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# Overview of Regular Path Queries in Graphs


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# Outlook

- Introduction
- Application Fields
- Types of Graphs
- Regular Path Queries (RPQ)
- Extensions of RPQ

# Introduction

- Query languages for graph databases ...
  - are navigational/recursive
  - traverse the labeled edges/nodes
  - query the topology of the data, but not the data itself
- Basic building blocks for this languages are often regular path queries (RPQ)
- RPQ are used in many graph query languages, so i.e. in
  - G
  - GraphLog
  - Cypher
  - XPath
  - SPARQL 1.1

# Application Fields for Graphs and Regular Graph Queries

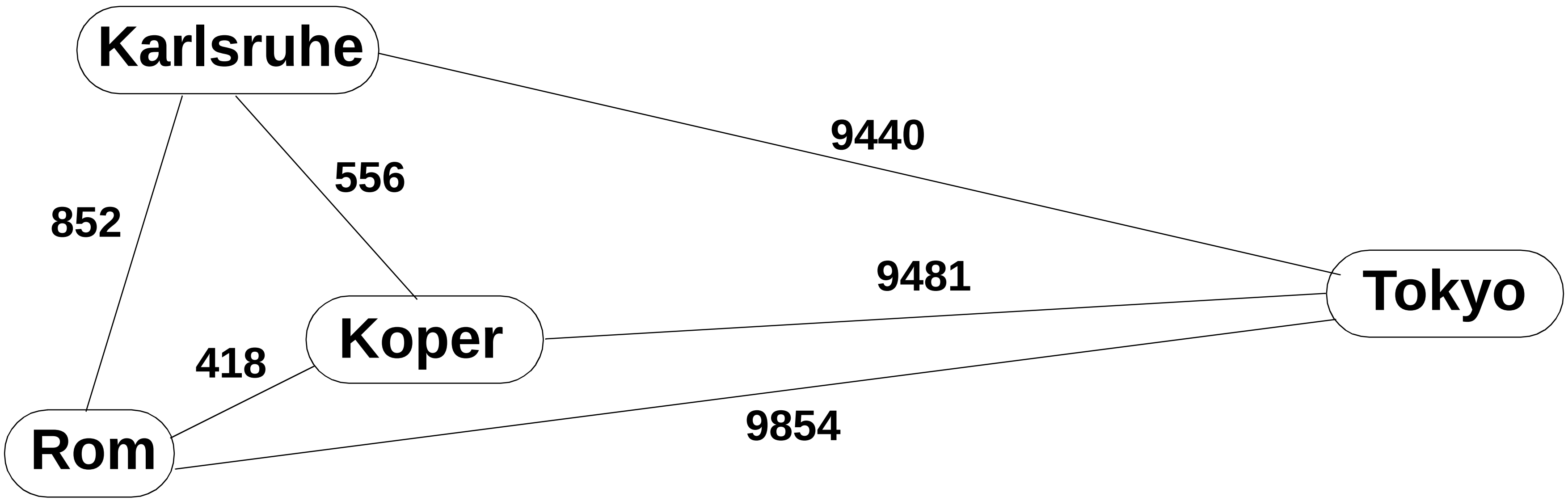
- Knowledge representation (RDF/s, OWL, Ontologies like Yago, Taxonomies)
  - connection between entities, instance and subclass relationships
- Transportation networks (airline, train, bus, streets)
  - Reachability, shortest path, critical path
- geographical information
- biological applications
- bibliographic citation analysis
- social networks
- program analysis
  - reachability of code, variables used before defined, deadlocks

# Query Types

- Graph Pattern Matching (subgraph matching)
- Path Finding (finding nodes connected by graphs)
- Extraction of edge label variables
- Aggregation
- ...

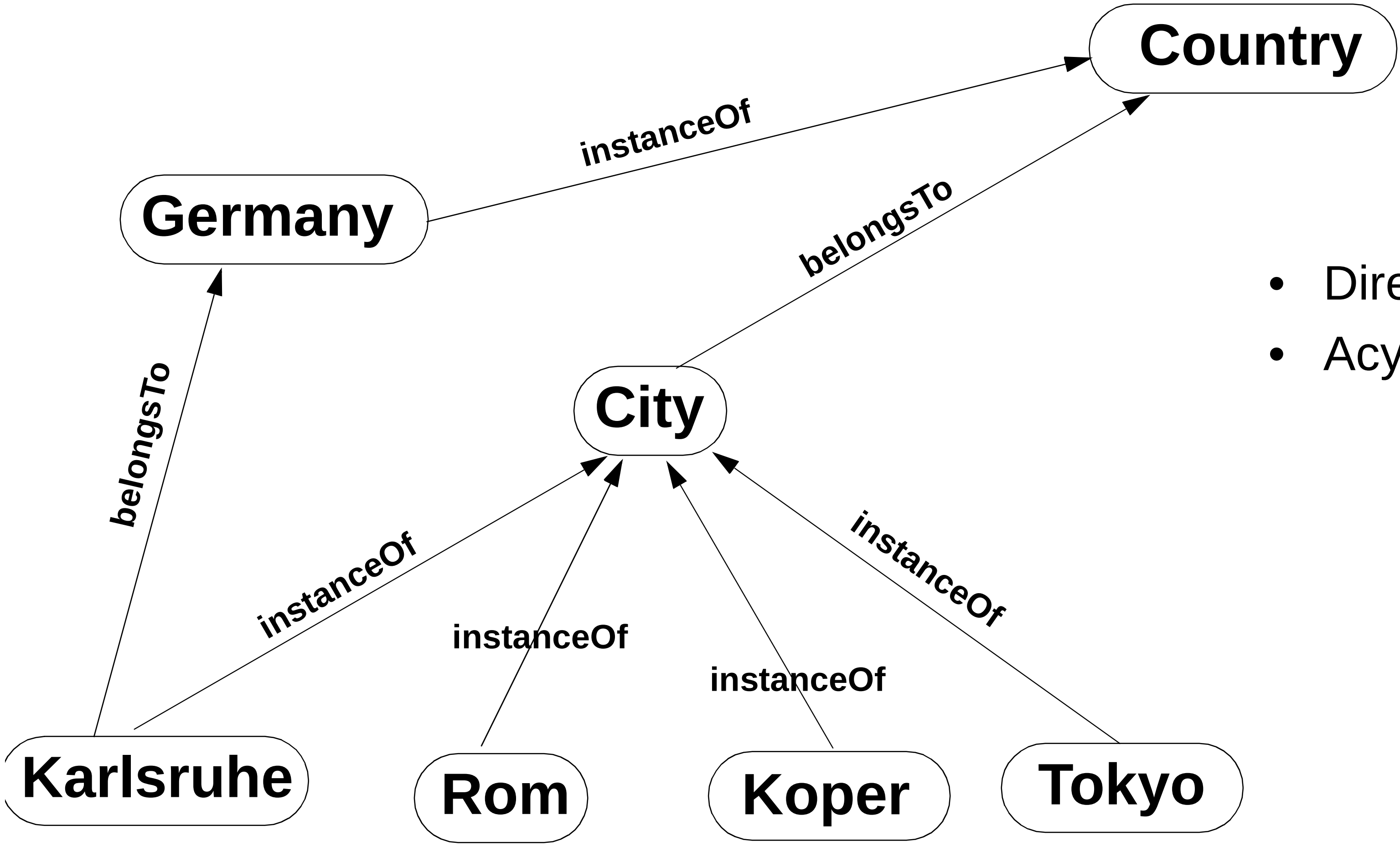
# Types of Graphs

- Undirected
- Cyclic




**Distances from http://www.luftlinie.org**

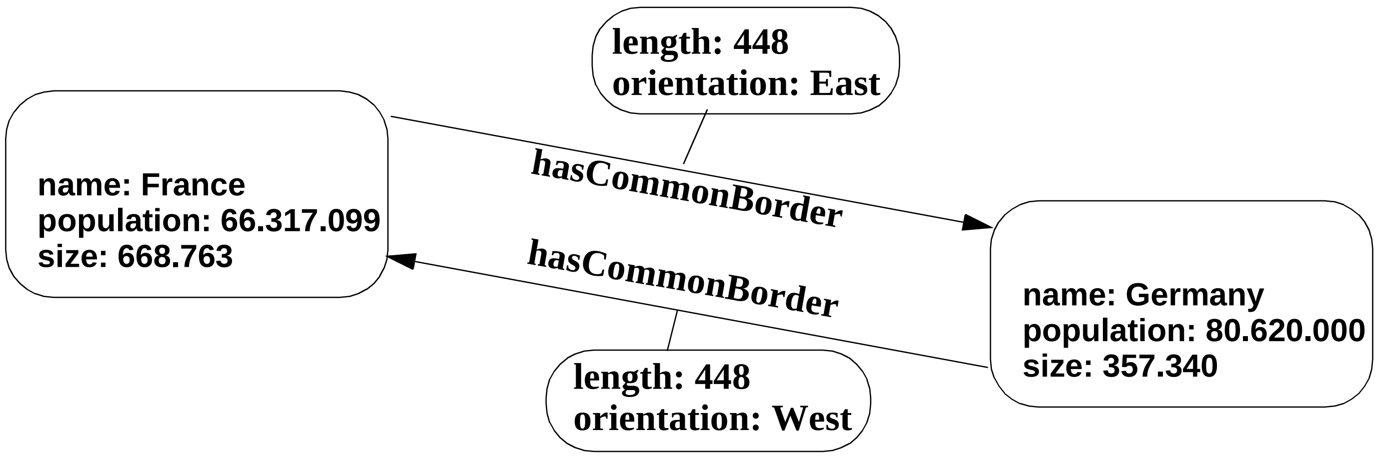
# Types of Graphs




- Directed
- Acyclic

# Property Graph

- directed
- cyclic
- Nodes and relations have properties



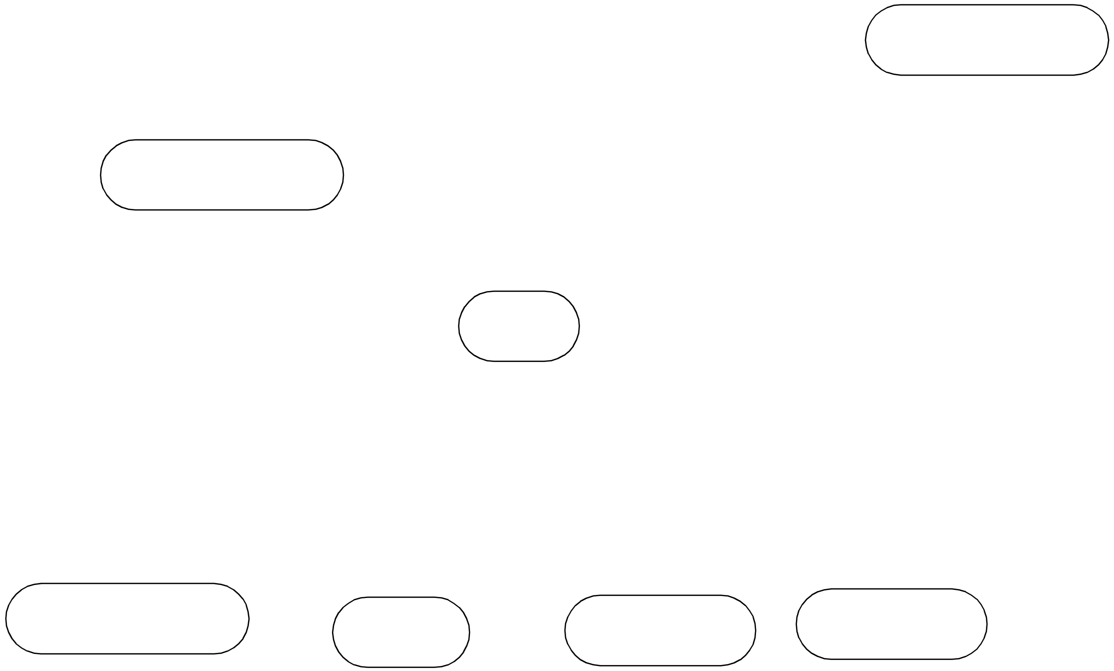
# Yet another Graph: Type ?

# Definition of Database Graph

G=(N, E)

Directed, labeled graph with:

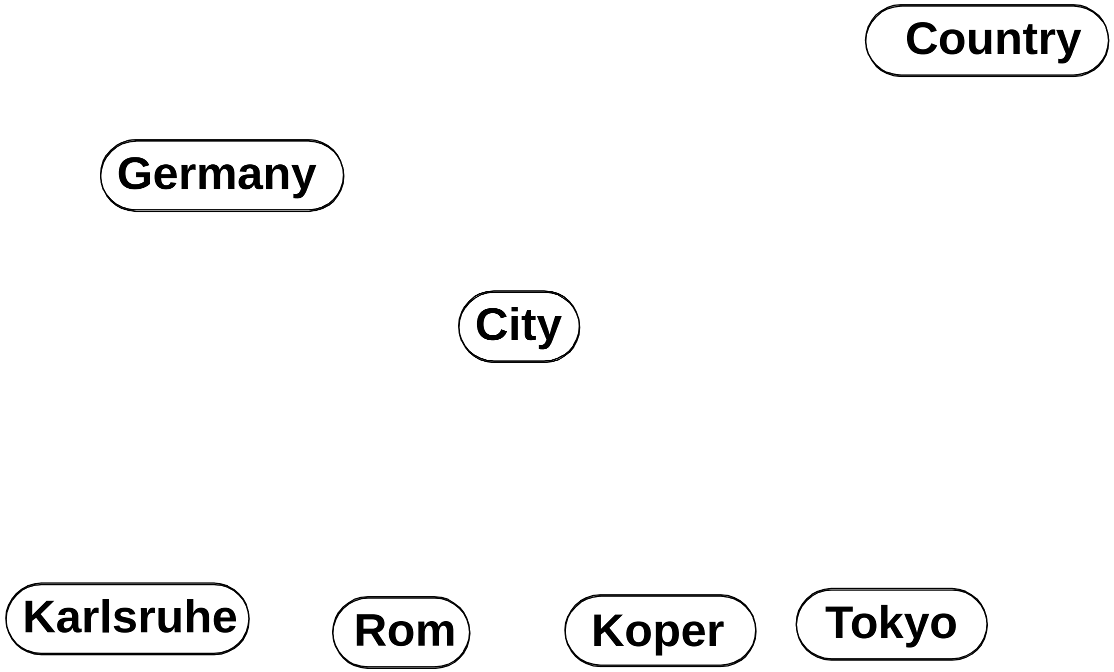
- N: set of nodes



G=(N, E)

Directed, labeled graph with:

- N: set of nodes, representing entities from the real world

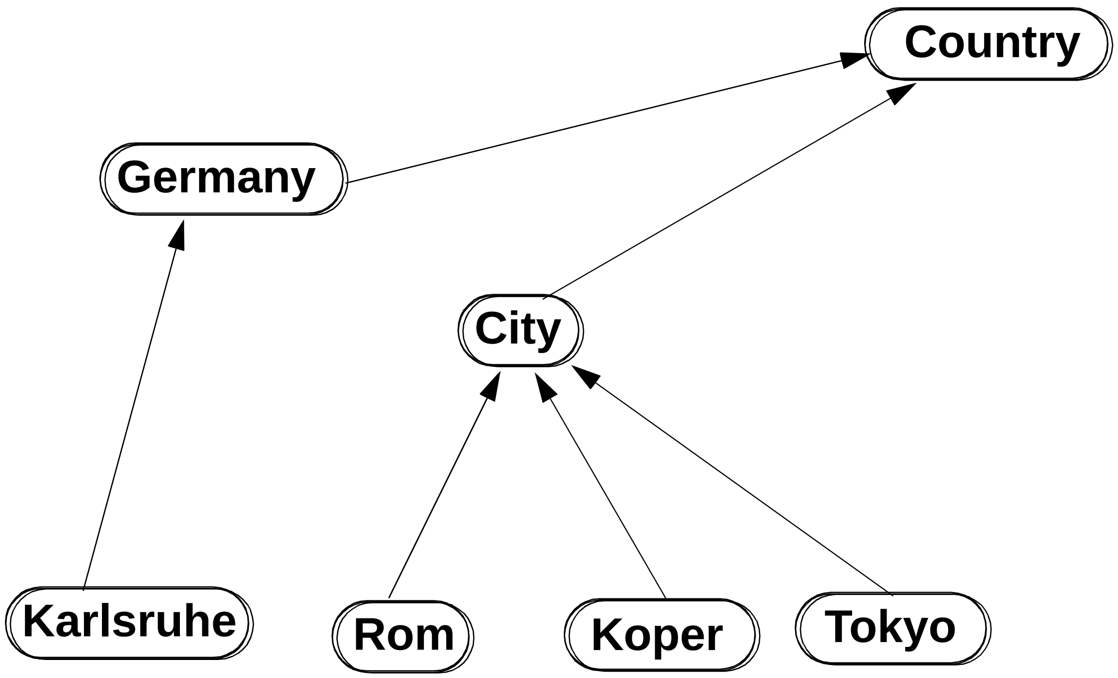


# Definition of Database Graph [MW89]

G=(N, E)

Directed, labeled graph with:

- N: set of nodes,, representing entities from the real world
- E: set of directed edges

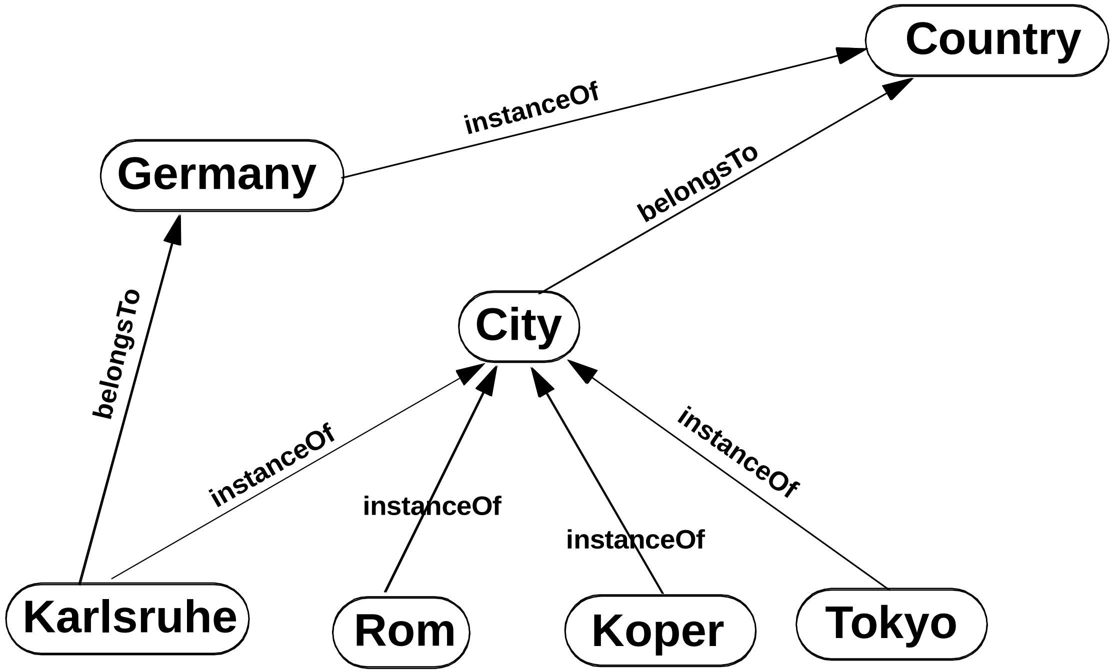


# Definition of a Database Graph for RQP

G=(N, E)

Directed, labeled graph with:

- N: set of nodes
- E: set of directed edges
- S: finite set of symbol for labeling of edges (vocabulary)



# Regular Path Queries (RPQ)

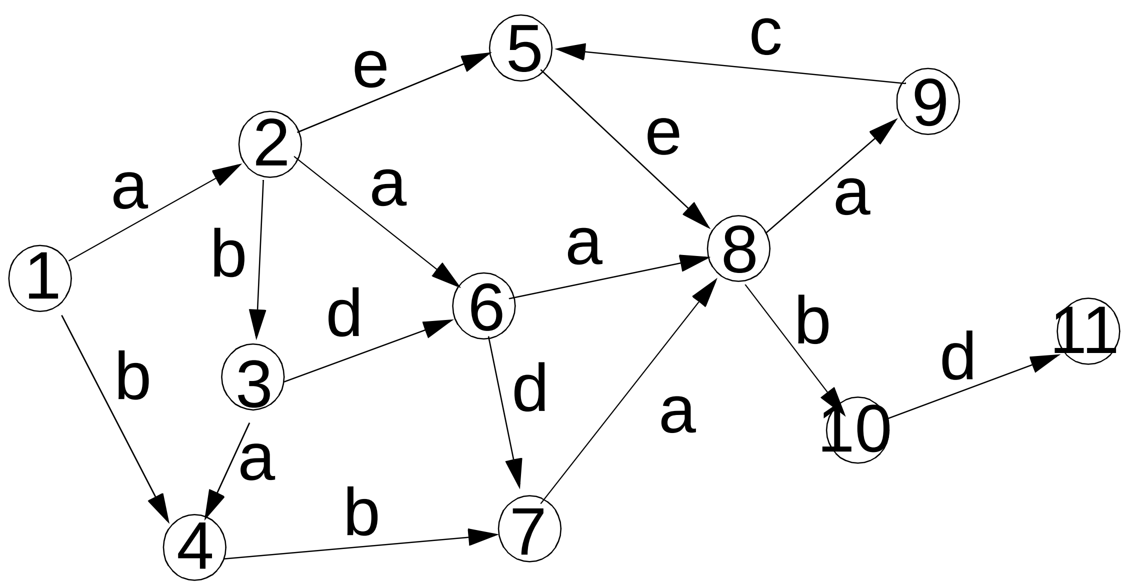
- RPQ have the form:
  RQP(x,y) := (x, R, y)
  where R is a regular expression over the vocabulary of edge labels

- Construction of regular expressions:
  R ::= s | R.R | R|R | R* | R? | (R)          // s element from S

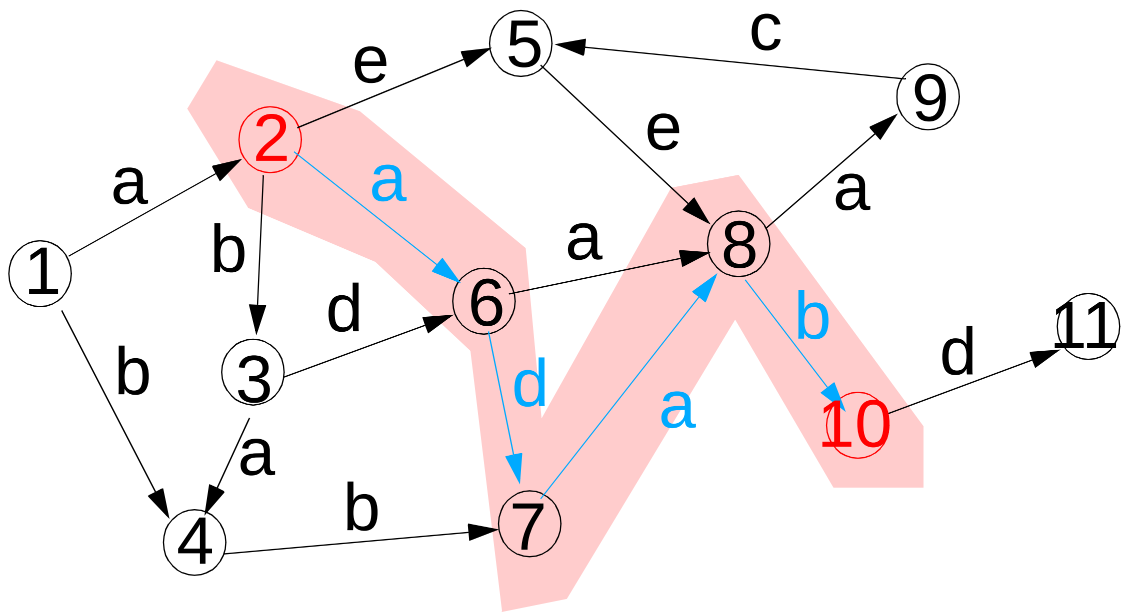
- Examples:
  - Ancestors:
    isChildOf+
  - Cousins
    isChildOf . isMarriedWith . isChildOf . hasChild . hasChild

# RPQ Example

$R = a+(d|b)ab$



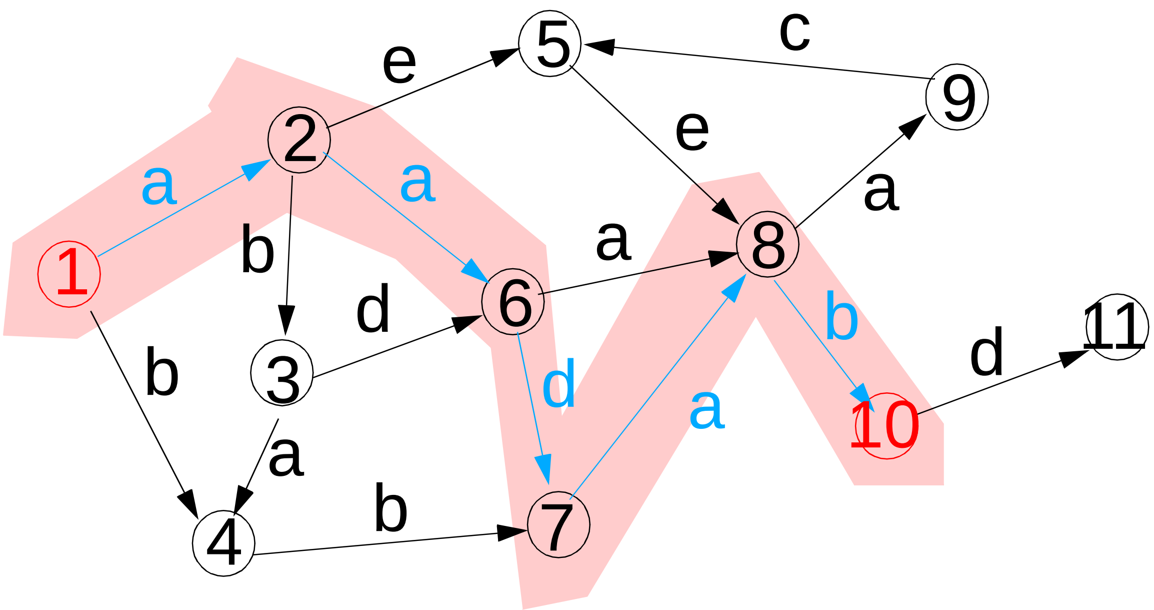
# RPQ Example




R = a+(d|b)ab

adab --> (2, 10)

# RPQ Example

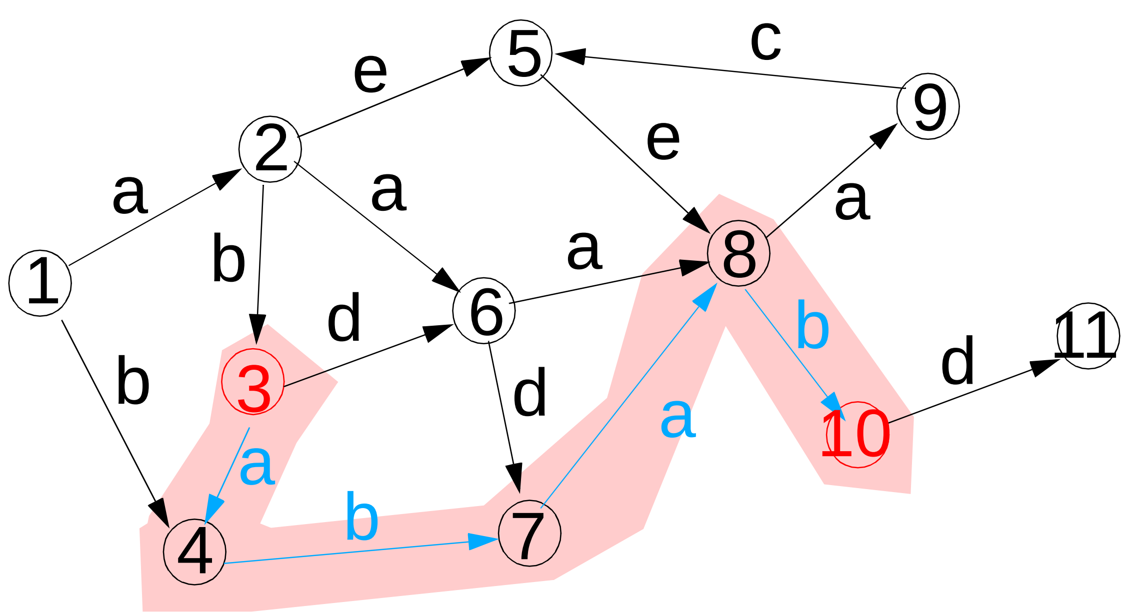



R = a+(d|b)ab

adab --> (2, 10)

aadab --> (1, 10)

# RPQ Example




R = a+(d|b)ab

adab --> (2, 10)

aadab --> (1, 10)

abab --> (3, 10)

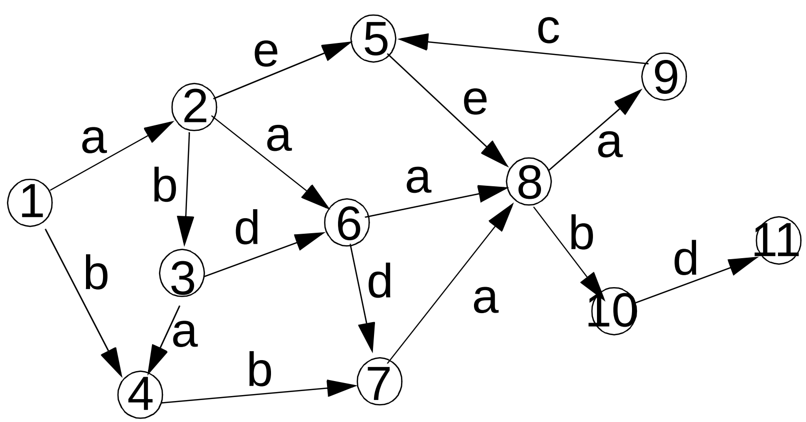
# Algorithms for Answering RPQ

- Mapping to finite automaton [Mendelzon, Wood, 1995]
  - Construct finite nondeterministic automata from query with start state $s_0$ und final state $s_f$
  - Consider G as NFA with start state x and final state y
  - Form product automaton
  - Determine if there is a path form ($s_0$, x) to ($s_f$, y)

- Search for rare labels and start BFS [Koschmieder, 2012]
  - Look for mandatory rare labels in the query (concering the graph)
  - Use the nodes from the rare edge labels as starting points for a two-way search between endpoints and startpoints of the rare edges

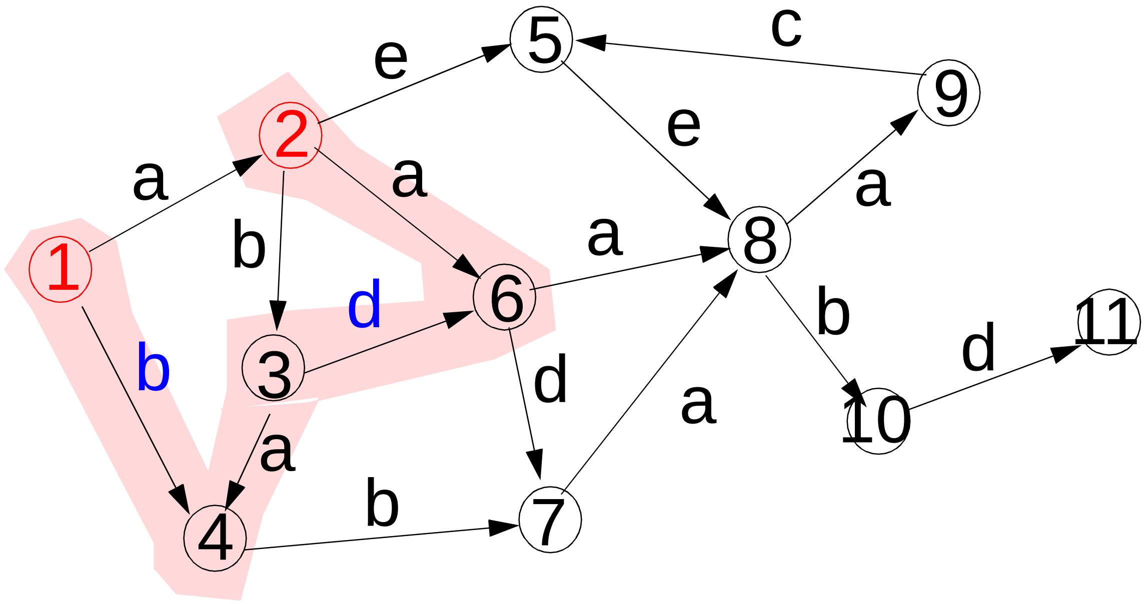
# Two-way Regular Path Queries (2RQP)

- 2RPQ extend the vocabulary of RPQ by the „inverse“ of each relationship symbol.
- Foreach symbol s in S: there exist a symbol $s^-$
- Example:




$R = a+d^-ab^-$

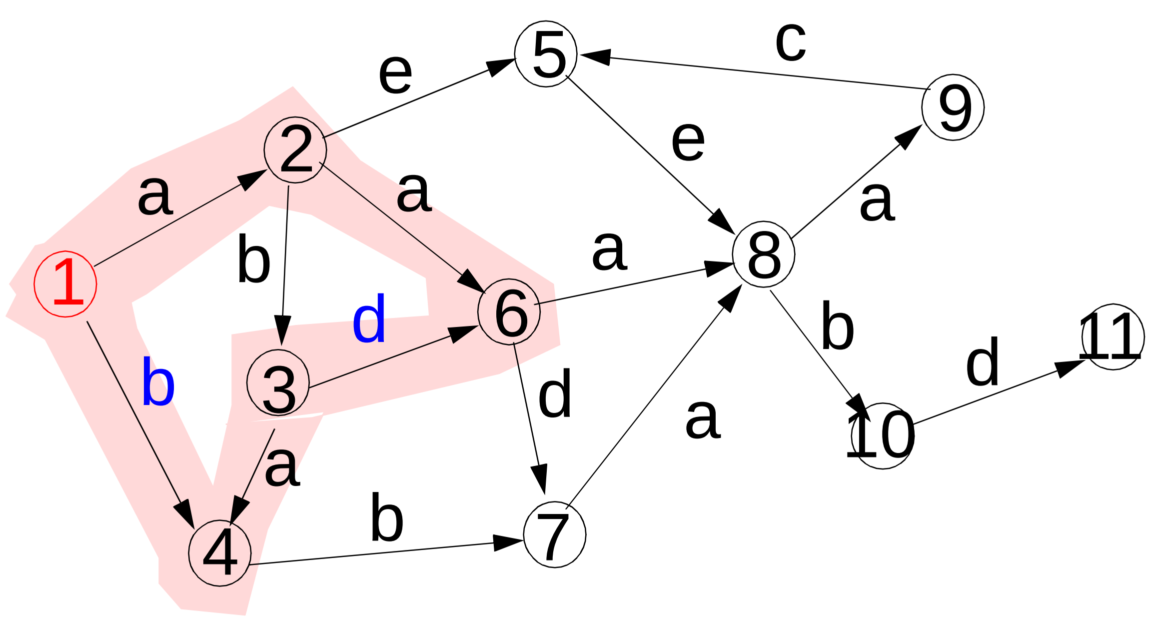
# 2RPQ Example




$R = a+d^{-}ab^{-}$

Results: (2,1)

# 2RPQ Example




$R = a+d^{-}ab^{-}$

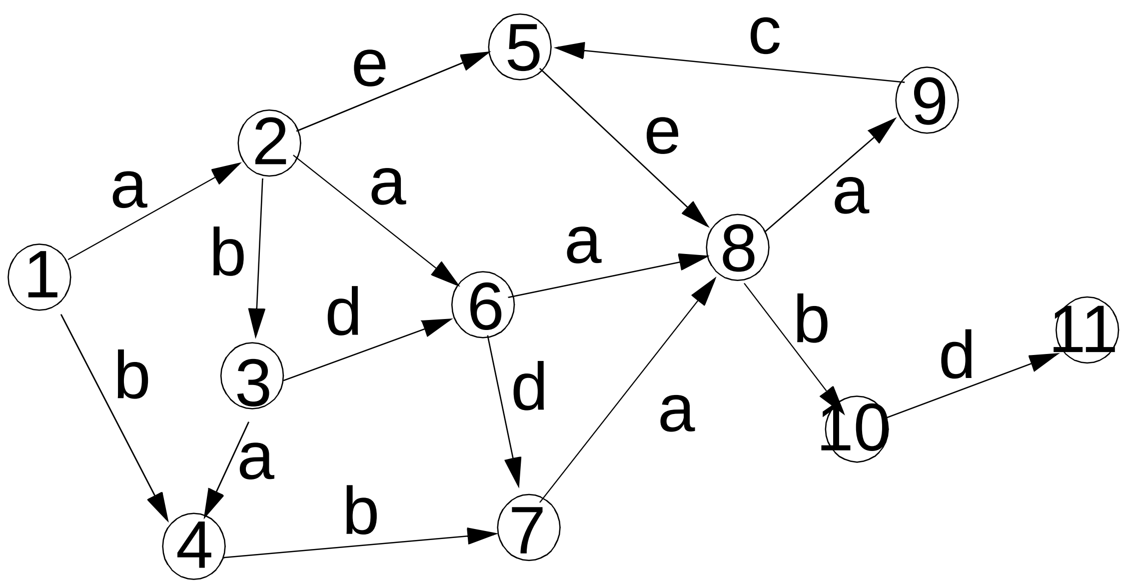
Results: (2,1)
(1,1)

# Conjunctive Regular Path Queries (CRPQ)

- $CRPQ(z_1, ..., z_n) = AND_{(1<=i<=m)} (x_i, R_i, y_i)$ // each $z_i$ is a $x_i$, $y_i$
- Examples:
  - Which couples are married by a pontifex?
    CRPQ(x,y,p) := (x, isMarriedWith, y) AND
    (x, isMarriedBy, p) AND
    (y, isMarriedBy, p) AND
    (p, isa, 'Pontifex')
  - Related at mostly over '5 edges' (navigating the family tree)
    CRPQ(x,y) := (x, isChildOf{5}, z) AND
    (y, isChildOf{5}, z)

# CRPQ Example

(x, a+, y)  AND  (x, e+, y)

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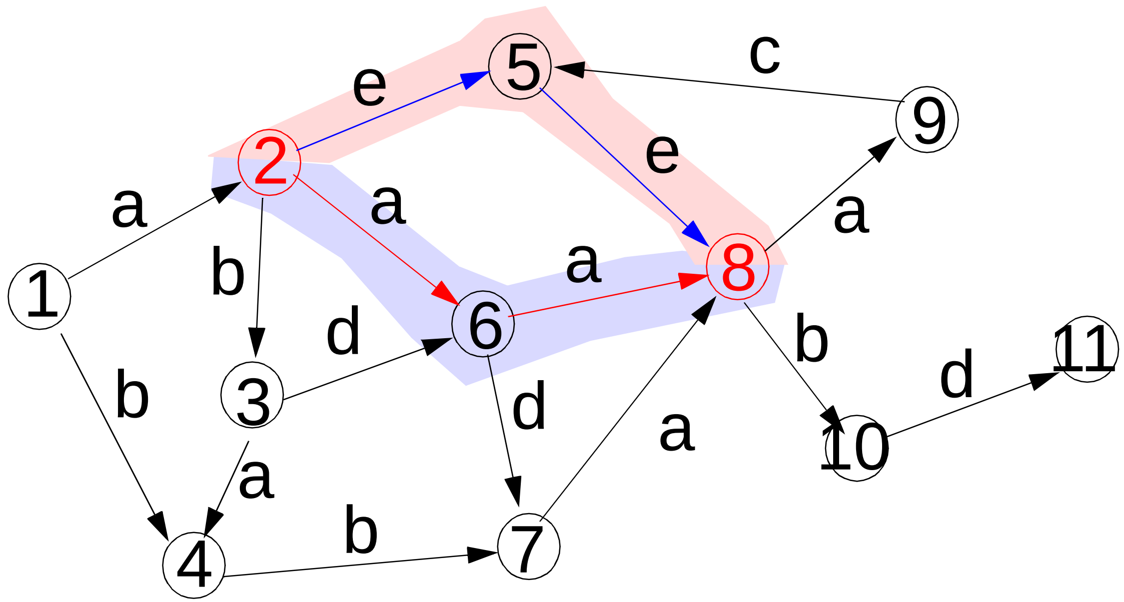
# CRPQ Example

(x, a+, y)  AND  (x, e+, y)




Result: (2, 8)

# Extended Conjunctive Regular Path Queries (ECRPQ)

- CRPQ extended by
  - allow free path variables in the query
  - checking relations on sets of paths
- Example 1: Return all paths between x and y, which have a concrete node e (id:123) in between:
  - ECRPQ $(p_1, p_2)$ = $(x, R_1, e)$ AND $(e, R_2, y)$ AND (e, hasID, 123)
- Example 2: Path pattern match - Find all node connected by paths of the form $a^n b^n c^n$:
  - ECRPQ(x,y) = $(x, pv_1, z_1), (z_1, pv_2, z_2), (z_2, pv_3, y)$,
    $a+(pv_1), b+(pv_2), c+(pv_3)$,
    $el(pv_1, pv_2), el(pv_2, pv_3)$

$pv_3$ has the pattern c+

„equal-length“-relation

# Aggregation (AggCRPQ)

- CRPQ + Aggregation functions, i.e. for calculationg the distance between nodes
- Examples:
  - How many biological children does the husband of Carolyn has?:

    AggCRPQ (x,count(y)) = (x, isMarriedWith, ’Carolin’), (x, isParentOf, y)

  - Shortest path between x and y (with intermediate node z)

    AggCRPQ (x, y, min(len($p_1$)+len($p_2$))) = (x, $p_1$, z), (z, $p_2$, y)

# Summary & Outlook

- RPQ and its extensions are partly/complete realized in a number of graph query languages
- Different extensions of RPQ provide additonal power of expressiveness
- In most implementations of graph query languages RPQ are combined with additional data query functionalities
- Complexity and Containment is actual research field

# Literature


- Marcelo Fiore. Lecture Notes on Regular Languages and Finite Automata, Cambridge University Computer Laboratory, 2010
- Mendelzon, Wood. Finding regular simple path in graph databases. SIAM J. Computing., 24(6), 1995
- Peter Wood, Query Languages for Graph Databases; Sigmod Records (Volumne 41, No 1), 2012
- Pablo Barceló, Gaelle Fontaine; On the Data Complexity of Consistent Query Answering over Graph Databases. ICDT 2015.
- Pablo Barceló. Querying Graph Databases. PODS 2013.
- Pablo Barceló, Leonid Libkin, Carlos Hurtado, Peter Wood. Expressive languages for Path Queries over Graph-Structured Data, Pods 2010
- SPARQL Property Paths: http://www.w3.org/TR/sparql11-property-paths/

# SPARQL 1.1 path language

| Syntax Form | Matches |
| --- | --- |
| `uri` | A URI or a prefixed name. A path of length one. |
| `^elt` | Inverse path (object to subject). |
| `(elt)` | A group path `elt`, brackets control precedence. |
| `elt1 / elt2` | A sequence path of `elt1`, followed by `elt2` |
| `elt1 ^ elt2` | Shorthand for `elt1 / ^elt2`, that is `elt1` followed by the inverse of `elt2`. |
| `elt1 \| elt2` | A alternative path of `elt1`, or `elt2` (all possibilities are tried). |
| `elt*` | A path of zero or more occurrences of `elt`. |
| `elt+` | A path of one or more occurrences of `elt`. |
| `elt?` | A path of zero or one `elt`. |
| `elt{n,m}` | A path between n and m occurrences of `elt`. |
| `elt{n}` | Exactly `n` occurrences of `elt`. A fixed length path. |
| `elt{n,}` | `n` or more occurrences of `elt`. |
| `elt{,n}` | Between 0 and `n` occurrences of `elt`. |