COMP5338 – Advanced Data Models

Week 7: Graph Data and Neo4j Introduction

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Administrative

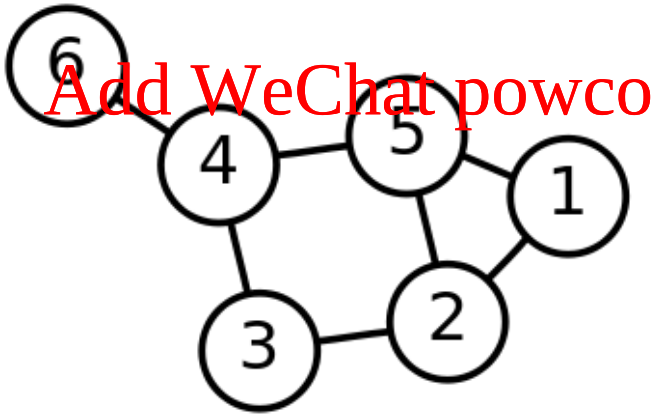
- The group project instruction and data set will be published this week (week 7)
- Group can have up to 2 students
  - Self-enrolled groups will be set up on Canvas
  - Group name indicates the lab you will demo
  - Ok to form groups across labs
- Project overview
  - You are given a data set (in a few tsv files) and some target queries
  - Design schema for two storage options
    - MongoDB based
    - Neo4j based
  - Load data, set up index, run target queries and observe performance
  - Describe your schema, query and performance in a report
  - Demo your solution to the tutor in week 10 lab
- Individual contribution will be assessed and members may get different marks

Outline

- Brief Review of Graphs
- Examples of Graph Data
- Modelling Graph Data
- Property Graph Model
- Cypher Query

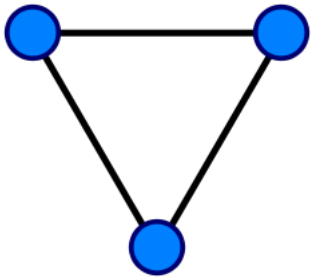
Graphs

- A graph is just a collection of *vertices* and *edges*
  - Vertex is also called Node
  - Edge is also called Arc/Link

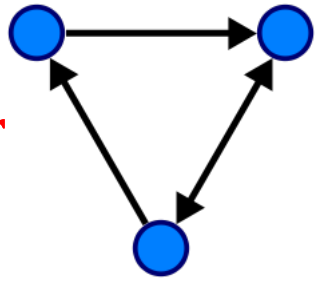


Type of Graphs

- Undirected graphs
  - Edges have no orientation (direction)
  - (a, b) is the same as (b, a)



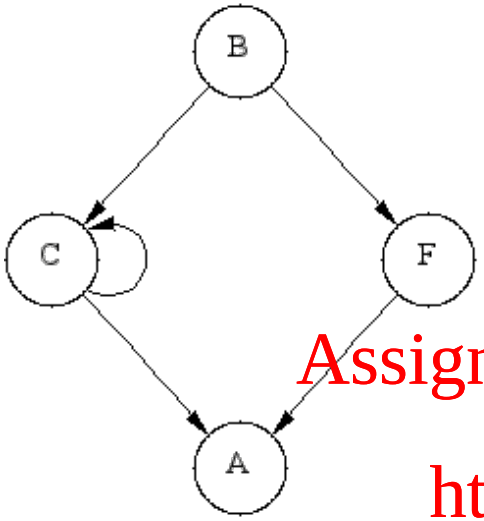
- Directed graphs
  - Edges have orientation (direction)
  - (a, b) is not the same as (b, a)

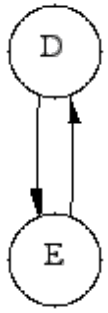


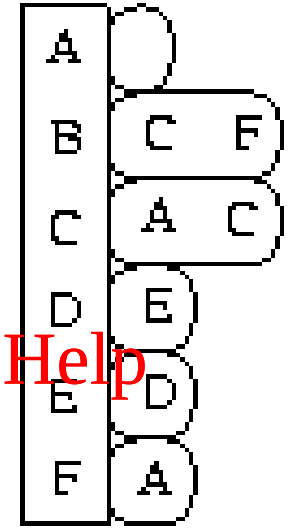
Representing Graph Data

- Data structures used to store graphs in programs
  - Adjacency list
  - Adjacency matrix

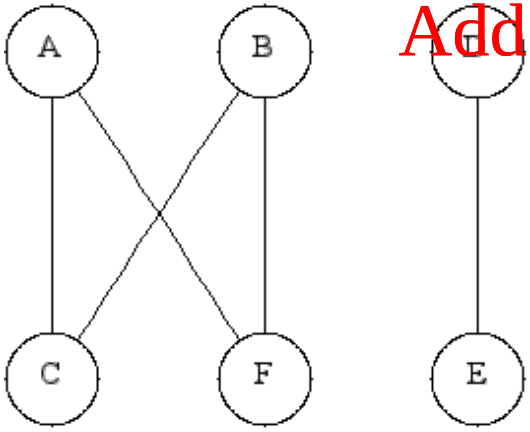
Adjacency List



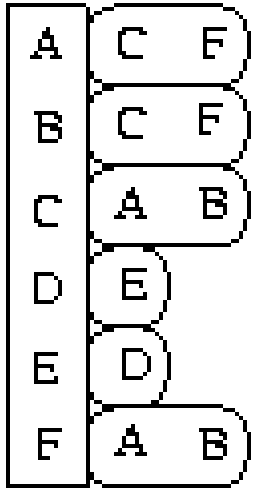




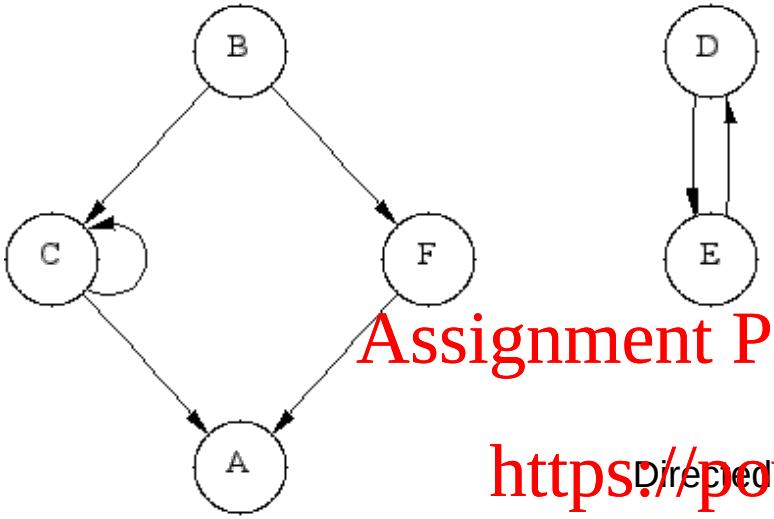
Directed Graph



Undirected Graph

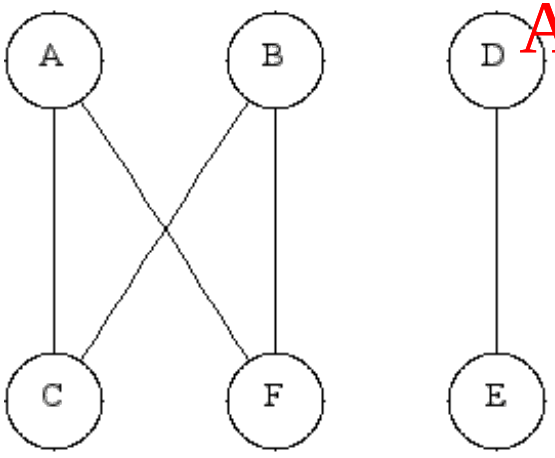


Adjacency matrix – Directed Graph



Directed Graph

	A	B	C	D	E	F
A	0	0	0	0	0	0
B	0	0	1	0	0	1
C	1	0	1	0	0	0
D	0	0	0	0	1	0
E	0	0	0	1	0	0
F	1	0	0	0	0	0



Undirected Graph

	A	B	C	D	E	F
A	0					
B	0	0				
C	1	1	0			
D	0	0	0	0		
E	0	0	0	1	0	
F	1	1	0	0	0	0

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- Brief Review of Graphs
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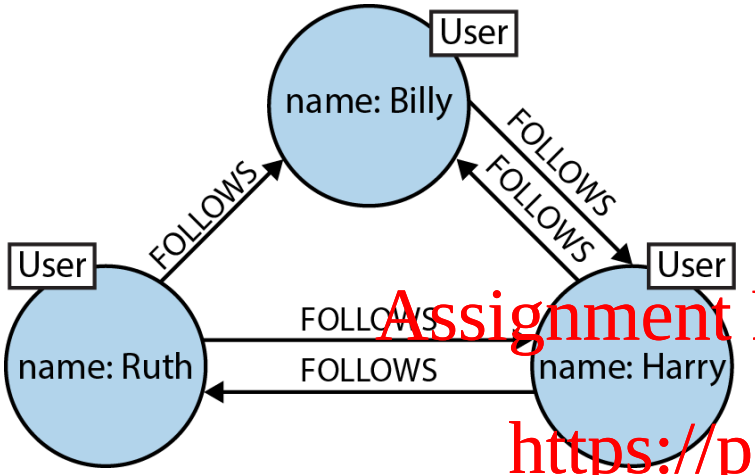
- Modelling Graph Data
- Introduction to Neo4j
- Cypher Query

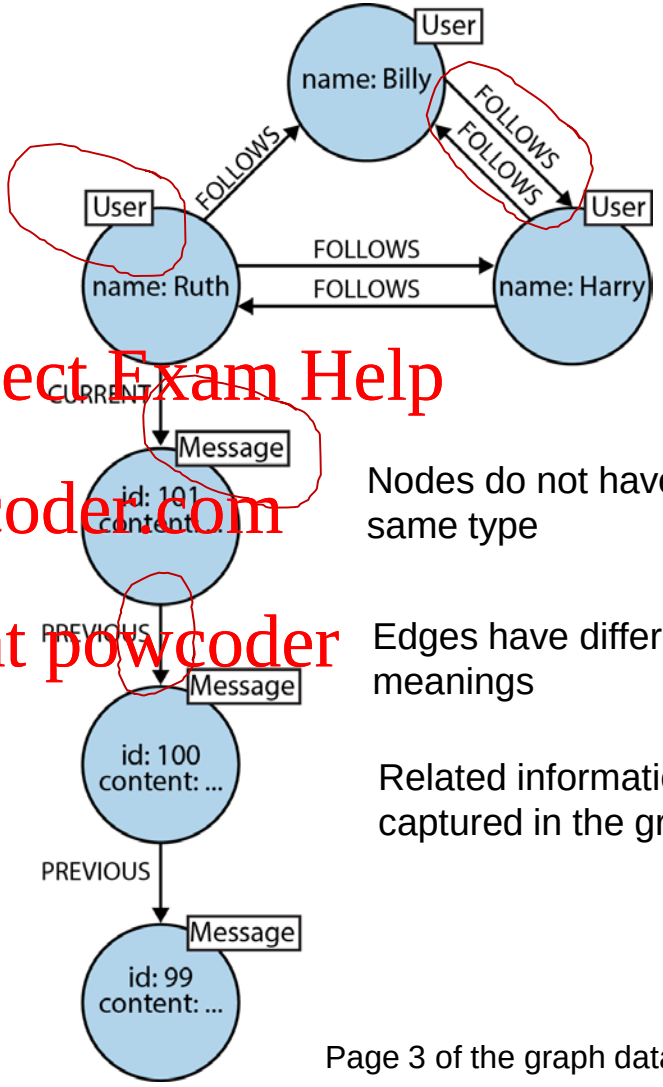
Examples of graphs

- Social graphs
  - Organization structure
  - Facebook, LinkedIn, etc.
- Computer Network topologies
  - Data centre layout
  - Network routing tables
- Road, Rail and Airline networks

Social Graphs and extension



A small social graph



Nodes do not have to be of same type

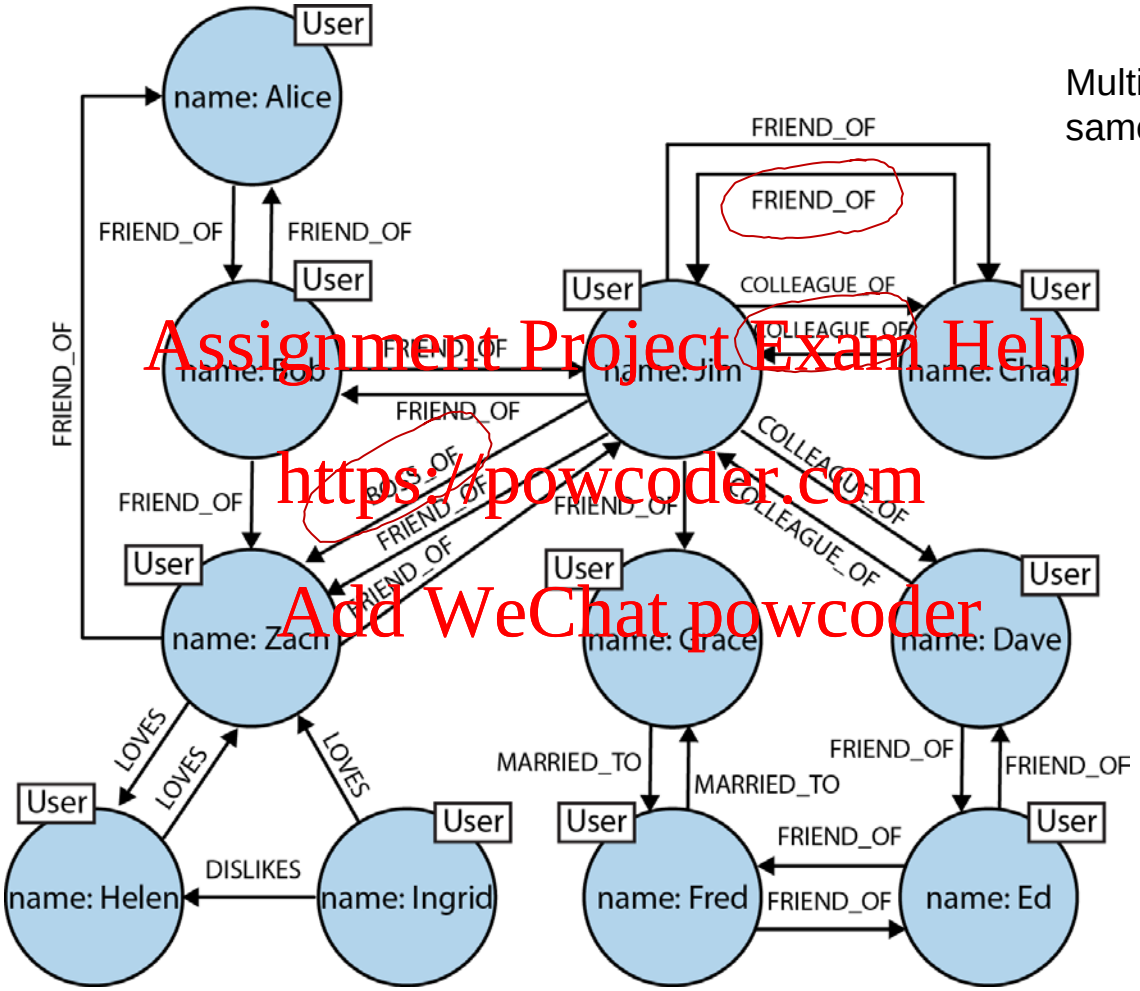
Edges have different meanings

Related information can be captured in the graph

Page 2 of the graph database book

Page 3 of the graph database book

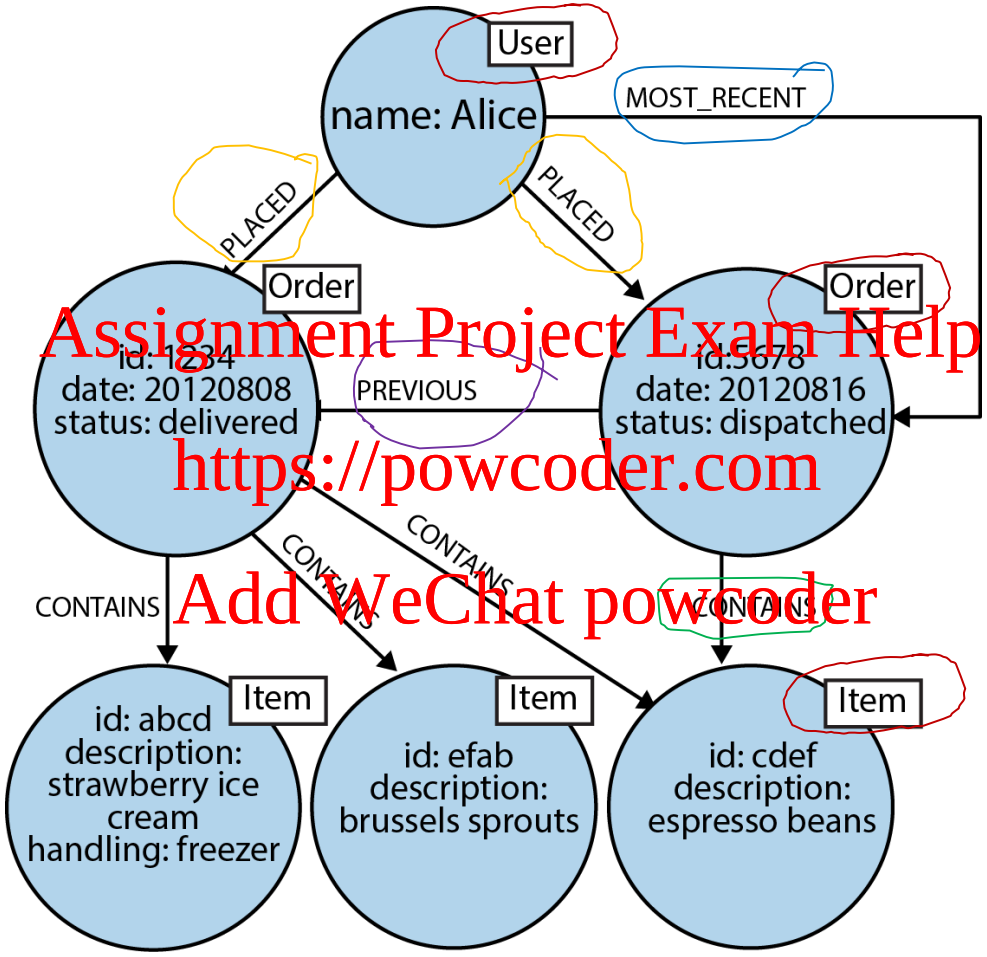
Social Graph with Various Relationships



Multiple edges between the same pair of nodes

Page 19 of the graph database book

Transaction information



This graph shows three types of entities

And various types of relationships among those entities

User PLACED order

User MOST_RECENT order

Order CONTAINS Item

Order PREVIOUS Order

Page 23 of the graph database book

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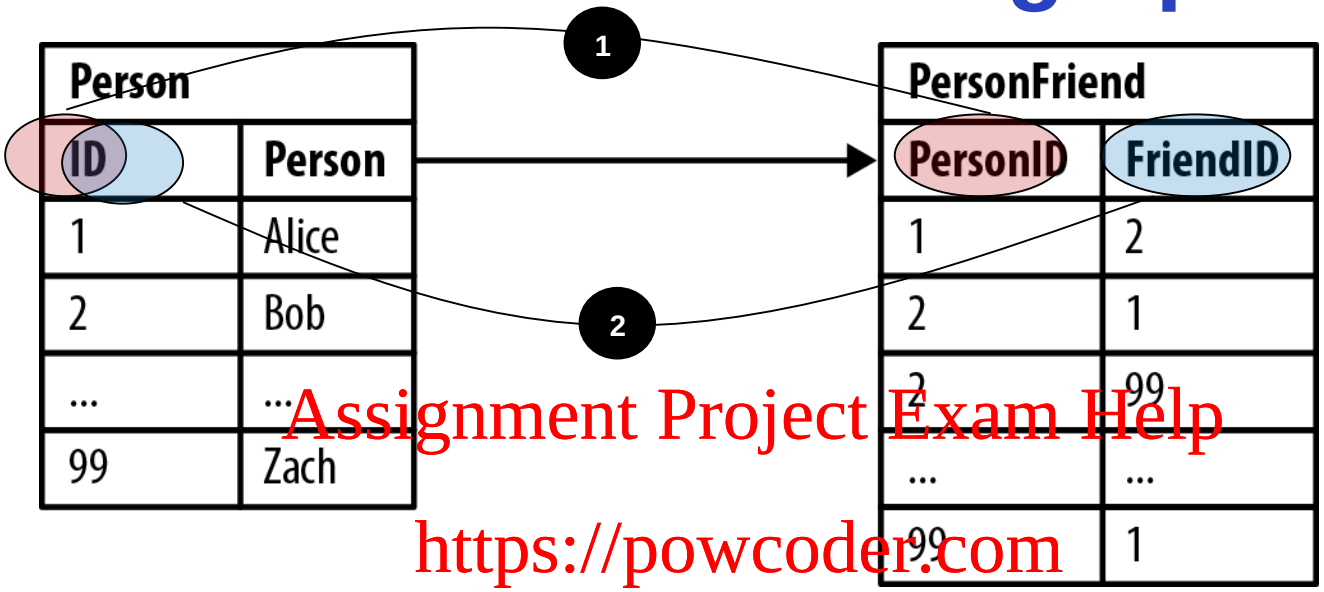
RDBMS to store graph



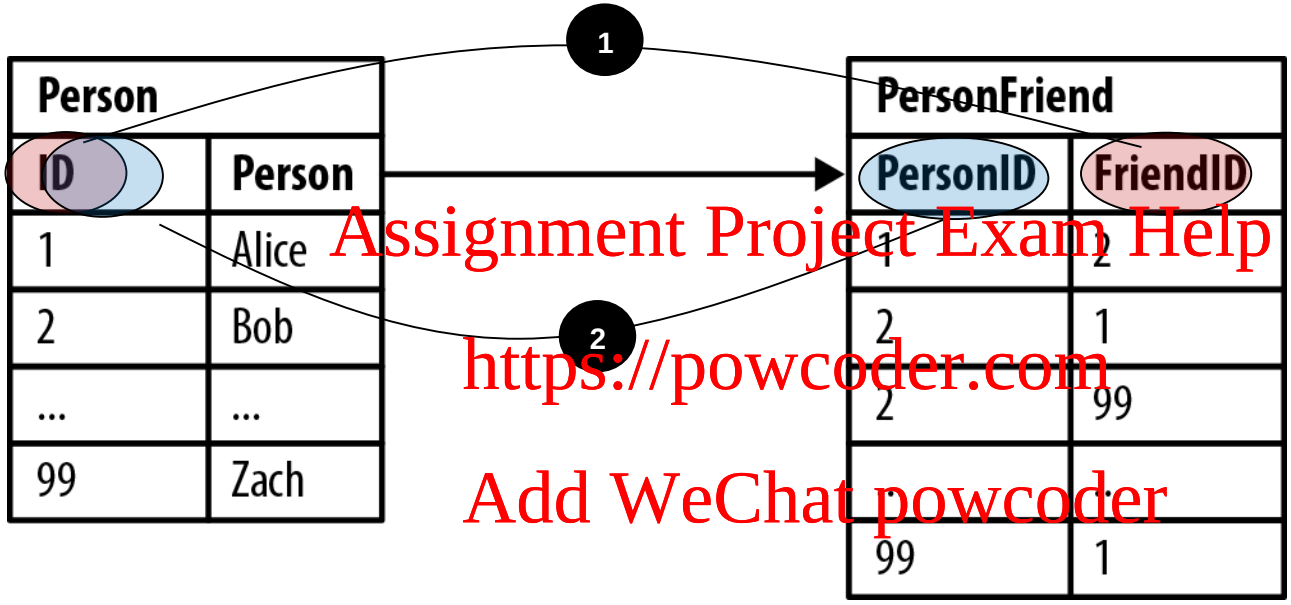
- Who are Bob's friends?

```
SELECT  p1.Person
FROM    Person p1 JOIN PersonFriend pf ON pf.FriendID = p1.ID
        JOIN Person p2 ON pf.PersonID = p2.ID
WHERE     p2.Person = ”Bob”
```

Page 13 of the graph database book

RDBMS to store Graphs

- Who are friends with Bob?




```
SELECT   p1.Person
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WHERE
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```
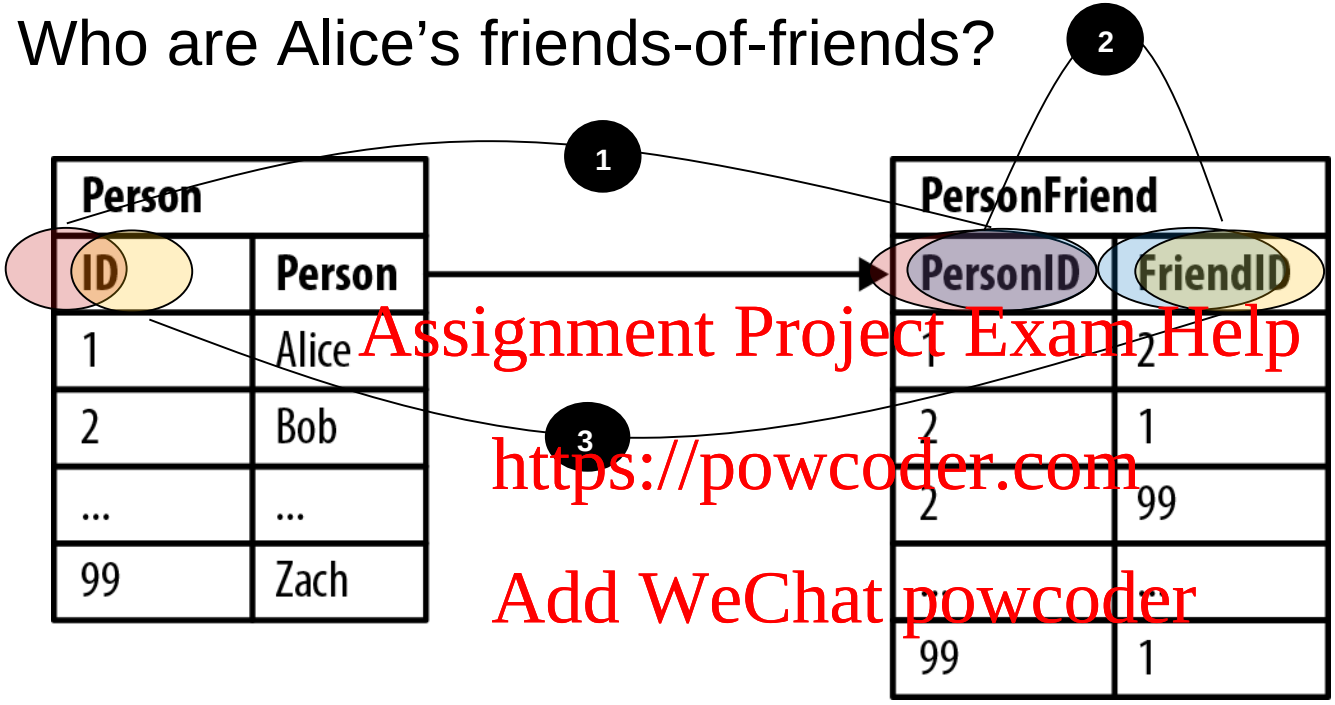

RDBMS to store Graphs

- Who are Alice's friends-of-friends?




```
SELECT   p1.Person AS PERSON, p2.Person AS FRIEND_OF_FRIEND
FROM     PersonFriend pf1 JOIN Person p1 ON pf1.PersonID = p1.ID
         JOIN PersonFriend pf2 ON pf2.PersonID = pf1.FriendID
         JOIN Person p2 ON pf2.FriendID = p2.ID
WHERE    p1.Person = "Alice" AND pf2.FriendID <> p1.ID
```

MongoDB to store Graph

persons collection

```
{ _id: 1,
  person: “Alice”,
  friends:[2]
}

{ _id: 2,
  person: “Bob”,
  friends:[1,99]
}

{ _id: 99,
  person: “Zach”,
  friends:[1]
}
```

- Who are Bob’s friends?
  - Find out Bob’s friends’ ID
    - `db.persons.find({person:”Bob”},{friends:1})`
  - For each id, find out the actual person
    - `db.persons.find({_id: 1},{person:1}),`
      `db.persons.find({_id: 99},{person:1}),`
    - `db.persons.find({_id:{$in:[1,99]}}, {person:1})`
- Who are friends with Bob?
  - Find out Bob’s id
    - `db.persons.find({person:”Bob”})`
  - Find out the persons that are friends with Bob
    - `db.persons.find({friends: 2}, {person:1})`
- Who are Alice’s friends-of-friends?
  - Find out Alice’s friends ID
    - `db.persons.find({person:”Alice”},{friends:1})`
  - For each id, find out the friends ID again
    - `db.persons.find({_id:{$in:[2]}}, {friends:1}`
  - For each id, find out the actual person
    - `db.persons.find({_id:{$in:[1,99]}}, {person:1})`
- The MongDB 3.4 and later has a new aggregation stage called `$graphLookup`

$graphLookup

```
db.persons.aggregate([
 {$match:{person:“Alice"}},
 {$graphLookup:{
    from: "persons",
    startWith: "$friends",
    connectFromField:"friends",
    connectToFirld:"pid",
    maxDepth: 1,
    as: "friendsnetwork"}}
  ])
```

```
{“_id" : 1,
   “person" : "Alice",
   "friends" : [ 2],
   "friendsnetwork" : [
      {“_id" : 99.0,
         "name" : "Zach",
         "friends" : [ 1, 3],
         "depth" : 1 },
      {“_id" : 1,
         "name" : "Alice",
         "friends" : [ 2],
         "depth" : 1},
      {“_id" : 2,
         "name" : "Bob",
         "friends" : [1, 99],
         "depth" : 0}
   ] }
```

In Summary

- It is possible to store graph data in various storage systems
  - Shallow traversal
    - Relatively easy to implement
    - Performance OK
  - Deep traversal or traversal in other direction
    - Complicated to implement
      - Multiple joins or multiple queries or full table scan
    - Less efficient
    - Error prone

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Graph Technologies

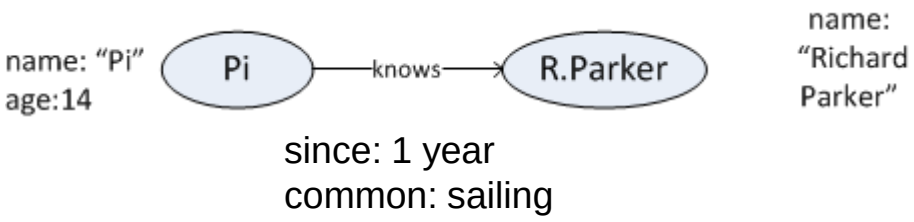
- Graph Processing
  - take data in any input format and perform graph related operations
  - OLAP – OnLine Analysis Processing of graph data
  - Google Pregel, Apache Giraph
- Graph Databases
  - manage, query, process graph data
  - support high-level query language
  - native storage of graph data
  - OLTP – OnLine Transaction Processing possible
  - OLAP – also possible

Graph Data Models

- RDF (Resource Description Framework) Model
  - Express node-edge relation as “subject, predicate, object” triple (RDF statement)
  - SPARQL query language
  - Examples: AllegroGraph, Apache Jena
- Property Graph Model
  - Express node and edge as object like entities, both can have properties
  - Various query language
  - Examples
    - Apache Titan
      - Support various NoSQL storage engine: BerkeleyDB, Cassandra, HBase
      - Structural query language: Gremlin
    - Neo4j
      - Native storage manager for graph data (Index-free Adjacency)
      - Declarative query language: Cypher query language

Property Graph Model

- Proposed by **Neo** technology
- No standard definition or specification
- Both Node and Edges can have property
  - RDF model cannot express edge property in a natural and easy to understand way
- The actual storage varies
- The query language varies



Neo4j

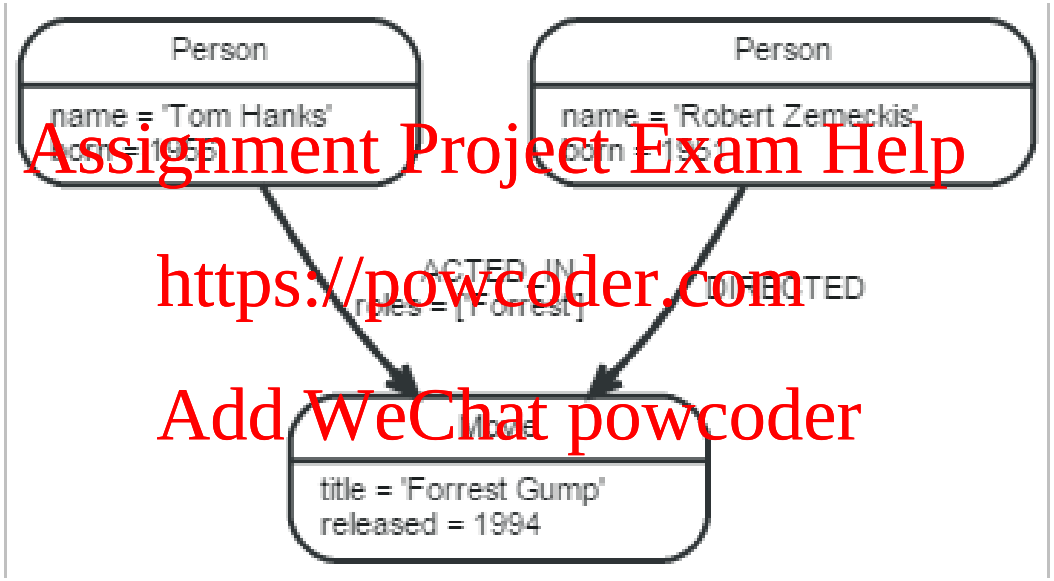
- Native graph storage using **property graph model**
- Index-free Adjacency
  - Nodes and Relationships are stored
- Supports indexes
- Replication
  - Single master-multiple slaves replication
- Neo4j cluster is limited to master/slave replication configuration
  - Database engine is not distributed
- **Cypher** – query language

Property Graph Model as in Neo4j

- Property graph has the following characteristics
  - It contains nodes and relationships
  - Nodes contain properties
    - Properties are stored in the form of key-value pairs
    - A node can have labels (classes)
  - Relationships connect nodes
    - Has a *direction*, an optional *type*, a *source node* and a *target node*
    - No dangling relationships (can't delete node with a relationship)
  - Properties
    - Both nodes and relationships have properties
    - Useful in modeling and querying based on properties of relationships

http://docs.neo4j.org/chunked/milestone/graphdb-neo4j.html

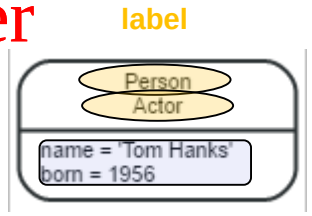
Property Graph Model Example



It models a graph with three entities: 2 person and one movie, each with a set of properties;
It also models the relationship among them: one person acted in the movie with a role, another person directed the movie

Property Graph Model: Nodes

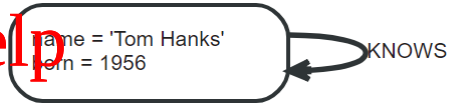
- Nodes are used often used to represent entities, e.g. objects
  - It has properties
  - It can have labels
- A label is a way to group similar nodes
  - It acts like the 'class' concept in programming world
- Label is a dynamic and flexible feature
  - It can be added or removed during run time
  - It can be used to tag node temporarily
    - E.g. :Suspend, :OnSale, etc

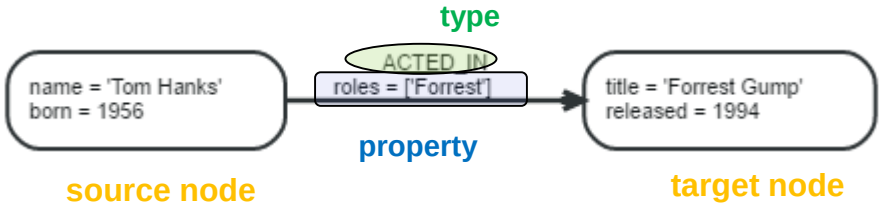


A node with two labels and two properties

Property Graph Model: Relationships

- A relationship connects two nodes: source node and target node
  - The source and the target node can be the same one
- It always has a direction
  - But traversal can happen in either direction
- It can have a type
- It can have properties

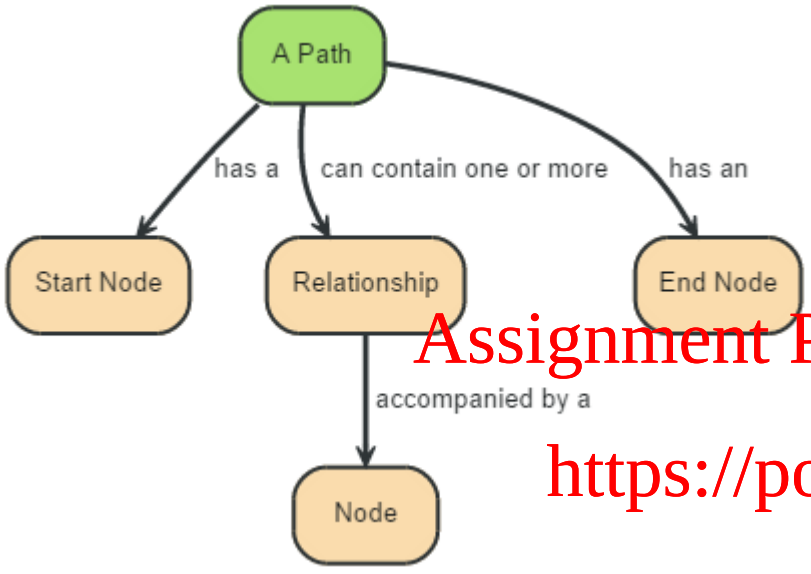




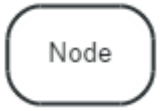
Property Graph Model: Properties

- A property is a pair of property key and property value
- The property value can have the following type:
  - Number: Integer and Float
  - String
  - Boolean
  - Spatial Type: Point
  - Temporal Type
    - Date
    - Time
    - …

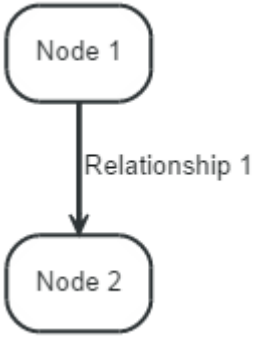
Property Graph Model: Paths



- A path is one or more nodes with connecting relationships, typically retrieved as a query or traversal result.



A path of length zero



A path of length one

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Cypher

- Cypher is a query language specific to Neo4j
- Easy to read and understand
- It uses **patterns** to represents core concepts in the property graph model
  - E.g. a pattern may represents that a user node is having a transaction with the item formula in it
  - There are basic pattern representing nodes, relationships and path
- It uses **clauses** to build queries, Certain clauses and keywords are inspired by SQL
  - A query may contain multiple clauses
- **Functions** can be used to perform aggregation and other types of analysis

Cypher patterns: node

- A single node
  - A node is described using a pair of parentheses, and is typically given an identifier (variable)
  - E.g.: **(n)** means a node **n**
  - The variable's scope is restricted in a single query statement
- Labels
  - Label(s) can be attached to a node
  - E.g.: **(a:User)** or **(a:User:Admin)**
- Specifying properties
  - Properties are a list of name value pairs enclosed in a curly brackets
  - E.g.: **(a { name: "Andres", sport: "Brazilian Ju-Jitsu" })**

https://neo4j.com/docs/developer-manual/current/cypher/syntax/patterns/

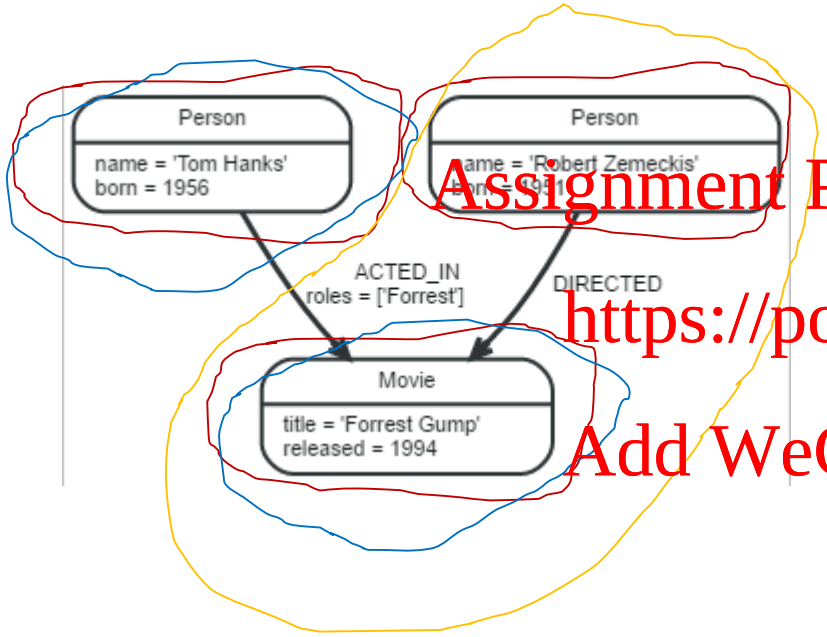
Cypher patterns: relationships

- Relationship is expressed as a pair of dashes (--)
  - Arrowhead can be added to indicate direction
  - Relationship always need a source and target node.
- Basic Relationships
  - Directions are not important: `(a)--(b)`
  - Named relationship: `(a)-[r]->(b)`
  - Named and typed relationship: `(a)-[r:REL_TYPE]->(b)`
  - Specifying Relationship that may belong to one of a set of types: `(a)-[r:TYPE1|TYPE2]->(b)`
  - Typed but not named relationship: `(a)-[:REL_TYPE]->(b)`

Relationship patterns (cont'd)

- Relationship of variable lengths
  - **(a)-[*2]->(b)** describes a path of length 2 between node **a** and node **b**
    - **This is equivalent to (a)-->()-->(b)**
  - **(a)-[*3..5]->(b)** describes a path of minimum length of 3 and maximum length of 5 between node **a** and node **b**
  - Either bound can be omitted **(a)-[*3..]->(b)**, **(a)-[*..5]->(b)**
  - Both bounds can be omitted as well **(a)-[*]->(b)**

Pattern Examples



- Pattern: **(n)**
- Matches all nodes in the graph

- Pattern: **(m:Movie)**
- Matches the movie node in the graph

- Pattern: **(p:{name: 'Tom Hanks'})**
- Matches the person node with name 'Tom Hanks' in the graph

- Pattern: **(p1)-[r:DIRECTED]->(m1)**
- Matches the path from person Robert Zemeckis to movie "Forrest Grum'

Cypher Clauses - Create

- CREATE
  - Create nodes or relationships with properties

- Create a node **matrix1** with the label **Movie**

```
CREATE (matrix1:Movie {title:'The Matrix', released:1999,
        tagline:'Welcome to the Real World'})
```

We give the node an identifier so we can refer to the particular node later in the same query

- Create a node **keanu** with the label **Actor**

```
CREATE (keanu:Actor {name:'Keanu Reeves', born:1964})
```

- Create a relationship **ACTS_IN**

```
CREATE (keanu)-[:ACTS_IN {roles:'Neo'}]->(matrix1)
```

The identifier "Keanu" and "matrix1" are used in the this create clause.
We did not give the relationship a name/identifier.
We need to write the three clauses in a single query statement to be able to use those variables

Cypher – Read

- **MATCH … RETURN**
  - MATCH is the main reading clause
  - RETURN is a projecting clause
  - They are chained to make a query
- Return all nodes:

```
MATCH (n) RETURN n
```


- Return all nodes with a given label: select * from movie

```
MATCH (movie:Movie) RETURN movie
```

- Return all actors' name in the movie "The Matrix"

We give the Actor node an identifier "a" so we can use refer to in the RETURN sub-clause

```
MATCH (a:Actor)-[:ACTS_IN]->(:Movie{title:"The Matrix"})
RETURN a.name
```

We do not need to return the relationship so we did not give an identifier to it

We do not need to give an identifier to the Movie node too,

Cypher - Update

- **MATCH … SET/REMOVE … RETURN**

- Set the age property for all actor nodes

```
MATCH (n:Actor)
SET n.age = 2014 - n.born
RETURN n
```

- Remove a property

```
MATCH (n:Actor)
REMOVE n.age
RETURN n
```

- Remove a label

```
MATCH (n:Actor{name:"Keanu Reeves"})
REMOVE n:Actor
RETURN n
```

Cypher - Delete

- **MATCH … DELETE**

- Delete relationship

```
MATCH (n{name:"Keanu Reeves"})-[r:ACTS_IN]->()
DELETE r
```


- Delete a node and all possible relationship

```
MATCH (m{title:"The Matrix"})-[r]->()
DELETE m,r
```

More on READ: WHERE

- The **WHERE** sub clause can be used to specify various query conditions

```
MATCH (n)
WHERE n.age <30 and n.employ>=3
RETURN n.name
```

Functions

- Functions may appear in various clauses
  - Build-in and user-defined functions
- Build-in functions
  - Prediction functions
  - Scalar functions
  - Aggregation functions
  - List functions
  - Mathematical functions
  - String functions
  - Temporal functions
  - Spatial Functions

Aggregating Functions

- GROUP BY feature in Neo4j is achieved using aggregating functions
  - E.g. **count()**, **sum()**, **avg()**, **max()**, **min()** and so on
- The grouping key is implied in the return clause
  - None aggregate expression in the return clause is the grouping key
  - **RETURN n, count(*)**
    - **n** is a variable declared in a previous clause, and it is the grouping key
  - **MATCH(n:PERSON) RETURN n.gender, COUNT(*)**
    - Count the number of nodes representing male and female in the graph
    - A person's gender is the grouping key
- A grouping key is not always necessary, the aggregation function can apply to all results returned
  - **MATCH (n:PERSON) RETURN COUNT(*)**
    - To count the number of Person nodes in the graph

Aggregation Examples

- To find out the earliest year a Person was born in the data set

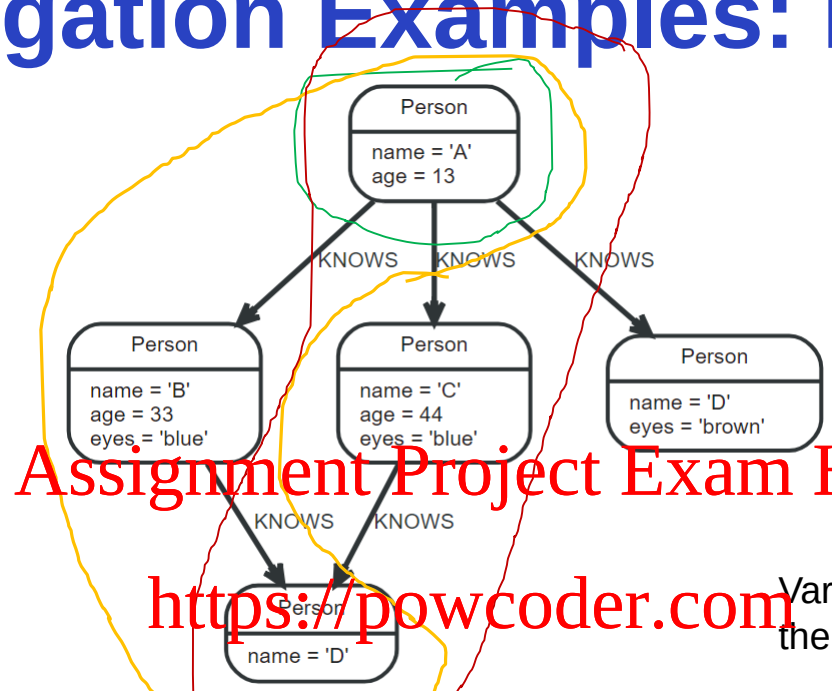
  MATCH (n:PERSON) RETURN min (n.born)

- To find out the distribution of relationship types belonging to nodes with certain feature


```
MATCH (n { name: 'A' })-[r]->()
RETURN type(r), count(*)
```


The grouping key is type(r) which is a scalar function, returns the type of relationship in the matching results

Aggregation Examples: DISTINCT



Variable **friend_of_friend** refers to the same node in both matches


```
MATCH (me:Person)-->(friend:Person)-->(friend_of_friend:Person)
WHERE me.name = 'A'
RETURN count(DISTINCT friend_of_friend), count(friend_of_friend)
```

count(DISTINCT friend_of_friend)	count(friend_of_friend)
1	2
1 row	

More on READ: subqueries

- The **WITH** clause can chain different query parts together in a pipeline style
  - Used to apply conditions on aggregation result
  - Used to modify (order, limiting, etc) the results before collecting them as a list
- Examples
  - Find the person who has directed 3 or more movies

```
MATCH (p:Person)-[:DIRECTED]->(m:Movie)
WITH p, count(*) as movies
WHERE movies >= 3
RETURN p.name, movies
```

  - Return the oldest 3 person as a list

```
MATCH (n:Person)
WITH n
ORDER by n.age DESC LIMIT 3
RETURN collect(n.name)
```

```
MATCH (n:Person)
RETURN n.name
ORDER by n.age DESC LIMIT 3
```

Dealing with Array type

- Array literal is written in a similar way as it is in most programming languages
  - examples
    - An array of integer: [1,2,3]
    - An array of string: ["Sydney", "University"]
- Both node and relationship can have property of array type
  - Example: create an relationship with array property

    create (Keanu)-[:ACTED_IN {roles:['Neo']}]->(TheMatrix)
  - Example: update an existing node with array property

    MATCH (n:Person{name: "Tom Hanks"})

    set n.phone=["0123456789","93511234"]

Dealing with Array type (cont'd)

- Querying array property
  - The IN operator: check if a value is in an array
    - Example: find out who has played 'Neo' in which movie

```
MATCH (a:Person) -[r:ACTED_IN]->(m:Movie)
WHERE 'Neo' IN r.roles
RETURN a , m
```

  - The UNWIND operator: flatten an array into multiple rows
    - Example: find all the movies released in 1999 or in 2003

```
UNWIND [1999,2003] as year
MATCH (m: Movie)
WHERE m.released = year
RETURN m.title, m.released
```

This is equivalent to

```
MATCH(m: Movie)
WHERE m.released IN [1999,2003]
RETURN m.title, m.released
```

```
$ UNWIND [1999,2003] as year MATCH (m: Movie) WHERE m.releas...
```

m.title	m.released
The Matrix	1999
Snow Falling on Cedars	1999
The Green Mile	1999
Bicentennial Man	1999
The Matrix Reloaded	2003
The Matrix Revolutions	2003
Something's Gotta Give	2003

Returned 7 rows in 37 ms.

Dealing with Array Type (cont'd)

- A relatively complex query
  - Update another node

    MATCH (n:Person{name: "Meg Ryan"}) set n.phone=["0123456789"]
  - Run a query to see who shares any phone number with Tom Hanks

    MATCH (n:Person{name: "Tom Hanks"})

    WITH n.phone as phones, n

    UNWIND phones as phone

    MATCH (m:Person)

    WHERE phone in m.phone and n<>m

    RETURN m.name

Where to find more about cypher query:
Developer's guide: http://neo4j.com/docs/developer-manual/current/cypher/
Reference card: https://neo4j.com/docs/cypher-refcard/current/

Indexing

- Neo4j supports index on properties of labelled node
- Index has similar behaviour as those in relational systems
- Create Index
  - **CREATE INDEX ON :Person(name)**
- Drop Index
  - **DROP INDEX ON :Person(name)**
- Storage and query execution will be covered in week 8

References

- Ian Robinson, Jim Webber and Emil Eifrem, *Graph Databases*, Second Edition, O'Reilly Media Inc., June 2015
  - You can download this book from the Neo4j site, http://www.neo4j.org/learn will redirect you to http://graphdatabases.com/
- The Neo4j Document
  - The Neo4j Graph Database Concept (http://neo4j.com/docs/stable/graphdb-neo4j.html)
- Noel Yuhanna, *Market Overview: Graph Databases*, Forrester White Paper, May, 2015
- Renzo Angeles, *A Comparison of Current Graph Data Models*, ICDE Workshops 2013 (DOI-10.1109/ICDEW.2012.31)
- Renzo Angeles and Claudio Gutierrez, *Survey of Graph Database Models*, ACM Computing Surveys, Vol. 40, N0. 1, Article 1, February 2008 (DOI-10.1145/1322432.1322433)