Center for Semantic Web Research

www.ciws.cl, @ciwschile
Three institutions

PUC, Chile
- Marcelo Arenas (Boss)
  - SW, data exchange, semistructured data
- Juan Reutter
  - SW, graph DBs, DLs
- Cristian Riveros
  - data exchange, semistr. data
- Jorge Baier
  - planning, search
- Carlos Buil
  - SW

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- Renzo Angles (SW)

Univ. of Chile
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  - graph DBs, DB theory
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  - SW, graph DBs
- Jorge Pérez
  - SW, data exchange
- Aidan Hogan
  - SW, semistr. data
- Bárbara Poblete
  - web mining, SNA
- Benjamín Bustos
  - multimedia
Alberto Mendelzon Workshop (AMW)
AMW 2016

- Panama City, 6-10 June, 2016
- PC Chairs:
  
  Altigran Soares da Silva (UFAM), Reinhard Pichler (TU Wien)
- Invited speakers:
  
  - Diego Calvanese (Data-driven verification)
  - Juliana Freire (Urban data)
  - Lise Getoor (Relational statistical learning)
  - Raghu Ramakrishnan (Big data)
- Long & short submissions (due on Feb. 29th, 2016)
- AMW School (4 tutorials), 4-5 June, 2016
- Very nice environment
Query Languages for Graph DBs:
Bridging the Gap Between Theory and Practice

Pablo Barceló
DCC, Universidad de Chile
Center for Semantic Web Research (www.ciws.cl)
BACKGROUND AND OBJECTIVES
Graph databases

Trendy applications:

- Social network analysis
- Semantic web
- Scientific databases
- Software bug localization
- Geo-routing
Graph databases

Trendy applications:

- Social network analysis
- Semantic web
- Scientific databases
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More in general:

- Wherever connections are as important as data
What is a graph database?

A data management system that exposes a graph data model.¹

¹*Graph databases.* Robinson, Webber, & Eifrem. O'Reilly, 2013.
What is a graph database?

A data management system that exposes a graph data model.\textsuperscript{1}

Several existing graph DB engines and query languages:

- DEX/Sparksee - basic algebra
- IBM System G - Gremlin
- Neo4J - Cypher
- Oracle PGX - PGQL
- RDF stores (Virtuoso, AllegroGraph, Oracle, IBM) - SPARQL

\textsuperscript{1}Graph databases. Robinson, Webber, & Eifrem. O’Reilly, 2013.
What graph databases are good for?

- Flexible modelling of interconnected data
- Agile evolution of the data model
- Scalable evaluation of join-intensive queries
My personal story

- Since 2009: Working on theory of query languages for graph DBs
- Since 2015: Working group of LDBC for the design of such language
My personal story

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Conclusion:
- Theory and practice are more connected than expected
Objectives

- Identify topics of common interest for theoreticians and developers
- Formalize relevant concepts (syntax, semantics, terminology, etc)
- Understand tradeoff expressiveness/efficiency
THE DATA MODEL: PROPERTY GRAPHS
The data model is important as it must be:

- Flexible enough to accommodate scenarios of practical interest
- Simple enough to allow for a clean presentation
- Expressive enough for theoretical issues to appear in full force
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This is accomplished by the model of property graphs
A property graph
What is a property graph then?

- It is a graph
- It is directed
- It is labeled in nodes and edges
- Nodes and edges can be attributed
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GRAPH PATTERNS
Graph patterns are:

The basic unit for querying property graphs
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The basic unit for querying property graphs

Definition of graph pattern:

- A directed graph
- Nodes are given by variables $x, y, z, \ldots$
- Edges are given by variables $X, Y, Z, \ldots$
- Nodes and edges satisfy label and attribute constraints (selection)
  - E.g., $l(x) = \text{Author}$, $l(Y) = \text{authored by}$ & $Y@\text{corresponding} = \text{YES}$
- Some of the variables are selected (projection)
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Example of a graph pattern

Find pairs of authors who coauthored a paper in PODS83:
More examples

Get the common friends of Peter, John and Mary:
More examples

Get the common friends of Peter, John and Mary:

Find friends of John who are (1) mutual friends, and (2) have lovers that are colleagues
Evaluation of graph patterns

1. Find all *matchings* of the pattern over the property graph
2. Project over the variables in the output
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Evaluation of graph patterns

1. Find all *matchings* of the pattern over the property graph
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An example of evaluation

The property graph
An example of evaluation

The graph pattern
An example of evaluation
A matching
An example of evaluation
Its projection
An example of evaluation
Another matching
An example of evaluation

Its projection
But what is a matching?
But what is a matching?

A mapping from:
- nodes of the pattern to nodes of the graph, and
- edges of the pattern to edges of the graph

which preserves the structure of the pattern in the graph
Different notions of matching

Homomorphism: No restriction on the mapping

- ≠ nodes in the pattern can map to the same node in the graph
Different notions of matching

Homomorphism: No restriction on the mapping
  - nodes in the pattern can map to the same node in the graph

Mostly studied in database theory (PODS)
Different notions of matching

**Isomorphism:** Mapping is injective

- $\neq$ elements in the pattern map to $\neq$ elements in the graph
Different notions of matching

**Isomorphism:** Mapping is injective

- $\neq$ elements in the pattern map to $\neq$ elements in the graph

Mostly studied in database systems (SIGMOD)
Different notions of matching

**Edge-injective**: Self-describing

- ≠ edges in the pattern map to ≠ edges in the graph
Different notions of matching

**Edge-injective:** Self-describing

- \( \neq \) edges in the pattern map to \( \neq \) edges in the graph

Implemented in some graph DB engines (Neo4J)
Is there a matching?
Is there a matching?

An NP-complete problem
Is there a matching?

An NP-complete problem

How to address this problem?
Solution 1: Restriction on graph patterns

In many applications, graph patterns are *tame*:

- Homomorphism/isomorphism can be solved efficiently for them
Solution 1: Restriction on graph patterns

In many applications, graph patterns are *tame*:

- Homomorphism/isomorphism can be solved efficiently for them

**Tame**: The underlying graph is almost acyclic

- Bounded *treewidth* (database/graph theory)
Solution 2: Heuristics for real-world datasets

Structural optimization techniques for reducing search space:
  - Join ordering, pruning, indexes (database systems)
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Structural optimization techniques for reducing search space:

- Join ordering, pruning, indexes (database systems)

Real databases have structure that can be exploited
Solution 3: Inexact evaluation

Use weaker forms of matching that can be evaluated efficiently:

- Bisimulations, approximations (database theory/systems)
Solution 3: Inexact evaluation

Use weaker forms of matching that can be evaluated efficiently:
- Bisimulations, approximations (database theory/systems)

Compromise the quality of the answer in favor of efficiency
Solution 4: Use different notions of complexity

Graphs and patterns are different beasts:
- Graphs are BIG, patterns are small
Solution 4: Use different notions of complexity

Graphs and patterns are different beasts:
- Graphs are BIG, patterns are small

Assume pattern is fixed (data complexity/database theory):
- Matching can be solved very efficiently
Solution modifiers on graph patterns

Relational operations:
- Union
- Difference
- Cartesian product
Solution modifiers on graph patterns

Relational operations:
  - Union
  - Difference
  - Cartesian product

The language becomes relational complete
OPTIONAL: An important solution modifier

Allows to match parts of the data only if available
- Important in the context of semistructured data
- Developed by the RDF community
- Corresponds to *left-outer join* in relational algebra
An example with OPTIONAL

The property graph

Paper
name: AKV85
year: 1985

Conference
name: STOC85

text: “This paper...”

Paper
name: Saf85
year: 1985

published in
published in

evaluated in
An example with OPTIONAL

The property graph

The pattern with optional

\[(x, \text{published\_in}, y) \text{ OPTIONAL } (y, \text{evaluated\_in}, z)\]
An example with OPTIONAL

A matching

The pattern with optional

\((x, \text{published\_in}, y)\) OPTIONAL \((x, \text{evaluated\_in}, z)\)
An example with OPTIONAL

Another matching

The pattern with optional

$$(x, \text{published\_in}, y) \text{ OPTIONAL } (x, \text{evaluated\_in}, z)$$
Conclusion

- Graph patterns are a versatile and simple language for querying PGs
- Graph pattern evaluation comes in different flavors
- This problem is challenging (theory/practice)
- Different operators can be added in order to increase expressiveness
NAVIGATION
Graphs are there to be navigated
Recall our property graph?
Graphs are there to be navigated

Find pairs of authors linked by a coauthorship sequence
Do practical query languages navigate?

Very little:

- Check if there is a directed path between two nodes (DFS)
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The previous query cannot be expressed (save for a few exceptions)
Do practical query languages navigate?

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No support for regular path queries (database theory, RDF, DL)

- Is there a directed path whose label satisfies a regex?
Are RPQs harder to evaluate?
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Not really (in theory):
- Convert the regex into an automata
- Take the cross product of the property graph and the automata
- Check if there is a path from an initial to a final state (DFS)
Are RPQs harder to evaluate?

Not really (in theory):
- Convert the regex into an automata
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- Check if there is a path from an initial to a final state (DFS)

Cost is linear in the size of the data and the regex
But, what is the semantics?

Is there a path or a simple path?

- Database theory concentrates on the former (why?)
- Graph DB engines implement the latter (why?)
But, what is the semantics?

Is there a path or a *simple* path?

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Our algorithm evaluates RPQs under arbitrary path semantics
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Is there a path or a simple path?

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Our algorithm evaluates RPQs under arbitrary path semantics

Is it possible to use it under a simple path semantics?
RPQs under simple paths

Is there a simple path whose label satisfies a regex?

- This problem is NP-complete even if the regex is fixed!
- High complexity only dependent on the size of the data
RPQs under simple paths

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**Example:** Consider the RPQ \((aa)^*\)

1. It asks whether there is a simple path of even length from \(x\) to \(y\)
2. This problem is NP-complete
Adding RPQs to graph patterns

Give rise to the class of conjunctive RPQs
- Has received considerable attention in theory
- (Essentially) unexplored from a practical point of view
- Challenging because of matching and RPQ evaluation
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Give rise to the class of **conjunctive RPQs**
- Has received considerable attention in theory
- (Essentially) unexplored from a practical point of view
- Challenging because of matching and RPQ evaluation
Are paths the only form of navigation?
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No! We can allow stronger forms of recursion (DB theory, DL, MC):

- Navigate with branching
  (nested regexs, similar evaluation to RPQs)
- Allow transitive closure on top of conjunctive RPQs
  (regular queries, harder to evaluate)
- Allow arbitrary recursion
  (datalog, very hard to evaluate, non-parallelizable)
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Conclusions (really, questions)

- Are RPQs useful in practice?
- Can they be implemented?
- Under which semantics?
- What about conjunctive RPQs?
- Or even stronger forms of recursion?
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RETURNING PATHS
Paths in the output

Query languages such as Cypher & PGQL allow:

- Return one path
- Return one shortest path (DFS)
- Return all paths
- Return all shortest paths
Paths in the output

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But, what does it mean to return all paths?

... there can be infinitely many
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But, what does it mean to return all paths?

... there can be infinitely many

Systems return simple paths

... but there can be exponentially many
Even more interesting for RPQs

- Return a shortest path whose label satisfies a regex
- And all shortest paths
- Return all paths whose label satisfies a regex
- And all paths
A solution from database theory

Instead of returning all paths ... return a *compact* representation of them
A solution from database theory

Instead of returning all paths ...

return a compact representation of them

Compact representation: A property graph with all paths in the output
- Can be constructed efficiently (in data) for arbitrary paths
- Impossible for simple paths
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Conclusions

- Returning paths is difficult under all interpretations
- “All paths” can be compactly represented, but simple paths cannot
- The right semantics still needs to be settled
UNGROUPING
Paths can appear in the output
Paths can appear in the output

We can *ungroup* them

- List the nodes that appear in them
Paths can appear in the output

We can *ungroup* them
  - List the nodes that appear in them

We can check if a path visits all nodes
  - Travelling salesman problem!
Paths can appear in the output

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Paths can appear in the output

We can \textit{ungroup} them
  
  \begin{itemize}
    \item List the nodes that appear in them
  \end{itemize}

We can check if a path visits all nodes
  
  \begin{itemize}
    \item Travelling salesman problem!
  \end{itemize}

Interaction with other operators expresses even more complex properties
A query language for paths

- Variables for paths and nodes
- Can check if a node belongs to a path
- Can check if the label of a path satisfies a regex
- Closure under quantification over nodes and paths
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Complexity of evaluation is astronomical (in data)
- (Severely) restricting the language leads to efficiency
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Question

What ungropuing can do and should do?
Final thoughts

- Exciting times for studying graph DBs (theory/practice)
- Lots of fine tuning needed
- Some issues still unexplored:
  - Comparing paths
  - Ranking of answers
  - Constraints
MANY THANKS
Bibliography

Surveys:


Regular path queries:


Conjunctive regular path queries:

Bibliography

Queries with more expressive recursion:


Queries that compare nodes:


Queries with paths as first-class citizens and negation: