NDBI040

Big Data Management and NoSQL Databases

Lecture 9. Graph databases – Neo4j

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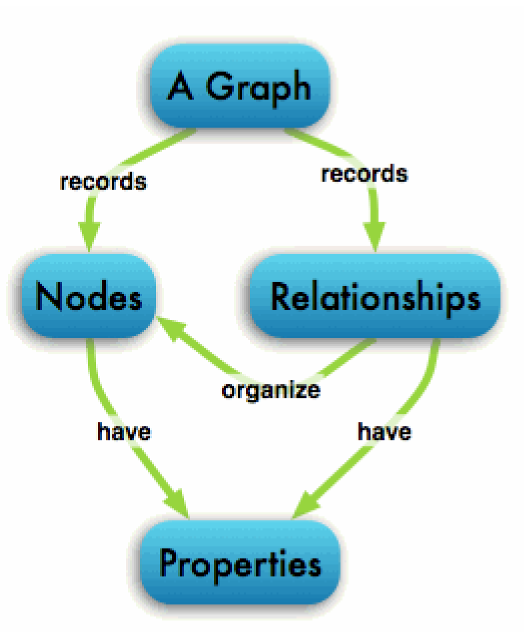
Neo4j

- Open source graph database
  - The most popular
- Initial release: 2007
- Written in: Java
- OS: cross-platform
- Stores data in nodes connected by directed, typed relationships
  - With properties on both
  - Called property graph



http://www.neo4j.org/

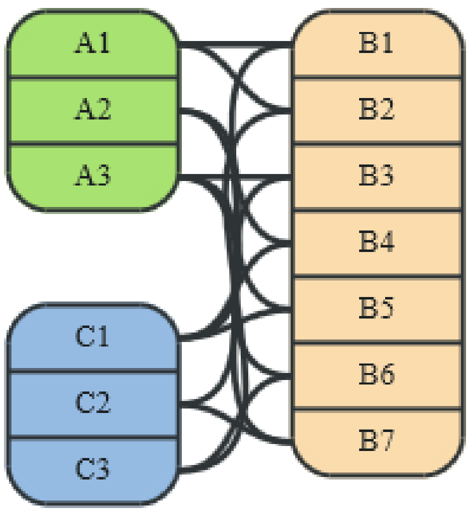
Neo4j

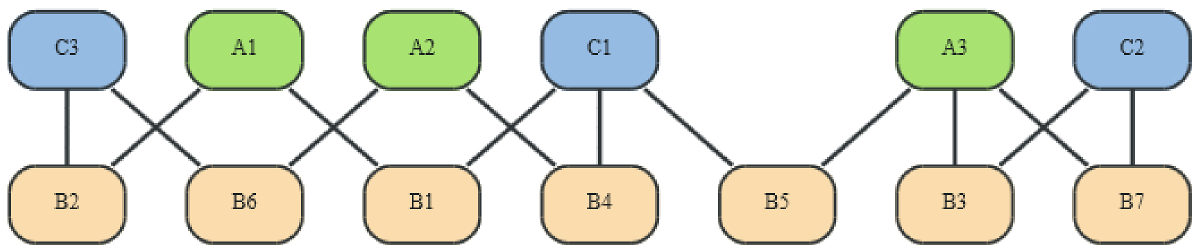
Main Features (according to Authors)

- intuitive – a graph model for data representation
- reliable – with full ACID transactions
- durable and fast – disk-based, native storage engine
- massively scalable – up to several billions of nodes / relationships / properties
- highly-available – when distributed across multiple machines
- expressive – powerful, human readable graph query language
- fast – powerful traversal framework
- embeddable
- simple – accessible by REST interface / object-oriented Java API

RDBMS vs. Neo4j

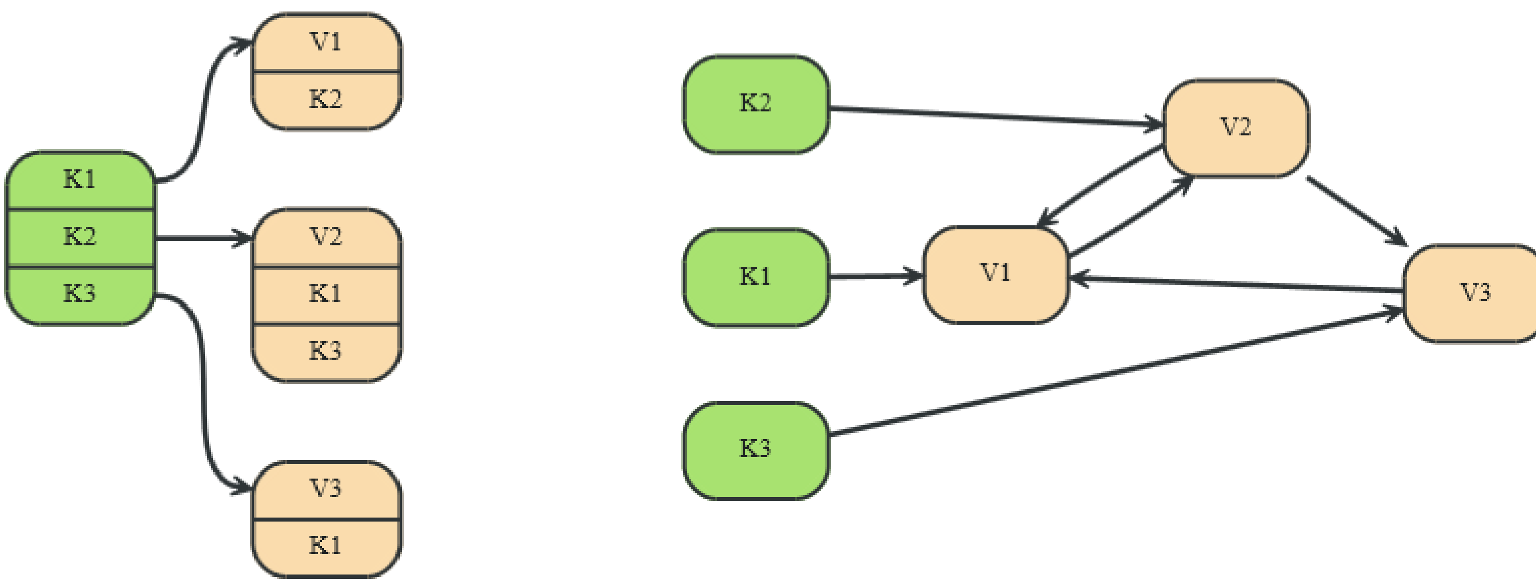
- RDBMS is optimized for aggregated data
- Neo4j is optimized for highly connected data





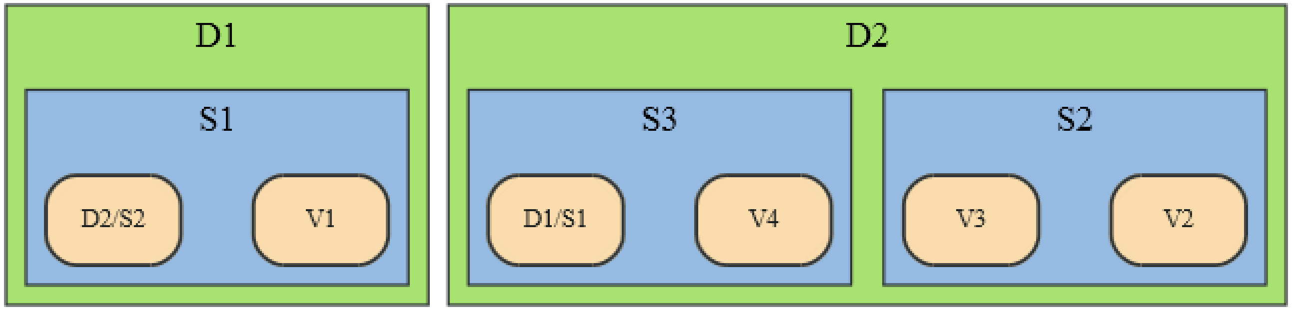
Key-Value (Column Family) Store vs. Neo4j

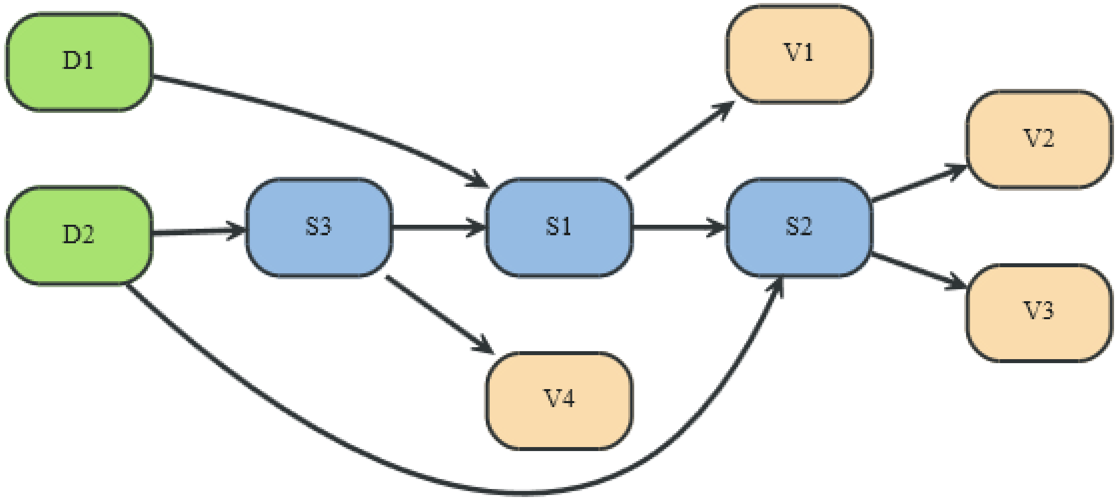
- Key-Value model is for lookups of simple values or lists
  - Column family store can be considered as a step in evolution of key/value stores
    - The value contains a list of columns
- Neo4j lets you elaborate the simple data structures into more complex data
  - Interconnected



Document Store vs. Neo4j

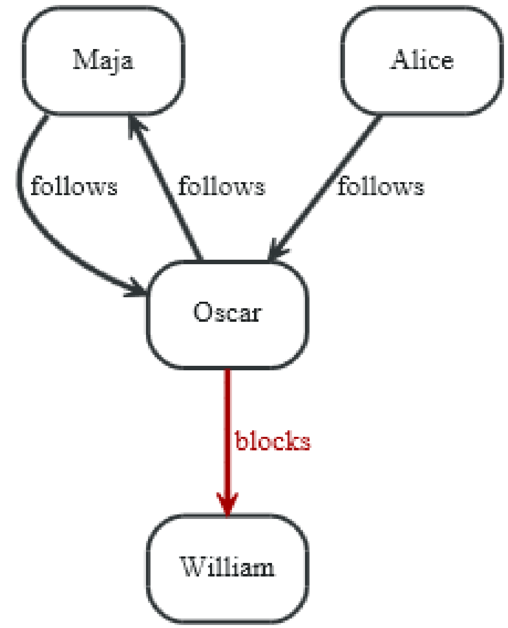
- Document database accommodates data that can easily be represented as a tree
  - Schema-free
- References to other documents within the tree = more expressive representation



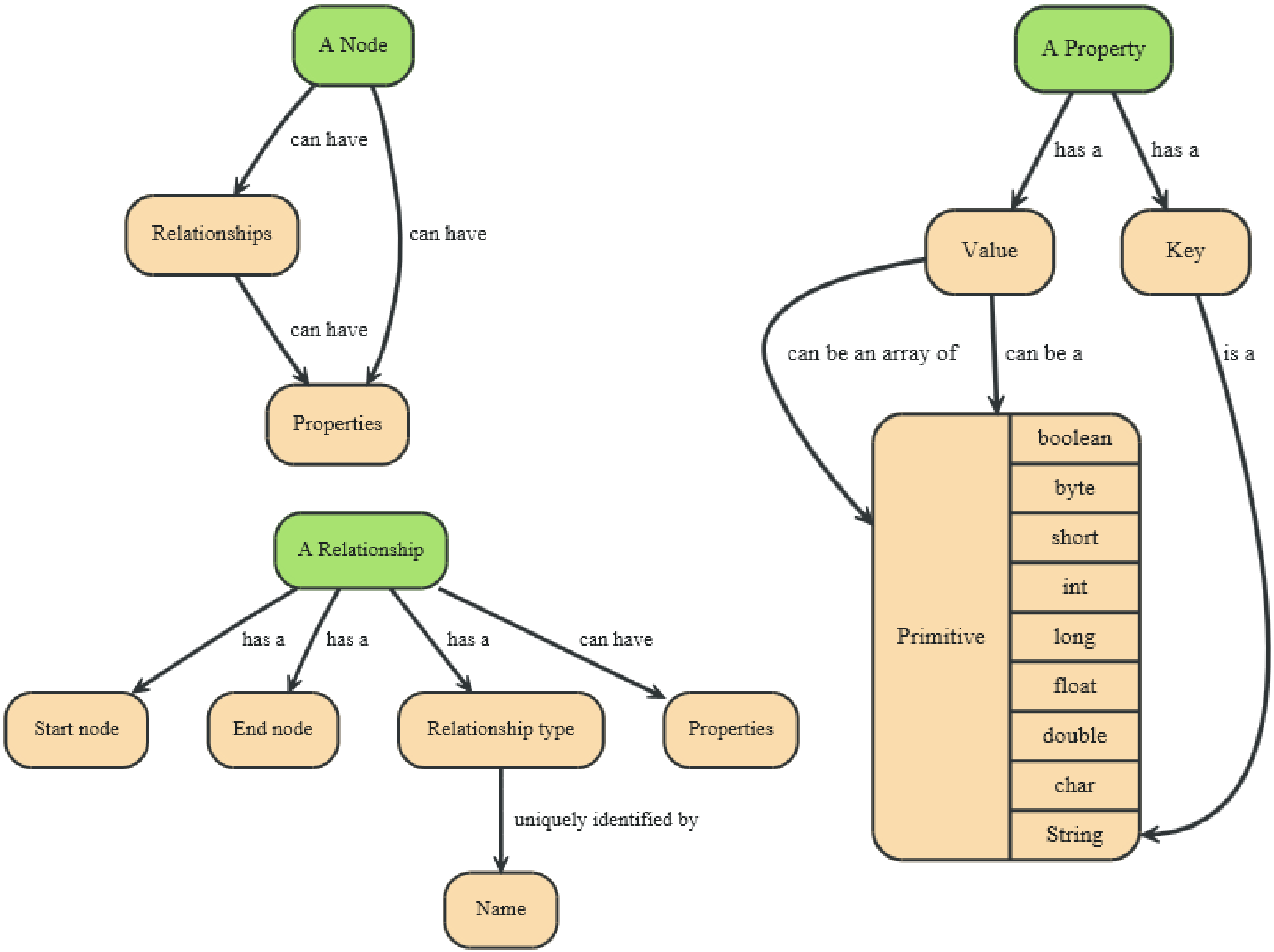


Neo4j

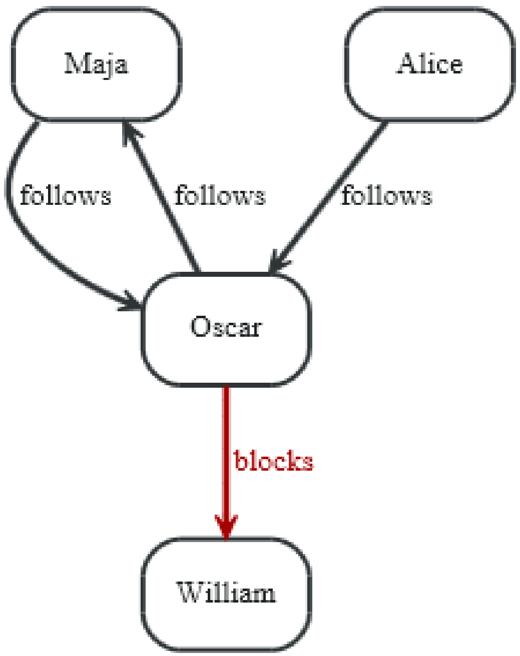
Data Model – Node, Relationship, Property



- Fundamental units: nodes + relationships
- Both can contain properties
  - Key-value pairs where the key is a string
  - Value can be primitive or an array of one primitive type
    - e.g., `String`, `int`, `int[]`, …
  - `null` is not a valid property value
    - nulls can be modelled by the absence of a key
- Relationships
  - Directed (incoming and outgoing edge)
    - Equally well traversed in either direction = no need to add both directions to increase performance
    - Direction can be ignored when not needed by applications
  - Always have start and end node
  - Can be recursive

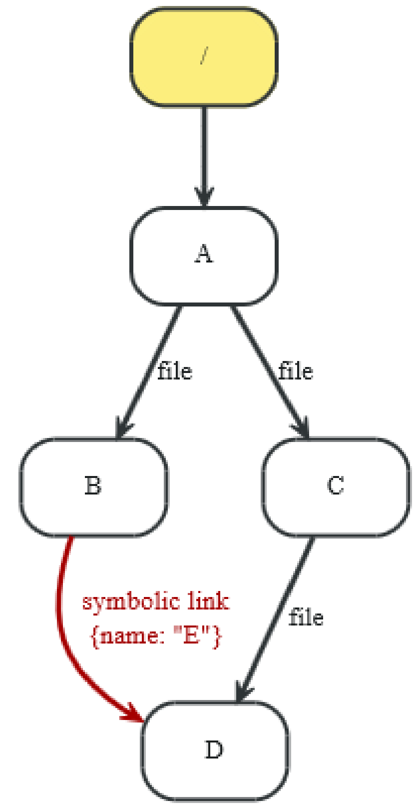

A Node
can have
Relationships
can have
can have
Properties
A Relationship
has a
has a
has a
can have
Start node
End node
Relationship type
Properties
uniquely identified by
Name
A Property
has a
has a
Value
Key
can be an array of
can be a
is a
Primitive
boolean
byte
short
int
long
float
double
char
String

Type	Description	Value range
boolean		true/false
byte	8-bit integer	-128 to 127, inclusive
short	16-bit integer	-32768 to 32767, inclusive
int	32-bit integer	-2147483648 to 2147483647, inclusive
long	64-bit integer	-9223372036854775808 to 9223372036854775807, inclusive
float	32-bit IEEE 754 floating-point number	
double	64-bit IEEE 754 floating-point number	
char	16-bit unsigned integers representing Unicode characters	u0000 to uffff (0 to 65535)
String	sequence of Unicode characters	



What	How
get who a person follows	outgoing `follows` relationships, depth one
get the followers of a person	incoming `follows` relationships, depth one
get who a person blocks	outgoing `blocks` relationships, depth one
get who a person is blocked by	incoming `blocks` relationships, depth one

What	How
get the full path of a file	incoming `file` relationships
get all paths for a file	incoming `file` and `symbolic link` relationships
get all files in a directory	outgoing `file` and `symbolic link` relationships, depth one
get all files in a directory, excluding symbolic links	outgoing `file` relationships, depth one
get all files in a directory, recursively	outgoing `file` and `symbolic link` relationships



Neo4j

"Hello World" Graph – Java API

```
// enum of types of relationships:
private static enum RelTypes implements RelationshipType
{
    KNOWS
};

GraphDatabaseService graphDb;
Node firstNode;
Node secondNode;
Relationship relationship;

// starting a database (directory is created if not exists):
graphDb = new
     GraphDatabaseFactory().newEmbeddedDatabase(DB_PATH);

// …
```

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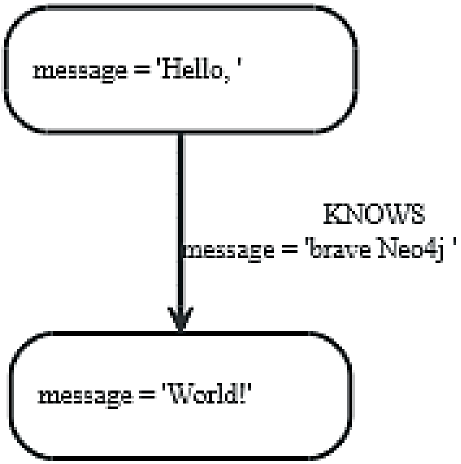
"Hello World" Graph

```
// create a small graph:
firstNode = graphDb.createNode();
firstNode.setProperty( "message", "Hello, " );
secondNode = graphDb.createNode();
secondNode.setProperty( "message", "World!" );

relationship = firstNode.createRelationshipTo
   (secondNode, RelTypes.KNOWS);
relationship.setProperty
   ("message", "brave Neo4j ");

// …
```



Neo4j
"Hello World" Graph

```
// print the result:
System.out.print( firstNode.getProperty( "message" ) );
System.out.print( relationship.getProperty( "message" ) );
System.out.print( secondNode.getProperty( "message" ) );

// let's remove the data:
firstNode.getSingleRelationship
   (RelTypes.KNOWS, Direction.OUTGOING).delete();
firstNode.delete();
secondNode.delete();

// shut down the database:
graphDb.shutdown();
```

Neo4j

“Hello World” Graph – Transactions

```
// all writes (creating, deleting and updating any data)
// have to be performed in a transaction,
// otherwise NotInTransactionException

Transaction tx = graphDb.beginTx();
try
{
    // updating operations go here
    tx.success();          // transaction is committed on close
}
catch (Exception e)
{
    tx.failure();          // transaction is rolled back on close
}
finally
{
    tx.close();            // or deprecated tx.finish()
}
```

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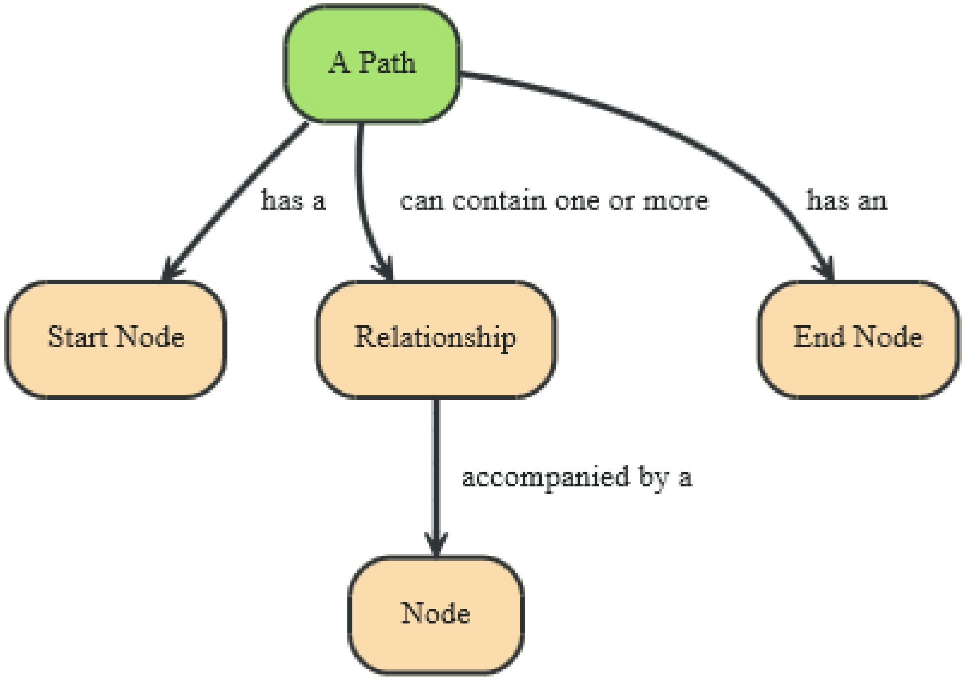
Data Model – Path, Traversal

- Path = one or more nodes with connecting relationships
  - Typically retrieved as a query or traversal result
- Traversing a graph = visiting its nodes, following relationships according to some rules
  - Mostly a subgraph is visited
  - Neo4j: Traversal framework + Java API, Cypher, Gremlin



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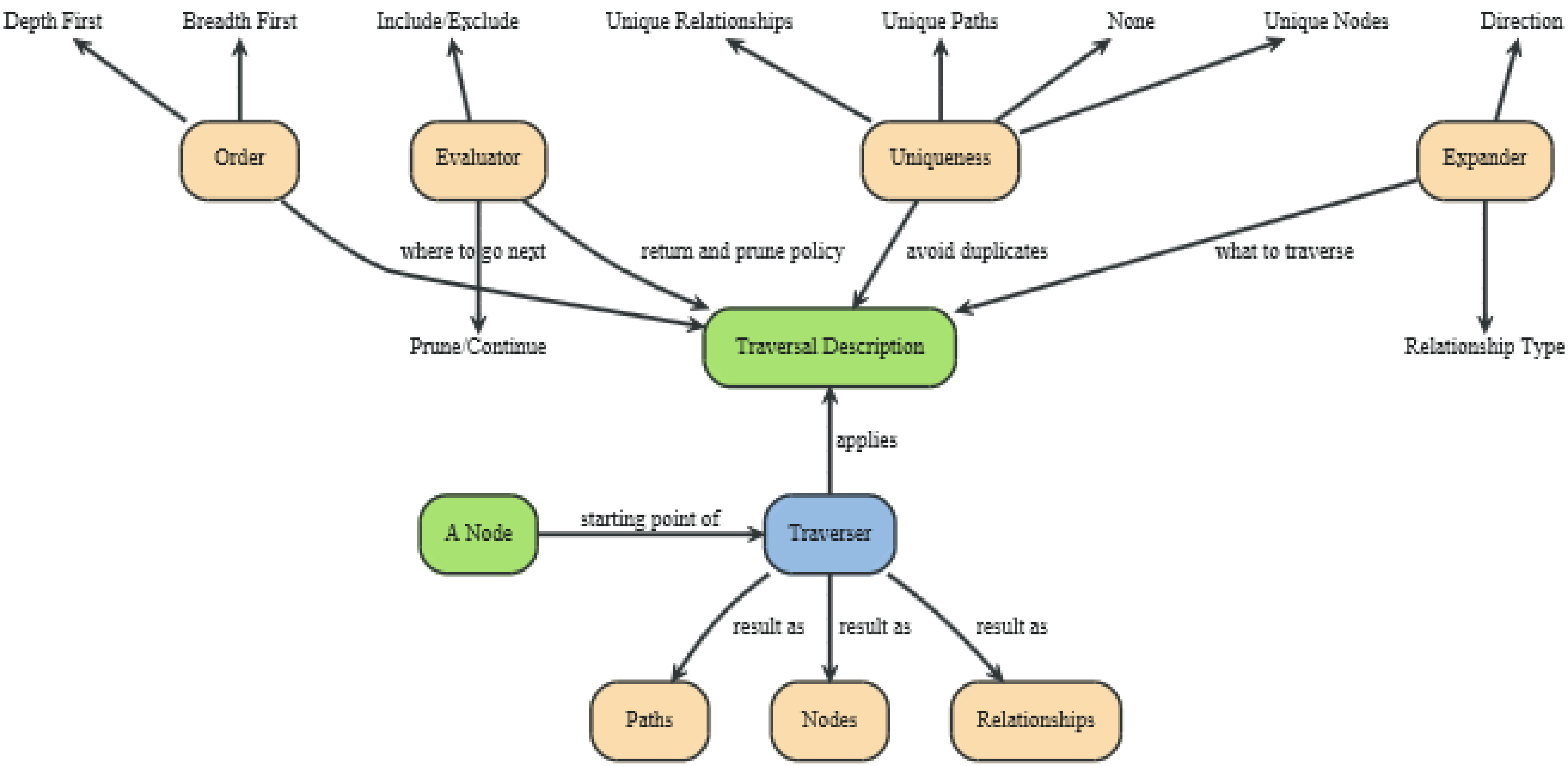
Traversal Framework

- A traversal is influenced by
  - Expanders – define what to traverse
    - i.e., relationship direction and type
  - Order – depth-first / breadth-first
  - Uniqueness – visit nodes (relationships, paths) only once
  - Evaluator – what to return and whether to stop or continue traversal beyond a current position
  - Starting nodes where the traversal will begin


Depth First
Breadth First
Include/Exclude
Unique Relationships
Unique Paths
None
Unique Nodes
Direction
Order
Evaluator
Uniqueness
Expander
where to go next
return and prune policy
avoid duplicates
what to traverse
Prune/Continue
Traversal Description
Relationship Type
applies
A Node
starting point of
Traverser
result as
result as
result as
Paths
Nodes
Relationships

Neo4j

Traversal Framework – Java API

- **TraversalDescription**
  - The main interface used for defining and initializing traversals
  - Not meant to be implemented by users
    - Just used
  - Can specify branch ordering
    - **`breadthFirst()`** / **`depthFirst()`**
- **Relationships**
  - Adds a relationship type to traverse
    - Empty (default) = traverse all relationships
    - At least one in the list = traverse the specified ones
  - Two methods: including / excluding direction
    - **`Direction.BOTH`**
    - **`Direction.INCOMING`**
    - **`Direction.OUTGOING`**

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Traversal Framework – Java API

- **Evaluator**
  - Used for deciding at each position: should the traversal continue, and/or should the node be included in the result
  - Actions:
    - **`Evaluation.INCLUDE_AND_CONTINUE`**: Include this node in the result and continue the traversal
    - **`Evaluation.INCLUDE_AND_PRUNE`**: Include this node in the result, but do not continue the traversal
    - **`Evaluation.EXCLUDE_AND_CONTINUE`**: Exclude this node from the result, but continue the traversal
    - **`Evaluation.EXCLUDE_AND_PRUNE`**: Exclude this node from the result and do not continue the traversal
  - Pre-defined evaluators:
    - **`Evaluators.excludeStartPosition()`**
    - **`Evaluators.toDepth(int depth)`** / **`Evaluators.fromDepth(int depth)`**
    - …

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Traversal Framework – Java API

- **Uniqueness**
  - Can be supplied to the `TraversalDescription`
  - Indicates under what circumstances a traversal may revisit the same position in the graph
    - **`NONE`**: Any position in the graph may be revisited.
    - **`NODE_GLOBAL`**: No node in the graph may be re-visited (default)
    - …
- **Traverser**
  - Traverser which is used to step through the results of a traversal
  - Steps can correspond to
    - **`Path`** (default)
    - **`Node`**
    - **`Relationship`**

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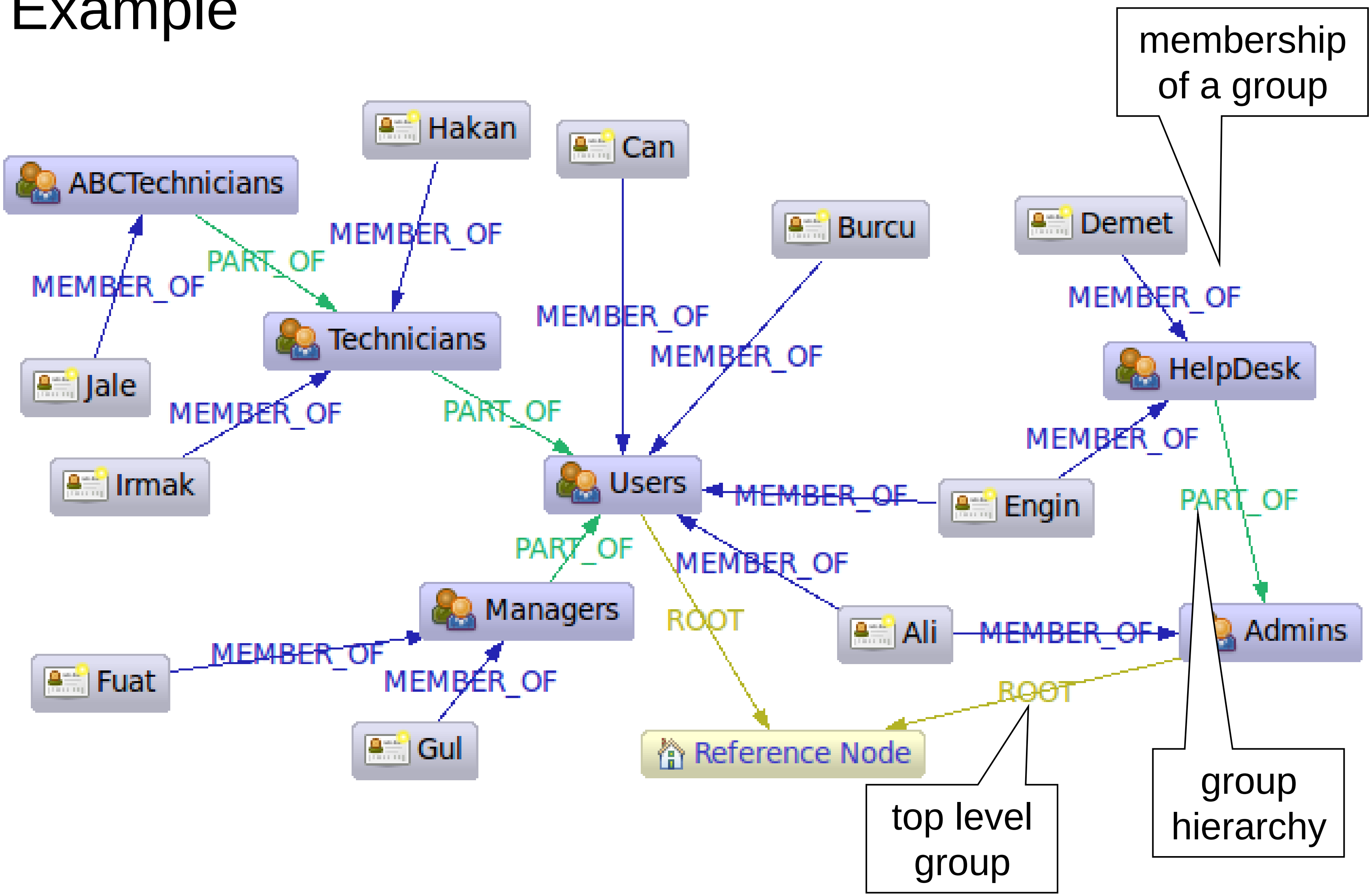
Example



Neo4j

Task 1. Get the Admins

```
Node admins = getNodeByName( "Admins" );
TraversalDescription traversalDescription = Traversal.description()
        .breadthFirst()
        .evaluator( Evaluators.excludeStartPosition() )
        .relationships( RoleRels.PART_OF, Direction.INCOMING )
        .relationships( RoleRels.MEMBER_OF, Direction.INCOMING );
Traverser traverser = traversalDescription.traverse( admins );

String output = "";
for ( Path path : traverser )
{
    Node node = path.endNode();
    output += "Found: "
            + node.getProperty( NAME ) + " at depth: "
            + ( path.length() - 1 ) + "\n";
}
```

```
Found: HelpDesk at depth: 0
Found: Ali at depth: 0
Found: Engin at depth: 1
Found: Demet at depth: 1
```

Neo4j

Task 2. Get Group Membership of a User

```
Node jale = getNodeByName( "Jale" );
traversalDescription = Traversal.description()
        .depthFirst()
        .evaluator( Evaluators.excludeStartPosition() )
        .relationships( RoleRels.MEMBER_OF, Direction.OUTGOING )
        .relationships( RoleRels.PART_OF, Direction.OUTGOING );
traverser = traversalDescription.traverse( jale );
```

```
Found: ABCTechnicians at depth: 0
Found: Technicians at depth: 1
Found: Users at depth: 2
```

Neo4j

Task 3. Get All Groups

```
Node referenceNode = getNodeByName( "Reference_Node" ) ;
traversalDescription = Traversal.description()
        .breadthFirst()
        .evaluator( Evaluators.excludeStartPosition() )
        .relationships( RoleRels.ROOT, Direction.INCOMING )
        .relationships( RoleRels.PART_OF, Direction.INCOMING );
traverser = traversalDescription.traverse( referenceNode );
```

```
Found: Admins at depth: 0
Found: Users at depth: 0
Found: HelpDesk at depth: 1
Found: Managers at depth: 1
Found: Technicians at depth: 1
Found: ABCTechnicians at depth: 2
```

Neo4j

Task 4. Get All Members of a Group

```
Node referenceNode = getNodeByName( "Reference_Node" ) ;
traversalDescription = Traversal.description()
        .breadthFirst()
        .evaluator(
                Evaluators.includeWhereLastRelationshipTypeIs
                        ( RoleRels.MEMBER_OF ) );
traverser = traversalDescription.traverse( referenceNode );
```

```
Found: Ali at depth: 1
Found: Engin at depth: 1
Found: Burcu at depth: 1
Found: Can at depth: 1
Found: Demet at depth: 2
Found: Gul at depth: 2
Found: Fuat at depth: 2
Found: Hakan at depth: 2
Found: Irmak at depth: 2
Found: Jale at depth: 3
```

Cypher

- Neo4j graph query language
  - For querying and updating
- Still growing = syntax changes are probable
- Declarative – we describe what we want, not how to get it
  - Not necessary to express traversals
- Human-readable
  - Inspired by SQL and SPARQL

http://docs.neo4j.org/chunked/stable/cypher-query-lang.html

Cypher Clauses

- START: Starting points in the graph, obtained via index lookups or by element IDs.
- MATCH: The graph pattern to match, bound to the starting points in START.
- WHERE: Filtering criteria.
- RETURN: What to return.
- CREATE: Creates nodes and relationships.
- DELETE: Removes nodes, relationships and properties.
- SET: Set values to properties.
- FOREACH: Performs updating actions once per element in a list.
- WITH: Divides a query into multiple, distinct parts.

Cypher Examples

Creating Nodes

```
CREATE n

(empty result)
Nodes created: 1
```

```
CREATE (a {name : 'Andres'})
RETURN a

a
Node[2]{name:"Andres"}
1 row
Nodes created: 1
Properties set: 1
```

```
CREATE (n  {name : 'Andres', title : 'Developer'})

(empty result)
Nodes created: 1
Properties set: 2
```

Cypher Examples

Creating Relationships

```
START a=node(1), b=node(2)
CREATE a-[r:RELTYPE]->b
RETURN r
```

```
r
:RELTYPE[1] {}
1 row
Relationships created: 1
```

```
START a=node(1), b=node(2)
CREATE a-[r:RELTYPE {name : a.name + '<->' + b.name }]->b
RETURN r
```

```
r
:RELTYPE[1] {name:"Andres<->Michael"}
1 row
Relationships created: 1
Properties set: 1
```

Cypher Examples

Creating Paths

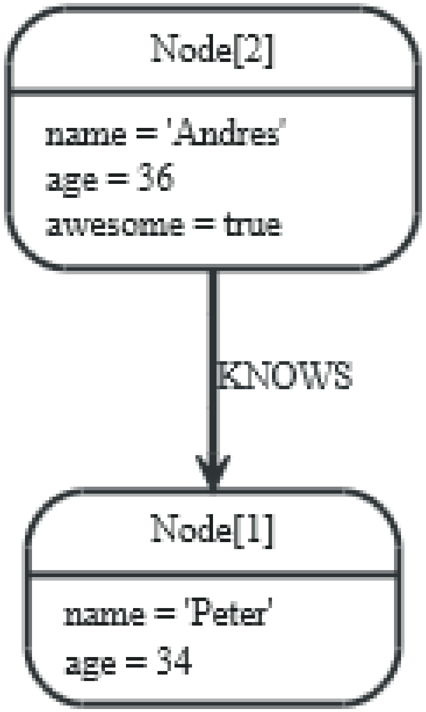
```
CREATE p = (andres {name:'Andres'})-[:WORKS_AT]->neo<-
   [:WORKS_AT]-(michael {name:'Michael'})
RETURN p
```

```
p
[Node[4]{name:"Andres"},:WORKS_AT[2]
   {},Node[5]{},:WORKS_AT[3] {},Node[6]{name:"Michael"}]
1 row
Nodes created: 3
Relationships created: 2
Properties set: 2
```

all parts of the pattern not already in scope are created

Cypher Examples

Changing Properties




```
START n = node(2)
SET n.surname = 'Taylor'
RETURN n
```

```
n
Node[2]{name:"Andres",age:36,awesome:true,surname:"Taylor"}
1 row
Properties set: 1
```

```
START n = node(2)
SET n.name = null
RETURN n
```

```
n
Node[2]{age:36,awesome:true}
1 row
Properties set: 1
```

Cypher Examples

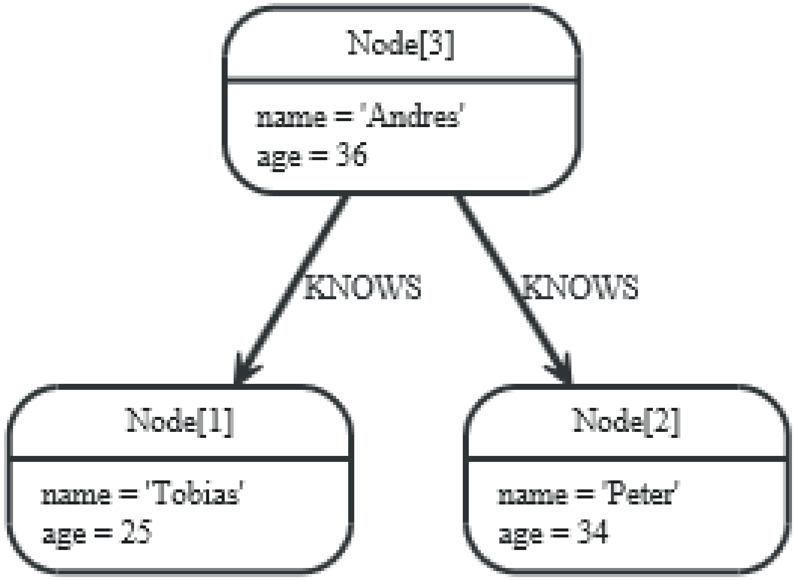
Delete

```
START n = node(4)
DELETE n
```

```
(empty result)
Nodes deleted: 1
```

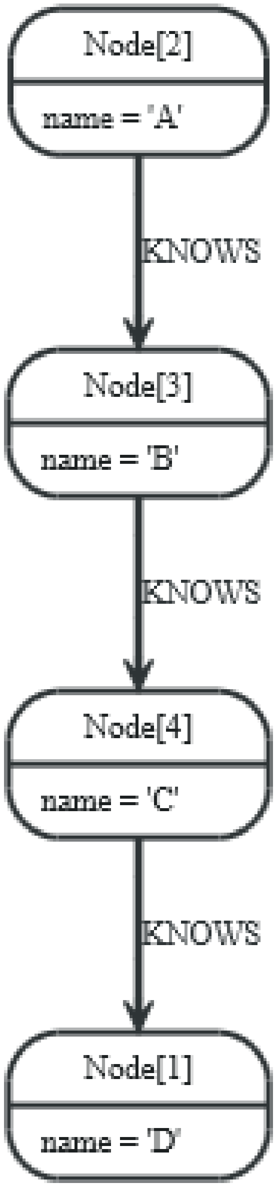
```
START n = node(3)
MATCH n-[r]-()
DELETE n, r
```

```
(empty result)
Nodes deleted: 1
Relationships deleted: 2
```



Cypher Examples

Foreach




```
START begin = node(2), end = node(1)
MATCH p = begin -[*]-> end foreach(n in nodes(p) :
SET n.marked = true)
```

```
(empty result)
Properties set: 4
```

can be combined with any update command

Cypher Examples

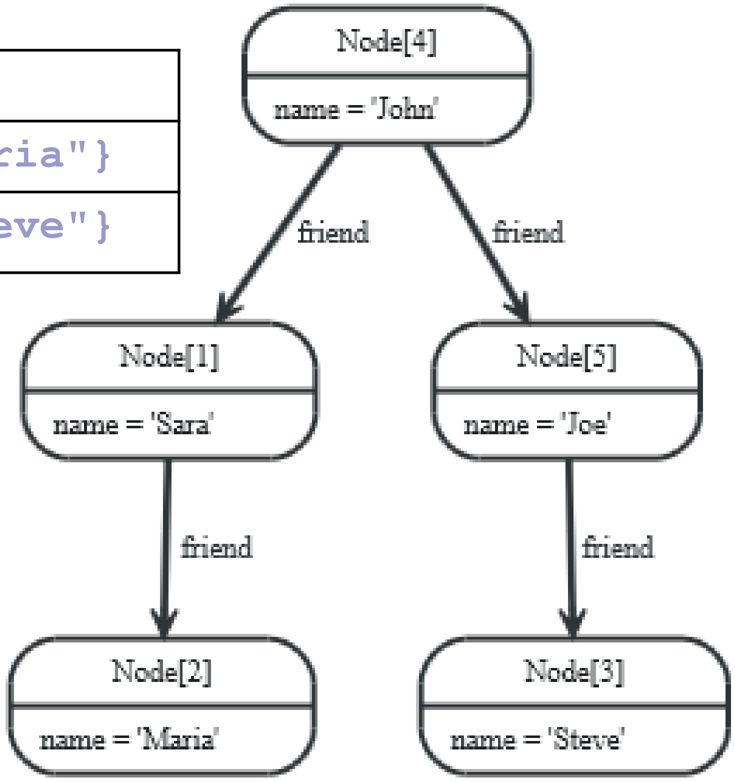
Querying

in general: **node:index-name(key = "value")**

```
START john=node:node_auto_index(name = 'John')
MATCH john-[:friend]->()-[:friend]->fof
RETURN john, fof
```

john	fof
Node[4]{name:"John"}	Node[2]{name:"Maria"}
Node[4]{name:"John"}	Node[3]{name:"Steve"}

```
neo4j.properties file:
...
node_auto_indexing=true
relationship_auto_indexing=true
node_keys_indexable=name,phone
relationship_keys_indexable=since
...
```



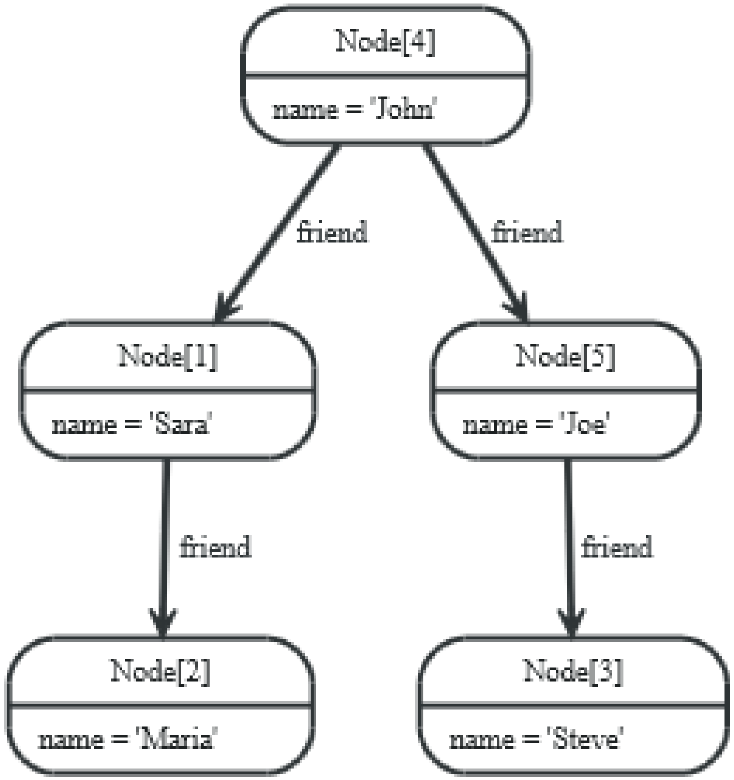
Cypher Examples

Querying

```
START user=node(5,4,1,2,3)
MATCH user-[:friend]->follower
WHERE follower.name =~ 'S.*'
RETURN user, follower.name
```

List of users

user	follower.name
Node[5]{name:"Joe"}	"Steve"
Node[4]{name:"John"}	"Sara"



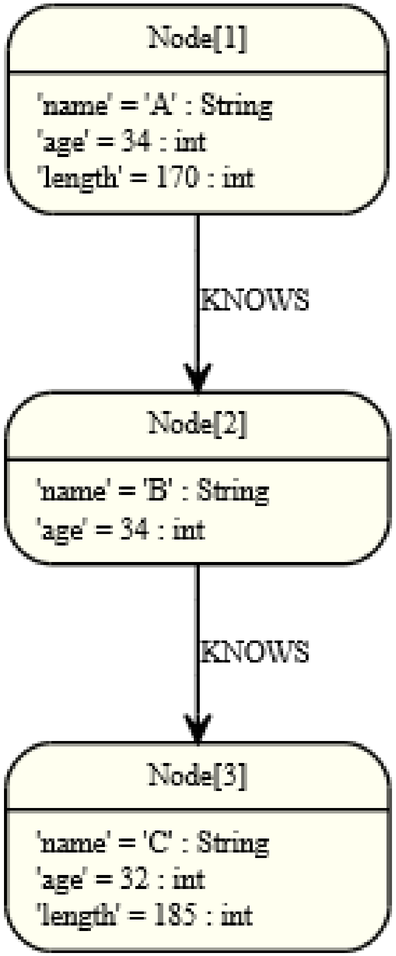
Cypher Examples

Order by

```
START n=node(3,1,2)
RETURN n
ORDER BY n.name
```

We can use:
- multiple properties
- asc/desc

n
Node[1]{name->"A",age->34,length->170}
Node[2]{name->"B",age->34}
Node[3]{name->"C",age->32,length->185}



Cypher Examples

Count

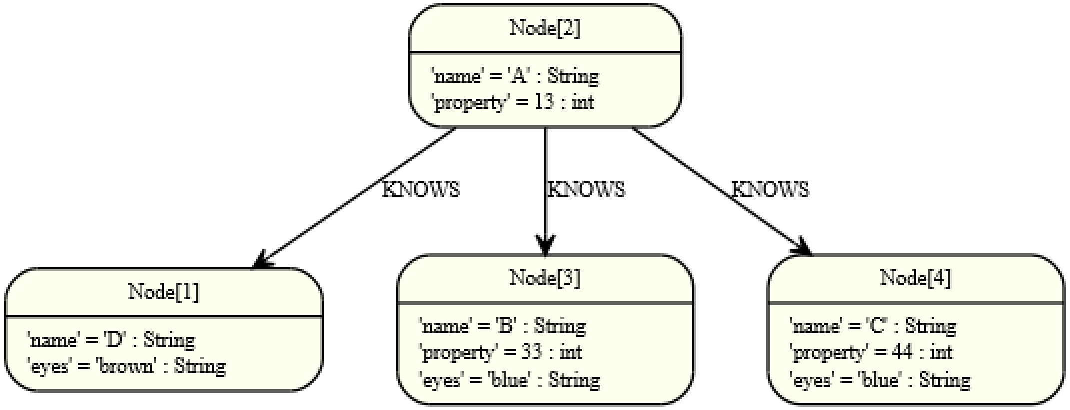
```
START n=node(2)
MATCH (n)-->(x)
RETURN n, count(*)
```

n	count(*)
Node[2]{name->"A",property->13}	3

```
START n=node(2)
MATCH (n)-[r]->()
RETURN type(r), count(*)
```

TYPE(r)	count(*)
"KNOWS"	3

count the groups of relationship types



Cypher

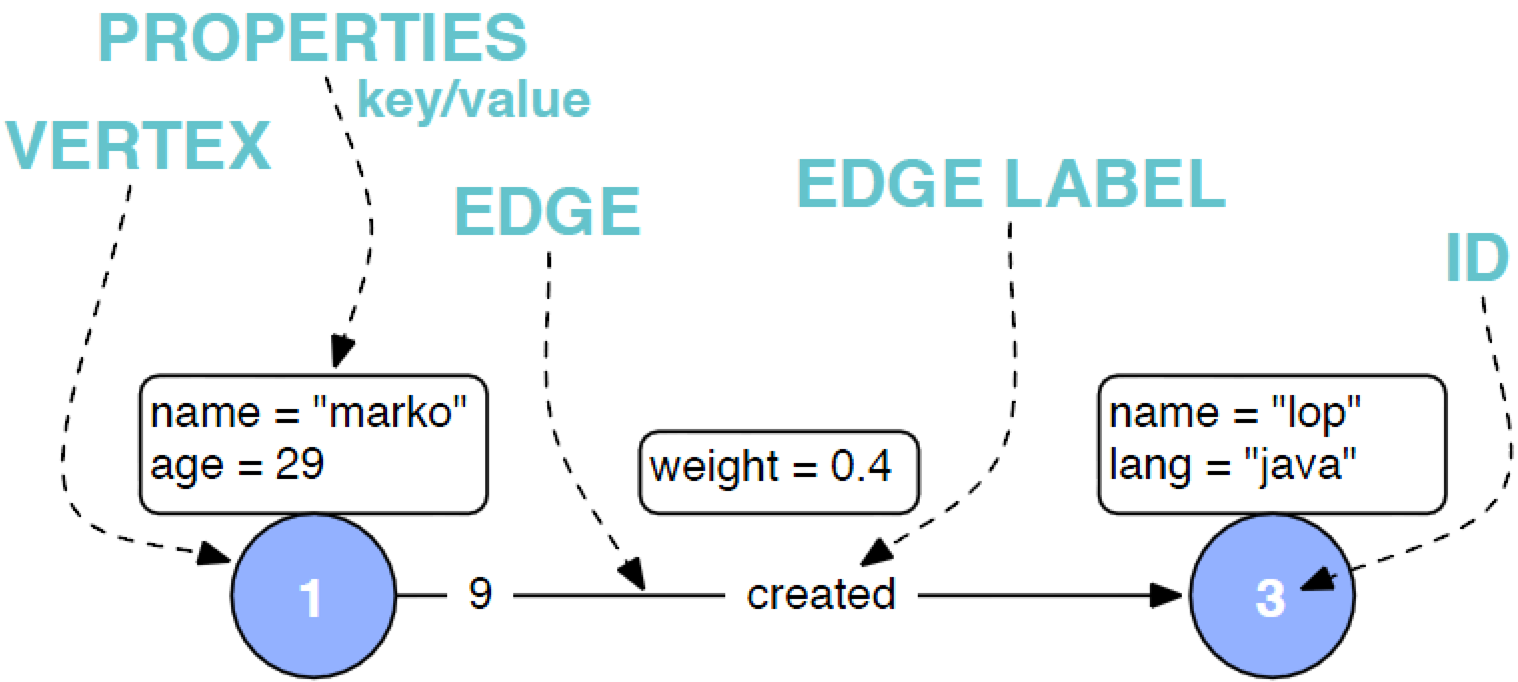
- And there are many other features
  - Other aggregation functions
    - Count, sum, avg, max, min
  - LIMIT n - returns only subsets of the total result
    - SKIP n = trimmed from the top
    - Often combined with order by
  - Predicates ALL and ANY
  - Functions
    - LENGTH of a path, TYPE of a relationship, ID of node/relationship, NODES of a path, RELATIONSHIPS of a path, …
  - Operators
  - …

Gremlin

- Gremlin = graph traversal language for traversing property graphs
  - Maintained by TinkerPop
    - Open source software development group
    - Focuses on technologies related to graph databases
  - Implemented by most graph database vendors
  - Neo4j Gremlin Plugin
- Scripts are executed on the server database
- Results are returned as Neo4j `Node` and `Relationship` representations

http://gremlindocs.com/

Gremlin
Property Graph



http://www.slideshare.net/sakrsherif/gremlin

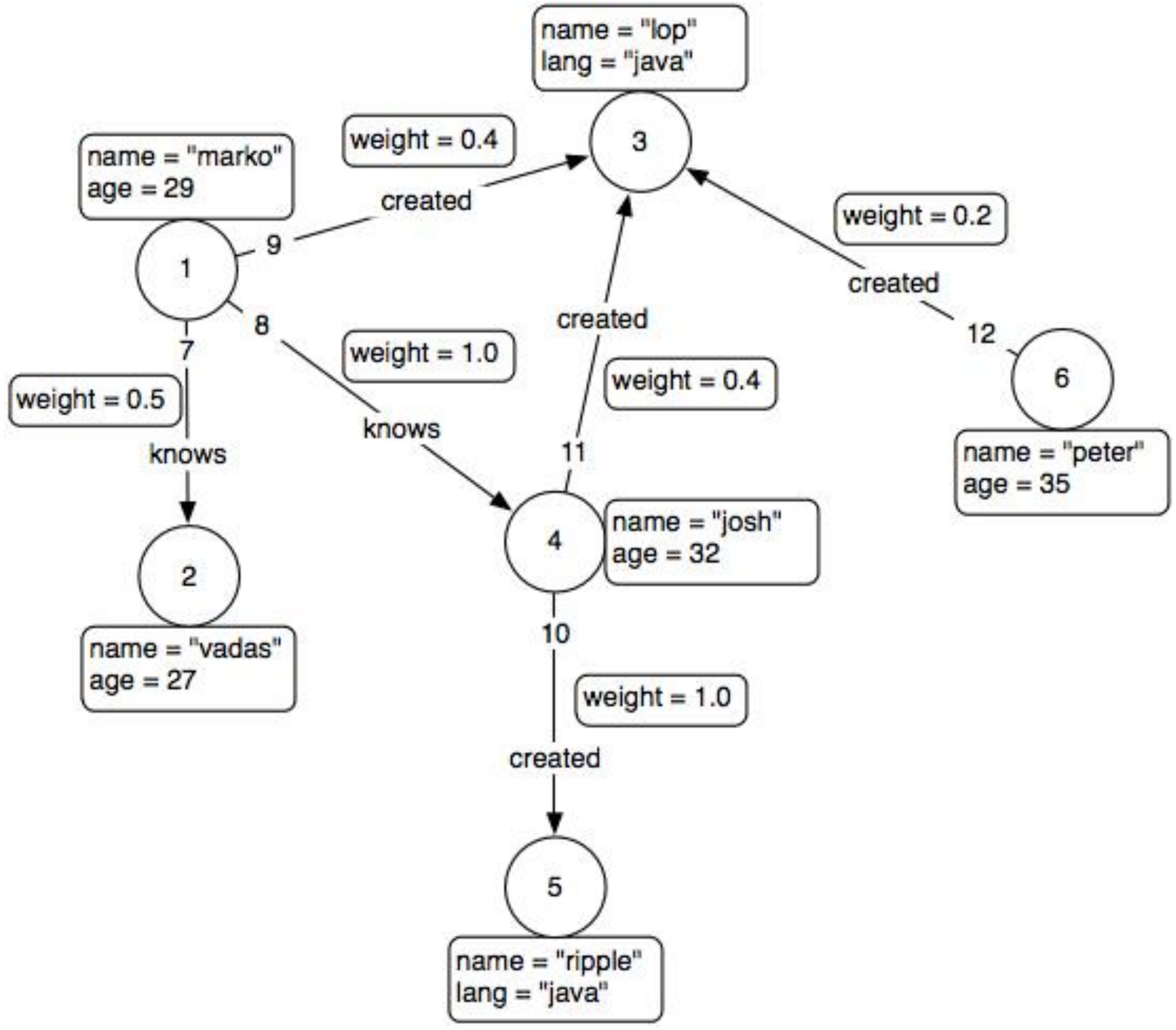
TinkerPop and Related Stuff

- Blueprints – interface for graph databases
  - Like ODBC (JDBC) for graph databases
- Pipes – dataflow framework for evaluating graph traversals
- Groovy – superset of Java used by Gremlin as a host language

http://groovy.codehaus.org/ http://www.tinkerpop.com/

Gremlin

Examples



https://github.com/tinkerpop/gremlin/wiki/Basic-Graph-Traversals

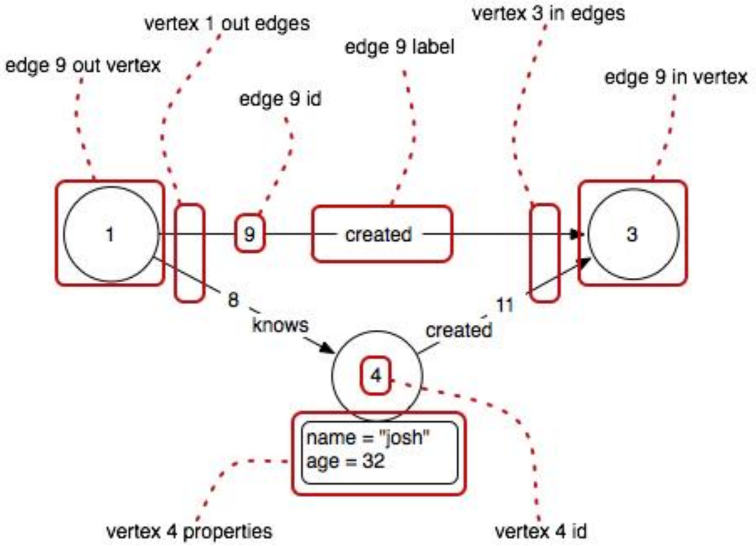
Gremlin

Examples

```
gremlin> g = new Neo4jGraph('I:\\tmp\\myDB.graphdb')
==> neo4jgraph[EmbeddedGraphDatabase[I:\tmp\myDB.graphdb]]
gremlin> v = g.v(1)
==>v[1]
gremlin> v.outE
==>e[7][1-knows->2]
==>e[9][1-created->3]
==>e[8][1-knows->4]
gremlin> v.outE.inV
==>v[2]
==>v[3]
==>v[4]
gremlin> v.outE.inV.outE.inV
==>v[5]
==>v[3]
```

Gremlin steps:

- adjacency: outE, inE, bothE, outV, inV, bothV
- to skip edges: out, in, and both



Gremlin

Examples

variable

```
gremlin> v = g.v(1)
==>v[1]
gremlin> v.name
==>marko
gremlin> v.outE('knows').inV.filter{it.age > 30}.name
==>josh
gremlin> v.out('knows').filter{it.age >
   21}.as('x').name.filter{it.matches('jo.{2}|JO.{2}')}.bac
   k('x').age
==>32
```

regular expression

Gremlin

Examples

```
gremlin> g.v(1).note= "my friend" // set a property
==> my friend
gremlin> g.v(1).map                 // get property map
==> {name=marko, age=29, note=my friend}
gremlin> v1= g.addVertex([name: "irena"])
==> v[7]
gremlin> v2 = g.v(1)
==> v[1]
gremlin> g.addEdge(v1, v2, 'knows')
==> e[7][7-knows->1]
```

More on Internals

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Transaction Management

- Support for ACID properties
- All write operations that work with the graph must be performed in a transaction
  - Can have nested transactions
  - Rollback of nested transaction $\Rightarrow$ rollback of the whole transaction
- Required steps:
  1. Begin a transaction
  2. Operate on the graph performing write operations
  3. Mark the transaction as successful or not
  4. Finish the transaction
     - Memory + locks are released (= necessary step)

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Transaction Example

```
// all writes (creating, deleting and updating any data)
// have to be performed in a transaction,
// otherwise NotInTransactionException

Transaction tx = graphDb.beginTx();
try
{
    // updating operations go here
    tx.success();          // transaction is committed on close
}
catch (Exception e)
{
    tx.failure();          // transaction is rolled back on close
}
finally
{
    tx.close();            // or deprecated tx.finish()
}
```

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Transaction Management – Read

- Default:
  - Read operation reads the last committed value
  - Reads do not block or take any locks
    - Non-repeatable reads can occur
      - A row is retrieved twice and the values within the row differ between reads
- Higher level of isolation: read locks can be acquired explicitly

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Transaction Management – Write

- All modifications performed in a transaction are kept in memory
  - Very large updates have to be split
- Default locking:
  - Adding/changing/removing a property of a node/relationship $\Rightarrow$ write lock on the node/relationship
  - Creating/deleting a node $\Rightarrow$ write lock on the specific node
  - Creating/deleting a relationship $\Rightarrow$ write lock on the relationship + its nodes
- Deadlocks:
  - Can occur
  - Are detected and an exception is thrown

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Transaction Management – Delete Semantics

- Node/relationship is deleted $\Rightarrow$ all properties are removed
- Deleted node can not have any attached relationships
  - Otherwise an exception is thrown
- Write operation on a node or relationship after it has been deleted (but not yet committed) $\Rightarrow$ exception
  - It is possible to acquire a reference to a deleted relationship / node that has not yet been committed
  - After commit, trying to acquire new / work with old reference to a deleted node / relationship $\Rightarrow$ exception

Neo4j

Indexing

- Index
  - Has a unique, user-specified name
  - Indexed entities = nodes / relationships
- Index = associating any number of key-value pairs with any number of entities
  - We can index a node / relationship with several key-value pairs that have the same key

    $\Rightarrow$ An old value must be deleted to set new (otherwise we have both)

Neo4j

Indexing – Create / Delete Index

```
graphDb = new
   GraphDatabaseFactory().newEmbeddedDatabase(DB_PATH);
IndexManager index = graphDb.index();

// check existence of an index
boolean indexExists = index.existsForNodes("actors");

// create three indexes
Index<Node> actors = index.forNodes("actors");
Index<Node> movies = index.forNodes("movies");
RelationshipIndex roles = index.forRelationships("roles");

// delete index
actors.delete();
```

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Indexing – Add Nodes

```
Node reeves = graphDb.createNode();
reeves.setProperty("name", "Keanu Reeves");
actors.add(reeves, "name", reeves.getProperty("name"));

Node bellucci = graphDb.createNode();
bellucci.setProperty("name", "Monica Bellucci");

// multiple index values for a field
actors.add(bellucci, "name", bellucci.getProperty("name"));
actors.add(bellucci, "name", "La Bellucci");

Node matrix = graphDb.createNode();
matrix.setProperty("title", "The Matrix");
matrix.setProperty("year", 1999);
movies.add(matrix, "title", matrix.getProperty("title"));
movies.add(matrix, "year", matrix.getProperty("year"));
```

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Indexing – Add Relationships, Remove

```
Relationship role1 =
   reeves.createRelationshipTo(matrix, ACTS_IN);
role1.setProperty("name", "Neo");
roles.add(role1, "name", role1.getProperty("name"));

// completely remove bellucci from actors index
actors.remove( bellucci );
// remove any "name" entry of bellucci from actors index
actors.remove( bellucci, "name" );
// remove the "name" -> "La Bellucci" entry of bellucci
actors.remove( bellucci, "name", "La Bellucci" );
```

3 options for removal

Neo4j

Indexing – Update

```
Node fishburn = graphDb.createNode();
fishburn.setProperty("name", "Fishburn");

// add to index
actors.add(fishburn, "name", fishburn.getProperty("name"));

// update the index entry when the property value changes
actors.remove
   (fishburn, "name", fishburn.getProperty("name"));
fishburn.setProperty("name", "Laurence Fishburn");
actors.add(fishburn, "name", fishburn.getProperty("name"));
```

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Indexing – Search using `get()`

```
// get single exact match
IndexHits<Node> hits = actors.get("name", "Keanu Reeves");
Node reeves = hits.getSingle();

Relationship persephone =
   roles.get("name", "Persephone").getSingle();
Node actor = persephone.getStartNode();
Node movie = persephone.getEndNode();

// iterate over all exact matches from index
for ( Relationship role : roles.get("name", "Neo") )
{
    // this will give us Reeves e.g. twice
    Node reeves = role.getStartNode();
}
```

iterator

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Indexing – Search using **`query()`**

```
for ( Node a : actors.query("name", "*e*"))
{
    // This will return Reeves and Bellucci
}

for (Node m : movies.query("title:*Matrix* AND year:1999"))
{
    // This will return "The Matrix" from 1999 only
}
```

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Indexing – Search for Relationships

```
// find relationships filtering on start node (exact match)
IndexHits<Relationship> reevesAsNeoHits =
   roles.get("name", "Neo", reeves, null);
Relationship reevesAsNeo =
   reevesAsNeoHits.iterator().next();
reevesAsNeoHits.close();

// find relationships filtering on end node (using a query)
IndexHits<Relationship> matrixNeoHits =
   roles.query( "name", "*eo", null, theMatrix );
Relationship matrixNeo = matrixNeoHits.iterator().next();
matrixNeoHits.close();
```

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Automatic Indexing

- One automatic index for nodes and one for relationships
  - Follow property values
  - By default off
- We can specify properties of nodes / edges which are automatically indexed
  - We do not need to add them explicitly
- The index can be queried as any other index

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Automatic Indexing – Setting (Option 1)

```
GraphDatabaseService graphDb =
   new GraphDatabaseFactory().
   newEmbeddedDatabaseBuilder(storeDirectory).
   setConfig(GraphDatabaseSettings.node_keys_indexable,
       "nodeProp1,nodeProp2").
   setConfig(
   GraphDatabaseSettings.relationship_keys_indexable,
       "relProp1,relProp2").
   setConfig(GraphDatabaseSettings.node_auto_indexing,
       "true").
   setConfig(GraphDatabaseSettings.relationship_auto_indexing,
       "true").
   newGraphDatabase();
```

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Automatic Indexing – Setting (Option 2)

```
// start without any configuration
GraphDatabaseService graphDb = new GraphDatabaseFactory()
   .newEmbeddedDatabase(storeDirectory);

// get Node AutoIndexer, set nodeProp1, nodeProp2 as auto indexed
AutoIndexer<Node> nodeAutoIndexer =
   graphDb.index().getNodeAutoIndexer();
nodeAutoIndexer.startAutoIndexingProperty("nodeProp1");
nodeAutoIndexer.startAutoIndexingProperty("nodeProp2");

// get Relationship AutoIndexer, set relProp1 as auto indexed
AutoIndexer<Relationship> relAutoIndexer = graphDb.index()
   .getRelationshipAutoIndexer();
relAutoIndexer.startAutoIndexingProperty("relProp1");

// none of the AutoIndexers are enabled so far - do that now
nodeAutoIndexer.setEnabled(true);
relAutoIndexer.setEnabled(true);
```

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Automatic Indexing – Search

```
// create the primitives
node1 = graphDb.createNode();
node2 = graphDb.createNode();
rel = node1.createRelationshipTo(node2,
      DynamicRelationshipType.withName("DYNAMIC") );

// add indexable and non-indexable properties
node1.setProperty("nodeProp1", "nodeProp1Value");
node2.setProperty("nodeProp2", "nodeProp2Value");
node1.setProperty("nonIndexed", "nodeProp2NonIndexedValue");
rel.setProperty("relProp1", "relProp1Value");
rel.setProperty("relPropNonIndexed",
                "relPropValueNonIndexed");
```

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Automatic Indexing – Search

```
// Get the Node auto index
ReadableIndex<Node> autoNodeIndex = graphDb.index()
        .getNodeAutoIndexer().getAutoIndex();

// node1 and node2 both had auto indexed properties, get them
assertEquals(node1,
   autoNodeIndex.get("nodeProp1", "nodeProp1Value")
       .getSingle());
assertEquals(node2,
   autoNodeIndex.get("nodeProp2", "nodeProp2Value")
       .getSingle());

// node2 also had a property that should be ignored.
assertFalse(autoNodeIndex.get("nonIndexed",
   "nodeProp2NonIndexedValue").hasNext());
```

Neo4j

Data Size

nodes	2^{35} (~ 34 billion)
relationships	2^{35} (~ 34 billion)
properties	2^{36} to 2^{38} depending on property types (maximum ~ 274 billion, always at least ~ 68 billion)
relationship types	2^{15} (~ 32 000)

Neo4j

High Availability (HA)

- Provides the following features:
  - Enables a fault-tolerant database architecture
    - Several Neo4j slave databases can be configured to be exact replicas of a single Neo4j master database
  - Enables a horizontally scaling read-mostly architecture
    - Enables the system to handle more read load than a single Neo4j database instance can handle
- Transactions are still atomic, consistent and durable, but eventually propagated out to other slaves

Neo4j

High Availability

- Transition from single machine to multi machine operation is simple
  - No need to change existing applications
  - Switch from **`GraphDatabaseFactory`** to **`HighlyAvailableGraphDatabaseFactory`**
    - Both implement the same interface
- Always one master and zero or more slaves
  - Write on master: eventually propagated to slaves
    - All other ACID properties remain the same
  - Write on slave: (immediate) synchronization with master
    - Slave has to be up-to-date with master
    - Operation must be performed on both

Neo4j

High Availability

- Each database instance contains the logic needed in order to coordinate with other members
- On startup Neo4j HA database instance will try to connect to an existing cluster specified by configuration
  - If the cluster exists, it becomes a slave
  - Otherwise, it becomes a master
- Failure:
  - Slave – other nodes recognize it
  - Master – a slave is elected as a new master
- Recovery:
  - Slave – synchronizes with the cluster
  - Old master – becomes a slave

References

- Neo4j http://www.neo4j.org/
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- Neo4j Gremlin Plugin http://docs.neo4j.org/chunked/stable/gremlin-plugin.html
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