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Neo4j: A graph database

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What is a database?

- Organized collection of structured information, or data, stored in a computer system
- Usually controlled by a database management system (DBMS)
- Together, data and DBMS, are referred to as a *database system*, often shortened to just database
- Data stored in a database can be easily accessed, managed, modified, updated, controlled, and organized

Types ofdatabases

- Many types of databases, that mainly differ on data models
  - E.g., relational databases, NoSQL databases, graph databases
- The best type depends on how you intend to use data
- Relational databases
  - The most common type
  - Data is modeled in rows and columns in a series of tables to make processing and data querying efficient
  - Use Structured Query Language (SQL) for writing and querying data

Neo4j: a graph database

- Graph database: database designed to treat relationships between data as equally important to (or even more important than) data itself
  - Purpose-built to store and navigate relationships
  - Uses nodes to store data entities, and links to store relationships between entities

- Neo4j: an open-source, native graph database https://neo4j.com/

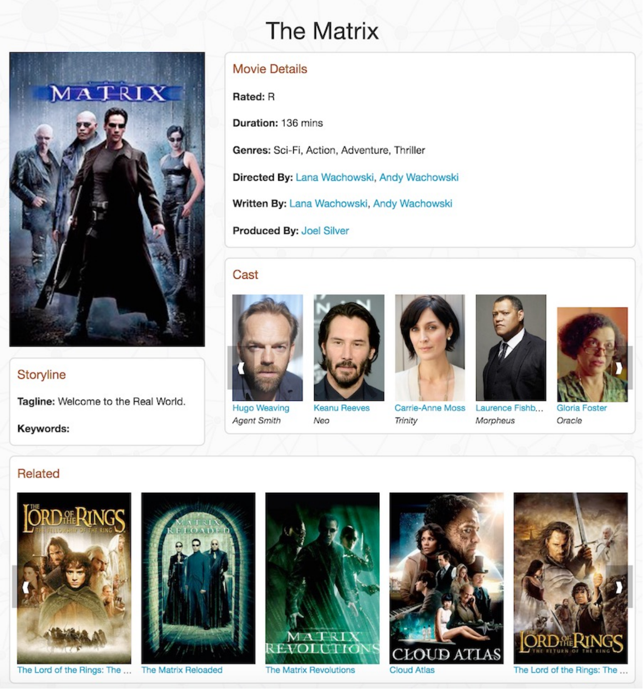
Graph data model

- Powerful data model
  - Designed to treat relationships between data
  - Focus on visual representation of information (more human-friendly)

- Data model based on graph (network) structure
  - *Nodes* are the entities and have a set of attributes
  - *Links* are the relationships between the entities
    - E.g.: an author writes a book

Graph data model: movies example

- How can we model information regarding the movie The Matrix?



The Matrix

Movie Details

Rated: R

Duration: 136 mins

Genres: Sci-Fi, Action, Adventure, Thriller

Directed By: Lana Wachowski, Andy Wachowski

Written By: Lana Wachowski, Andy Wachowski

Produced By: Joel Silver

Cast

Hugo Weaving *Agent Smith*

Keanu Reeves *Neo*

Carrie-Anne Moss *Trinity*

Laurence Fishb... *Morpheus*

Gloria Foster *Oracle*

Storyline

Tagline: Welcome to the Real World.

Keywords:

Related

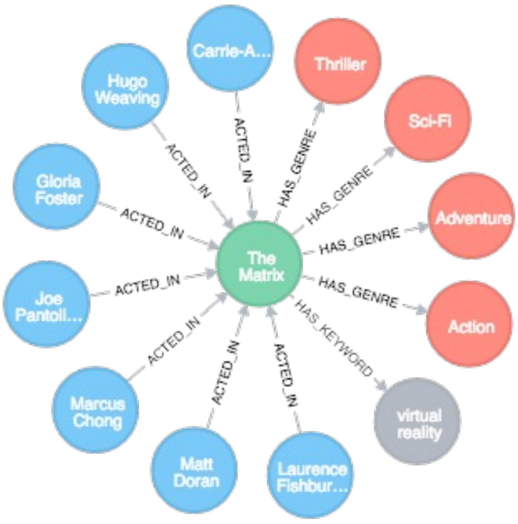
The Lord of the Rings: The ...

The Matrix Reloaded

The Matrix Revolutions

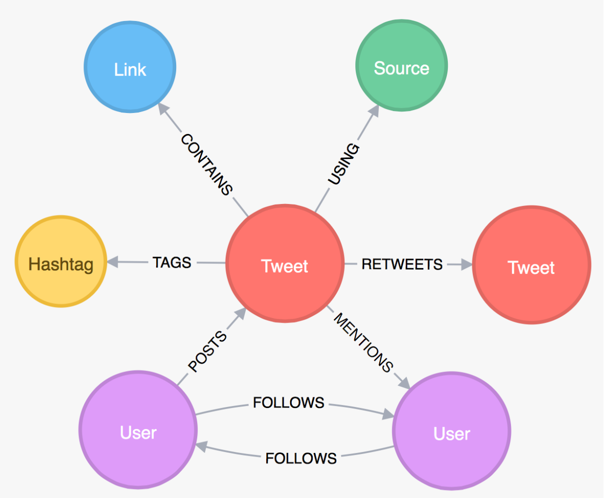
Cloud Atlas

The Lord of the Rings: The ...



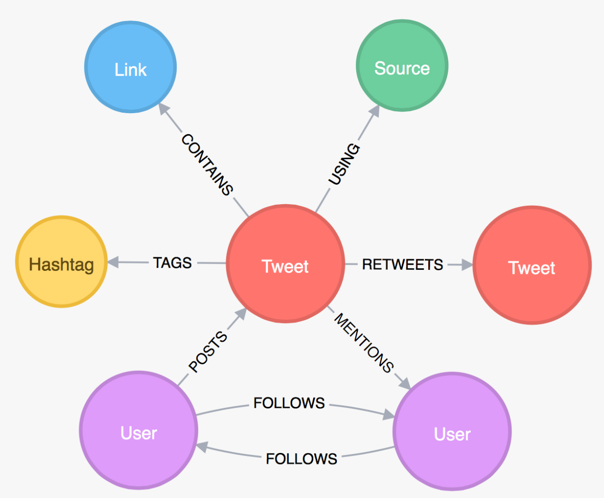
Graph data model: Twitter example

- How can we represent Twitter data and relationships?
- Choice depends also on what we want to analyze: let's assume social media activity
- Nodes in the graph model
  - `User`: represents a Twitter user
  - `Tweet`: represents a tweet
  - `Hashtag`: represents a hashtag
  - `Link`: represents a shared link in a tweet
  - `Source`: represents the platform used by Twitter users to tweet from



Graph data model: Twitter example

- Relationships in the graph:
  - `POST` relationship between a `User` and a `Tweet`: indicates that this user is the tweet author
  - `RETWEETS` relationship between two `Tweets`: indicates the first `Tweet` retweets the second `Tweet`
  - `TAGS` relationship between a `Tweet` and a `Hashtag`
  - `FOLLOWS` relationship between two `Users`: indicates the first `User` follows the second `User`
  - `MENTIONS` relationship between `Tweet` and `User`: indicates that the `Tweet` mentions the `User`

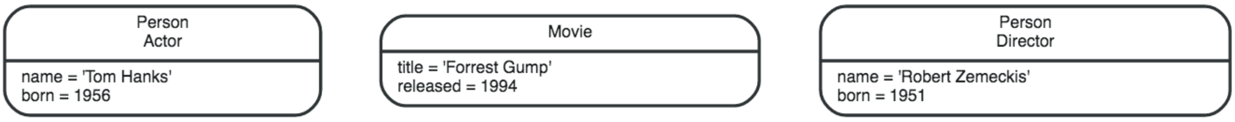


Suitable use cases for graph databases

- Good for applications where:
  - you need to model entities and relationships between them
  - and the focus is on querying for relationships between entities and analyzing relationships
- Some example of applications
  - Social network analysis
  - Recommendations
  - Fraud detection
  - Supply chain management

Neo4j: concepts

- Graph
  - Nodes, relationships, properties, and labels
- We use nodes to represent entities
  - A node can have properties and labels
  - A node can have relationships to other nodes, including itself
- Nodes and relationships have individual attributes called properties
- Properties consist of key-value pairs, e.g.,
  - name = ‘Tom Hanks’, born = 1956
  - title = ‘Forrest Gump’, released = 1994



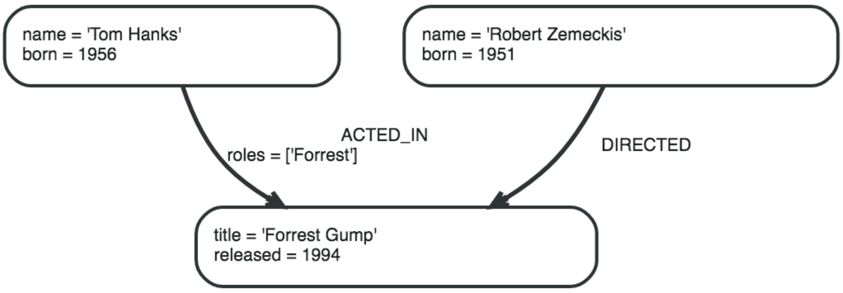
Person
Actor
name = 'Tom Hanks'
born = 1956

Movie
title = 'Forrest Gump'
released = 1994

Person
Director
name = 'Robert Zemeckis'
born = 1951

Neo4j: concepts

- Nodes can be tagged with labels (i.e., node types)
  - Labels are used to group nodes into sets, so that all nodes with a given label belong to the same set (e.g., Actor and Director are labels for Person nodes)
- Relationships connect nodes, are unidirectional and can have properties
  - E.g., ACTED_IN, DIRECTED
- Properties are key-value pairs that are used to add qualities to nodes and relationships



Neo4j: Cypher

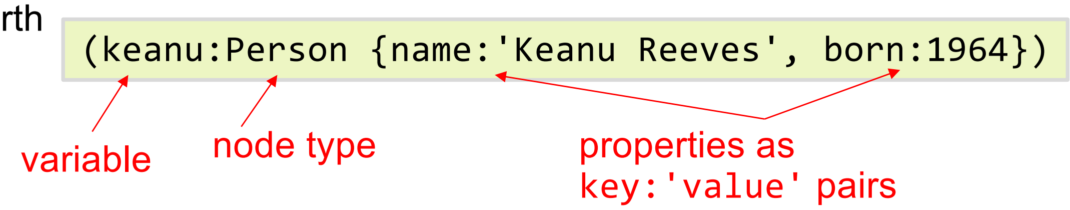
- **Cypher**: Neo4j's graph query language
- Allows users to read data from and write data to Neo4j https://neo4j.com/docs/getting-started/current/cypher-intro/
- It uses a declarative way to query the graph powered by traversals and other techniques
  - A traversal navigates through the graph to find paths
    - Starts from starting nodes to related nodes, finding answers to queries
  - A path is one or more nodes with connecting relationships, typically retrieved as a query or traversal result
- It is a textual declarative query language
  - Uses a form of ASCII art to represent graph-related patterns
  - E.g., `(:nodes)-[:ARE_CONNECTED_TO]->(:otherNodes)`

Cypher syntax: node

- Cypher uses a pair of parentheses ( ), usually containing a text string, to represent a node

```
(varname:Label { p_name: p_value, ... } )
```

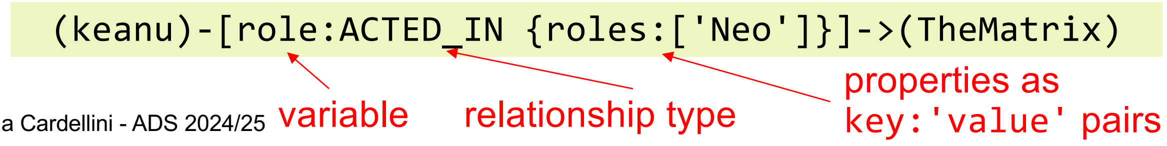
  - ( ) represents a node
  - `varname` (optional) is a variable that we can assign to the node and use later in a query to refer to that node
  - `Label` (prefixed with a colon `:`) declares node's type (or *label*)
  - Node's properties are represented as a list of key/value pairs, enclosed within a pair of { }
  - E.g., to represent a Person node with name and year of birth



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

Cypher syntax: relationship

- Cypher uses a pair of dashes `--` to represent an undirected relationship. Directed relationships have an arrowhead at one end `<--` `-->`
  - It is possible to create only directed relationships, although they can be queried as undirected
- Bracketed expressions `[ ]` are used to add details to a relationship:
  - We can assign a variable (e.g., `role`) also to a relationship and use it later in a query
  - Relationship's type (e.g., `:ACTED_IN`) is analogous to the node's label
  - Relationship's properties (e.g., `roles`) are analogous to node's properties



```
(keanu)-[role:ACTED_IN {roles:['Neo']}]->(TheMatrix)
```

Cypher syntax: pattern variables

- To increase modularity and reduce repetition, Cypher allows patterns to be assigned to variables
  - This allows the matching paths to be inspected, used in other expressions, etc.
- E.g., `acted_in` is a variable

```
acted_in = (:Person)-[:ACTED_IN]->(:Movie)
```

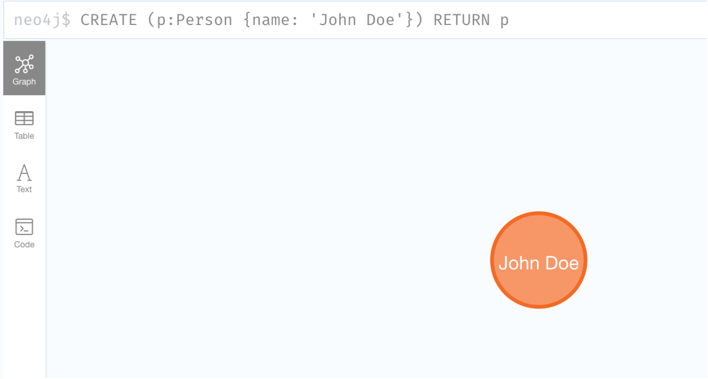
Operations on data

- We consider only a subset of operations available in Cypher
- How to perform write operations?
  - CREATE, DELETE
  - E.g., to create nodes and relationships between nodes
- How to perform read operations?
  - MATCH

Cypher syntax: CREATE

- Use CREATE to insert data (nodes and relationships) in the database
  - Example: create a node with label Person and property name with value John Doe
  - RETURN defines what to include in the query result

```
CREATE (p:Person {name: 'John Doe'})
RETURN p
```



```
neo4j$ CREATE (p:Person {name: 'John Doe'}) RETURN p
```

Cypher syntax: CREATE

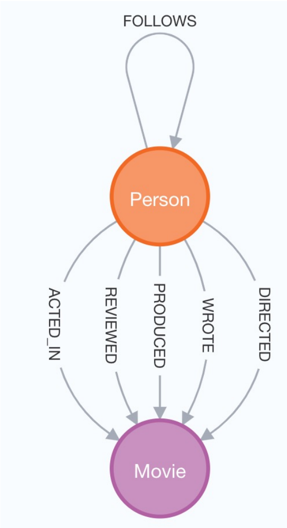
- Use CREATE to insert data (nodes and relationships)
  - Example: create a Person node and a Movie node and their relationship

```
CREATE (a:Person {name: 'Tom Hanks', born: 1956})-
[r:ACTED_IN {roles: ['Forrest']}]->(m:Movie {title:
'Forrest Gump', released: 1994})
CREATE (d:Person {name: 'Robert Zemeckis', born:
1951})-[:DIRECTED]->(m)
RETURN a, d, r, m
```

Cypher syntax: display graph model

- Once we have created data (or we use a pre-populated database), we can display the graph model in terms of node types and relationship types

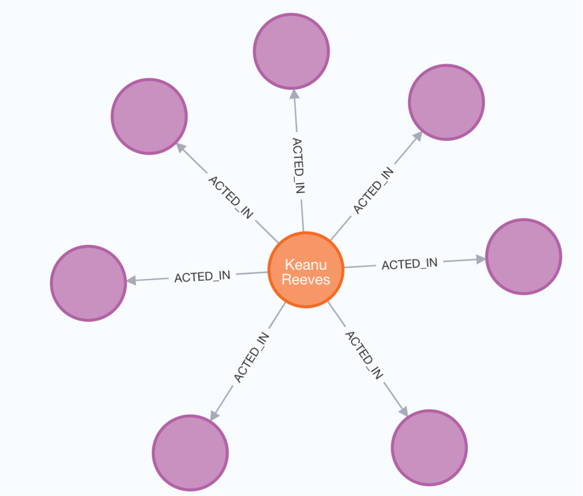
```
call db.schema.visualization()
```



Cypher syntax: MATCH

- Use MATCH to read data from database
  - MATCH specifies the patterns to search for in the database
  - E.g., find which movies Keanu Reeves has acted in

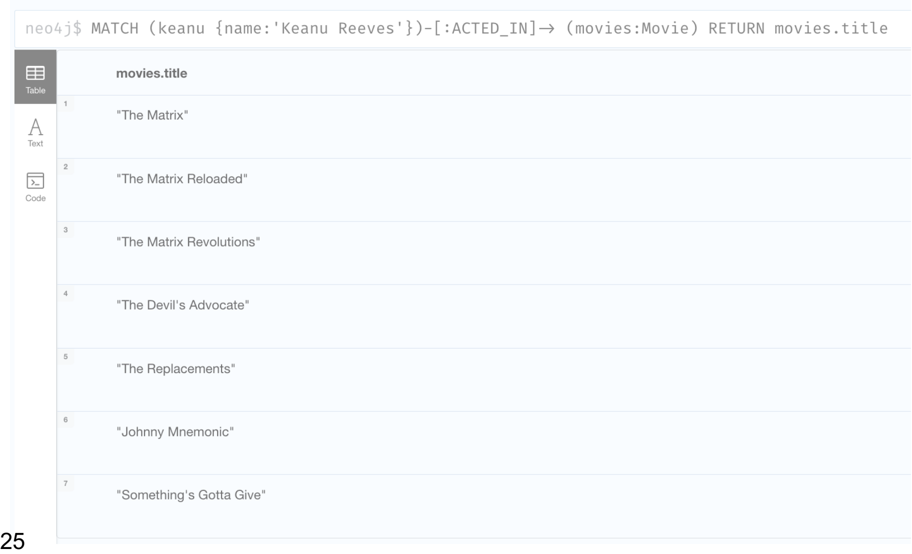
```
MATCH (keanu {name:'Keanu Reeves'})-[:ACTED_IN]->
(movies:Movie) RETURN keanu, movies
```



Cypher syntax: MATCH

- Use `MATCH` to read data from database
  - E.g., find which movies Keanu Reeves has acted in but now return only the movies title

```
MATCH (keanu {name:'Keanu Reeves'})-[:ACTED_IN]->
(movies:Movie) RETURN movies.title
```



```
neo4j$ MATCH (keanu {name:'Keanu Reeves'})-[:ACTED_IN]→ (movies:Movie) RETURN movies.title
```

	movies.title
1	"The Matrix"
2	"The Matrix Reloaded"
3	"The Matrix Revolutions"
4	"The Devil's Advocate"
5	"The Replacements"
6	"Johnny Mnemonic"
7	"Something's Gotta Give"

Cypher syntax: MATCH and WHERE

- Use `WHERE` to add constraints to the patterns in a `MATCH` clause
  - E.g., find the movie with title The Matrix

```
MATCH (m:Movie)
WHERE m.title = 'The Matrix'
RETURN m
```

Cypher syntax: DELETE

- Use DELETE to delete a node, e.g.,

```
MATCH (p:Person {name: 'John Doe'})
DELETE p
```

- Node cannot be deleted if it participates in a relationship. To remove also relationships, we need to detach the node, delete it and its relationships:

```
MATCH (d:Person {name: 'Greg Kinnear'})
DETACH DELETE d;
```

Cypher syntax: search for patterns using length

- Cypher can be used to match patterns also of fixed, variable or unknown length
- Relationship pattern length:

```
(a)-[*2]->(b)
```

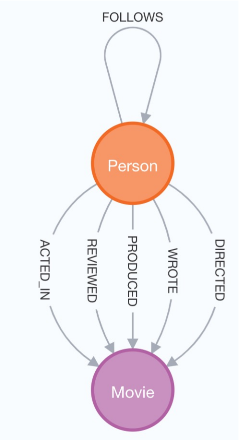
- It is possible to specify a length (e.g., 2) in the relationship description of a pattern

It can be a variable length:

`*3..5` (between 3 and 5)
`*3..` (greater than 3)
`*..5` (less than 5)
`*` (any length)

Example: movie database

- Let's use as case study the movie database provided by Neo4j as sandbox with pre-populated data
  - Basic dataset of *Actors* acting in *Movies*
  - Available at https://neo4j.com/sandbox/
  - Data model of the movie database is



Example: movie database

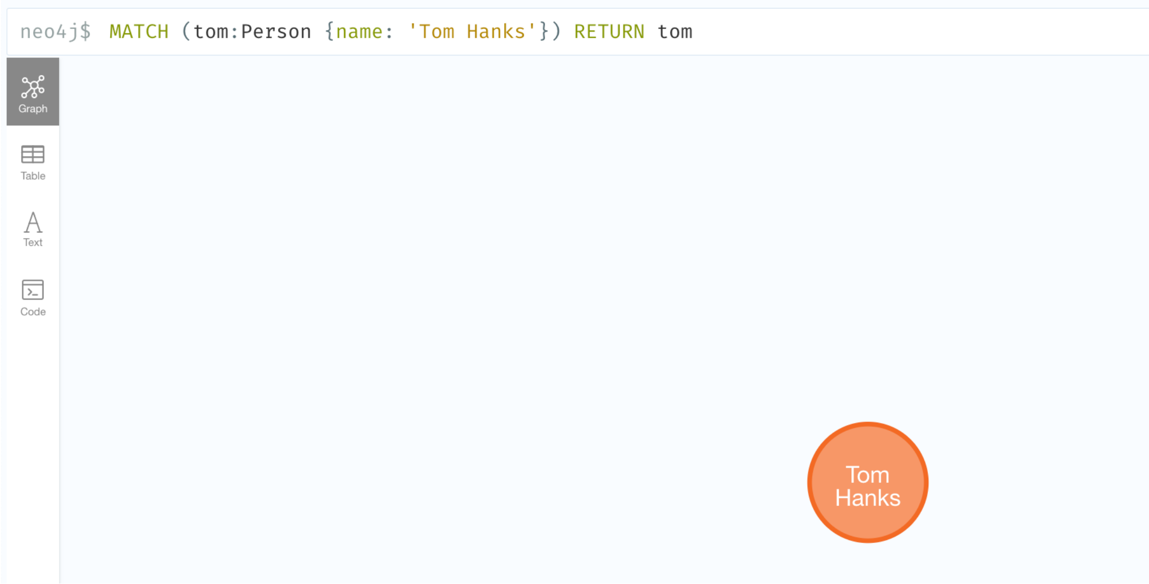
- The goal of our analysis is to show recommendations for other actors to work with
  - By following the meaningful relationships between actors and movies, we can determine:
    - Occurrences of actors working together
    - Frequency of actors working with one another
    - Movies they have in common in the graph

- Let's start with simple queries and then increase their complexity

Some basic queries

- Let's find a single actor like *Tom Hanks*

```
MATCH (tom:Person {name: 'Tom Hanks'}) RETURN tom
```



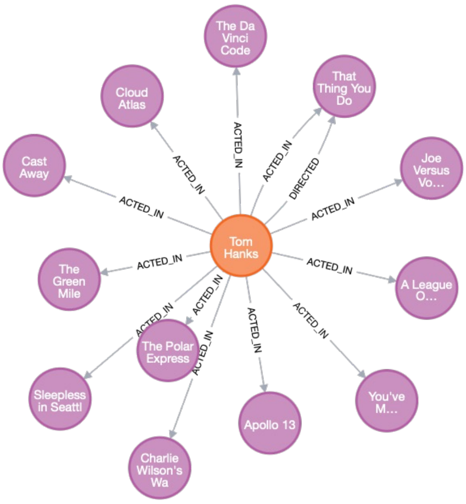
```
neo4j$ MATCH (tom:Person {name: 'Tom Hanks'}) RETURN tom
```

Some basic queries

- Let's retrieve all Tom Hanks' movies by starting from Tom Hanks node and following ACTED_IN relationships

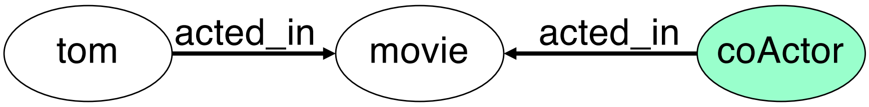
```
MATCH (tom:Person {name: 'Tom Hanks'})-[r:ACTED_IN]-
>(movie:Movie) RETURN tom, r, movie
```

  - The query result looks like a graph

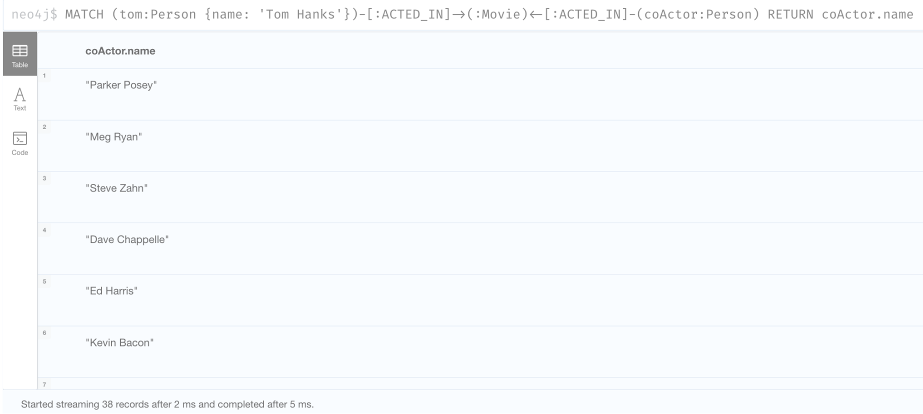


Some basic queries

- Tom Hanks has colleagues who acted with him in his movies, let’s find these co-actors:



```
MATCH (tom:Person {name: 'Tom Hanks'})-[:ACTED_IN]-
>(:Movie)<-[:ACTED_IN]-(coActor:Person) RETURN
coActor.name
```



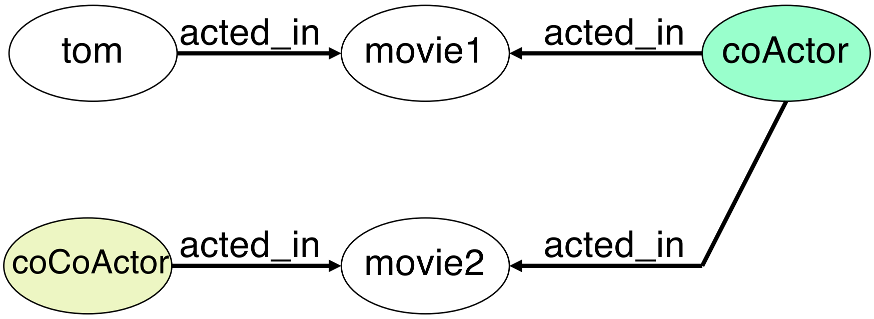
```
neo4j$ MATCH (tom:Person {name: 'Tom Hanks'})-[:ACTED_IN]→(:Movie)←[:ACTED_IN]-(coActor:Person) RETURN coActor.name
```

	coActor.name
1	"Parker Posey"
2	"Meg Ryan"
3	"Steve Zahn"
4	"Dave Chappelle"
5	"Ed Harris"
6	"Kevin Bacon"
7	

Started streaming 38 records after 2 ms and completed after 5 ms.

Recommendations queries

- Let’s find Tom’s co-co-actors, i.e., the second-degree actors in Tom’s network



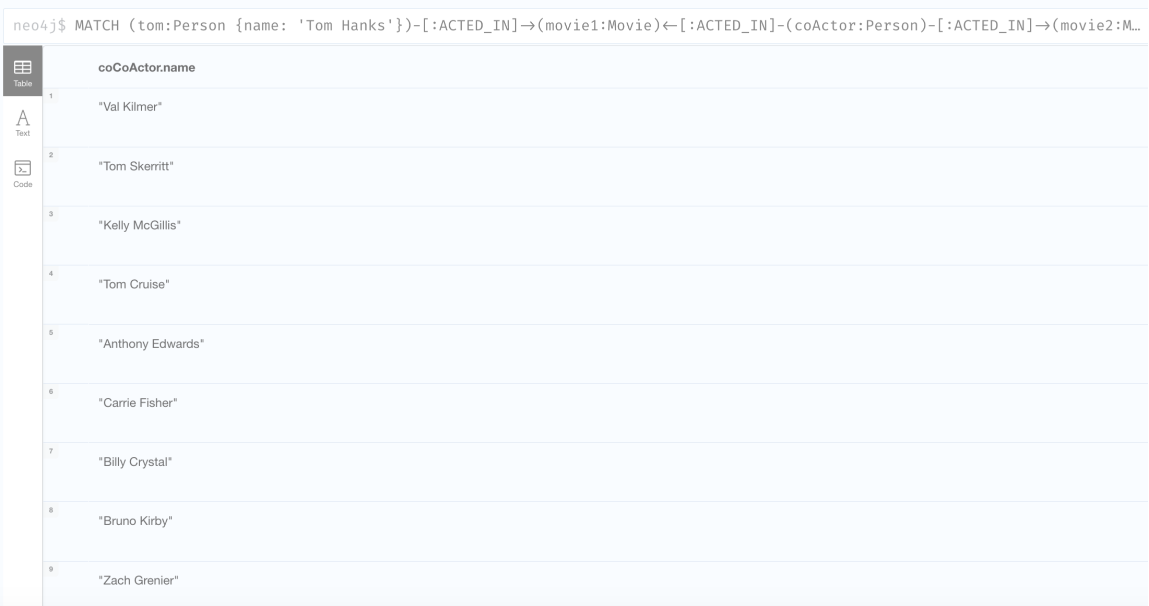
Recommendations queries

- Let's find the co-co-actors, i.e., the second-degree actors in Tom's network. This will show us all the actors Tom may not have worked with yet, and we can specify a criterium to be sure he hasn't directly acted with that person

```
MATCH (tom:Person {name: 'Tom Hanks'})-[:ACTED_IN]-
>(movie1:Movie)<-[:ACTED_IN]-(coActor:Person)-
[:ACTED_IN]->(movie2:Movie)<-[:ACTED_IN]-
(coCoActor:Person) WHERE tom <> coCoActor AND NOT
(tom)-[:ACTED_IN]->(:Movie)<-[:ACTED_IN]-
(coCoActor) RETURN coCoActor.name
```

Recommendations queries

- In the query result a few names appear multiple times, because there are multiple paths to follow from *Tom Hanks* to these actors



```
neo4j$ MATCH (tom:Person {name: 'Tom Hanks'})-[:ACTED_IN]→(movie1:Movie)←[:ACTED_IN]-(coActor:Person)-[:ACTED_IN]→(movie2:M…
```

	coCoActor.name
1	"Val Kilmer"
2	"Tom Skerritt"
3	"Kelly McGillis"
4	"Tom Cruise"
5	"Anthony Edwards"
6	"Carrie Fisher"
7	"Billy Crystal"
8	"Bruno Kirby"
9	"Zach Grenier"

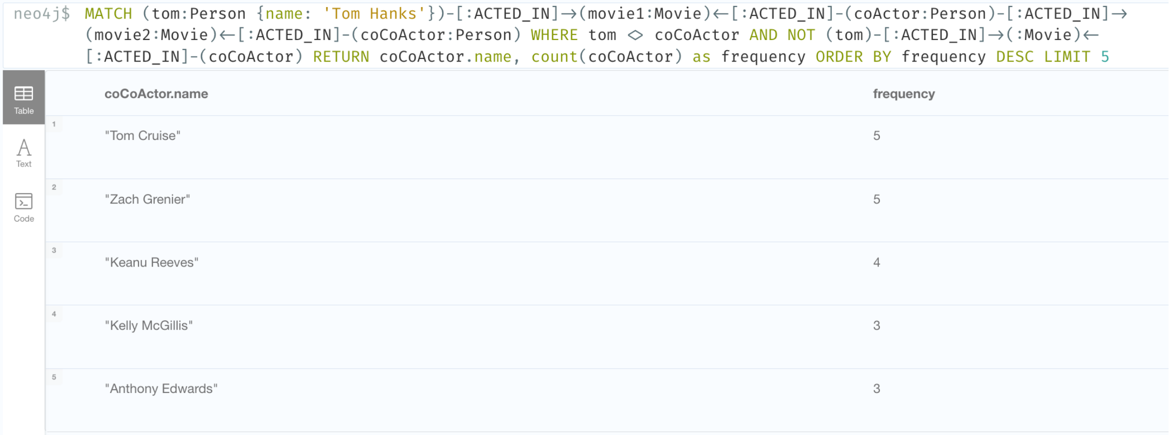
Recommendations queries

- Let's see which co-co-actors appear most often in Tom's network: we can take frequency of occurrences into account by counting the number of paths between *Tom Hanks* and each coCoActor and ordering them by highest to lowest value

```
MATCH (tom:Person {name: 'Tom Hanks'})-[:ACTED_IN]-
>(movie1:Movie)<-[:ACTED_IN]-(coActor:Person)-
[:ACTED_IN]->(movie2:Movie)<-[:ACTED_IN]-
(coCoActor:Person) WHERE tom <> coCoActor AND NOT
(tom)-[:ACTED_IN]->(:Movie)<-[:ACTED_IN]-
(coCoActor) RETURN coCoActor.name, count(coCoActor)
as frequency ORDER BY frequency DESC LIMIT 5
```

Recommendations queries

- The query result



```
neo4j$ MATCH (tom:Person {name: 'Tom Hanks'})-[:ACTED_IN]→(movie1:Movie)←[:ACTED_IN]-(coActor:Person)-[:ACTED_IN]→
       (movie2:Movie)←[:ACTED_IN]-(coCoActor:Person) WHERE tom <> coCoActor AND NOT (tom)-[:ACTED_IN]→(:Movie)←
       [:ACTED_IN]-(coCoActor) RETURN coCoActor.name, count(coCoActor) as frequency ORDER BY frequency DESC LIMIT 5
```

	coCoActor.name	frequency
1	"Tom Cruise"	5
2	"Zach Grenier"	5
3	"Keanu Reeves"	4
4	"Kelly McGillis"	3
5	"Anthony Edwards"	3

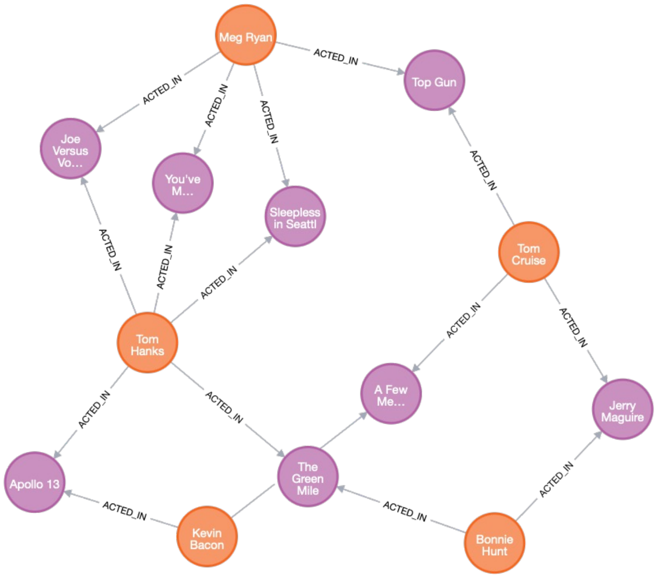
Recommendations queries

- One of the most frequent “co-co-actors” is *Tom Cruise*. Now let’s see which movies and actors are between the two Toms so we can find out who can introduce them

```
MATCH (tom:Person {name: 'Tom Hanks'})-[:ACTED_IN]-
>(movie1:Movie)<-[:ACTED_IN]-(coActor:Person)-
[:ACTED_IN]->(movie2:Movie)<-[:ACTED_IN]-
(cruise:Person {name: 'Tom Cruise'}) WHERE NOT
(tom)-[:ACTED_IN]->(:Movie)<-[:ACTED_IN]-(cruise)
RETURN tom, movie1, coActor, movie2, cruise
```

Recommendations queries

- The query result: there are multiple paths between the two Toms
  - And there is Kevin Bacon in one of the paths: see the six degrees of Kevin Bacon game https://en.wikipedia.org/wiki/Six_Degrees_of_Kevin_Bacon



Degree centrality

- The Neo4j Graph Data Science (GDS) library contains many graph algorithms
- Let’s find which actor has acted in the most movies using degree centrality
- We first need to create a graph projection using **`gds.graph.project`** procedure
  https://neo4j.com/docs/graph-data-science/current/management-ops/graph-creation/graph-project/

```
CALL gds.graph.project(
  'proj',
  ['Person','Movie'],
  'ACTED_IN'
  );
```

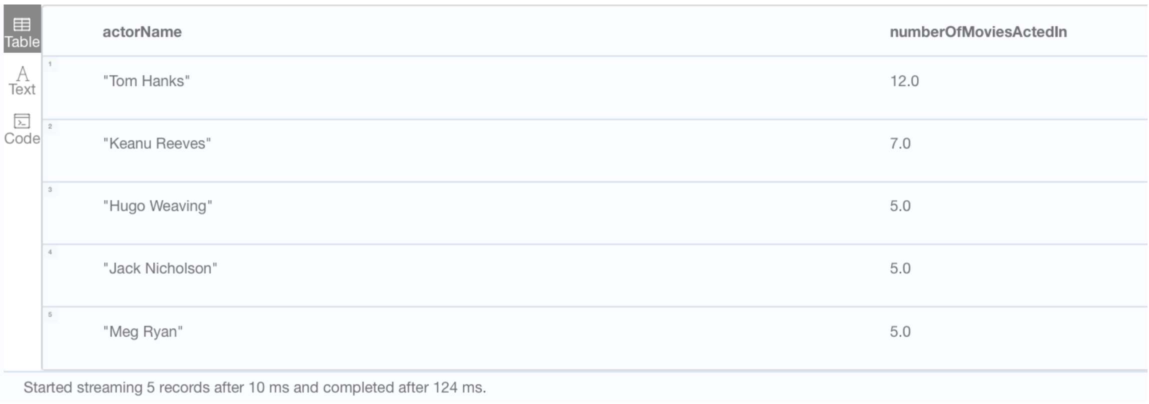
Degree centrality

- Then we run the degree centrality algorithm on the projected graph using **`gds.degree.stream`** procedure
- We also order the results to determine which actor has directed the most movies

```
CALL gds.degree.stream('proj')
YIELD nodeId, score
RETURN
  gds.util.asNode(nodeId).name AS actorName,
  score AS numberOfMoviesActedIn
ORDER BY numberOfMoviesActedIn DESCENDING,
actorName LIMIT 5
```

Degree centrality

- The query result is



	actorName	numberOfMoviesActedIn
1	"Tom Hanks"	12.0
2	"Keanu Reeves"	7.0
3	"Hugo Weaving"	5.0
4	"Jack Nicholson"	5.0
5	"Meg Ryan"	5.0

Started streaming 5 records after 10 ms and completed after 124 ms.

Shortest path

- What is the shortest path between Kevin Bacon and Clint Eastwood?
- We first need to create a graph projection using **gds.graph.project** procedure

```
// Create projection
CALL gds.graph.project(
    'proj2',
    ['Person','Movie'],
    {
        ACTED_IN:{orientation:'UNDIRECTED'},
        DIRECTED:{orientation:'UNDIRECTED'}
    }
);
```

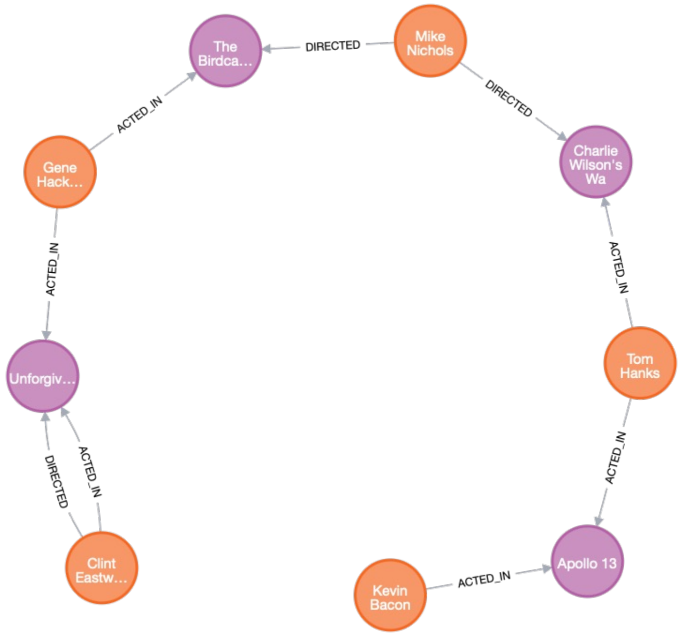
Shortest path

- We match the 2 Person nodes and then use **`gds.shortestPath.dijkstra.stream`** procedure to find the shortest path

```
MATCH (kevin:Person{name : 'Kevin Bacon'})
MATCH (clint:Person{name : 'Clint Eastwood'})
CALL gds.shortestPath.dijkstra.stream(
    'proj2',
    {
        sourceNode:kevin,
        TargetNode:clint
    }
)
YIELD sourceNode, targetNode, path
RETURN sourceNode, targetNode, nodes(path) as path;
```

Shortest path

- The query result is



Neo4j sandboxes

- As project for the course, you are going to use one of the Neo4j sandboxes
  - Online tool, not requiring a local installation https://neo4j.com/sandbox/
  - Pre-populated with domain data and focus on use-case specific queries
    - See sandbox description on the course web site
  - Each sandbox is available for at least 3 days after creation and can be extended for 7 additional days before expiration; after the additional days, you need to restart the sandbox from scratch (in this case, you will lose new data you have written to the database)

References

- Neo4J fundamentals (1-hour course) https://graphacademy.neo4j.com/courses/neo4j-fundamentals/
- Cypher fundamentals (1-hour course) https://graphacademy.neo4j.com/courses/cypher-fundamentals/