UMD DATA605 - Big Data Systems

Graph Data Management Neo4J

Instructor: Dr. GP Saggese - gsaggese@umd.edu
TAs: Krishna Pratardan Taduri, kptaduri@umd.edu Prahar Kaushikbhai Modi, pmodi08@umd.edu
v1.1

Overview

- Motivation
- Graph data models
- Storing graph data
- Querying graph data
- Typical graph analysis tasks
- Executing graph analysis tasks

Overview

- Motivation
- Graph data models
  - E.g., RDF, Property Graph, XML
- Storing graph data
  - E.g., Neo4j
- Querying graph data
  - E.g., Cypher, SPARQL, Gremlin
- Typical graph analysis tasks
  - E.g., PageRank, clustering
- Executing graph analysis tasks
  - E.g., Google Pregel, Apache Giraph, Spark GraphX

Overview

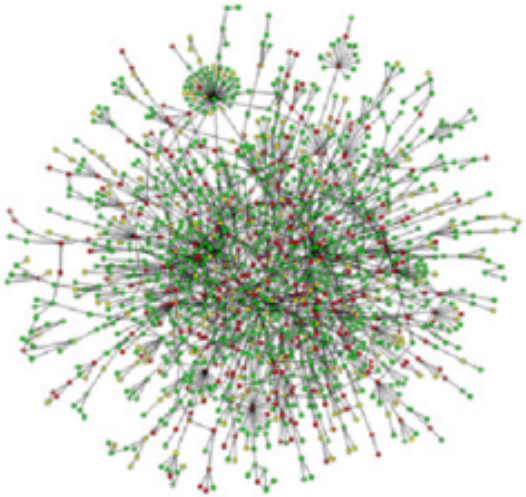
- **Motivation**
- Graph data models
- Storing graph data
- Querying graph data
- Typical graph analysis tasks
- Executing graph analysis tasks

Graphs: Background

- A *graph* (or* network)* captures a set of entities and interconnections between pairs of them
  - Entities / objects represented by *vertices or nodes*
  - Interconnections between pairs of vertices called *edges* (or *links*, *arcs*, *relationships*)
- Graph theory and algorithms widely studied in Computer Science
  - Not as much work on managing graph-structured data

Graph Data Structures: Motivation

- Increasing interest in querying and reasoning about the *underlying graph structure* in a variety of disciplines

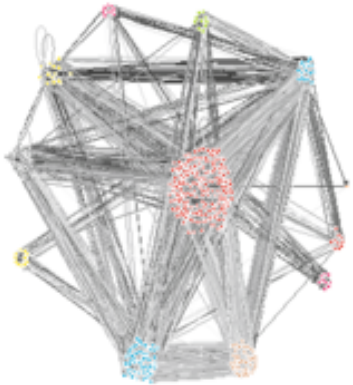


A protein-protein interaction network

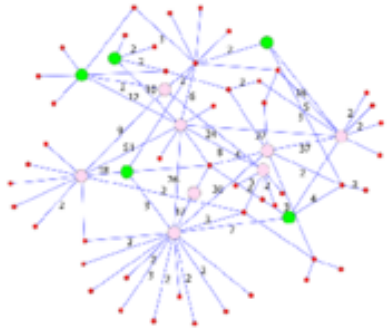
facebook twitter LinkedIn

Social networks

Supreme court citation network

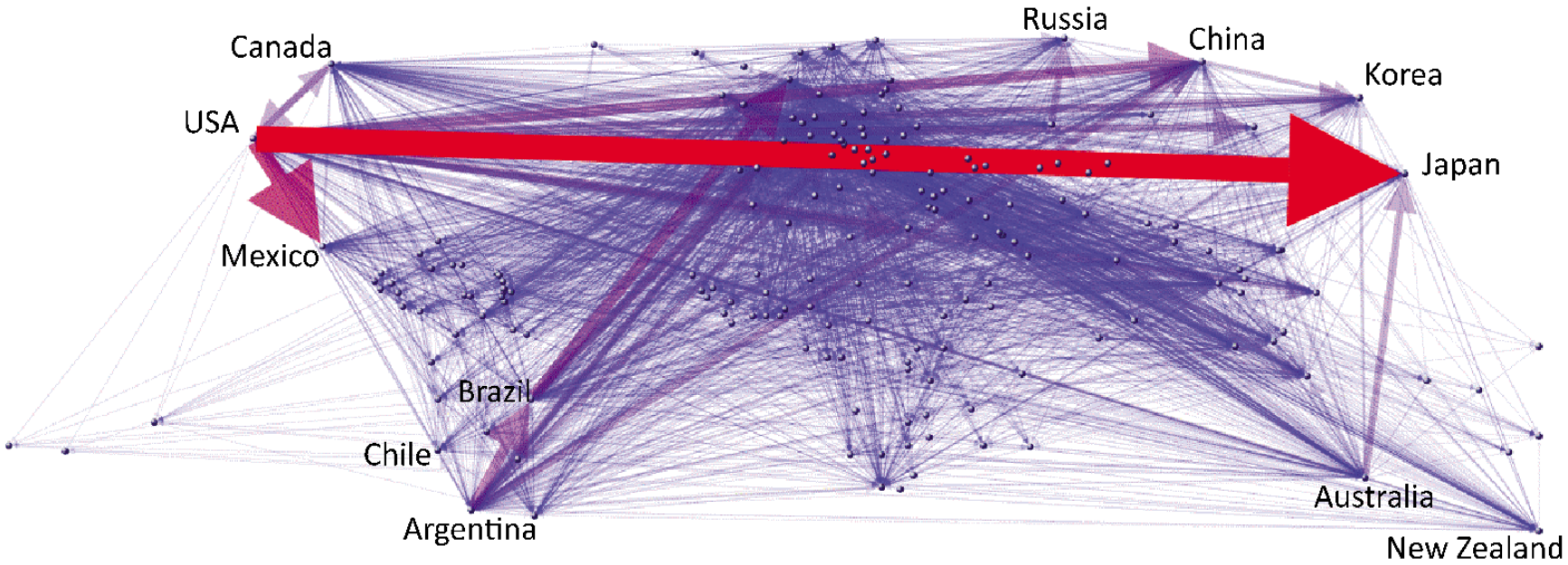


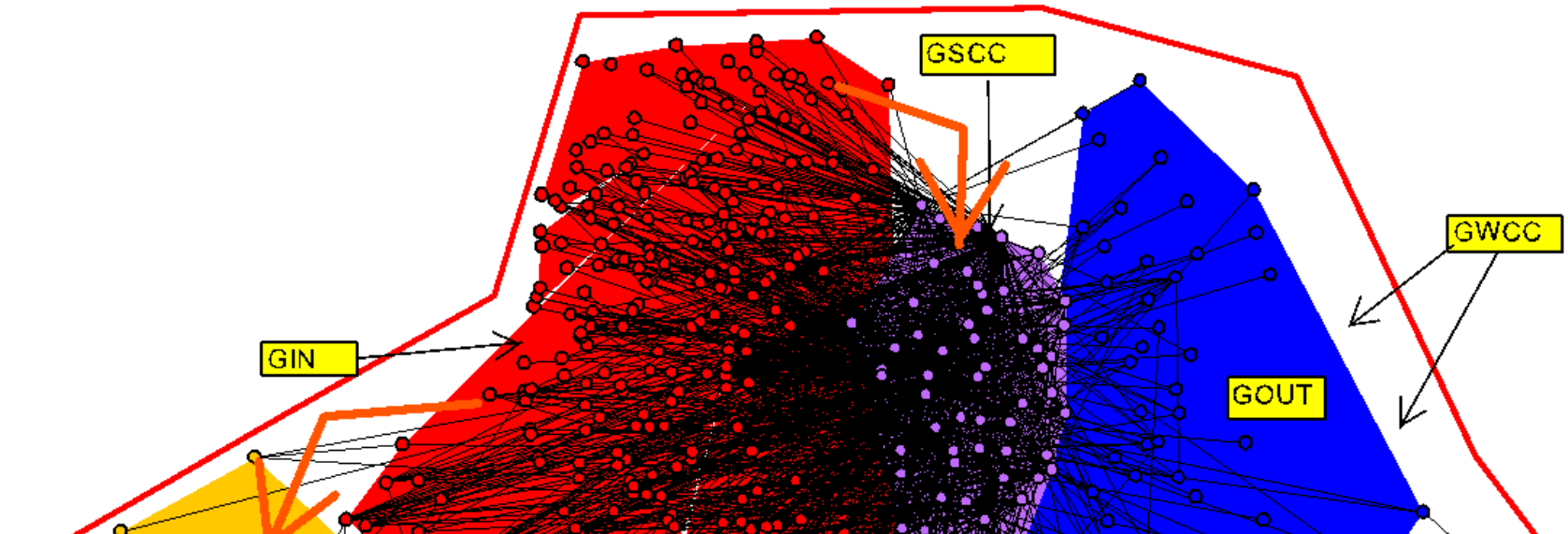
Financial transaction networks



Stock Trading Networks

Motivation


Russia
Canada
China
Korea
USA
Japan
Mexico
Brazil
Chile
Australia
Argentina
New Zealand


GSCC
GWCC
GIN
GOUT

Motivation

- **Graph data structures have not changed that much over time**
  - Same problems in representing the data in 1960s than today
- **What has changed in recent years**
  - Large data volumes and easier availability
  - Reasoning about the graph structure can provide useful and actionable insights
    - Lose too much information if graph structure ignored
  - Not easy to query using traditional tools (e.g., relational DBs)
    - Need specialized tools (e.g., Neo4j)
  - Hard to efficiently process graph-structured queries using existing tools
    - Dedicated solutions: Google Pregel / Apache Giraph, Spark GraphX
    - Problems getting worse with increasingly large graphs seen in practice

Overview

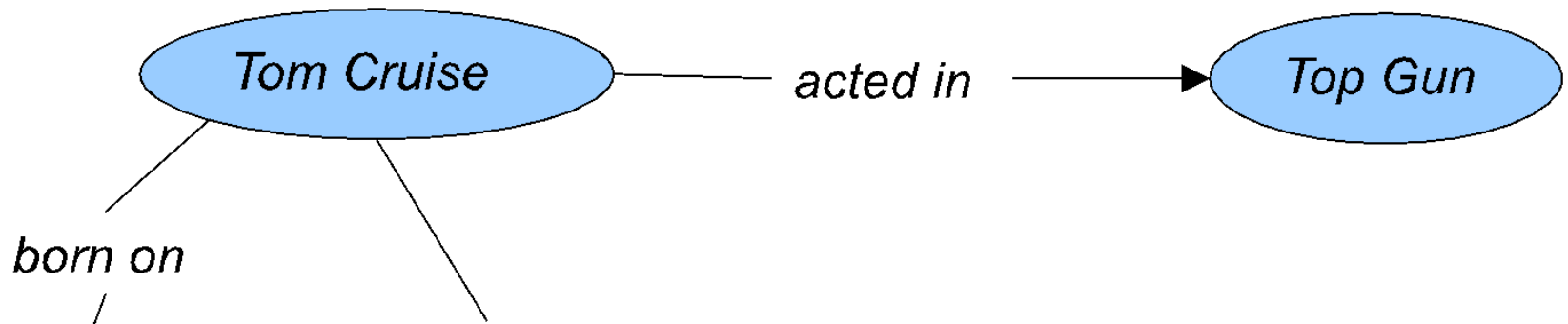
- Motivation
- **Graph data models**
- Storing graph data
- Querying graph data
- Typical graph analysis tasks
- Executing graph analysis tasks

Knowledge Graphs

- **Representation of knowledge in the form of graphs**
  - Capture entities, relationships, and properties
  - Provide a structured view of real-world information
- Can be represented using RDF or Property Graph models
  - E.g., Google Knowledge Graph, DBpedia, Wikidata
- **Applications**
  - Enable machine understanding of complex domains
  - Support semantic search, recommendation, and analytics
  - Used in various industries for data integration, knowledge discovery, and AI applications
- **Ontologies**
  - Provide a formal representation of knowledge
  - Promote interoperability across knowledge bases

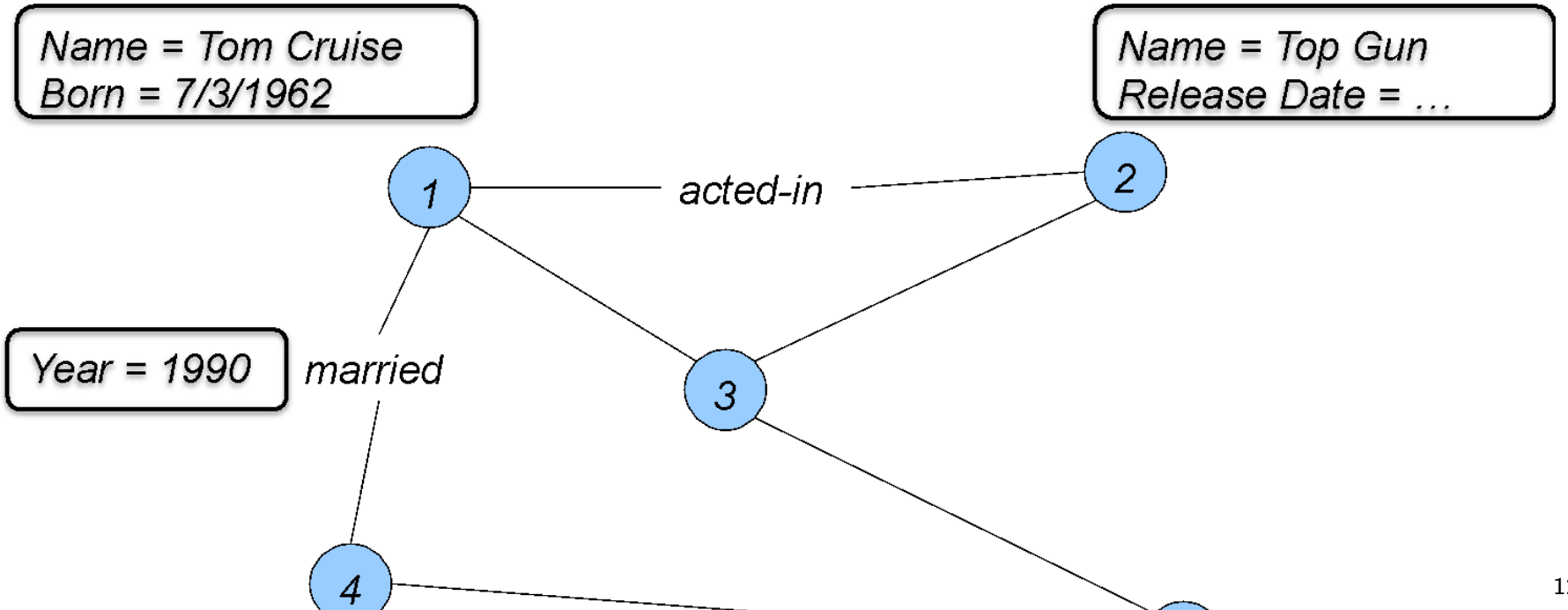
Graph Data Models: RDF

- Resource Description Framework
- RDF uses triples subject-predicate-object
  - Each triple connects a "subject" and an "object" through a "predicate"
  - E.g., "TomCruise-acted-TopGun"
- **Used to represent knowledge bases**
  - Typically queried through SPARQL
- **Pros**
  - Standardization
    - Standard W3C to model data
    - Subject and object can be URI (Uniform Resource Identifier) in semantic web
  - Interoperability
    - Can merge RDF data store
  - Extensibility
    - Can add new nodes and relationships
    - Support ontologies



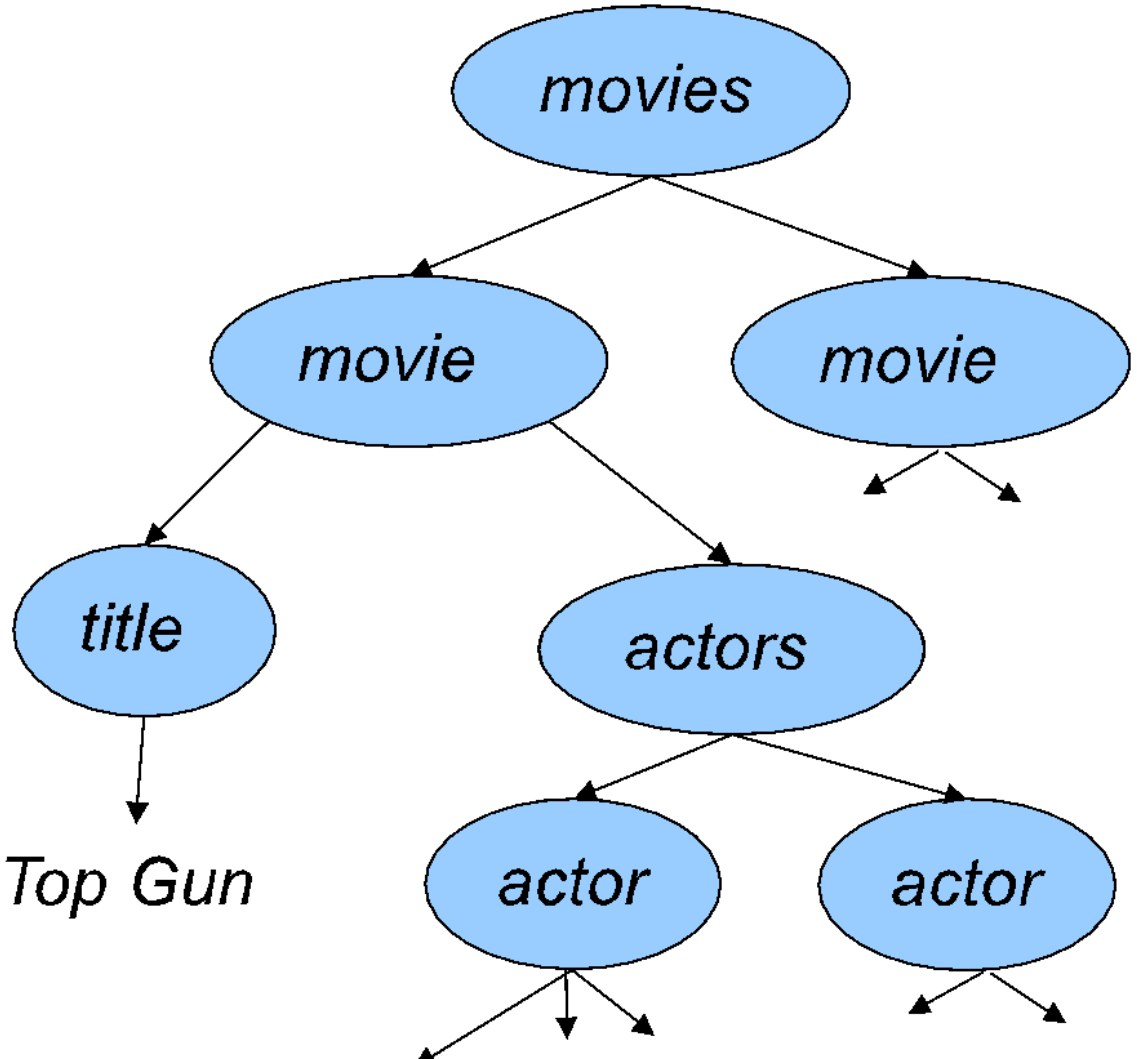
Graph Data Models: Property Graph

- A directed graph where each node and each edge may be associated with a set of *properties* (*key-values*)
- Query languages
  - Cypher (e.g., Neo4j)
  - Gremlin (e.g., Apache TinkerPop)
- Lack universal standard
- Similar expressive power to RDFs but less "schema" so more difficult to interoperate
- Used by many open-source graph data management tools



Graph Data Models: XML

- Commonly used data model for representing data without rigid structure
- It is a directed labeled tree
- Popular data exchange format for non-tabular data



Overview

- Motivation
- Graph data models
- **Storing graph data**
- Querying graph data
- Typical graph analysis tasks
- Executing graph analysis tasks

Storing Graph Data

- **File systems**
- Very simple
- No support for transactions, ACID
- Minimal functionality (e.g., must build the analysis/querying on top)
- **Relational database**
- Mature technology
- All the good stuff (SQL, transactions, ACID, toolchains)
- Minimal functionality
- **NoSQL key-value stores**
- Can handle very large datasets efficiently in a distributed fashion
- Minimal functionality
- **Graph database***
- Efficiently support for queries / tasks (e.g., graph traversals)
- Not as a mature as RDBMs
- Often no declarative language (similar to SQL)
  - You need to write programs

Graph Databases

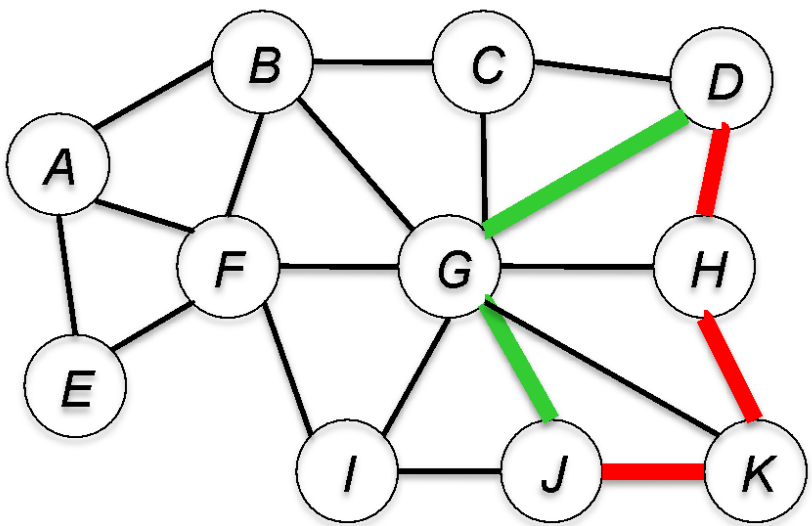
- Many specialized graph database systems in recent years
  - E.g., Neo4j, Titan, OrientDB, AllegroGraph
- A few key distinctions from relational databases
  - Built to manage and query graph-structured data
  - Store the graph structure explicitly using data structures with pointers
    - Avoid the need for joins, making graph traversals easier
    - More natural to write *queries* and *graph algorithms* (reachability or shortest paths)
  - Support graph query languages like SPARQL, Cypher, Gremlin
  - Fairly rudimentary declarative interfaces
  - Most applications need to be written using programmatic interfaces
  - Expose a programmatic API to write arbitrary graph algorithms

```text

#### Overview
- Motivation
- Graph data models
- Storing graph data
- **\textcolor{red}{Querying graph data}**
- Typical graph analysis tasks
```

Queries: Connection Subgraphs

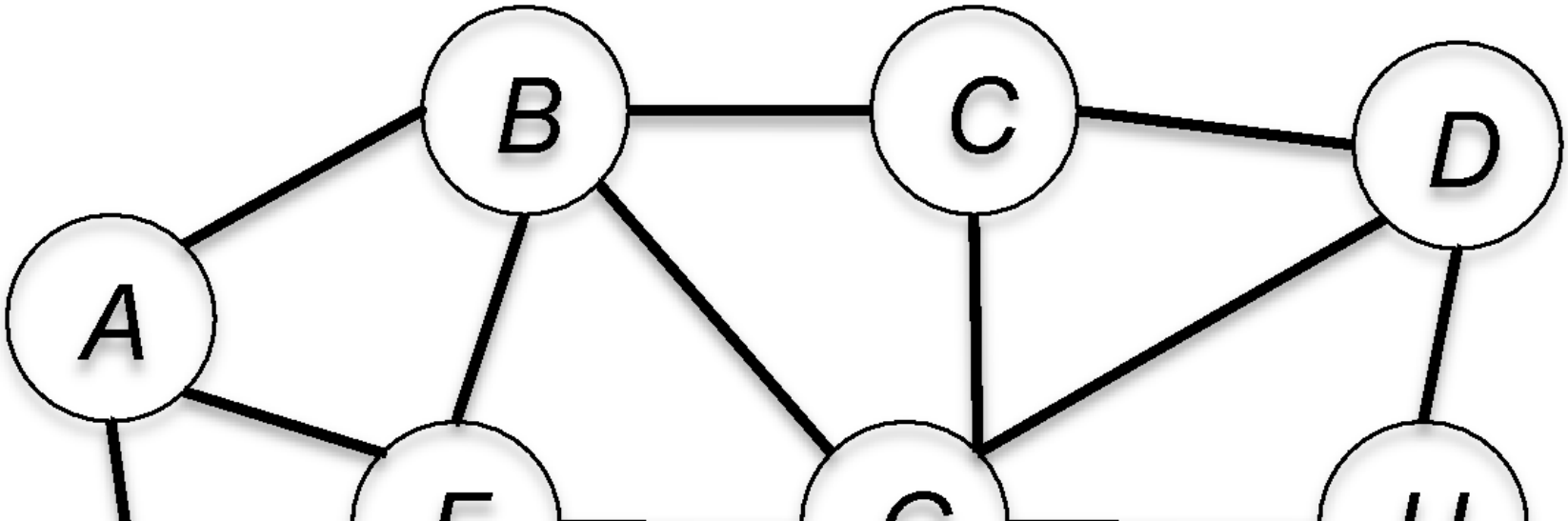
- Given a data graph and two (or more) nodes in it, find a small subgraph that best captures the relationship between the nodes
- How to define "best captures"?
  - E.g., "shortest path": but that may not be most informative



The "red" path between D and J maybe more informative than the "green" path

Graph Analysis: Centrality Measures

- Centrality measure: a measure of the relative importance of a vertex within a graph
- Many different definition of centrality measures
  - Can give fairly different results
- Degree centrality of a node
  - Number of edges incident on
- Betweenness centrality of a node
  - Number *of shortest paths between pairs of vertices that go through
- Page **R**ank of a node
  - *P*robability that a random surfer (who is following links randomly) ends up at node



Graph Analysis: Community Detection

- Goal: partitioning the vertices into (potentially overlapping) groups based on the interconnections between them
  - Basic intuition: More connections within a community than across communities
  - Provide insights into how networks function; identify functional modules; improve performance of Web services; etc.
- Numerous techniques proposed for community detection over the years
  - Graph partitioning-based methods
  - Maximizing some "goodness" function
  - Recursively removing high centrality edges
  - And so on ...

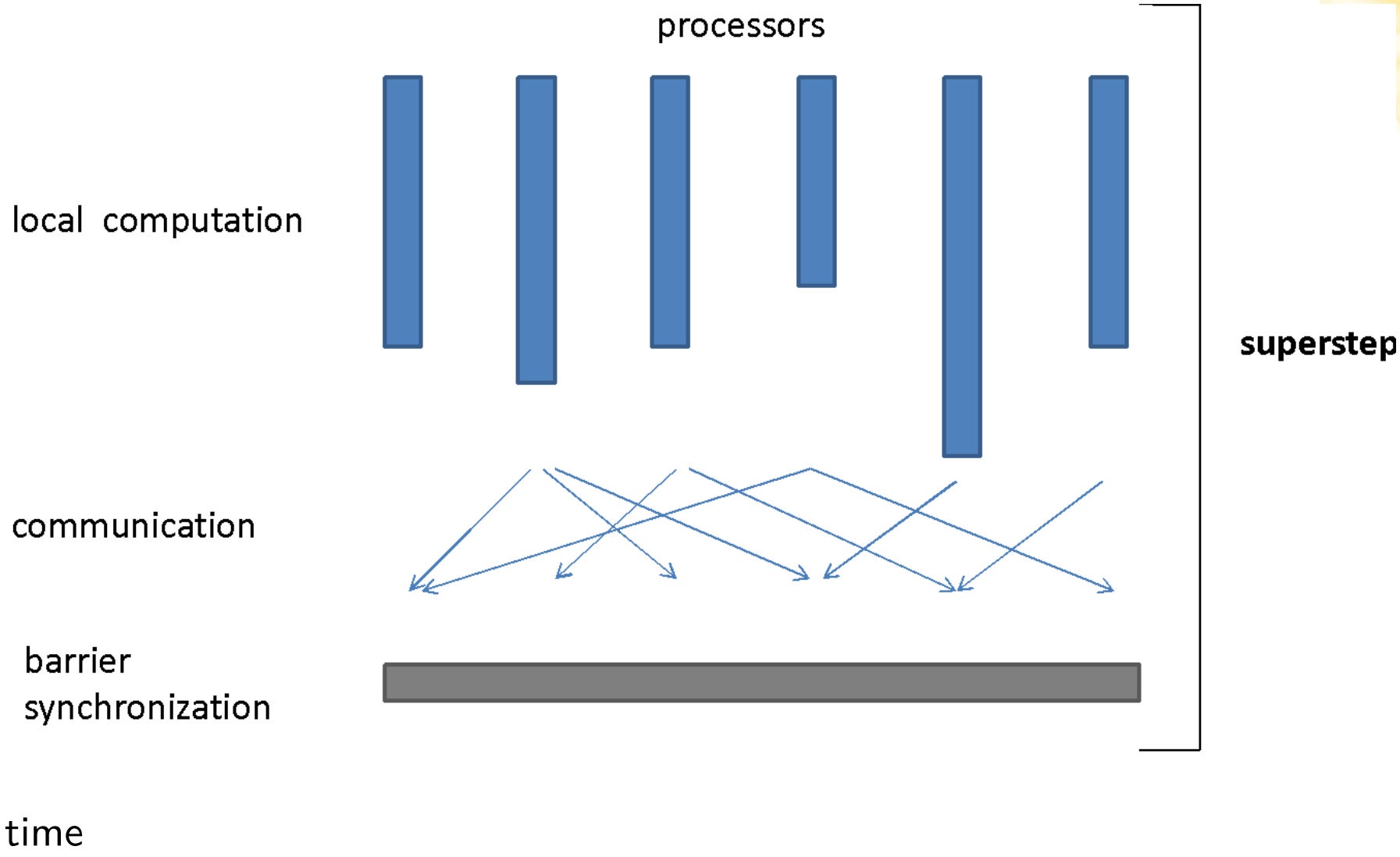
Overview

- Motivation
- Graph data models
- **Storing graph data**
- Querying graph data
- Typical graph analysis tasks
- **Executing graph analysis tasks**

Bulk Synchronous Parallel (BSP)

- BSP model is a computational model used to design parallel algorithms for distributed systems
- Computation is divided into a series of *supersteps*, each consisting of three main phases
  - **Local computation phase**
    - Each processing unit performs calculations independently and concurrently, without any interaction
  - **Communication phase**
    - The processing units exchange information with each other by sending and receiving messages
    - These messages can be exchanged asynchronously without waiting for a response
  - **Synchronization phase**
    - Aka barrier
    - Ensures that all processing units have completed their local computations and communication before proceeding to the next superstep
    - This guarantees that all messages from the previous superstep have been received and processed
- Suitable for iterative graph algorithms
  - E.g., PageRank and Shortest Path

Bulk Synchronous Parallel (BSP)



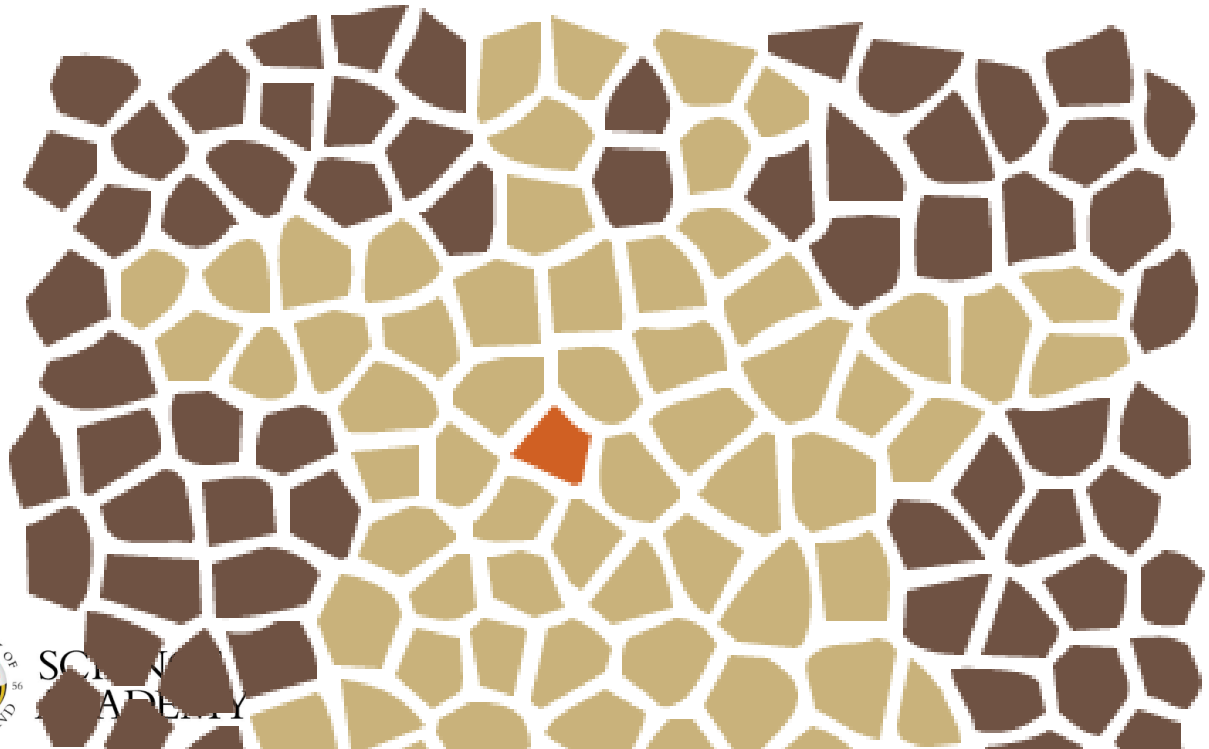
SCIENCE ACADEMY

Pregel System

- Large-scale graph processing system developed by Google
  - Pregel paper, 2010
- Inspired by the Bulk Synchronous Parallel (BSP) model
  - Vertex-centric programming model
  - Asynchronous message passing between vertices
- Fault-tolerant using checkpointing mechanism
- Scalable and distributed architecture
- Designed for processing large graphs with billions of vertices and edges
- Handles graph mutations and updates during computation
- Not open-source, used internally at Google

Apache Giraph

- Apache Giraph
- Open-source graph processing framework, inspired by Google's Pregel
- Implemented by Facebook and then open-sourced
- Built on top of Apache Hadoop
- Fault-tolerant using Hadoop checkpointing mechanism
- Scalable and distributed architecture
- Suitable for large-scale graph analytics and machine learning algorithms
- Actively maintained and widely adopted in the open-source community



Apache Spark GraphX

- Apache Spark GraphX
- Graph processing library for Apache Spark
- Built on top of Spark's RDD (Resilient Distributed Dataset) model
- Supports both directed and undirected graphs
- Provides a flexible graph computation API
- Optimized for iterative graph computations
- Scalable and fault-tolerant architecture
- Supports in-memory graph processing for improved performance
- Suitable for large-scale graph analytics and machine learning tasks
- Implements various graph algorithms
  - E.g., PageRank, Connected Components, and Shortest Path