NoSQL and Graph Databases: Principles

Agenda

- Graph Databases: Mission, Data, Example
- A Bit of Graph Theory
  - Graph Representations
  - Types of Queries
- Graph Databases
- Neo4j
  - Data model
  - Traversal of the graph
  - Cypher query language

RDBMS recap

- RDBMS are predominant database technologies
  - Since 1970

- Data modeled as relations (tables)
  - object = tuple of attribute values
  - tables contain objects of the same type
  - tables interconnected via foreign keys

- Use SQL query language

Advantages of Relational Databases

- A (mostly) standard data model
- Many well developed technologies
  - physical organization of the data
  - search indexes: hash indexes
  - query optimization, search operator implementations
- Reliable concurrency control (ACID)
  - transactions: atomicity, consistency, isolation, durability
- Many reliable integration mechanisms
  - “shared database integration” of applications

NoSQL Databases

- What is "NoSQL"?
  - term used in late 90s for a different type of technology
  - "Not Only SQL"?
    - but many RDBMS are also "not just SQL"

"NoSQL is an accidental term with no precise definition"

- first used at an informal meetup in 2009 in San Francisco (presentations from Voldemort, Cassandra, Dynomite, HBase, Hypertable, CouchDB, and MongoDB)

[Sadalage & Fowler: NoSQL Distilled, 2012]

NoSQL Databases..

- NoSQL: Database technologies that are (mostly):
  - Not using the relational model (nor the SQL language)
  - Designed to run on large clusters (horizontally scalable)
  - No schema - fields can be freely added to any record
  - Based on the needs of 21st century web estates

[Sadalage & Fowler: NoSQL Distilled, 2012]

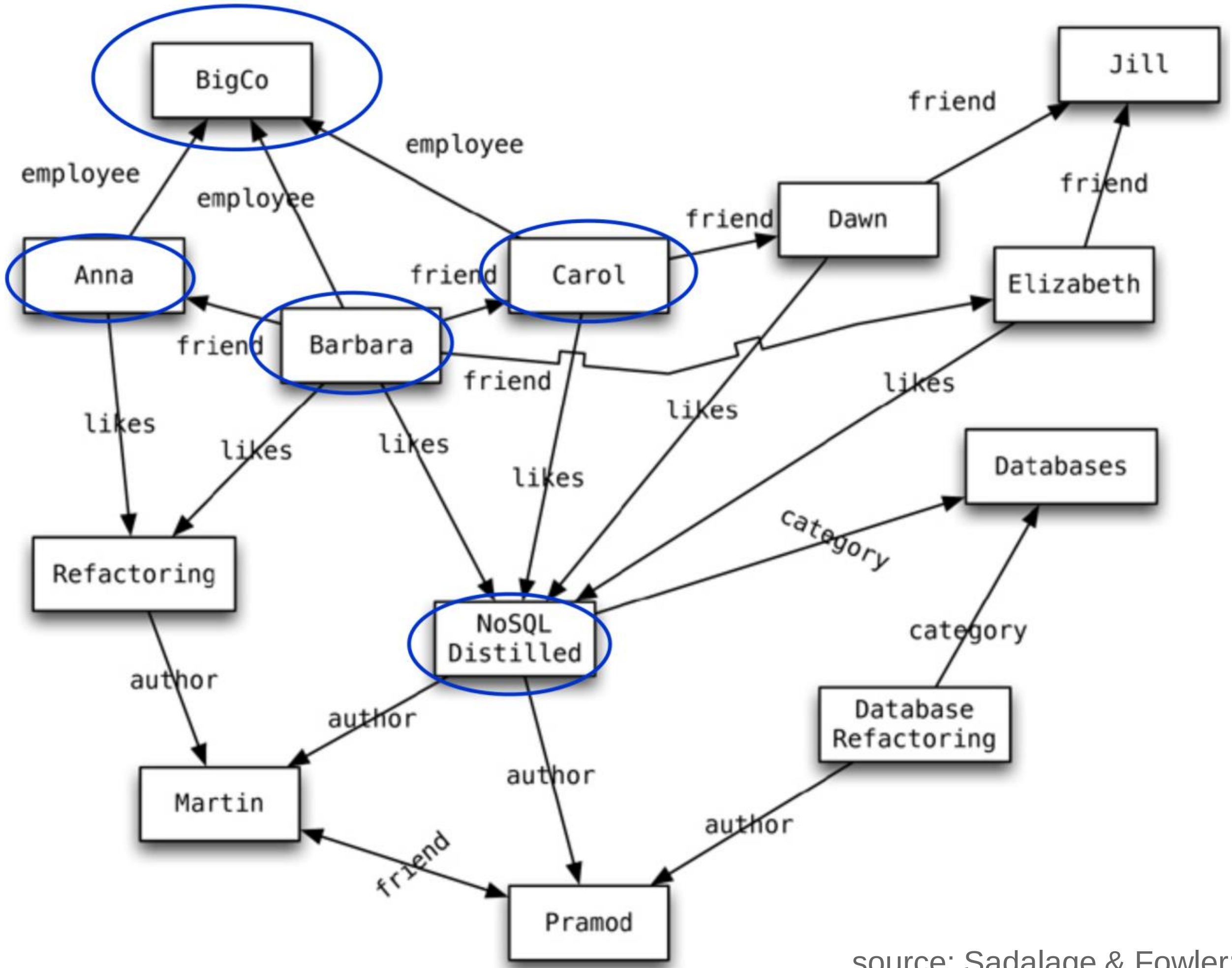
- Other characteristics (often true):
  - easy replication support (fault-tolerance, query efficiency)
  - simple API
  - eventually consistent (not ACID)

Four Basic Types of NoSQL Databases

- Key-value stores
- Document databases
- Column-family stores
- Graph databases

In this course we will discuss only graph databases and document databases in details

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, …

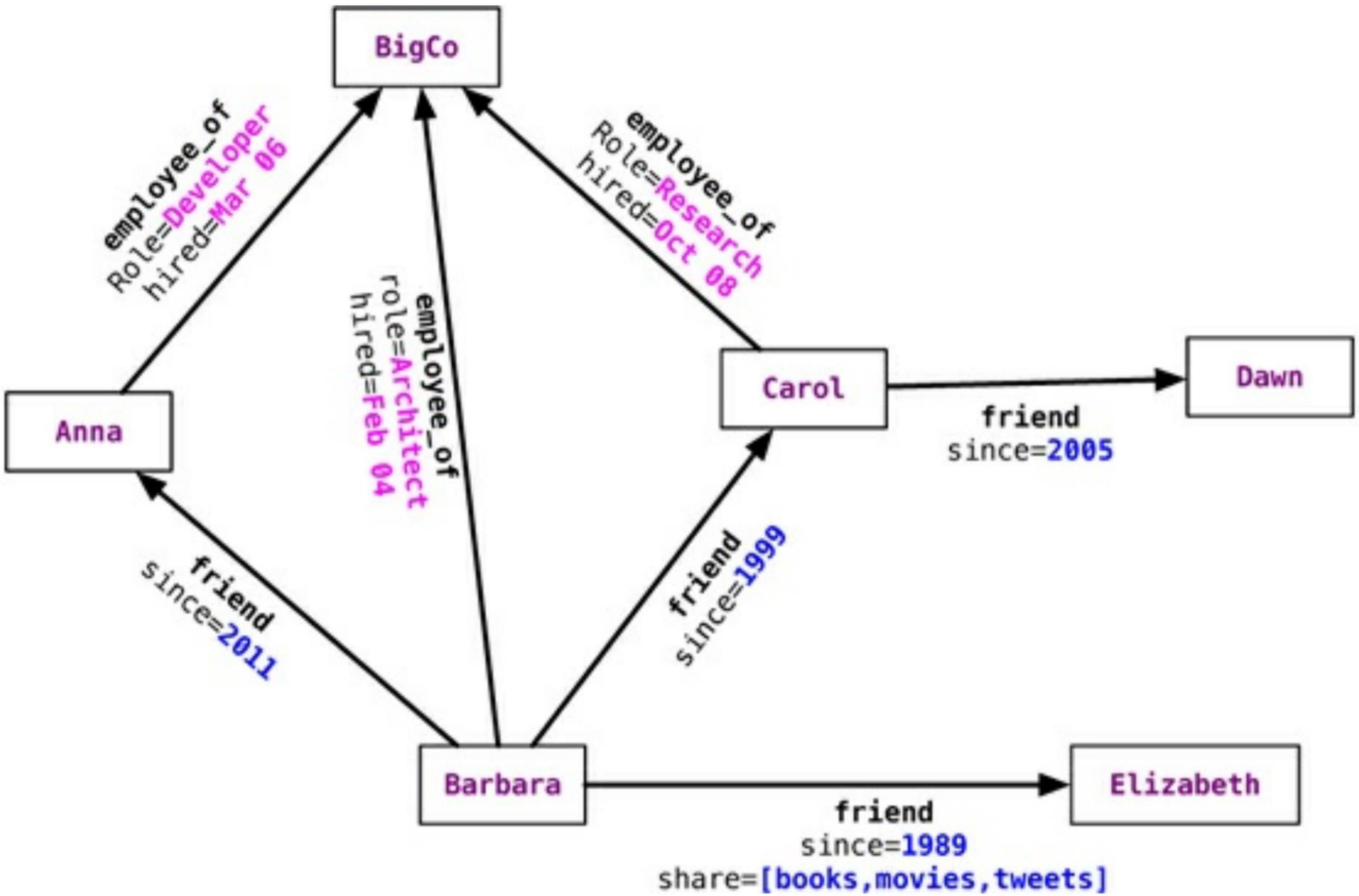
- Nodes are organized by relationships
  - Allow to find interesting patterns
  - **example:** Get all nodes that are “employee” of “Big Company” and that “likes” “NoSQL Distilled”

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..
- No limit to the number and kind of relationships

- Relationships have: type, start node, end node, own properties
  - e.g., “since when” did they become friends

Relationship Properties: Example



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A Bit of a Theory

- 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, ...

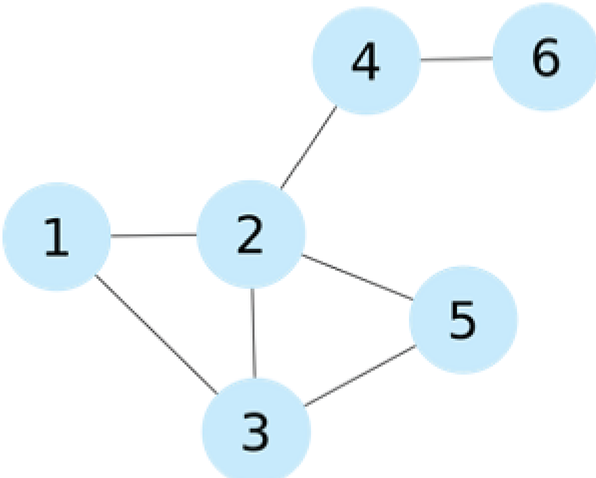
  => we need efficient graph operations
- A graph $G = (V, E)$ is a pair commonly modelled as
  - set of nodes (vertices) V
  - set of edges E
  - $n = |V|$, $m = |E|$
- Which data structure to use?

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

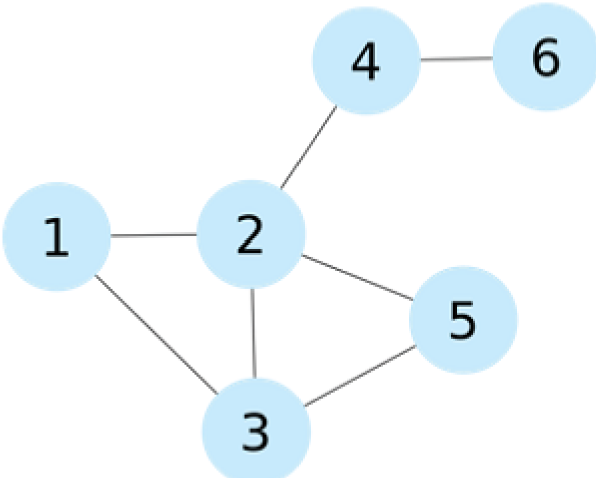
- Variants:
  - (Un)directed graphs
  - Weighted graphs…

Adjacency Matrix: Example



$$
\begin{array}{c c}
 & \begin{array}{cccccc} 1 & 2 & 3 & 4 & 5 & 6 \end{array} \\
\begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \end{array} &
\begin{pmatrix}
0 & 1 & 1 & 0 & 0 & 0 \\
1 & 0 & 1 & 1 & 1 & 0 \\
1 & 1 & 0 & 0 & 1 & 0 \\
0 & 1 & 0 & 0 & 0 & 1 \\
0 & 1 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0
\end{pmatrix}
\end{array}
$$

Adjacency Matrix: Example



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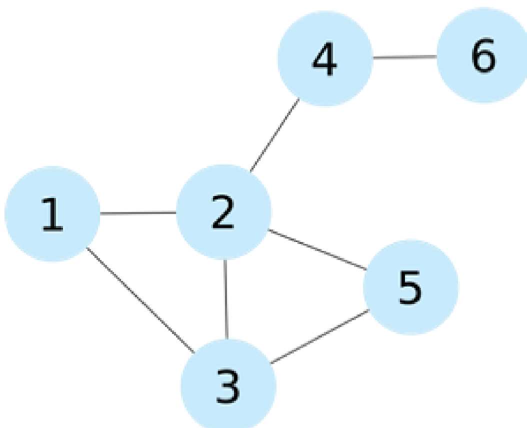
$$

- 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

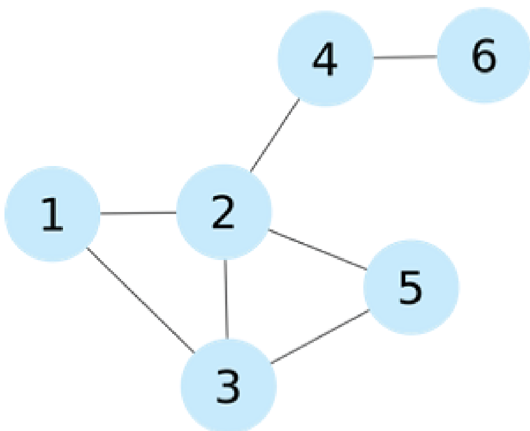
- A set of lists, each enumerating neighbours of one node
  - A vector of *n* pointers to adjacency lists
- Undirected graph:
  - An edge connects nodes *i* and *j*
  - => the adjacency list of *i* contains node *j* and vice versa
- Often compressed
  - Exploiting regularities in graphs, difference from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

Adjacency List: Example



1 -> {2, 3}
2 -> {1, 3, 4, 5}
3 -> {1, 2, 5}
4 -> {2, 6}
5 -> {2, 3}
6 -> {4}

Adjacency List: Example



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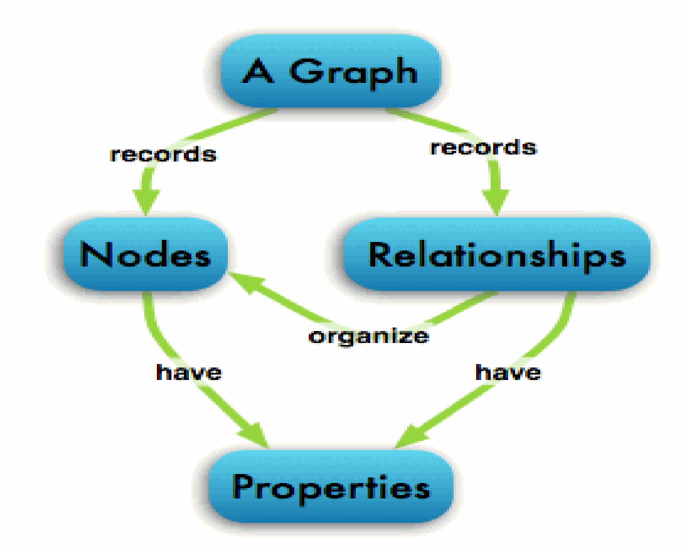
- Pros:
  - Getting the neighbours of a node
  - Cheap addition of nodes
  - More compact representation of sparse graphs
- Cons:
  - Checking if there is an edge between two nodes

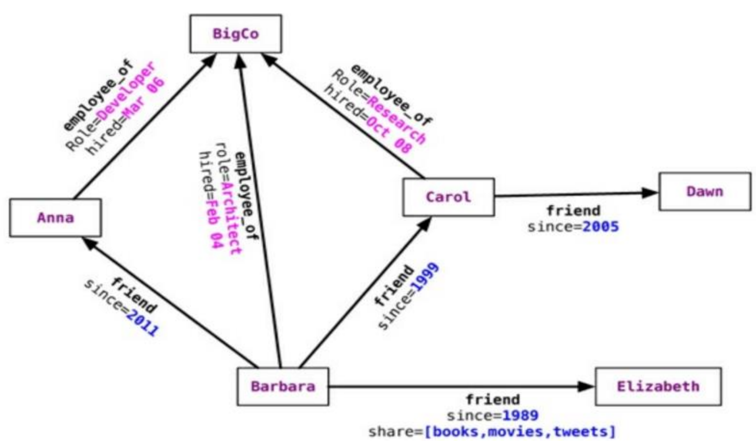
Graphs Relationships

- Single-relational graphs
  - Edges are homogeneous in meaning
    - e.g., all edges represent friendship



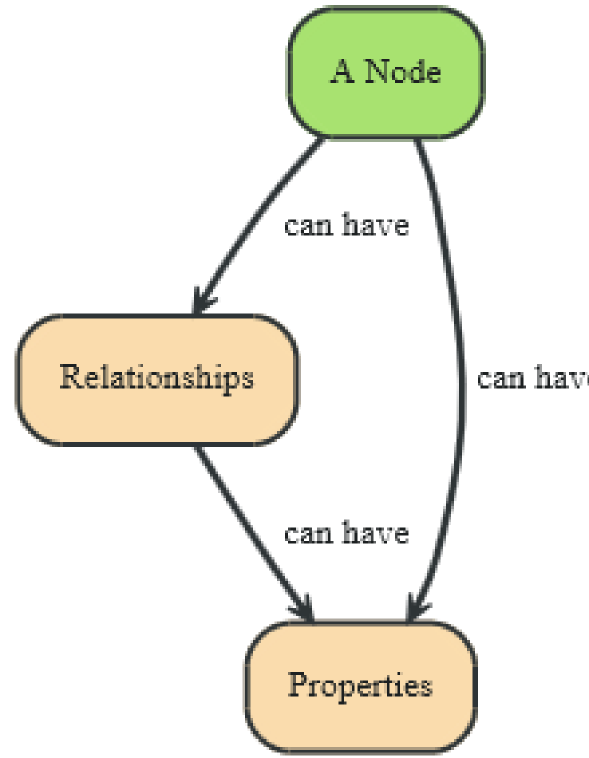
Graphs Relationships..

- 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



Neo4j: Data Model

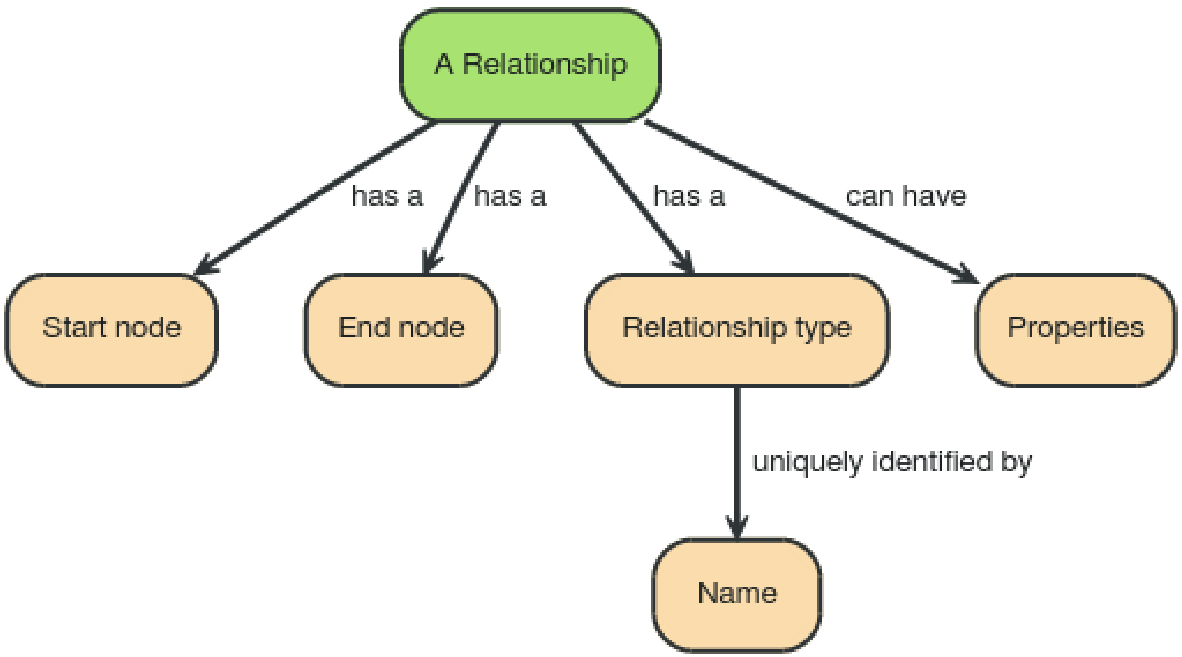
- Fundamental units: nodes + relationships
- Both can contain properties
  - Key-value pairs
  - Value can be of primitive type or an array of primitive type
  - null is not a valid property value
    - nulls can be modelled by the absence of a key



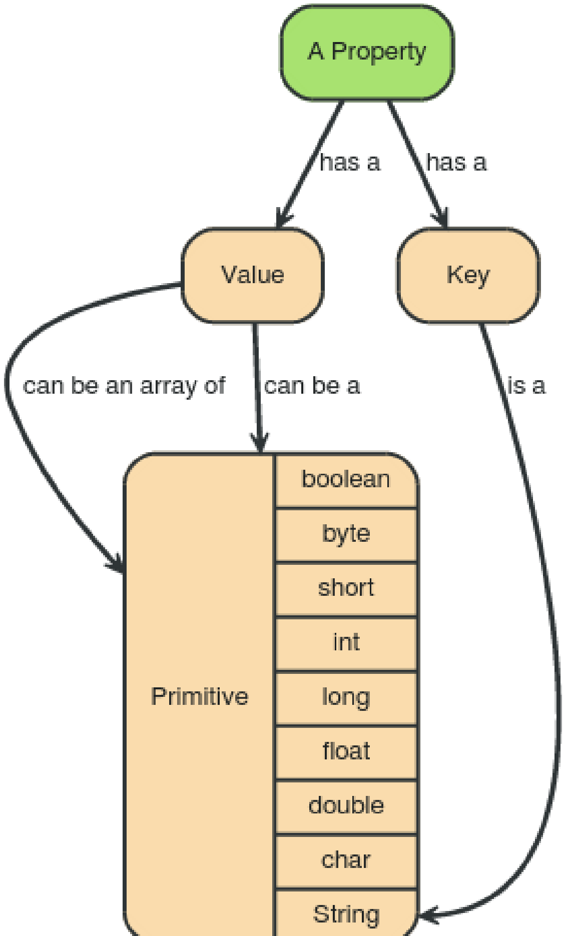
http://db-engines.com/en/system/Neo4j

Data Model: Relationships

- Directed relationships
  - Incoming and outgoing edge
    - Equally efficient traversal in both directions
    - Direction can be ignored when not needed by applications
  - Always have start and end node
    - Can be recursive



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 integers representing Unicode characters
String	sequence of Unicode characters

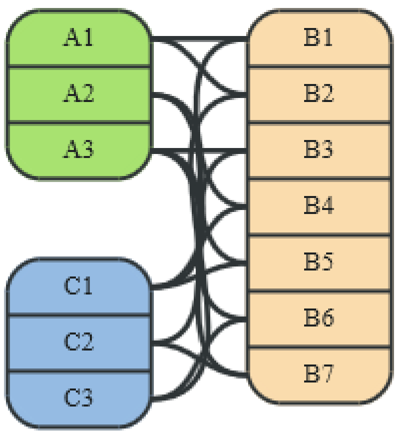
Graphs (Neo4j) vs. RDBMS

- 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

Graphs (Neo4j) vs. RDBMS (2)

- RDBMS is optimized for aggregated data
- Neo4j is optimized for highly connected data
  - It uses adjacency list as a data structure

Relational data



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

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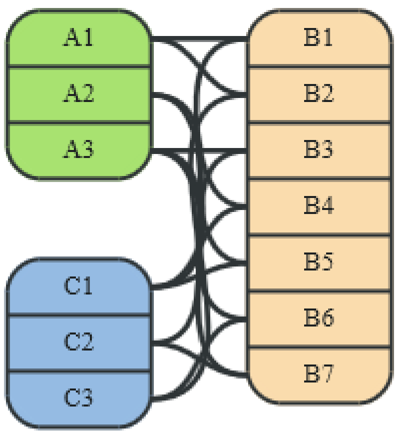
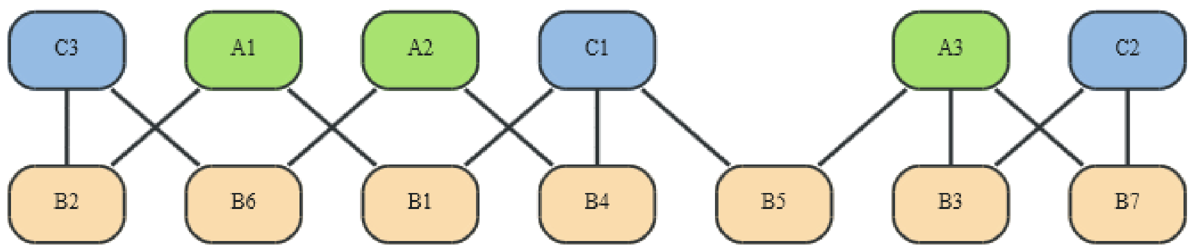


Graph data



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

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

Neo4j: Basic Info

- Open source graph database
- Initial release: 2007
- Written in: Java
- OS: cross-platform
- Full transactions (ACID)
- Partitioning: None
- Replication: Master-slave
  - Eventual consistency

Neo4j in Server mode

- Two ways to use Neo4j:
  - Self-standing server + connections
  - Embeded: Used directly within a Java application

- Server mode:
  - download from https://neo4j.com/download-center/
  - extract `neo4j-community-X.Y.Z.tar.gz`
  - `start neo4j and create a new graph database`
  - go to: http://localhost:7474/

Cypher: Common Clauses

- **MATCH**: The graph pattern to match
- **WHERE**: Filtering criteria
- **RETURN**: What to return
- **CREATE**: Creates nodes and relationships.
- **DELETE**: Remove nodes, relationships
- **REMOVE**: Removes properties from nodes and relationships
- **SET**: Set values to properties
- **WITH**: Divides a query into multiple parts

Cypher: Creating Nodes

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

CREATE (p: Employee {name : 'David'})
RETURN p;
(create a node with label ‘Employee’ and ‘name’ property ‘David’)

Cypher: Creating Nodes

```
CREATE
(a:Airport{name:"Schiphol",city:"Amsterdam",capacity:20000, size:"Medium"})
        <-[i1:Includes]-(t1:Terminal{code:"A", open:true}),
      (a)<-[i2:Includes]-(t2:Terminal{code:"B", open:false}),
      (a)<-[i3:Includes]-(t3:Terminal{code:"C", open:true}),
RETURN a
```

(create a node labeled as ‘Airport’ with some properties that includes multiple terminals’)

Cypher: Creating Nodes

 # assuming there is a node with the property name ‘Schiphol’

MATCH (a:Airport{name:"Schiphol"})

CREATE

    (a)<-[t1:Travel{from:"Berlin", dep:time("13:00")}]-(f1:Flight{code:"12f"}),

    (a)<-[t2:Travel{from:"Verona", dep:time("15:33")}]-(f2:Flight{code:"1245"})

RETURN a

(match an existing node labeled as ‘Airport’ and named as ‘Schiphol’, then create multiple flights that travel to this this airport)

Cypher: Selecting Nodes

 # assuming you have multiple nodes that have ‘Works’ relationship with other nodes

MATCH (n)-[:Works]-(m) **RETURN** n

(find all nodes that have similar relationships no matter in which direction)

MATCH (n)-[:Works]->(m) **RETURN** n

(find all nodes that have similar relationships where the direction is specified from left to right)

MATCH (n)<-[:Works]-(m) **RETURN** n

(find all nodes that have similar relationships where the direction is specified from right to left)

Cypher: Changing Properties

 # assuming only one employee with the name ”Andres” exists
MATCH (p: Employee {name: 'Andres'})
SET p.**s**urname = 'Taylor'
RETURN p
(find a node with name ‘Andres’ and set it surname ‘Taylor’)

Cypher: Deleting Nodes

 # assuming some nodes labeled as employees with different names exists
MATCH (p: Employee {name: 'Andres'})
DELETE p
(delete all employees with the name 'Andres')

 # assuming a node with the name 'Andres' exists
MATCH (p: Employee {name: 'Andres'})
DETACH DELETE p
(Delete all relationships of node with name 'Andres')

Cypher: Finding Nodes and Matching Patterns

 # assuming age property is created
MATCH (p: Employee)
WHERE p.age > 18 **AND** p.age < 30
RETURN p.name
(return names of all employees between 18 and 30)

 # assuming the relationship "works" to the node company is created
MATCH (p: Employee) – [w:Works]-> (**c:Company{location: "New York"}**)
RETURN p.name, c.name
(find all 'employees' that have a work relationship with a company located in 'new york')

Cypher: Finding Nodes and Matching Patterns

 # assuming some airports with the property size that have relationships to other nodes are created

MATCH (a:Airport{size:"Medium"})-[i]-(m)

RETURN a.name, type(i), count(i)

(Find all medium sized airports, their relationships and the number of the relationships of the same type)

 # assuming some airport nodes and their relationships to other nodes exists

MATCH (a:Airport)-[r]-(m)

WITH a.name **AS** airportname, type(r) **AS** tr ,count(r) **AS** cnt

WHERE cnt > 3 and cnt < 10

RETURN *

(Find all airports, their relationships and the number of the relationships of the same type and return only those where the number of relations of the same kind is between 3 and 10)

Cypher: Queries (2)

 # assuming the node with the name 'Andres' is related through many intermediate nodes to other nodes

MATCH (andres: Employee {name: 'Andres'})-[*1..3]-(n)
RETURN andres, n ;
(find all nodes within three hops from 'Andres')

 # assuming the node with the name 'Andres' is related through different intermediate nodes to the node with the name 'David'

MATCH p=shortestPath(
 (andres:Employee {name: 'Andres'})-[*]-(david {name:'David'})
)
RETURN p ;
(find the shortest connection between 'Andres' and 'David')

Table translation

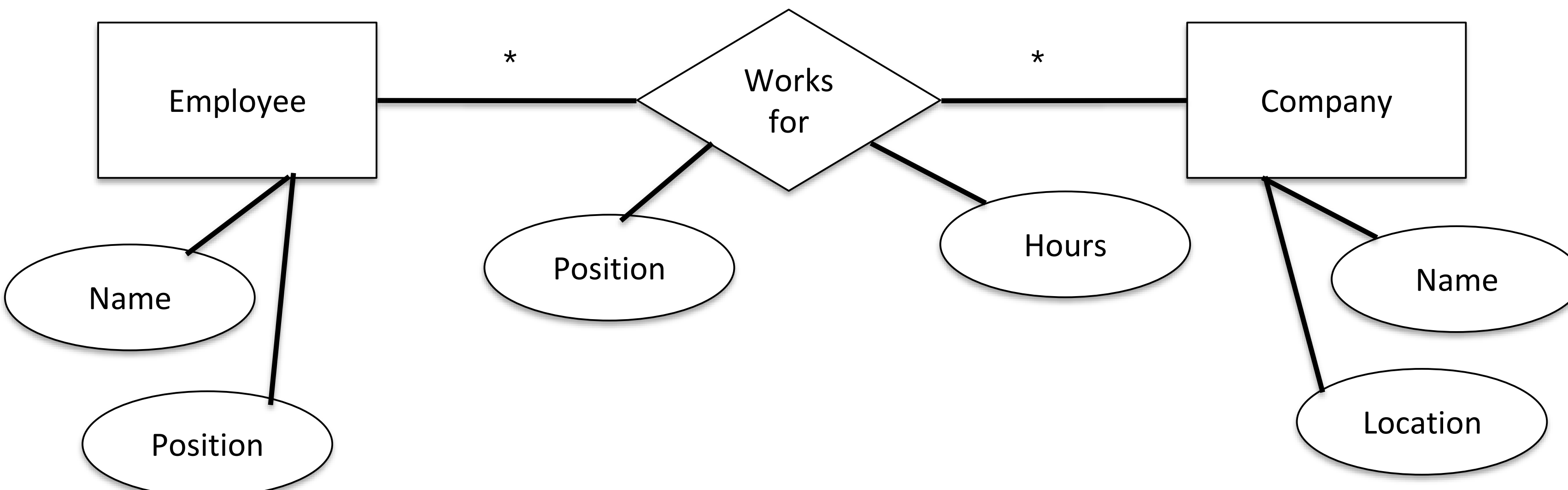
- You cannot translate tables directly.
- In a RDBMS you define the structure of the table.
- In a Graph DB you insert the data as nodes and you give them a <u>type</u>

Person			
name	address	job	married

- CREATE (p:Person{name :‘Jim Raynor’, address: ’Somehwere’ , job: ’Detective’, married:false})
  RETURN p;

Join table translation

- In a RDBMS you model relationship as tables.
- The relationship is modelled as data with PK-FK connections.
- In a Graph DB you can type the edges and use them as relationships.



Guidelines on Data model Transformation (Relational -> graph)

- Each entity table is represented by a label on nodes
- Each row in a entity table is a node
- Columns on those tables become node properties.
- Replace foreign keys with relationships to the other table
- Remove data with default values, no need to store those
- Indexed column names, might indicate an array property (like email1, email2, email3)
- Join tables are transformed into relationships, columns on those tables that are not part of the primary key become relationship properties
- Each relationship which is not binary (ternary, quaternary, …) becomes a node in the graph. All the attributes of the relationship are stored in the node. All entities participating in the relationship are linked to this node.