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PGX.ISO: Parallel and Efficient In-Memory Engine for Subgraph Isomorphism

Raghavan Raman , PhD
Oskar van Rest
Sungpack Hong, PhD
Zhe Wu, PhD
Hassan Chafi*, PhD
Jay Banerjee, PhD

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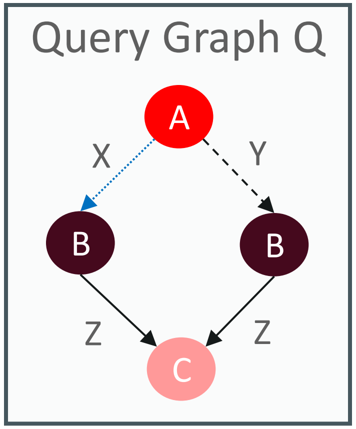
The Subgraph Isomorphism Problem

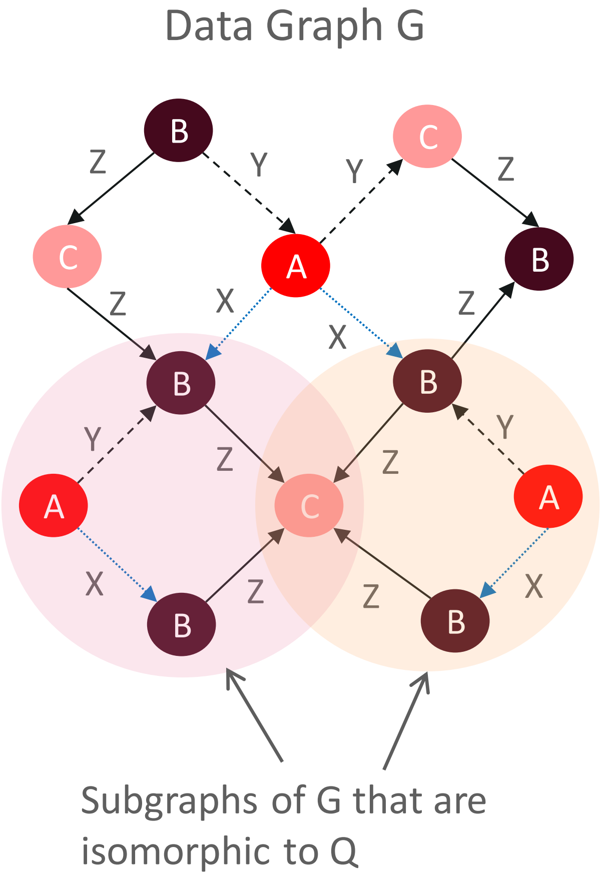
Q: Query Graph
G: Data Graph
A, B, C – Node Properties
X, Y, Z – Edge Properties

Problem: Find all subgraphs of G that are isomorphic to Q

Matching Criteria:

1. Topology of the graphs and
2. Properties on nodes and edges





Existing Solutions

- Graph Databases
  - RDF data Model
    - Oracle, Virtuoso, …
    - SPARQL: standard query language
  - Property Graph (PG) data model
    - Neo4J, …
    - No standard query language yet

➔ Disk-based solutions

- [pro] Process very large graphs
- [con] Disk latency becomes performance bottleneck

- *In-Memory* Solutions
  - Mostly from academia
    - VF2, QuickSI, TurboISO, etc…
  - Mostly sequential algorithms
  - Common approach:

backtracking + filtering ➔ prune partial solutions

[Issues and Lessons]

- Parallelizing backtracking algorithm s challenging – esp. load balancing
- Poor spatial locality from depth-first approaches
- Matching Order is important
- Need efficient partial solutions handling

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Our Approach (1) : PGX.ISO

- Parallel, In-memory engine for subgraph isomorphism
  - Use efficient data structure for graph and partial solutions
  - Considers load balancing and workload distribution
- Breadth-first search
  - Fixed order of query nodes for matching
  - Better for parallelization and more cache friendly
- Other optimizations
  - Different matching strategies for different graph patterns
  - Edge-first matching to improve performance

→ Visit our poster for details

Our Approach (2) : GMQL

- GMQL: Graph Matching Query Language
  - A Query Language for *Property Graph* Data Model
  - First-class constructs for nodes, edges and properties
  - Compiles query into PGX.ISO
- Native SPARQL support
  - Automatic conversion: SPARQL → GMQL
- IDE and Visualization
  - Pluggable to Eclipse
  - Visualize query (and result)
  - Built from Spoofax language bench (TU DELFT)

→ Visit our poster for details

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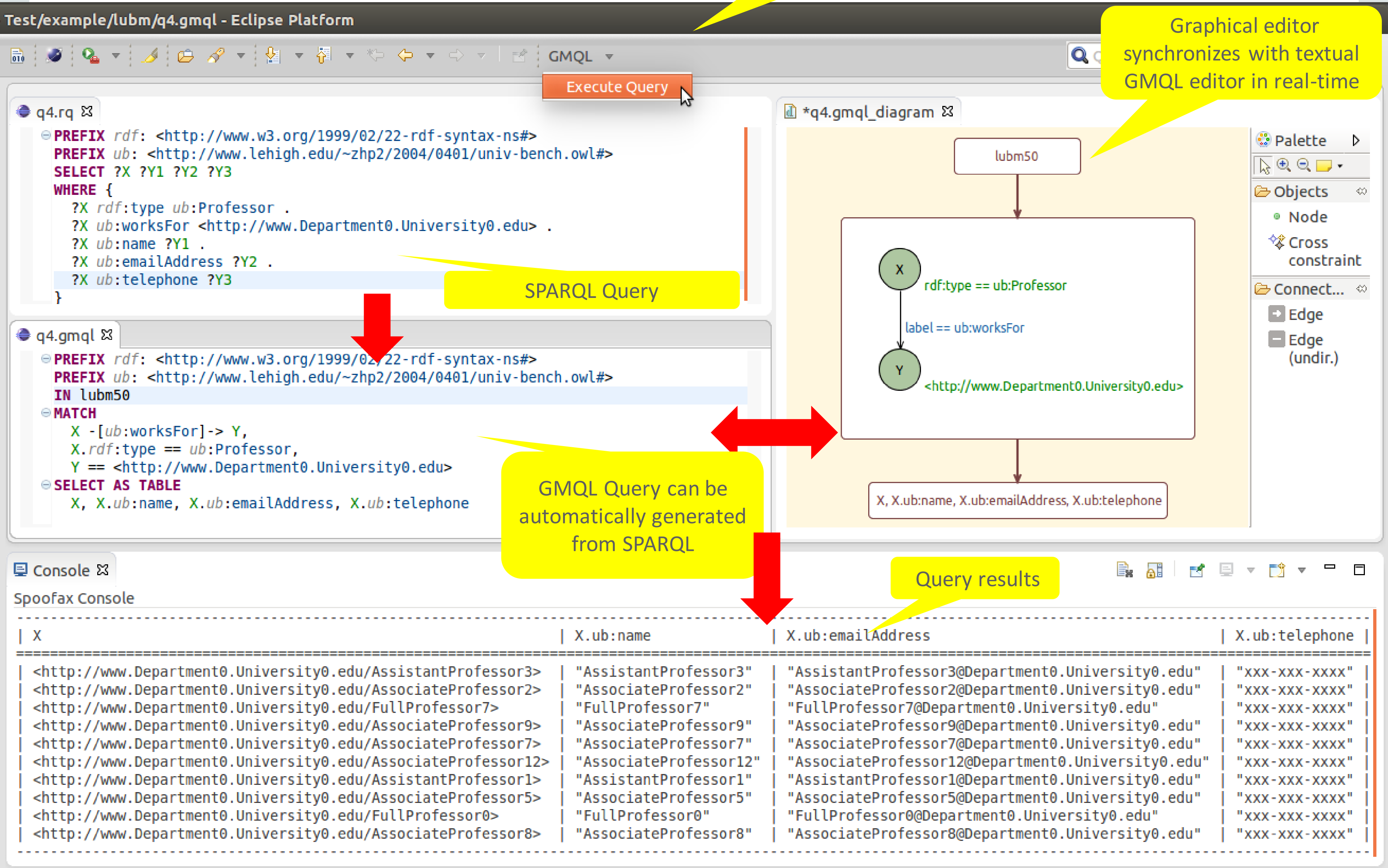
GMQL: Look and Feel



Integrated with Eclipse

Graphical editor synchronizes with textual GMQL editor in real-time

SPARQL Query

GMQL Query can be automatically generated from SPARQL

Query results

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX ub: <http://www.lehigh.edu/~zhp2/2004/0401/univ-bench.owl#>
SELECT ?X ?Y1 ?Y2 ?Y3
WHERE {
  ?X rdf:type ub:Professor .
  ?X ub:worksFor <http://www.Department0.University0.edu> .
  ?X ub:name ?Y1 .
  ?X ub:emailAddress ?Y2 .
  ?X ub:telephone ?Y3
}
```

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX ub: <http://www.lehigh.edu/~zhp2/2004/0401/univ-bench.owl#>
IN lubm50
MATCH
  X -[ub:worksFor]-> Y,
  X.rdf:type == ub:Professor,
  Y == <http://www.Department0.University0.edu>
SELECT AS TABLE
  X, X.ub:name, X.ub:emailAddress, X.ub:telephone
```

```
-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------
| X                                                              | X.ub:name              | X.ub:emailAddress                                      | X.ub:telephone |
=============================================================================================================================================================================
| <http://www.Department0.University0.edu/AssistantProfessor3>   | "AssistantProfessor3"  | "AssistantProfessor3@Department0.University0.edu"      | "xxx-xxx-xxxx" |
| <http://www.Department0.University0.edu/AssociateProfessor2>   | "AssociateProfessor2"  | "AssociateProfessor2@Department0.University0.edu"      | "xxx-xxx-xxxx" |
| <http://www.Department0.University0.edu/FullProfessor7>        | "FullProfessor7"       | "FullProfessor7@Department0.University0.edu"           | "xxx-xxx-xxxx" |
| <http://www.Department0.University0.edu/AssociateProfessor9>   | "AssociateProfessor9"  | "AssociateProfessor9@Department0.University0.edu"      | "xxx-xxx-xxxx" |
| <http://www.Department0.University0.edu/AssociateProfessor7>   | "AssociateProfessor7"  | "AssociateProfessor7@Department0.University0.edu"      | "xxx-xxx-xxxx" |
| <http://www.Department0.University0.edu/AssociateProfessor12>  | "AssociateProfessor12" | "AssociateProfessor12@Department0.University0.edu"     | "xxx-xxx-xxxx" |
| <http://www.Department0.University0.edu/AssistantProfessor1>   | "AssistantProfessor1"  | "AssistantProfessor1@Department0.University0.edu"      | "xxx-xxx-xxxx" |
| <http://www.Department0.University0.edu/AssociateProfessor5>   | "AssociateProfessor5"  | "AssociateProfessor5@Department0.University0.edu"      | "xxx-xxx-xxxx" |
| <http://www.Department0.University0.edu/FullProfessor0>        | "FullProfessor0"       | "FullProfessor0@Department0.University0.edu"           | "xxx-xxx-xxxx" |
| <http://www.Department0.University0.edu/AssociateProfessor8>   | "AssociateProfessor8"  | "AssociateProfessor8@Department0.University0.edu"      | "xxx-xxx-xxxx" |
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```

Performance Evaluation: PGX.ISO

- Dataset : LUBM Lubm datasets evaluated:
  - A standard benchmark for RDF/SPARQL
  - Lubm 8K – 173.8 million nodes, 701.8 million edges
  - Lubm 25K – 543 million nodes, 2.1 billion edges
- Environments (x86 and SPARC)
  - X86: 2 x 8-Core Intel(R) Xeon(R) CPU E5-2660 @ 2.2 GHz (X3-2)
  - SPARC: 8 x 16-Core SPARC T5 processor @ 3.6 GHz
- Comparisons
  - Oracle SPARQL SQL with Oracle RDBMS 12.1.0.1
  - SPARQL SQL queries run directly on the Oracle RDBMS
  - Graph is loaded into memory before running SPARQL queries in PGX

Performance on LUBM Queries

LUBM Query	LUBM 8K	Execution Time on x86 (s)	
	#Solutions	SQL	PGX.ISO
Query 1	4	0	0
Query 2	2528	21.26	0.1
Query 3	6	0	0
Query 4	34	0	0
Query 5	719	0.02	0
Query 6	83557706	23.56	0.14
Query 7	67	0.01	0
Query 8	7790	0.23	0
Query 9	2178420	58	0.58
Query 10	4	0	0
Query 11	224	0.01	0
Query 12	15	0.14	0
Query 13	37118	1.15	0.03
Query 14	63400587	21.09	0.1

Focus on 4 queries

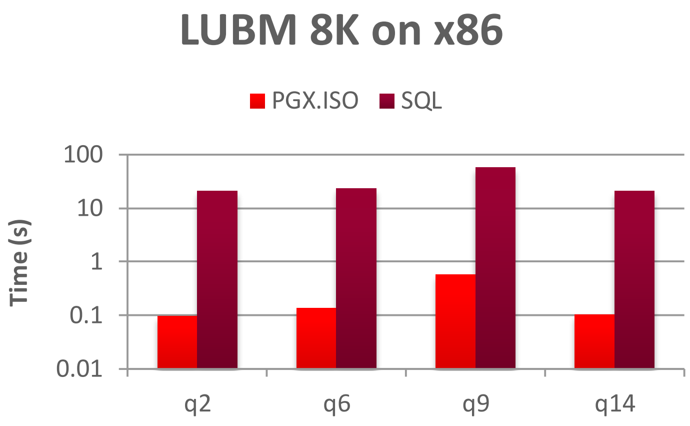
Time < 0.01 (s) is considered 0

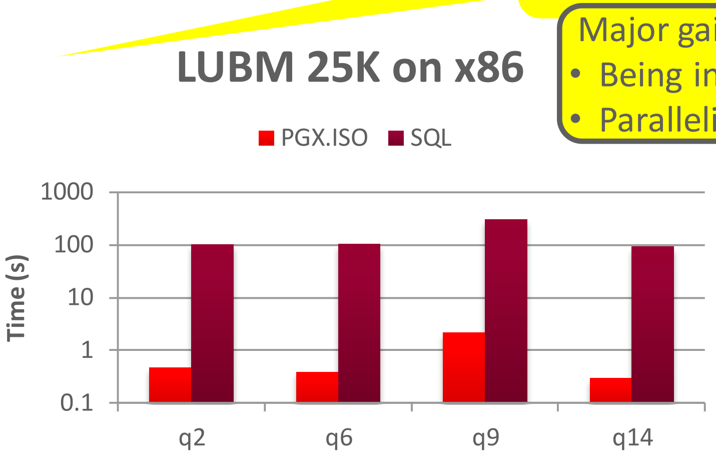
Comparison of PGX.ISO and Oracle-SQL

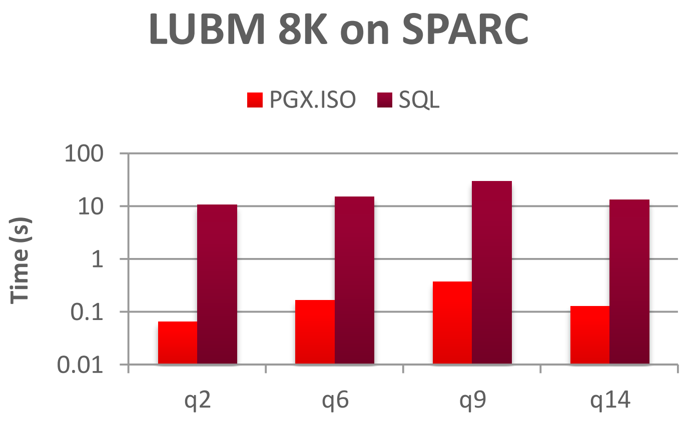
LUBM 8K and 25K on x86 and Sparc

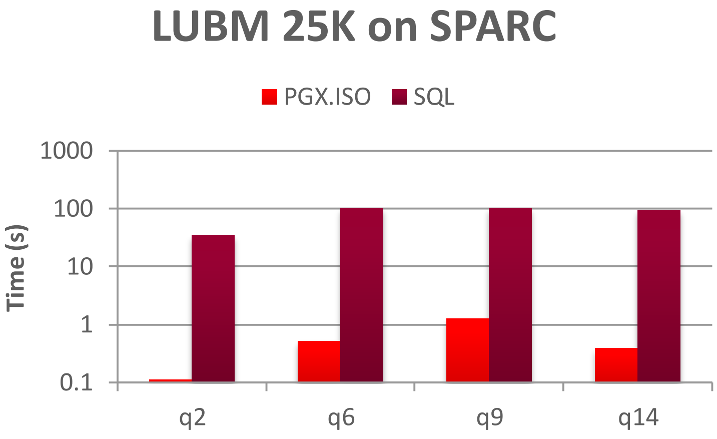
100x improvement over SQL for all queries

Major gains from :
- Being in-memory
- Parallelization


LUBM 8K on x86


LUBM 25K on x86

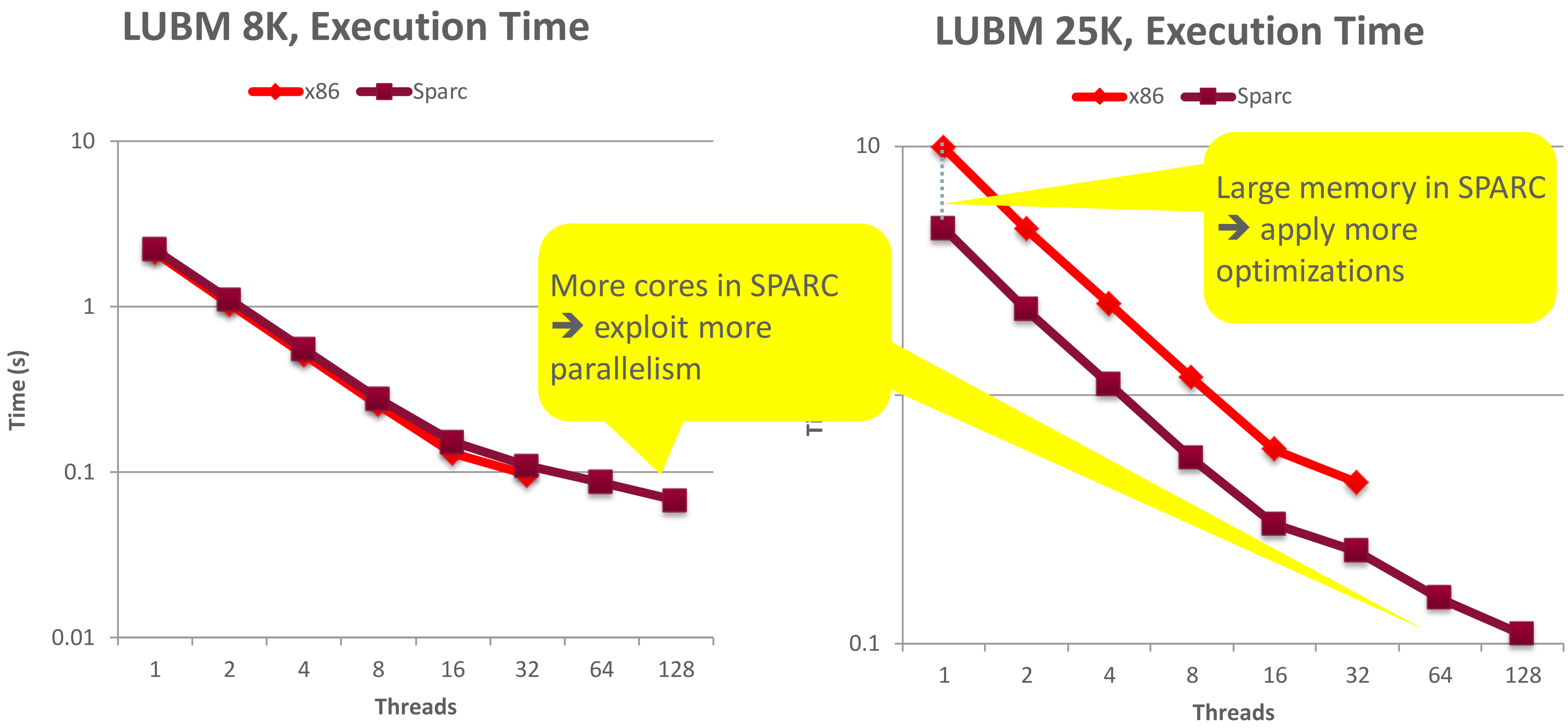

LUBM 8K on SPARC


LUBM 25K on SPARC

Scalability of PGX.ISO

LUBM Query 2 Scalability on x86 and SPARC

PGX.ISO is well-parallelized (for x86 and SPARC)

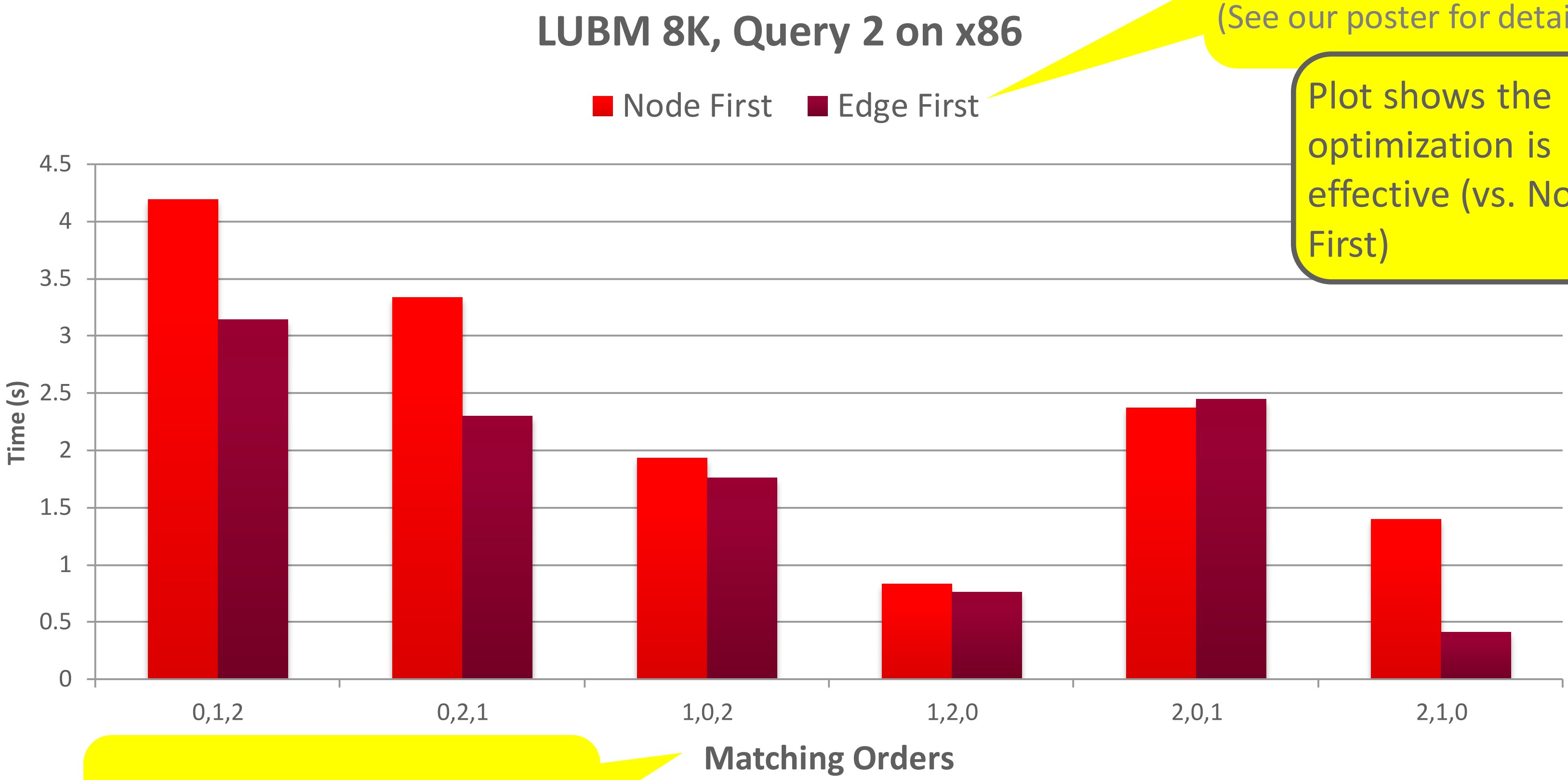


More cores in SPARC ➔ exploit more parallelism

Large memory in SPARC ➔ apply more optimizations

*Best numbers for x86 and SPARC (with different optimizations and matching orders)

Closer Look and Remaining Issues



Edge First: one of our optimization
(See our poster for details)

Plot shows the optimization is effective (vs. Node First)

[Observation] Performance depends on matching order

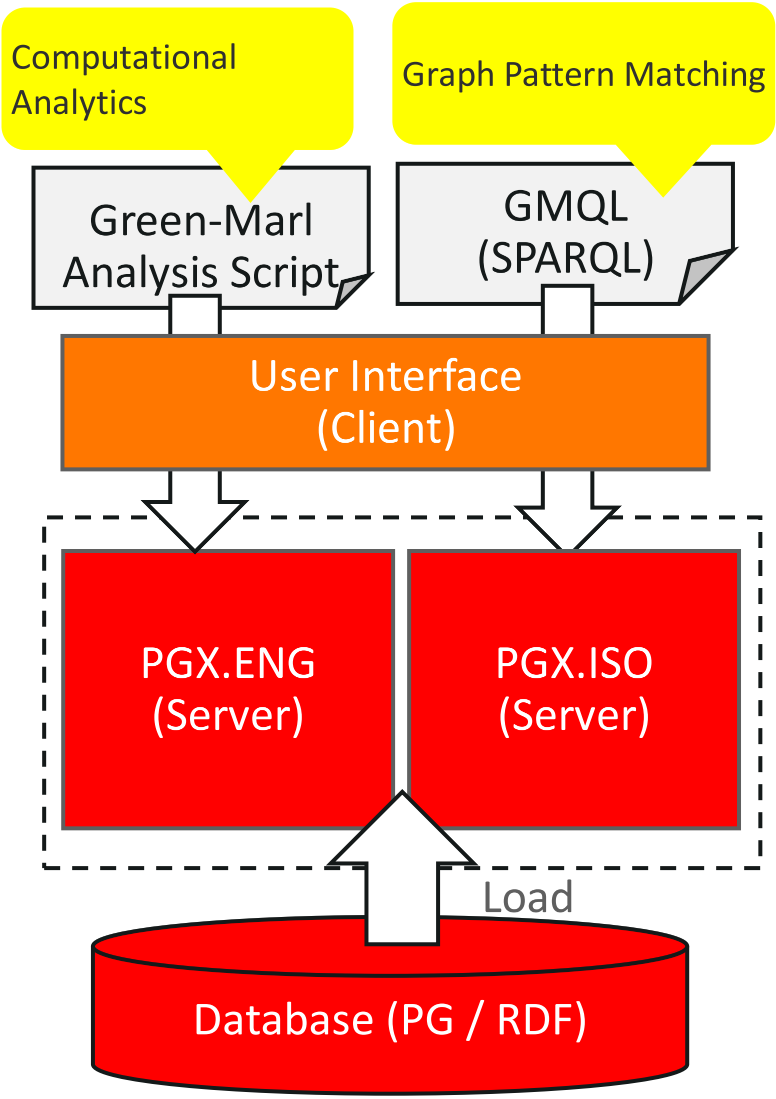
➔ On-going research: finding best matching order

The whole PGX System

- PGX
  - In-memory, parallel graph analytic engine
  - Use database as persistence layer
  - Load graph into memory
- Two kinds of workloads
  - Graph query (this paper)
  - ➔ Find patterns in graph
  - Computational analytics (OTN)
  - ➔ Page rank, community detection, …
  - We are merging these two engines

Check PGX engine at :

http://tinyurl.com/olabspgx



Summary

- PGX.ISO
  - Parallel, in-memory solution for subgraph isomorphism
- GMQL
  - a query language for property graph data
  - Provides RDF/SPARQL compatibility
- Evaluation with LUBM
  - With x86 and SPARC
  - Up to 300x faster than SQL-based Implementation

Hardware and Software

Engineered to Work Together

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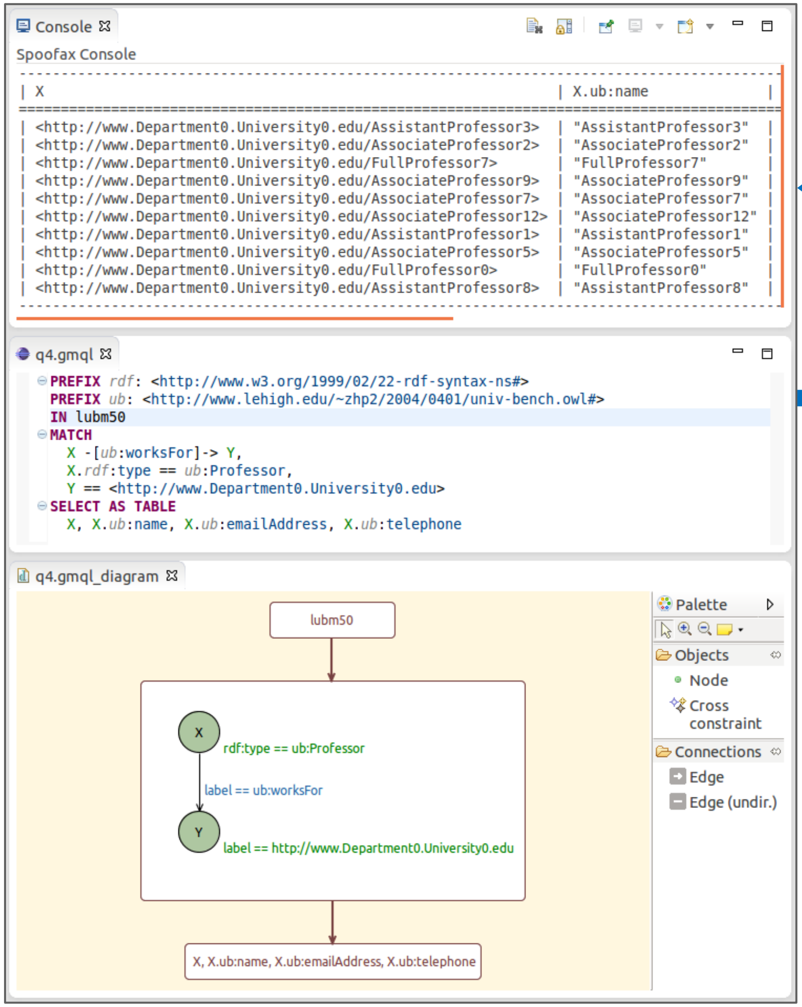
Backup Slides

GMQL: Graph-Matching Query Language



```
-------------------------------------------------------------------------------------------
| X                                                       | X.ub:name                 |
===========================================================================================
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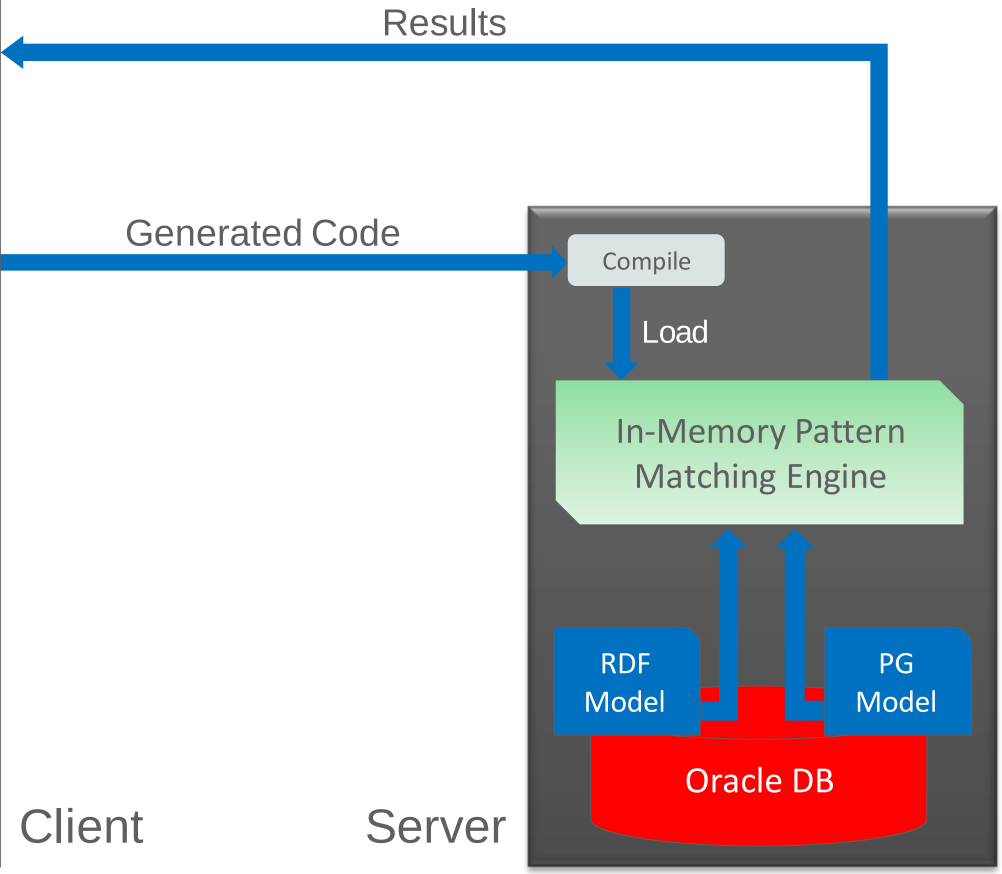
Results
Generated Code
Compile
Load
In-Memory Pattern Matching Engine
RDF Model
PG Model
Oracle DB
Client
Server