3612/7204 ICT Database Systems

Graph Databases

David Meibusch
Principal Software Engineer
Oracle Labs Australia

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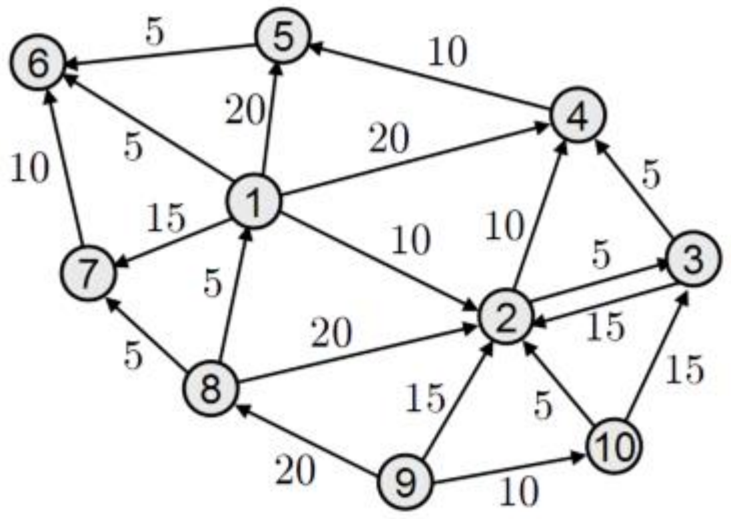
Graph Theory

- Nodes (vertices)
- Relationships (edges)



Mathematical properties

- Cyclic, acyclic
- Directed, undirected
- Reachability
- Transitive closures
- Shortest paths

Applications of Graph Theory

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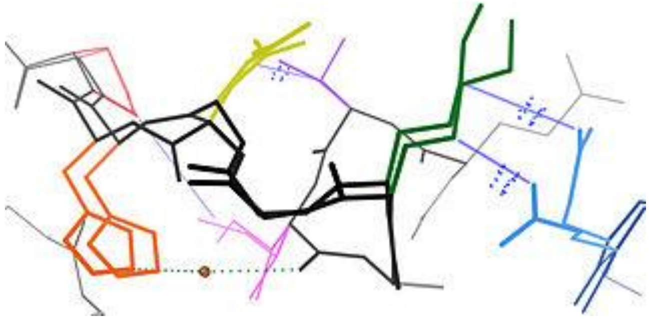

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Frappé

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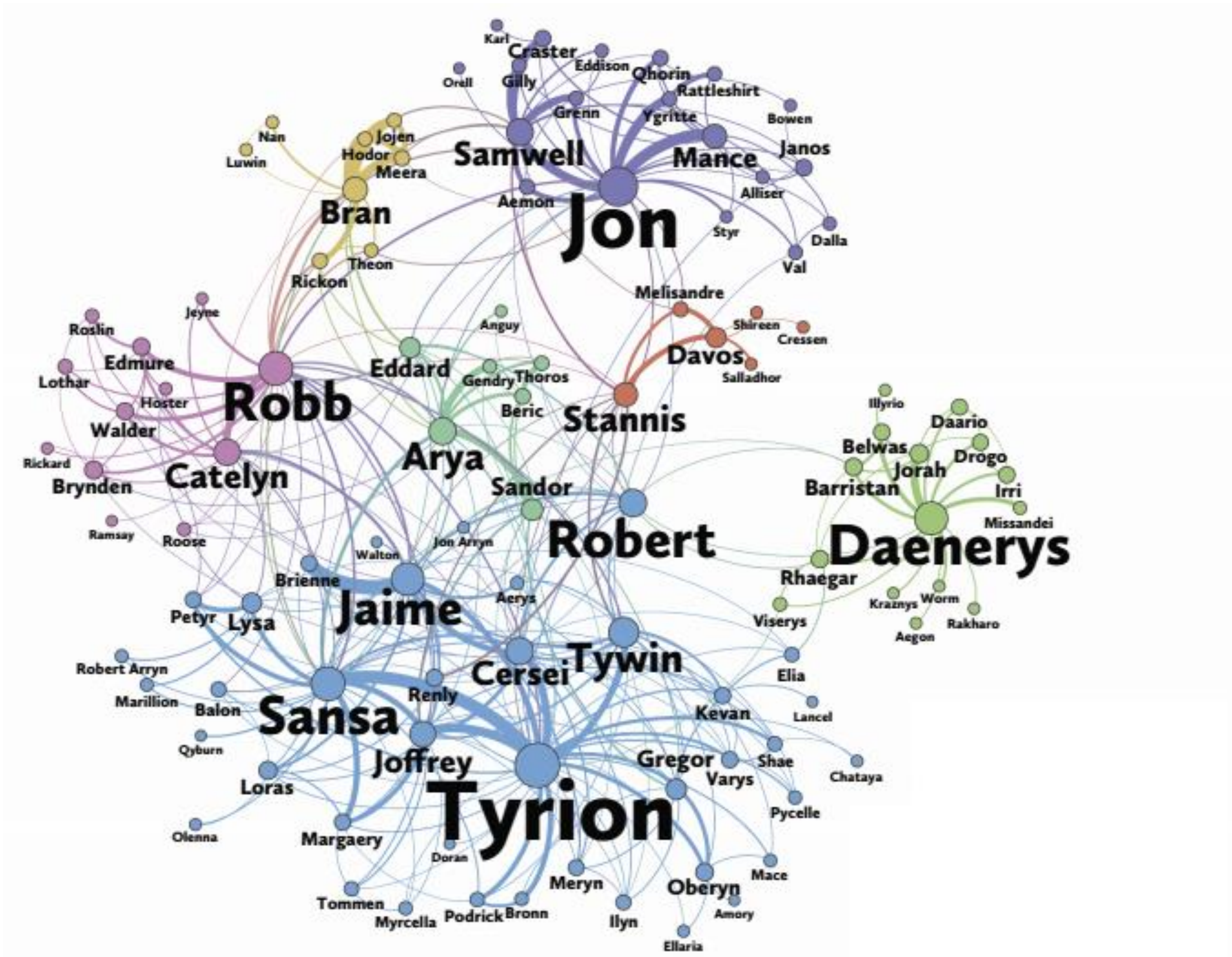
Graph Algorithms

Centrality

- Degree Centrality
- Closeness Centrality
- Betweenness Centrality
- PageRank
- …



Network of Thrones © The Mathematical Association of America, 2016 - http://dx.doi.org/10.4169/mathhorizons.23.4.18

Modelling Graph in Relational DB

Node and Edge tables

id	name
1	Tyrion
2	Cersei
3	Sansa
4	Robb
5	Stannis

type	start	end
talked-to	1	2
talked-to	1	3
talked-to	3	4
fought	1	4
fought	2	5

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Modelling Graph in Relational DB

Tyrion has talked to…

id	name
1	Tyrion
2	Cersei
3	Sansa
4	Robb
5	Stannis

type	start	end
talked-to	1	2
talked-to	1	3
talked-to	3	4
fought	1	4
fought	2	5

```
SELECT n.name
FROM node n
LEFT JOIN edge e ON n.id = e.end
WHERE e.start = 1;
```

Modelling Graph in Relational DB

Tyrion conversations

id	name
1	Tyrion
2	Cersei
3	Sansa
4	Robb
5	Stannis

type	from	to
talked-to	1	2
talked-to	1	3
talked-to	3	4
fought	1	4
fought	2	5

```
SELECT n.name
WHERE id IN (
 SELECT start FROM edge WHERE end = 1
 UNION
 SELECT end FROM edge WHERE start = 1
);
```

Modelling Graph in Relational DB

Tyrion Chinese Whispers

id	name
1	Tyrion
2	Cersei
3	Sansa
4	Robb
5	Stannis

type	from	to
talked-to	1	2
talked-to	1	3
talked-to	3	4
fought	1	4
fought	2	5

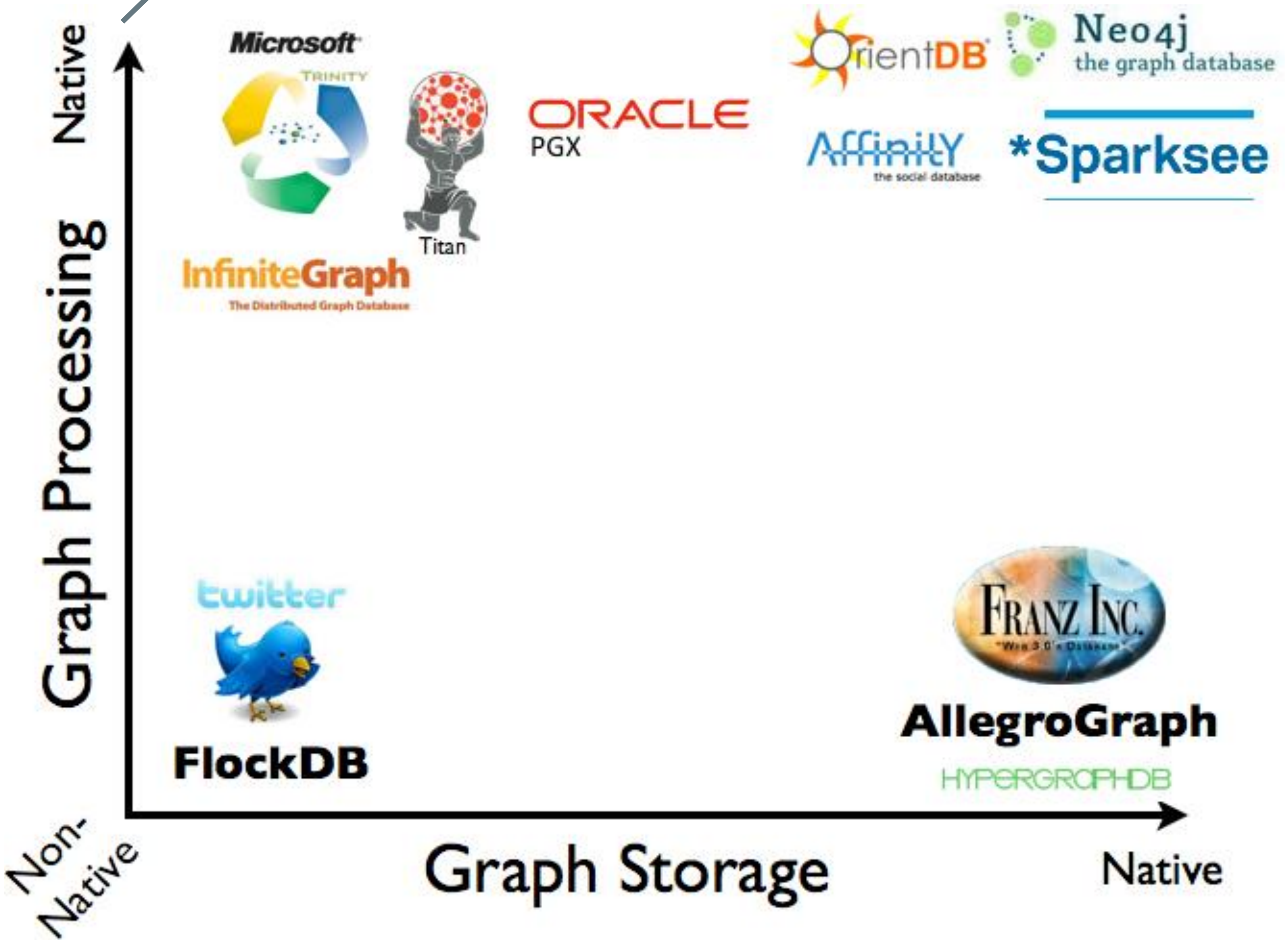
```
WITH RECURSIVE closure(id, name) AS
(
 SELECT n.id, n.name FROM node
 WHERE n.id = 1
UNION ALL
 SELECT n.id, n.name FROM node n
 LEFT JOIN edge e ON n.id = e.end
 WHERE e.start = id
)
SELECT * FROM closure;
```

Graph Database

- Use nodes, edges, and properties to represent and store data
- Provide means to traverse the graph
- Allows fast implementation of graph algorithms

Graph Databases

Index free adjacency



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Neo4J

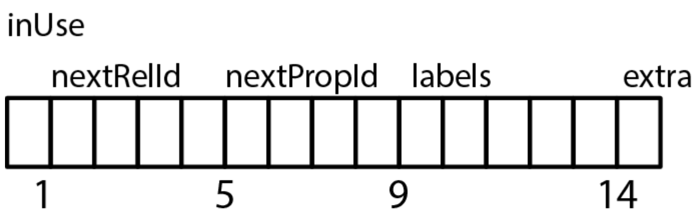
- Graph on-disk with in-memory cache
- CRUD
  - Create, Read, Update, Delete
- ACID transactions
- OLTP

- Labelled Property Graph Model
  - Node and relationships
  - Node/value pairs (properties)
  - Nodes can be labelled
  - Relationships are named and directed
  - Relationship/value pairs (properties)

Neo4J Implementation

- Node and Relationship store files (on disk)

Node (15 bytes)

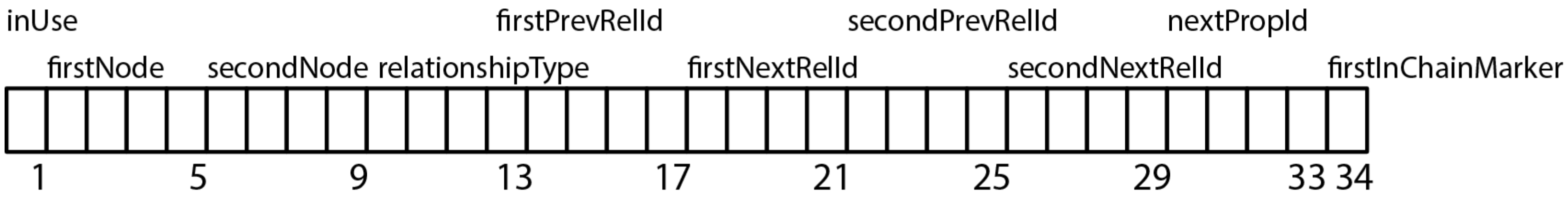


inUse

nextRelId nextPropId labels extra

1 5 9 14

Relationship (34 bytes)



inUse firstPrevRelId secondPrevRelId nextPropId

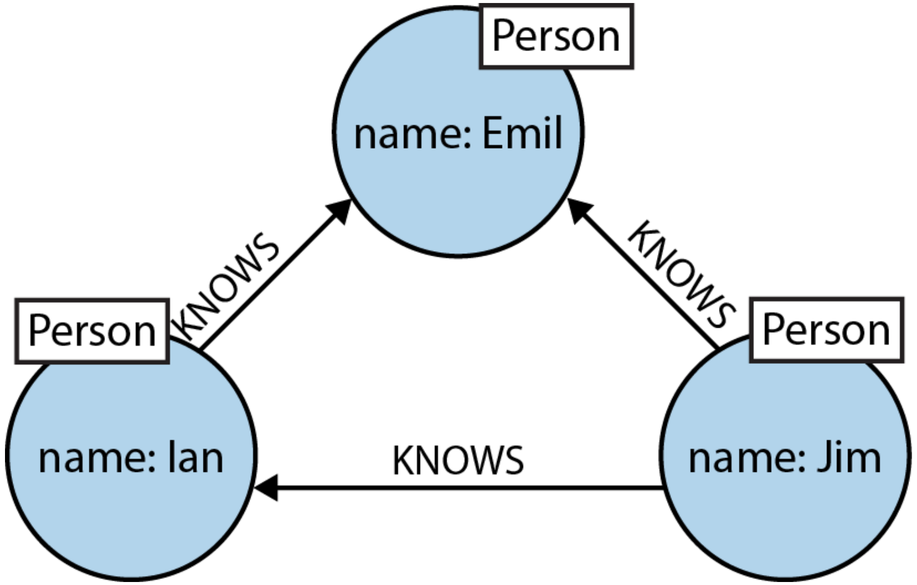
firstNode secondNode relationshipType firstNextRelId secondNextRelId firstInChainMarker

1 5 9 13 17 21 25 29 33 34

Accessing Neo4J graph

- Java core API, traversal API

- Cypher query language
  - “ASCII art” for graph matching



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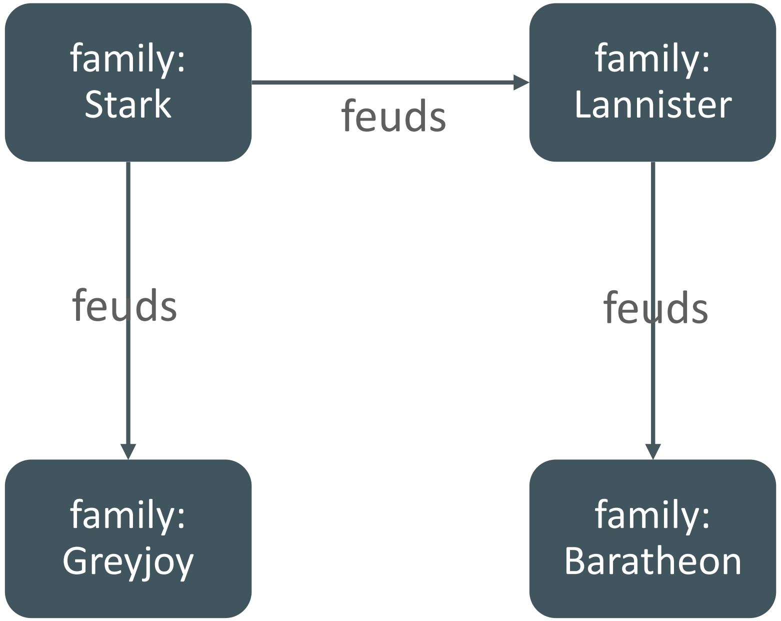
```
(emil)<-[:KNOWS]-(jim)-[:KNOWS]->(ian)-[:KNOWS]->(emil)
```

Cypher example



family: Stark

feuds

family: Lannister

feuds

feuds

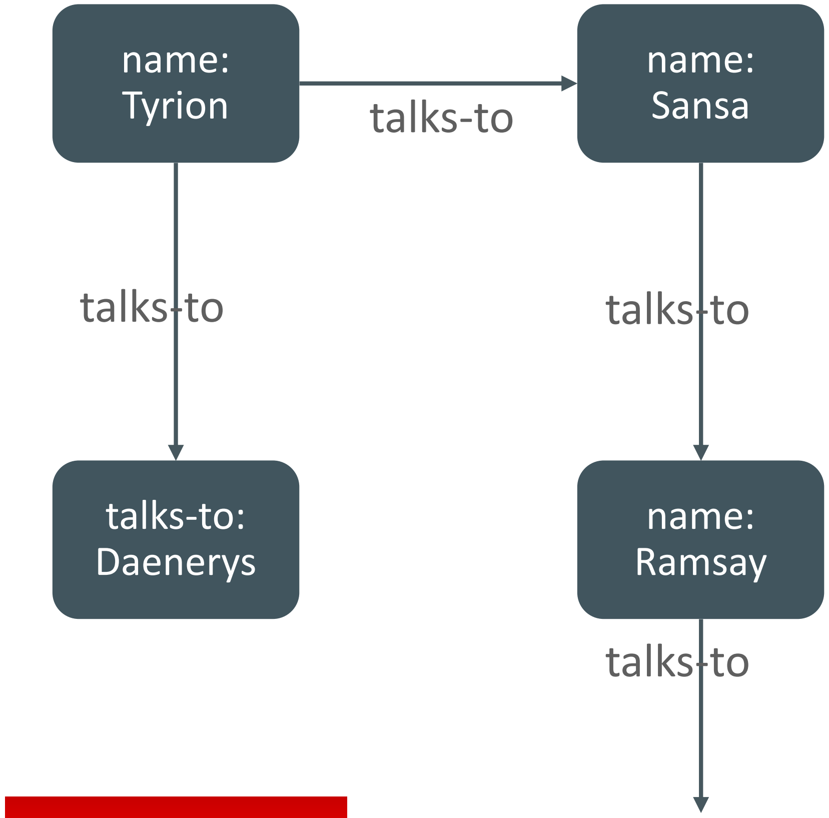
family: Greyjoy

family: Baratheon

Enemy of my enemy

```
MATCH (kin)-[:feuds]->(enemy)-[:feuds]->(friend)
WHERE kin.family = 'Stark'
RETURN kin, friend
```

Cypher example 2



Chinese Whispers (transitive closure)

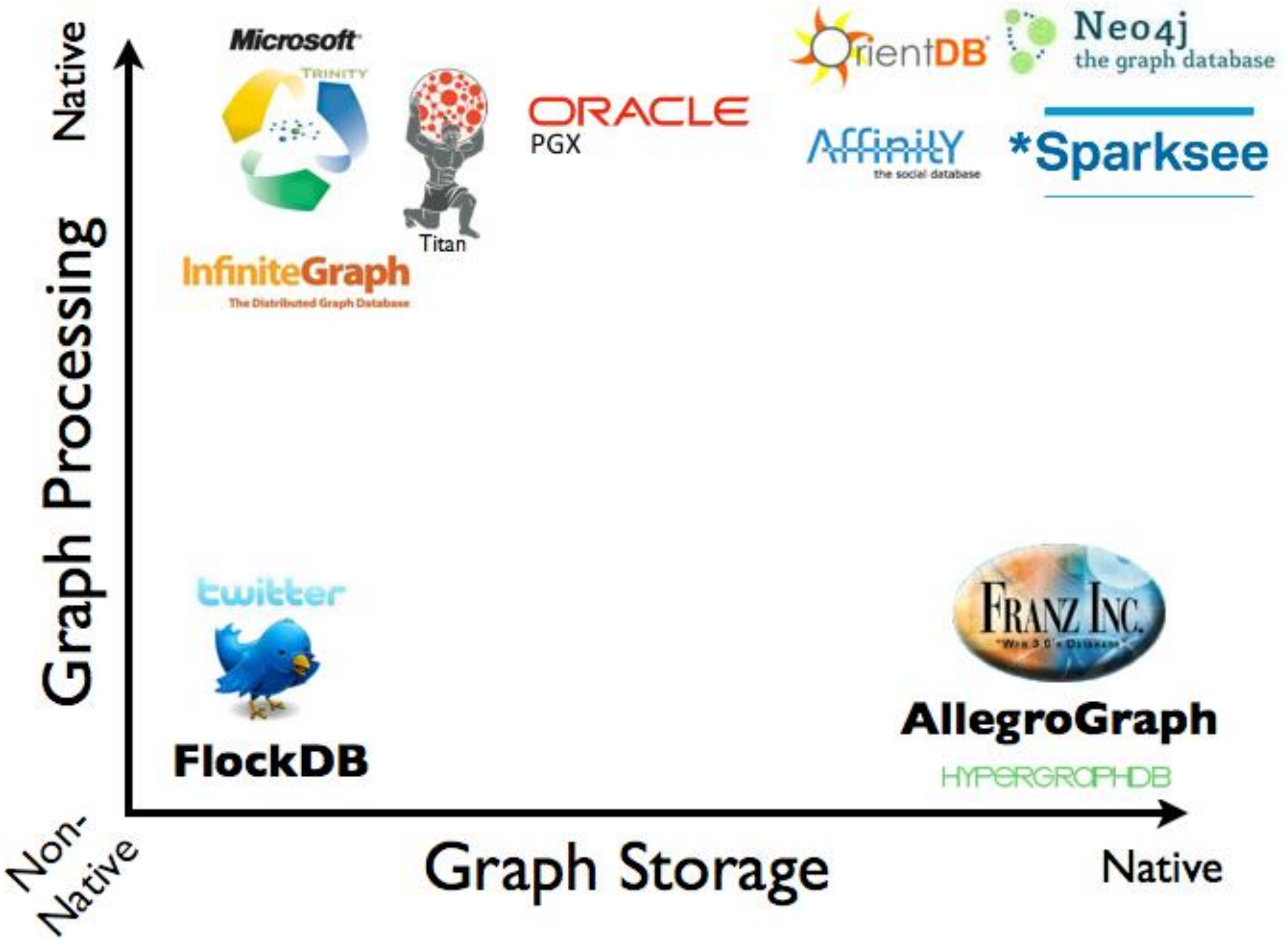
```
MATCH (tyrion: {name = 'Tyrion'})
       -[:talks-to*]->(people)

RETURN people
```

```
MATCH p=shortestPath(
  (tyrion: {name = 'Tyrion'})-[:talks-to*]->
  (ramsay: {name = 'Ramsay'}))

RETURN p
```

Graph Databases



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PGX

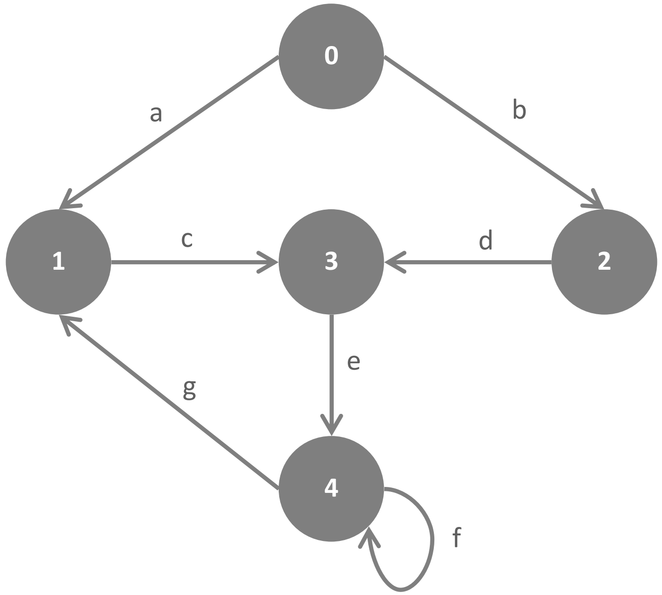
Oracle® Parallel Graph Analytics (PGX)

- Parallel, in-memory graph analytic framework
- Must fit in memory
- Immutable graph
  - Mutating creates a new graph
- No ACID, OLTP…

- Property Graph Model
- Execute graph algorithms
- Write custom graph algorithms in Green-Marl
- PGQL query language

PGX Implementation

Adjacency Matrix



	0	1	2	3	4
0		a	b		
1				c	
2				d	
3					e
4	g				f

- Edge iteration
  - loop through the array
- Large space requirements
  - Great for dense graphs, but most are very sparse

PGX Implementation

Compressed Sparse Row

	0	1	2	3	4
0		a	b		
1				c	
2				d	
3					e
4	g				f

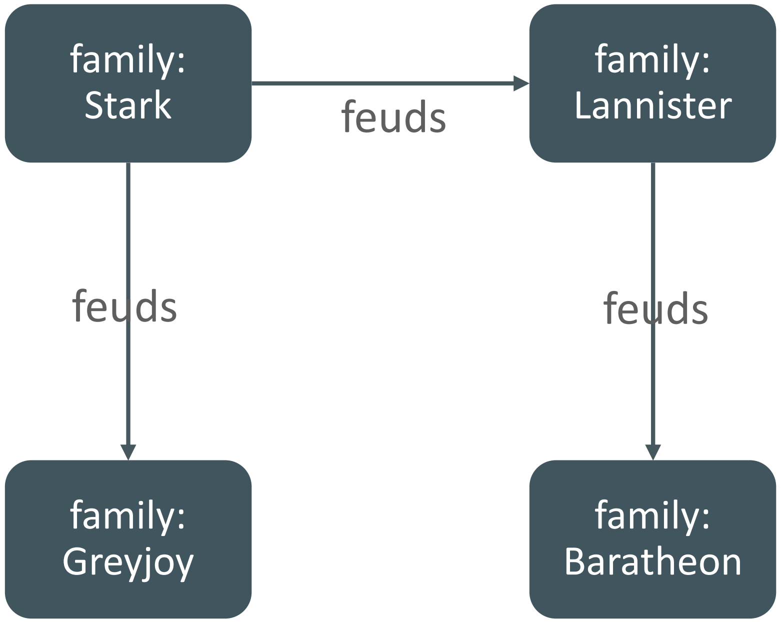
```
Array of nodes    [0, 1, 2, 3, 4]
Array of edges    [a, b, c, d, e, g, f]
Edge column       [1, 2, 3, 3, 4, 0, 4]
Row offsets       [0,    2, 3, 4, 5]
```

- Space dependent on the edge + node count

Accessing PGX Graph

- Java™ API
- Green-Marl algorithm
- PGQL query language

PGQL example



Enemy of my enemy

```
SELECT kin, friend
WHERE (kin WITH name = 'Stark')
 -[e1:feuds]->(enemy)
 -[e2:feuds]->(friend)
```

Comparing

RDBMS

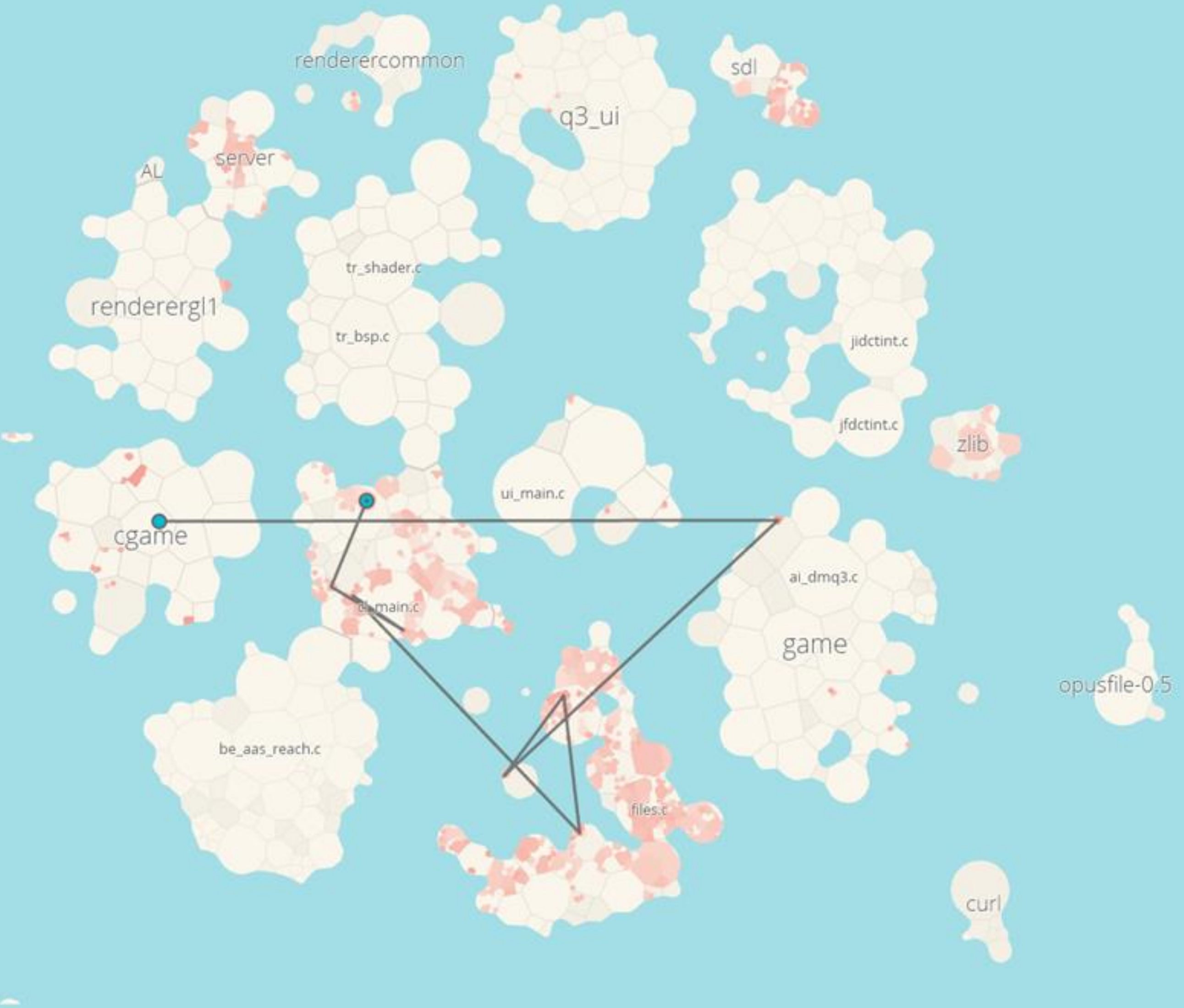
- Faster on large numbers of records
- Use less storage space
- Tortuous SQL for paths
- Very mature technology

Graph Database

- Faster on highly connected data
- Must store relationships
- Natural path queries
- Re-emerging technology

Frappé

Code Comprehension Tool



Current Tools for C/C++ Codebases

- IDEs
  - Issues with build integration
  - Use own indexer (not the compilers)
  - Instead…
- Fall back to text editors and text-search tools
  - Vim and emacs
  - Grep and cscope
- Fast and simple but imprecise

```
static VALUE mnew(…) {
    …
    data->id = rid;
    …
}
```

Find definition

```
  method.h:70
  node.h:244
  thread_pthread.c:594
  (+ 17 more)
```

Actual definition (14th)

```
  proc.c:21
```

Higher Level Task

- Tools provide defs/refs
  - Can go from a symbol to its definition or its references
- But usually have higher level task in mind
  - Where did this invalid value get introduced?
  - If I change this, what’s going to break?
  - How did the code reach this point?
- Can we answer these queries directly?

Frappé Graph Model

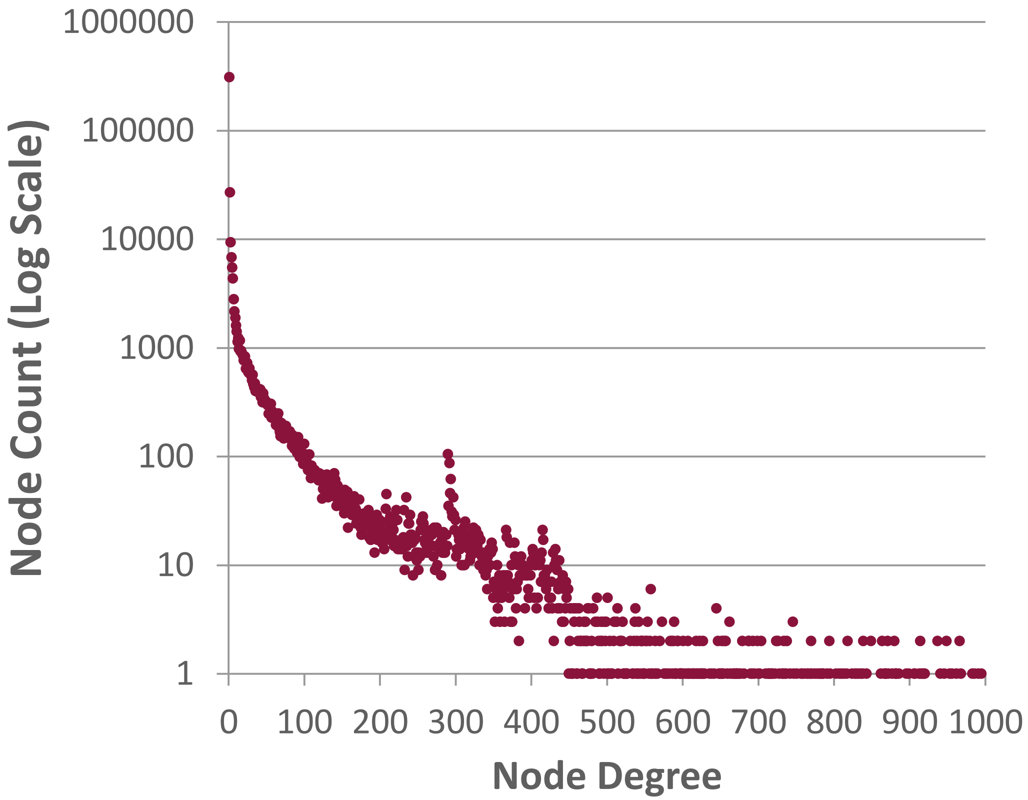
- Code entities are nodes
  - With properties: name, modifiers, etc.
- References are edges
  - With properties: source location, qualifiers, etc.
- Includes data from
  - File system: directory and file hierarchy
  - Preprocessor: includes, macros, their expansion and interrogations
  - AST: functions, locals, types, and relations between them
  - Build system: modules, libraries, executables, and linking information between them

Linux Kernel Graph

Oracle® Linux Kernel 2.6

- Approximately 11.4 million LOC
  - Around 1.6 million lines compiled

Node count	508 032
Edge count	3 991 063
DB Size	787 MB



Experiences and Challenges

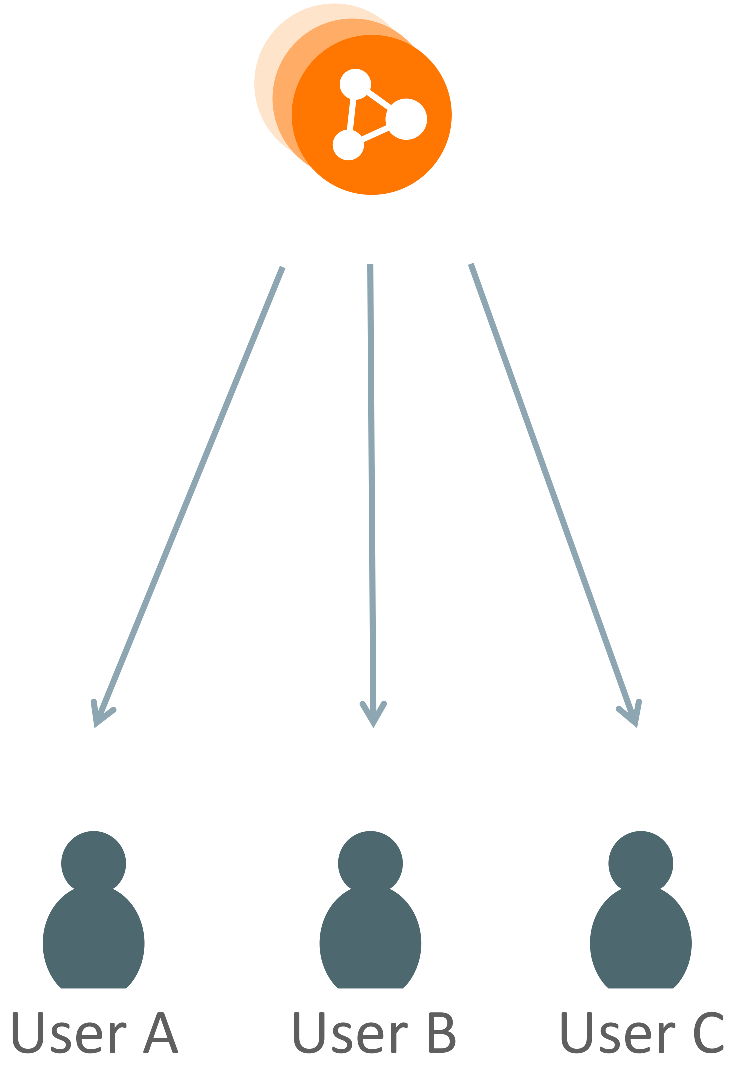
Temporal

- Developers work on multiple versions of the code
  - Hours to weeks ago if working on a bug fix
  - Weeks to months ago if working on a new feature
  - Months to years ago if backporting a bug fix
- Need to be able to query any of these versions

Experiences and Challenges

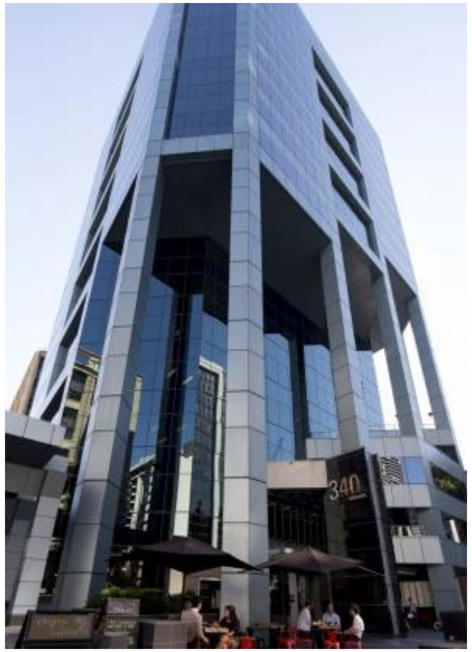
Temporal

- Could include temporal aspect in model
  - Complicates model and makes queries verbose
- Ideally the database layer would handle it
  - Efficient storage
  - Succinct cross-version queries
- Difficult, but has applications in many domains



Database Futures

- 1960s – Hierarchical
- 1970s, 1980s, 1990s – Relational
- 1990s –Object, Object Relational
- 2000s – NoSQL
  - Key-Value, Document, Distributed, **Graph**, …



Thank You!

David Meibusch
Oracle Labs, Australia
340 Adelaide St, Brisbane

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