# Advanced Data Management (CSCI 490/680)

## Graph Databases

Dr. David Koop

# Recent History in Databases

- Early 2000s: Commercial DBs dominated, Open-source DBs missing features
- Mid 2000s: MySQL adopted by web companies
- Late 2000s: NoSQL dos scale horizontally out of the box
- Early 2010s: New DBMSs that can scale across multiple machines natively and provide ACID guarantees

[A. Pavlo]

# NewSQL

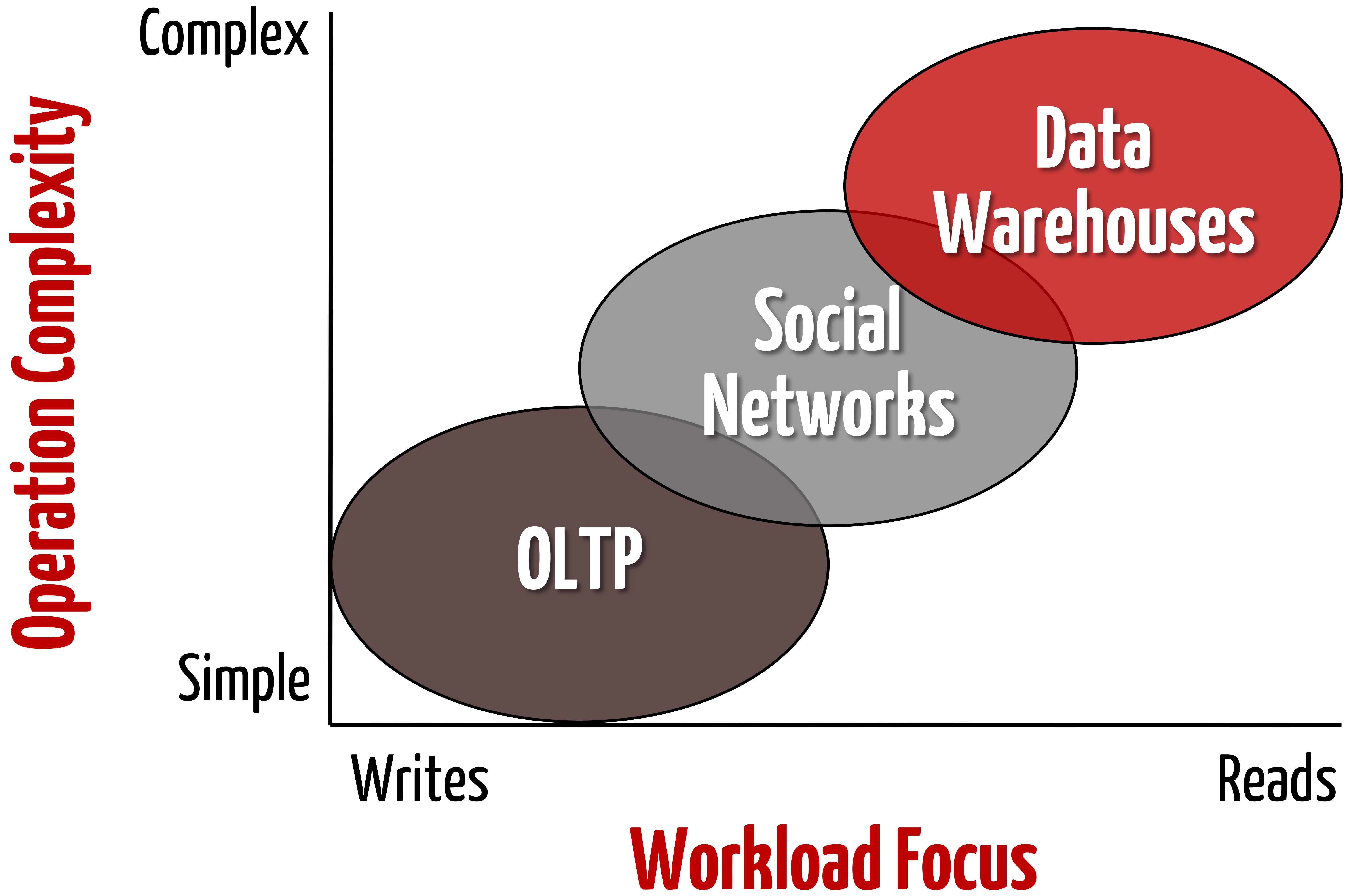
[A. Pavlo]

# NewSQL

- 451 Group's Definition:
  - A DBMS that delivers the scalability and flexibility promised by NoSQL while retaining the support for SQL queries and/or ACID, or to improve performance for appropriate workloads.
- Stonebraker's Definition:
  - SQL as the primary interface
  - ACID support for transactions
  - Non-locking concurrency control
  - High per-node performance
  - Parallel, shared-nothing architecture

[A. Pavlo]

# OLTP Workload




[A. Pavlo]

# Ideal OLTP System

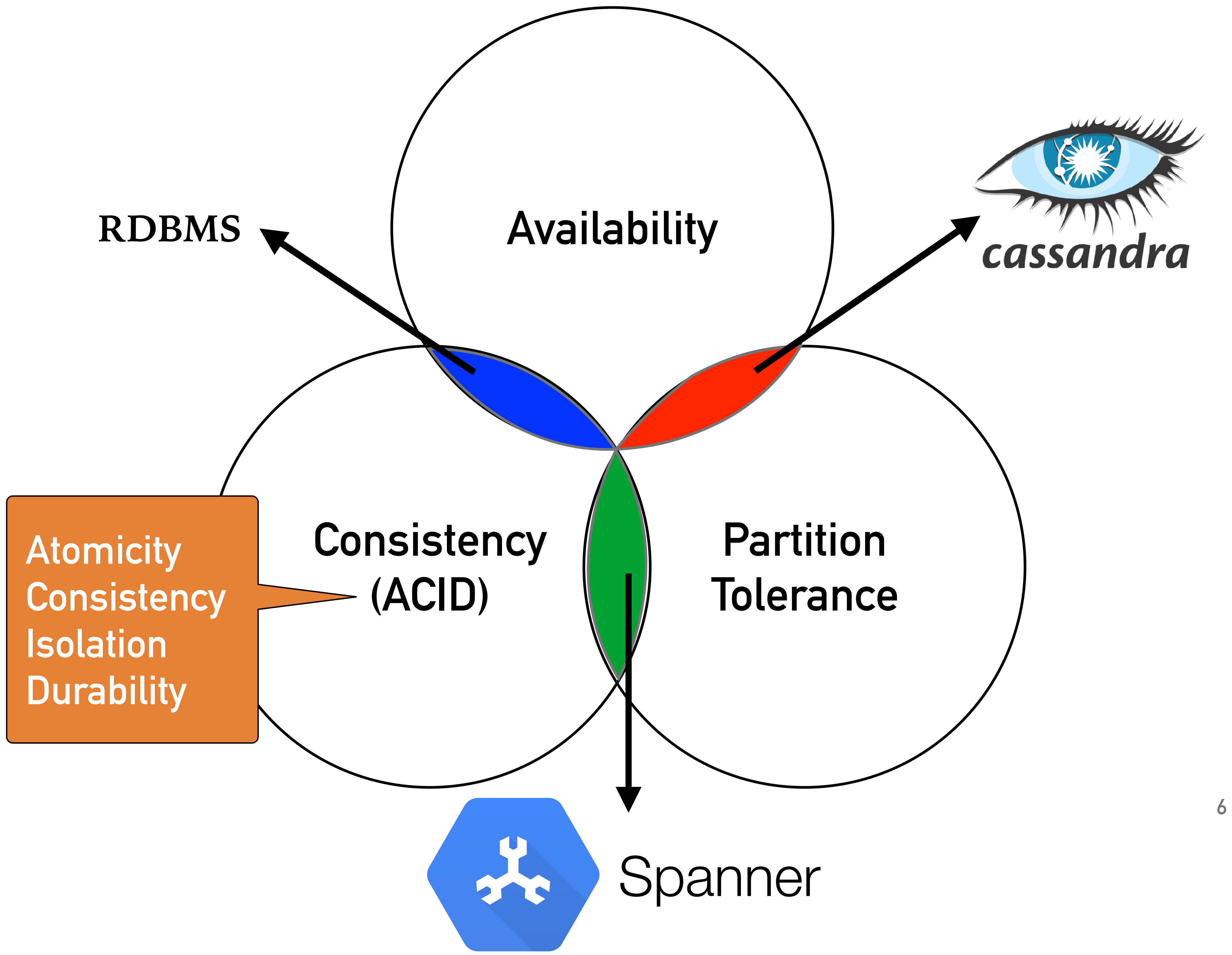
- Main Memory Only
- No Multi-processor Overhead
- High Scalability
- High Availability
- Autonomic Configuration

[A. Pavlo]

# Spanner Overview

- Focus on scaling databases focused on OLTP (not OLAP)
- Since OLTP, focus is on sharding **rows**
- Tries to satisfy CAP (which is impossible per CAP Theorem) by not worrying about 100% availability
- External consistency using multi-version concurrency control through timestamps
- ACID is important
- Structured: universe with zones with zone masters and then spans with span masters
- SQL-like (updates allow SQL to be used with Spanner)

# Spanner and the CAP Theorem




- Which type of system is Spanner?
  - C: consistency, which implies a single value for shared data
  - A: 100% availability, for both reads and updates
  - P: tolerance to network partitions
- Which two?
  - CA: close, but not totally available
  - So actually **CP**

# External Consistency

- Traditional DB solution: **two-phase locking**—no writes while client reads
- "The system behaves as if all transactions were executed sequentially, even though Spanner actually runs them across multiple servers (and possibly in multiple datacenters) for higher performance and availability" [Google]
- Semantically indistinguishable from a single-machine database
- Uses multi-version concurrency control (MVCC) using **timestamps**
- Spanner uses **TrueTime** to generate monotonically increasing timestamps across all nodes of the system

# Google Cloud Spanner: NewSQL

| | CLOUD SPANNER | TRADITIONAL RELATIONAL | TRADITIONAL NON-RELATIONAL |
|---|---|---|---|
| Schema | ✓ **Yes** | ✓ Yes | ✗ No |
| SQL | ✓ **Yes** | ✓ Yes | ✗ No |
| Consistency | ✓ **Strong** | ✓ Strong | ✗ Eventual |
| Availability | ✓ **High** | ✗ Failover | ✓ High |
| Scalability | ✓ **Horizontal** | ✗ Vertical | ✓ Horizontal |
| Replication | ✓ **Automatic** | ⟳ Configurable | ⟳ Configurable |

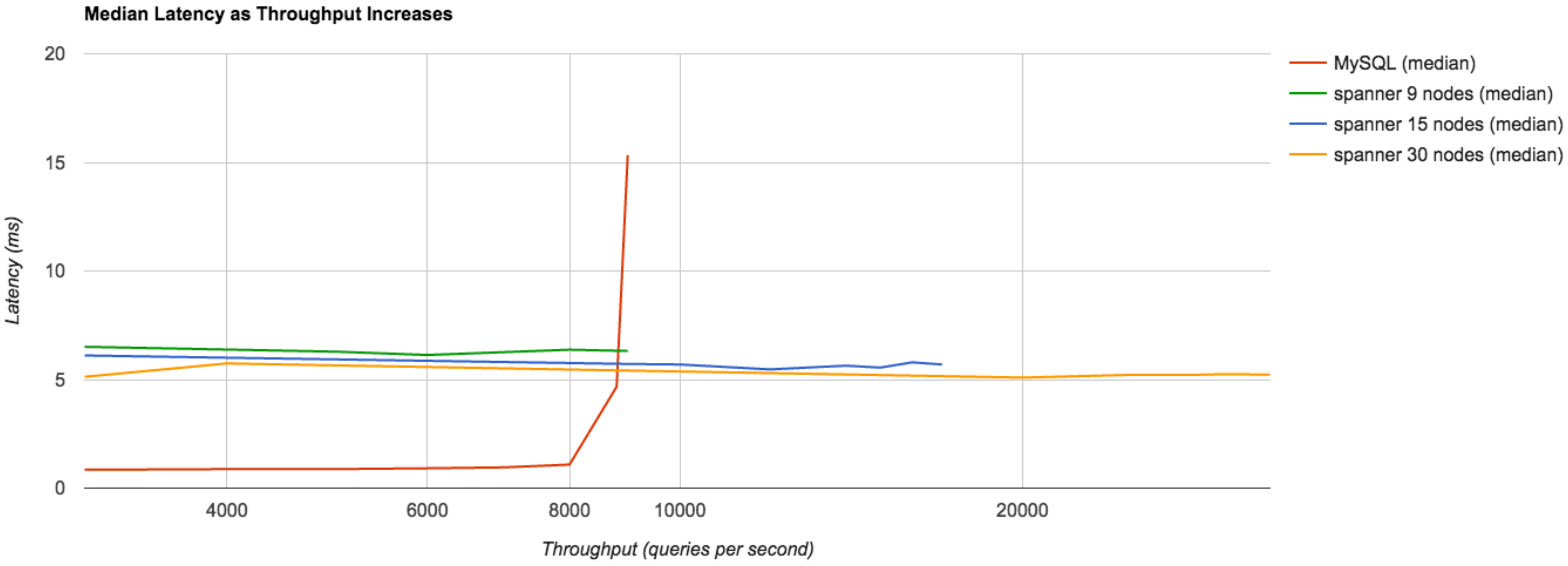
[https://cloud.google.com/spanner/]

# Spanner as "Effectively CA"

- Criteria for being "effectively CA"
  1. At a minimum it must have very high availability in practice (so that users can ignore exceptions), and
  2. As this is about partitions it should also have a low fraction of those outages due to partitions.
- Spanner meets both of these criteria
- Spanner relies on Google's **network** (private links between data centers)
- TrueTime helps create **consistent snapshots**, sometimes have a commit wait

[E. Brewer, 2017]

# Throughput: Spanner vs. MySQL




[P. Bakkum and D. Cepeda, 2017]

# Assignment 4

- World Education Data
- Collected/collated by UNESCO, World Bank, and OECD
- Transform World Bank Data
- Impute missing year data
- Integrate teacher and student numbers
- Fuse three datasets
- Think about how to integrate based on country
- Last part: country name can be any (consider 'first' aggregation option)
- Due Monday

# Specific Types of Data

# Graphs: Social Networks


[P. Butler, 2010]

# What is a Graph?

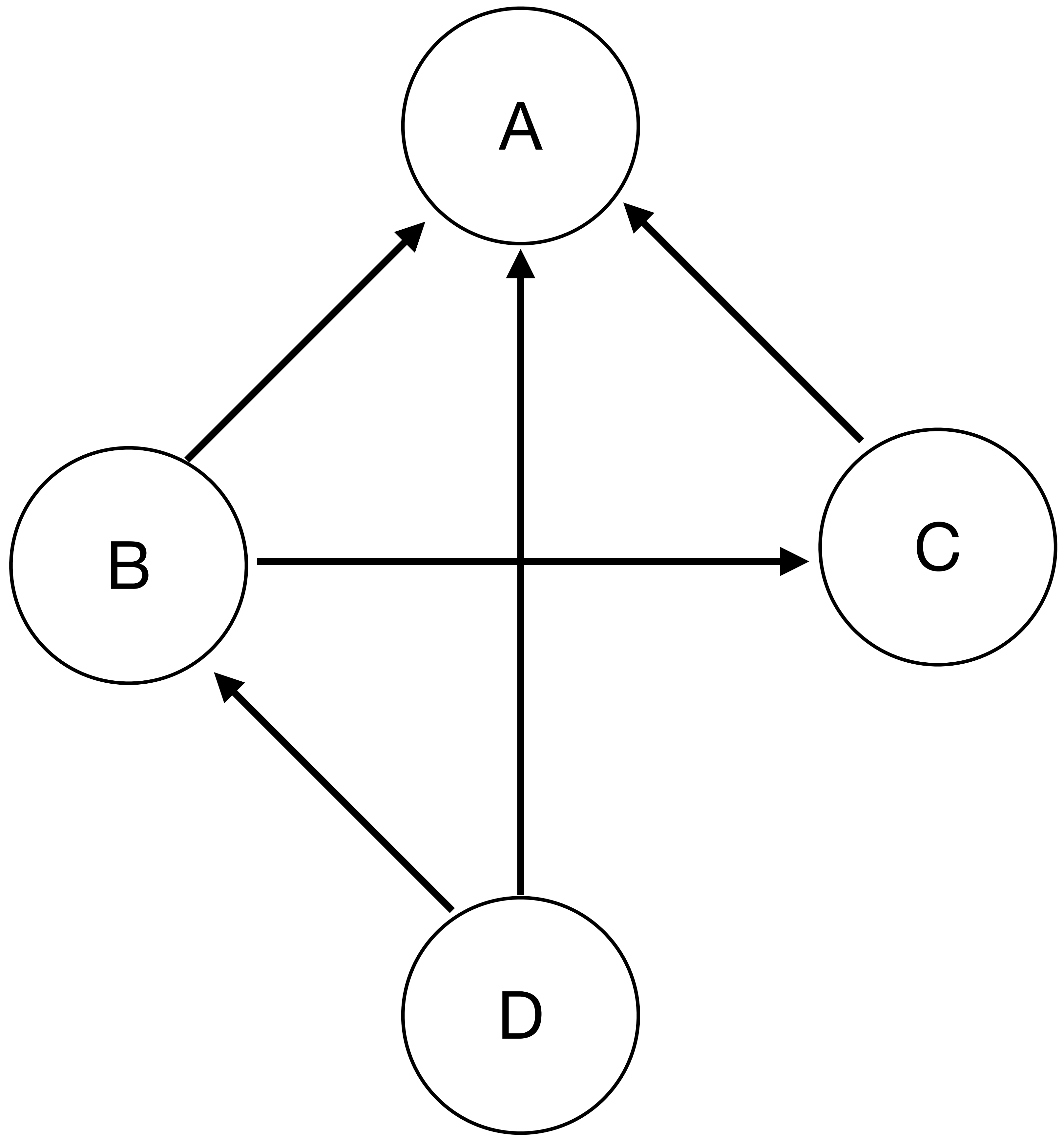
- An abstract representation of a set of objects where some pairs are connected by links.


Object (Vertex, Node)

Link (Edge, Arc, Relationship)

[M. De Marzi, 2012]

# What is a Graph?

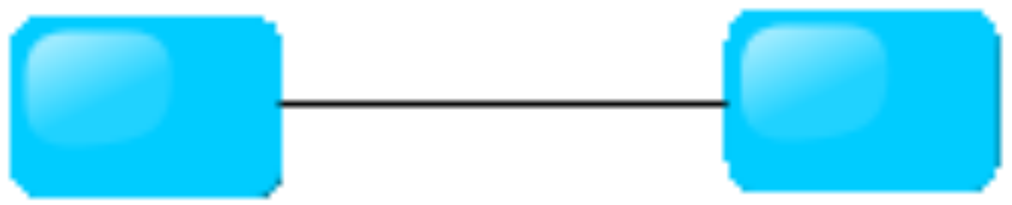



- In computing, a **graph** is an abstract **data structure** that represents set objects and their relationships as **vertices** and **edges/links**, and supports a number of graph-related **operations**
- Objects (nodes): `{A,B,C,D}`
- Relationships (edges): `{(D,B),(D,A),(B,C),(B,A),(C,A)}`
- Operation: shortest path from `D` to `A`

[K. Salama, 2016]

# Different Kinds of Graphs

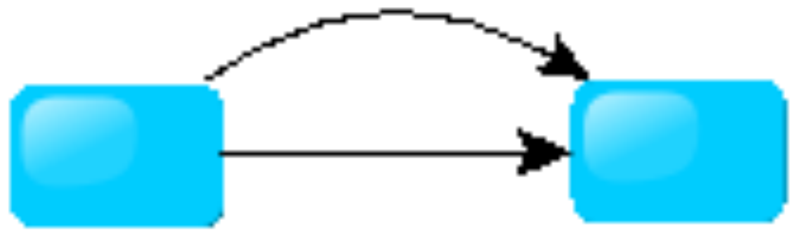
- Undirected Graph



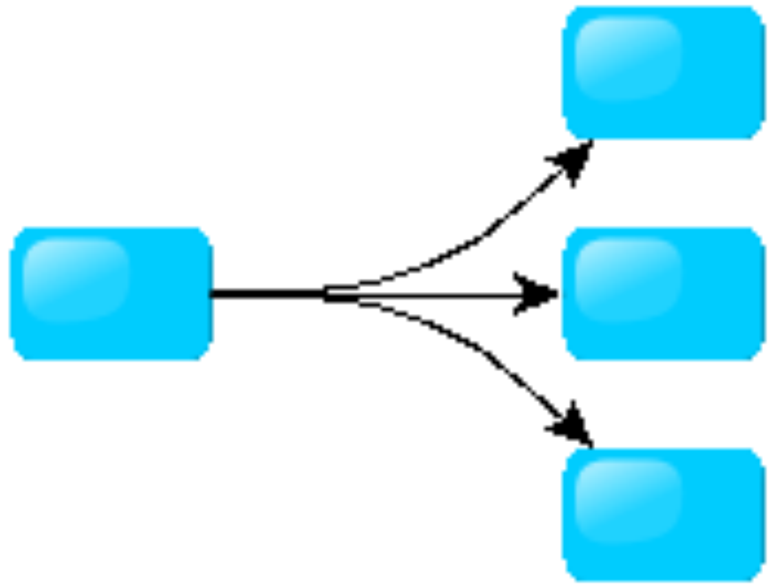
- Directed Graph

- Pseudo Graph

- Multi Graph



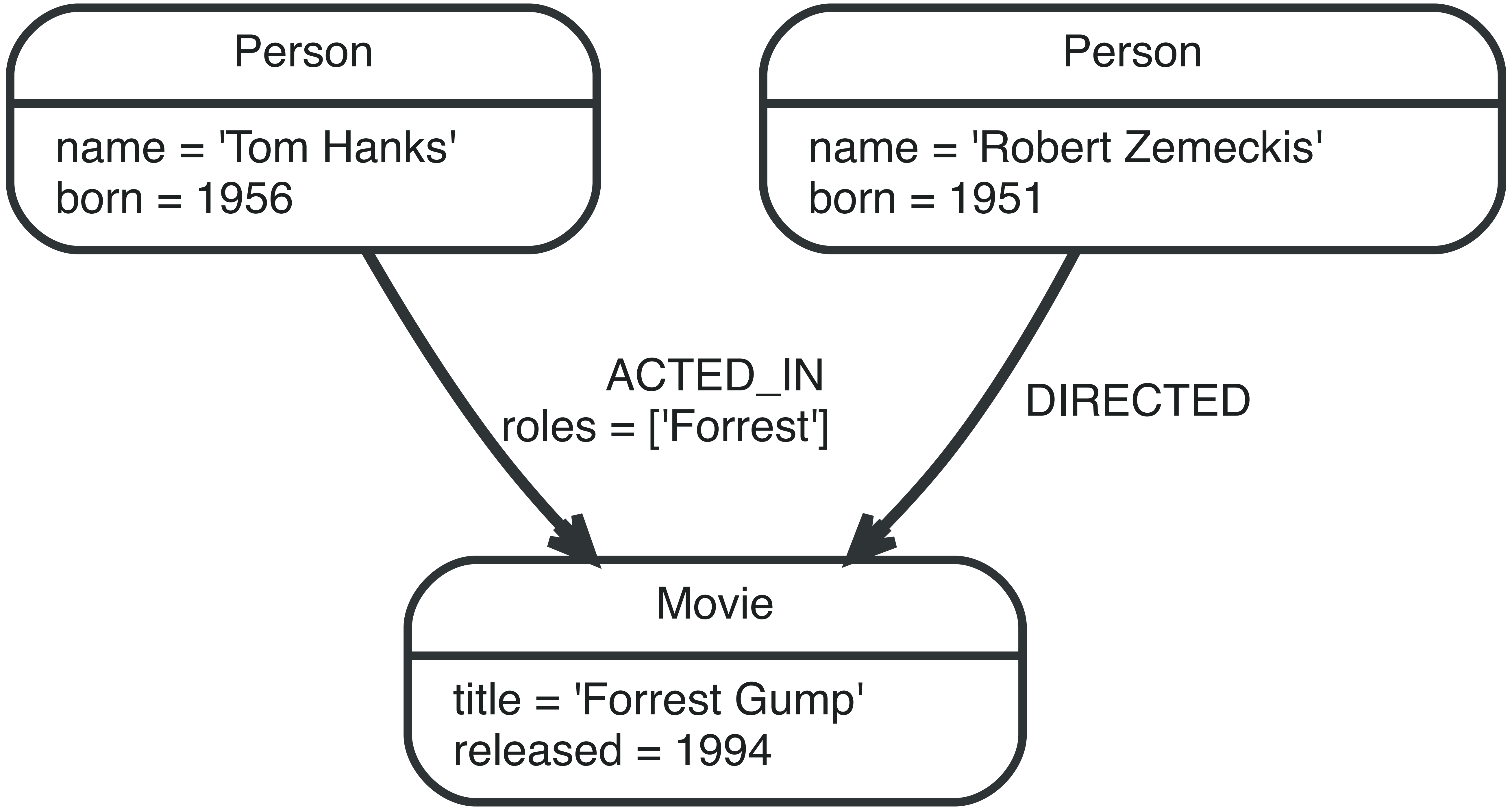
- Hyper Graph



[M. De Marzi, 2012]

# Graphs with Properties

- Each vertex or edge may have properties associated with it
- May include identifiers or classes




[neo4j]

# Types of Graph Operations

- Connectivity Operations:
  - number of vertices/edges, in- and out-degrees of vertices
  - histogram of degrees can be useful in comparing graphs
- Path Operations: cycles, reachability, shortest path, minimum spanning tree
- Community Operations: clusters (cohesion and separation)
- Centrality Operations: degree, vulnerability, PageRank
- Pattern Matching: subgraph isomorphism
  - can use properties
  - useful in fraud/threat detection, social network suggestions

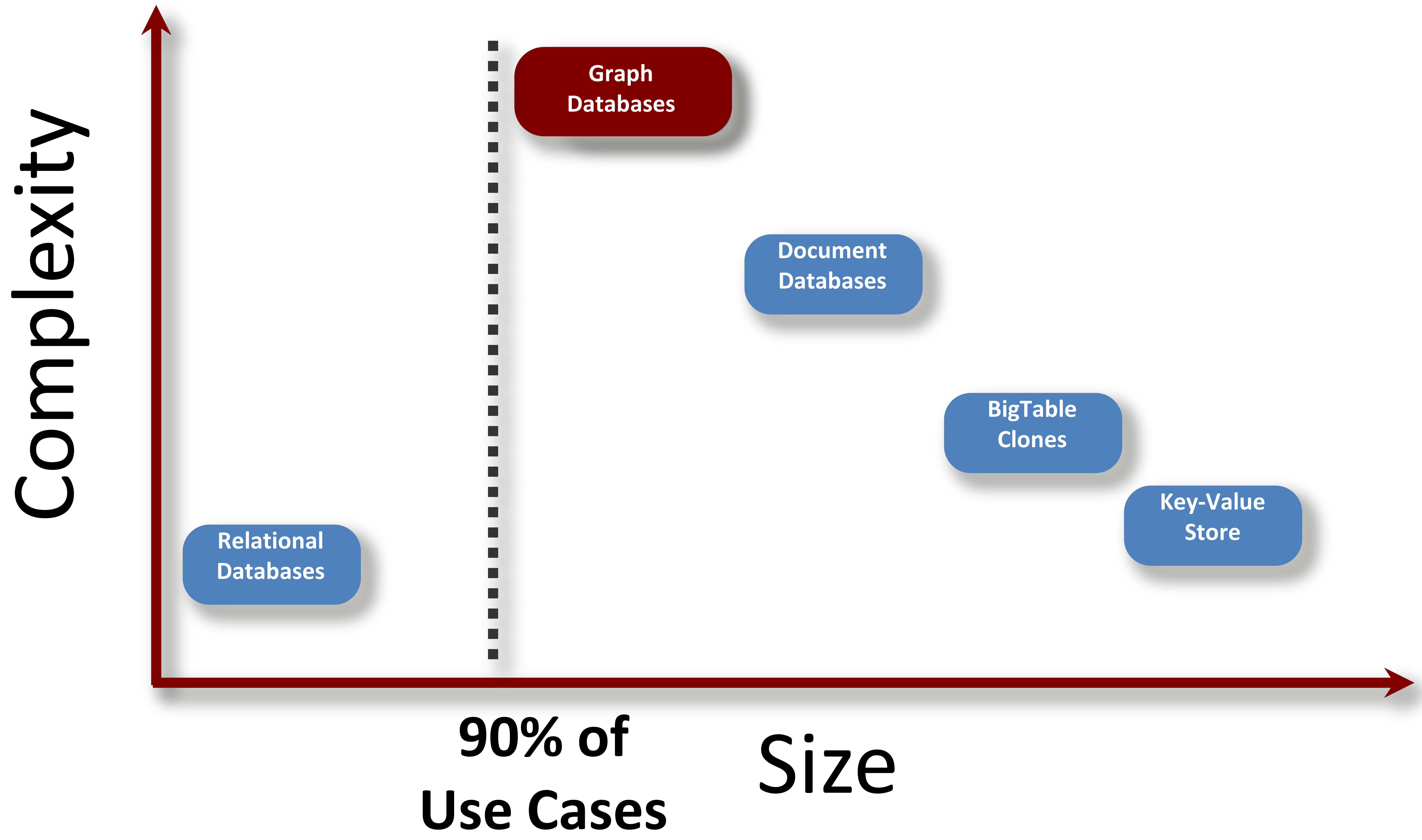
[K. Salama, 2016]

# What is a Graph Database?

- A database with an explicit graph structure
- Each node knows its adjacent nodes
- As the number of nodes increases, the cost of a local step (or hop) remains the same
- Plus an Index for lookups

[M. De Marzi, 2012]

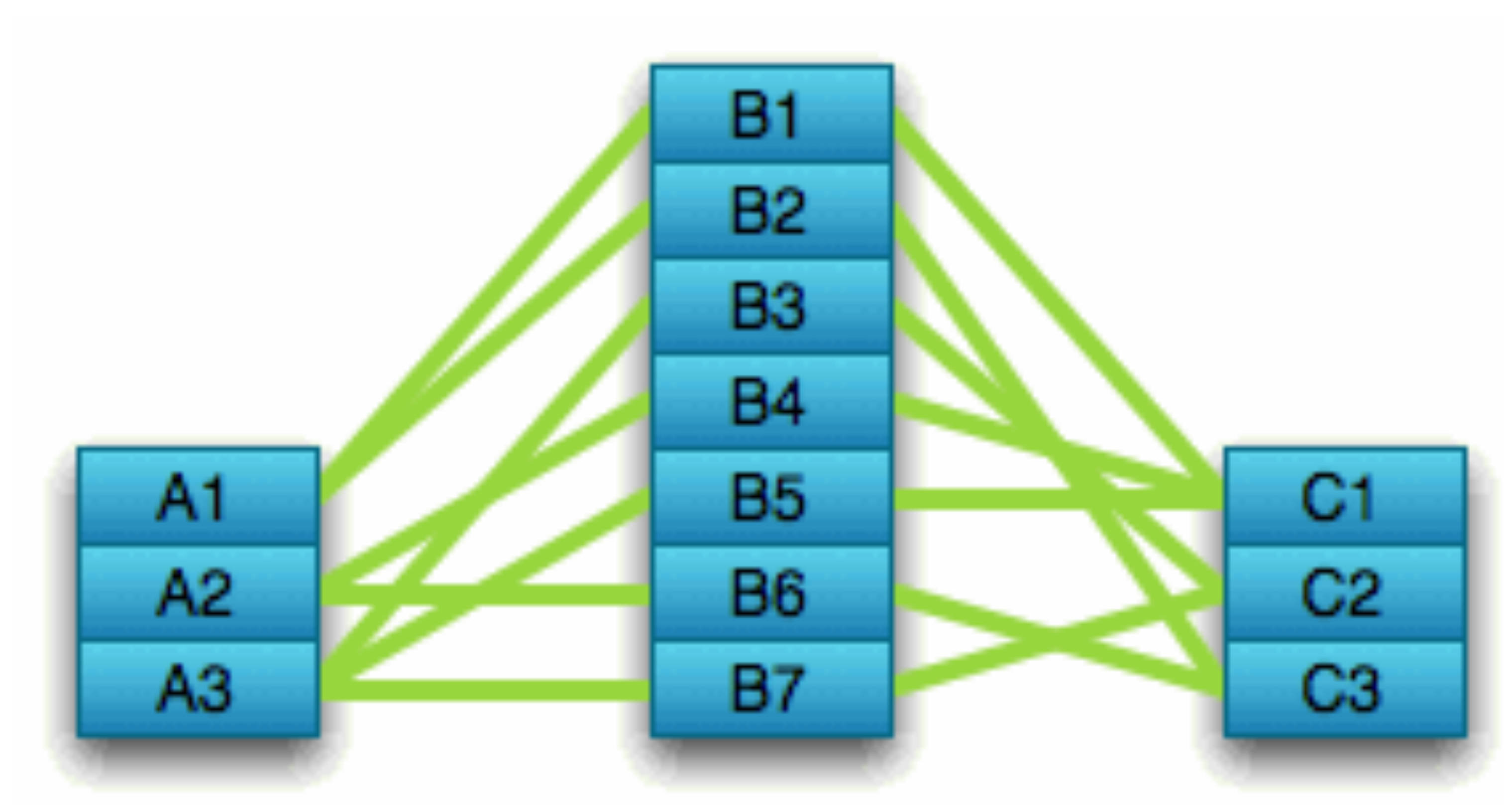
# How do Graph Databases Compare?



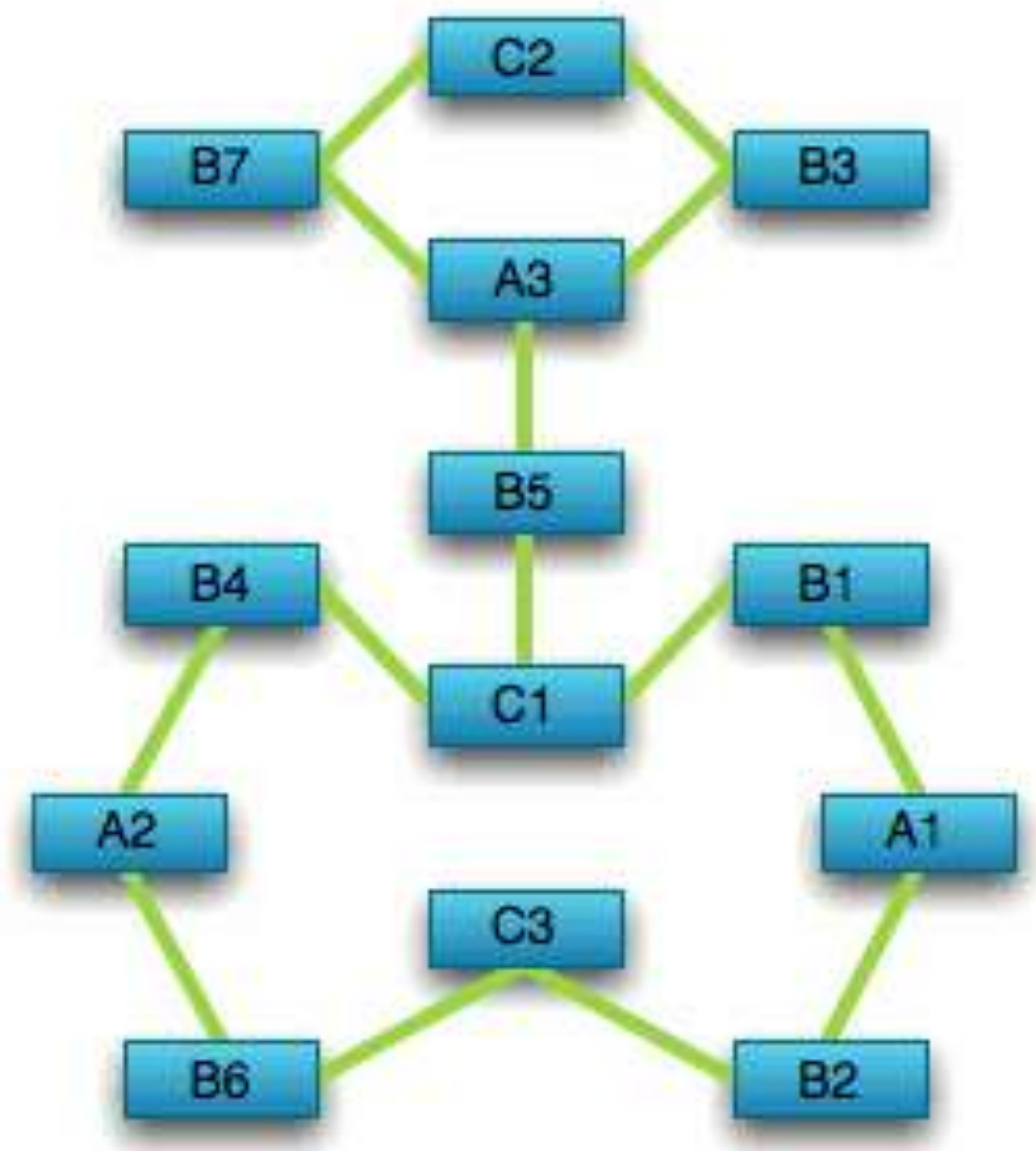

[M. De Marzi, 2012]

# Graph Databases Compared to Relational Databases

Optimized for aggregation




Optimized for connections

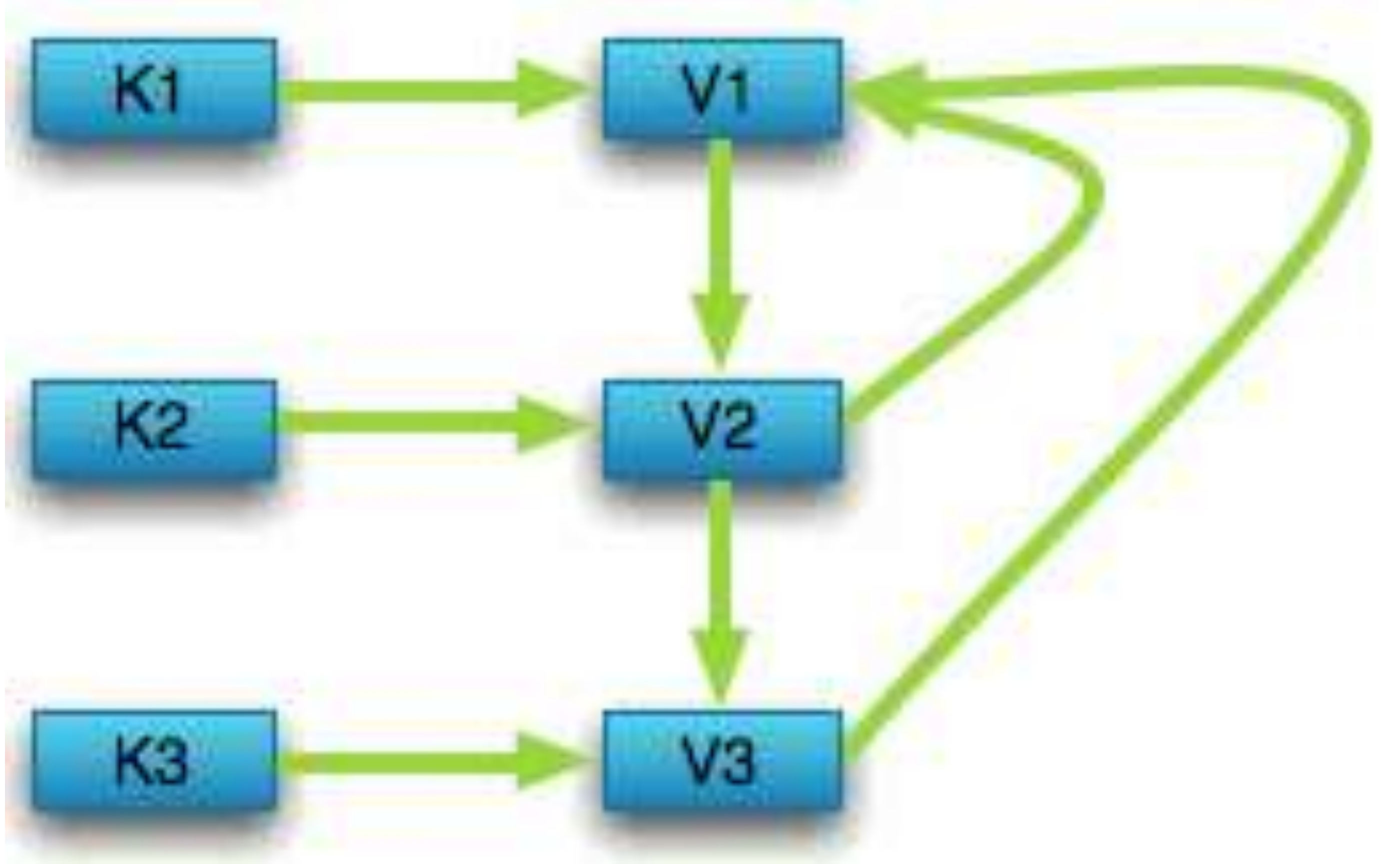



[M. De Marzi, 2012]

# Graph Databases Compared to Key-Value Stores

Optimized for simple look-ups


Optimized for traversing connected data

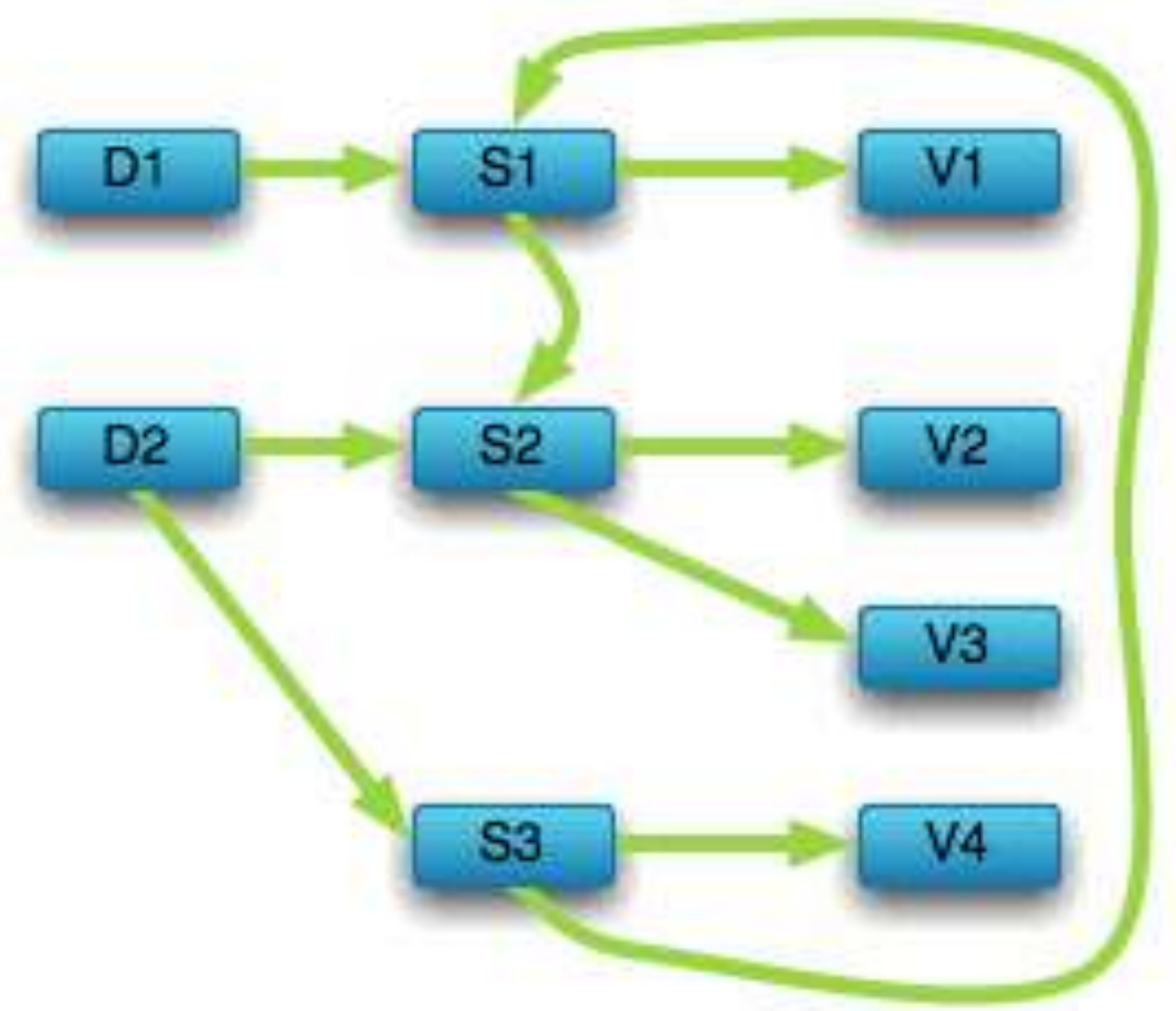



[M. De Marzi, 2012]

# Graph Databases Compared to Document Stores

Optimized for "trees" of data


Optimized for seeing the forest and the trees, and the branches, and the trunks




[M. De Marzi, 2012]

# Graph Databases

D. Lembo and R. Rosati

# Why Graph Database Models?

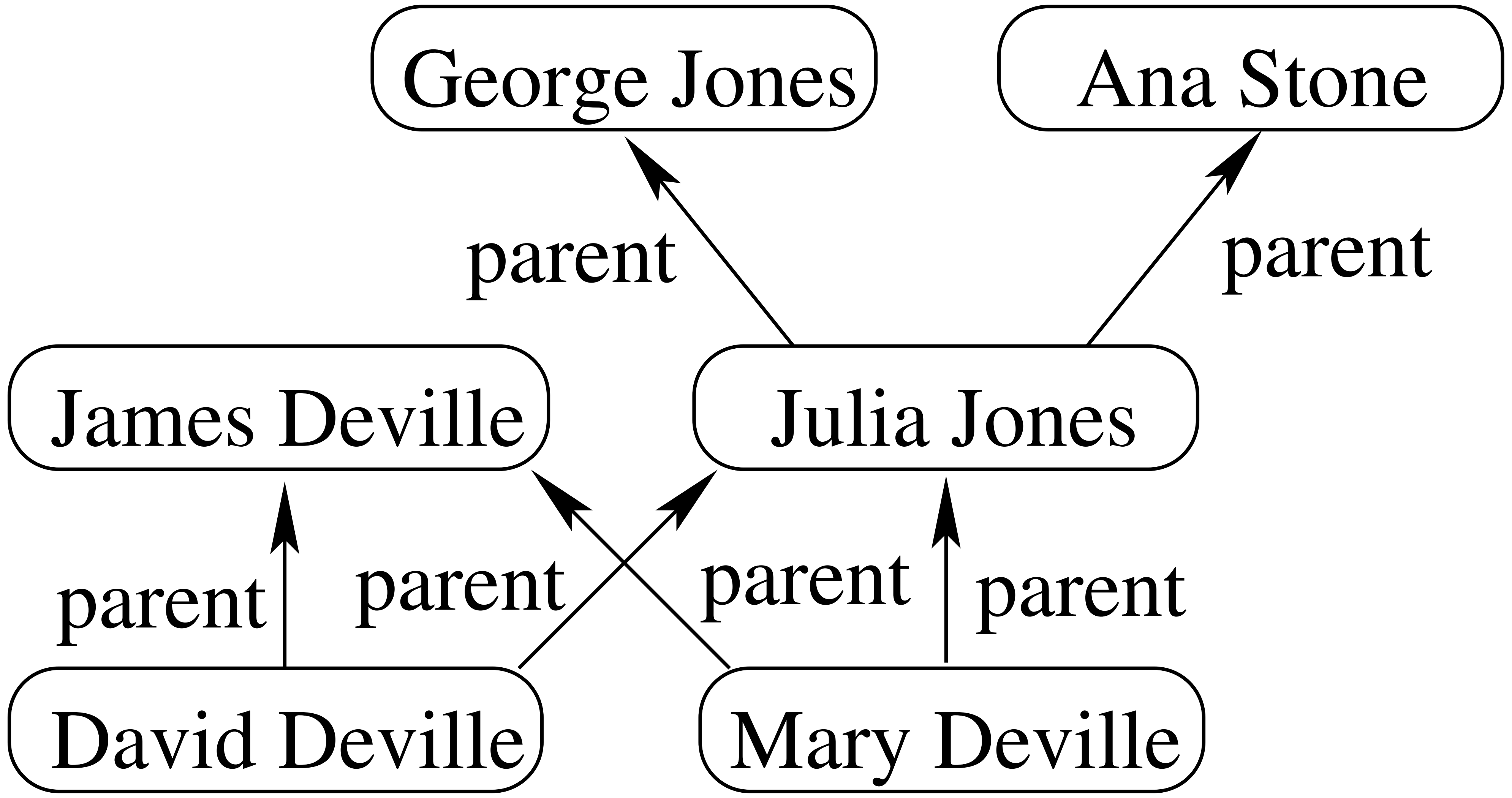
- Graphs has been long ago recognized as one of the most simple, natural and intuitive knowledge representation systems
- Graph data structures allow for a natural modeling when data has graph structure
- Queries can address direct and explicitly this graph structure
- Implementation-wise, graph databases may provide special graph storage structures, and take advantage of efficient graph algorithms available for implementing specific graph operations over the data

[R. Angles and C. Gutierrez, 2017]

# Relational Model

| NAME | LASTNAME |
|---|---|
| George | Jones |
| Ana | Stone |
| Julia | Jones |
| James | Deville |
| David | Deville |
| Mary | Deville |

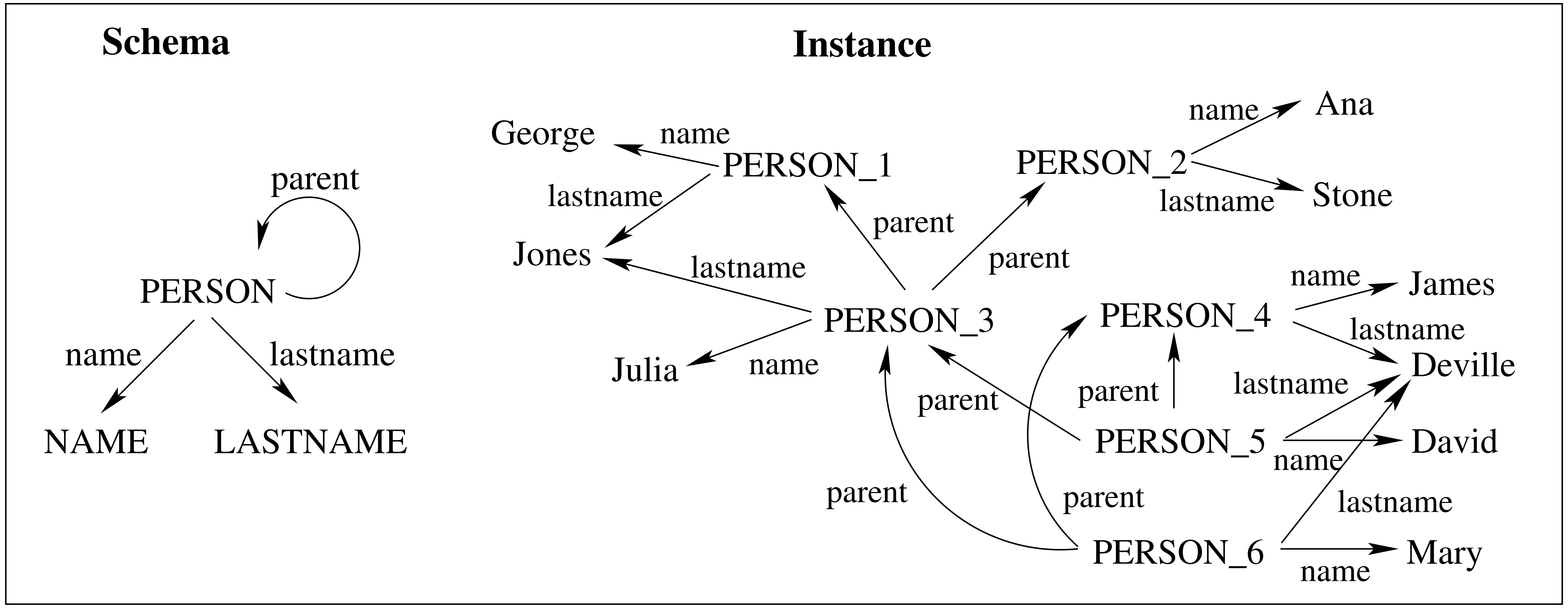
| PERSON | PARENT |
|---|---|
| Julia | George |
| Julia | Ana |
| David | James |
| David | Julia |
| Mary | James |
| Mary | Julia |




[R. Angles and C. Gutierrez, 2017]

# Basic Labeled Model (Gram)

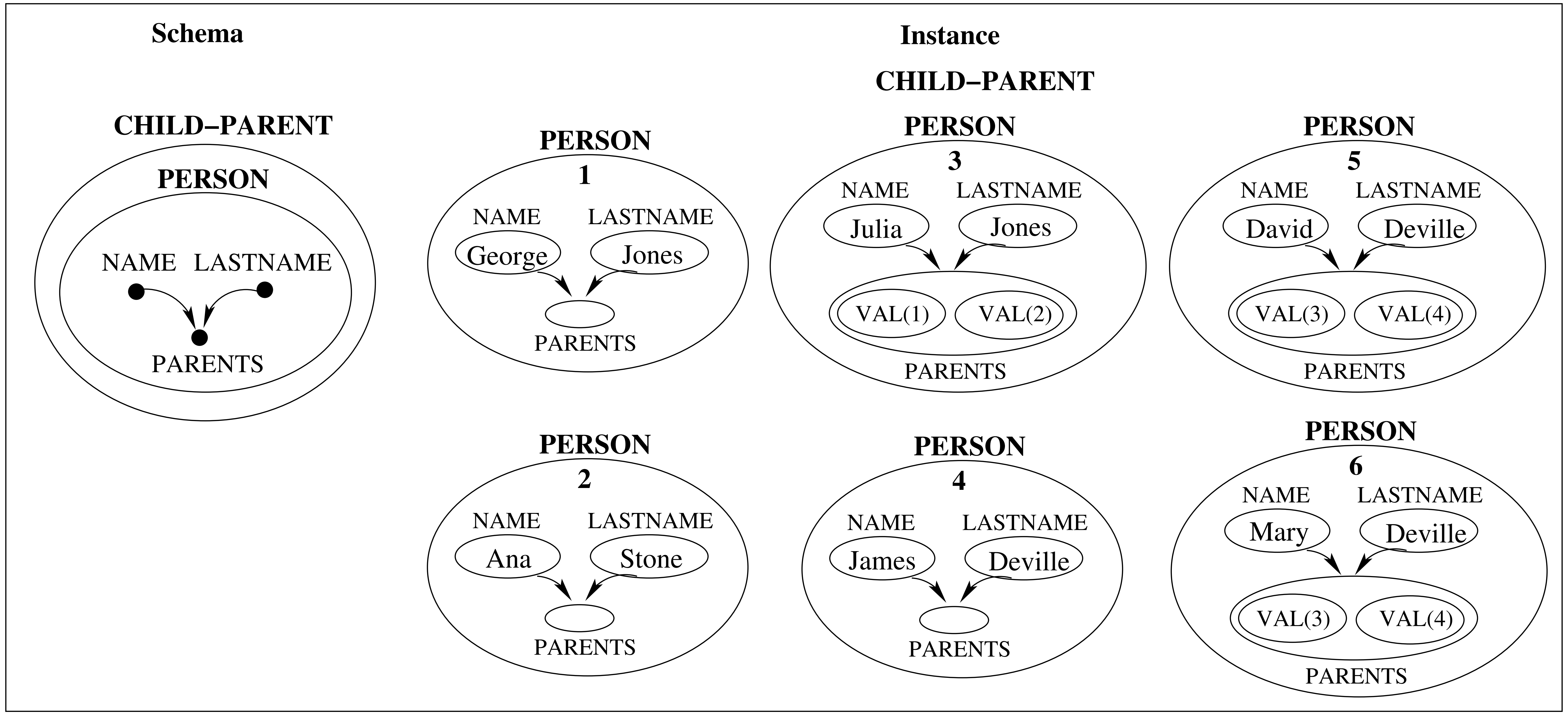
- Directed graph with nodes and edges labeled by some vocabulary
- Gram is a directed labeled multigraph
  - Each node is labeled with a symbol called a **type**
  - Each edge has assigned a label representing a **relation** between types




[R. Angles and C. Gutierrez, 2017]

# Hypergraph Model (Groovy)

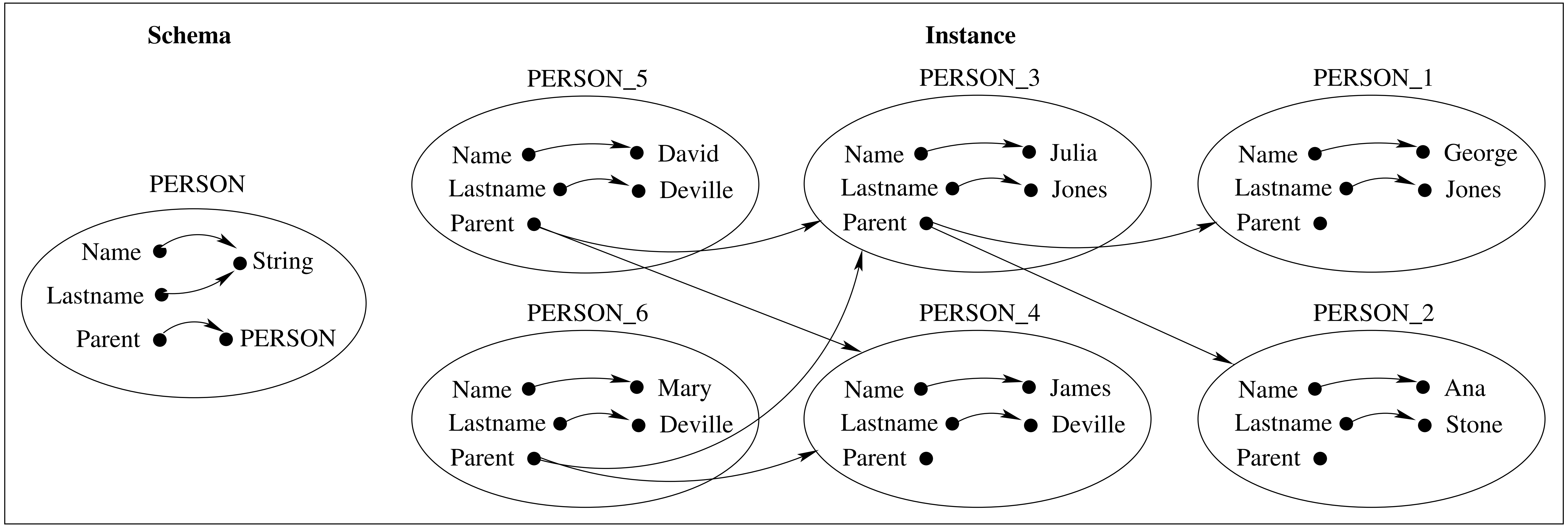
- Notion of edge is extended to **hyperedge**, which relates an arbitrary set of nodes
- Hypergraphs allow the definition of complex objects (undirected), functional dependencies (directed), object-ID and (multiple) structural inheritance




[R. Angles and C. Gutierrez, 2017]

# Hypernode Model

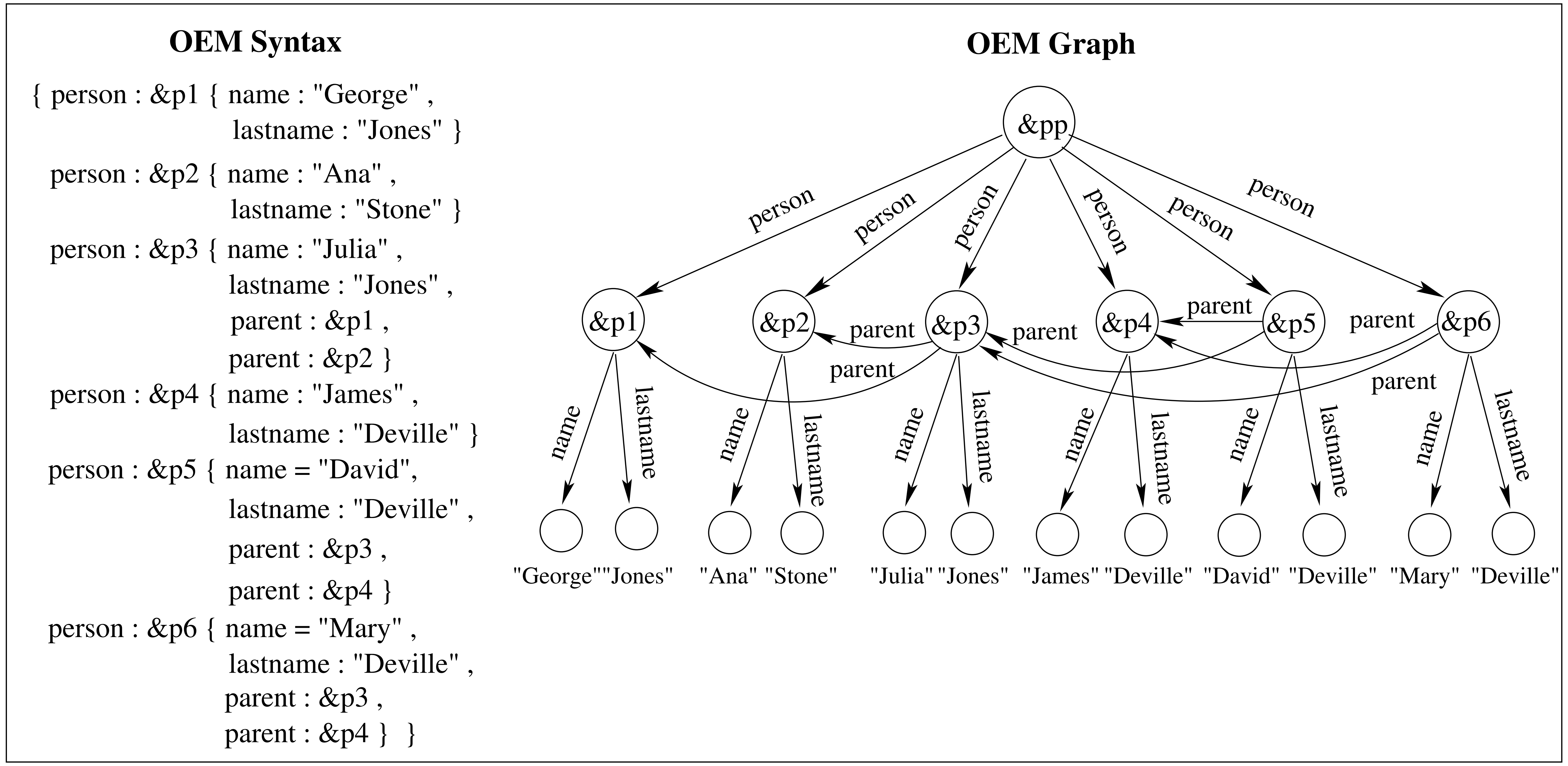
- Hypernode is a directed graph whose nodes can themselves be graphs (or hypernodes), allowing **nesting** of graphs
- **Encapsulates** information




[R. Angles and C. Gutierrez, 2017]

# Semistructured (Tree) Model: (OEM Graph)

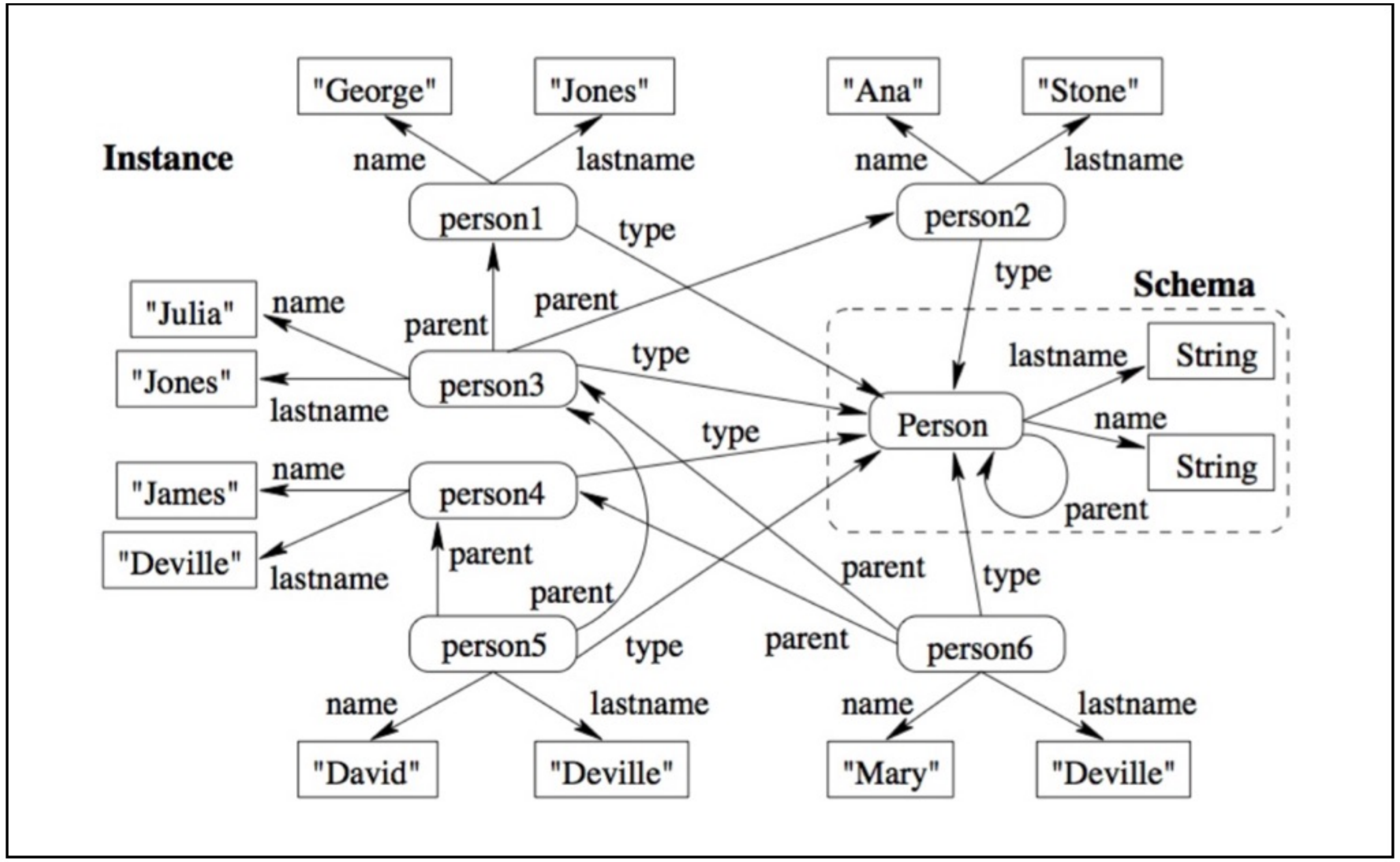
- "Self-describing" data like JSON and XML
- OEM uses pointers to data in the tree




[R. Angles and C. Gutierrez, 2017]

# RDF (Triple) Model

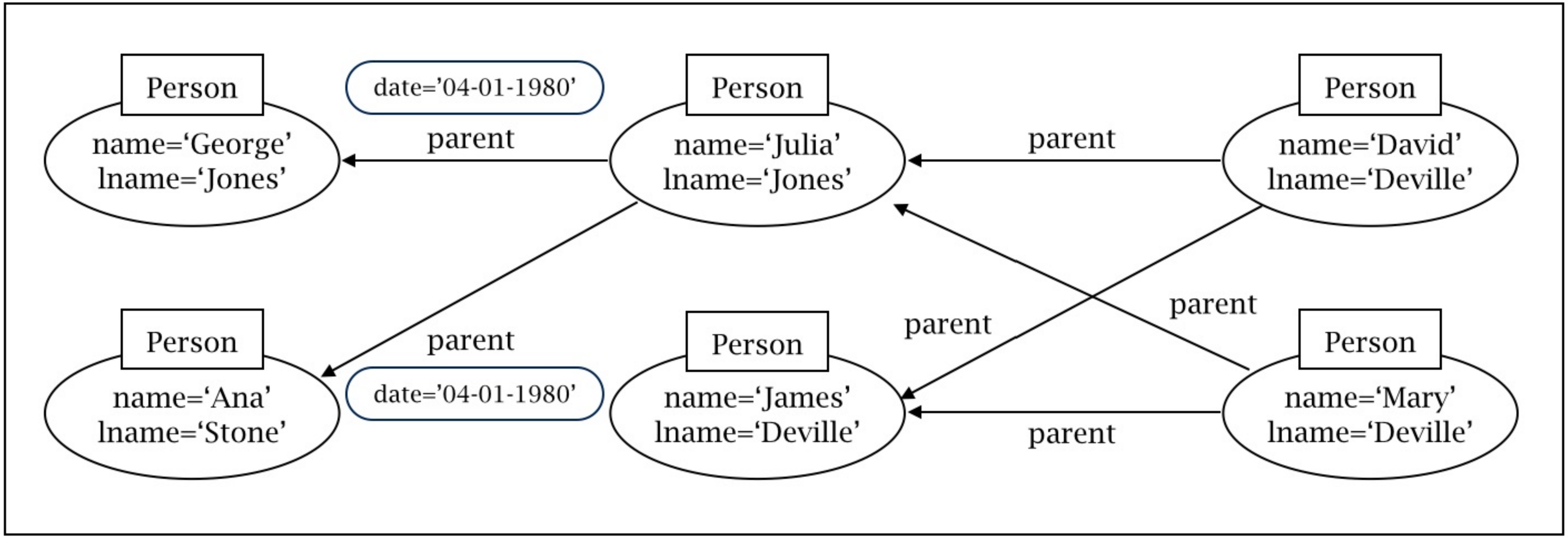
- Interconnect resources in an extensible way using graph-like structure for data
- Schema and instance are **mixed** together
- SPAQL to query
- Semantic web




[R. Angles and C. Gutierrez, 2017]

# Property Graph Model (Cypher in neo4j)

- Directed, labelled, attributed multigraph
- Properties are **key/value pairs** that represent metadata for nodes and edges




[R. Angles and C. Gutierrez, 2017]

# Types of Graph Queries

- Adjacency queries (neighbors or neighborhoods)
- Pattern matching queries (related to graph mining)
  - Graph patterns with structural extension or restrictions
  - Complex graph patterns
  - Semantic matching
  - Inexact matching
  - Approximate matching
- Reachability queries (connectivity)

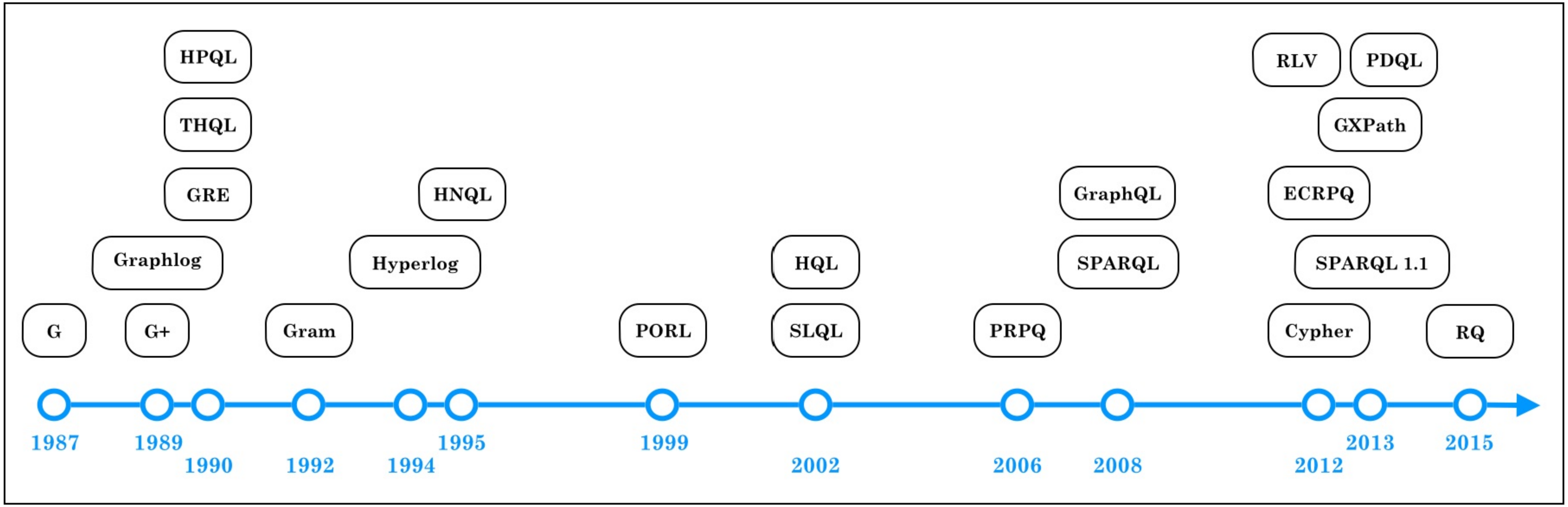
[R. Angles and C. Gutierrez, 2017]

# Types of Graph Queries (continued)

- Analytical queries
  - Summarization queries
  - Complex analytical queries (PageRank, characteristic path length, connected components, community detection, clustering coefficient)

[R. Angles and C. Gutierrez, 2017]

# Graph Query Languages




[R. Angles and C. Gutierrez, 2017]

# Cypher

- Implemented by neo4j system
- Expresses reachability queries via path expressions
  - `p = (a)-[:knows*]->(b)`: nodes from `a` to `b` following `knows` edges
- ```
  START x=node:person(name="John")
  MATCH (x)-[:friend]->(y)
  RETURN y.name
  ```

[R. Angles and C. Gutierrez, 2017]
  ```

# SPARQL (RDF)

- Uses SELECT-FROM-WHERE pattern like SQL
- ```
  SELECT ?N
  FROM <http://example.org/data.rdf>
  WHERE { ?X rdf:type voc:Person . ?X voc:name ?N }
  ```

[R. Angles and C. Gutierrez, 2017]
  ```

# Comparing Graph Database Systems: Features

## Data Storage

| *Graph Database* | Main memory | External memory | Backend Storage | Indexes |
|---|---|---|---|---|
| AllegroGraph | • | • | | • |
| DEX | • | • | | • |
| Filament | • | | • | |
| G-Store | | • | | |
| HyperGraphDB | • | • | • | • |
| InfiniteGraph | | • | | • |
| Neo4j | • | • | | • |
| Sones | • | | | • |
| vertexDB | | • | • | |

## Operations/Manipulation

| *Graph Database* | Data Definition Language | Data Manipulat. Language | Query Language | API | GUI |
|---|---|---|---|---|---|
| AllegroGraph | • | • | • | • | • |
| DEX | | | | • | |
| Filament | | | | • | |
| G-Store | • | | • | • | |
| HyperGraphDB | | | | • | |
| InfiniteGraph | | | | • | |
| Neo4j | | | | • | |
| Sones | • | • | • | • | • |
| vertexDB | | | | • | |

[R. Angles, 2012]

# Comparing Graph Database Systems: Representation

## Graph Data Structures

| | Graphs | | | | Nodes | | Edges | | |
|---|---|---|---|---|---|---|---|---|---|
| *Graph Database* | Simple graphs | Hypergraphs | Nested graphs | Attributed graphs | Node labeled | Node attribution | Directed | Edge labeled | Edge attribution |
| AllegroGraph | • | | | | • | | • | • | |
| DEX | | | | • | • | • | • | • | • |
| Filament | • | | | | • | | • | • | |
| G-Store | • | | | | • | | • | • | |
| HyperGraphDB | | • | | | • | | • | • | |
| InfiniteGraph | | | | • | • | • | • | • | • |
| Neo4j | | | | • | • | • | • | • | • |
| Sones | | • | | • | • | • | • | • | • |
| vertexDB | • | | | | • | | • | • | |

## Entites & Relations

| | Schema | | | Instance | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Graph Database* | Node types | Property types | Relation types | Object nodes | Value nodes | Complex nodes | Object relations | Simple relations | Complex relations |
| AllegroGraph | | | | | • | | | • | |
| DEX | • | | • | • | • | | • | • | |
| Filament | | | | | • | | | • | |
| G-Store | | | | | • | | | • | |
| HyperGraphDB | • | | • | | • | | | • | • |
| InfiniteGraph | • | | • | • | • | | • | • | |
| Neo4j | | | | • | • | | • | • | |
| Sones | | | | | • | | | • | • |
| vertexDB | | | | | • | | | • | |

[R. Angles, 2012]

# Comparing Graph Database Systems: Queries

## Query Support

| | Type | | | Use | | |
|---|---|---|---|---|---|---|
| *Graph Database* | Query Lang. | API | Graphical Q. L. | Retrieval | Reasoning | Analysis |
| AllegroGraph | ○ | ● | ● | ● | ● | ● |
| DEX | | ● | | ● | | ● |
| Filament | | ● | | ● | | |
| G-Store | ● | | | ● | | |
| HyperGraphDB | | ● | | ● | | |
| InfiniteGraph | | ● | | ● | | |
| Neo4j | ○ | ● | | ● | | |
| Sones | ● | | ● | ● | | ● |
| vertexDB | | ● | | ● | | |

## Types of Queries

| | Adjacency | | Reachability | | | | |
|---|---|---|---|---|---|---|---|
| *Graph Database* | Node/edge adjacency | k-neighborhood | Fixed-length paths | Regular simple paths | Shortest path | Pattern matching | Summarization |
| Allegro | ● | | ● | | | ● | |
| DEX | ● | | ● | ● | ● | ● | |
| Filament | ● | | ● | | | ● | |
| G-Store | ● | | ● | ● | ● | ● | |
| HyperGraph | ● | | | | | ● | |
| Infinite | ● | | ● | ● | ● | ● | |
| Neo4j | ● | | ● | ● | ● | ● | |
| Sones | ● | | | | | ● | |
| vertexDB | ● | | ● | ● | | ● | |

[R. Angles, 2012]