Querying Graphs

TIW2
Interoperability 2021-2022

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Lyon 1 University

8 November 2021

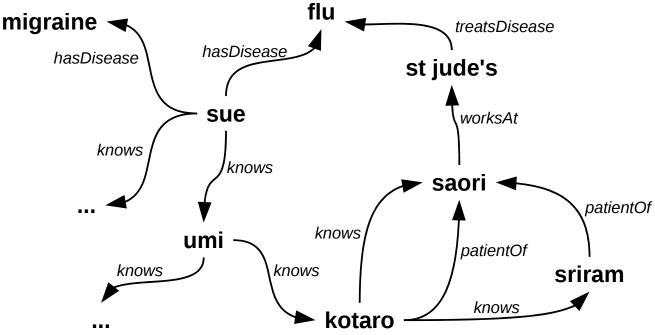
Agenda

1. Querying over graph data
   - query languages for graphs
   - openCypher

Graph queries

A small graph

Let's consider a graph with edge labels: knows, worksAt, patientOf, hasDisease, and treatsDisease.



Query language capabilities

Graph query languages typically feature one or both of the following basic capabilities

- subgraph matching
- finding nodes connected by paths

and possibly additional advanced features such as approximate matching, aggregation, and comparing paths.

Subgraph matching

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- A query is then a finite set of rules (of the same arity).

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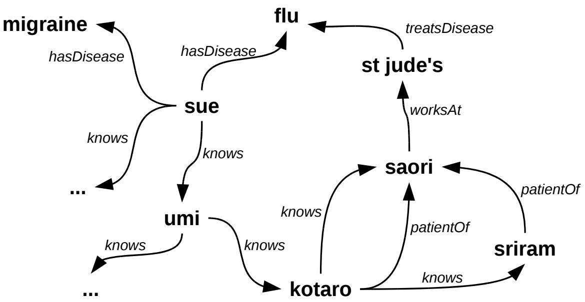
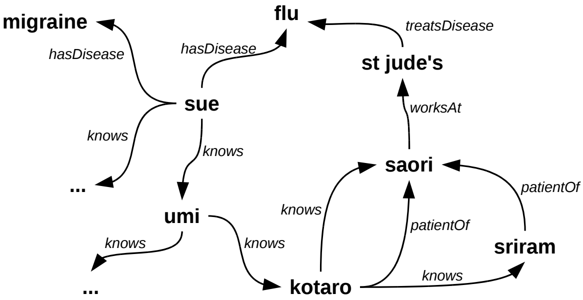


Example: People and the doctors of their friends

$$Q \quad = \quad (?p, \mathit{friendDoctor}, ?d) \leftarrow (?p, \mathit{knows}, ?f), (?f, \mathit{patientOf}, ?d)$$

Subgraph matching



Example: People who know someone who knows a doctor.

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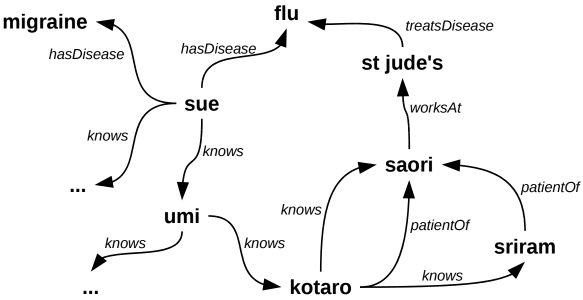

Example: Patients and their friends

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Subgraph matching

The semantics $Q(G)$ of evaluating query a Q on graph G is based on embeddings of the rule *body*'s of Q in G:

$$Q(G) \;=\; \bigcup_{head \leftarrow body \in Q} \{h(head) \mid h(body) \subseteq G\}$$

where h is a homomorphism, i.e., a function with domain $N \cup \mathit{Variables}$ and range N that is the identity on N.

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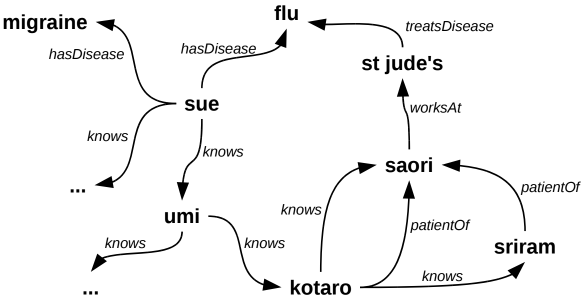
In the property graph model, a distinction is also sometimes made between node-isomorphism (i.e., our notion here) and edge-isomorphism (see Angles et al. 2016).

Subgraph matching



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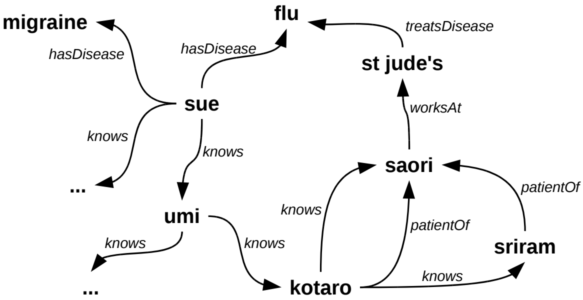
$$\begin{aligned} Q &= (?p, \mathit{friendDoctor}, ?d) \leftarrow (?p, \mathit{knows}, ?f), (?f, \mathit{patientOf}, ?d) \\ Q(G) &= \{(\mathit{umi}, \mathit{friendDoctor}, \mathit{saori}), (\mathit{kotaro}, \mathit{friendDoctor}, \mathit{saori}), \ldots\} \end{aligned}$$

Subgraph matching



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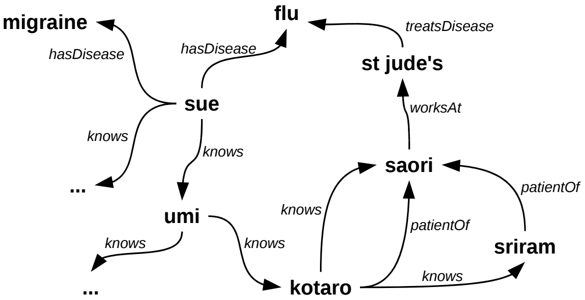
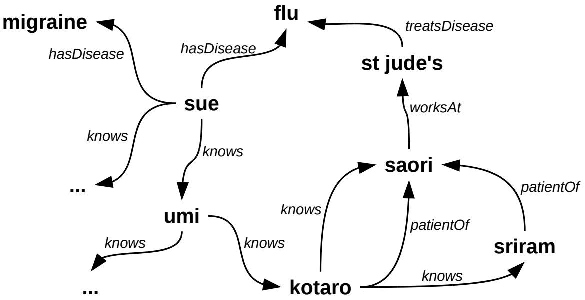


Example: Patients and their friends (homomorphisms)

$$Q \;=\; \langle ?p, ?f \rangle \leftarrow (?p, \mathit{knows}, ?f), (?p, \mathit{patientOf}, ?d)$$
$$Q(G) \;=\; \{\langle \mathit{kotaro}, \mathit{saori} \rangle, \langle \mathit{kotaro}, \mathit{sriram} \rangle, \ldots\}$$

Subgraph matching



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$$Q(G) = \{\cancel{\langle kotaro, saori \rangle}, \langle kotaro, sriram \rangle, \ldots\}$$

Subgraph matching

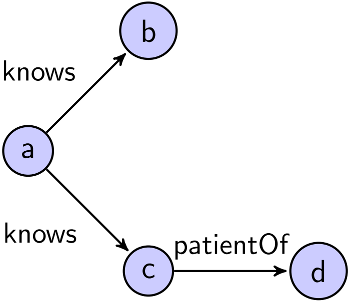
Evaluation of subgraph matching queries is NP-complete in combined complexity (i.e., in the size of Q and G) and logspace in data complexity (i.e., for a fixed query, in the size of G). This follows from the intractability of the subgraph homomorphism problem.

Subgraph matching: simulations

That is, instead of homomorphisms embedding Q in G, we look for a binary relation S between the nodes and variables of (a given) body of Q and the nodes of G such that

1. for each constant n in the body of Q, n is a node of G and $(n, n) \in S$;
2. for each variable v in the body of Q there exists a node n of G such that $(v, n) \in S$; and,
3. for each $(x, n) \in S$ and each edge pattern $(x, \ell, x') \in Q$, there is an edge $n \xrightarrow{\ell} n' \in G$ such that $(x', n') \in S$.

Subgraph matching: simulations



Example. The following boolean query is simulated in the graph above, but evaluates to "false" under standard query semantics

$$\langle\rangle \leftarrow (?x, \mathit{knows}, ?y), (?x, \mathit{knows}, ?z), (?z, \mathit{patientOf}, ?y)$$

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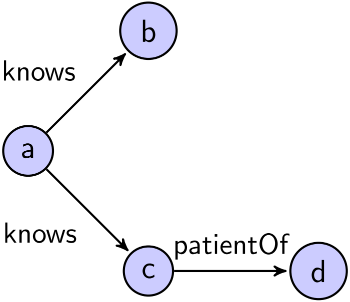

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Here a simulation is $S = \{(?x, a), (?z, c), (?y, b), (?y, d)\}$

Path navigation: reachability

The simplest form of path matching is reachability, namely, computing

$$G^* \;=\; \{(s,t) \mid \text{there is a path in } G \text{ from } s \text{ to } t\}$$

or, given $x, y \in N$, determining whether or not $(x, y) \in G^*$.

Extensively studied in the DB community since the 80's (see the survey of Yu et al.).

Path navigation: label-constrained reachability

Generalizing reachability, we have the label-constrained reachability queries: given $x, y \in N$ and a set of labels $L \subseteq \mathcal{L}$, determining whether or not (x, y) is in the set

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Note that this is equivalent to the following problem

- determine whether or not there is a path in G from x to y such that the concatenation of the edge labels along the path forms a string in the language denoted by the regular expression $(\ell_1 \cup \cdots \cup \ell_n)^*$

where $L = \{\ell_1, \ldots, \ell_n\}$, $\cup$ is disjunction, and $*$ is the Kleene star ...

Path navigation: regular path queries

Regular path queries return all paths (i.e., pairs of nodes) connected by some regular expression over edge labels

- queries of the form

$$\langle ?x, ?y \rangle \leftarrow (?x, r, ?y)$$

  where r is a regular expression over $\mathcal{L}$
- semantics is the set of all node pairs (s, t) such that there is a path from s to t in G and the sequence of edge labels along the path forms a word in the language of r.
- query evaluation: $\mathcal{O}(|G||r|)$ time complexity

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For example, the "knowing" social network is

$$\langle ?x, ?y \rangle \leftarrow (?x, \text{knows}^+, ?y)$$

and the general social network is

$$\langle ?x, ?y \rangle \leftarrow (?x, (\text{knows} \cup \text{patientOf})^+, ?y)$$

Path navigation: regular path queries

Example. Co-authorship network

$$(?s, ?t) \;\leftarrow\; (?s, (authored/authored^{-1})^*, ?t)$$

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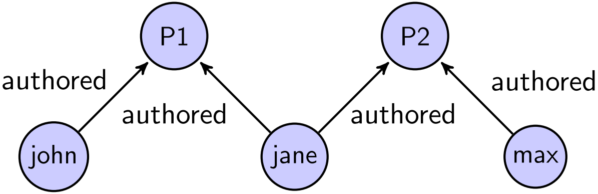

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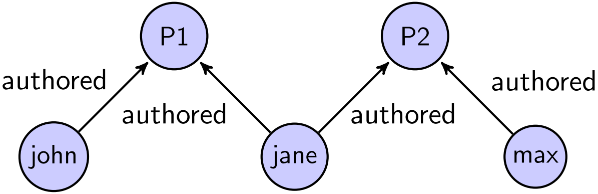

this query evaluates to

$$\{(john, john), (john, jane), (john, max), (jane, jane), (jane, john), (jane, max), (max, max), (max, jane), (max, john)\}.$$

Unions of conjunctions of RPQs

It is natural to combine the functionalities of subgraph matching and RPQs, in the shape of unions of conjunctions of RPQs (UCRPQs):

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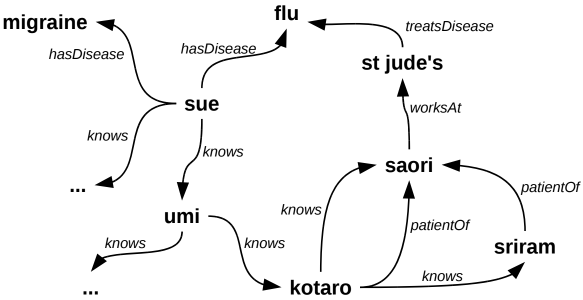

Example: Doctors and the patients in both their social and treatment networks

$$Q \quad = \quad \langle ?d, ?p \rangle \leftarrow (?d, \mathit{knows}^*, ?p), (?p, \mathit{patientOf}^*, ?d)$$

Regular queries

Note that all recursion in UCRPQs is captured in the Kleene star operation, R^*.

[1] http://drops.dagstuhl.de/opus/volltexte/2015/4984/pdf/11.pdf

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This leads us to the Regular Queries of Reutter et al., properly generalizing UCRPQs while maintaining all of their nice algorithmic properties

- equivalence is decidable; query evaluation is tractable.[1]

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Regular queries

Regular Queries. Non-recursive Datalog programs, where:

- All rules, except perhaps the output rule, are binary.
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For our co-authorship example, we have the following equivalent regular query:

$$\begin{aligned} \mathit{coAuthored}(S,T) &\leftarrow \mathit{authored}(S,X), \mathit{authored}(T,X) \\ \mathit{answer}(S,T) &\leftarrow \mathit{coAuthored}^*(S,T). \end{aligned}$$

Practical syntaxes

openCypher

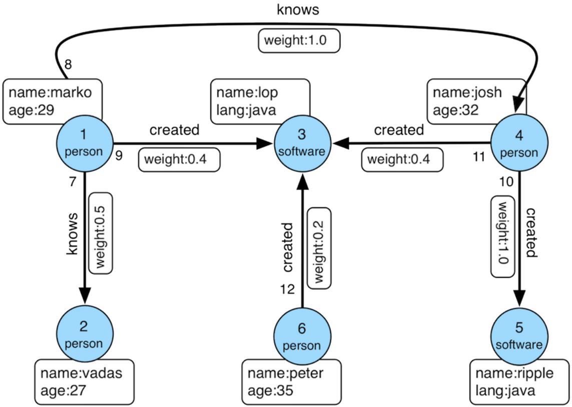
openCypher.

- Declarative graph query language of the popular open-source Neo4j graph database.

  `http://neo4j.com/developer/cypher/`

- Property graph model (cf. Angles et al. 2016)
  - directed node- and edge-labeled graph
  - nodes and edges have ID
  - nodes and edges carry sets of property-value pairs

openCypher: property graphs



(image credit: `http://tinkerpop.apache.org`)

openCypher: subgraph matching

The basic building block of queries is subgraph matching, via a MATCH clause, with isomorphic matching.

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MATCH (n:Person)-[:Created]->(m),
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Can be further combined using UNION, applying aggregation functions, string functions, etc.

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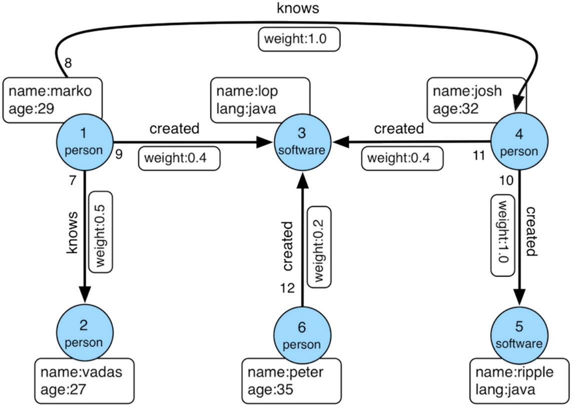


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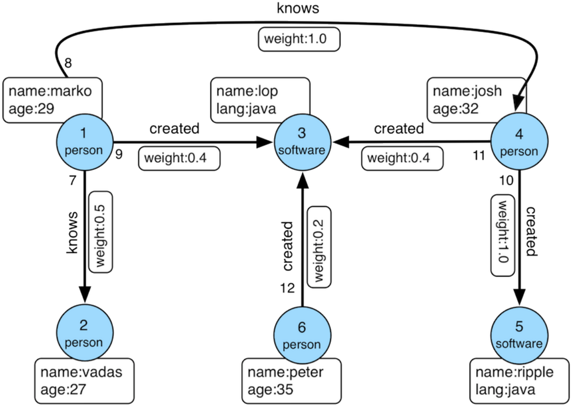


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Result is $\{\langle 4 \rangle\}$.

openCypher: path queries

Cypher also provides support for RPQs in the MATCH clause.

```
MATCH (n:Person)-[:knows*]->(p)
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openCypher: path queries

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```
MATCH (n:Person)-[:knows*]->(p)
WHERE n.name = "marko"
RETURN p
```

and with bounded recursion

```
MATCH (n:Person)-[:knows*2..7]->(p)
WHERE n.name = "marko"
RETURN p
```

Can also apply * to a disjunction of symbols

Popular imperative syntaxes

Gremlin.

- Part of the Apache TinkerPop graph computing framework. `http://tinkerpop.apache.org`
- Property graph model
- Example.

```
gremlin> g.V().has('name','kotaro').
               out('knows').in('patientOf').
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==>kotaro
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See also the recent Sparksee API for a similar approach to graph analytics

http://sparsity-technologies.com

References

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Recap

1. Querying over graph data
   - query languages for graphs
   - openCypher
   - Gremlin and Sparksee