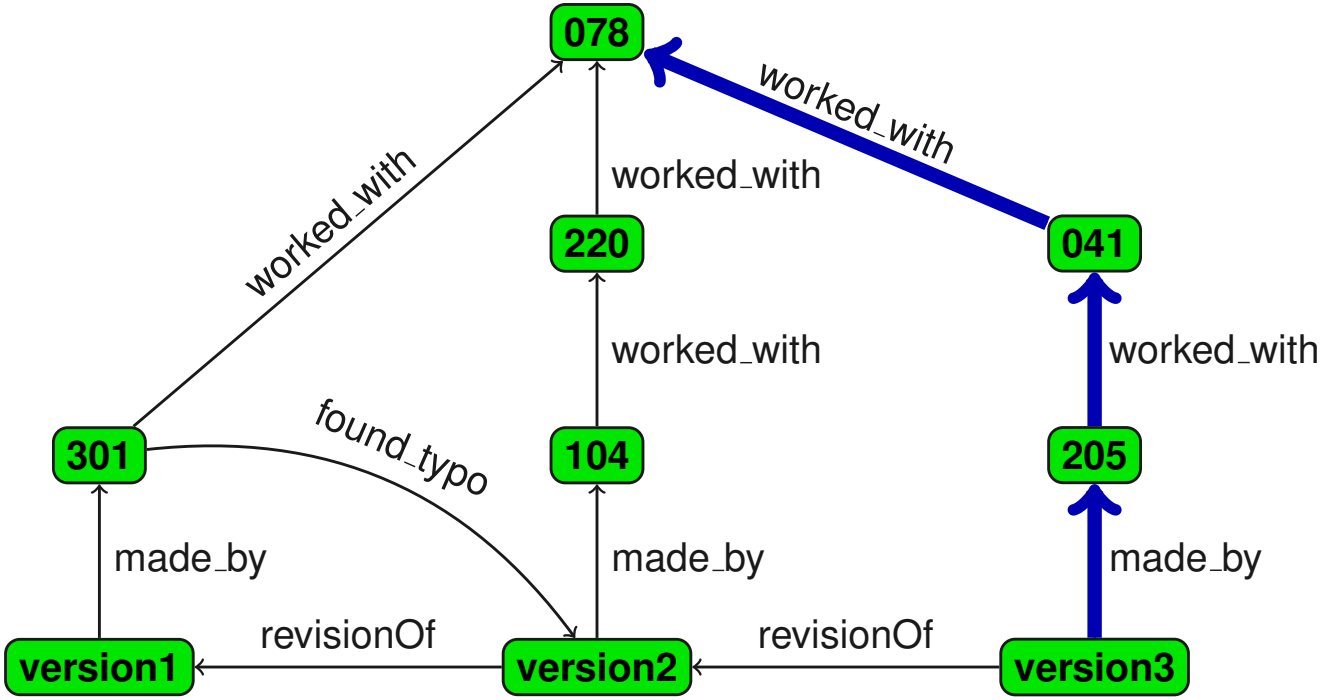

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RPQs is used as a primitive for querying paths

- Supported by various systems
- Simple, declarative language (easy to state what you want)
- Really efficient evaluation:
  Automata techniques allow to use fast reachability algorithms to evaluate RPQs.
- Lots of extensions

Outline

1. Graph databases
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In practice, things are not that simple

Graph DB systems struggle to support RPQs.

- Neo4j only supports concatenation, star

In practice, things are not that simple

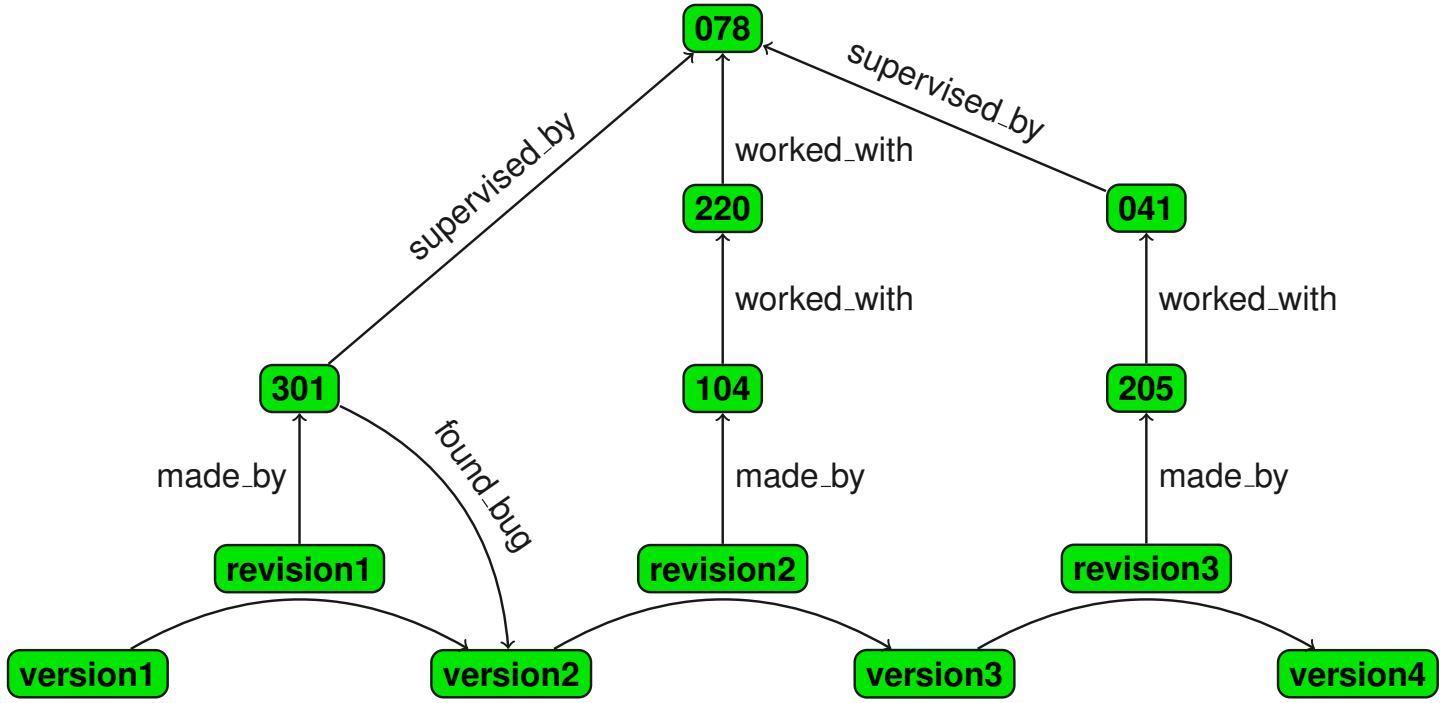
While RPQs are now part of SPARQL

- Semantics not clearly defined
  (many changes in last years)
- no clear guidelines for implementation

Problem with RPQs: limited expressivity

to study it we use SPARQL (with RPQs)

more or less like SQL + RPQs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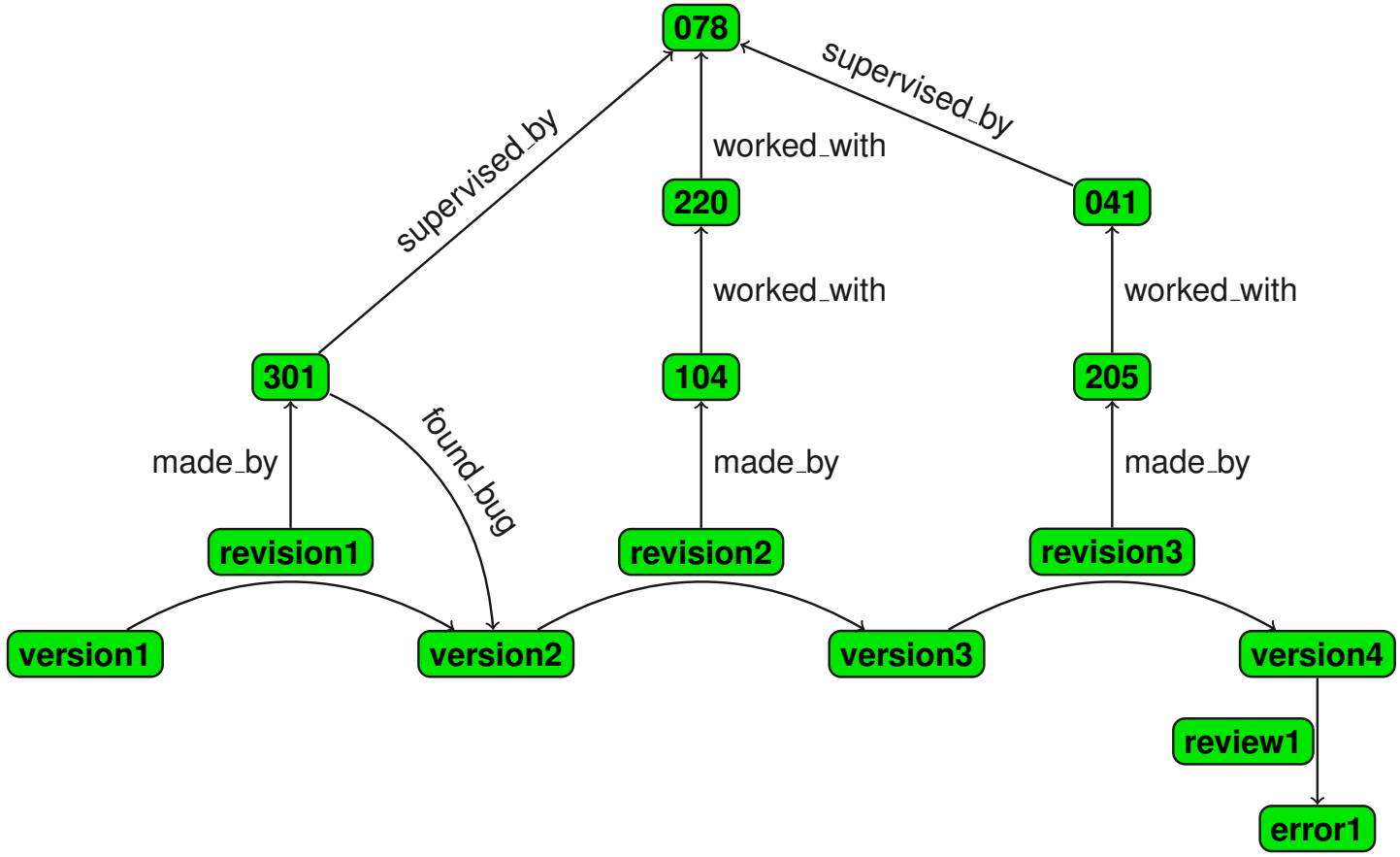
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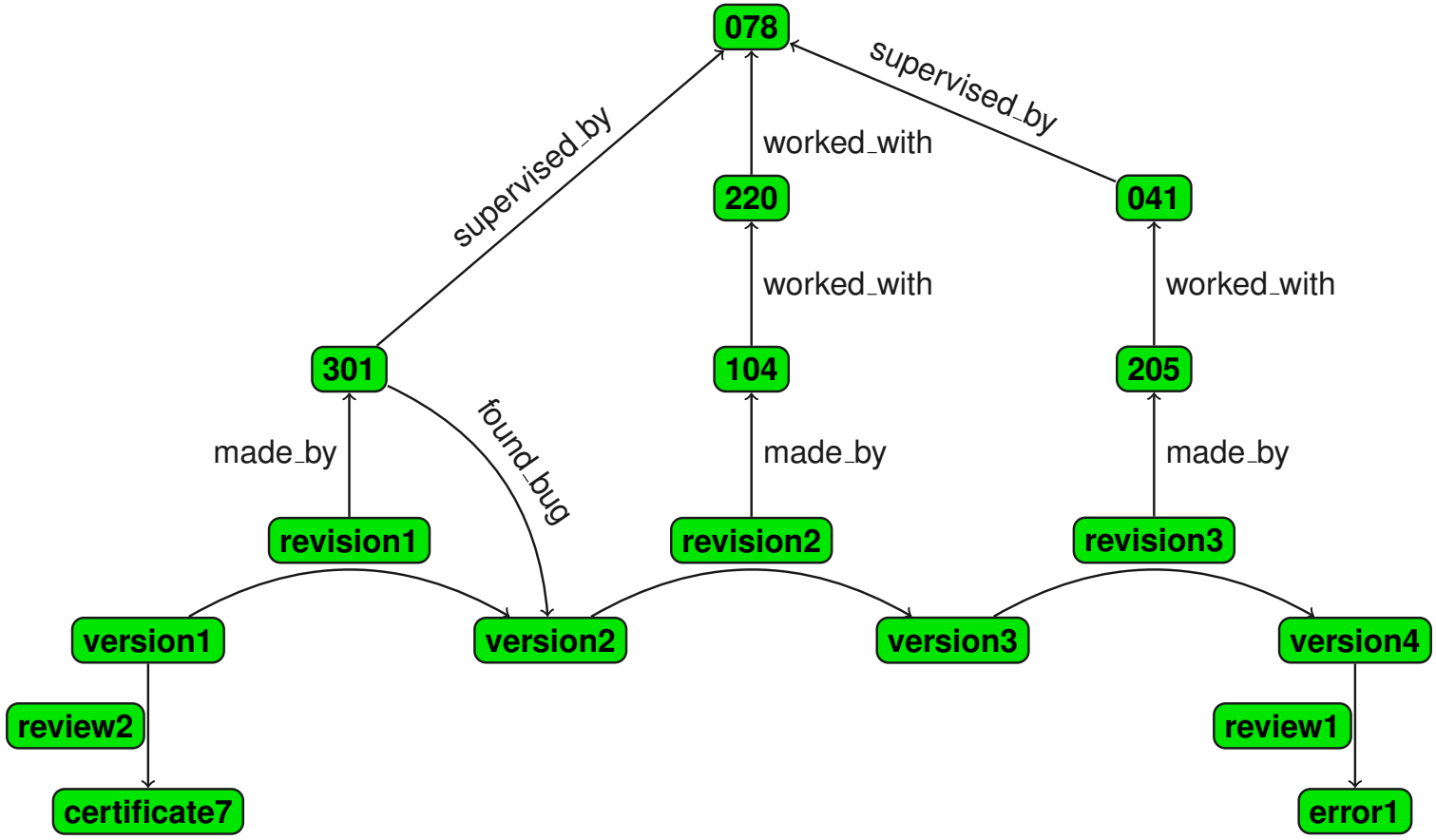
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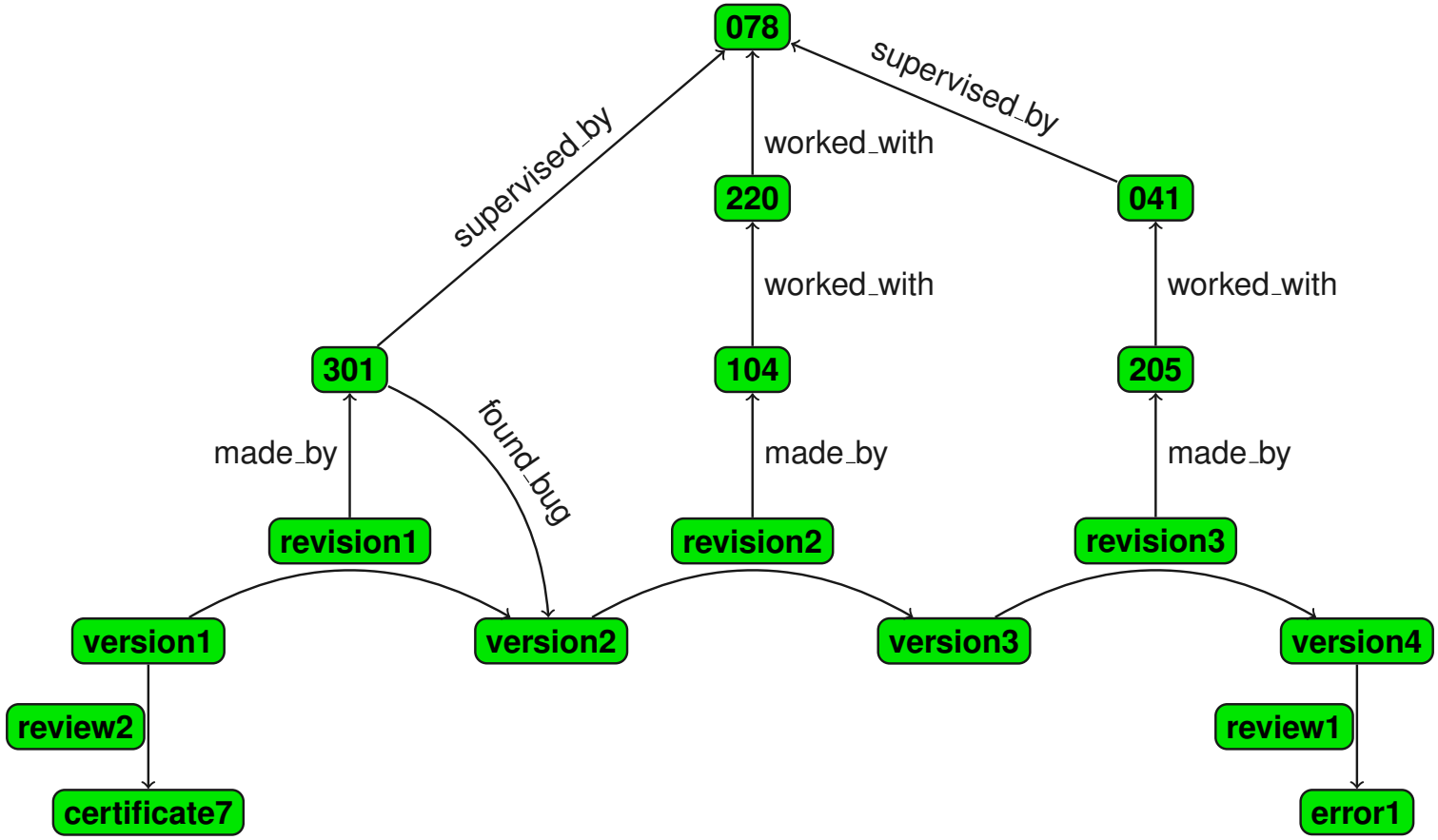

Q_1 : Find all versions with an error
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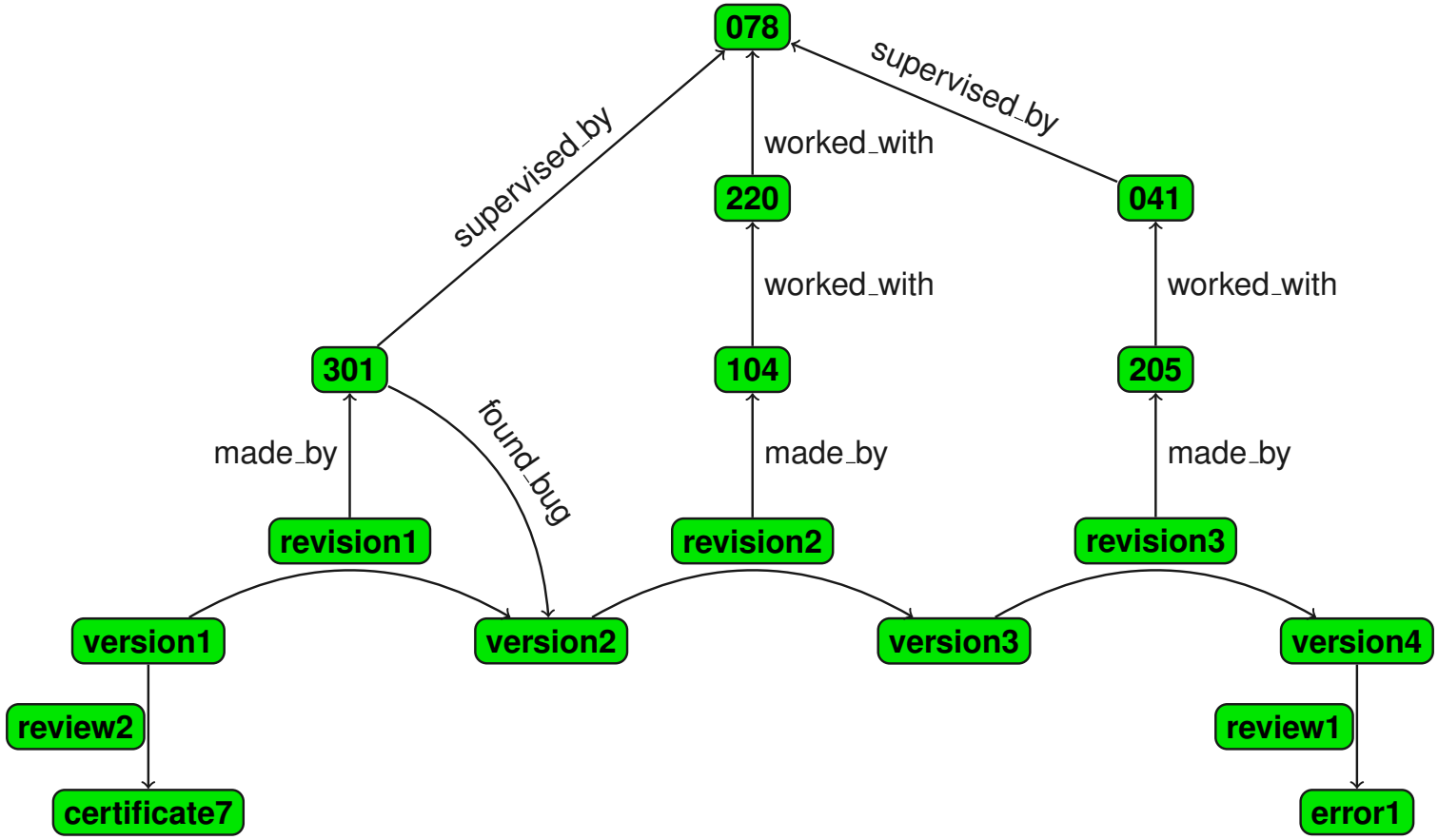

Q_2 : Find all versions with an error
That originate from a valid version
And the person responsible for this

What is the problem?

- Q_1 can be expressed using SPARQL (essentially SQL + RPQs)
- Q_2 can NOT be expressed in SPARQL
- Conclusion:
  - Need to reason while moving along paths
  - Cant do this using RPQs or similar primitives

Problem with RPQs: implementation

- Simple and efficient implementation using automata theory

Problem with RPQs: implementation

Traditionally, DB systems do not implement techniques that rely on automata theory.

- XML and XPath

Why not base implementation on relational queries

Next

Understanding connectivity queries

from a relational point of view

Next

Understanding connectivity queries

from a relational point of view

What are RPQs? What does (x, a^*, y) means?

- Let $S \circ S'$ be the composition of binary relations S and S' :

$$S \circ S' = \{(x, z) \mid (x, y) \in S \ \wedge (y, z) \in S'\}$$

What does (x, a^*, y) means?

- Take binary relation A given by all x, y that are connected via label a in the graph.

$$(x, a^+, y) = A \cup A \circ A \cup A \circ A \circ A \cup \dots$$

Compose A with itself over and over again... until we reach a fixed point.

$(x, \text{revisionOf}^*, y)$

R	Prop.	Obj.
	version3	version2
	version2	version1

$(x, \text{revisionOf}^*, y)$

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$(x, \text{revisionOf}^*, y) =$

R^*	Prop.	Obj.
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But from the eyes of relational algebra...

Composition is just a join!

$$S \circ S' = S \overset{1,2'}{\underset{2=1'}{\bowtie}} S'$$

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Thus reachability is just recursive iteration of joins.

TriAL: an algebra for graphs

We now define an algebra for triples, that:

- can express RPQs
- can even express queries such as Q2
- Is based on relational algebra

Composing ternary relation

We need to manage triples...
No obvious way to do it

$$(x, y, x) \quad \circ \quad (x', y', z')$$

Composing ternary relation

We need to manage triples...
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We take the approach of relational algebra, and define all possible compositions.

- Triple joins

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$$R \bowtie R'$$

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$$R \overset{1,3',3}{\bowtie} R'$$

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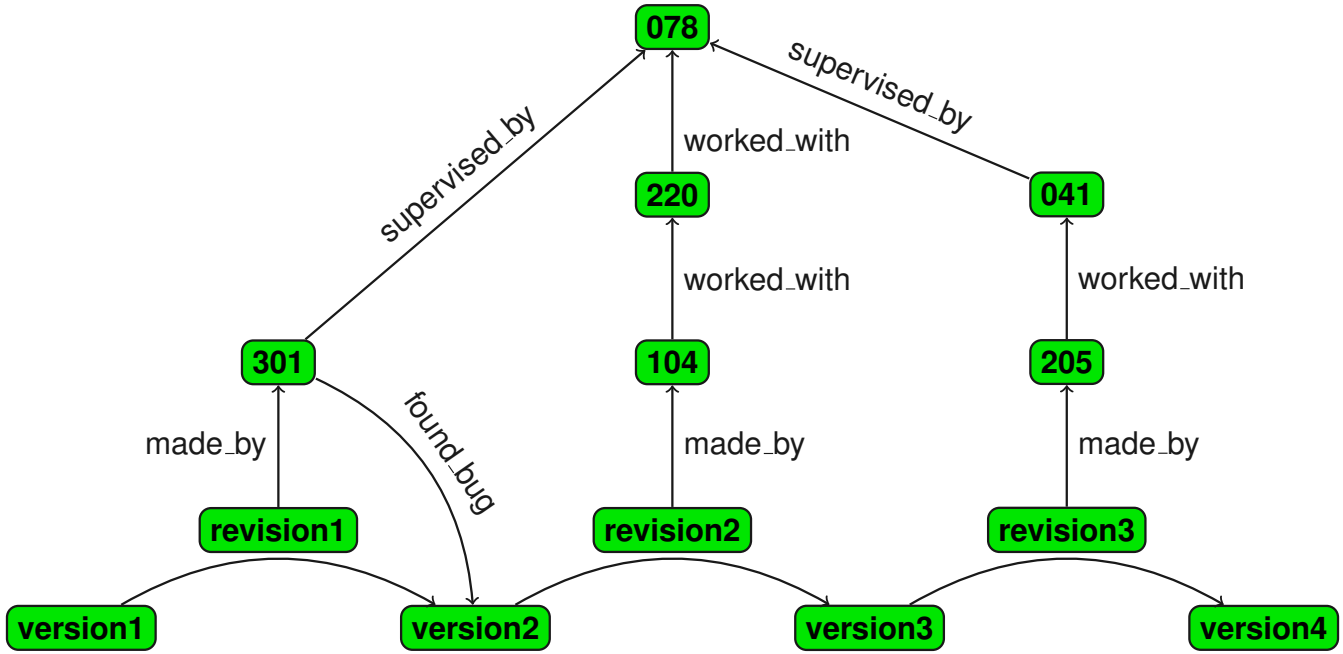
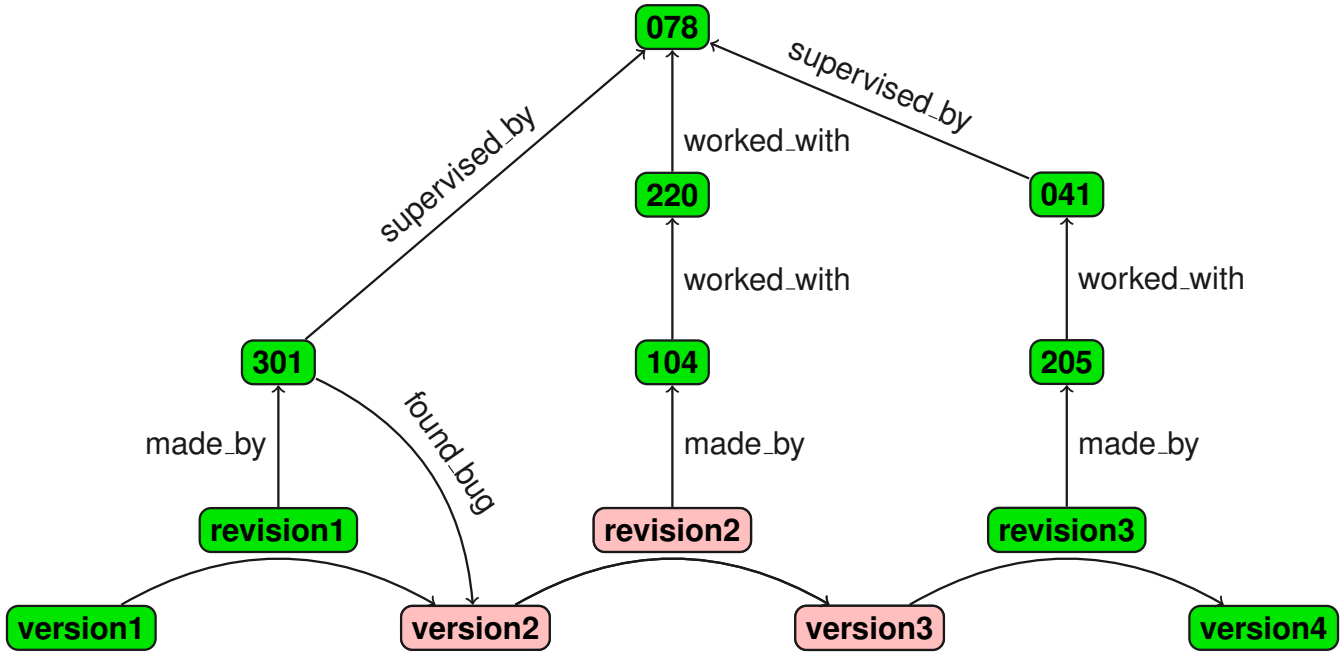
A simple join



$$E \overset{1,3',3}{\bowtie}_{2=1'} E$$

A simple join



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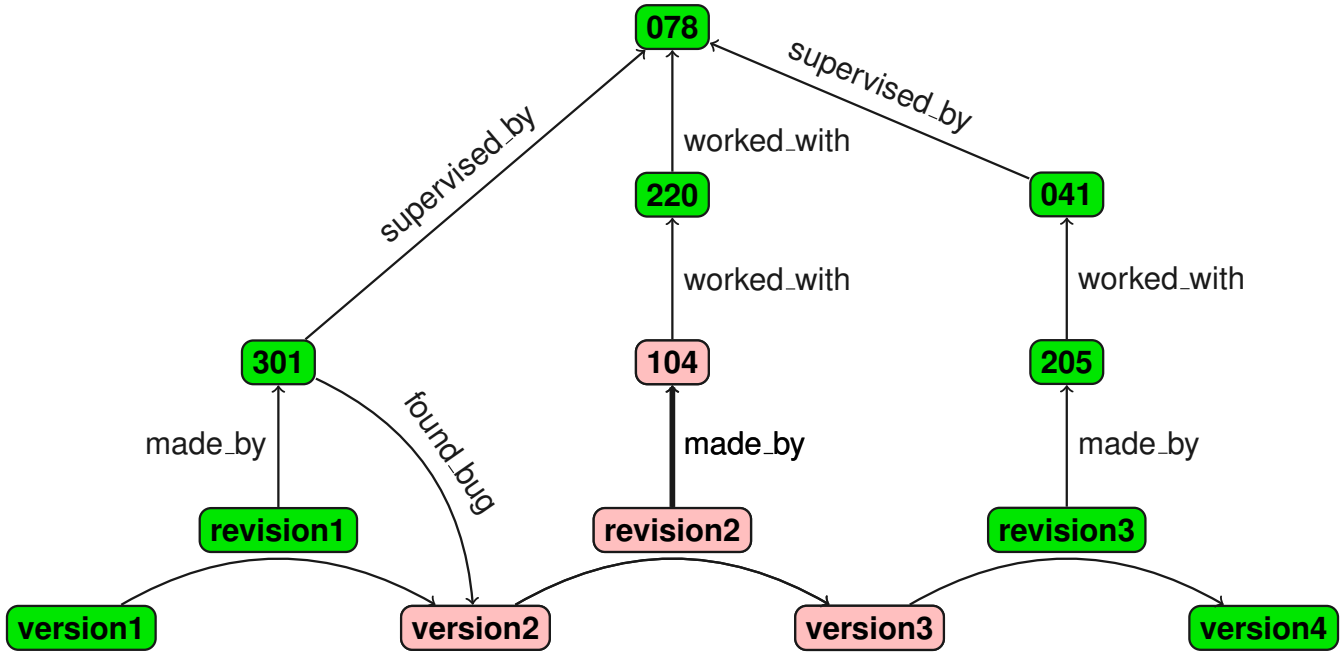

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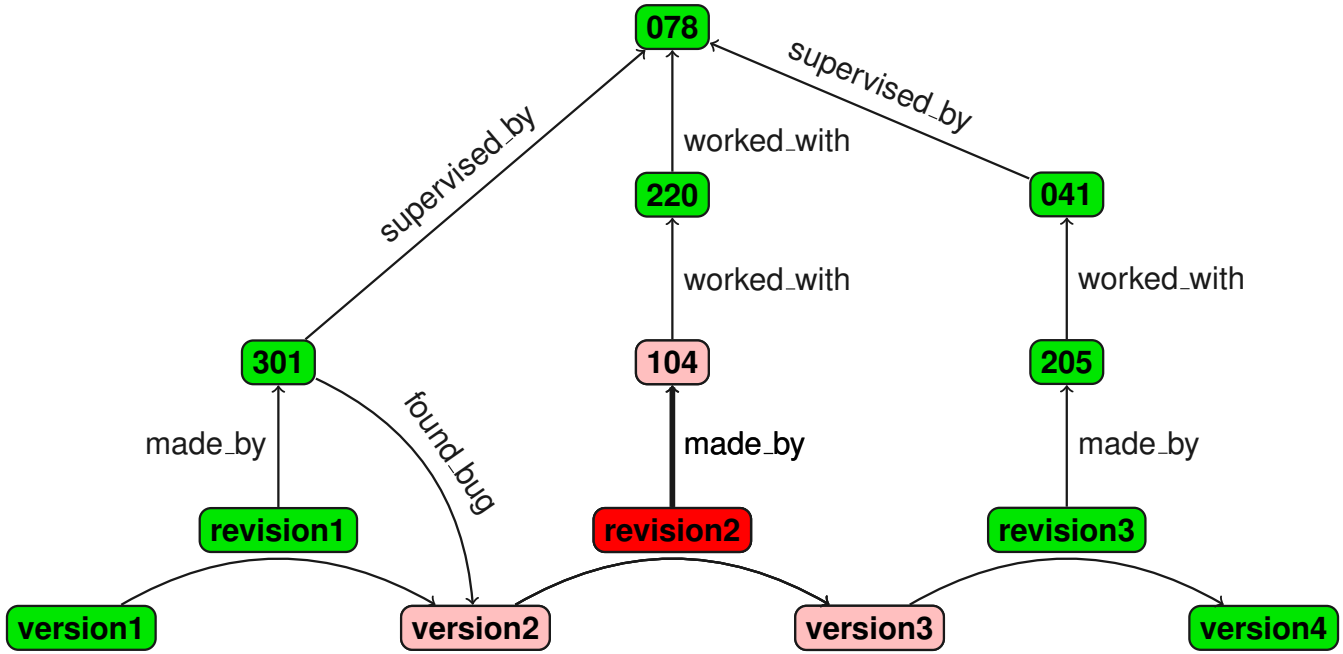

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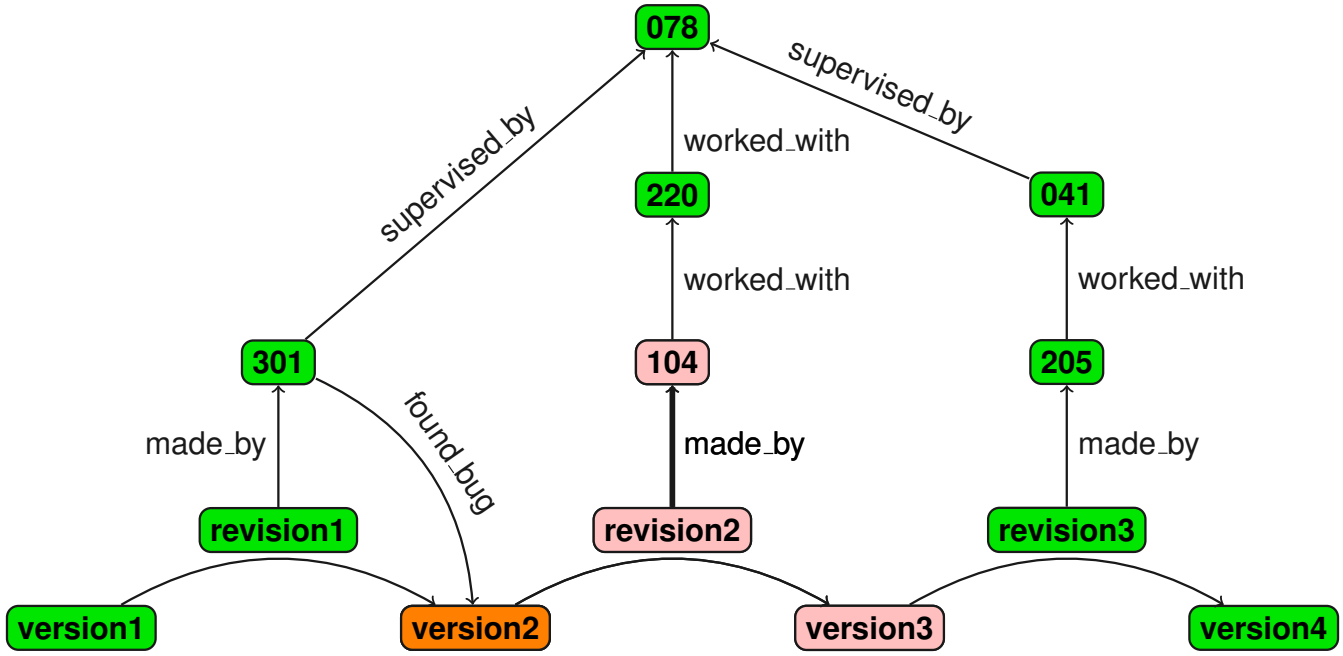
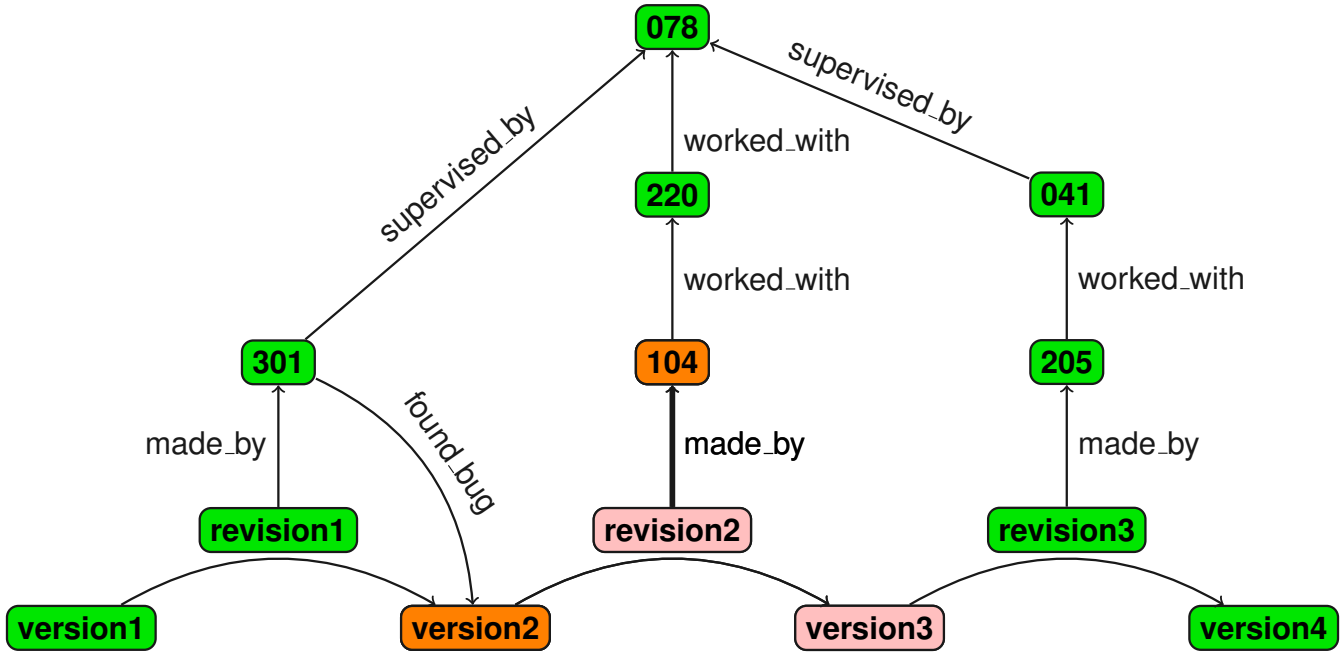


$$E \overset{1,3',3}{\underset{2=1'}{\bowtie}} E$$

A simple join



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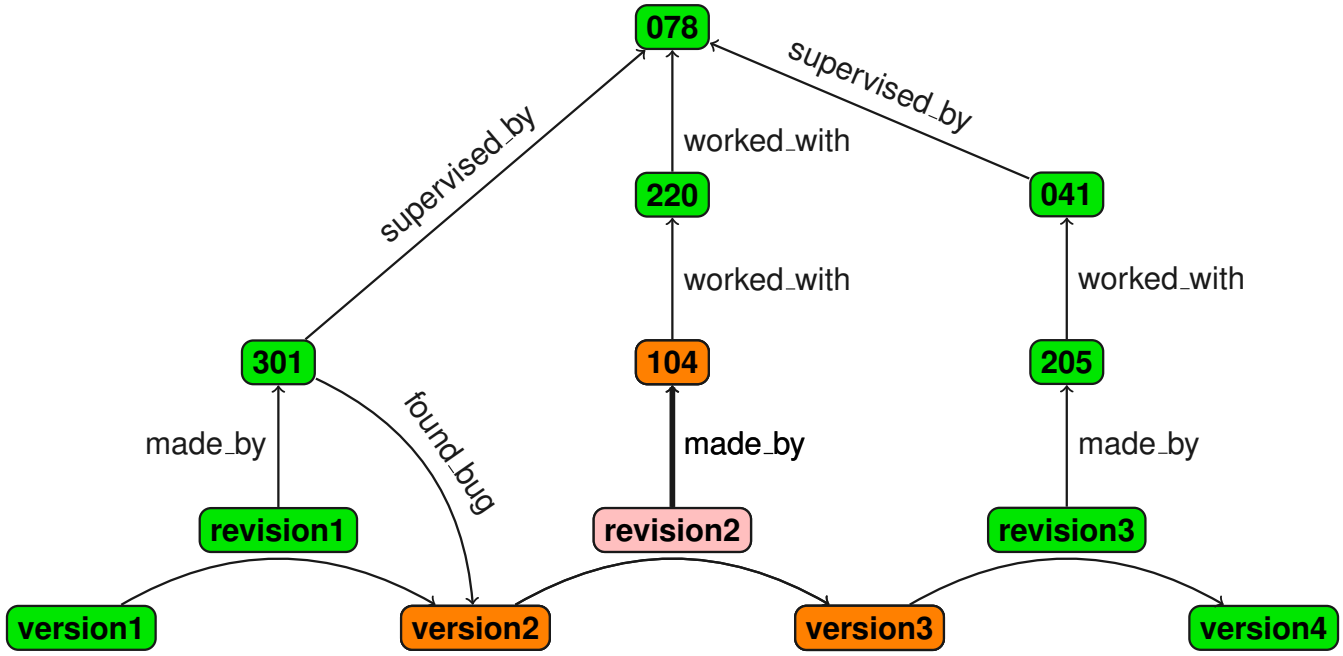

$$E \overset{1,3',3}{\bowtie}_{2=1'} E$$

TriAL: An algebra of triples

- R: set of triples
  Relational representation of a an RDF graph

A TriAL expression is built using

- Set R of triples
- Joins $\bowtie$
- Union $\cup$
- Difference $\setminus$

Adding recursion – TriAL*

- For binary reachability we just iterate the join
- For triples things are not symmetric
  - In particular some joins are not associative
  - So we need both left and right star

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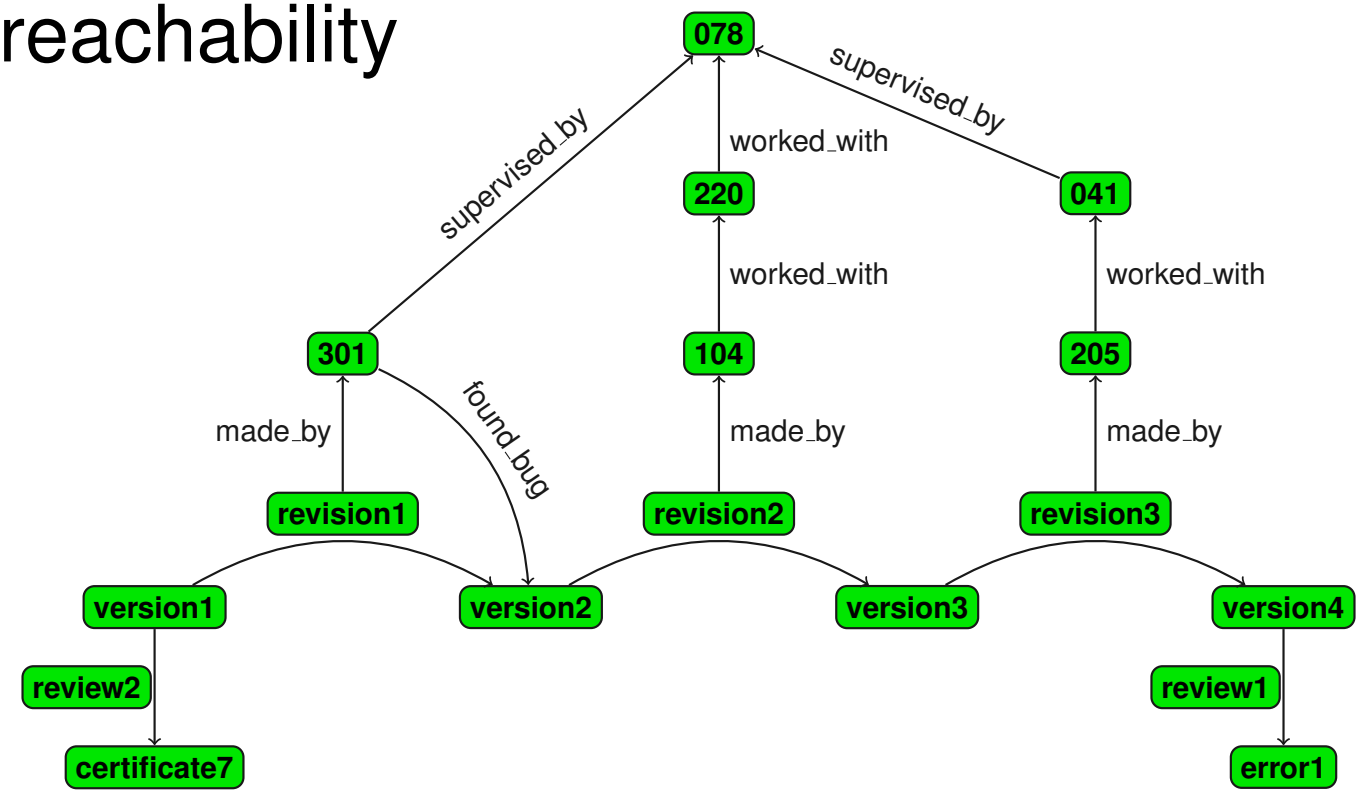
Simple reachability



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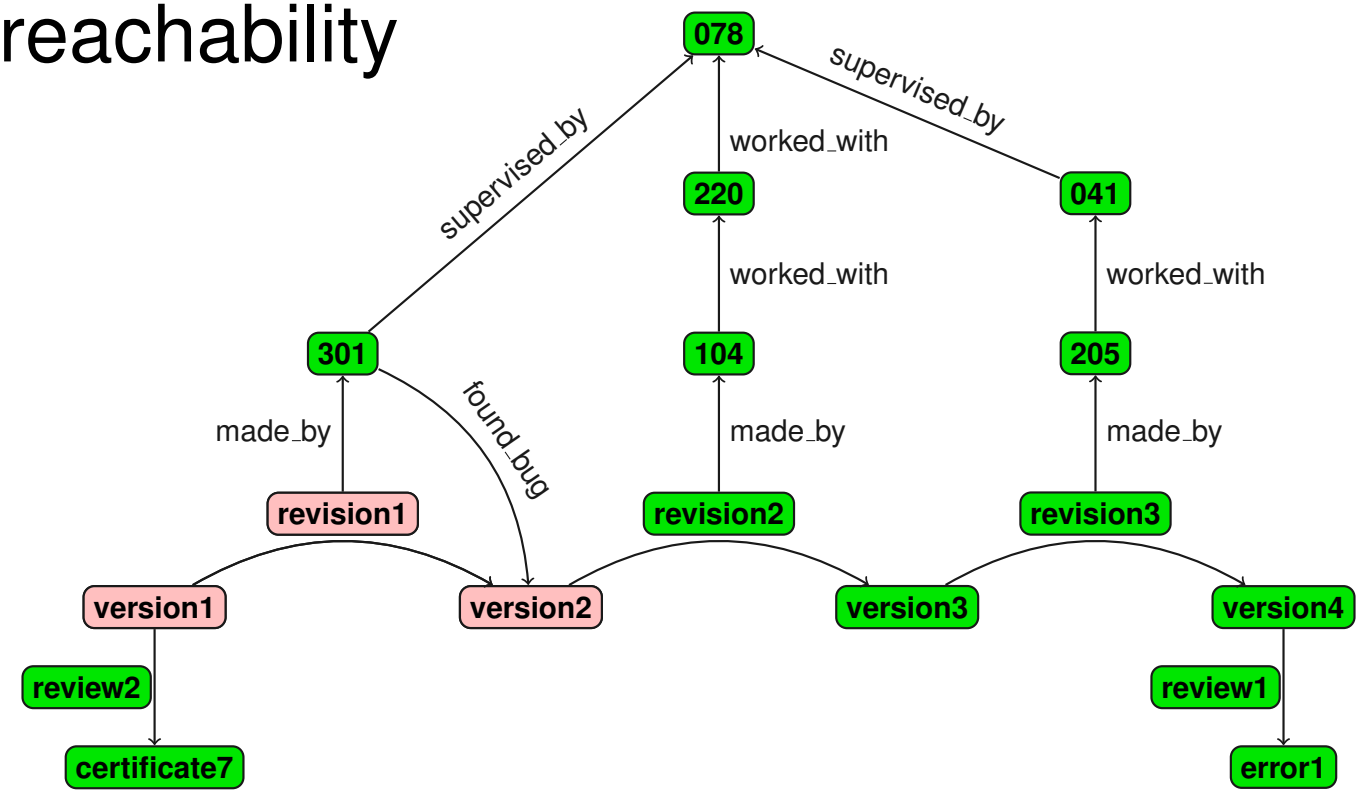
$$(E \bowtie^{1,2',3'}_{3=1'})^*$$

Simple reachability



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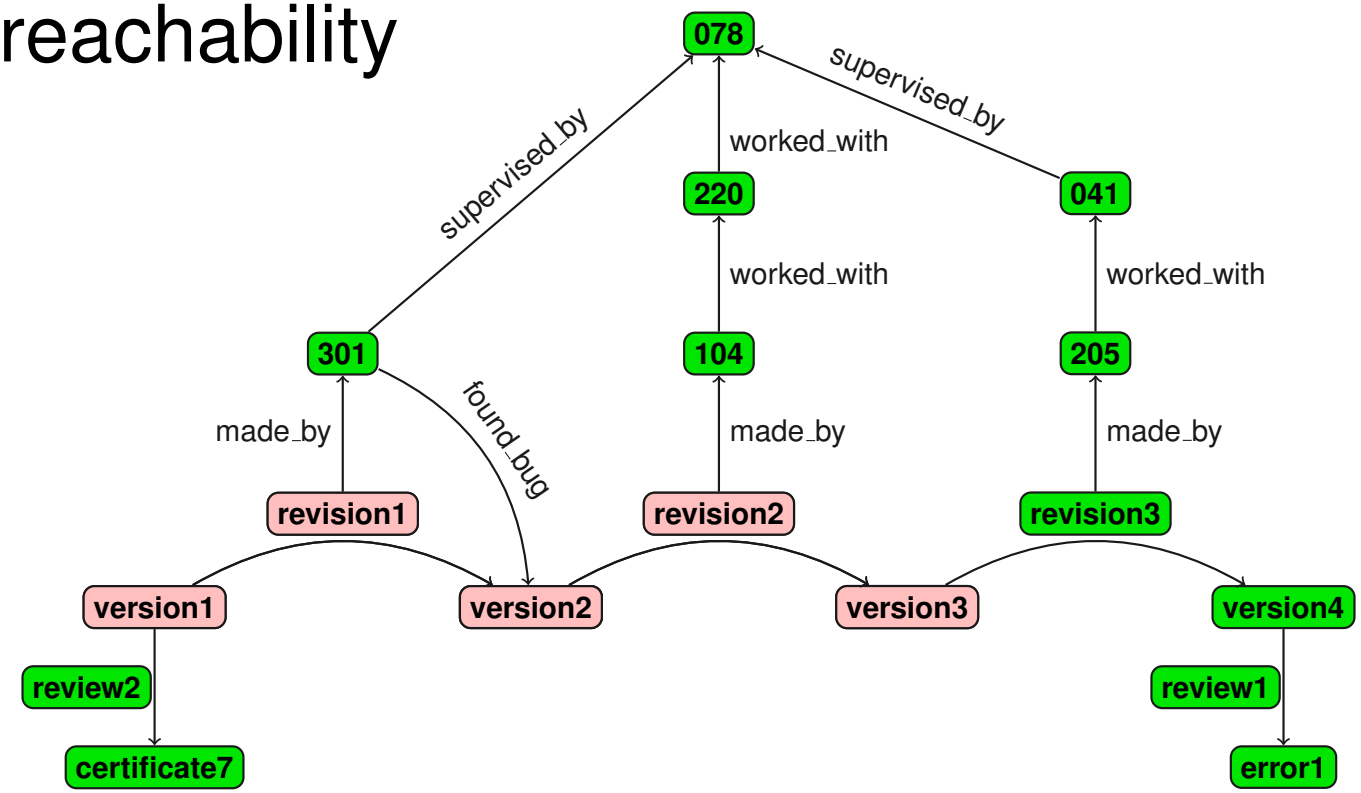

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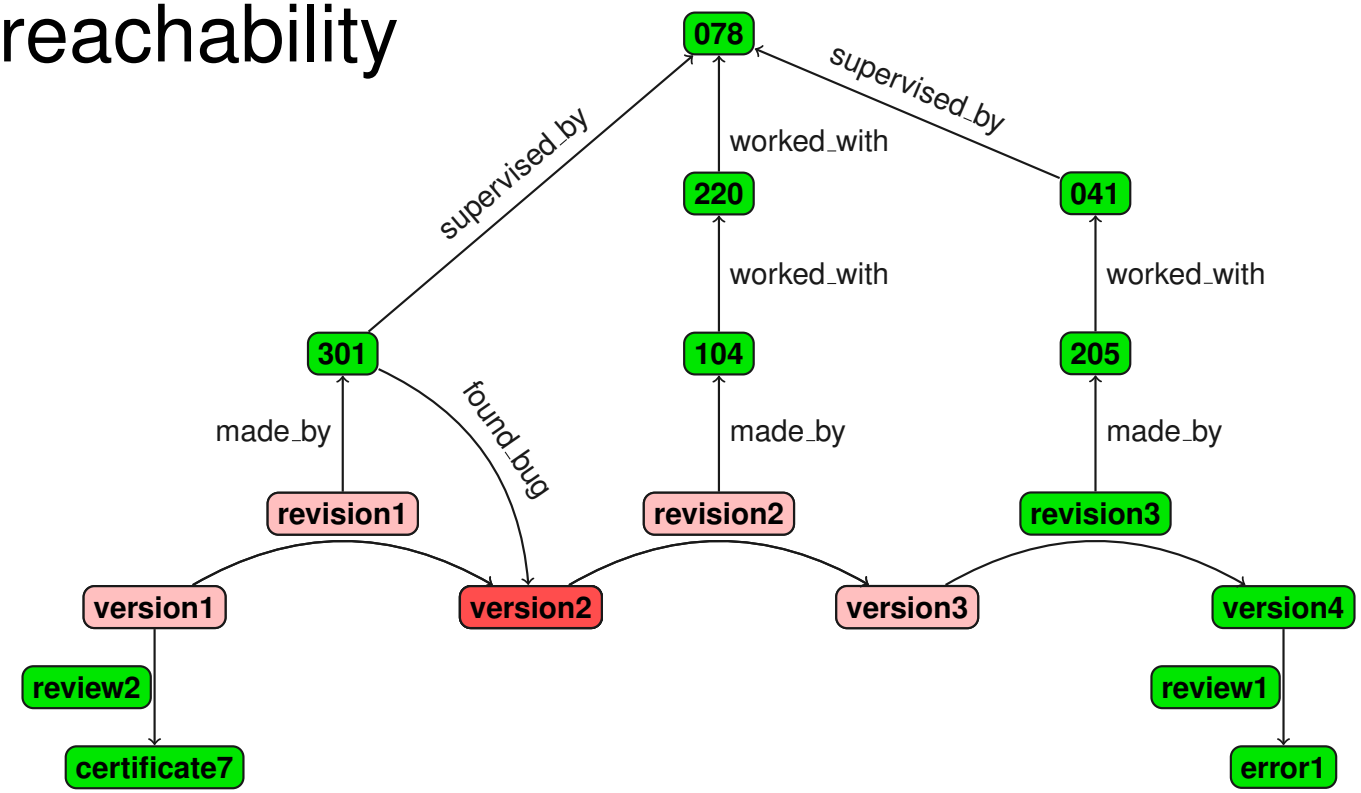

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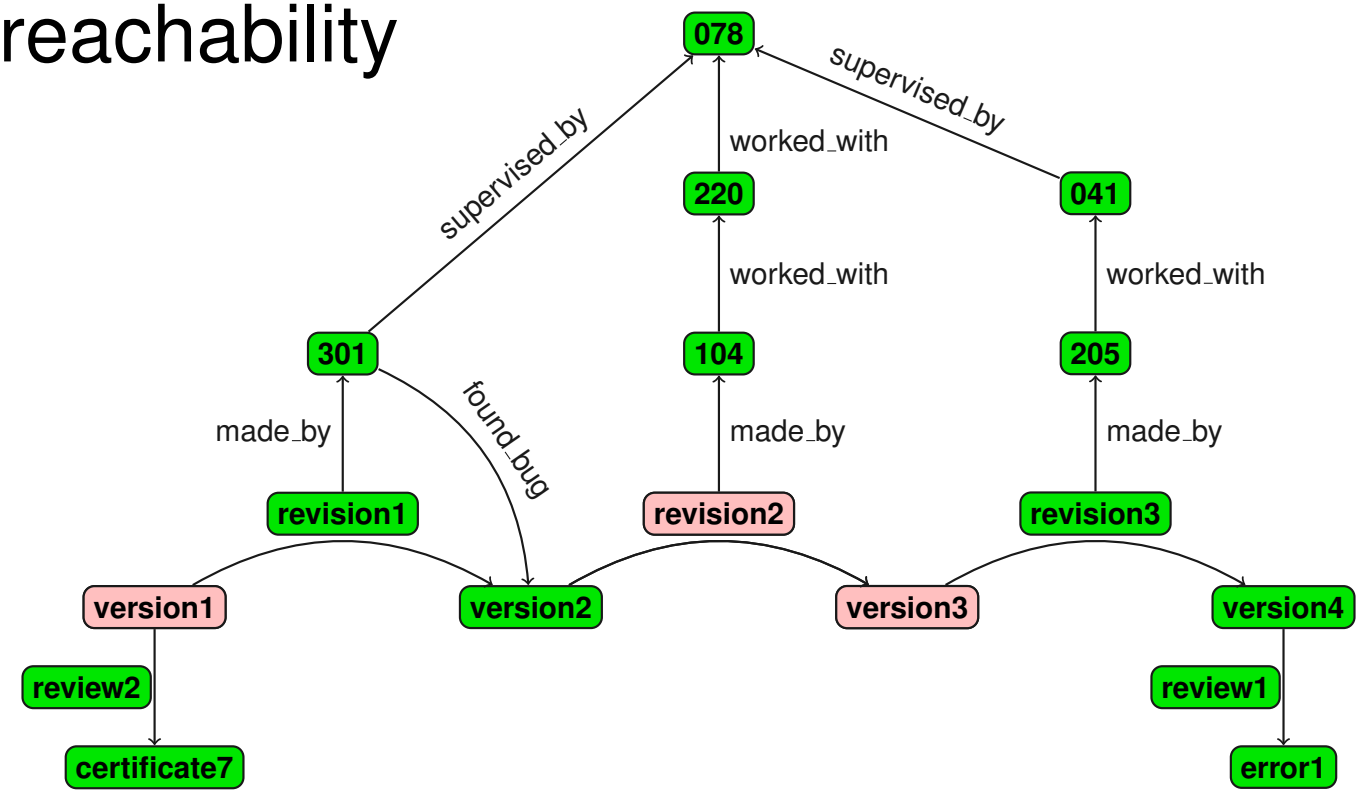
Simple reachability



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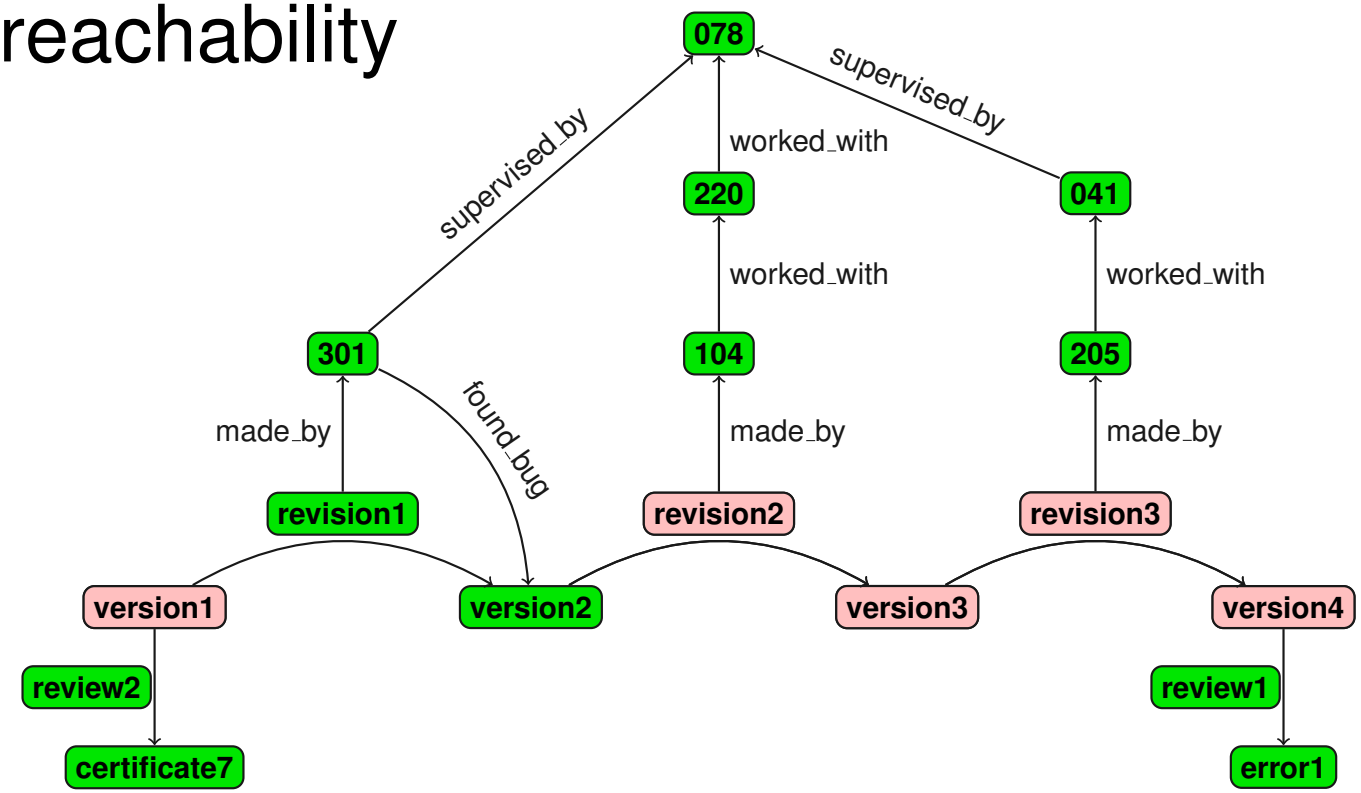
Simple reachability



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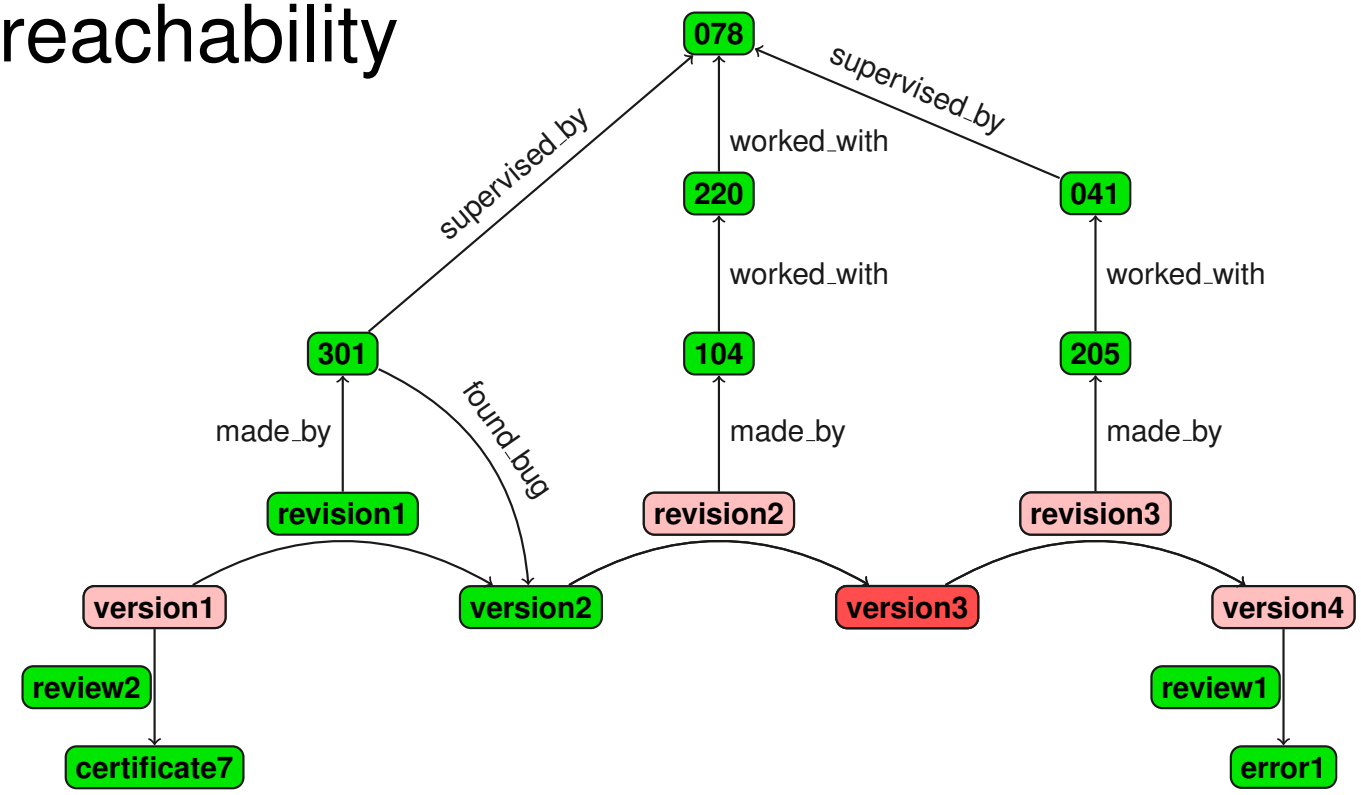

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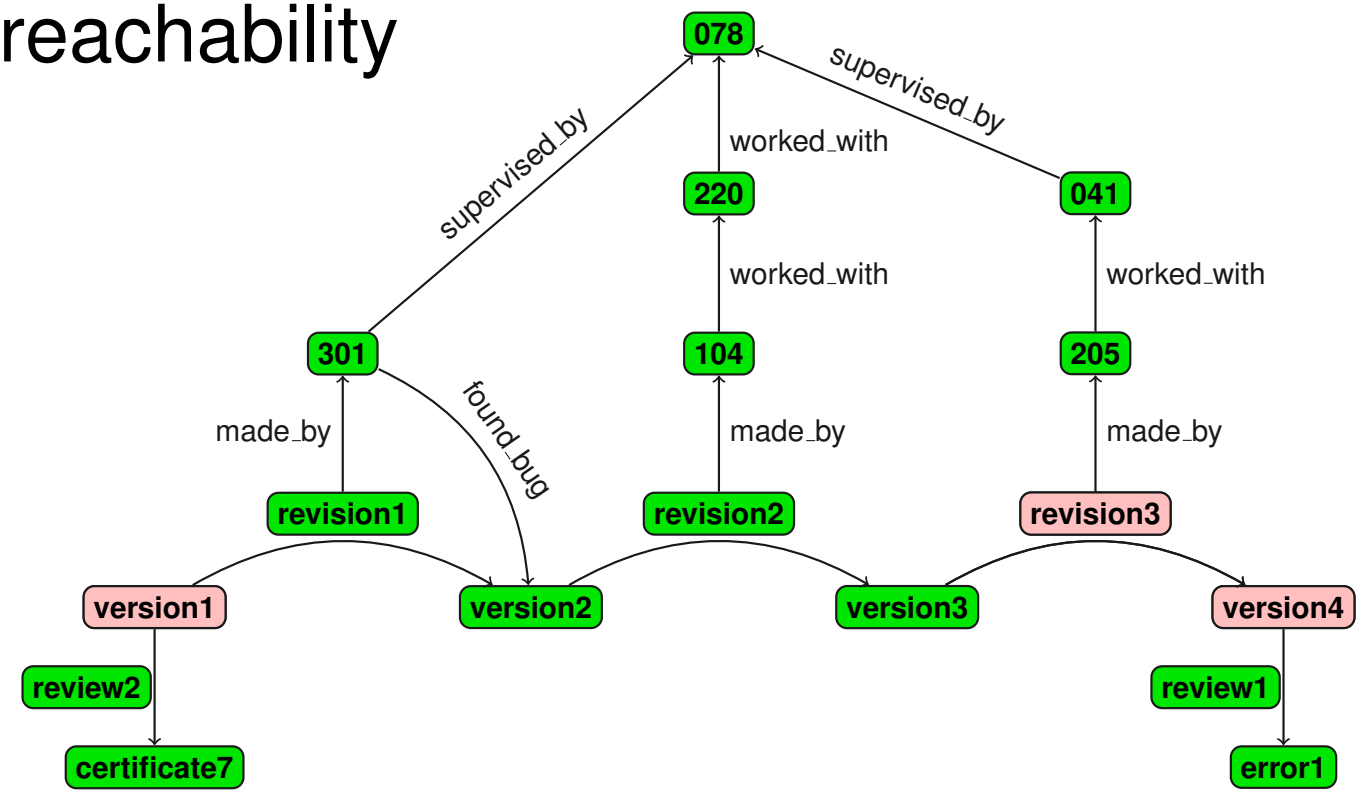

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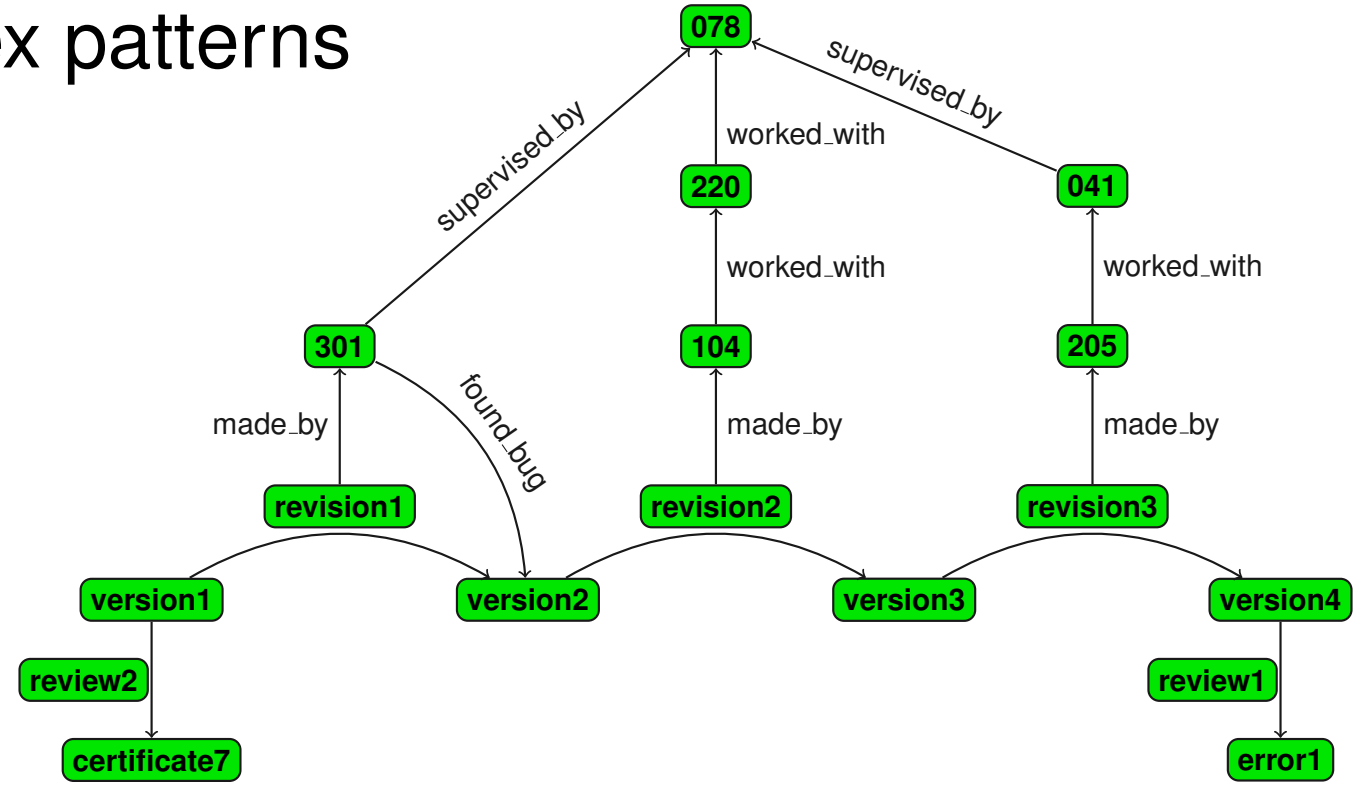
$$(E \bowtie_{3=1'}^{1,2',3'})^*$$

Complex patterns



- Q_2 : Find all versions with an error
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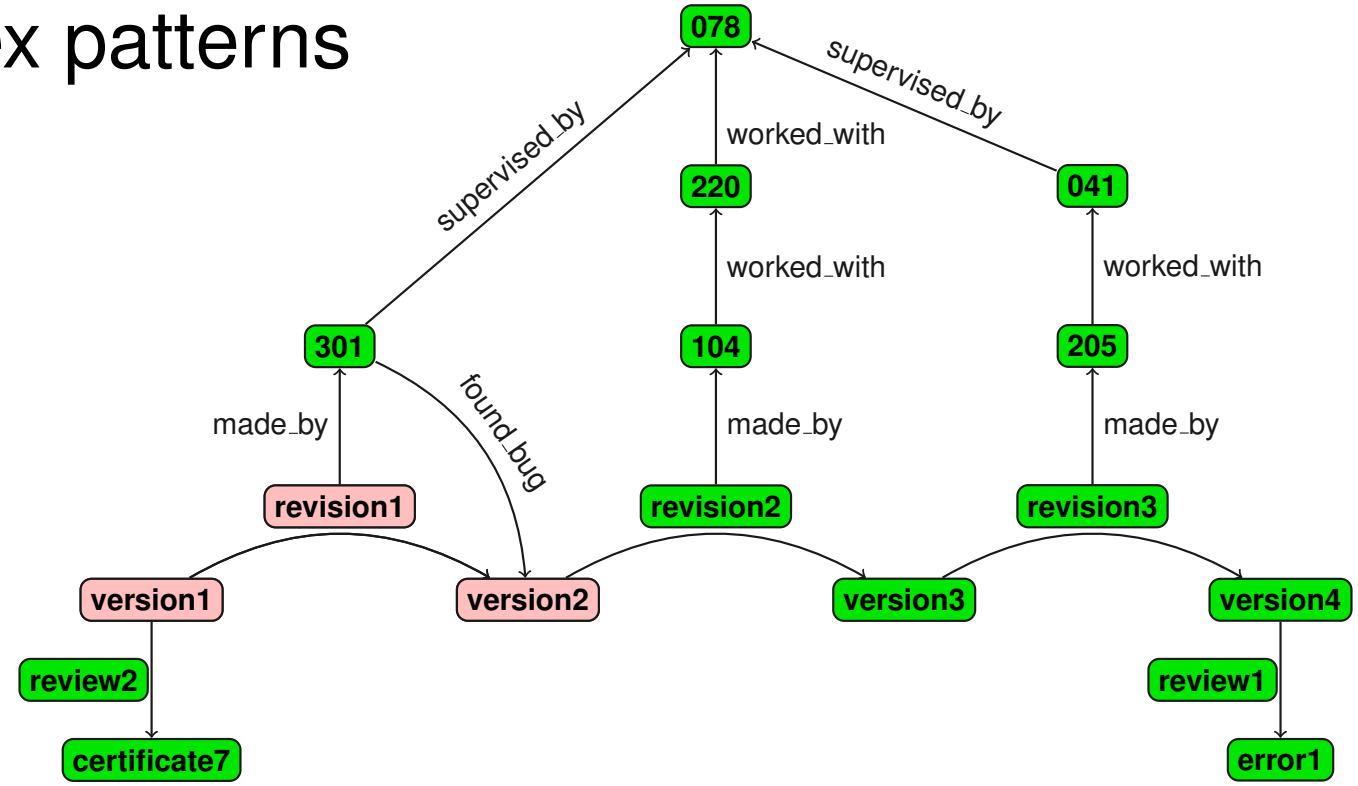
Complex patterns



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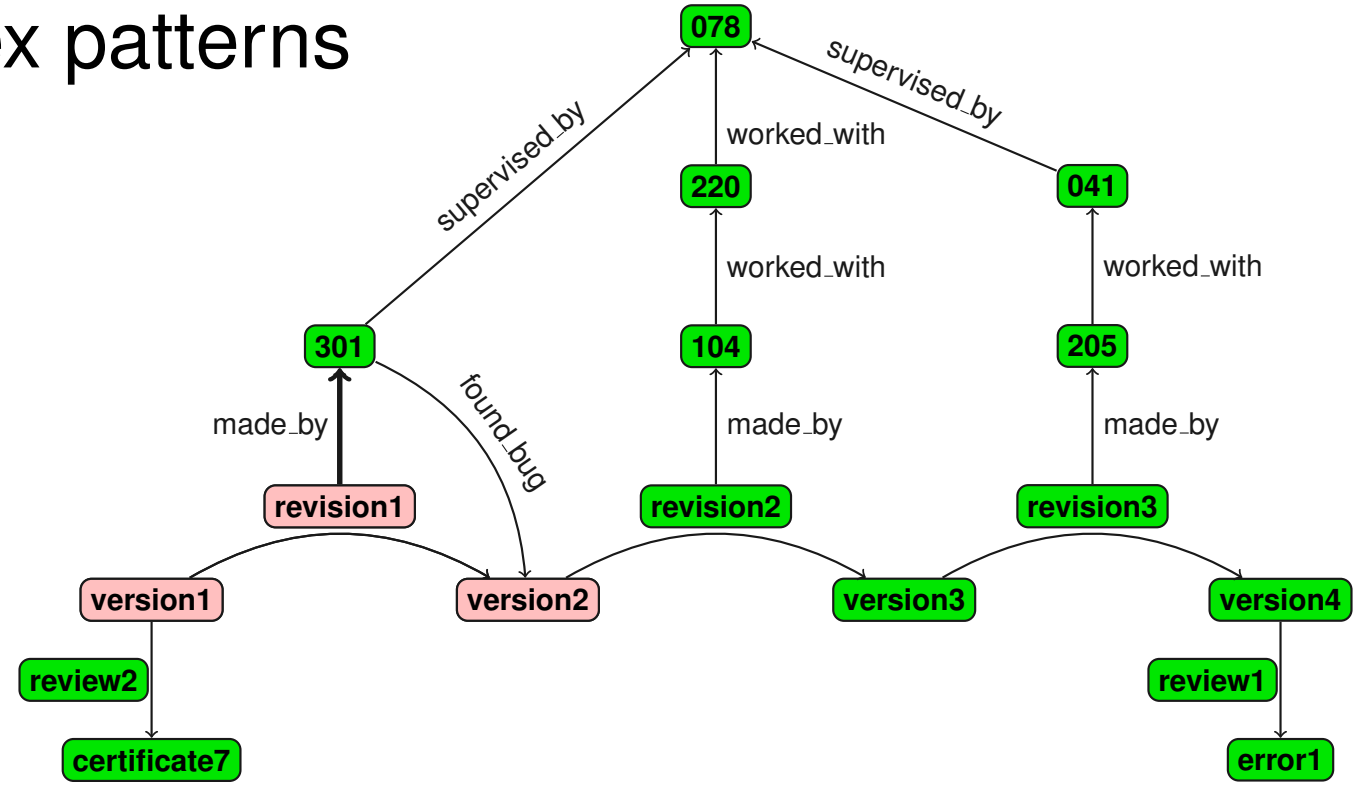
Complex patterns



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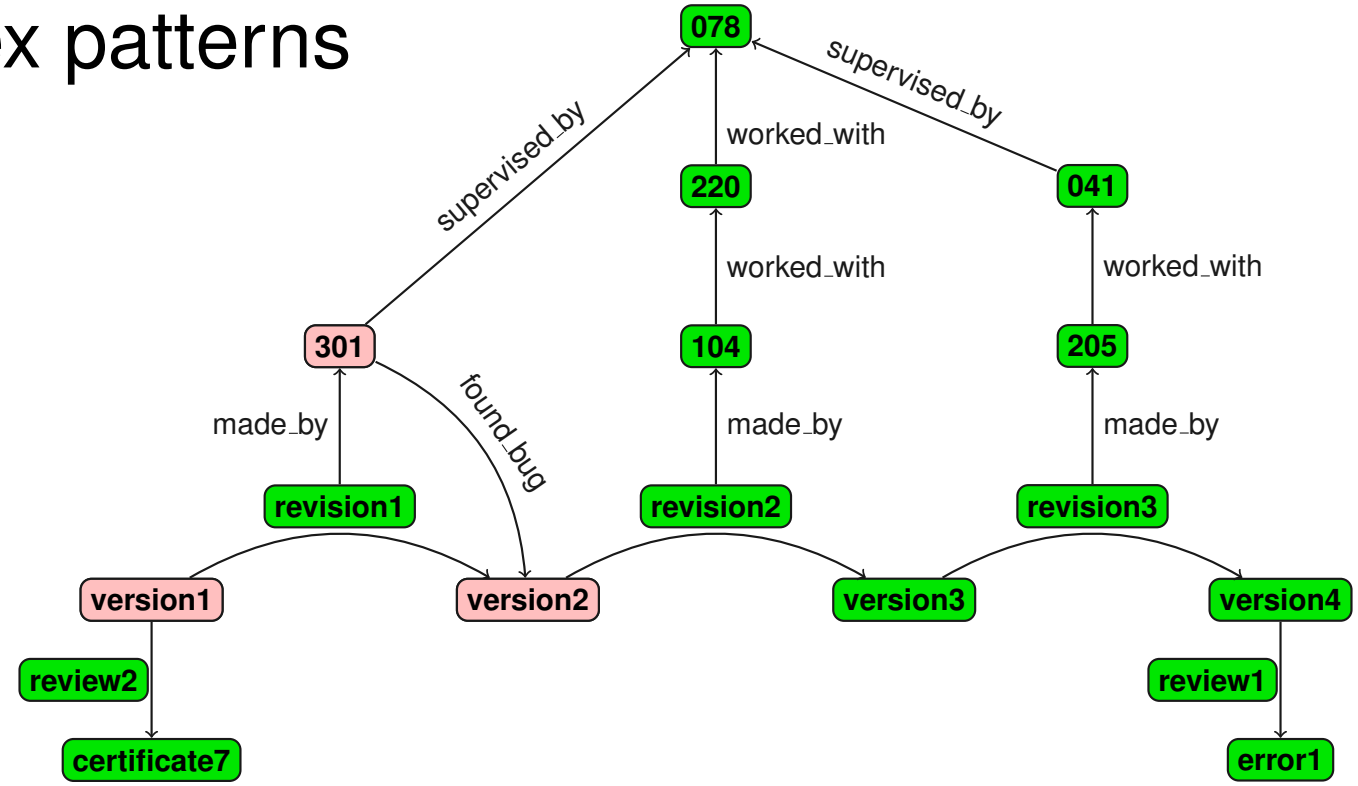

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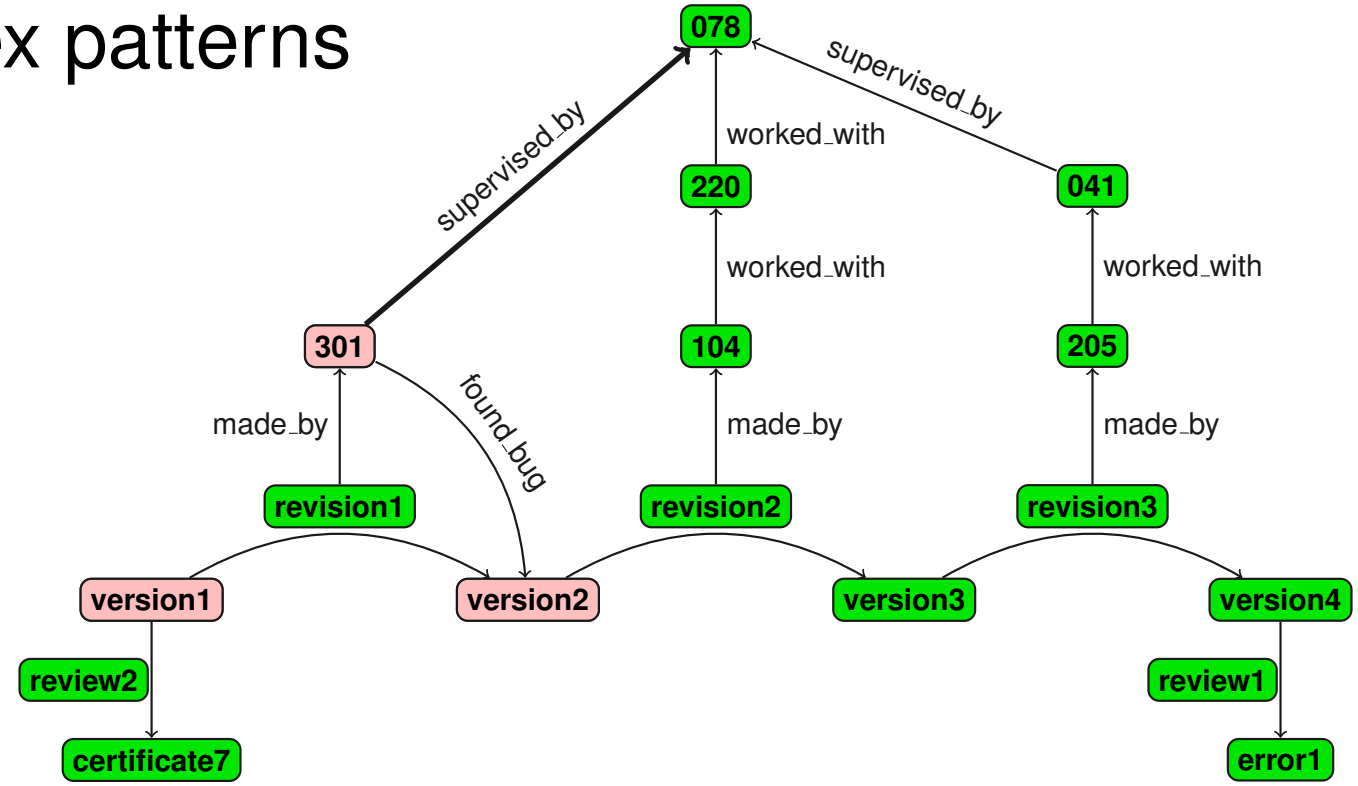
Complex patterns



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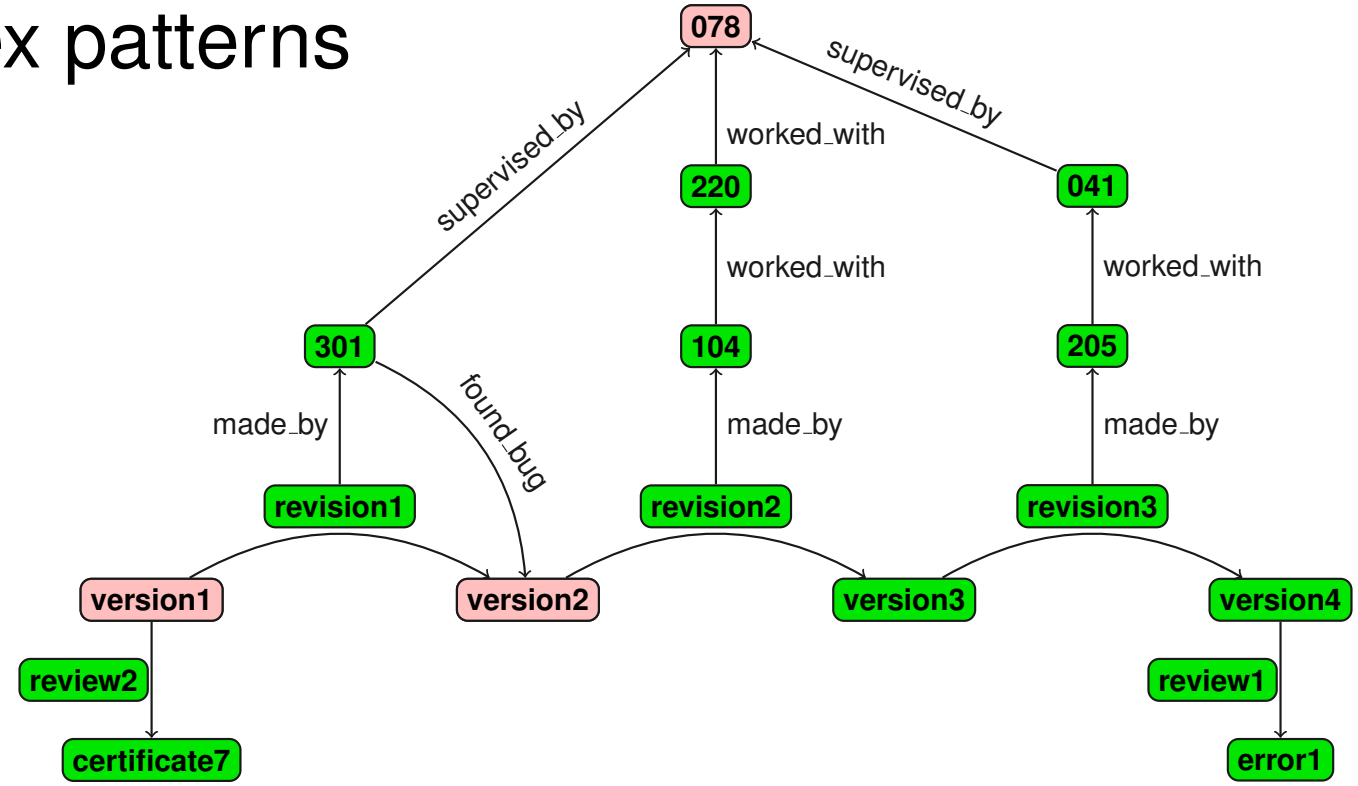
Complex patterns



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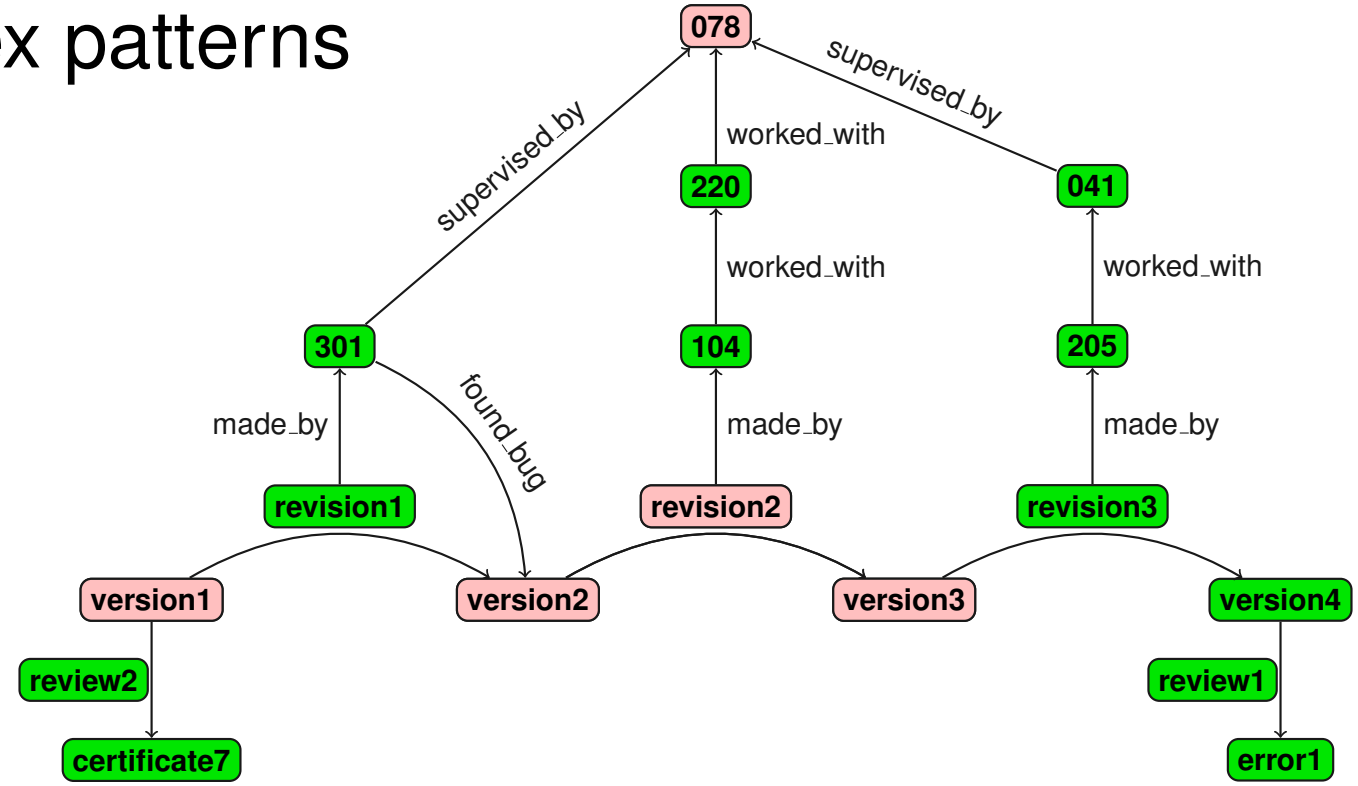

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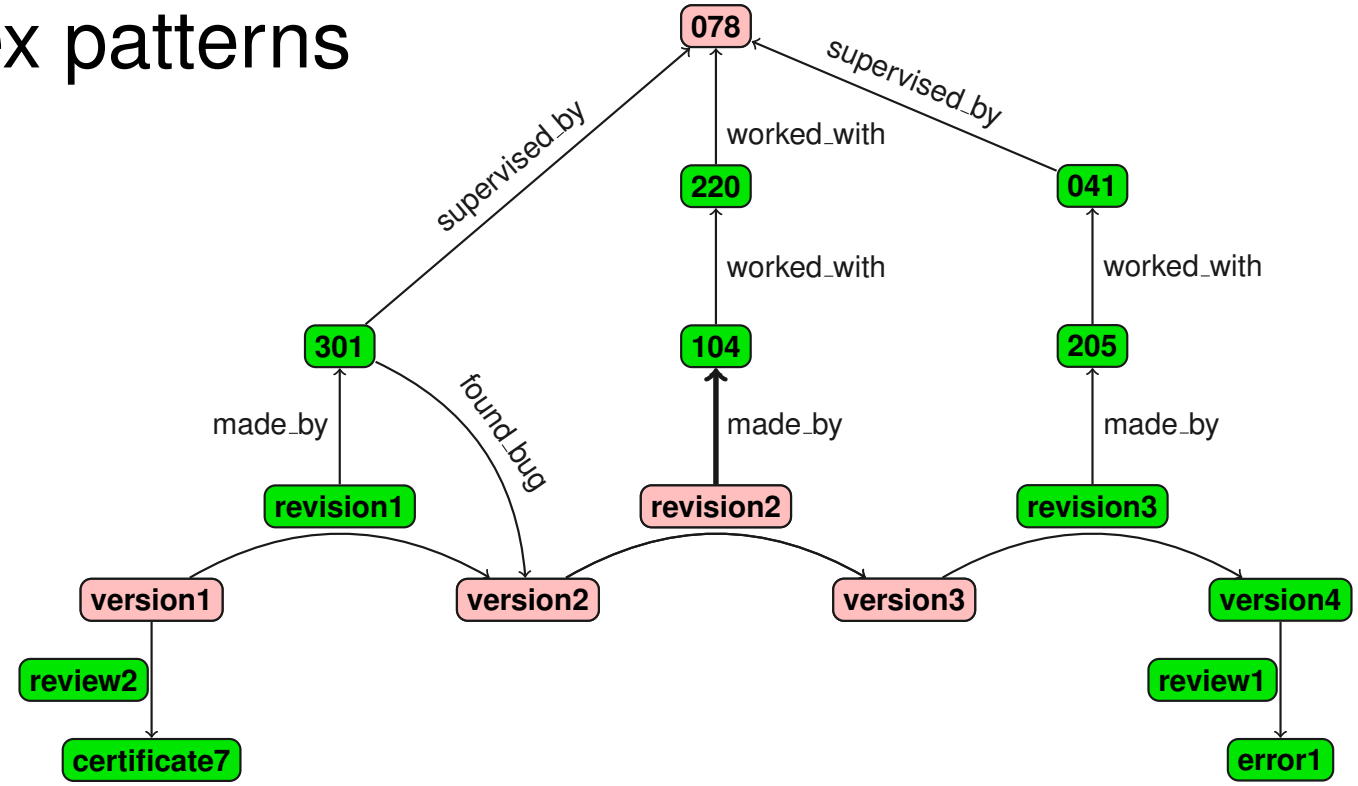
Complex patterns



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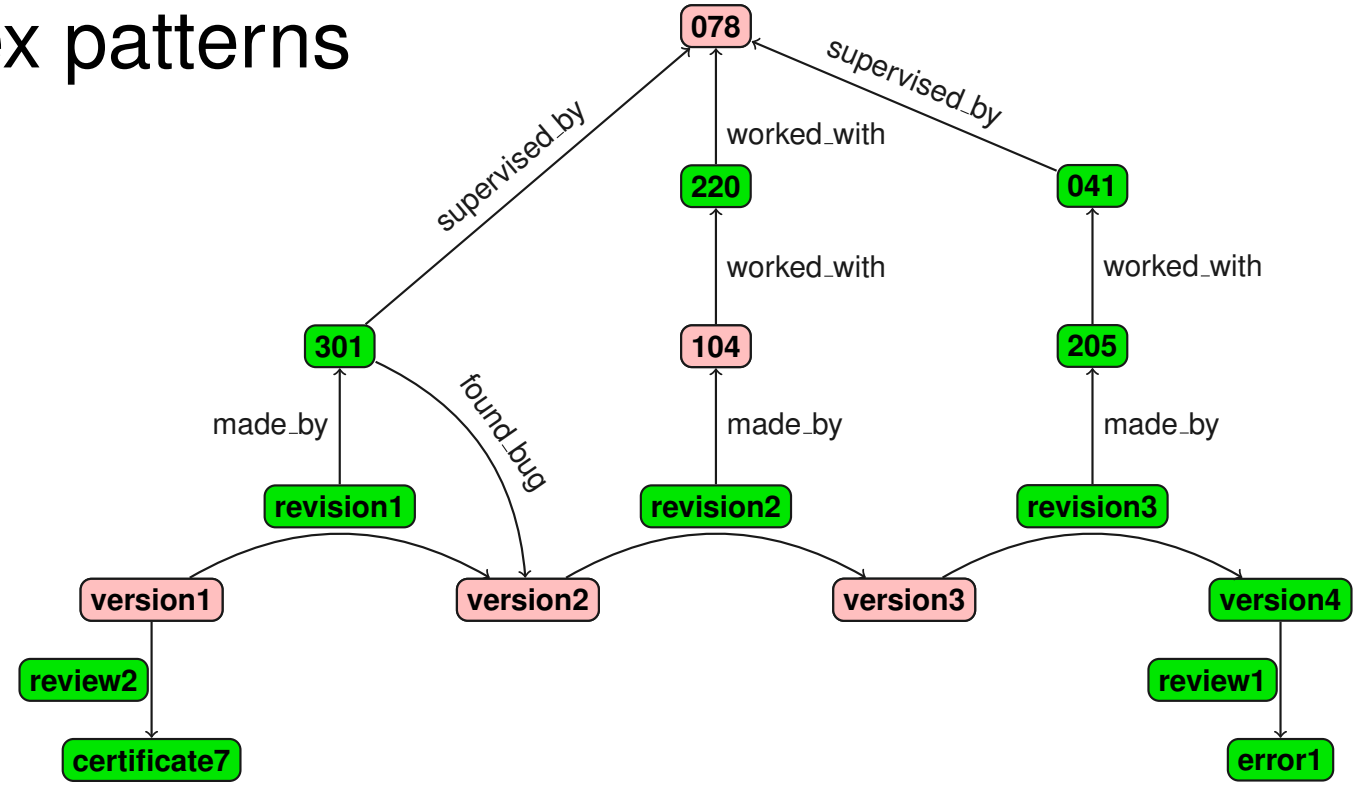
Complex patterns



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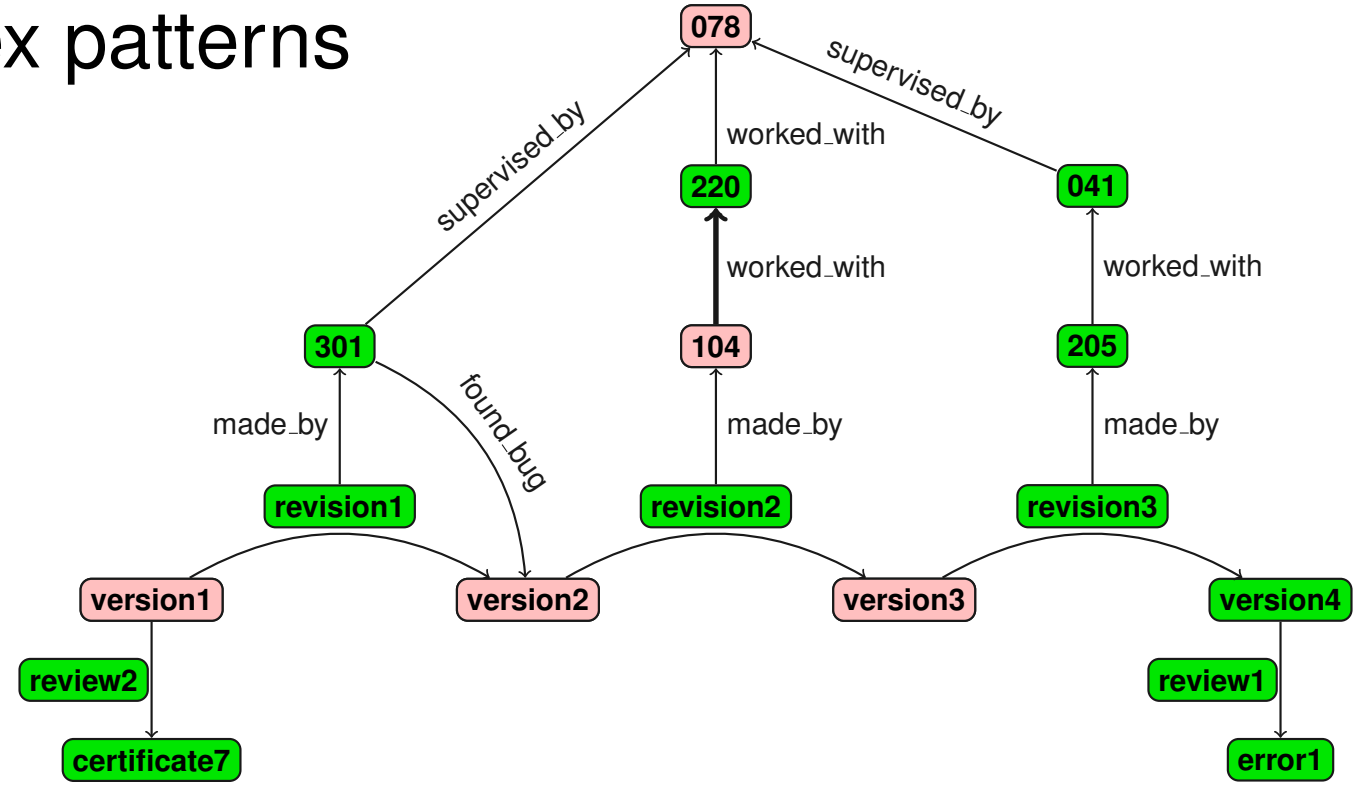

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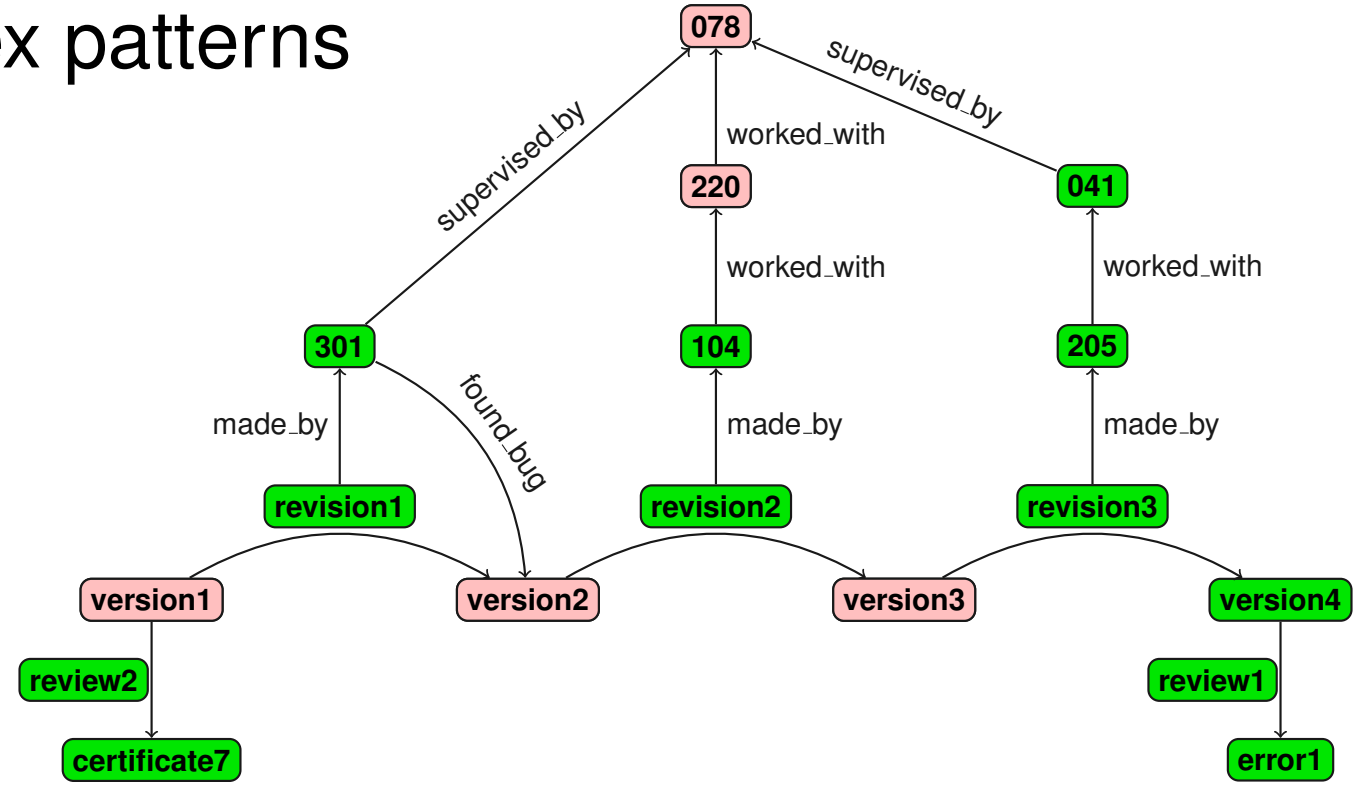

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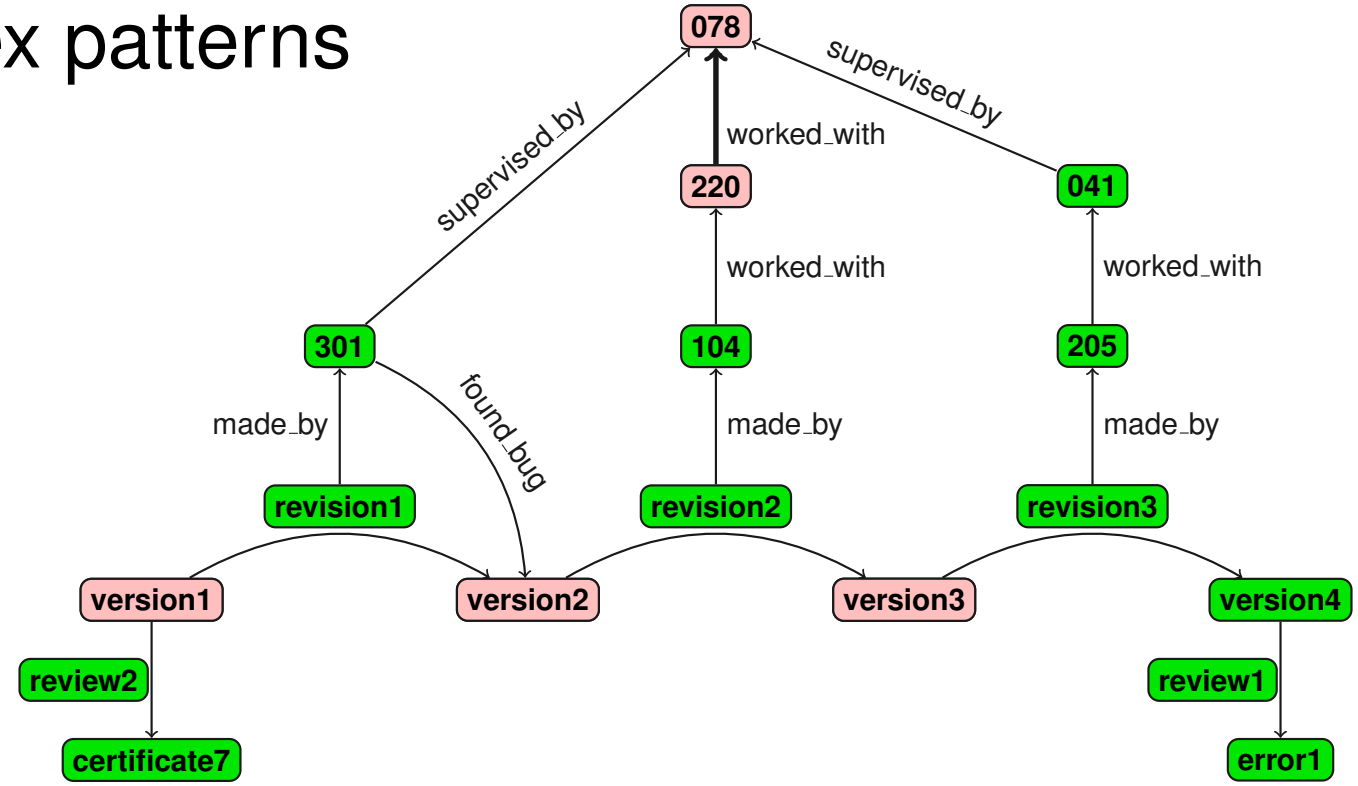

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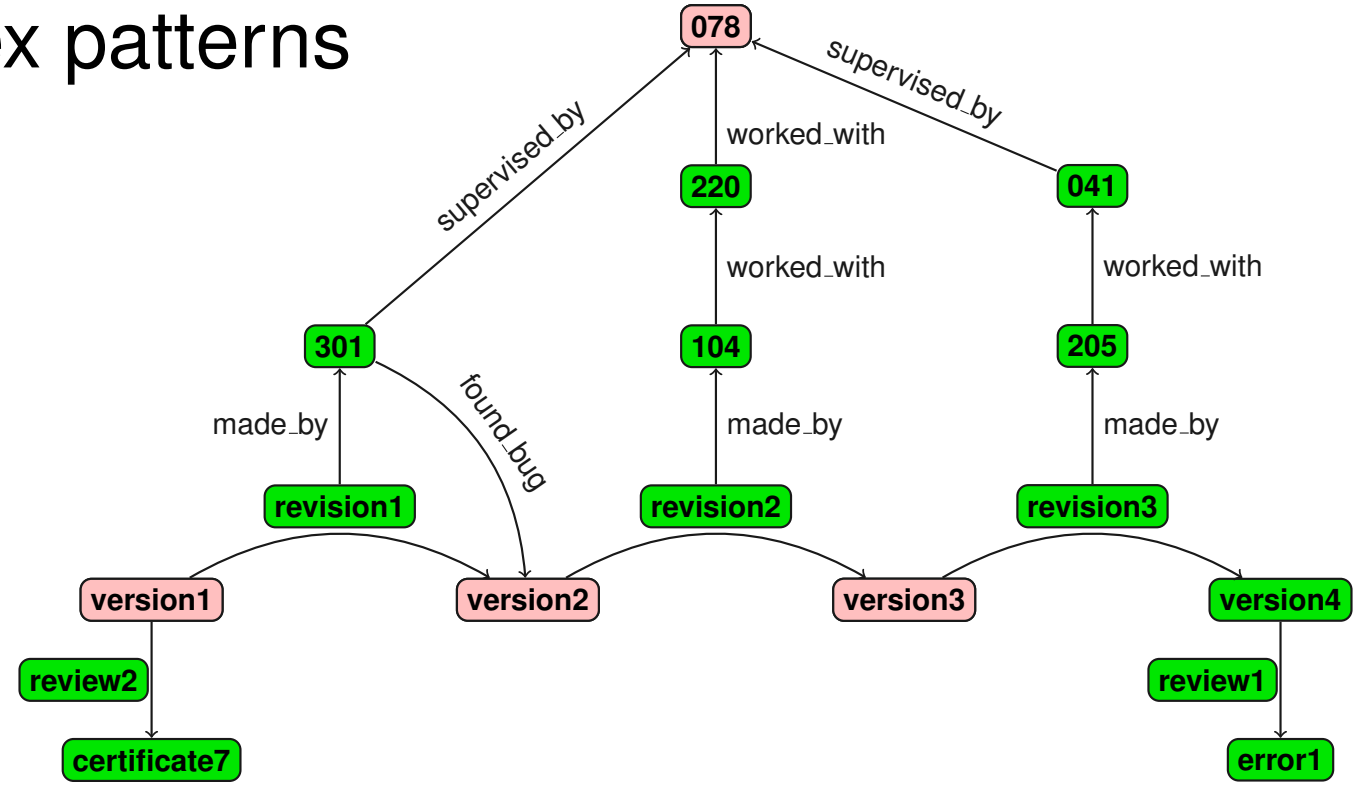

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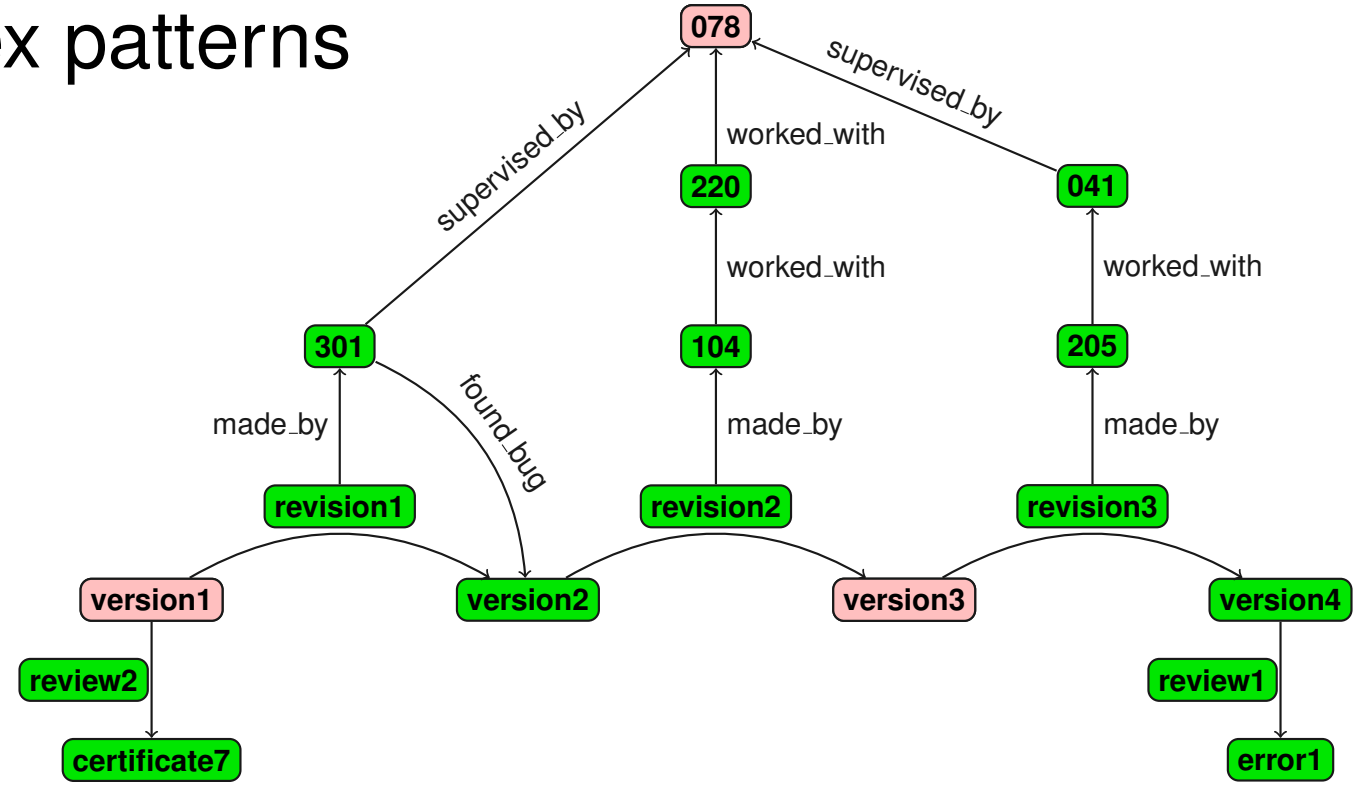

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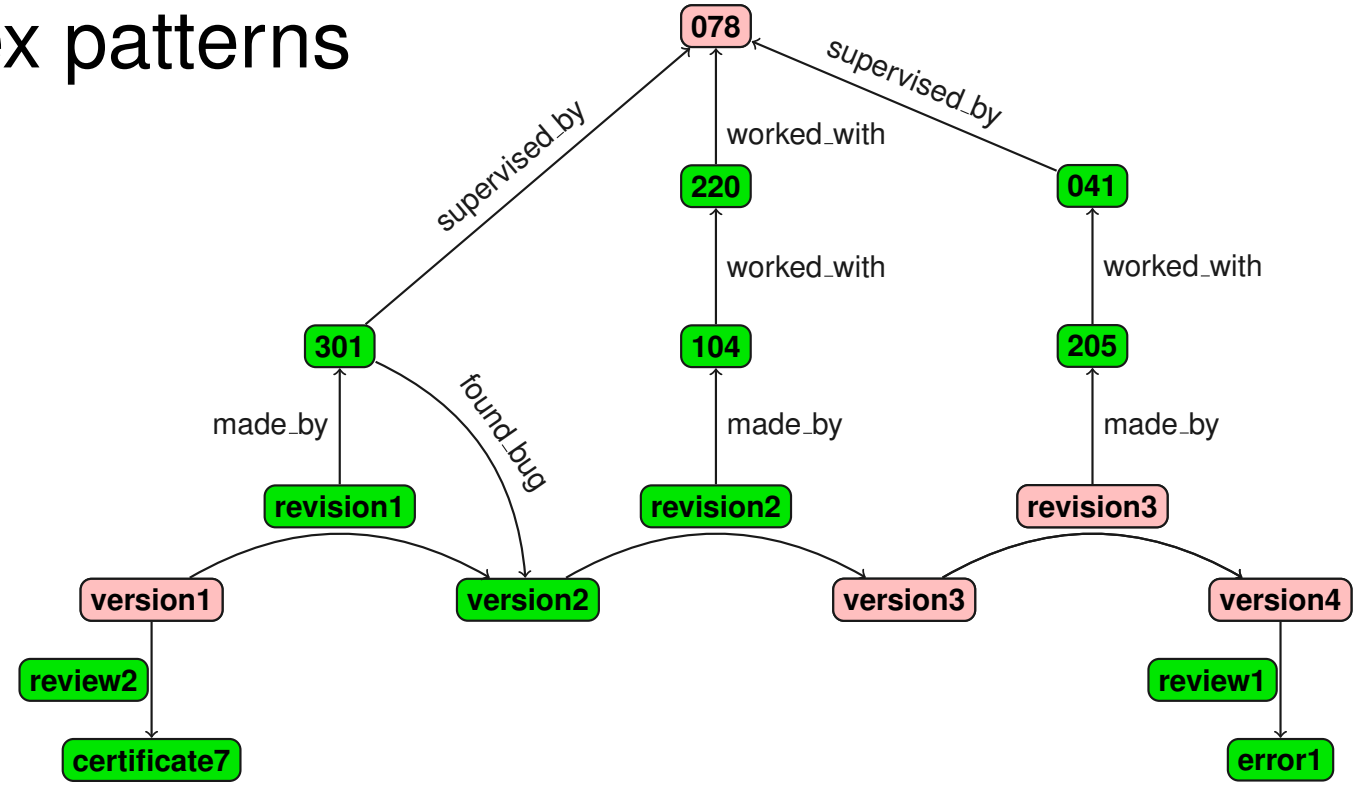

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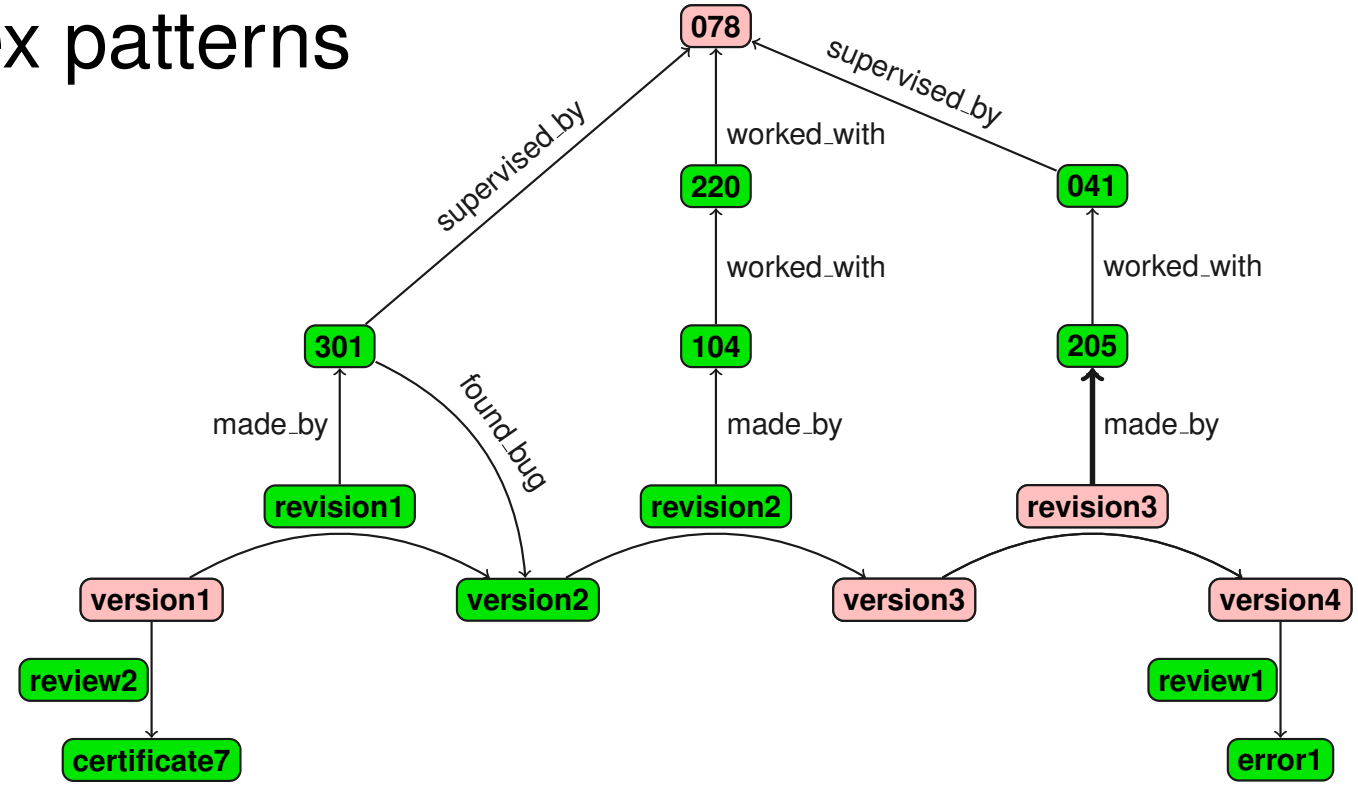

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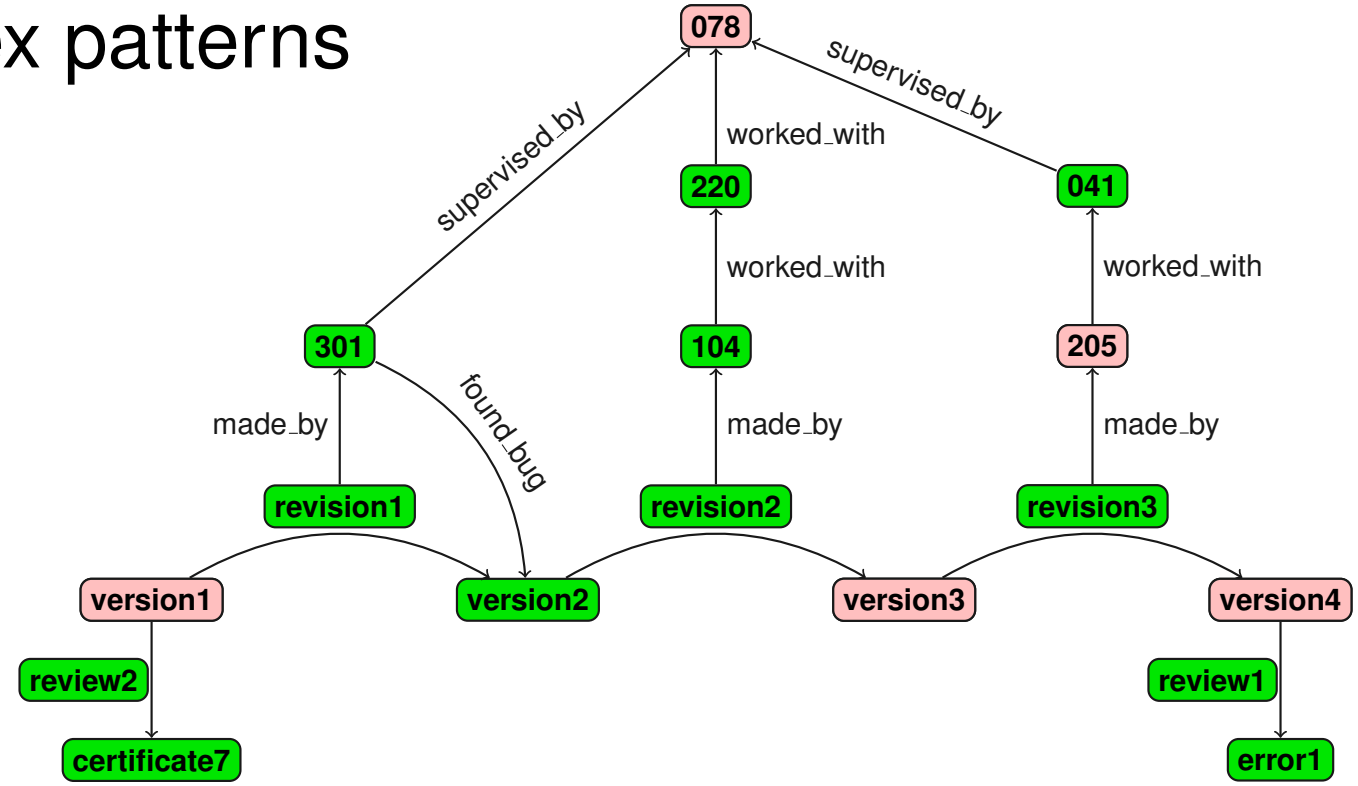

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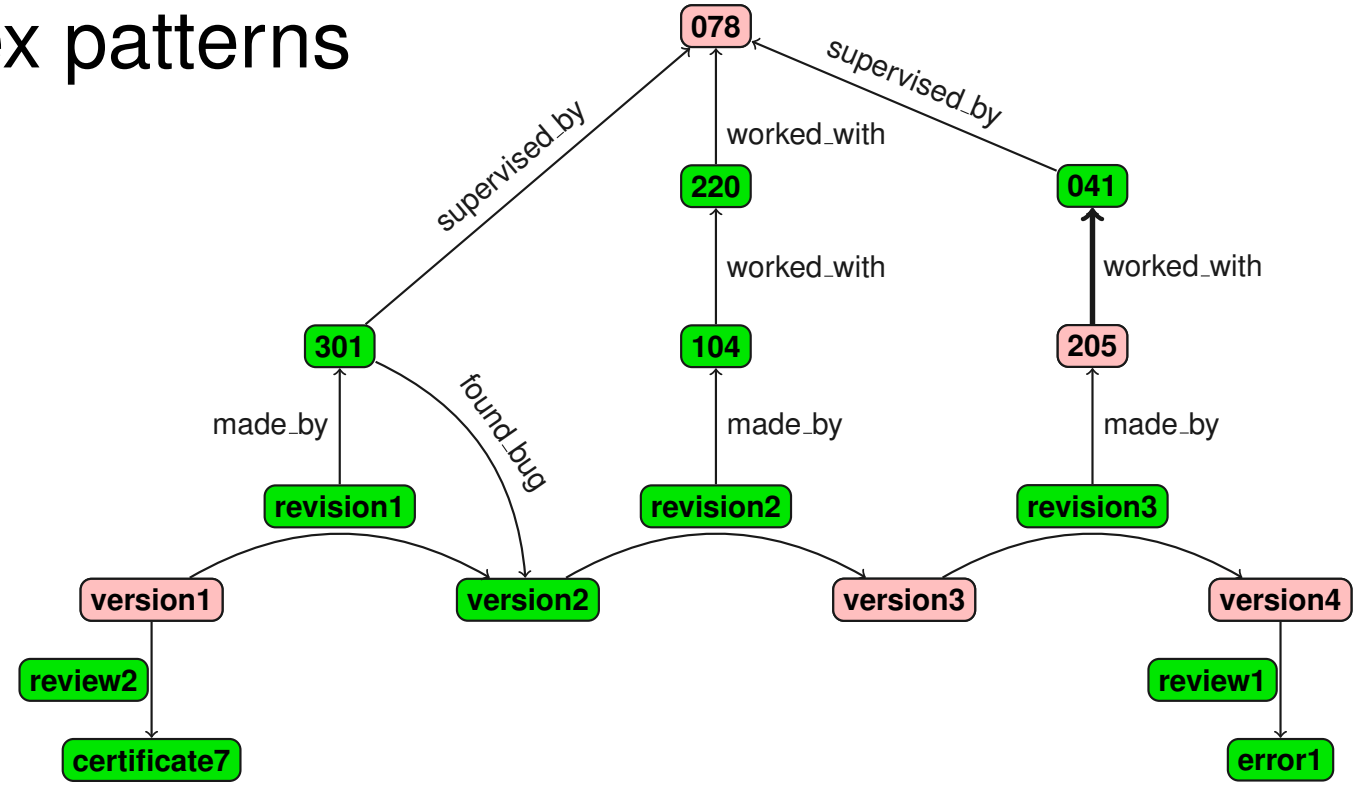

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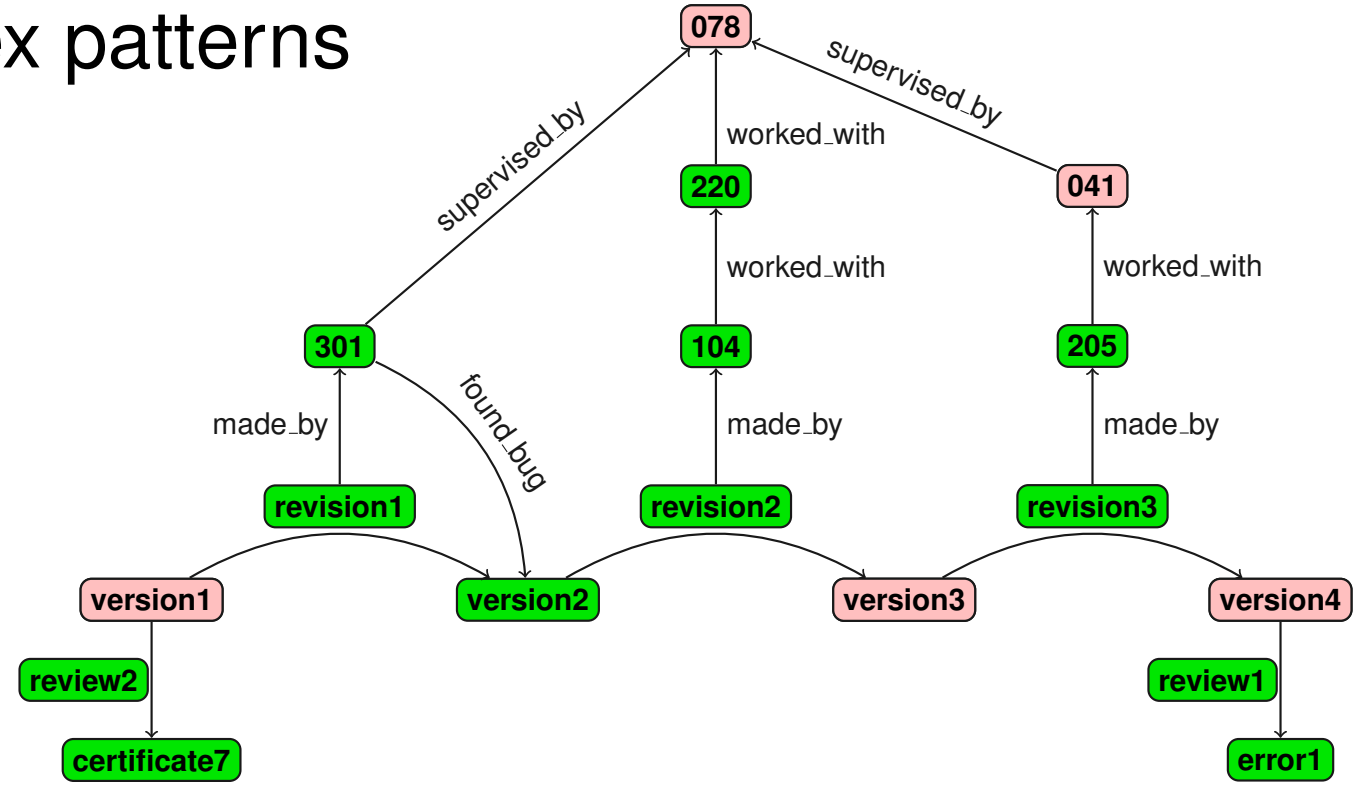

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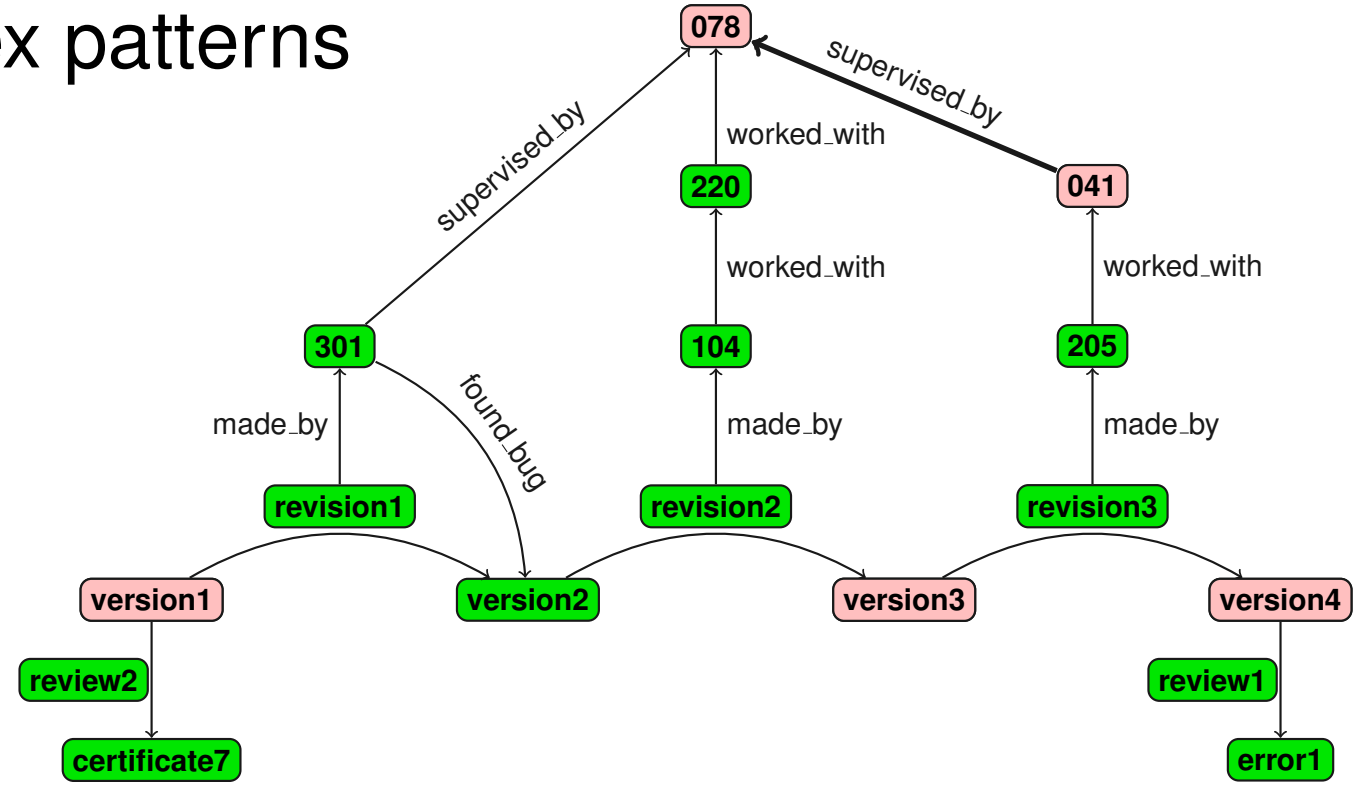

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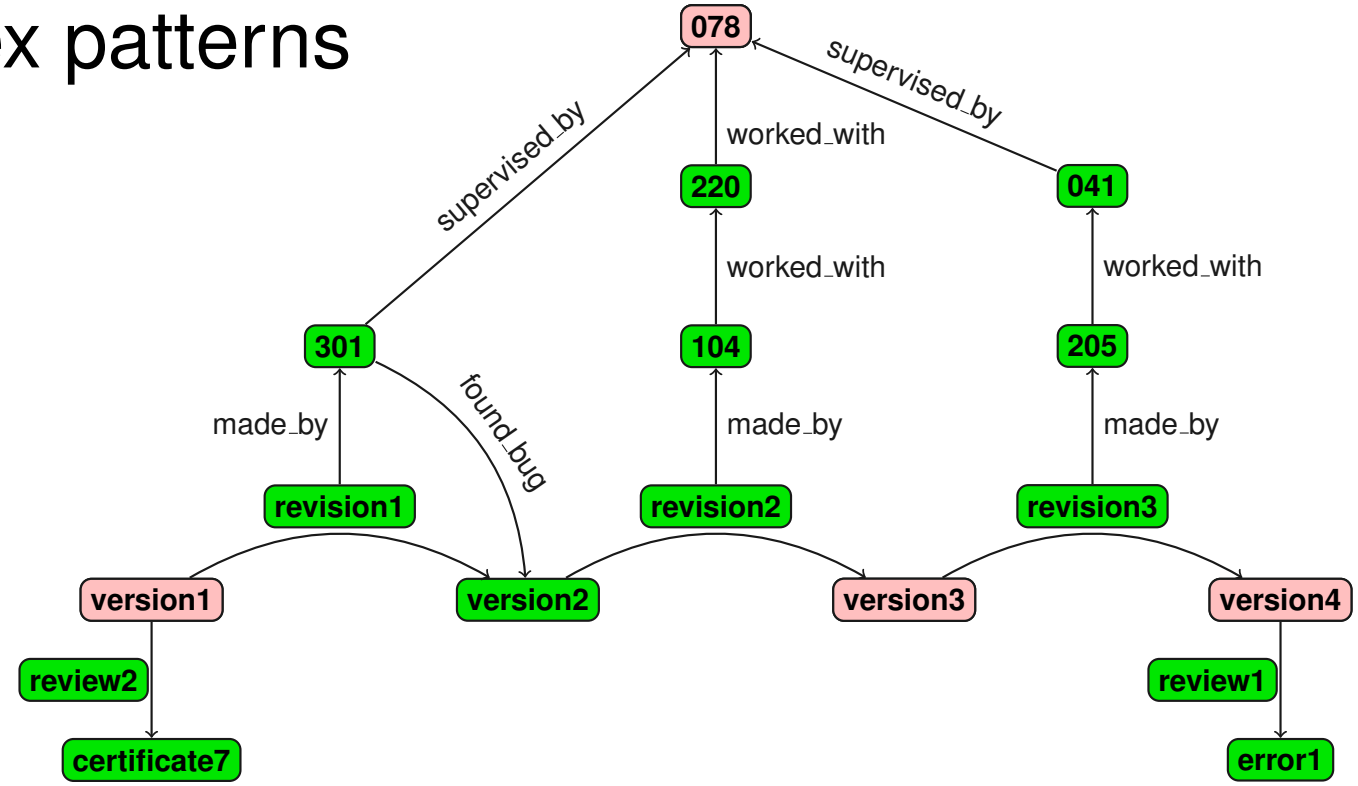

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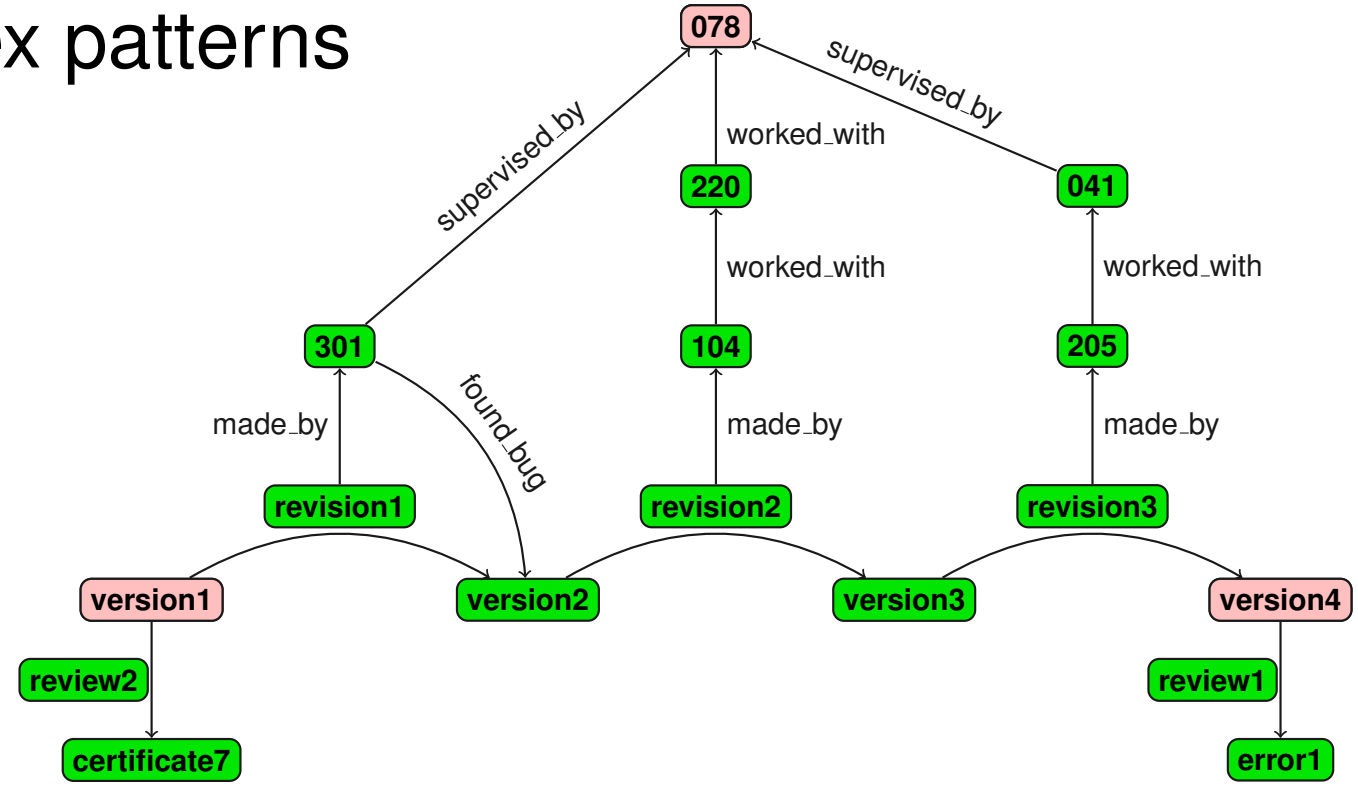

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TriAL*:

- Similar complexity bounds to RPQs
- Evaluation algorithm uses dynamic programming

TriAL*: fragment of relational algebra

- well known formalism
- can be translated into SQL- like statements (or datalog-like)
- fits right onto relational query implementations but we might need new heuristics

Other theoretical advantages of TriAL*

- know expressive power: First Order logic with transitive closure and fixed amount of variables
- Can I pose this query?

Outline

1. Graph databases
   Most studied connectivity queries

2. Relationship between connectivity and recursion
   An algebra for querying graphs

3. Where to go from here

What now?

Lets get back to what we know, and study connectivity queries from a relational perspective

- Shortest path
- Count number of paths
- Aggregate on paths (total distance, etc)

What now?

Include TriAL in graph implementations

- Include it in SPARQL
- compare performance with Neo4j, Dex
- RDF DBMS (Jenna, etc)