Advanced Data Management (CSCI 640/490)

Visualization and Databases

Dr. David Koop
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]
Graphs with Properties

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

Person

- name = 'Tom Hanks'
- born = 1956

Person

- name = 'Robert Zemeckis'
- born = 1951

Movie

- title = 'Forrest Gump'
- released = 1994

ACTED_IN roles = ['Forrest']

DIRECTED
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
Graph Databases Compared to Relational Databases

Optimized for aggregation

Optimized for connections

[M. De Marzi, 2012]
Graph Databases Compared to Relational Databases

• Relational Databases (querying is through joins)
  - In effect, the join operation forms a graph that is **dynamically constructed** as one table is linked to another table.
  - Must be inferred through a series of **index-intensive** operations

• Graph Databases (querying is through traversal paths)
  - There is no explicit join operation because vertices maintain **direct references** to their adjacent edges
  - Structures are "**hard-wired**", not computed at query time
Example: Friend of Friends Query

• Relational:


• Graph:

[Diagram showing relationships between nodes labeled Alice, with edges indicating 'FRIEND_OF' and 'LIVES_IN' among others.]

[Leombo & Rosati]
Graph Databases Compared to Key-Value Stores

- Optimized for simple look-ups
- Optimized for traversing connected data

[M. De Marzi, 2012]
Storing and Traversing Graphs

• Storage:
  - Adjacency List: nodes store their neighbors
  - Incidence List: nodes store edges and edges store incident nodes
  - Adjacency Matrix: adjacency list in matrix form (rows & cols are nodes)
  - Incidence Matrix: rows are vertices, columns are edges

• Traversal:
  - Breadth-first Search
  - Depth-first Search
Adjacency List vs. Incidence List

**Adjacency List**

- **Storage:** $O(|V| + |E| + |L|)$
- **Adjacent(G,x,y):** $O(|V|)$
- **Neighbors(G,x):** $O(|V|)$
- **AdjacentEdges(G,x,y):** $O(|V| + |E|)$
- **Add(G,x,y,l):** $O(|V| + |E|)$
- **Delete(G,x,y,l):** $O(|V| + |E|)$

**Properties:**

- (V1, {L1})
- (V1, {L2})
- (V3, {L3})
- (V4, {L1})

**Incidence List**

- **Storage:** $O(|V| + |E| + |L|)$
- **Adjacent(G,x,y):** $O(|E|)$
- **Neighbors(G,x):** $O(|E|)$
- **AdjacentEdges(G,x,y):** $O(|E|)$
- **Add(G,x,y,l):** $O(|E|)$
- **Delete(G,x,y,l):** $O(|E|)$

**Properties:**

- (source, L1)
- (source, L2)
- (source, L3)
- (destination, L1)
- (destination, L2)
- (destination, L3)

**Simplified version:** each edge has a different label

[From ABFRV14]
## Adjacency Matrix vs. Incidence Matrix

### Adjacency Matrix

<table>
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<tr>
<th></th>
<th>V1</th>
<th>V2</th>
<th>V3</th>
<th>V4</th>
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<td>V3</td>
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<td>V4</td>
<td>{L1}</td>
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### Incidence Matrix

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<th>L1</th>
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</thead>
<tbody>
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</tr>
<tr>
<td>source</td>
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<td>destination</td>
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</tbody>
</table>

**Properties:**

- **Storage:** $O(|V|^2)$
- **Adjacent(G,x,y):** $O(1)$
- **Neighbors(G,x):** $O(|V|)$
- **AdjacentEdges(G,x,y):** $O(|E|)$
- **Add(G,x,y,l):** $O(|E|)$
- **Delete(G,x,y,l):** $O(|E|)$

From [ABFRV14] [Acosta et al.]
Property Graph Model (Cypher in neo4j)

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

![Property Graph Diagram]

[R. Angles and C. Gutierrez, 2017]
Graph Query Languages: Cypher

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

[R. Angles and C. Gutierrez, 2017]
Graph DBMS Building Blocks

- Property graph data model
- Graph query language
- Graph visualization
- Subgraph matching
- Relational queries
- Path queries
- Stored procedures

[P. Boncz, 2022]
Graph DBMS Problems

- **performance**
  - Slow loading speeds
  - Query speeds over magnitude slower than RDBMS

- **scalability**
  - Low datasize limit, typically << RAM
  - Little benefit from parallelism

- **reliability**
  - Loads never terminate
  - Query run out of memory or crash
  - Bugs

[P. Boncz, 2022]
Response Monday

- Read Beast paper
- Response due at the beginning of class
Assignment 5

- Last assignment, coming soon
- Graphs, visualization, spatial data, time series
Data Exploration through Visualization
Transportation Data - NYC MTA
## MTA Fare Data Exploration

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<th>REMOTE</th>
<th>STATION</th>
<th>FF</th>
<th>SEN/DIS</th>
<th>7-D AFAS UNL</th>
<th>D AFAS/RMF</th>
<th>JOINT RR TKT</th>
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MTA Fare Data Exploration
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East 161st Street and River Avenue

![Graph showing fare data for East 161st Street and River Avenue from August 2008 to November 2011. The x-axis represents dates, and the y-axis represents the number of full fares purchased. The graph shows peaks in fare purchases on various dates, with the highest peak occurring on September 09.16.](image)
Definition of Visualization

“Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively” — T. Munzner
Why do we visualize data?

- Figures are richer; provide more information with less clutter and in less space.
- Figures provide the gestalt effect: they give an overview; make structure more visible.
- Figures are more accessible, easier to understand, faster to grasp, more comprehensible, more memorable, more fun, and less formal.

List adapted from: [Stasko et al. 1998]
## Why Visual?

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[Note: The table contains data points for various x and y values, and is accompanied by comments on the importance of visualizing data.]
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**Mean of x**: 9  
**Variance of x**: 11  
**Mean of y**: 7.50  
**Variance of y**: 4.122  
**Correlation**: 0.816

[F. J. Anscombe]
Why Visual?

[D. Koop, CSCI 640/490, Spring 2024]
Why Visual?

![Graphs showing the relationship between variables](image)

<table>
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<th>Variable</th>
<th>Value</th>
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<td>Mean of y</td>
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[F. J. Anscombe]
Visual Pop-out
Visual Pop-out
Visual Pop-out

[C. G. Healey]
Visual Perception Limitations
Visual Perception Limitations
Databases and Visualization?
Scalable Visualization

J. Heer
Mosaic: An Architecture for Scalable and Interoperable Data Views

J. Heer & D. Mortiz