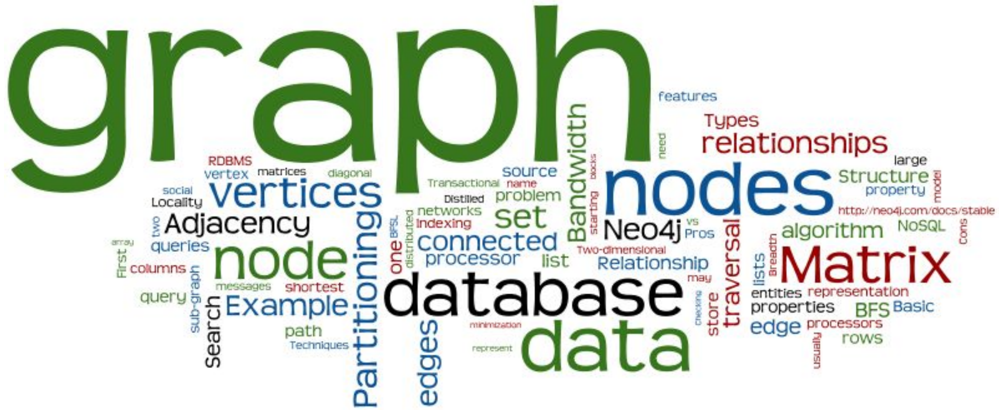


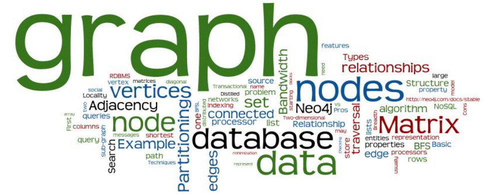
Graph Databases

Lecture 8 of *NoSQL Databases* (PA195)

David Novak & Vlastislav Dohnal
Faculty of Informatics, Masaryk University, Brno

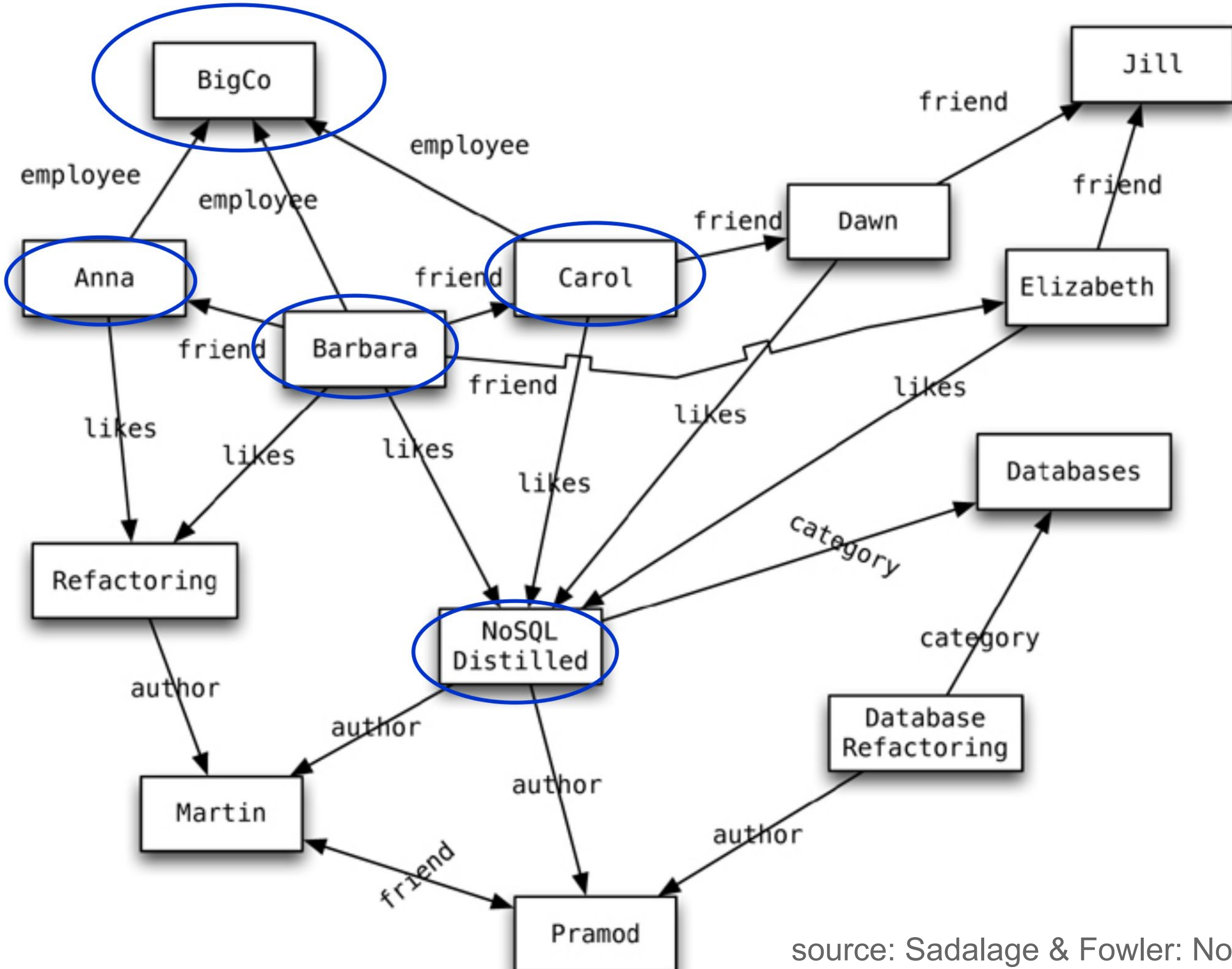
http://disa.fi.muni.cz/vlastislav-dohnal/teaching/nosql-databases-fall-2019/

Agenda



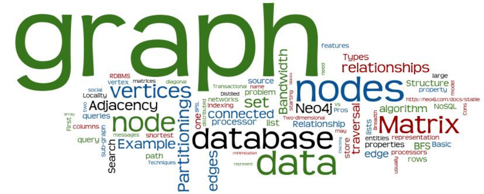
- Graph Databases: Mission, Data, Example
- A Bit of Graph Theory
  - Graph Representations
  - Algorithms: Improving Data Locality (efficient storage)
  - Graph Partitioning and Traversal Algorithms
- Graph Databases
  - Transactional databases
  - Non-transactional databases
- Neo4j
  - Basics, Native Java API, Cypher, Behind the Scene

Graph Databases: Example



source: Sadalage & Fowler: NoSQL Distilled, 2012

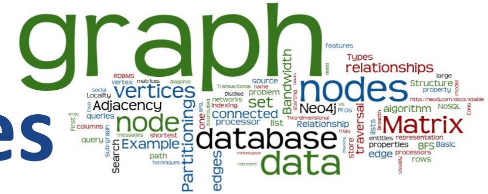
Graph Databases: Mission



- To store entities and relationships between them
  - Nodes are instances of objects
  - Nodes have properties, e.g., name
  - Edges connect nodes and have directional significance
  - Edges have types e.g., likes, friend, …

- Nodes are organized by relationships
  - Allow to find interesting patterns
  - **example:** Get all nodes that are “employee” of “Big Company” and that “likes” “NoSQL Distilled”

Graph Databases: Representatives



Neo4j

OrientDB

APACHE GIRAPH

TITAN

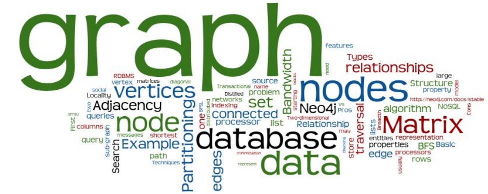
InfiniteGraph

Ranked list: http://db-engines.com/en/ranking/graph+dbms

A Bit of a Theory

Basics and graph representations

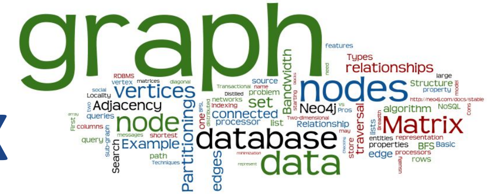
Basic Terminology



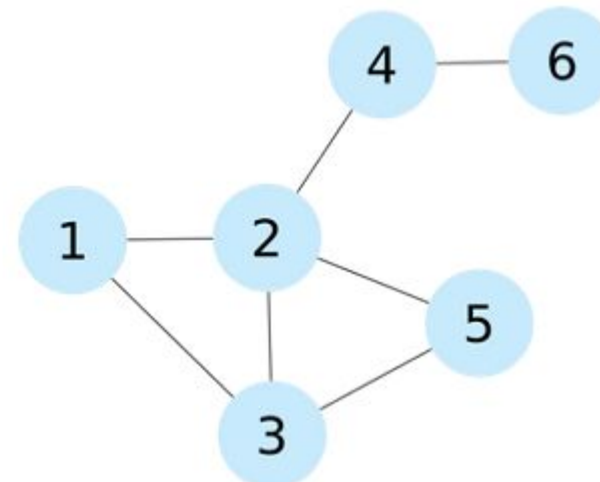
- Data: a set of entities and their relationships
  - => we need to efficiently represent graphs
- Basic operations:
    - finding the neighbours of a node,
    - checking if two nodes are connected by an edge,
    - updating the graph structure, …
  - => we need efficient graph operations

- Graph $G = (V, E)$ is usually modelled as
  - set of nodes (vertices) V, $|V| = n$
  - set of (directed) edges $E = (V_1,V_2)$, $|E| = m$
- Which data structure to use?

Data Structure: Adjacency Matrix



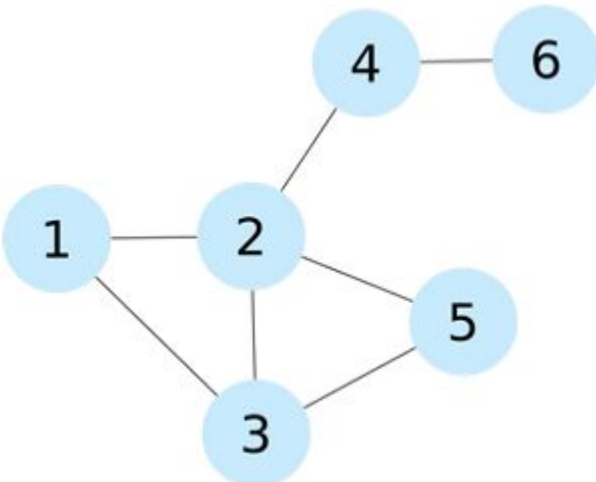
- Two-dimensional array A of $n \times n$ Boolean values
  - Indexes of the array = node identifiers of the graph
  - Boolean value A_{ij} indicates whether nodes i, j are connected



$$\begin{pmatrix} 0 & 1 & 1 & 0 & 0 & 0 \\ 1 & 0 & 1 & 1 & 1 & 0 \\ 1 & 1 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 & 0 & 1 \\ 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \end{pmatrix}$$

- Variants:
  - (Un)directed graphs
  - Weighted graphs…

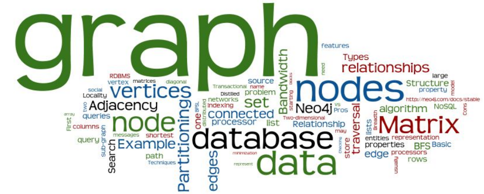
Adjacency Matrix: Properties



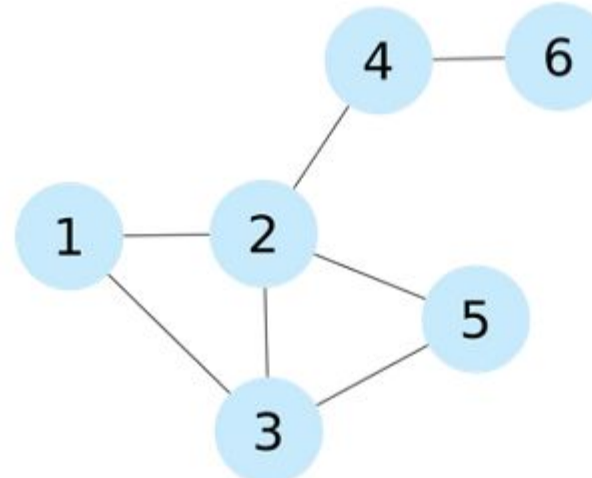
$$\begin{pmatrix} 0 & 1 & 1 & 0 & 0 & 0 \\ 1 & 0 & 1 & 1 & 1 & 0 \\ 1 & 1 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 & 0 & 1 \\ 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \end{pmatrix}$$

- Pros:
  - Adding/removing edges
  - Checking if 2 nodes are connected
- Cons:
  - Quadratic space: $O(n^2)$
  - We usually have sparse graphs
  - Adding nodes is expensive
  - Retrieval of all the neighbouring nodes takes linear time: $O(n)$

Data Structure: Adjacency List



- A set of lists, each enumerating neighbours of one node
  - Vector of *n* pointers to adjacency lists
- Undirected graph:
  - An edge connects nodes *i* and *j*
  - => the adjacency list of *i* contains node *j* and vice versa
- Often compressed
  - Exploiting regularities in graphs



N1 → {N2, N3}

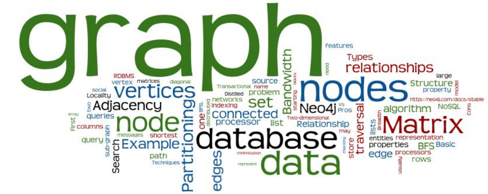
N2 → {N1, N3, N5}

N3 → {N1, N2, N5}

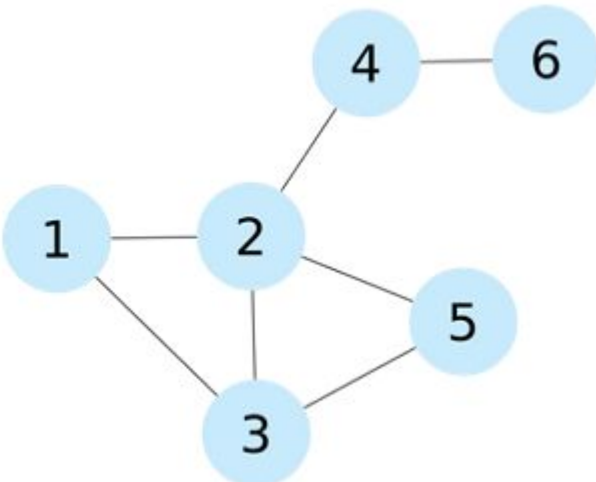
N4 → {N2, N6}

N5 → {N2, N3}

N6 → {N4}



Adjacency List: Properties



N1 → {N2, N3}

N2 → {N1, N3, N5}

N3 → {N1, N2, N5}

N4 → {N2, N6}

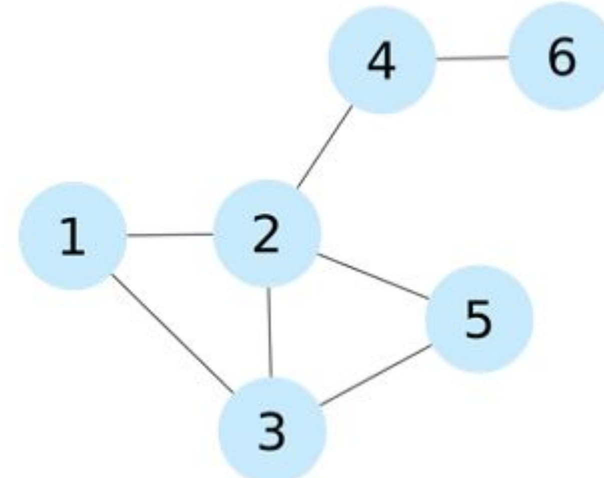
N5 → {N2, N3}

N6 → {N4}

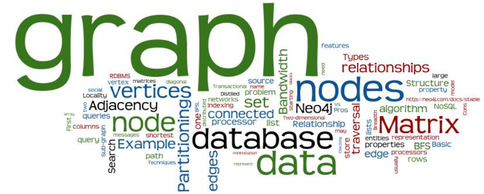
- Pros:
  - Getting the neighbours of a node
  - Cheap addition of nodes
  - More compact representation of sparse graphs
- Cons:
  - Checking if there is an edge between two nodes
    - Optimization: sorted lists => logarithmic scan, but also logarithmic insertion

Data Structure: Incidence Matrix

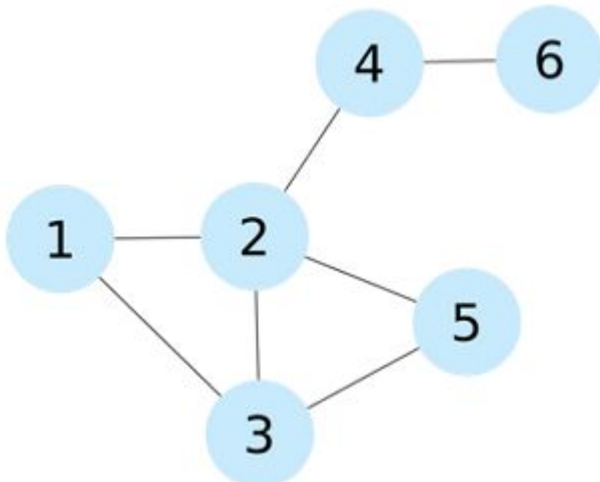
- Two-dimensional Boolean matrix of *n* rows and *m* columns
  - Each row represents a node
    - All edges that are connected to the node
  - Each column represents an edge
    - Nodes that are connected by a certain edge



$$\begin{pmatrix} 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & 1 & 1 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$



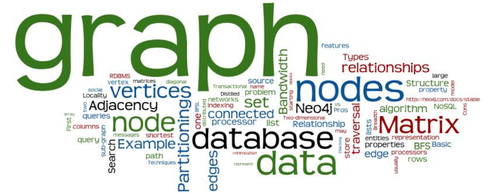
Incidence Matrix: Properties



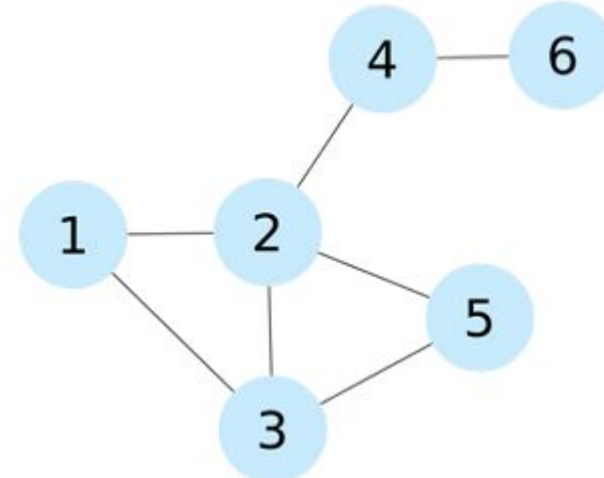
$$\begin{pmatrix} 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & 1 & 1 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

- Pros:
  - Representation of hypergraphs
    - where one edge connects an arbitrary number of nodes
- Cons:
  - Requires $n \times m$ bits (for most graphs $m \gg n$)
  - Listing neighborhood is slow

Data Structure: Laplacian Matrix

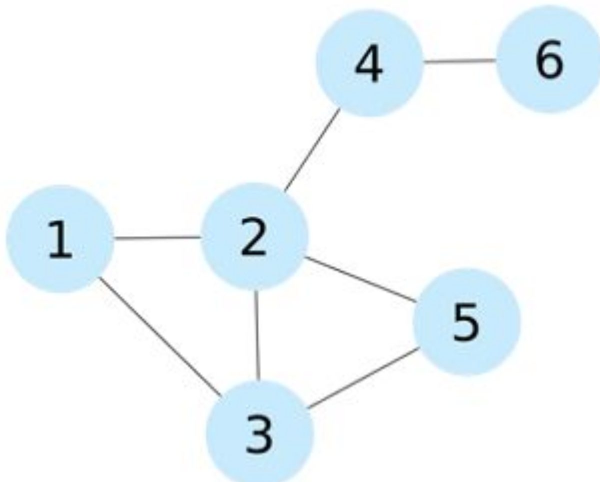


- Two-dimensional array of $n \times n$ integers
  - Similar structure as adjacency matrix
  - Diagonal of the Laplacian matrix indicates the degree of the node
  - The rest of positions are set to *-1* if the two vertices are connected, *0* otherwise



$$\begin{pmatrix} 2 & -1 & -1 & 0 & 0 & 0 \\ -1 & 4 & -1 & -1 & -1 & 0 \\ -1 & -1 & 3 & 0 & -1 & 0 \\ 0 & -1 & 0 & 2 & 0 & -1 \\ 0 & -1 & -1 & 0 & 2 & 0 \\ 0 & 0 & 0 & -1 & 0 & 1 \end{pmatrix}$$

Laplacian Matrix: Properties



$$\begin{pmatrix} 2 & -1 & -1 & 0 & 0 & 0 \\ -1 & 4 & -1 & -1 & -1 & 0 \\ -1 & -1 & 3 & 0 & -1 & 0 \\ 0 & -1 & 0 & 2 & 0 & -1 \\ 0 & -1 & -1 & 0 & 2 & 0 \\ 0 & 0 & 0 & -1 & 0 & 1 \end{pmatrix}$$

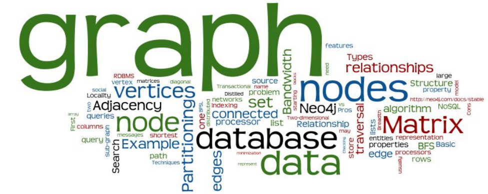
All features of adjacency matrix

- Pros:
  - Analyzing the graph structure by means of spectral analysis
    - Calculating the number of spanning trees
    - Approximation of the sparsest cut of the graph
    - Calculate eigenvalues of the matrix
  - A good summary: Wikipedia

A Bit of a Theory

Selected graph algorithms

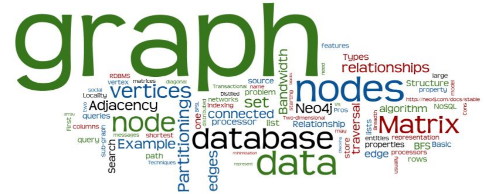
Basic Graph Algorithms



- Access all nodes reachable from given source:
  - Breadth-first Search (BFS)
  - Depth-first Search (DFS)
- Shortest path between two nodes
- Single-source shortest path problem
  - BFS (unweighted),
  - Dijkstra (nonnegative weights),
  - Bellman-Ford algorithm
- All-pairs shortest path problem
  - Floyd-Warshall algorithm

http://en.wikipedia.org/wiki/Shortest_path_problem

Improving Data Locality



- Performance of the read/write operations
  - Depends also on physical organization of the data
  - Objective: Achieve the best “data locality”

- Spatial locality:
  - if a data item has been accessed, the nearby data items are likely to be accessed in the following computations
    - e.g., during graph traversal

- Strategy:
  - in graph adjacency matrix representation, exchange rows and columns to improve the disk cache hit ratio
  - Specific methods: BFSL, Bandwidth of a Matrix, ...

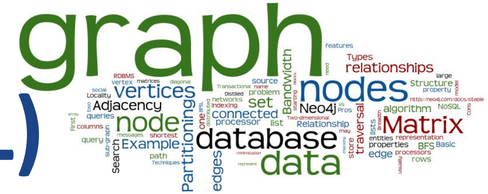
Data Locality: Example

$$\begin{pmatrix} 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 & 1 & 0 & 1 \\ 0 & 1 & 1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 & 0 & 1 & 0 & 1 \end{pmatrix}$$

$$\begin{pmatrix} 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 \end{pmatrix}$$

This matrix has better data locality, more efficient traversal

Breadth First Search Layout (BFSL)

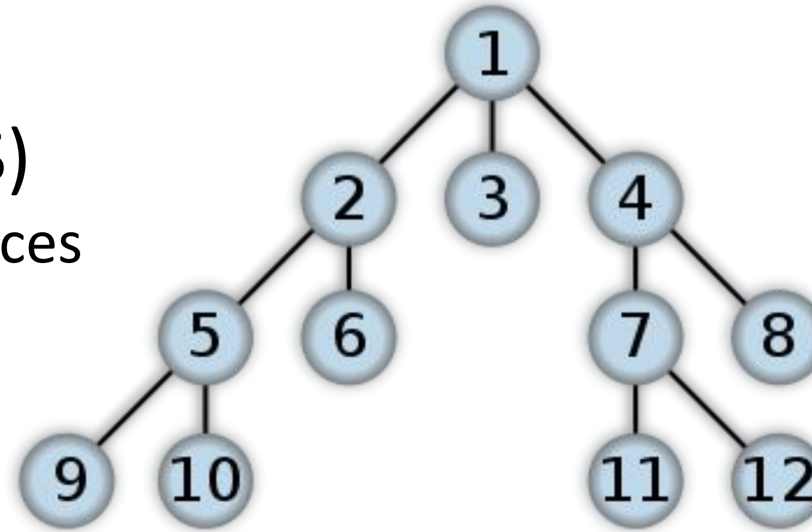


- Input: vertices of a graph
- Output: a permutation of the vertices
  - with better cache performance for graph traversals

- BFSL algorithm:
  1. Select a node (at random, the origin of the traversal)
  2. Traverse the graph using the BFS alg.
     - generating a list of vertex identifiers in the order they are visited
  3. Take the generated list as the new vertices permutation

Breadth First Search Layout (2)

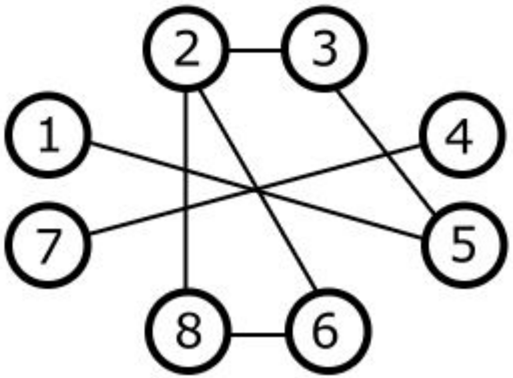
- Let us recall:
  Breadth First Search (BFS)
  - FIFO queue of frontier vertices

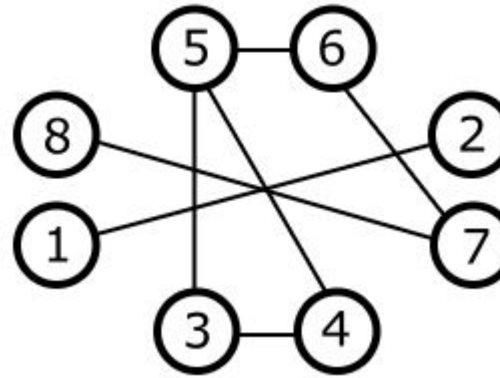


- Pros: optimal locality for traversal from the root
- Cons: starting traversal from other nodes
  - The further, the worse

Matrix Bandwidth: Motivation

- Graph represented by adjacency matrix

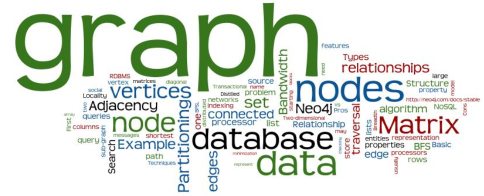




$$\begin{pmatrix} 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 & 1 & 0 & 1 \\ 0 & 1 & 1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 & 0 & 1 & 0 & 1 \end{pmatrix} \Rightarrow \begin{pmatrix} 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 \end{pmatrix}$$

Matrix Bandwidth: Formalization

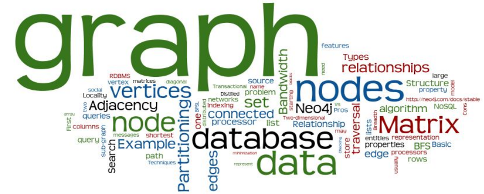
- The minimum bandwidth problem
  - Bandwidth of a row in a matrix = the maximum distance between nonzero elements, where one is left of the diagonal and the other is right of the diagonal
  - Bandwidth of a matrix = maximum bandwidth of its rows
- Low bandwidth matrices are more cache friendly
  - Non zero elements (edges) clustered about the diagonal
- Bandwidth minimization problem: NP hard
  - For large matrices the solutions are only approximated



A Bit of a Theory

Graph partitioning

Graph Partitioning



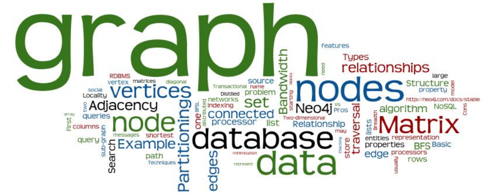
- Some graphs are too large to be fully loaded into the main memory of a single computer
  - Usage of secondary storage degrades the performance
  - Scalable solution: distribute the graph on multiple nodes

- We need to partition the graph reasonably
  - Usually for a particular (set of) operation(s)
    - The shortest path, finding frequent patterns, BFS, spanning tree search

Example: 1-Dimensional Partitioning

- Aim: Partition the graph to solve BFS efficiently
  - Distributed into shared-nothing parallel system
  - Partitioning of the adjacency matrix

- 1D partitioning of Adjacency Matrix:
  - Matrix rows are randomly assigned to the *P* nodes (processors) in the system
  - Each vertex (and its edges) are owned by one processor



	1	2	3	4	5	6	7	8	9	10	11	12
1	0	0	0	0	0	0	0	0	0	1	1	0
2	0	0	1	0	0	0	0	1	0	0	0	0
3	0	1	0	0	0	0	1	1	0	0	0	0
4	0	0	0	0	1	0	0	0	0	0	0	1
5	0	0	0	1	0	0	0	0	0	0	0	1
6	0	0	0	0	0	0	1	0	0	0	1	0
7	0	0	1	0	0	1	0	1	0	1	1	0
8	0	1	1	0	0	0	1	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	1	1
10	1	0	0	0	0	0	1	0	0	0	1	0
11	1	0	0	0	0	1	1	0	1	1	0	0
12	0	0	0	1	1	0	0	0	1	0	0	0

Starting BFS traversal at node 1:

1. (at black) 1 -> 10, 11
   visit green server
2. (at green) 10, 11 ->
   a. 1, back to black
   b. 6, visit red
   c. 7,9, visit blue
   d. 10, 11, myself
3. (at red) 6 -> 7
   visit blue
3. (at blue) 7,9 ->
   a. 3, back to black …
   b. 6, back to red
   c. 8 -> 2,3, back to black
   d. 10,11,12, back to green

Traversing Graph

- Traversing with 1D partitioning (e.g. BFS)
  1. Each **processor** keeps information about frontier vertices
  2. ...and also list of neighbouring vertices in other processors
  3. Messages are sent to other processors…

- 1D partitioning leads to high messaging
  - => 2D-partitioning of adjacency matrix
  - … lower messaging but still very demanding

Efficient sharding of a graph is very difficult

- and thus graph DBs are often centralized

Graph Databases

Types of Graphs

- Single-relational graphs
  - Edges are homogeneous in meaning
    - e.g., all edges represent friendship
- Multi-relational (property) graphs
  - Edges are typed or labeled
    - e.g., friendship, business, communication
  - Vertices and edges maintain a set of key/value pairs
    - Representation of non-graphical data (properties)
    - e.g., name of a vertex, the weight of an edge

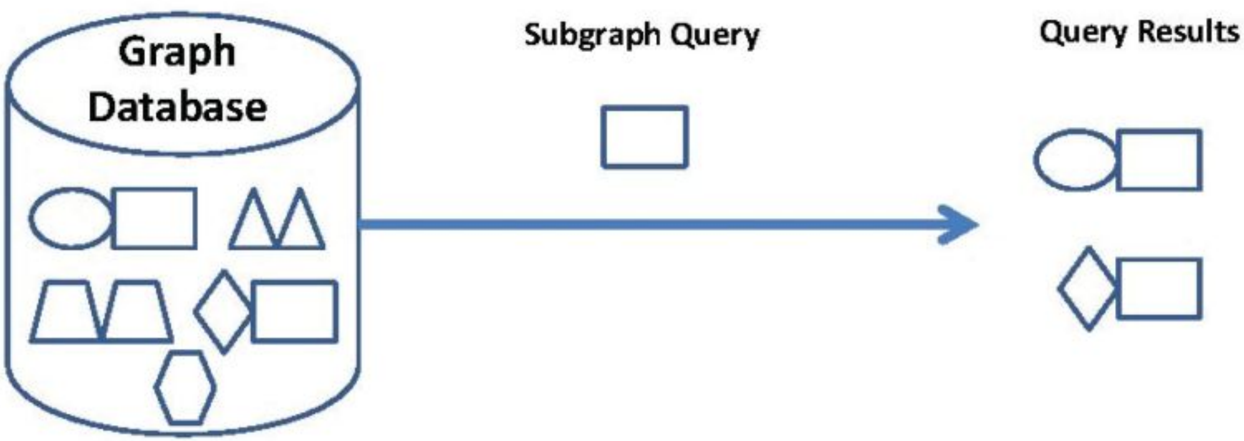
Graph Databases

- A graph database = a set of graphs

- Types of graph databases:
  - Transactional = a large set of small graphs
    - e.g., chemical compounds, biological pathways, …
    - Searching for graphs that match the query
  - Non-transactional = few numbers of very large graphs
    - or one huge (not necessarily connected) graph
    - e.g., Web graph, social networks, …

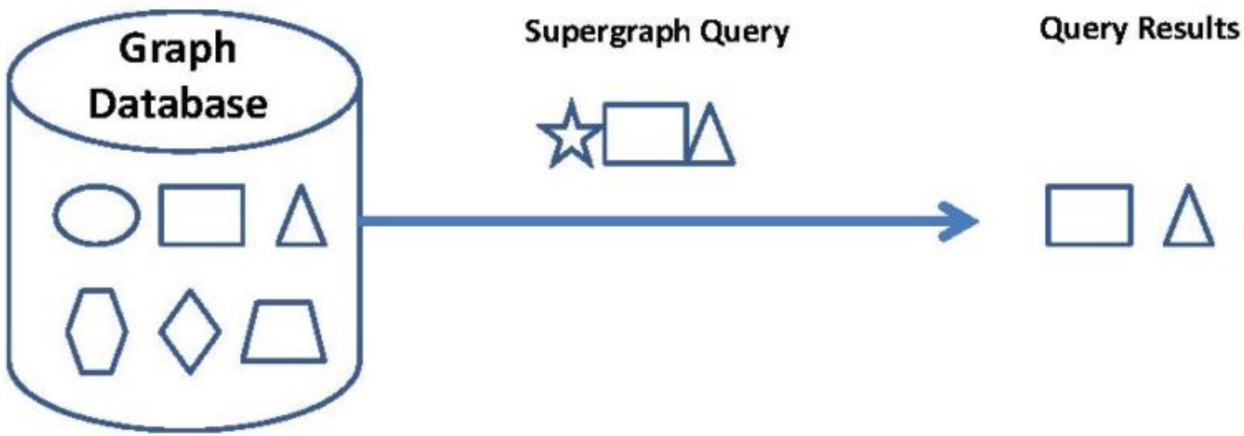
Transactional DBs: Queries

- Types of Queries
  - Subgraph queries
    - Searches for a specific pattern in the graph database
    - Query = a small graph
      - or a graph, where some parts are uncertain, e.g., vertices with wildcard labels
    - More general type: allow sub-graph isomorphism



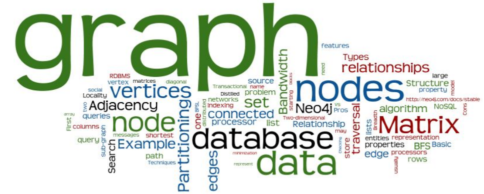
Transactional DBs: Queries (2)

- Super-graph queries
  - Search for graphs whose whole structure is contained in the query graph



- Similarity (approximate matching) queries
  - Finds graphs which are similar to a given query graph
    - but not necessarily isomorphic
  - Key question: how to measure the similarity

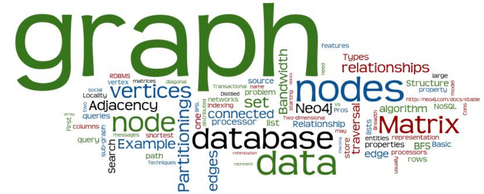
Indexing & Query Evaluation



- Extract certain characteristics from each graph
  - And index these characteristics for each $G_1, \dots, G_n$

- Query evaluation in transactional graph DB
  1. Extraction of the characteristics from query graph q
  2. Filter the database (index) and identify a candidate set
     - Subset of the $G_1, \dots, G_n$ graphs that should contain the answer
  3. Refinement - check all candidate graphs

Subgraph Query Processing

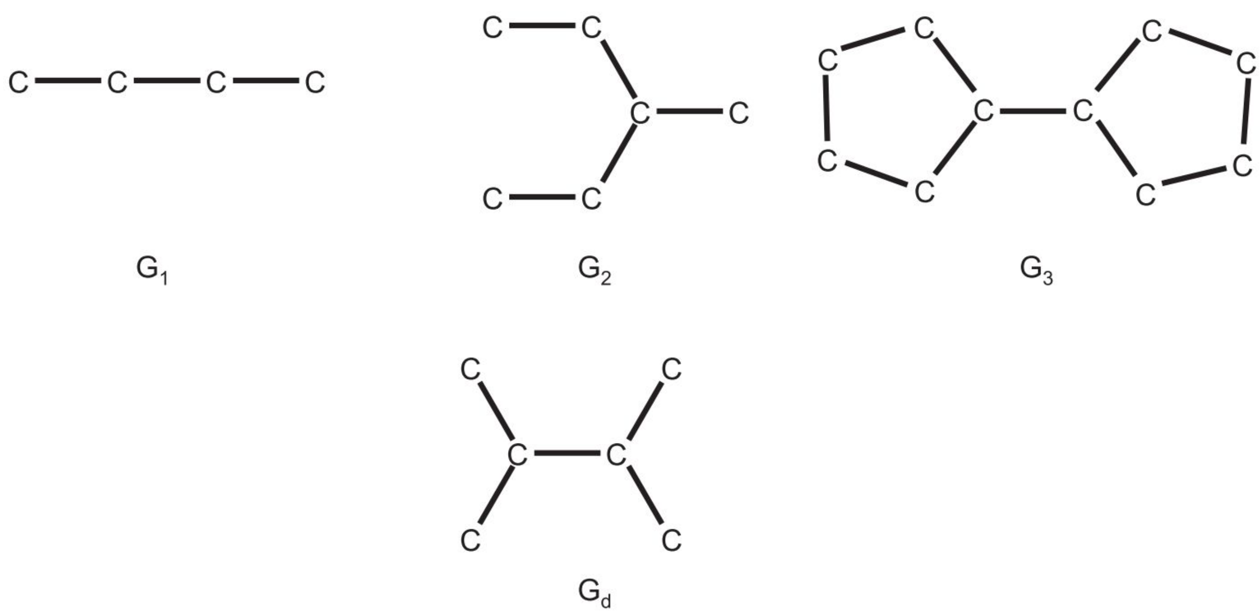


1. Mining-based Graph Indexing Techniques
   - Idea: if some features of query graph *q* do not exist in data graph *G*, then *G* cannot contain *q* as its subgraph
   - Apply graph-mining methods to extract some features (sub-structures) from the graph database members
     - e.g., frequent sub-trees, frequent sub-graphs
   - An inverted index is created for each feature

2. Non Mining-Based Graph Indexing Techniques
   - Indexing of the whole constructs of the graph database
     - Instead of indexing only some selected features

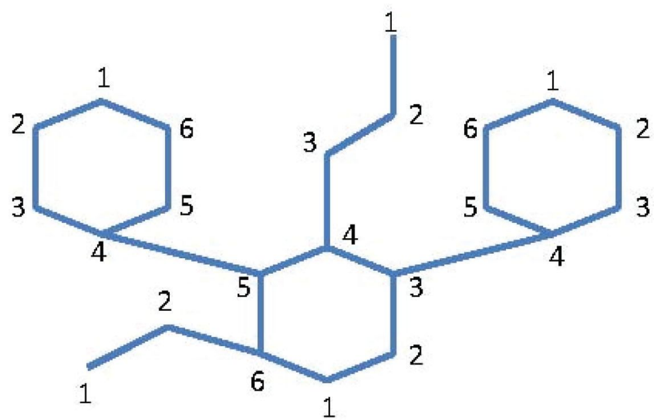
Mining-based Technique

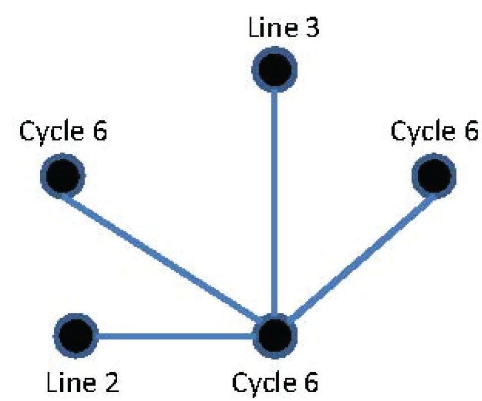
- Example method: GIndex [2004]
  - Indexing “frequent discriminative graphs”
  - Build inverted index for selected discriminative subgraphs

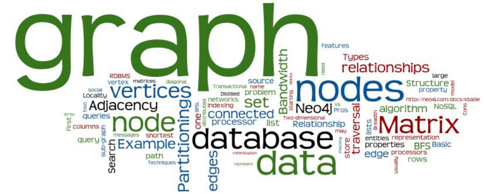


Non Mining-based Techniques

- **Example:** GString (2007)
  - Model the graphs in the context of organic chemistry using basic structures
    - Line = series of vertices connected end to end
    - Cycle = series of vertices that form a close loop
    - Star = core vertex directly connects to several vertices



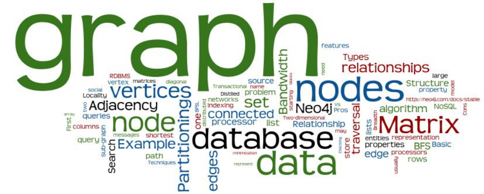




Graph Databases

Non-transactional Databases

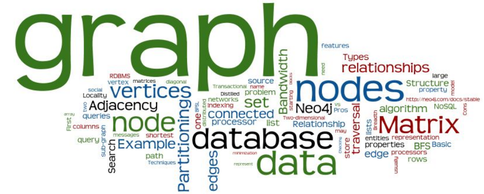
Non-transactional Databases



- A few very large graphs
  - e.g., Web graph, social networks, …
- Queries:
  - Nodes/edges with properties
  - Neighboring nodes/edges
  - Paths (all, shortest, etc.)

- Our example: Neo4j

Basic Characteristics

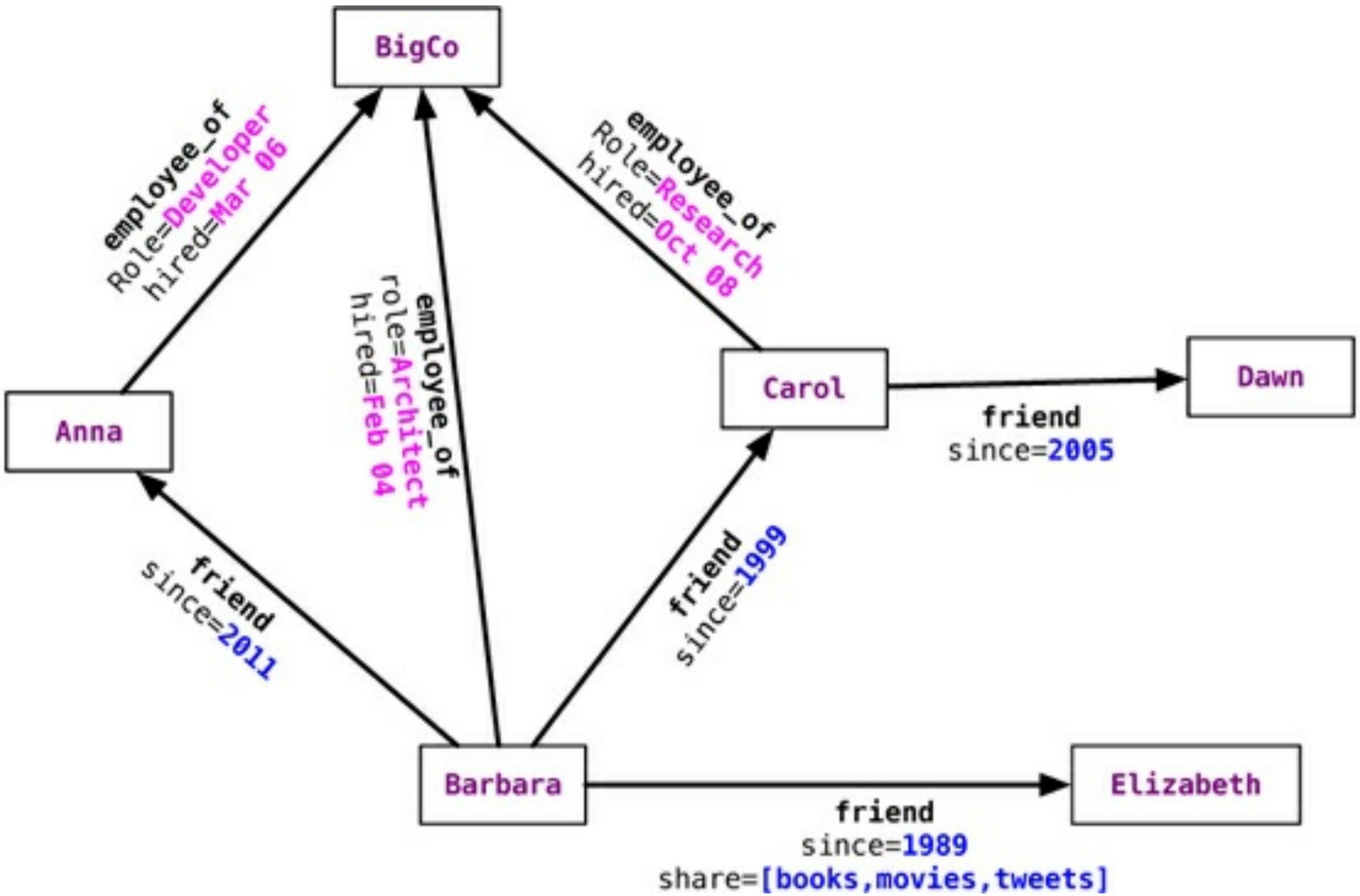


- Different types of relationships between nodes
  - To represent relationships between domain entities
  - Or to model any kind of secondary relationships
    - Category, path, time-trees, spatial relationships, …

- No limit to the number and kind of relationships

- Relationships have properties
  - e.g., Since when did they become friends?

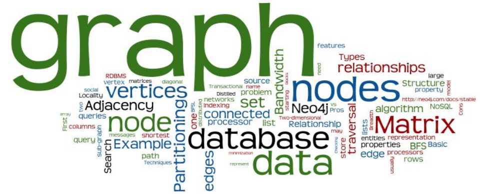
Relationship Properties: Example



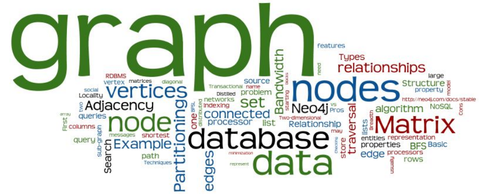
source: Sadalage & Fowler: NoSQL Distilled, 2012

Graph DB vs. RDBMS

- RDBMS designed for a single type of relationship
  - "Who is my manager"
- Adding another relationship usually means a lot of schema changes
- In RDBMS we model the graph beforehand based on the traversal we want
  - If the traversal changes, the data will have to change
  - Graph DBs: the relationship is not calculated but persisted

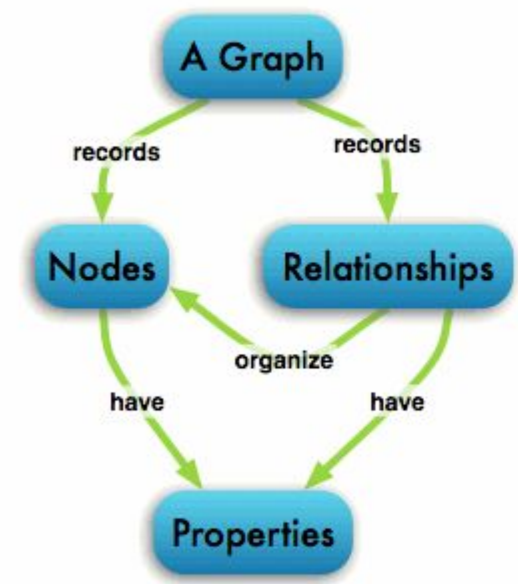


Neo4J: Basics & Concepts



Neo4j: Basic Info

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

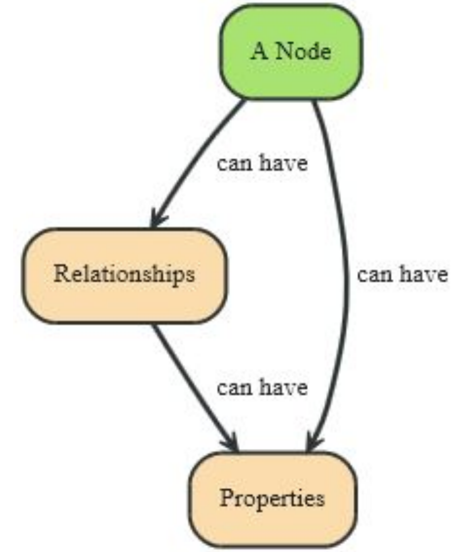


Neo4j: Basic Features

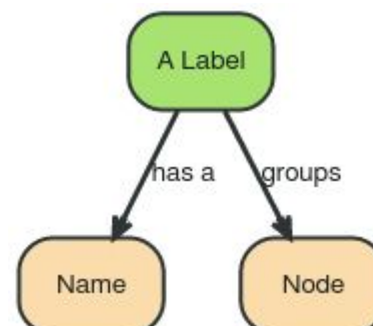
- reliable – with full ACID transactions
- durable and fast – disk-based, native storage engine
- scalable – up to several billion nodes/relationships/properties
- highly-available – when distributed (replicated)
- expressive – powerful, human readable graph query language
- fast – powerful traversal framework
- embeddable - in Java program
- accessible – simple REST interface & Java API

Data Model: Nodes

- Fundamental unit: node
- Nodes have properties
  - Key-value pairs
  - null is not a valid property value
    - nulls can be modelled by the absence of a key

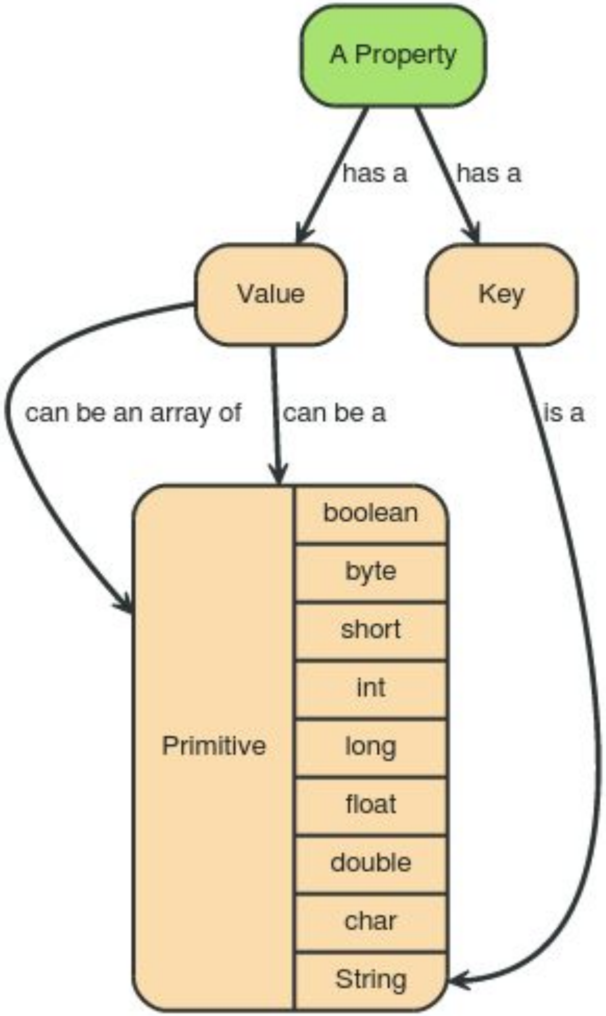


- Nodes have labels
  - labels typically express "type of node"



http://db-engines.com/en/system/Neo4j

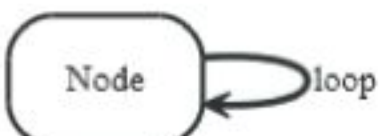
Data Model: Properties

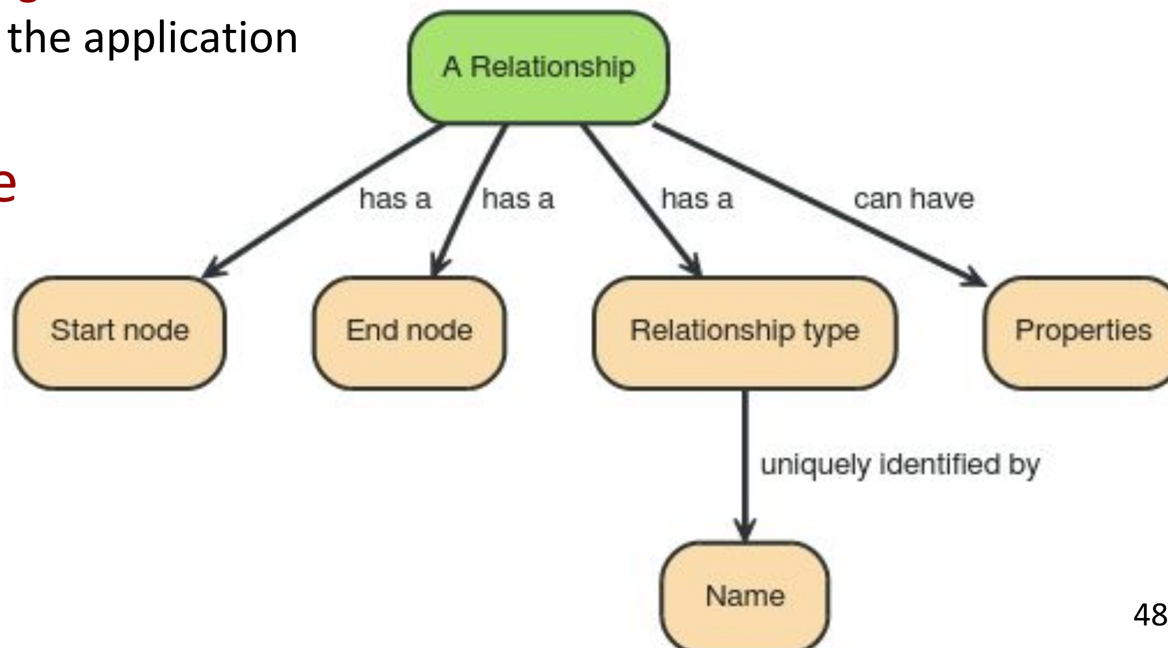


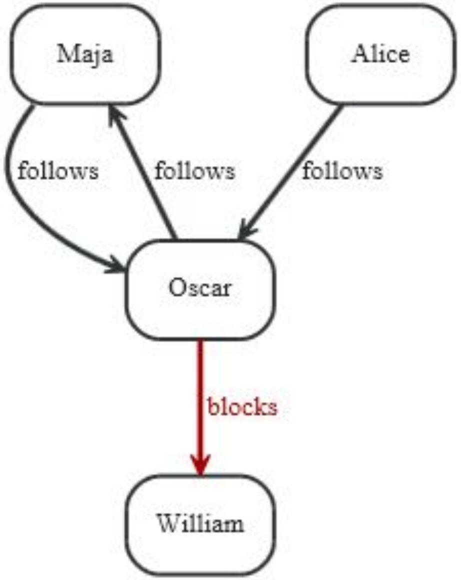
Type	Description
boolean	true/false
byte	8-bit integer
short	16-bit integer
int	32-bit integer
long	64-bit integer
float	32-bit IEEE 754 floating-point number
double	64-bit IEEE 754 floating-point number
char	16-bit unsigned integer representing a Unicode character
String	sequence of Unicode characters

Data Model: Relationships

- Directed relationships (edges)
  - Incoming and outgoing edge
    - Equally efficient traversal in both directions
    - Direction can be ignored if not needed by the application
  - Always a start and an end node
    - Can be recursive

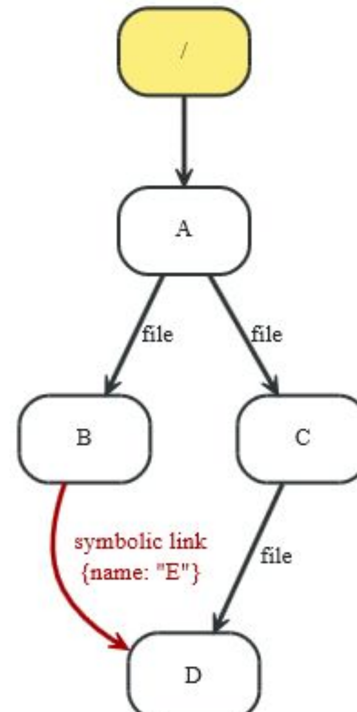




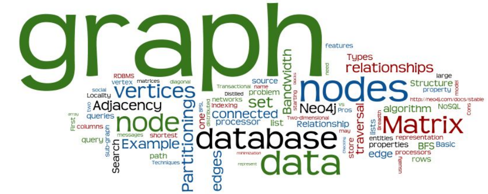


What	How
get who a person follows	outgoing *follows* relationships, depth one
get the followers of a person	incoming *follows* relationships, depth one
get who a person blocks	outgoing *blocks* relationships, depth one

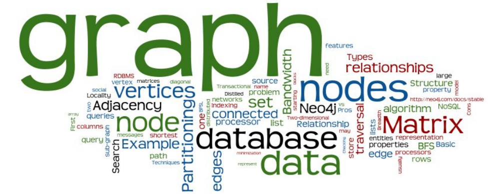
What	How
get the full path of a file	incoming *file* relationships
get all paths for a file	incoming *file* and *symbolic link* relationships
get all files in a directory	outgoing *file* and *symbolic link* relationships, depth one
get all files in a directory, excluding symbolic links	outgoing *file*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



Access to Neo4j

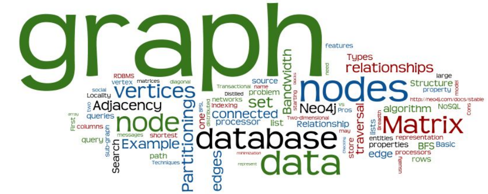


- Embedded database in Java system
- Language-specific connectors
  - Libraries to connect to a running Neo4j server
- Cypher query language
  - Standard language to query graph data
- HTTP REST API
- Gremlin graph traversal language (plugin)
- etc.



Neo4J: Native Java API & Graph Traversal

Native Java Interface: Example



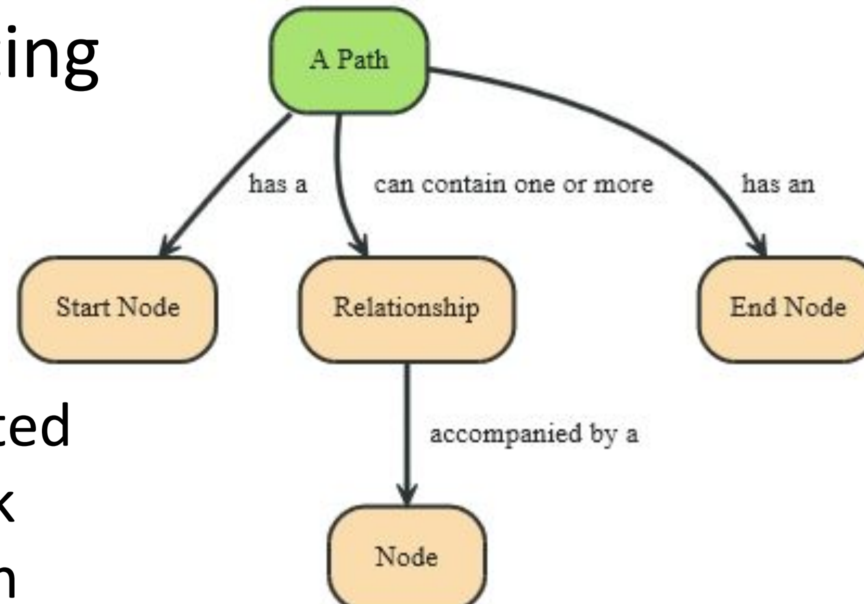

```java
Node irena = graphDb.createNode();
irena.setProperty("name", "Irena");
Node jirka = graphDb.createNode();
jirka.setProperty("name", "Jirka");

Relationship i2j = irena.createRelationshipTo(jirka, FRIEND);
Relationship j2i = jirka.createRelationshipTo(irena, FRIEND);

i2j.setProperty("quality", "a good one");
j2i.setProperty("since", 2003);
```

- Undirected edge:
  - Relationship between the nodes in both directions
  - **INCOMING** and **OUTGOING** relationships from a node

Data Model: Path & Traversal

- Path = specific nodes + connecting relationships
  - Path can be a result of a query or a traversal

- Traversing a graph = visiting its nodes, following relationships according to some rules
  - Typically, a subgraph is visited
  - Neo4j: Traversal framework in Java API, Cypher, Gremlin



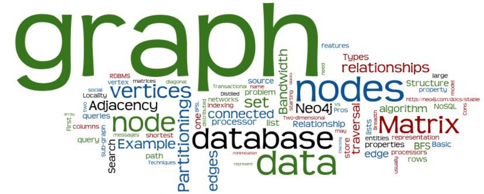
Traversal Framework

- A traversal is influenced by
  - Starting node(s) where the traversal begins
  - 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 beyond current position

Traversal = TraversalDescription + starting node(s)

Traversal Framework – Java API



- `org.neo4j...TraversalDescription`
  - The main interface for defining traversals
    - Can specify branch ordering `breadthFirst()` / `depthFirst()`

- `.relationships()`
  - Specify the relationship types to traverse
    - e.g., traverse only edge types: FRIEND, RELATIVE
    - Empty (default) = traverse all relationships
  - Can also specify direction
    - `Direction.BOTH`
    - `Direction.INCOMING`
    - `Direction.OUTGOING`

Traversal Framework – Java API (2)

- `org.neo4j...Evaluator`
  - Used for deciding at each node: should the traversal continue, and should the node be included in the result
    - `INCLUDE_AND_CONTINUE`: Include this node in the result and continue the traversal
    - `INCLUDE_AND_PRUNE`: Include this node, do not continue traversal
    - `EXCLUDE_AND_CONTINUE`: Exclude this node, but continue traversal
    - `EXCLUDE_AND_PRUNE`: Exclude this node and do not continue
  - Pre-defined evaluators:
    - `Evaluators.toDepth(int depth)` / `Evaluators.fromDepth(int depth)`,
    - `Evaluators.excludeStartPosition()`
    - ...

Traversal Framework – Java API (3)

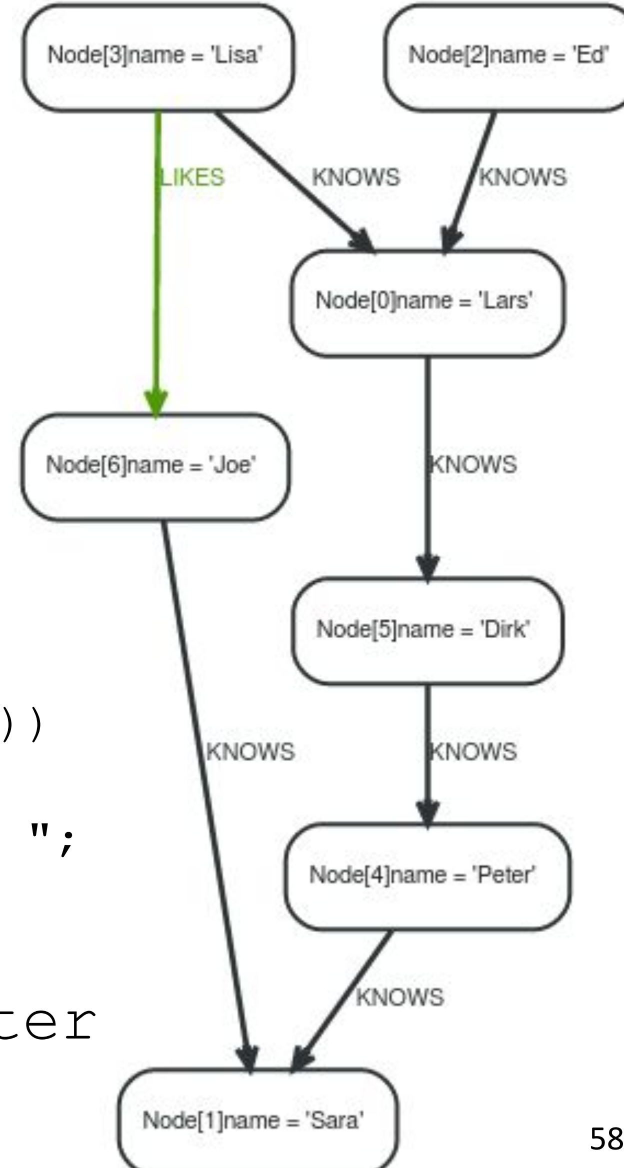
- `org.neo4j...Uniqueness`
  - Indicates under what circumstances a traversal may revisit the same position in the graph

- `Traverser`
  - Starts actual traversal given a TraversalDescription and starting node(s)
  - Returns an iterator over “steps” in the traversal
    - Steps can be: Path (default), Node, Relationship
  - The graph is actually traversed “lazily” (on request)

Example of Traversal

```
TraversalDescription desc =
  db.traversalDescription()
    .depthFirst()
    .relationships( Rels.KNOWS,
                 Direction.BOTH )
    .evaluator(Evaluators.toDepth(3));

// node is 'Ed' (Node[2])
for (Node n : desc.traverse(node).nodes())
{
    output += n.getProperty("name") + ", ";
}
```

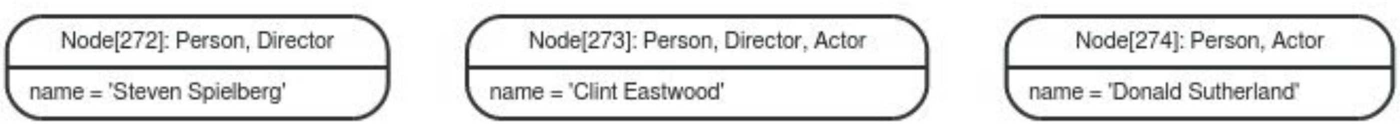
Output: `Ed, Lars, Lisa, Dirk, Peter`

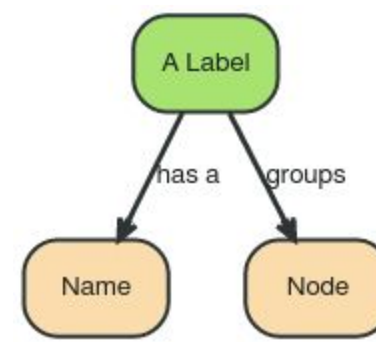


http://neo4j.com/docs/stable/tutorial-traversal-java-api.html

Access to Nodes

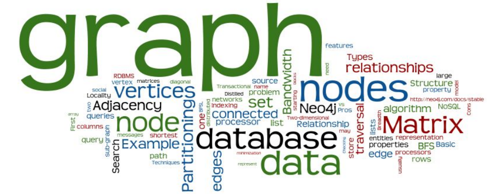
- How to get to the starting node(s) before traversal
  1. Using internal identifiers (generated IDs)
     - not recommended - Neo4j generates IDs for memory objs and reuses IDs
  2. Using properties of nodes
     - one of the properties is typically “ID” (user-specified ID)
     - recommended, properties can be indexed
       - automatic indexes
  3. Using “labels”
     - group nodes into “subsets” (named graph)
     - a node can have more than one label
       - belong to more subsets





Neo4J: Cypher Language

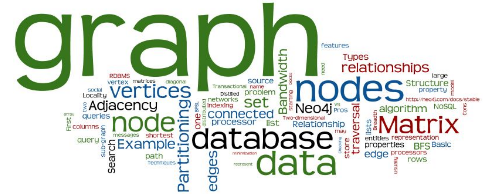
Cypher Language



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

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

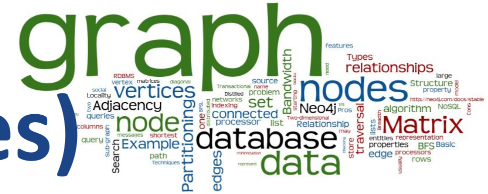
Cypher: Clauses



- **MATCH**: The graph pattern to match
- **WHERE**: Filtering criteria
- **RETURN**: What to return
- **START**: Starting points in the graph
  - by explicit index lookups or by node IDs (both deprecated)
- **WITH**: Divides a query into multiple parts

- **CREATE**: Creates nodes and relationships.
- **DELETE**: Remove nodes, relationships, properties
- **SET**: Set property values

Cypher: Creating Nodes (Examples)



CREATE (n);

*(create a node, assign to var **n**)*

```
Created 1 node, returned 0 rows
```

CREATE (a: Person {name : 'David'})
RETURN a;

(create a node with label ‘Person’ and ‘name’ property ‘David’)

```
Created 1 node, set 1 property, returned 1 row
```

Cypher: Creating Relationships

MATCH (a {name:’John’}), (b {name:’Jack’})
CREATE a-[r:Friend]->b
RETURN r ;

(create a relation Friend *between John and Jack)*

`Created 1 relationship, returned 1 row`

MATCH (a {name:’John’}), (b {name:’Jack’})
CREATE a-[r:Friend {name: a.name + '->' + b.name }]->b
RETURN r

(set property ‘name’ of the relationship)

`Created 1 node, set 1 property, returned 1 row`

Cypher: Queries

```
MATCH (p: Person)
WHERE p.age >= 18 AND p.age < 30
RETURN p.name
```

(return names of all adult people under 30)

```
MATCH (user: Person {name: 'Andres'})-[:Friend]->(follower)
RETURN user.name, follower.name
```

(find all ‘Friends’ of 'Andres')

Cypher: Queries (2)

MATCH (andres: Person {name: 'Andres'})-[*1..3]-(node)
RETURN andres, node ;

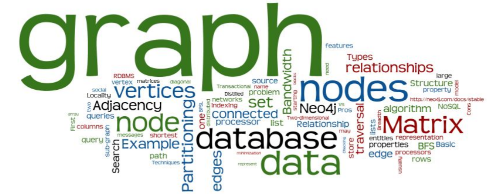
(find all 'nodes' within three hops from 'Andres')

MATCH p=shortestPath(
(andres:Person {name: 'Andres'})-[*]-(david {name:'David'})
)
RETURN p ;

(find the shortest connection between 'Andres' and 'David')

Neo4J: Behind the Scene

Neo4j Internals: Indexes



CREATE INDEX ON :Person(name);

(Create index on property name of nodes with label Person)

```
Indexes added: 1
```

- Since Neo4j v. 2, indexes are used automatically
  - Can be specified explicitly (which index to use)

MATCH (n:Person)
USING INDEX n:Person(surname)
WHERE n.surname = 'Taylor'
RETURN n

Neo4j Internals: Transactions

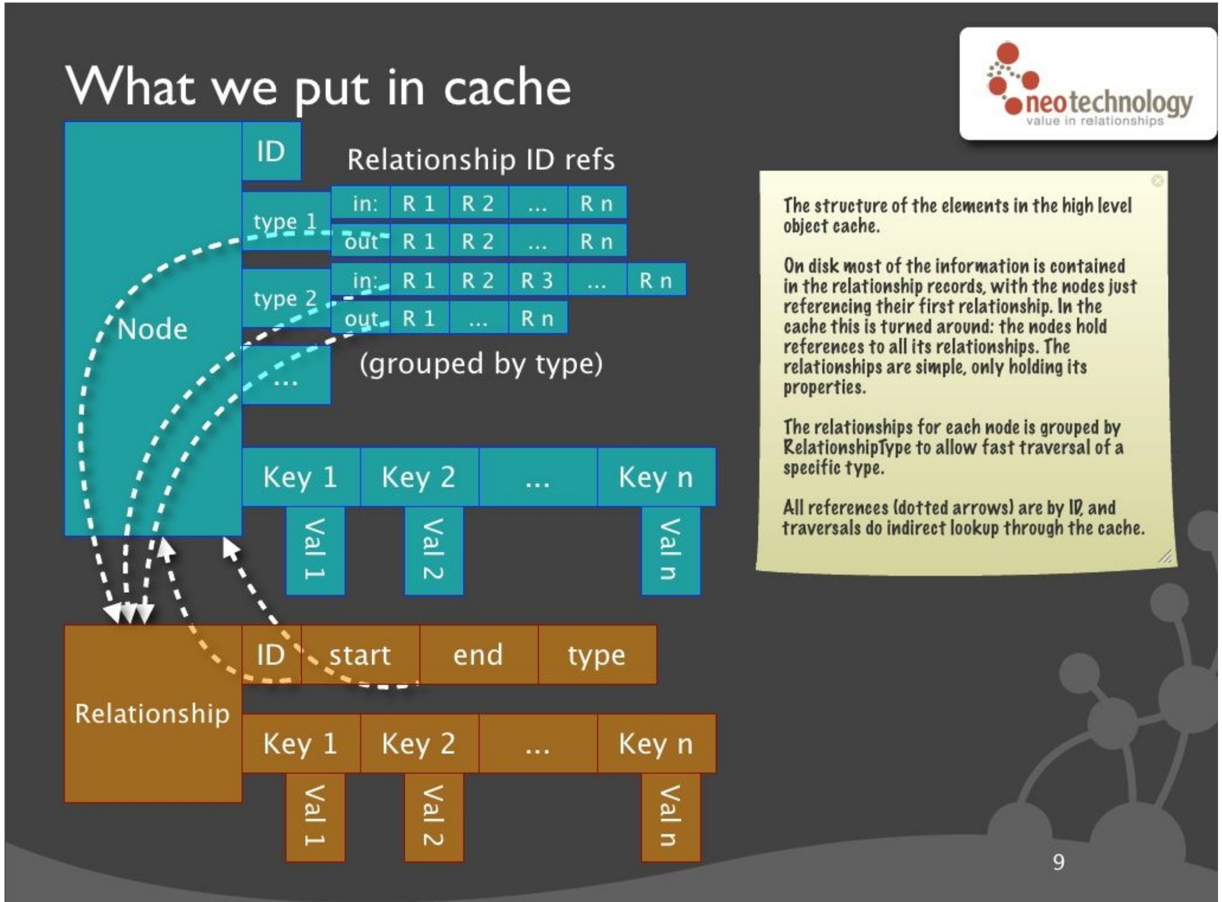
- Transactions in Neo4j
  - Support for ACID properties
  - All write operations must be performed in a transaction
  - Default transaction isolation level: Read committed
    - Operation can see the last committed value
    - Reads do not block or take any locks
    - If the same row is retrieved twice within a transaction, the values in the row CAN differ
  - Higher level of isolation can be achieved
    - By explicit acquiring the read locks

Neo4j Internals: High Availability

- Master-slave replication
  - Several Neo4j slave databases can be configured to be exact replicas of a single Neo4j master database

- Speed-up of read operations
  - Enables to handle more read load than a single node
- Fault-tolerance
  - In case a node becomes unavailable
- Transactions are still atomic, consistent and durable, but eventually propagated to the slaves

Neo4j: Storage Structure



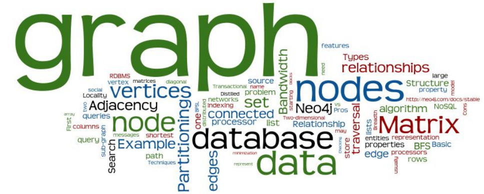
Monday, May 21, 2012

Source: https://www.slideshare.net/thobe/an-overview-of-neo4j-internals

Graph Databases: When (not) to Use

Graph DBs: Suitable Use Cases

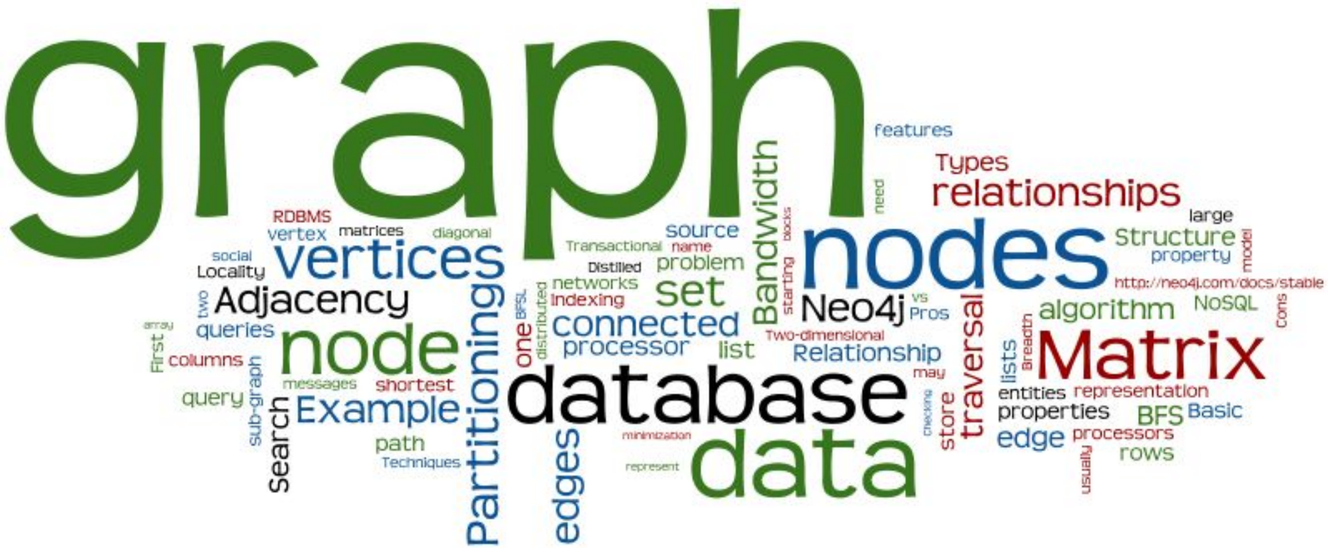
- Connected Data
  - Social networks
  - Any link-rich domain is well suited for graph databases
- Routing, Dispatch, and Location-Based Services
  - Node = location or address that has a delivery
  - Graph = nodes where a delivery has to be made
  - Relationships = distance
- Recommendation Engines
  - “your friends also bought this product”
  - “when buying this item, these others are usually bought”



Graph DBs: When Not to Use

- If we want to update all or a subset of entities
  - Changing a property on many nodes is not straightforward
    - e.g., analytics solution where all entities may need to be updated with a changed property
- Some graph databases may be unable to handle lots of data
  - Distribution of a graph is difficult

Questions?


graph
nodes
database
data
node
Matrix
vertices
relationships
Adjacency
Partitioning
edges
connected
Example
Bandwidth
traversal
Neo4j
set
processor
source
problem
networks
indexing
Relationship
algorithm
Structure
property
Types
features
NoSQL
http://neo4j.com/docs/stable
RDBMS
vertex
matrices
diagonal
social
Locality
queries
columns
query
shortest
messages
sub-graph
Search
path
Techniques
list
store
lists
entities
representation
properties
BFS
Basic
edge
processors
rows
Two-dimensional
Pros
Transactional
name
Distilled
one
two
First
large
model
Cons
Breadth
usually
need
starting
blocks
vs
may
checking
minimization
represent
array
BFSL
distributed

References

- I. Holubová, J. Kosek, K. Minařík, D. Novák. Big Data a NoSQL databáze. Praha: Grada Publishing, 2015. 288 p.
- RNDr. Irena Holubova, Ph.D. MMF UK course NDBI040: Big Data Management and NoSQL Databases
- Sherif Sakr - Eric Pardede: Graph Data Management: Techniques and Applications
- Sadalage, P. J., & Fowler, M. (2012). NoSQL Distilled: A Brief Guide to the Emerging World of Polyglot Persistence. Addison-Wesley Professional, 192 p.

- http://neo4j.com/docs/stable/