CSIT882 Data Management Systems

Graph Data Models

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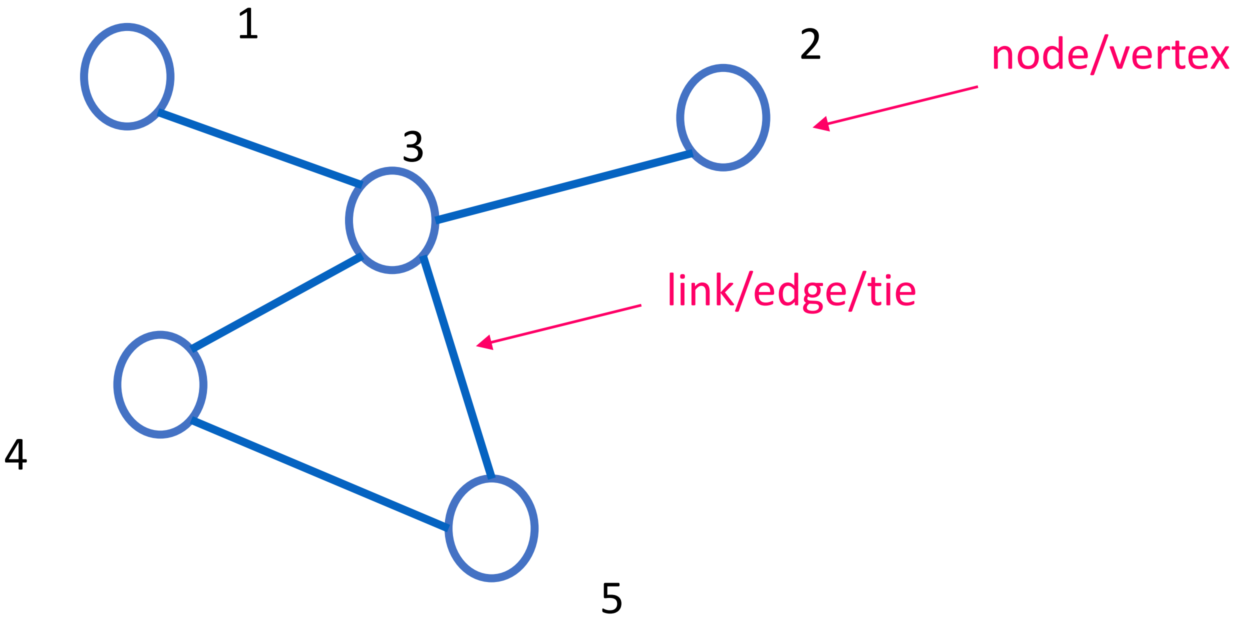
INTRODUCTION – What are Networks

- **Networks** are collections of **nodes (points)** connected by Edges **(lines)**



“Network” ≡ “Graph”

INTRODUCTION – Why we study graphs

- **Networks** are everywhere, and we live in a **highly-connected world**.
- e.g., easy to reach a place, to reach a person or to find information
- In many applications, we need to analyze **in the context of networks**, not just individuals.
  - Social networks
  - Information networks
  - Road networks
  - Protein-Protein-interaction networks
  - …

Social Networks – Network of thrones

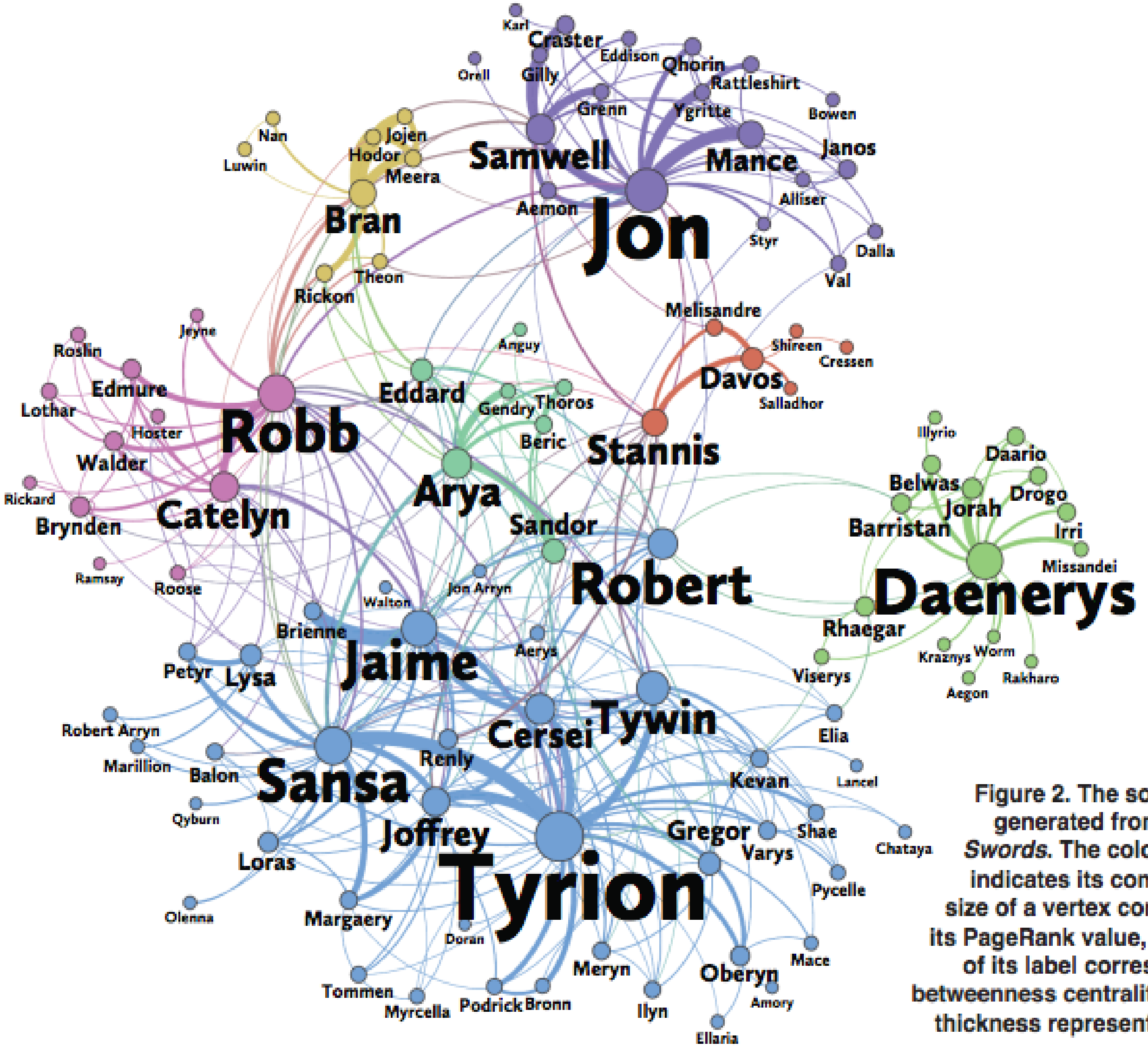


Figure 2. The social network generated from *A Storm of Swords*. The color of a vertex indicates its community. The size of a vertex corresponds to its PageRank value, and the size of its label corresponds to its betweenness centrality. An edge's thickness represents its weight.

http://www.maa.org/sites/default/files/pdf/Mathhorizons/NetworkofThrones%20%281%29.pdf

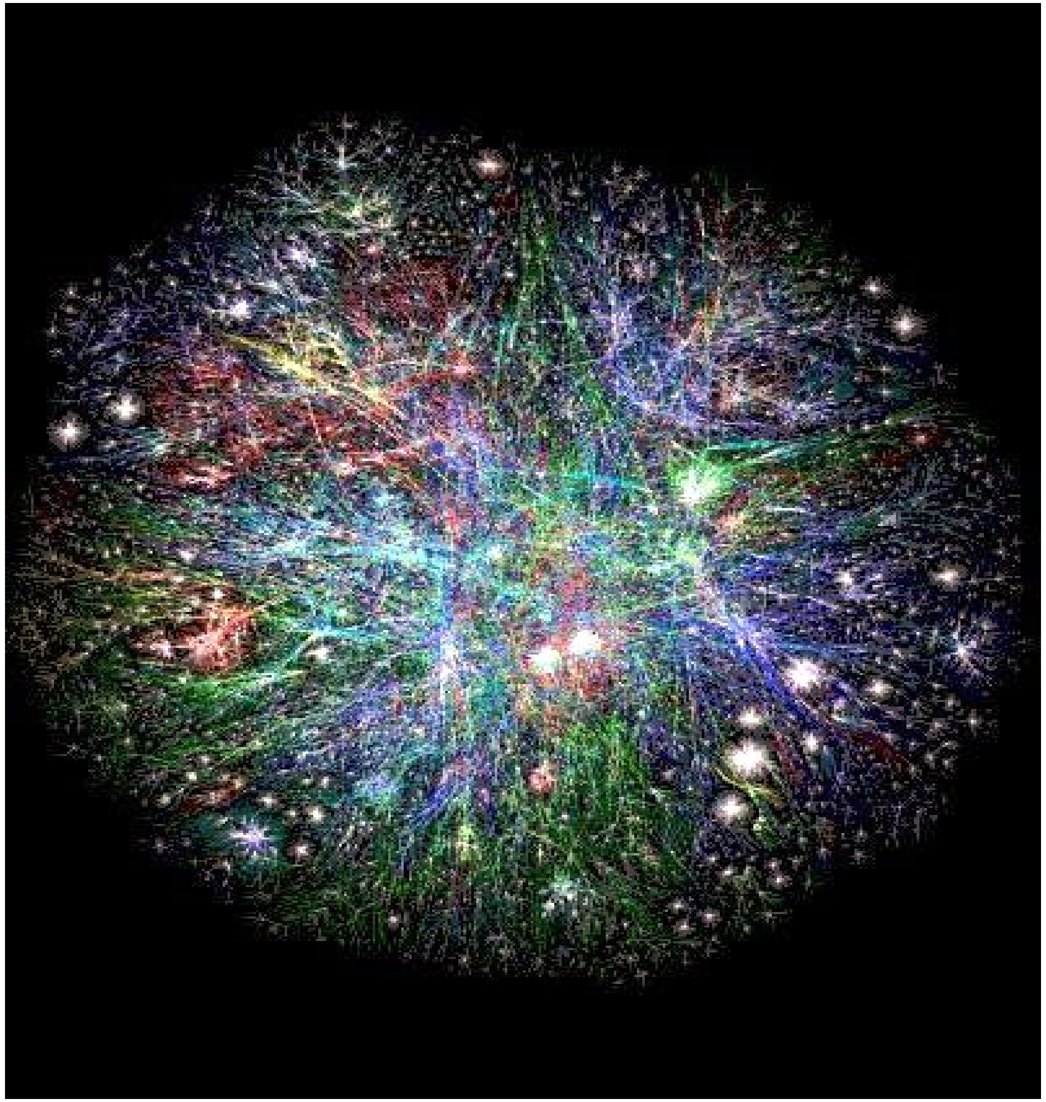
Social Networks – Facebook (location based visualization in 2011)

Monthly active users: around **1 billion** in **2012** and **2.32 billion** (2017) **-** now around **2.5 billion (2020)**

facebook
December 2010

*Facebook social graph, [Backstrom-Boldi-Rosa-Ugander-Vigna, **2011**]*

Information Networks – WWW

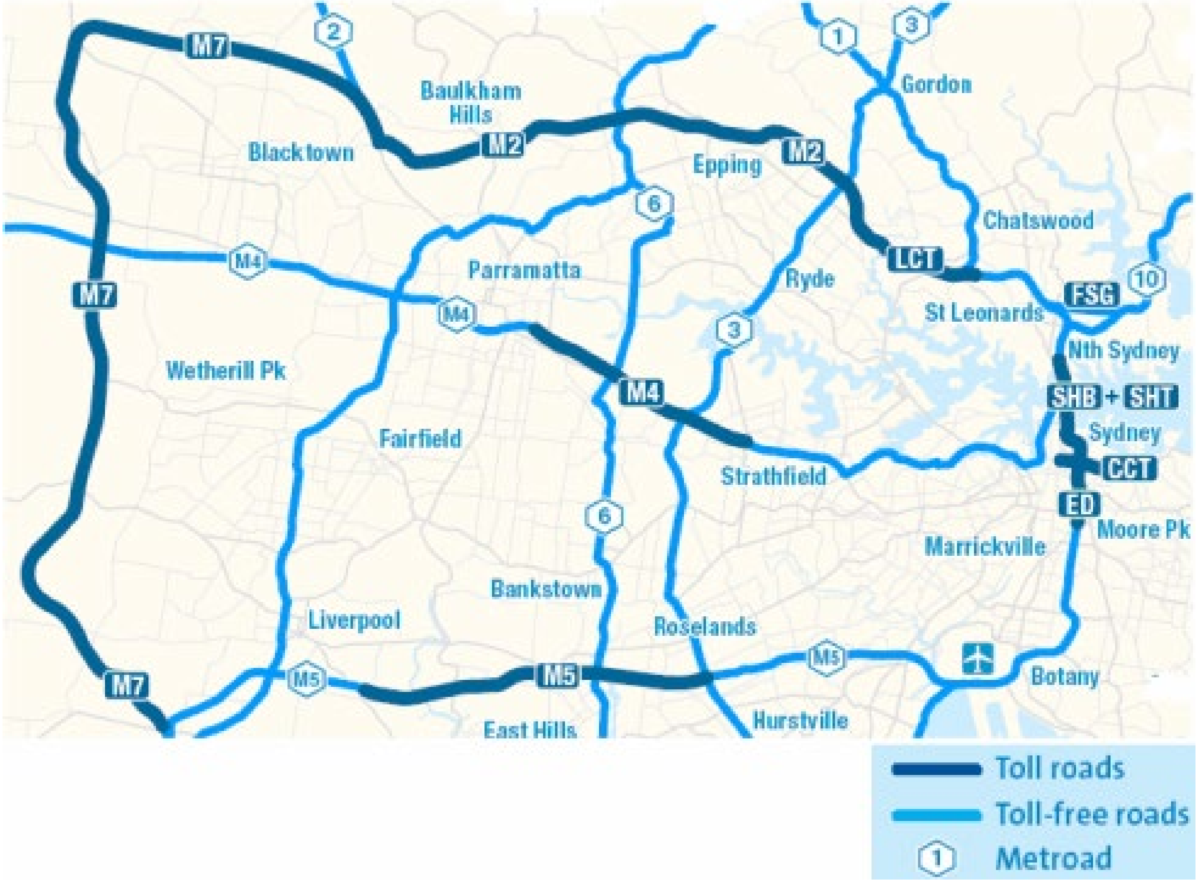


http://www.vlib.us/web/worldwideweb3d.html

3D Map of the World Wide Web

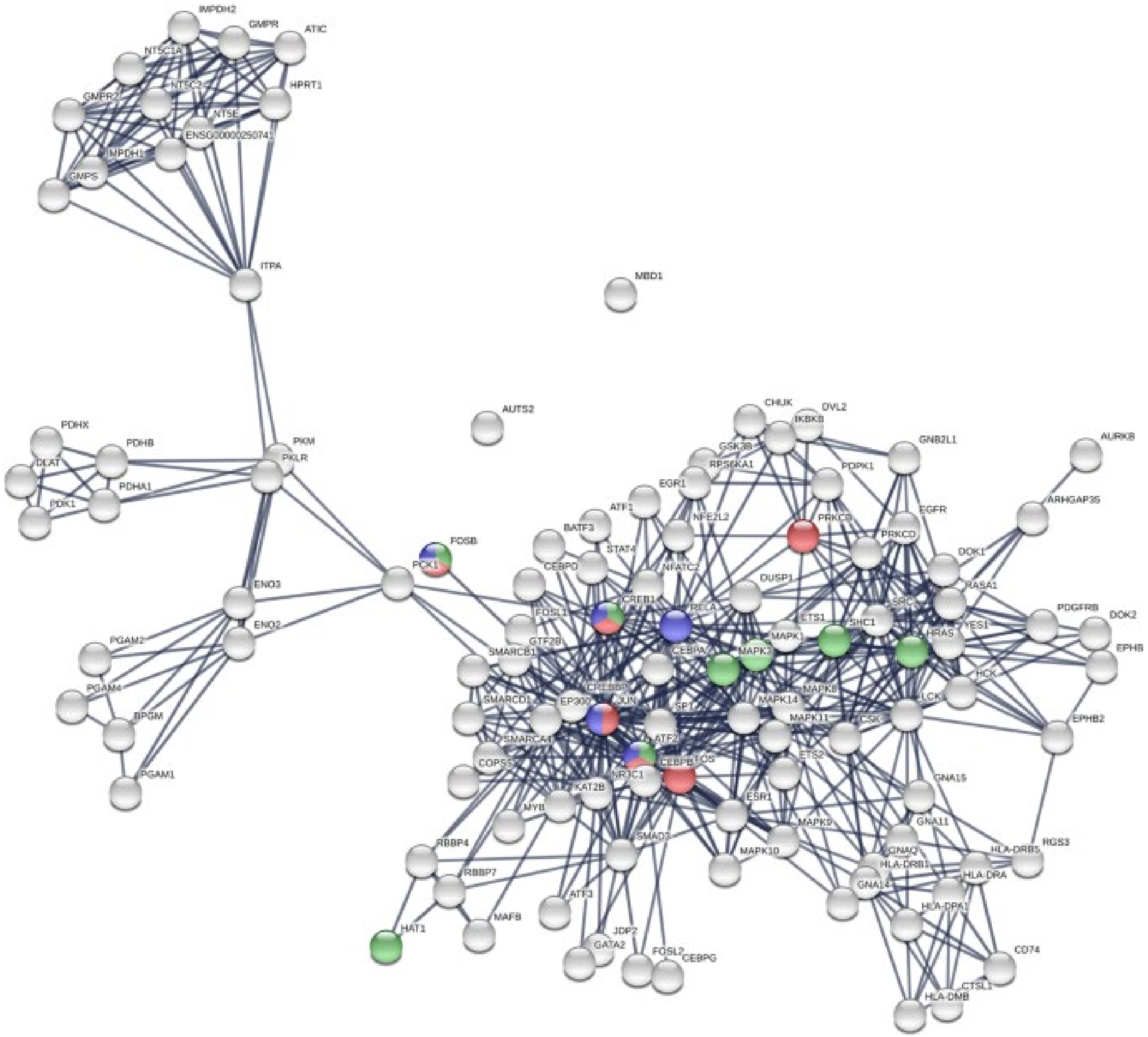
This illustrates in 3-D the actual domains and connections of the world wide web. **Colors** have been added to represent .edu, .gov, .com, etc. domains.

Other Networks



Sydney Road Network

http://www.brt.cl/opinion-pieces-i-tolled-you-so



Protein interaction network

https://www.nature.com/articles/s41598-019-41552-z

Graph Data Models

Outline

- Property Graph Model
- Hypergraph Data Model
- Nested Graph Data Model

Property Graph Data Model

A graph G consists of a set of nodes (N) and a set of edges (E), G = (N, E)

In an undirected graph an edge is represented by a set of 2 nodes $\{n_i, n_j\}$

In a directed graph an edge is represented by an ordered tuple of 2 nodes (n_i, n_j)

Multi-relational graph is a graph where types are introduced for nodes and edges

For example a multi-relational graph may have the names like STUDENT or PROJECT for node type and a name like WORKS-ON for edge type

A node is labelled with a node label and an edge is labelled with an edge label

A specification of type also includes attributes for nodes and edges

A pair (attribute,value) describes property of nodes and edges

Each node and each edge has a unique identifier

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Property Graph Data Model

A property graph is a labelled and attributed directed multigraph with identifiers

A property graph G is defined as $G = (N, E, L_n, L_e, ID)$ where

- N is a set of nodes
- E is a set of edges
- L_n is a set of node labels where a label has a set of node type definitions attached; a node type definition is a pair (type, set of attribute definitions) where an attribute definition is a pair (attribute name, attribute domain)
- L_e is a set of edge labels where a label has a set of attribute type definitions and restrictions for the types of source and target nodes attached;
- edge type definition is a quadruple (type, set of attribute definitions, type, type) where an attribute definition is a pair (attribute name, attribute domain)
- ID is a set of node and edge identifiers

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Property Graph Data Model

For example, students enrolling subjects taught by lecturers can be described by a property graph UNI = (N, E, L_n, L_e, ID) where

- N = {n_1, n_2, n_3}
- E = {e_1}
- L_n = {Student, Lecturer} where node type definitions are
  (Student, $A_{Student}$), $A_{Student}$ = {(name, string), (age, int)}
  (Lecturer, $A_{Lecturer}$), $A_{Lecturer}$ ={(name,string),(expert, string)}
- L_e ={Likes, Teaches}
  (Likes, A_{Likes}, Student, Student U Lecturer}, A_{Likes} ={(level,int)}
  (Teaches,$A_{Teaches}$, Lecturer, Student}, $A_{Teaches}$ ={(since,date)}
- ID = {1,2,3,4}
- n_1 = {1, Student, {name: Alice, age: 23}}
- n_2 = {2, Student,{name: Bob, age: 25}}
- n_3 = {3, Lecturer,{name: James, expert: databases}}
- e_1 = {4, Teaches,{since: 01-01-2023}, 3, 2}

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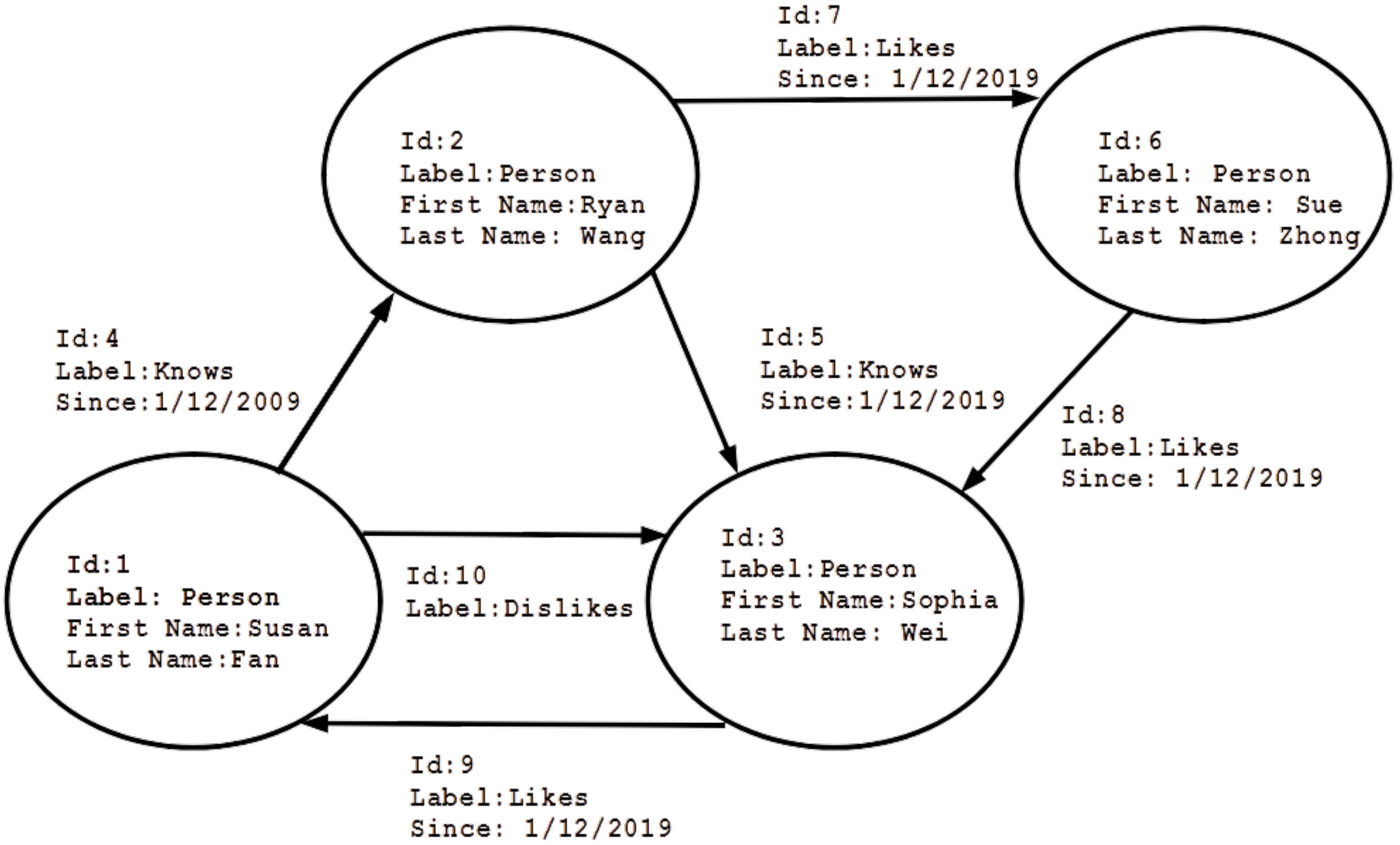
Property Graph Data Model

Visualisation of a sample instance of property graph



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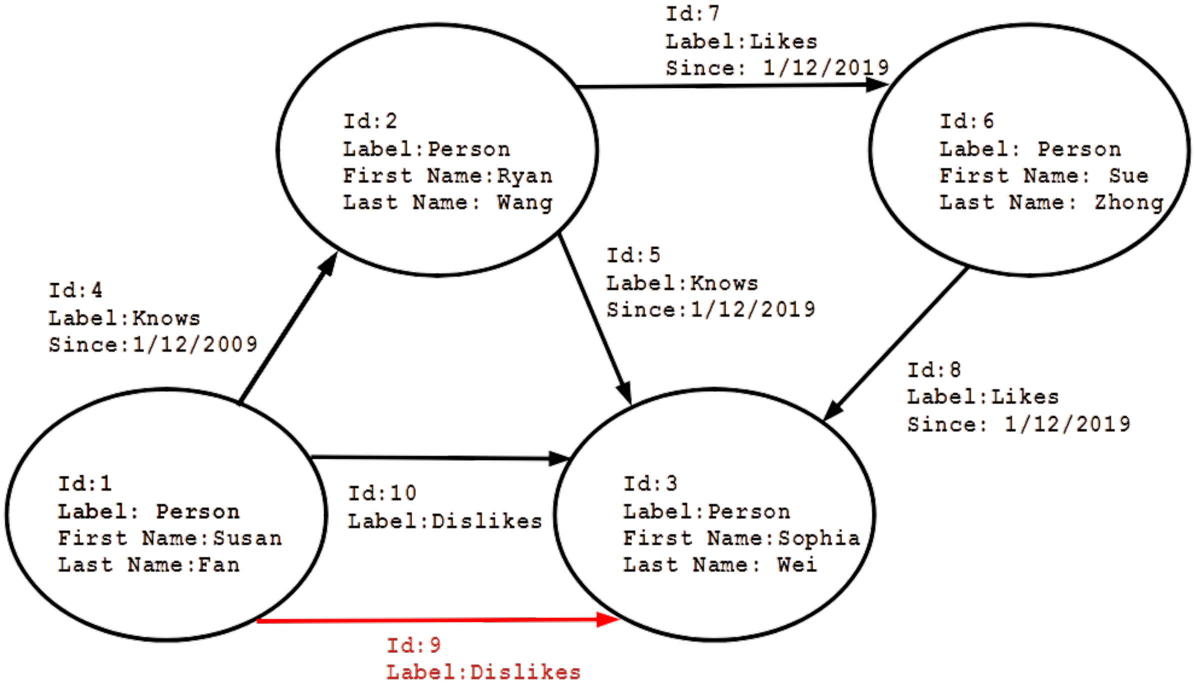
Property Graph Data Model

Property graph must satisfy a number of constraints

- Edges of certain type are allowed between the nodes of certain types, e.g. Teaches can occur only between the pairs of nodes (Lecturer, Student)
- Two nodes cannot be linked by two edges of the same type



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Graph Data Models

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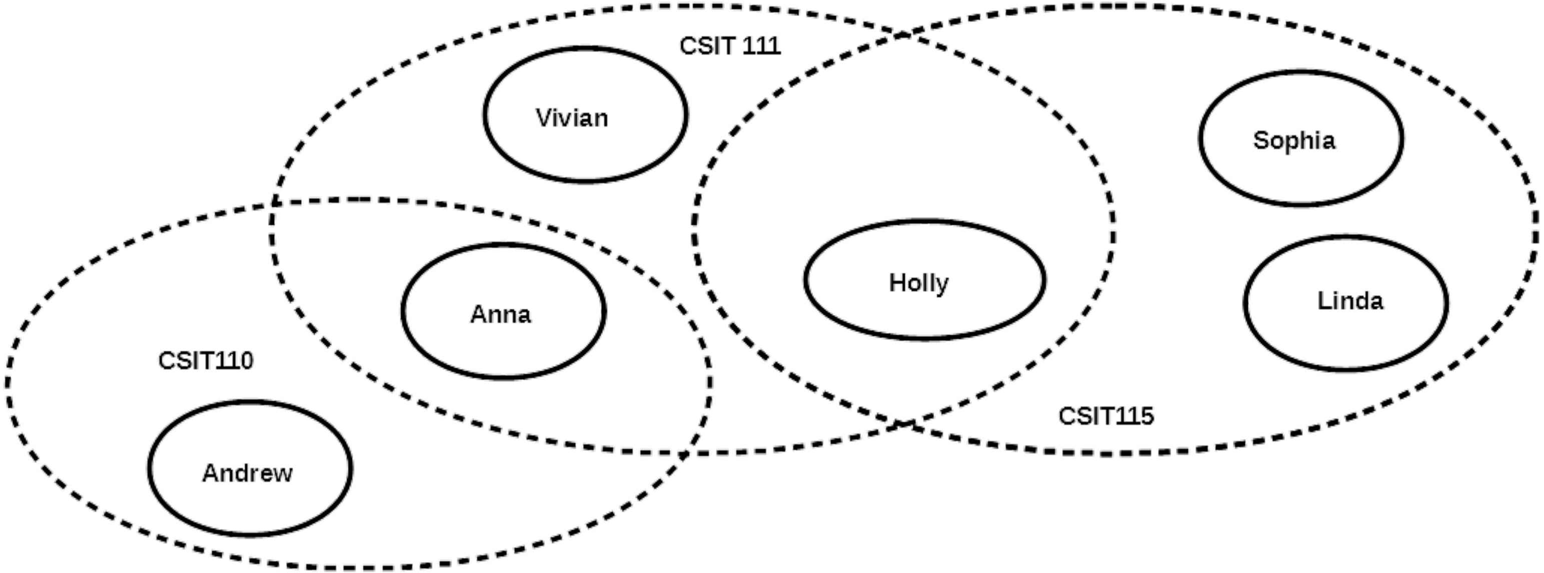
Hypergraph Graph Data Model

A hypergraph is a graph with hyperedges

An undirected hyperedge is a set of nodes

A hypergraph G consists of a set of nodes (N) and a set of hyperedges (E), G= (N, E)

In an undirected hypergraph an edge is represented by a set of k nodes $\{n_{i1}, n_{i2}, \dots , n_{ik}\}$



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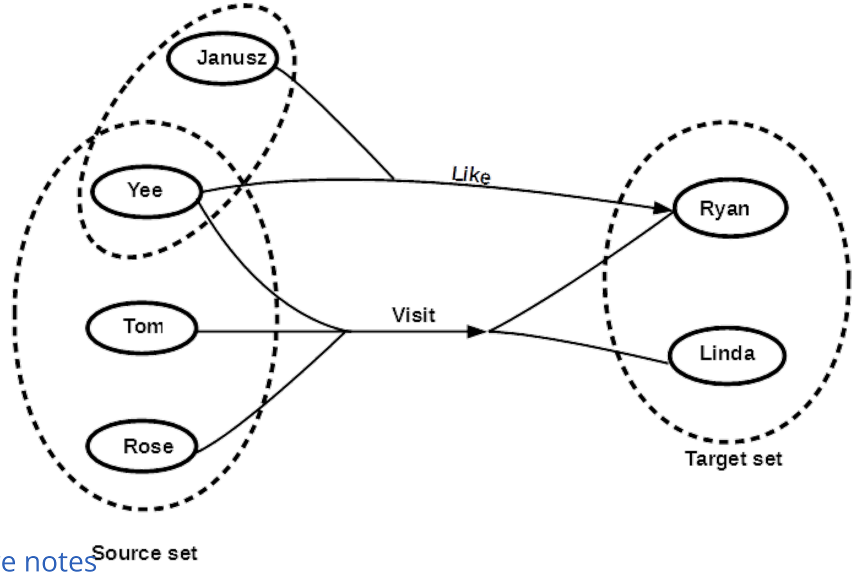
Hypergraph Graph Data Model

A Hypergraph Data Model can be used for data modeling where a database contains information about the groups of the real world objects

For example, a group of students taking French or Spanish classes, or a group of vehicles being cars, trucks, and trains

In directed hypergraph an edge is represented by an ordered tuple of 2 sets of nodes $(\{n_{i1}, n_{i2}, \ldots , n_{ik}\},\{n_{j1}, n_{j2}, \ldots , n_{jm}\})$



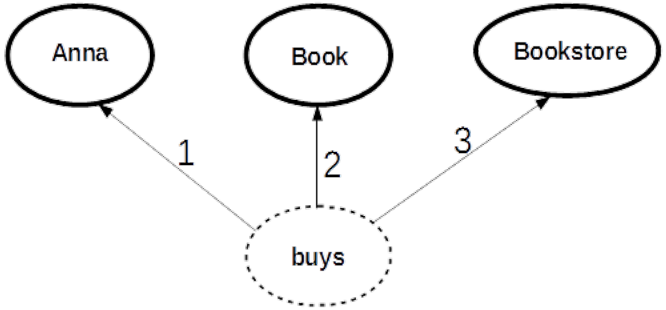
Hypergraph Graph Data Model

Multirelational hypergraph is a hypergraph where the types are introduced for nodes and edges

A Directed Hypergraph Data Model can be used for data modeling when a database contains information about the associations between entire groups of the real world objects

For example, a group pf people visiting another group of people or a group of researchers working on hardware computing devices and passing the results of research to a group working on software for the same computing devices

An oriented hyperedge is an arbitrary sequence of nodes, i.e. it is a tuple $(n_{i1}, \ldots, n_{ik})$



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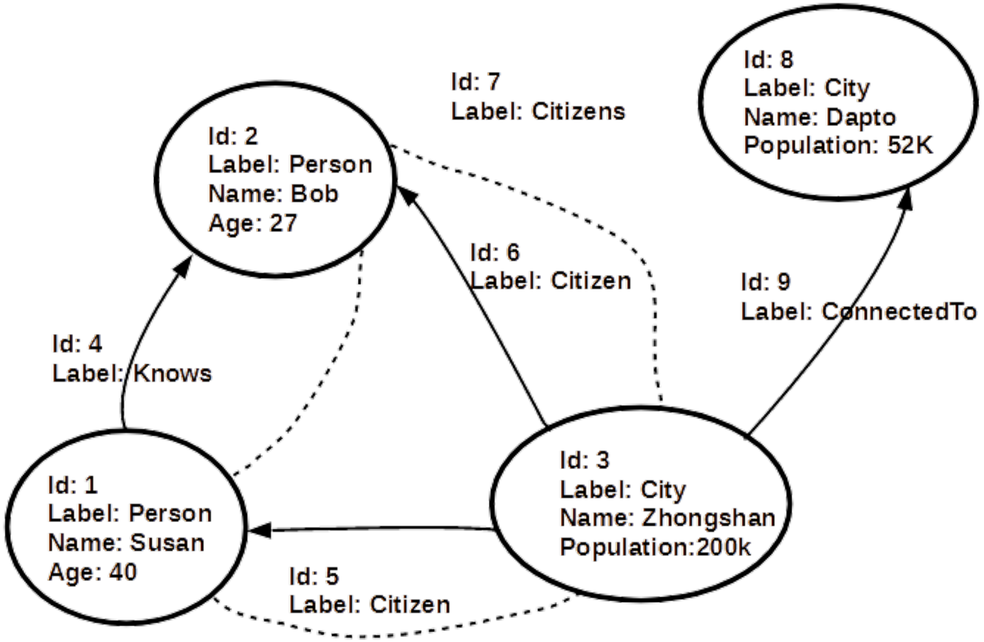
Hypergraph Graph Data Model

A generalized hyperedge groups together a set of nodes an edges

A generalized hyperedge is a set $e = \{a_i,\ldots a_j\}$ of an arbitrary number of elements where the elements a_i and a_j are either nodes or egdes, $a_i, a_j \in V \cup E$



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Nested Graph Data Model

A nested graph consists of hypernodes that can be used to represent complex objects

Hypernodes can encapsulate entire subgraphs that themselves can be nested

A definition of a hypernode can be recursive and because of that the depth of nestings can be unlimited

A nested graph consists of the following components:

- a set P of primitive nodes that contains keys and values of (key,value) pairs,
- a set I of identfiers
- A nested graph is defined by choosing and identifier G in I and then assigning a set of hypernodes and binary edges G =(N,E) such that each n ∈ N is either a primitive node or another identifier G' (N is included or equal to P ∪ I); a complex hypernode G' ∈ N is itself a nested graph
- a set E included in N × N is defined as a binary edge between two hypernodes restricted in such a way that an edge e ∈ E can map a key to a value or to an identifier

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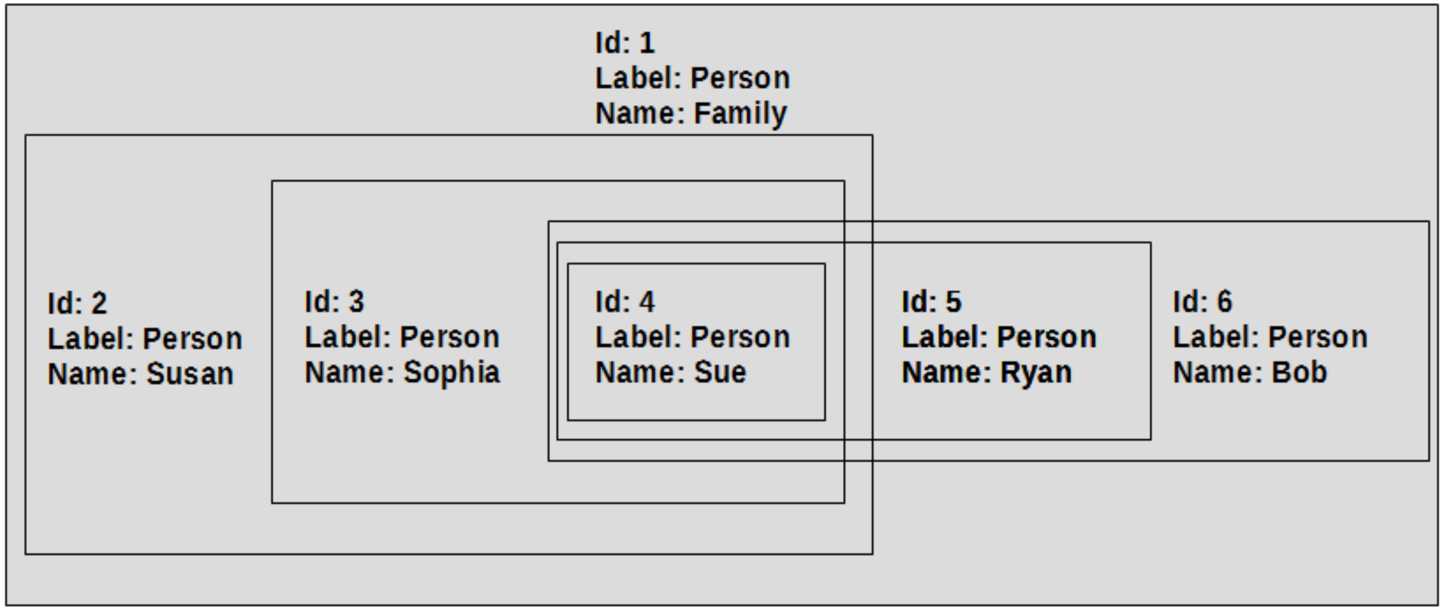
Nested Graph Data Model

A sample nested graph



References

Wiese L., Advanced Data Management, 2015, Chapter 4 Graph Databases