Graph Databases Overview and Applications

By Rodger Lepinsky

University of Winnipeg
April 29, 2013

Overview

- Literature search from blogs, online articles, company websites, videos, twitter
- Private research
- Only a little in the academic realm
- Originally intended to approach companies.

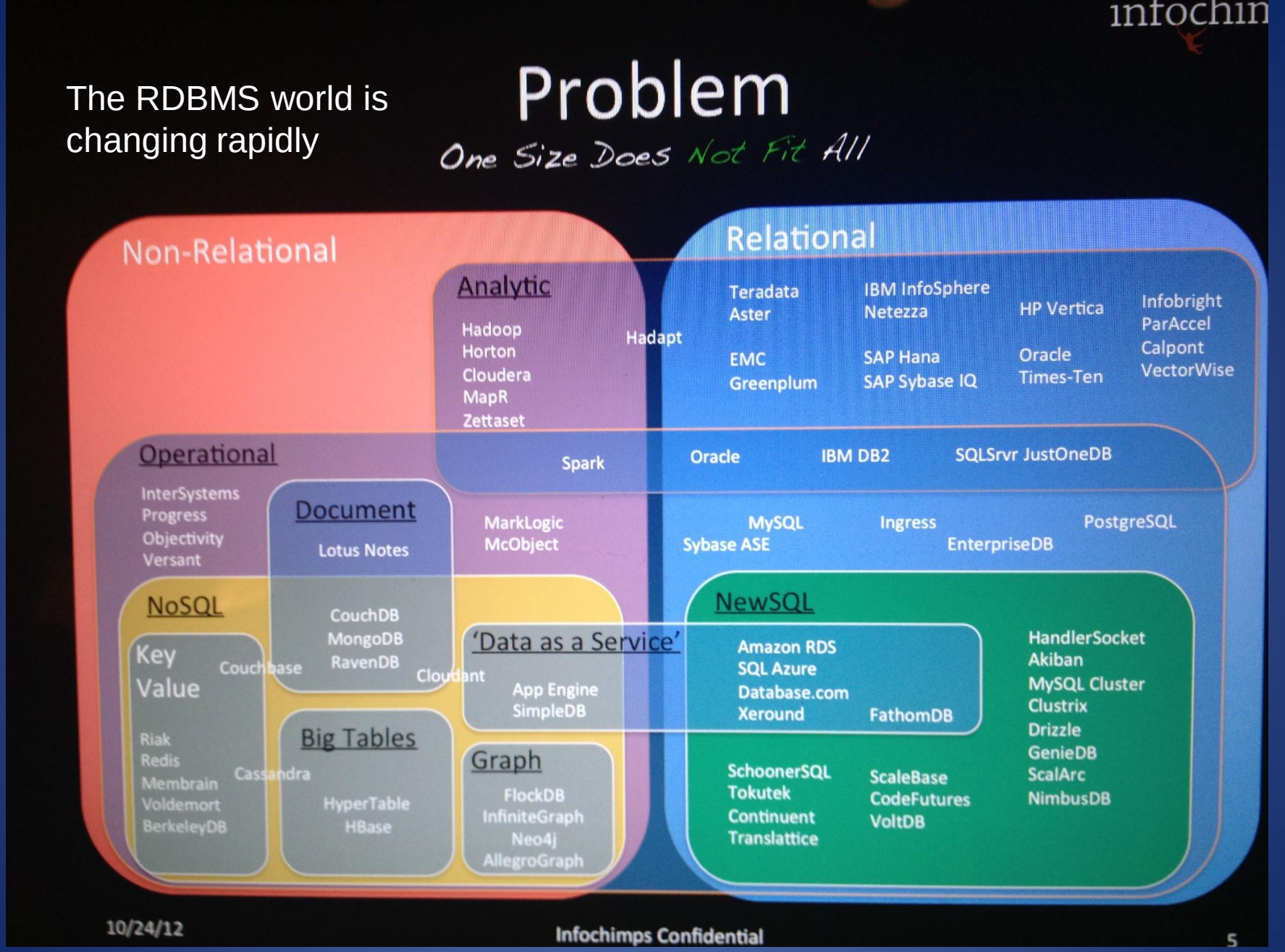
Rodger Lepinsky – Formal Training

- Bachelor of Commerce (Honours)
  - Asper - University of Manitoba
- Bachelor of Applied Computer Science
  - University of Winnipeg
- Passed Chartered Financial Analyst (CFA) Level 1 exam (pass rate: 33% to 40%)

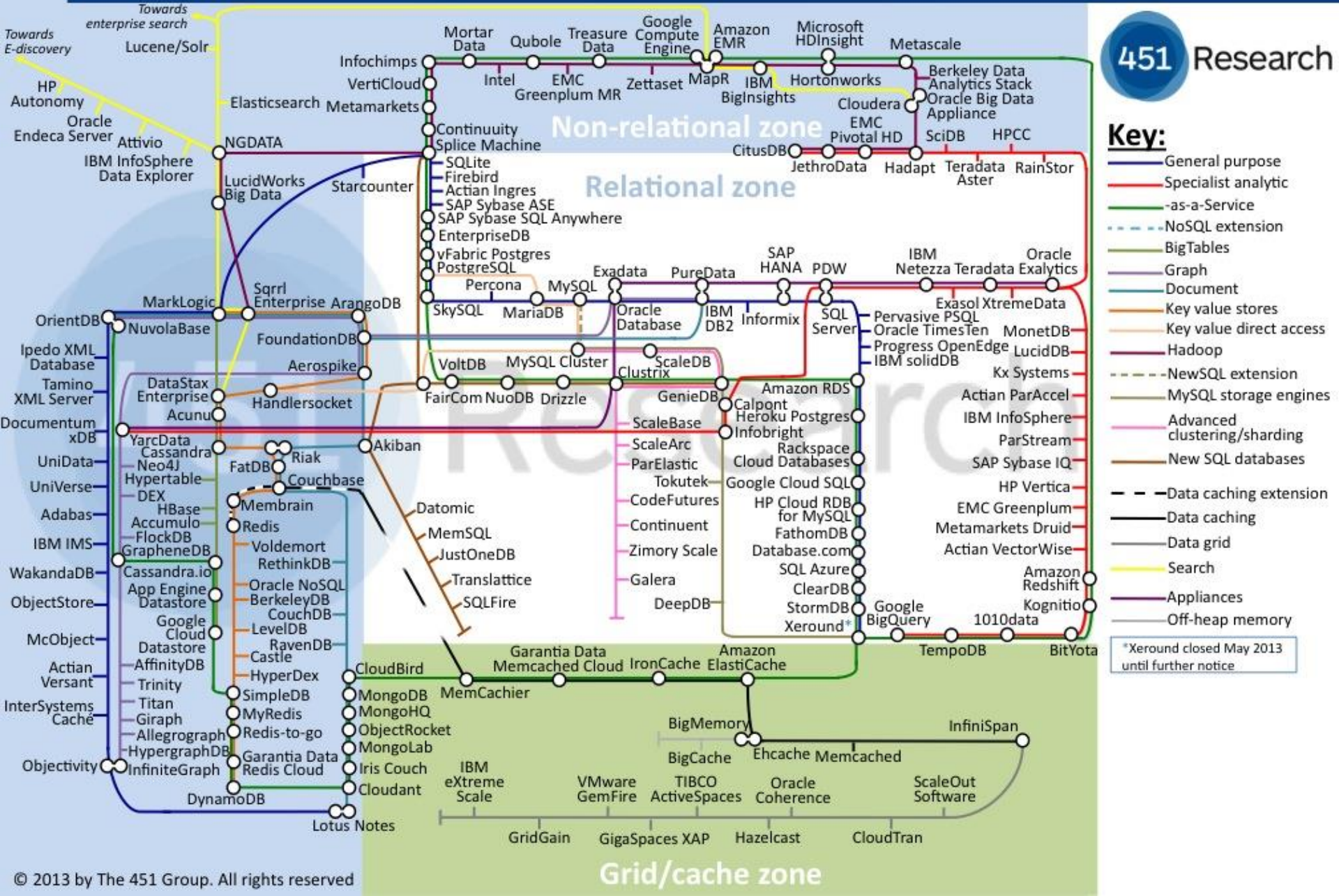
Rodger Lepinsky – RDBMS

- RDBMS Expert
- DB Architecture, Design, Development, Warehousing, Tuning, DB Administration
- Working with databases since 1992
- With enterprise Oracle, SQL Server, Sybase databases since 1995
- Oracle User Groups Presentations:
  - High Speed Database Tuning
  - Cartesian products
- Technical Blog: rodgersnotes.Wordpress.com
- Twitter: @rodgernotes

The RDBMS world is changing rapidly



Database Landscape Map – June 2013



Big Data

Volume, velocity, variety of data

Often machine generated:

Internet logs/analytics

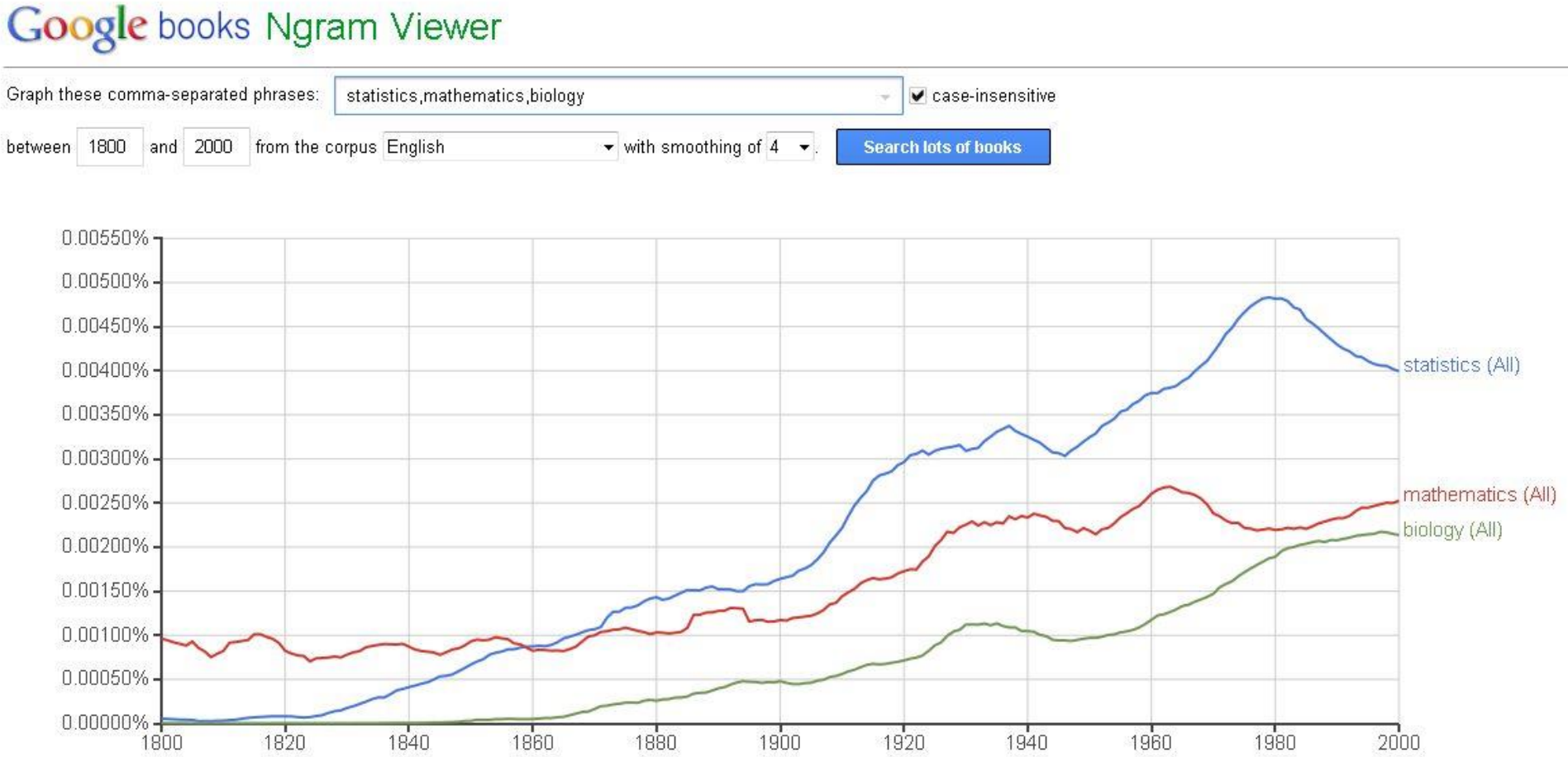
Sensors in machines like modern jets

Online gaming companies: ½ terabyte of new data, daily

Google's Paper – IEEE 2009

- The Unreasonable Effectiveness of Data: Alon Halevy, Peter Norvig, and Fernando Pereira
- "simple models and a lot of data trump more elaborate models based on less data."
- "simple n-gram models or linear classifiers based on millions of specific features perform better than elaborate models that try to discover general rules."

Big Data - Google Ngram



"each *n*-gram sequence from a corpus of billions or trillions of words"

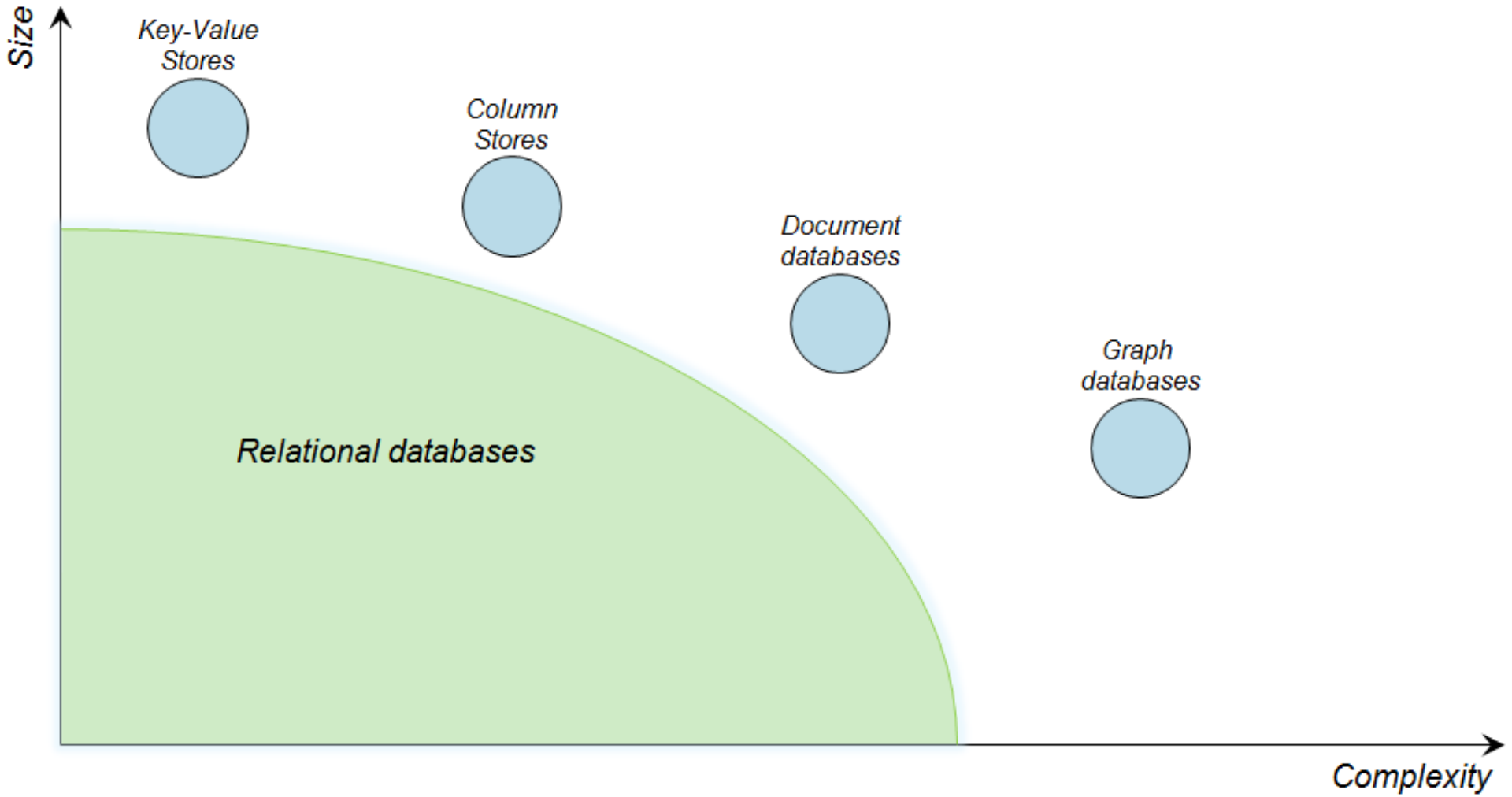
Big Data, NOSQL Databases

- NOSQL: Not Only SQL
- Also called New SQL

- Four main types of NOSQL Databases:

- Key Value
- Column
- Document
- Graph Database

NOSQL DB Compared



NOSQL DB – Key Value

- Works like a simple hashtable
- Tools: Memcached, Amazon's Dynamo, Project Voldemort, Riak, Redis
- Twitter, StackOverFlow, Instagram, Youtube, Wikipedia
- Use: Store user information, like Session, Profiles, Preferences, Shopping Cart
- Drawback: Can't query by value. No relationships. No rollbacks.

NOSQL – Column Databases

- Store data in column families. Ie. Person is usually queried by name or id, not salary.
- Tools: Cassandra, Hbase
- Ebay, Instagram, NASA, Twitter, Facebook, Yahoo
- Use: Logging, and Blogging. Tags, categories, posts in different column families.
- Drawback: No ACID transactions
- (Column databases are used in data warehouses)

http://pauloortins.com/nosql-databases-why-we-should-use-and-which-one-we-should-choose/

NOSQL – Document Databases

- Store data as documents using XML, JSON or JSONB
- Tools: MongoDB, CouchDB, RavenDB
- SAP, Codecademy, Foursquare, NBC News

- Use: No fixed schema. Store different info.
- Drawback: Does not support transactions between documents

NOSQL – Graph Databases

- Store data as graphs, not rows and columns.
- Tools: Neo4J, Infinite Graph, OrientDB
- Linked In, Facebook, Google, NSA
- Use: with data that is connected.
- Not all data can be modeled in graph. Ie. Spreadsheets rows and columns are better in RDBMS.

http://pauloortins.com/nosql-databases-why-we-should-use-and-which-one-we-should-choose/

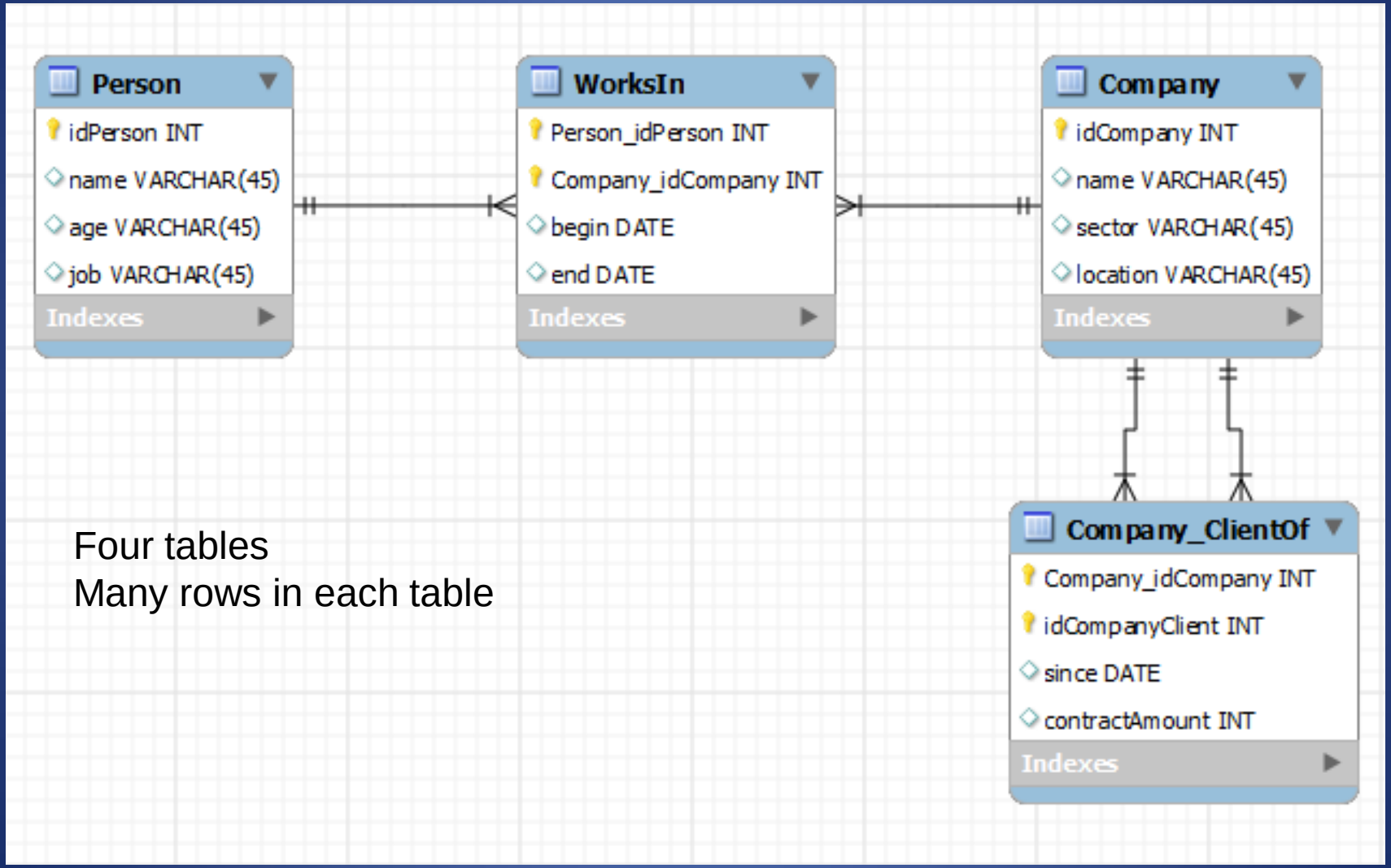
RDBMS Data Structure

- Rows and columns, like a spreadsheet
- Rows added/deleted, and columns updated frequently
- Table structures never change without a conscious decision
- Unlike programs, Relational DB Design is rarely refined

- Result: Awful DB designs are put into production, and huge amounts of code required to make them work.

- See: DB Design Mistakes To Avoid by Lepinsky

RDBMS Data Model

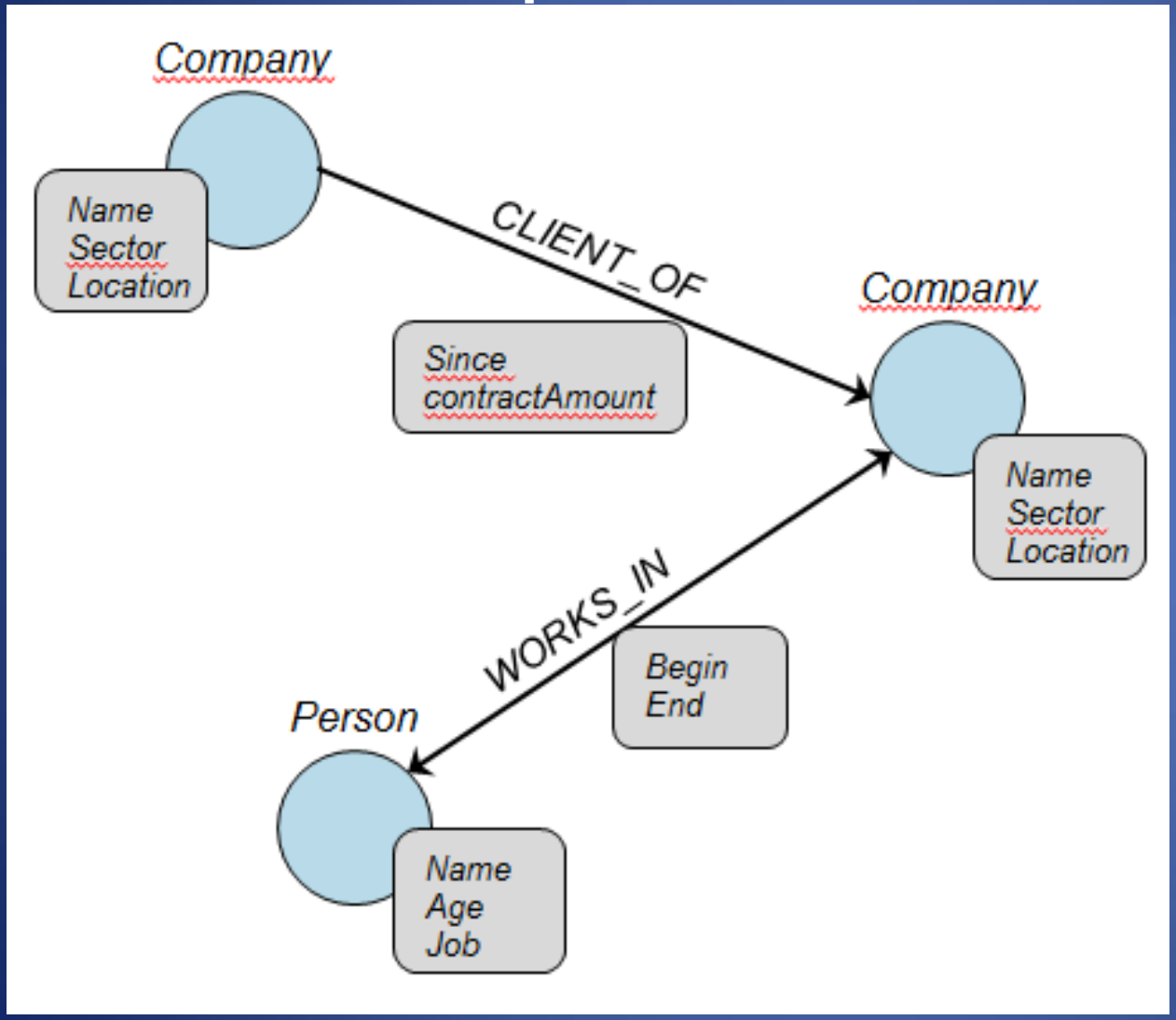


Four tables
Many rows in each table

Graph DB Data Structure

- Nodes/Vertices, and Edges
- Adding or modifying Nodes or Edges changes the structure
- Structure constantly changing, as nodes and edges are inserted and updated.

Graph DB Data Model



Each row becomes a node

Many nodes

Rows in M:N tables become an edge between nodes

New nodes can be inserted at will
Ie. News events

http://blog.octo.com/en/graph-databases-an-overview/

RDBMS vs Graph

- RDBMS:
- Good fit for static data structures, that do not change much
- Ubiquitous in business.

- Graph:
- Good for semi- or un-structured data
- Fits complex and dynamic data better
- Assumption: the relationships are as important as the records

http://www.zdnet.com/facebook-neo4j-7000009866/

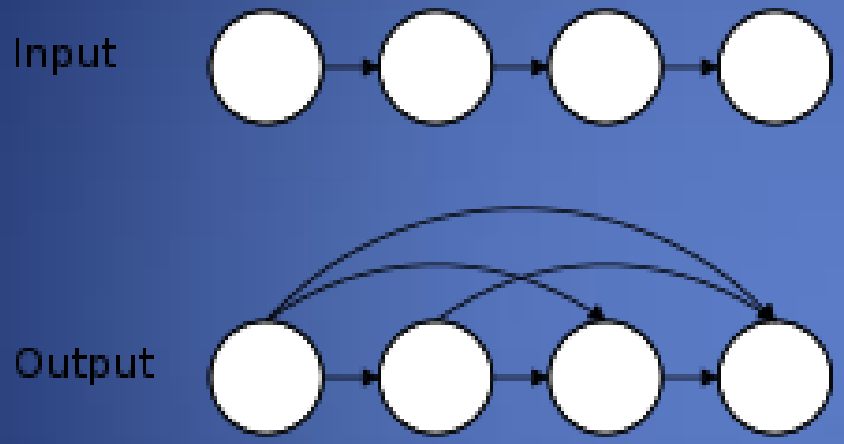
RDBMS vs Graph

- RDBMS:
- Join and query multiple tables to see relationship
- Retrieve rows and columns

- Graph:
- Query nodes and edges
- Edges are the relationship
- Relationship (edge) is labelled
- Queries can return edges only

http://www.zdnet.com/facebook-neo4j-7000009866/

Transitive Closure

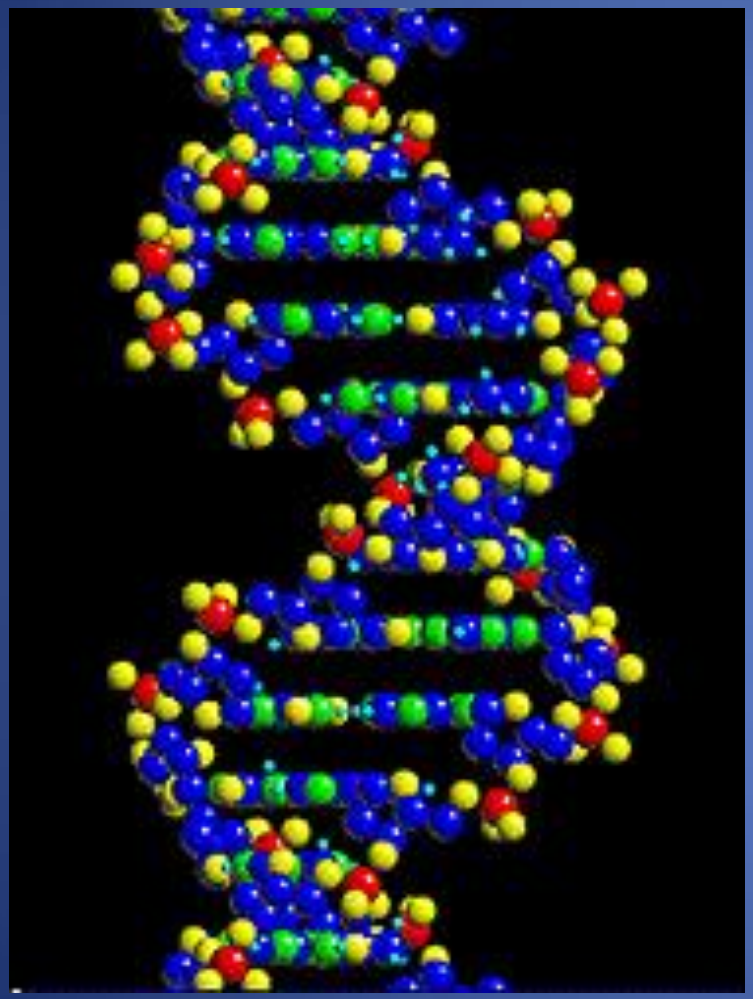


Lorenzo Alberton :

SQL has historically been unable to express recursive functions needed to maintain the transitive closure of a graph without an auxiliary table.

http://techportal.inviqa.com/2009/09/07/graphs-in-the-database-sql-meets-social-networks
https://en.wikipedia.org/wiki/Transitive_closure

BIOIT Problem



2003 – BIOIT conference

How to model (DNA) molecules in RDBMS?

http://www.nasa.gov/audience/foreducators/postsecondary/features/F_Space_Radiation_Project_prt.htm

Tree Structures

- Difficult to do represent or use in RDBMS
- Easy in Graph DB

- Lorenzo Alberton: Trees In The Database, Attempts to represent trees in RDBMS/SQL.
- 128 slides, but still no simple or complete solution.

My First Graph Problem

- DBA_Objects are created in a tree structure.
- Type, used in a table, used in a view, view used by multiple procedures.
- You can have a single procedure, reading 15 tables: pyramid
- Can have one table, Customer, or Error_Log, used by many procedures: inverted pyramid.
- What's the order of operations to build the objects?
- N factorial?

DBA_Objects

- Oracle's DBA_Dependencies only refers one level up, or down.
- Many recursive reads required to see the whole structure, and correct order of operations.
- SQL output: more like directory structure.
- Ultimate problem: SQL output is in rows and columns. But object structure is actually a tree.
- Software to solve problem by Yuri Slutsky:
- http://www.samtrest.com/

DBA_Objects

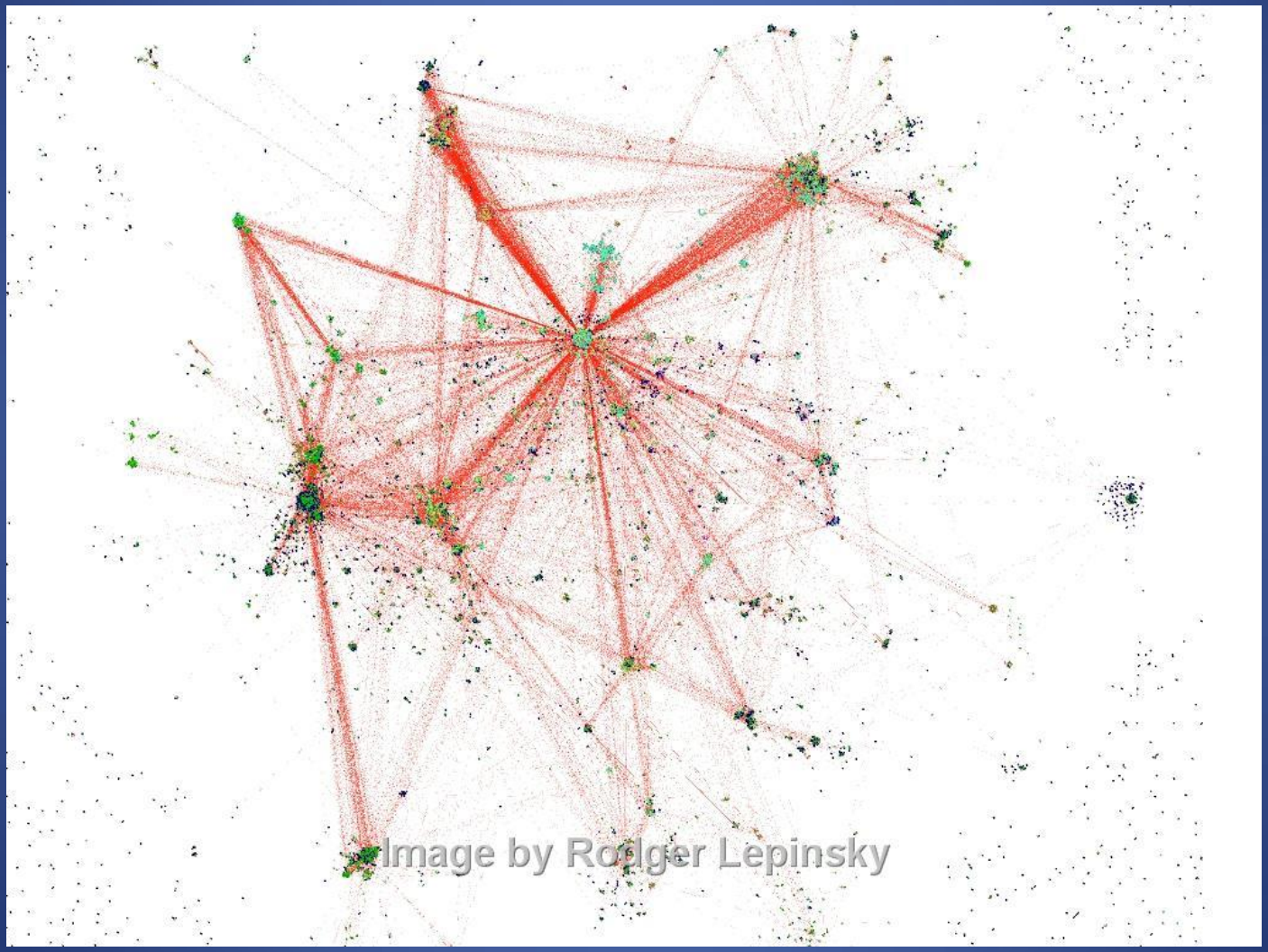
- SQL output: single object found in multiple places and branches in the output. No clear order of operations.

```
OBJECT_LVL_OBJID_ROWNUM
-----------------------------------------------------------
  PACKAGE BODY  APPS.HR_DELETE   1   278801   1
  PACKAGE BODY  APPS.HR_DELETE   1   278801   2
  PACKAGE BODY  APPS.HR_DELETE   1   278801   3
    SYNONYM  PUBLIC.USER_CATALOG   2   1167   4
      VIEW  SYS.USER_CATALOG   3   1166   5
      VIEW  SYS.USER_CATALOG   3   1166   6
        VIEW  SYS._CURRENT_EDITION_OBJ   4   3270113   7
        VIEW  SYS._CURRENT_EDITION_OBJ   4   3270113   8
  PACKAGE BODY  APPS.HR_DELETE   1   278801   9
    SYNONYM  PUBLIC.DBMS_SQL   2   2328   10
      PACKAGE  SYS.DBMS_SQL   3   2327   11
      PACKAGE  SYS.DBMS_SQL   3   2327   12
      PACKAGE  SYS.DBMS_SQL   3   2327   13
        PACKAGE  SYS.UTL_IDENT   4   3291213   14
```

DBA_OBJECTS as a Graph (Subset)

http://rodgersnotes.wordpress.com/2013/07/31/dba_objects-tree-modelled-as-a-graph/

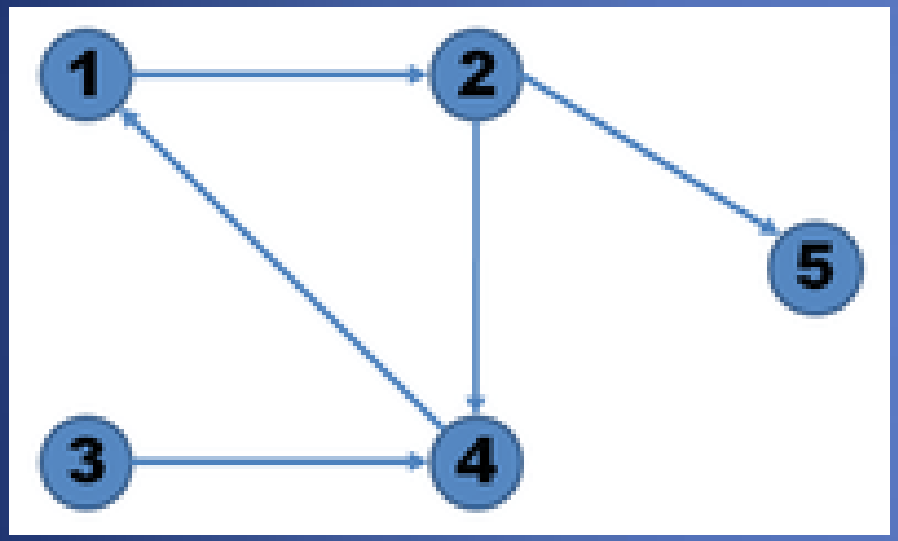
DBA_OBJECTS as a Graph (Gephi)



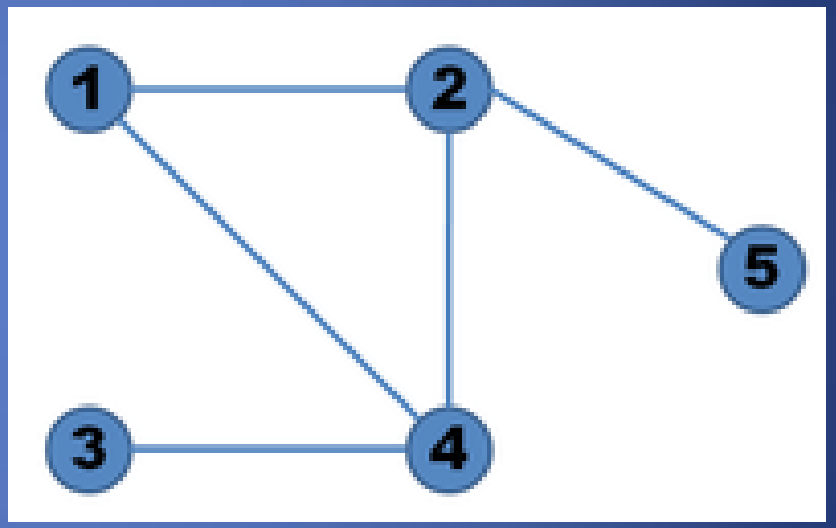
http://rodgersnotes.wordpress.com/2013/08/06/visualizing-fifty-thousand-dba_objects/

Graph Structures

Directed



Undirected



http://techportal.inviqa.com/2009/09/07/graphs-in-the-database-sql-meets-social-networks/

Applications For Graphs

- Where the data model is connected:
- social
- telecommunications
- logistics
- master data management
- bioinformatics
- fraud detection

Applications For Graphs

- Data Connections and complex interrelationships:

- network management
- content management
- property and asset management
- relationship management (CRM, ERM),
- Not only does an association between nodes state that a relationship exists, but also describes how.
-
- Most of the data inside of the enterprise is very complex: Key/value stores may not work.

Applications For Graphs

- Aggregate data stores (key-value, column, document db) - solve problems related to atomic intelligence

- Graph databases - leverage connected intelligence

Application For Graphs

- social networking
- logistics networks (for package routing)
- financial transaction graphs (for detecting fraud)
- telecommunications networks
- ad optimization
- recommendation engines
- bioinformatics

Application For Graphs

- Social
- Recommendations
- Geo
- Logistics Networks: for package routing, finding shortest Path
- Financial Transaction Graphs: for fraud detection
- Master Data Management
- Bioinformatics: Era7 to relate complex web of information that includes genes, proteins and enzymes
- Authorization and Access Control: Adobe Creative Cloud, Telenor

Applications For Graphs

- friend-of-friend
- shortest path
- Gartner: “five richest big data sources on the Web:”
- social graph
- intent graph
- consumption graph
- interest graph
- mobile graph

Organizations Using Graph Databases

- Facebook
- Linked In
- Google
- Cisco
- Mozilla (Firefox)
- T-Mobile
- NSA – US National Security Agency

Social Network Analysis

- Facebook became one of the most prominent technology companies in the world by understanding that the relationships connecting people are just as important as the people themselves.

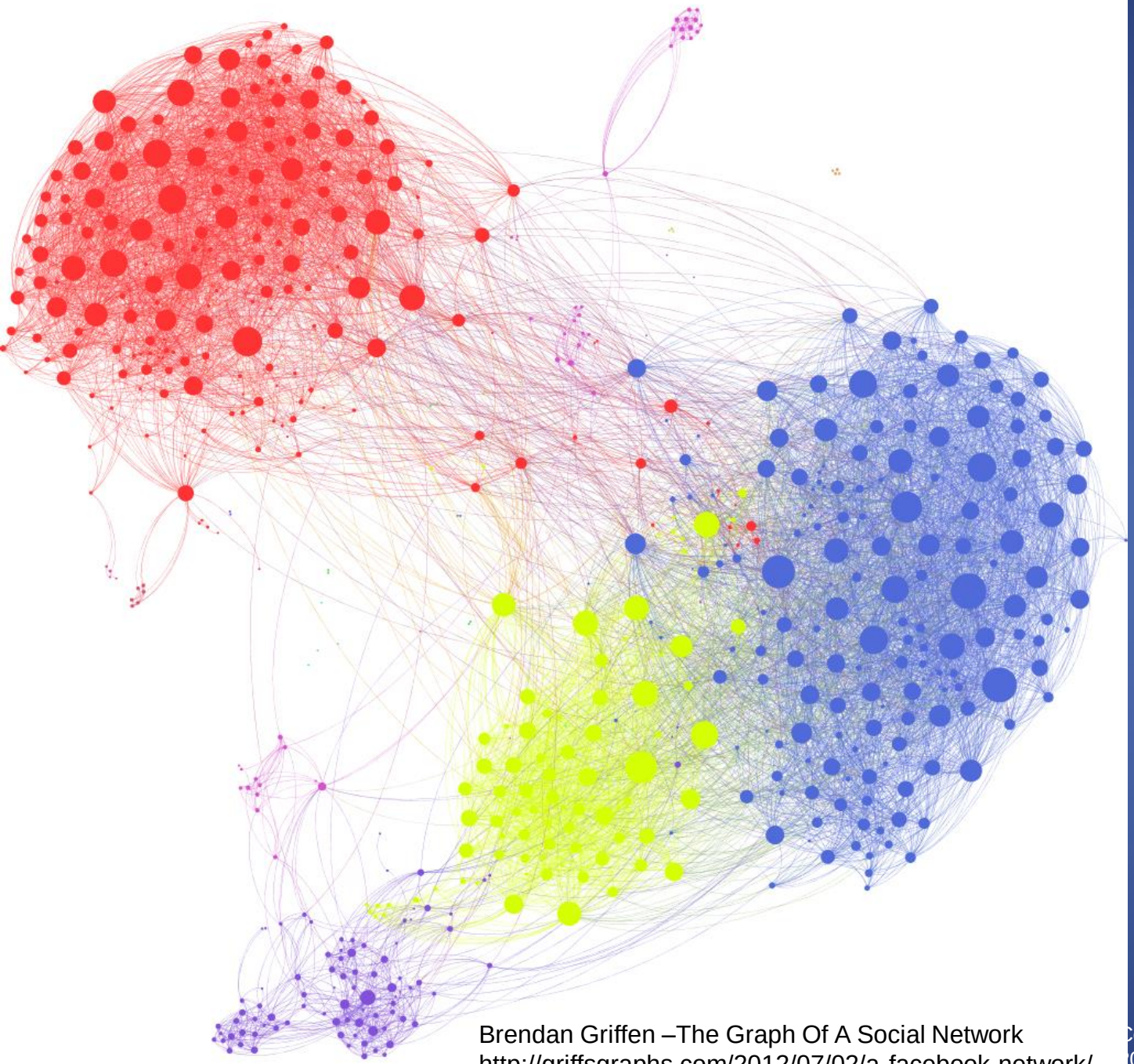
- Linked IN: Relationships matter

Facebook

- Facebook's Graph Search feature contains billions of nodes and trillions of edges (understood to be in the low trillions)

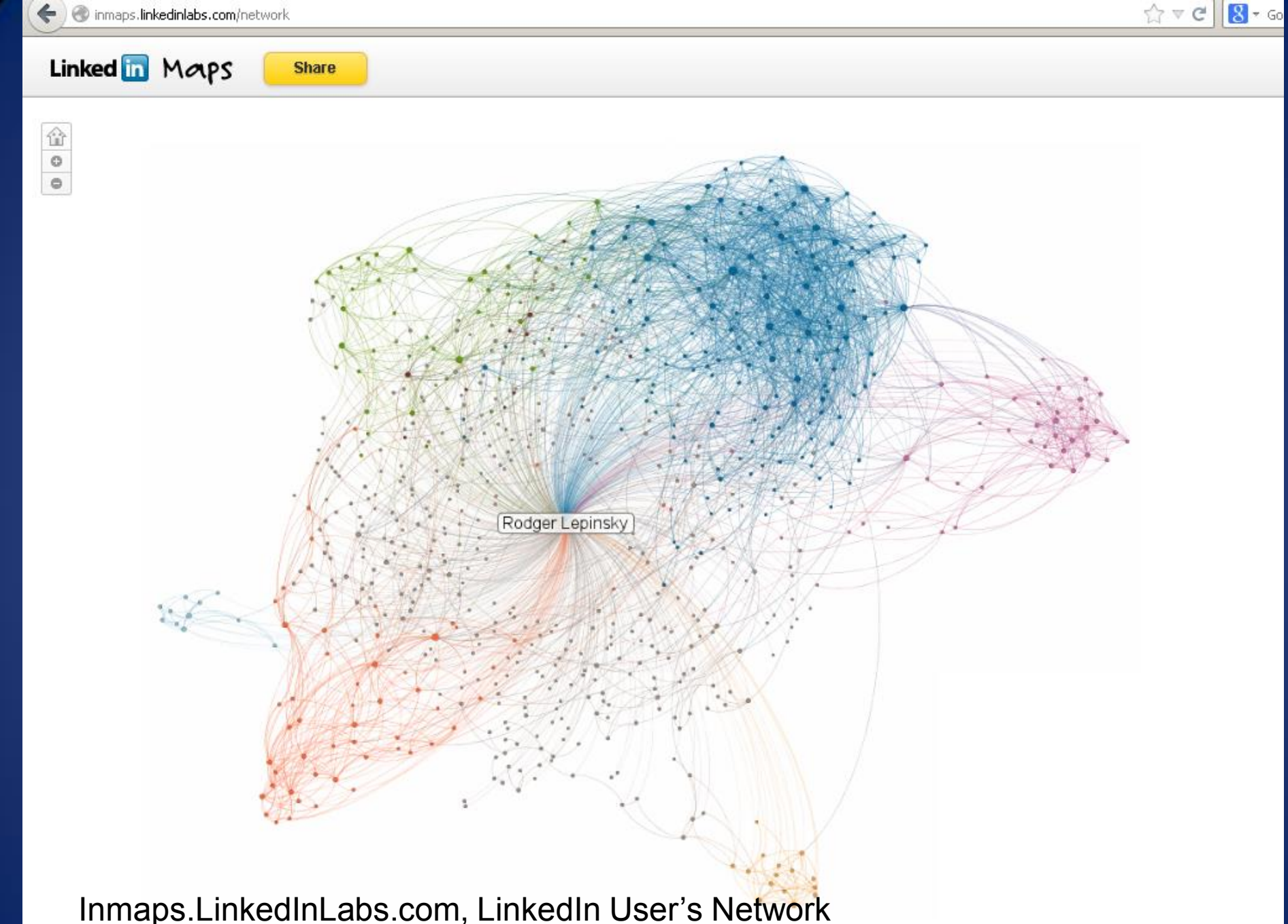
- Facebook users are generating more than 500 terabytes of new data every day.

http://gigaom.com/2013/06/06/heres-how-the-nsa-analyzes-all-that-call-data/
http://gigaom.com/2013/06/07/under-the-covers-of-the-nsas-big-data-effort/



Facebook User's Network of Connections

Brendan Griffen –The Graph Of A Social Network
http://griffsgraphs.com/2012/07/02/a-facebook-network/



Inmaps.LinkedInLabs.com, LinkedIn User's Network

Social Network Research Study

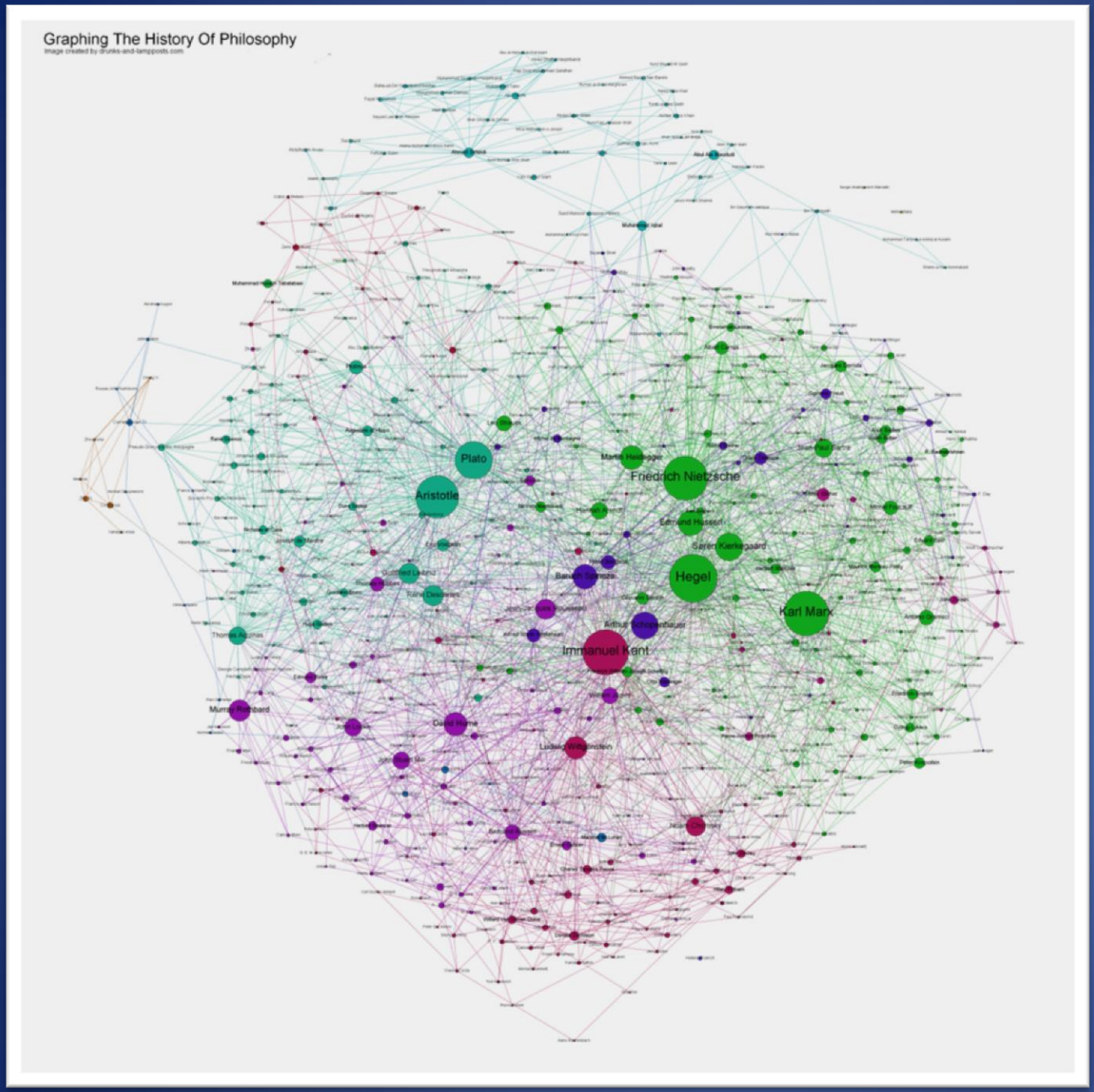
- Leskovic and Horvitz - 2008

- Analyzed Whole of Microsoft Messenger System
- 30 billion conversations
- 240 million people
- Mean: 125 conversations per person

Social Network Research Study

- Social network
- 180 million nodes
- 1.3 billion undirected edges
- Graph is well connected and robust to node removal

- Average path length among messenger users: 6.6
- "Six degrees of separation"



Use Case:

History of philosophy

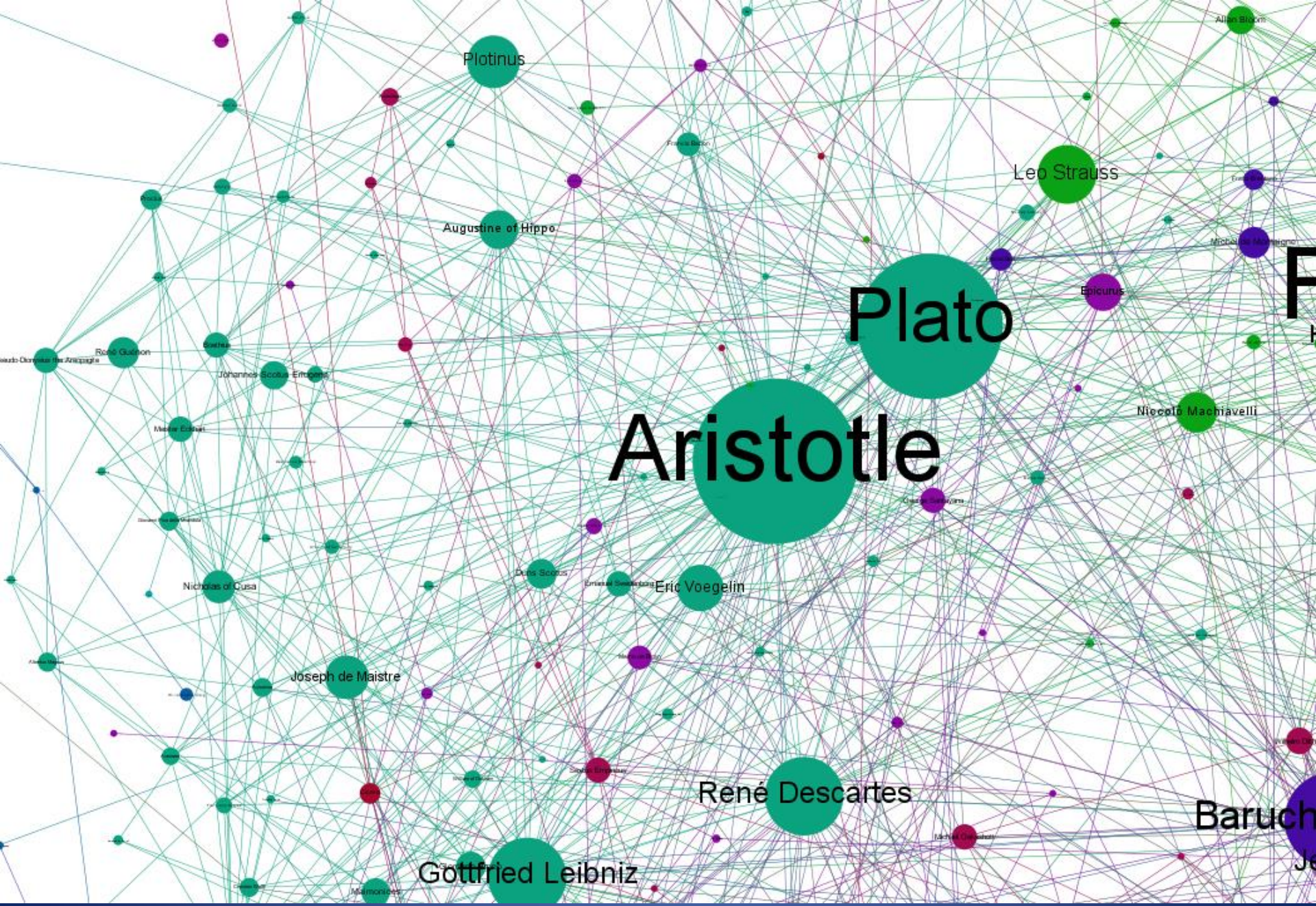
Each philosopher is a node in the network.

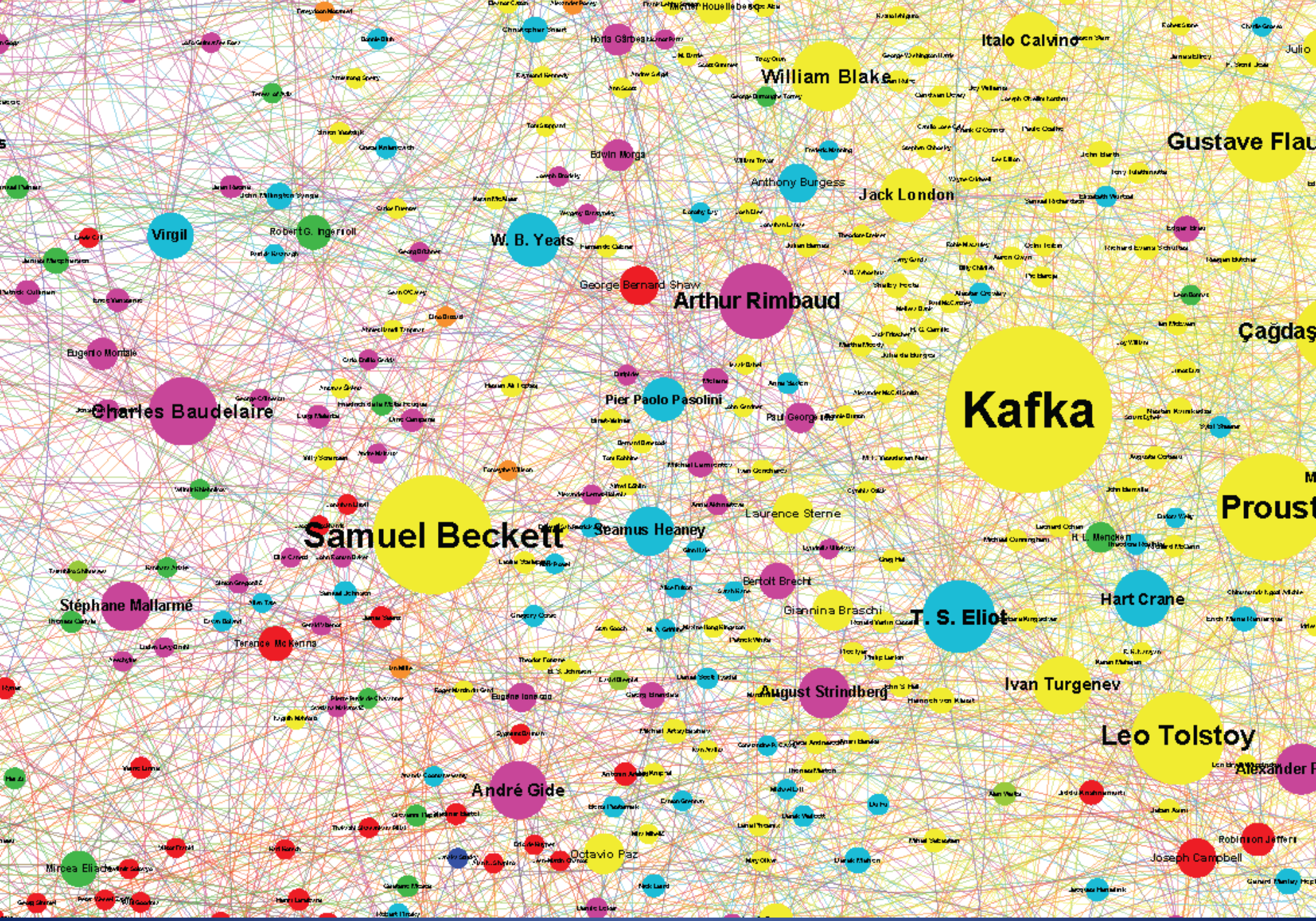
Edges represents lines of influence.

SPARQL - language to query the semantic web

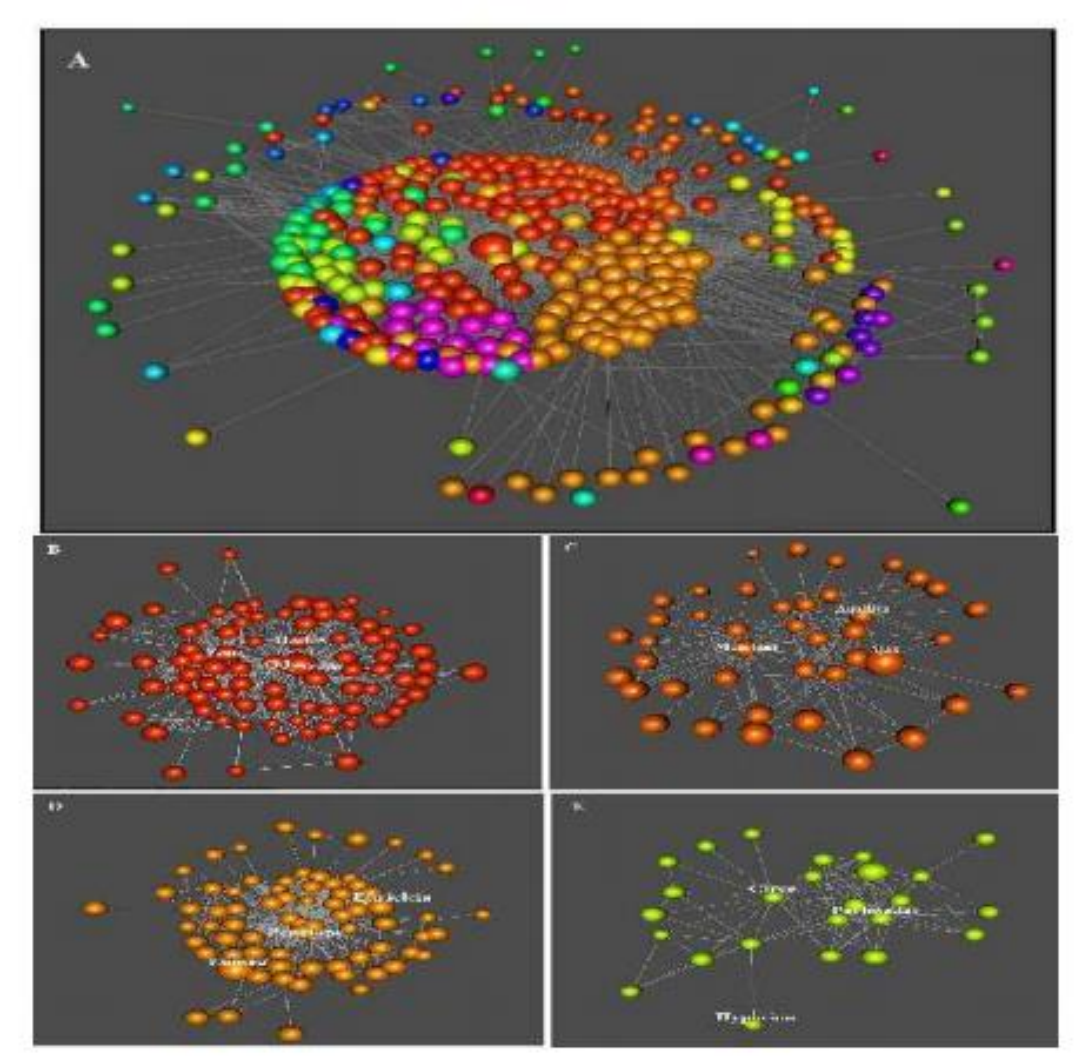
Queries information that is structured in triples subject-relationship-object

Simon Rapier - Graphing the history of philosophy
http://drunks-and-lampposts.com/2012/06/13/graphing-the-history-of-philosophy/





Social Network of Homer

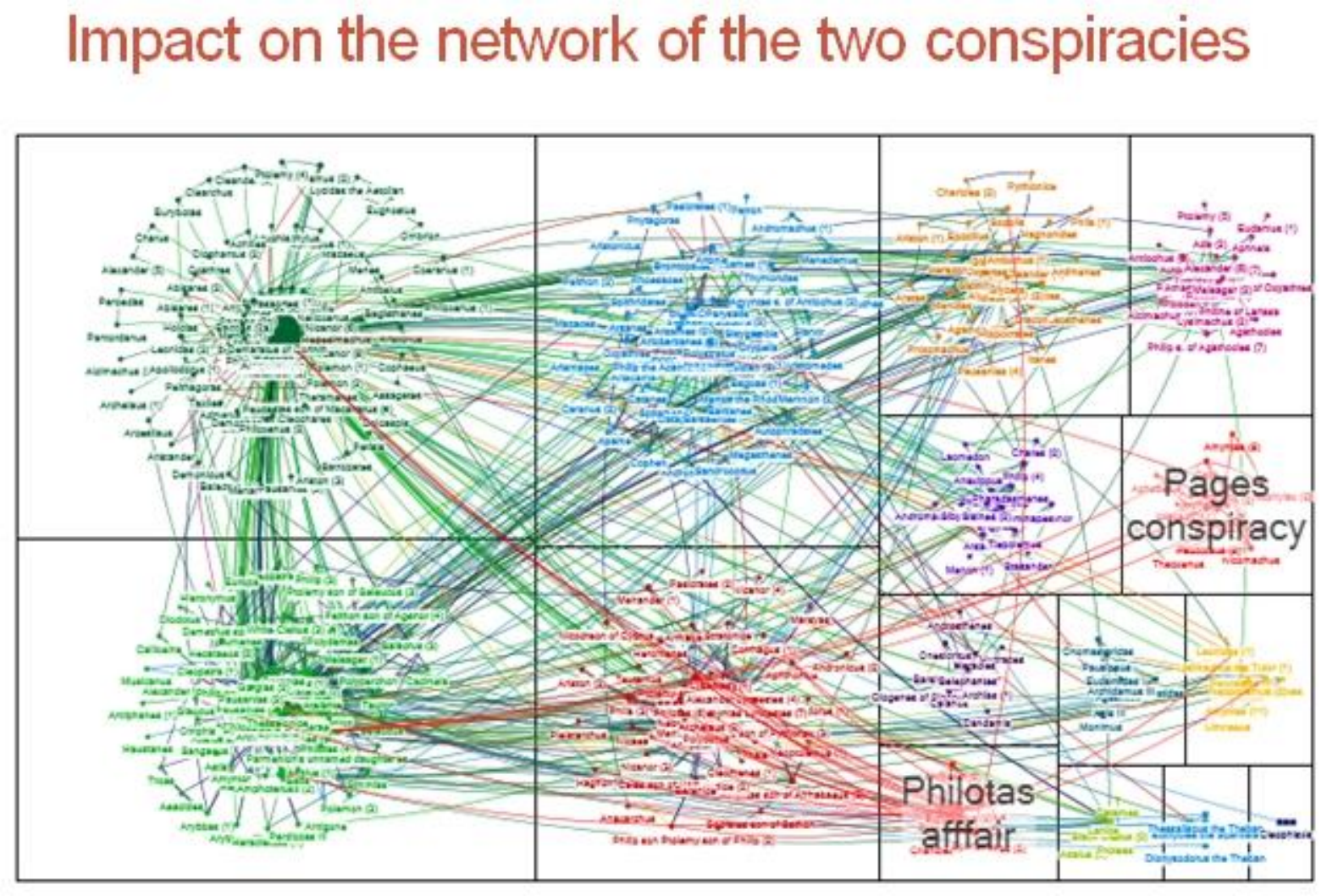


The social network between characters in Homer's Odyssey is remarkably similar to real social networks today.

Suggests the story is based, at least in part, on real events

http://www.technologyreview.com/view/516081/the-remarkable-properties-of-mythological-social-networks/

Social Network of Alexander The Great

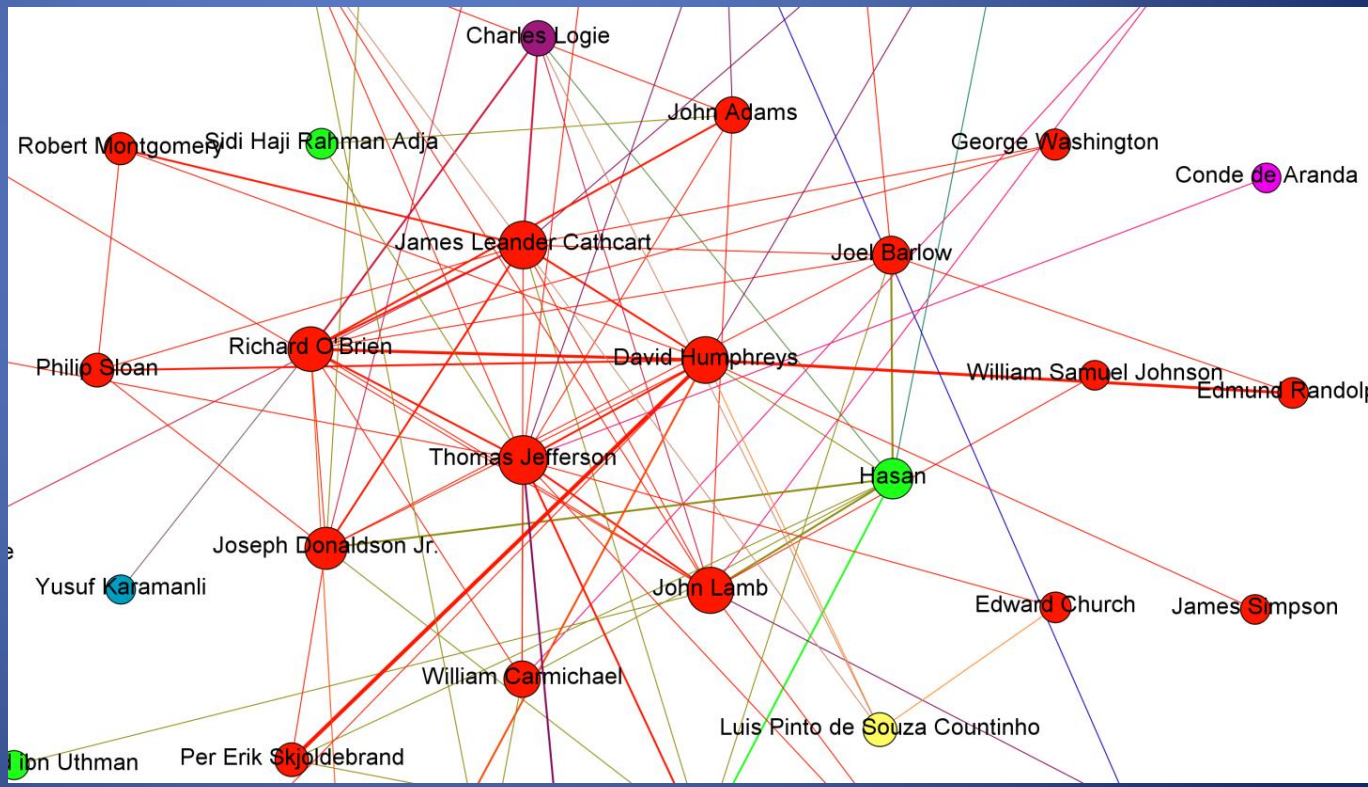


http://www.academia.edu/2153390/The_Social_network_of_Alexander_the_Great_Social_Network_Analysis_in_Ancient_History
Diane H. Cline, Ph.D. University of Cincinnati

World Events

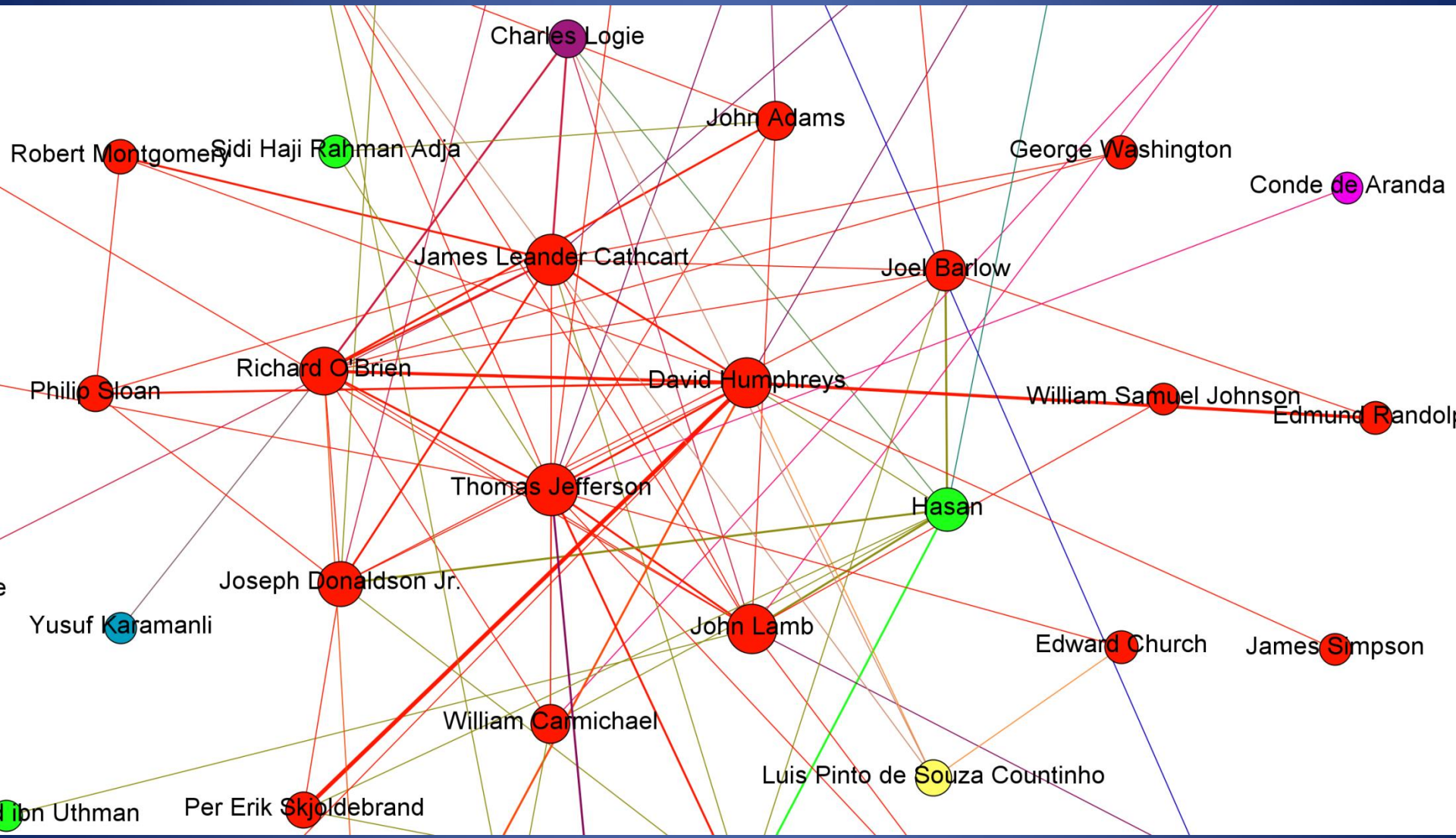
- US diplomatic relations with Algiers
- Network of parties involved
- 1785 to 1800

- Green: Algiers
- Red: United States
- Purple: England
- Light blue: Tripoli
- Darker blue: France
- Light purple: Spain
- Yellow: Portugal
- Orange: Sweden



A Graph of Diplomatic Wrangling in Algiers
http://abbymullen.org/a-graph-of-diplomatic-wrangling-in-algiers/

World Events

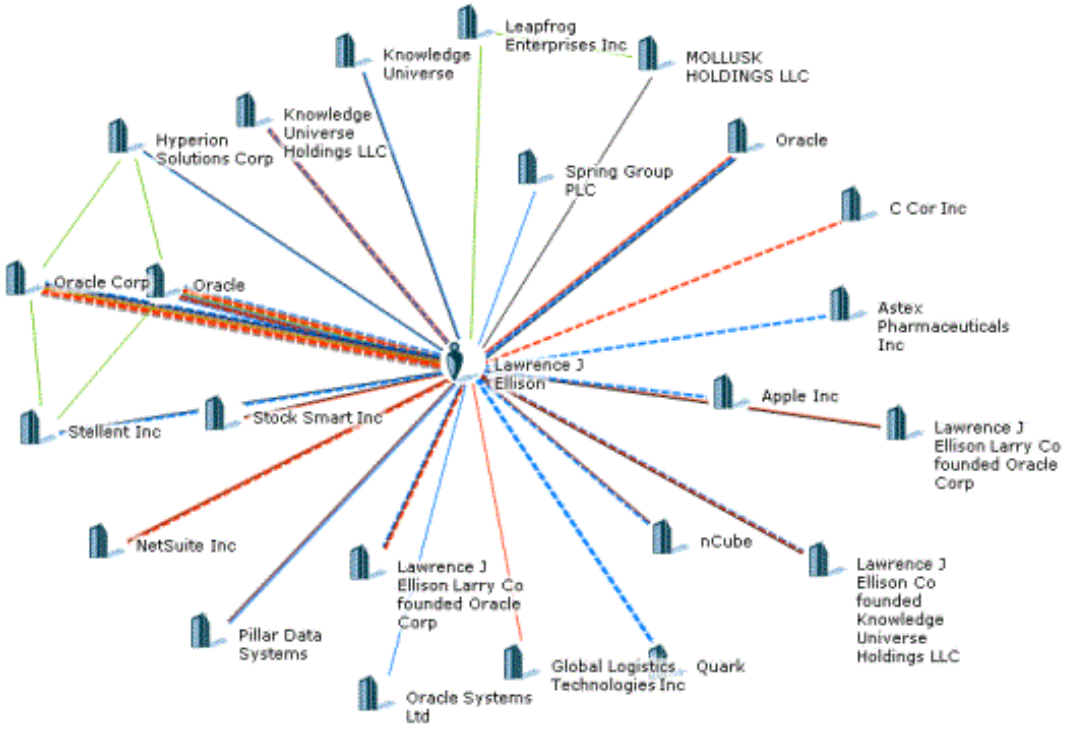


MarketVisual

My

Lawrence J Ellison

Lawrence J Ellison



Company Affiliations

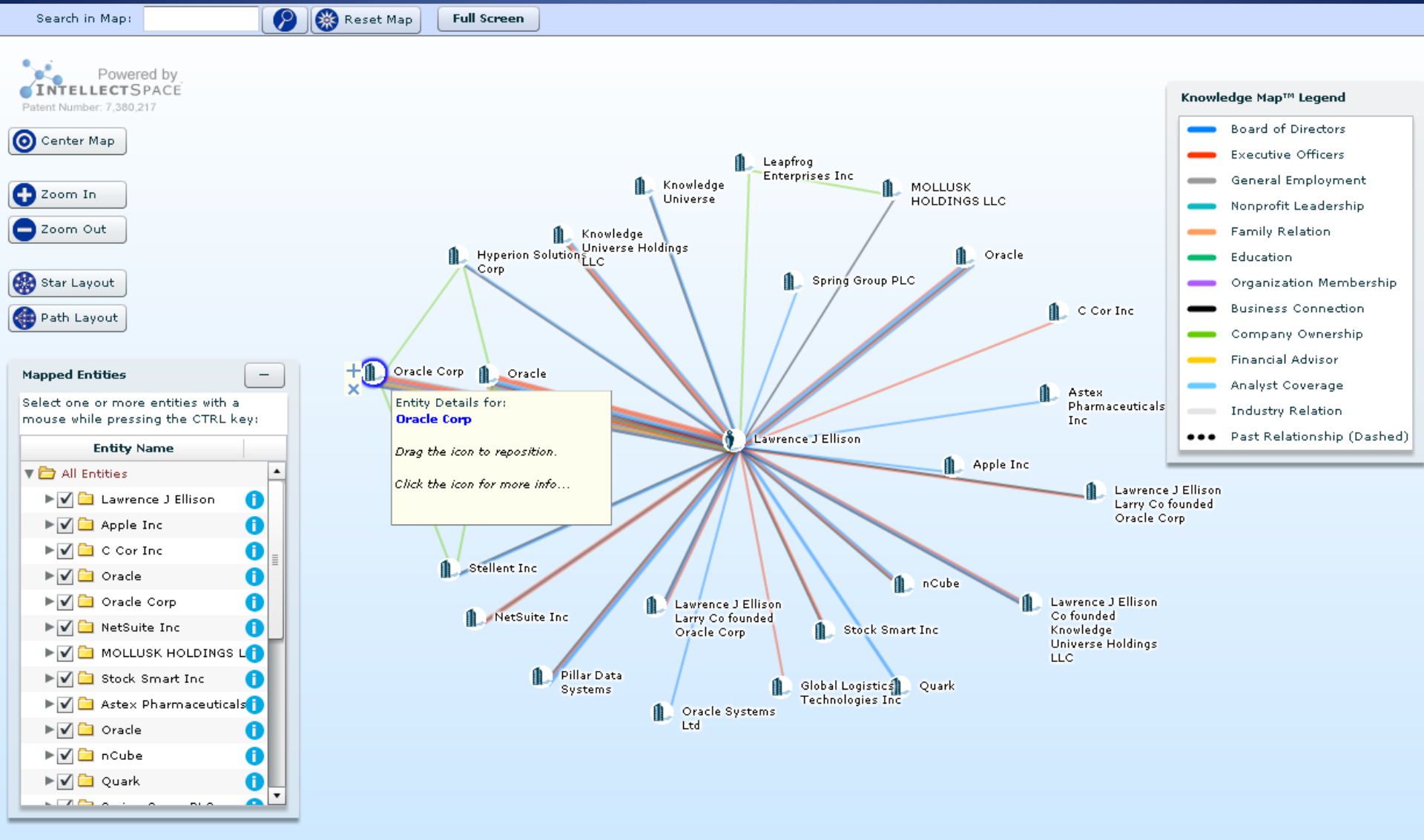
Current Affiliations

Marketing Intelligence

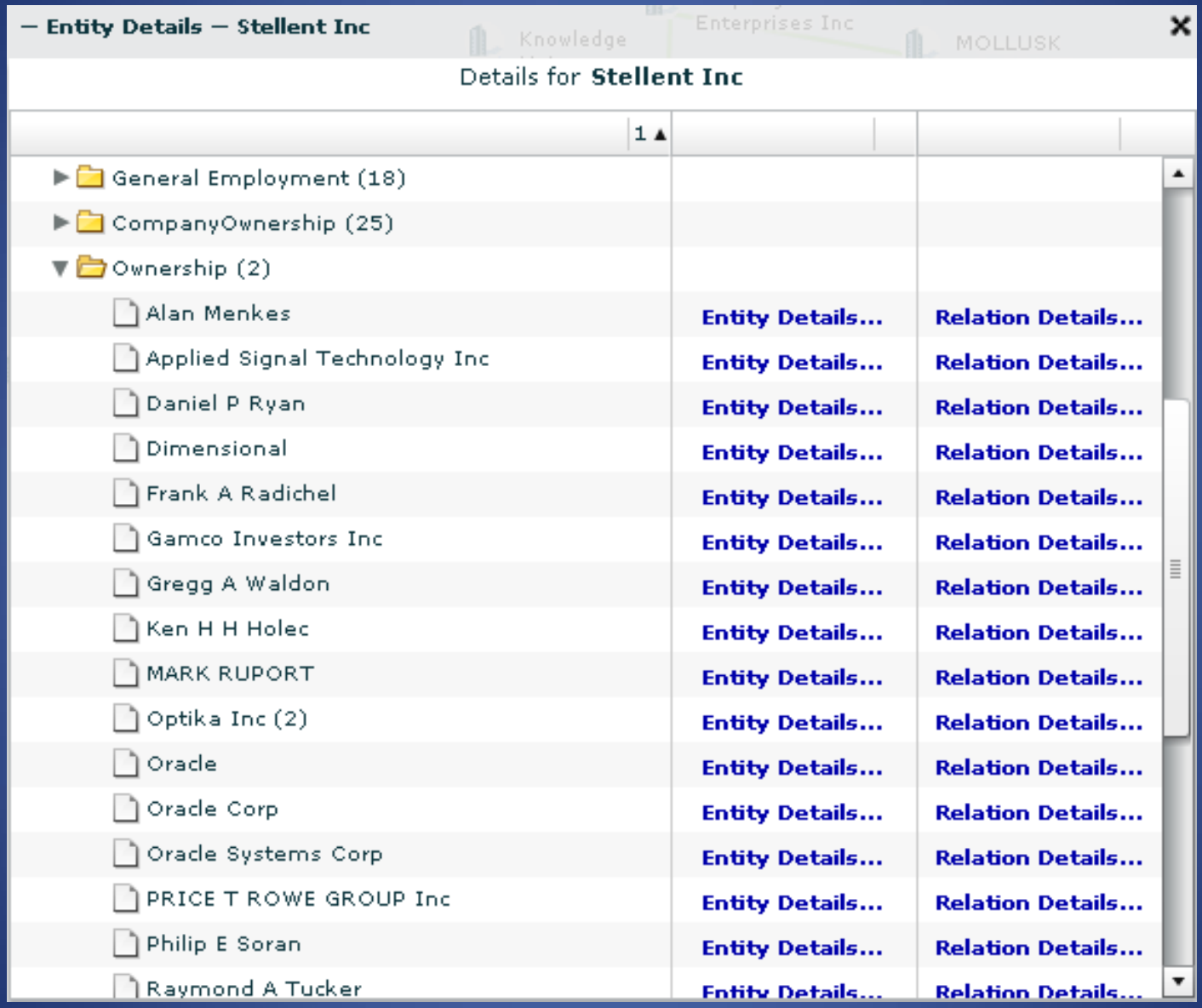
Are there any conflicts of interest in our proposal?

Who could refer or introduce me to Larry Ellison?

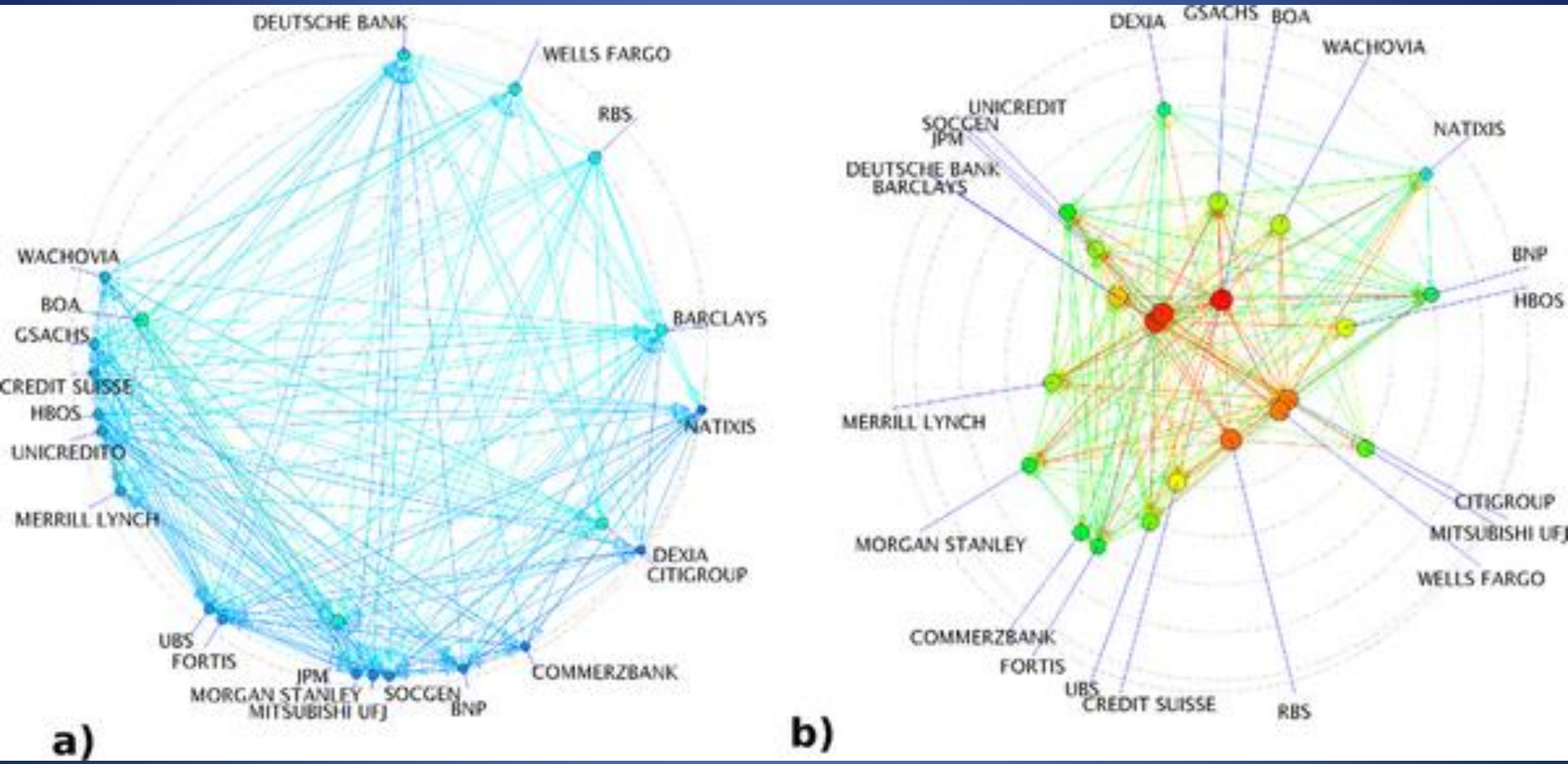
Market Intelligence



Financial Exposure



Financial Networks



Top borrowers, Financial Exposure

The network of the top borrowers.
http://www.nature.com/srep/2012/120802/srep00541/full/srep00541.html

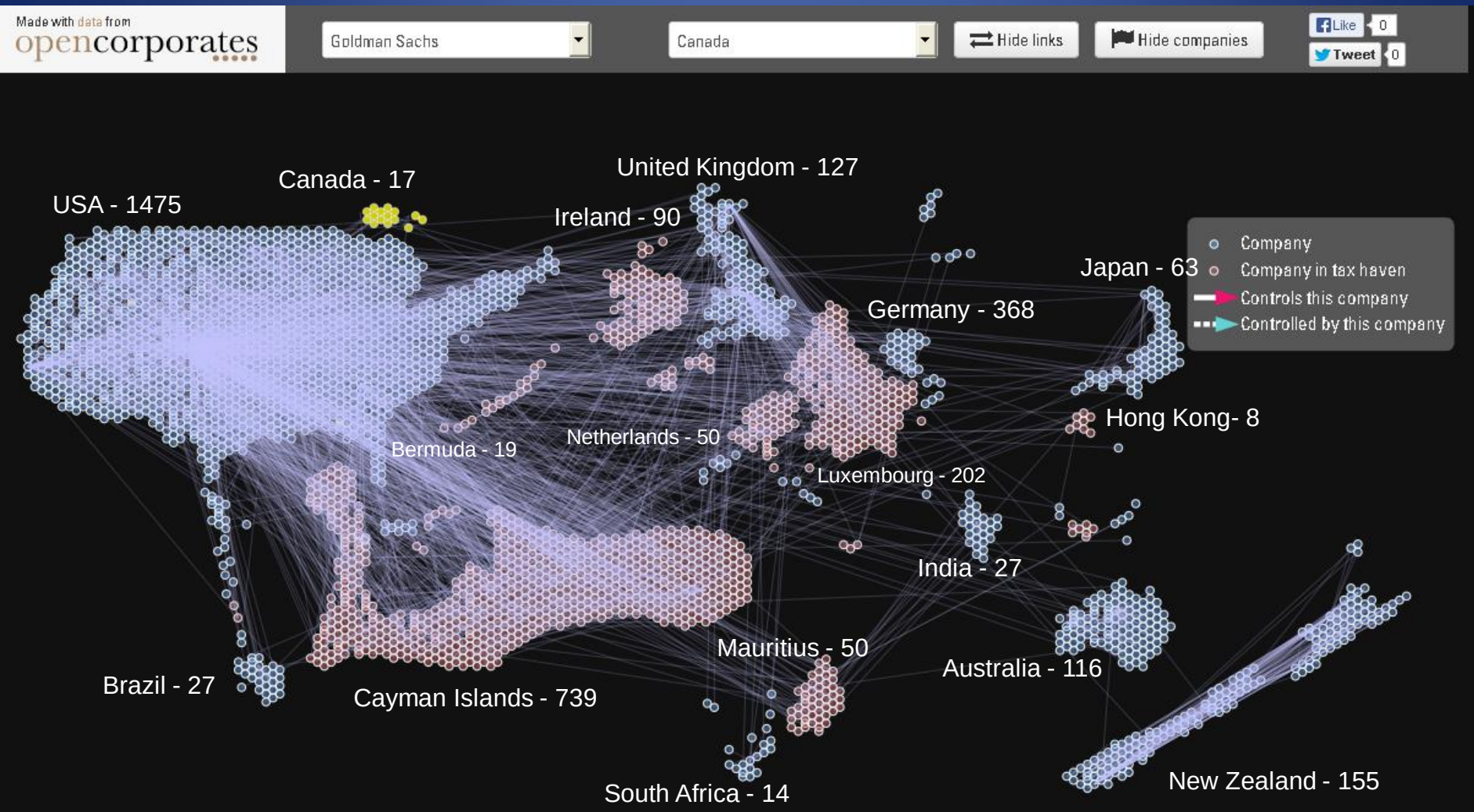
Corporate Ownership

- Can be very complex.

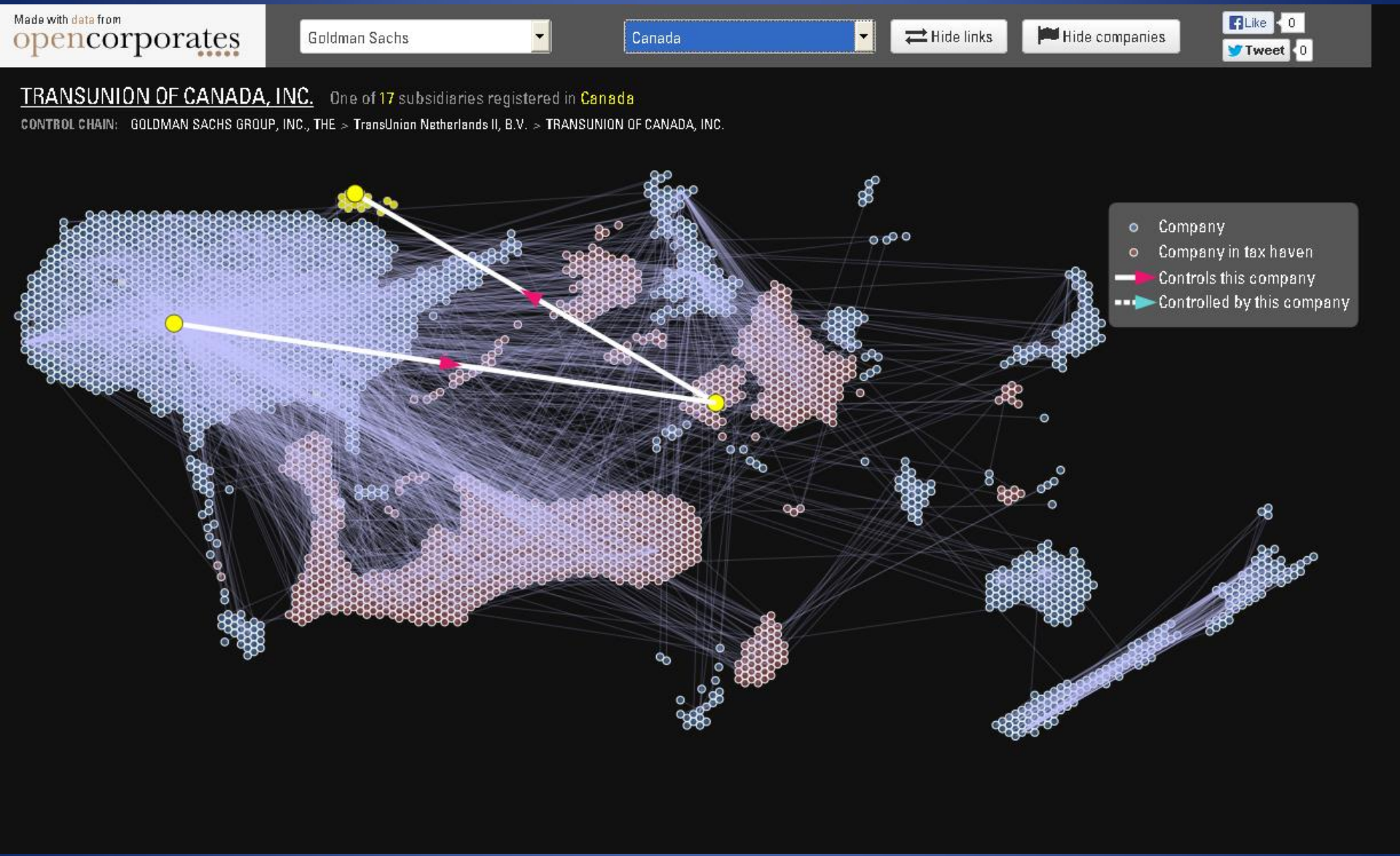
- Corporate Ownership can actually be circular:
- A owns B. B owns C. C owns stock in A.

- Accounting rules: conglomerates must aggregate intra-company sales.

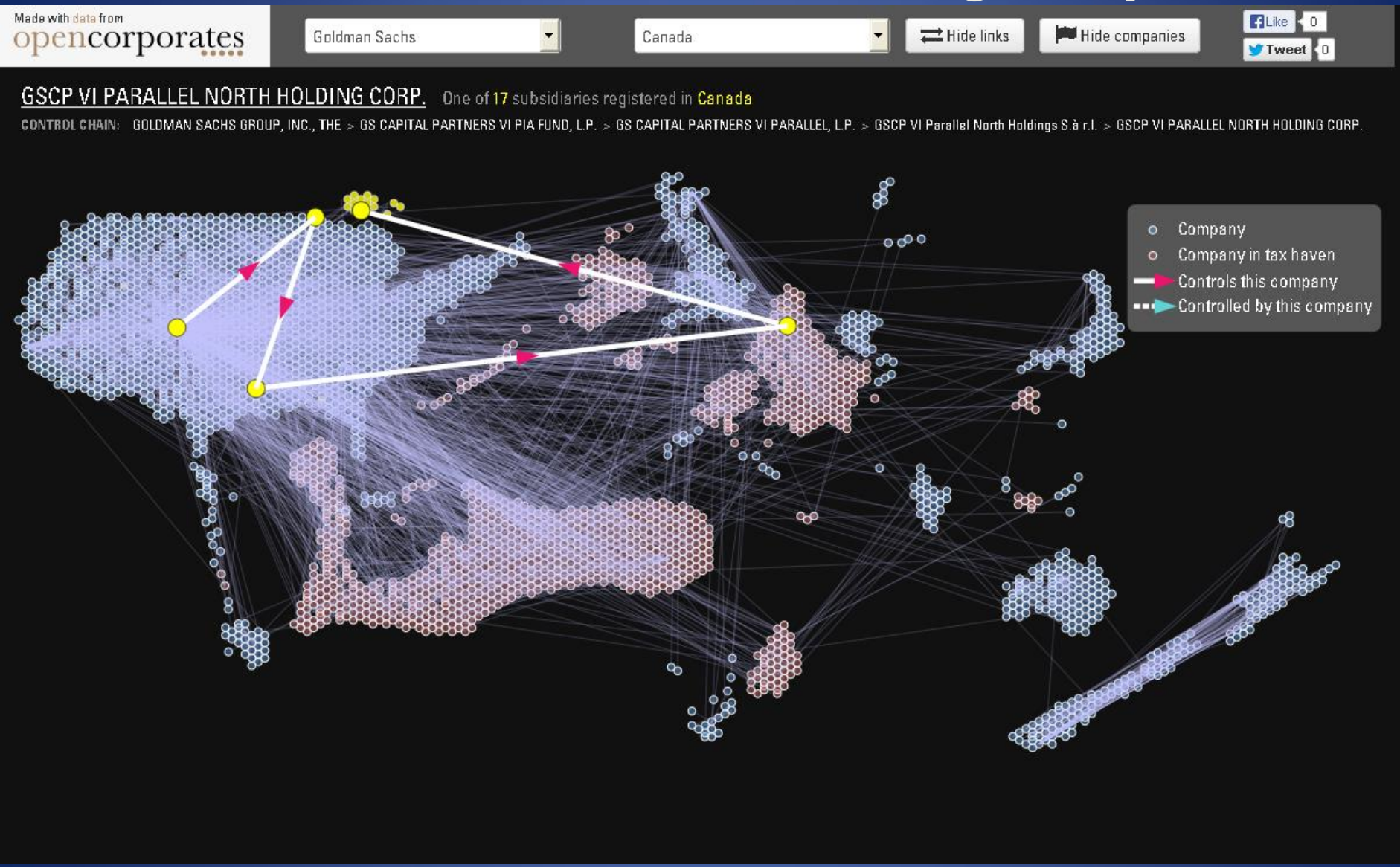
Corporate Ownership – Goldman Sachs



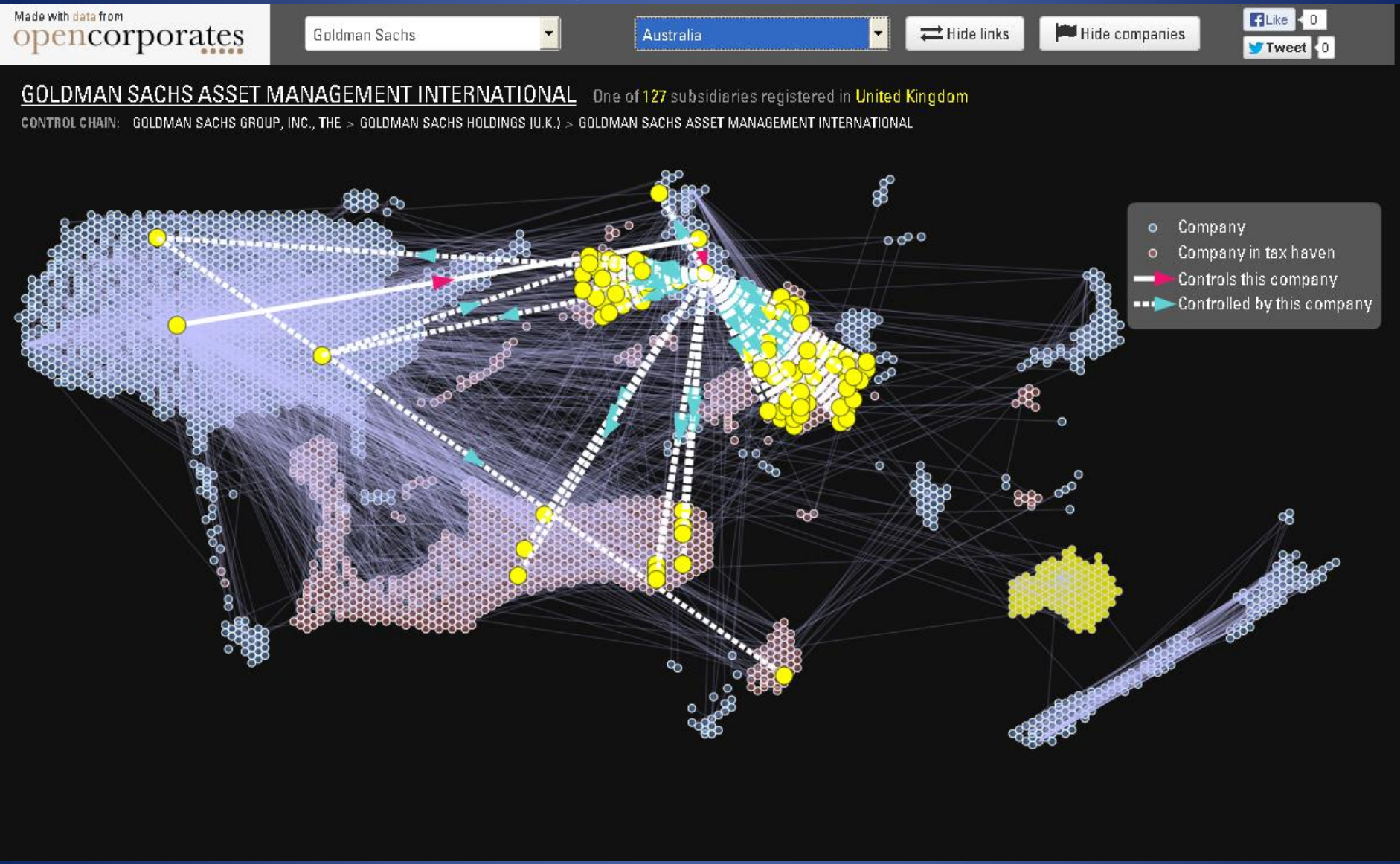
Corporate Ownership – TransUnion Canada



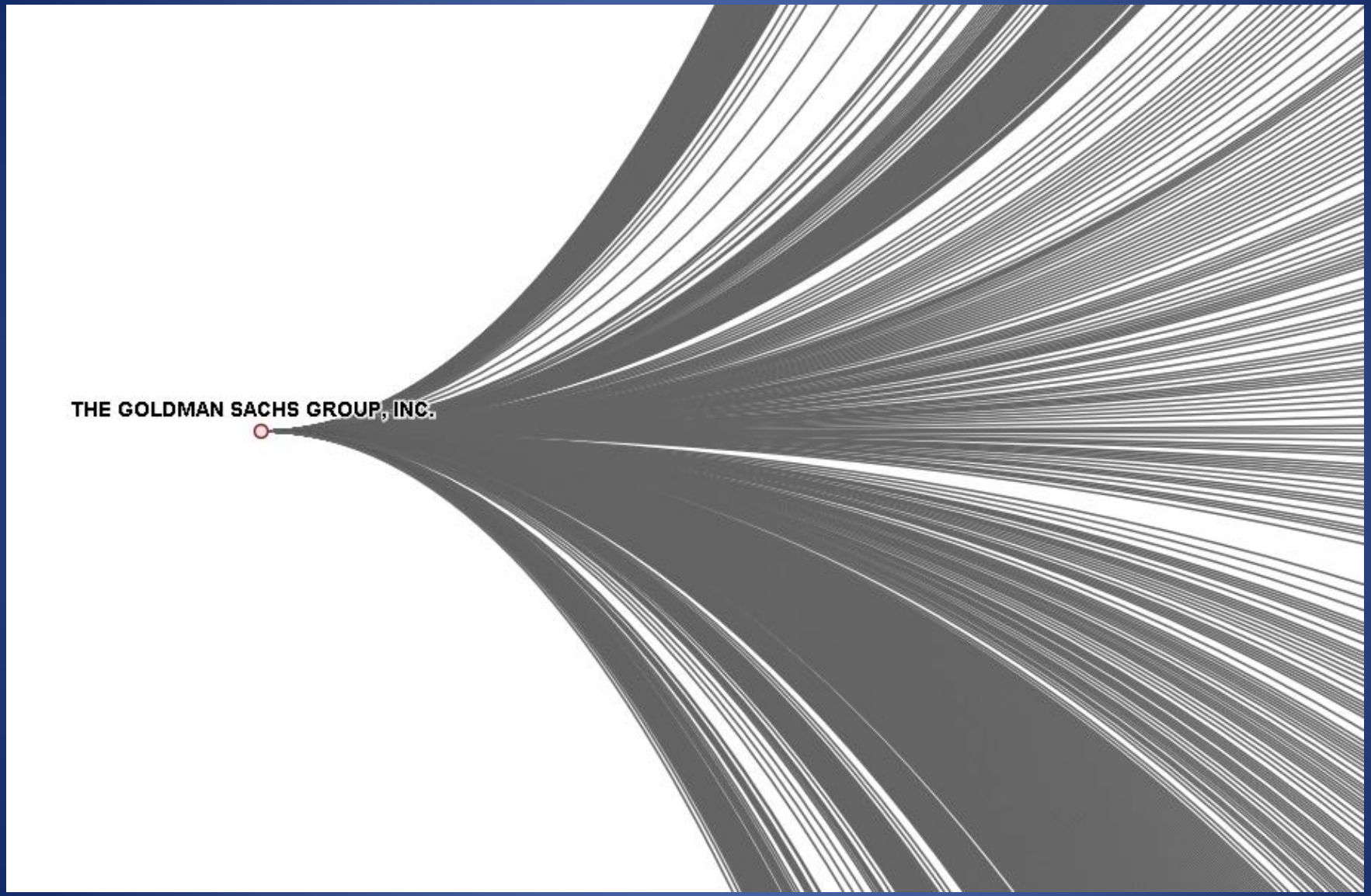
GSCP VI Parallel North Holding Corporation



GS Asset Management International - UK

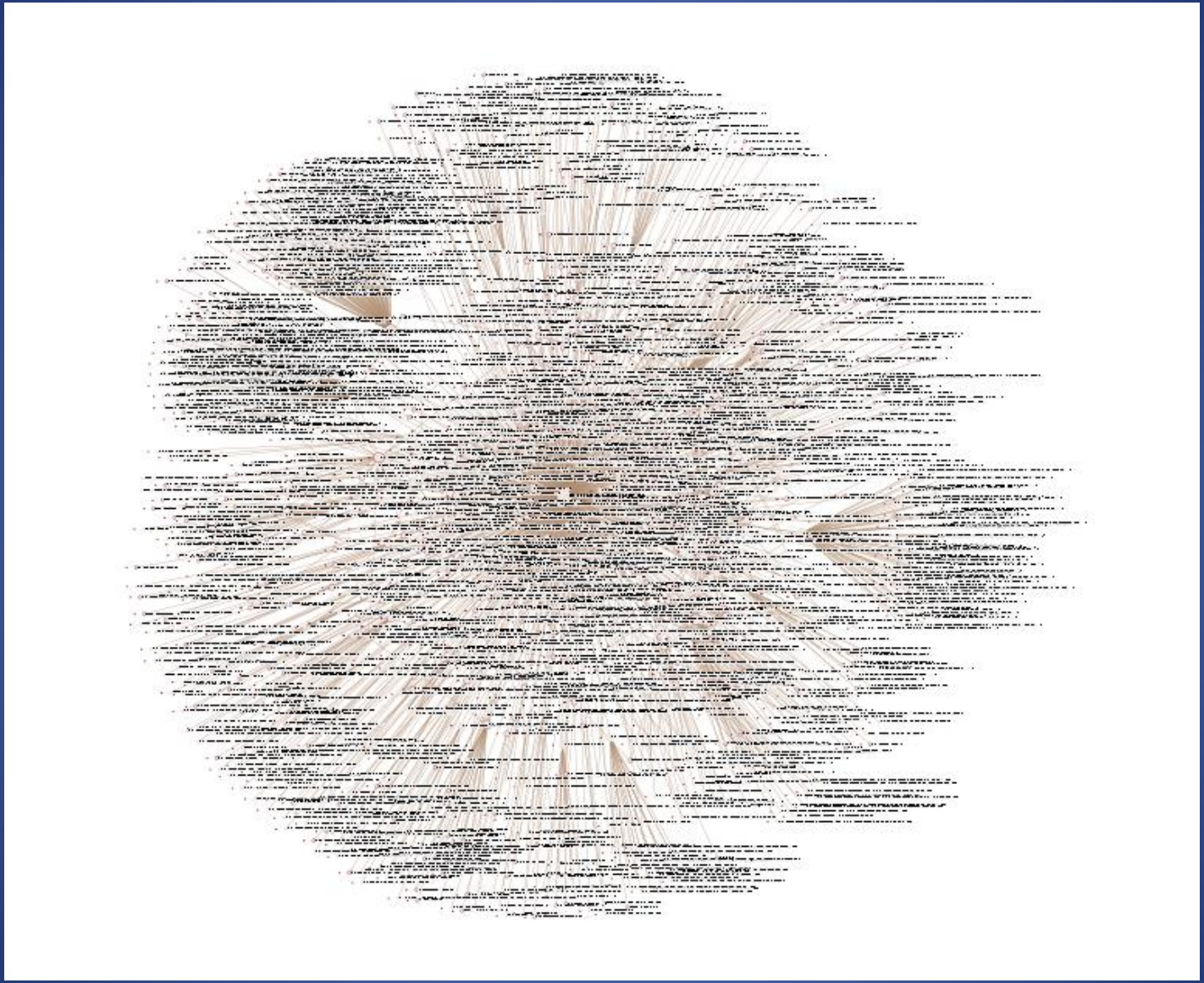


Goldman Sachs Group – As A Tree



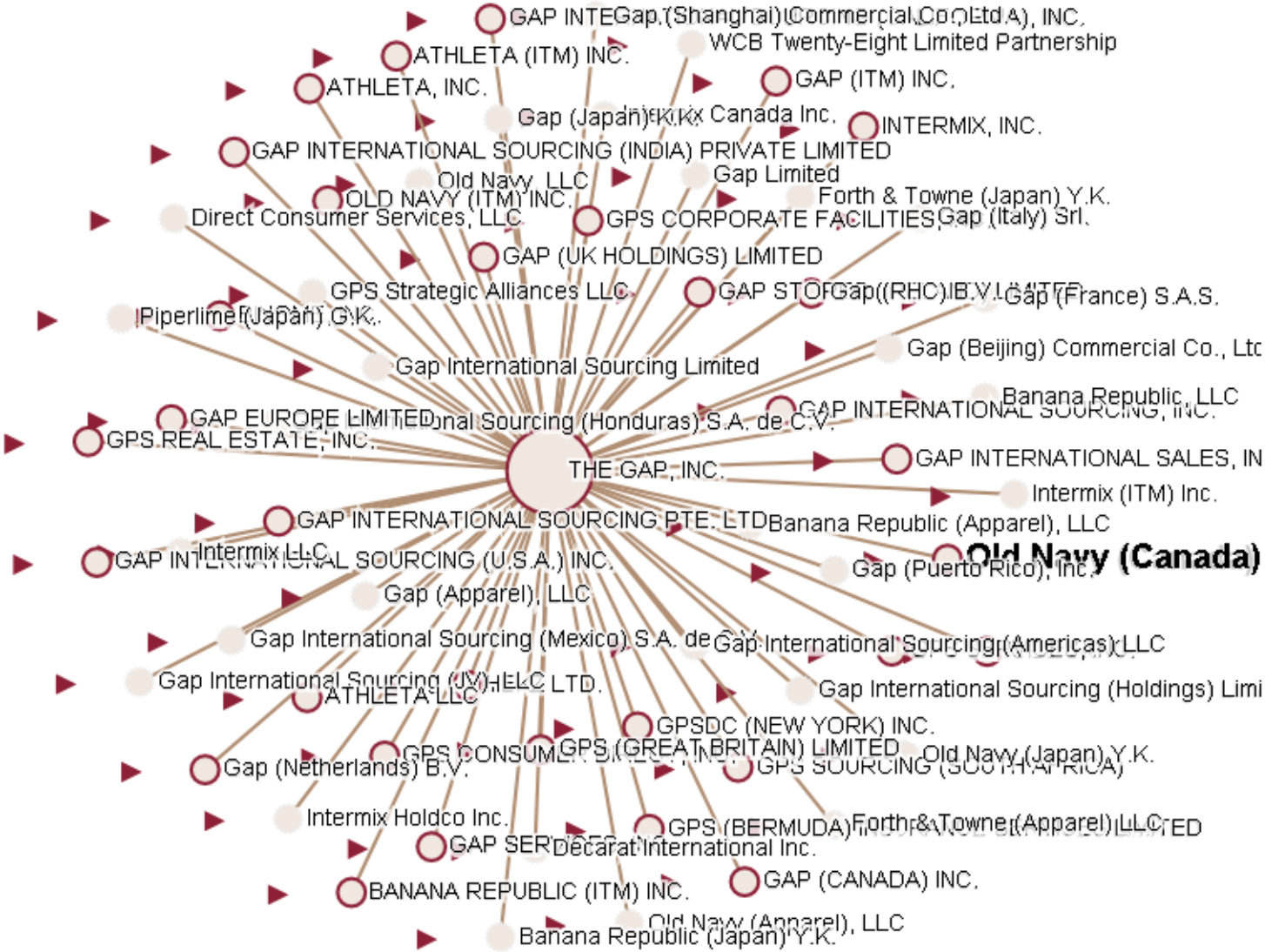
http://opencorporates.com/companies/us_de/2923466/network

Goldman Sachs Group – As A Network



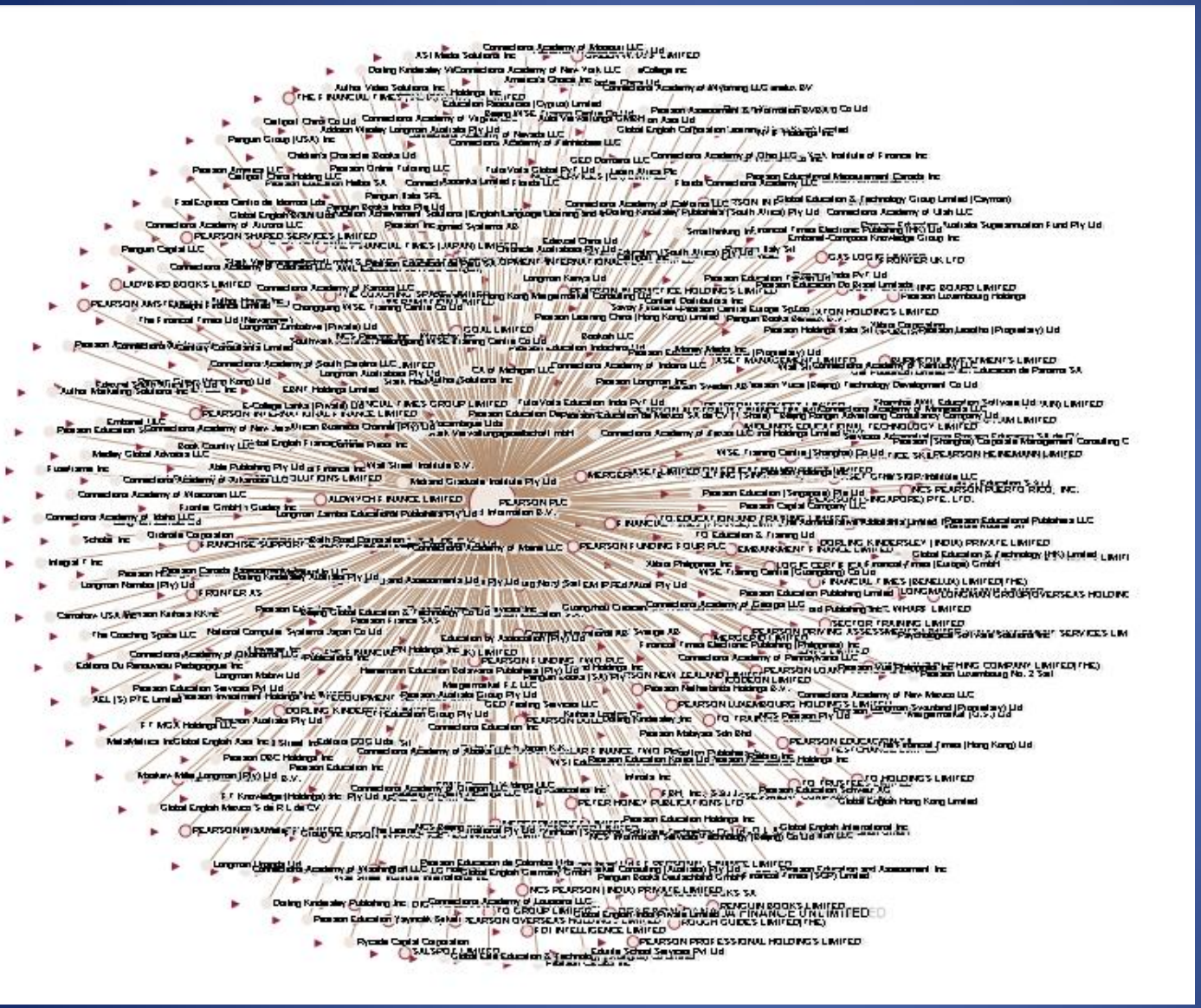
http://opencorporates.com/companies/us_de/2923466/network

Old Navy Canada – Subsidiary of The Gap



http://opencorporates.com/companies/ca/3659372/network

Pearson PLC



Pearson PLC
- UK Public Limited Company

- Owns Pearson Canada Finance Unlimited

Google And Graphs

- Social networks: graphs that describe relationships among people.
- Transportation routes: create a graph of physical connections among geographical locations
- Paths of disease outbreaks form a graph
- Games among soccer teams
- Computer network topologies
- Citations among scientific papers
- Internet / World Wide Web: documents are vertices and links are edges.

http://googleresearch.blogspot.com/2009/06/large-scale-graph-computing-at-google.html

Google And Graphs

- Pregel: Google's other data-processing infrastructure
- Google: MapReduce (Hadoop) is used for 80% of all the data processing needs: indexing web content, clustering engines for Google News, Google Trends, processing satellite imagery, language model processing for statistical machine translation, data backup and restore.
- The other 20% is handled by a lesser known infrastructure called "Pregel" which is optimized to mine relationships from "graphs".

http://www.royans.net/arch/pregel-googles-other-data-processing-infrastructure/

Google And Graphs

- Google extracts more than 200 signals from the web graph: language of webpages, number and quality of other pages pointing to it.
- Google: scalable infrastructure, named Pregel, to mine a wide range of graphs. In Pregel, programs are expressed as a sequence of iterations.
- PageRank, for example, takes only about 15 lines of code.
-

http://googleresearch.blogspot.com/2009/06/large-scale-graph-computing-at-google.html

Security – National Security Agency

- NSA Application: determine who else is in contact with suspected terrorists
- Stores tens of petabytes of data
- Internal system, built on top of Hadoop

- Accumulo is able to process:
- 4.4-trillion-node, 70-trillion-edge graph.
- Human brains:
- 100 billion nodes/vertices, 100 trillion edges

http://gigaom.com/2013/06/06/heres-how-the-nsa-analyzes-all-that-call-data/
http://www.pdl.cmu.edu/SDI/2013/slides/big_graph_nsa_rd_2013_56002v1.pdf

National Security Agency - NSA

NSA-RD-2013-056001v1

Graph500 Experiment

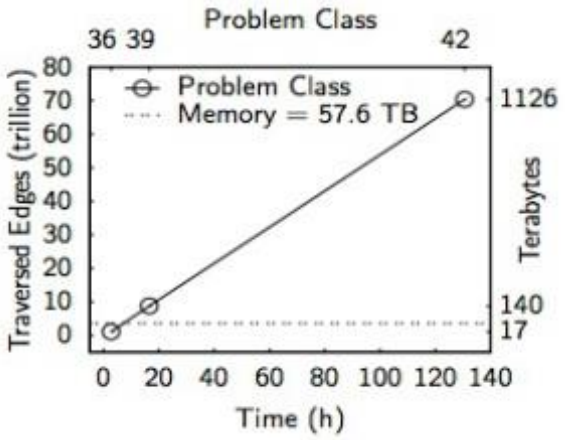
Graph500 Huge class — scale 42

2^{42} (4.40 trillion) vertices
2^{46} (70.4 trillion) edges
1 Petabyte

Cluster specs

1200 nodes
2 Intel quad-core per node
48 GB RAM per node
7200 RPM sata drives

- **Huge** problem is 19.5x more than cluster memory
- linear performance from 1 trillion to 70 trillion edges. . .
- despite multiple hardware failures!



Graph500 Scalability Benchmark

Paul Burkhardt, Chris Waring — An NSA Big Graph experiment

http://gigaom.com/2013/06/06/heres-how-the-nsa-analyzes-all-that-call-data/
http://www.pdl.cmu.edu/SDI/2013/slides/big_graph_nsa_rd_2013_56002v1.pdf

National Security Agency - NSA

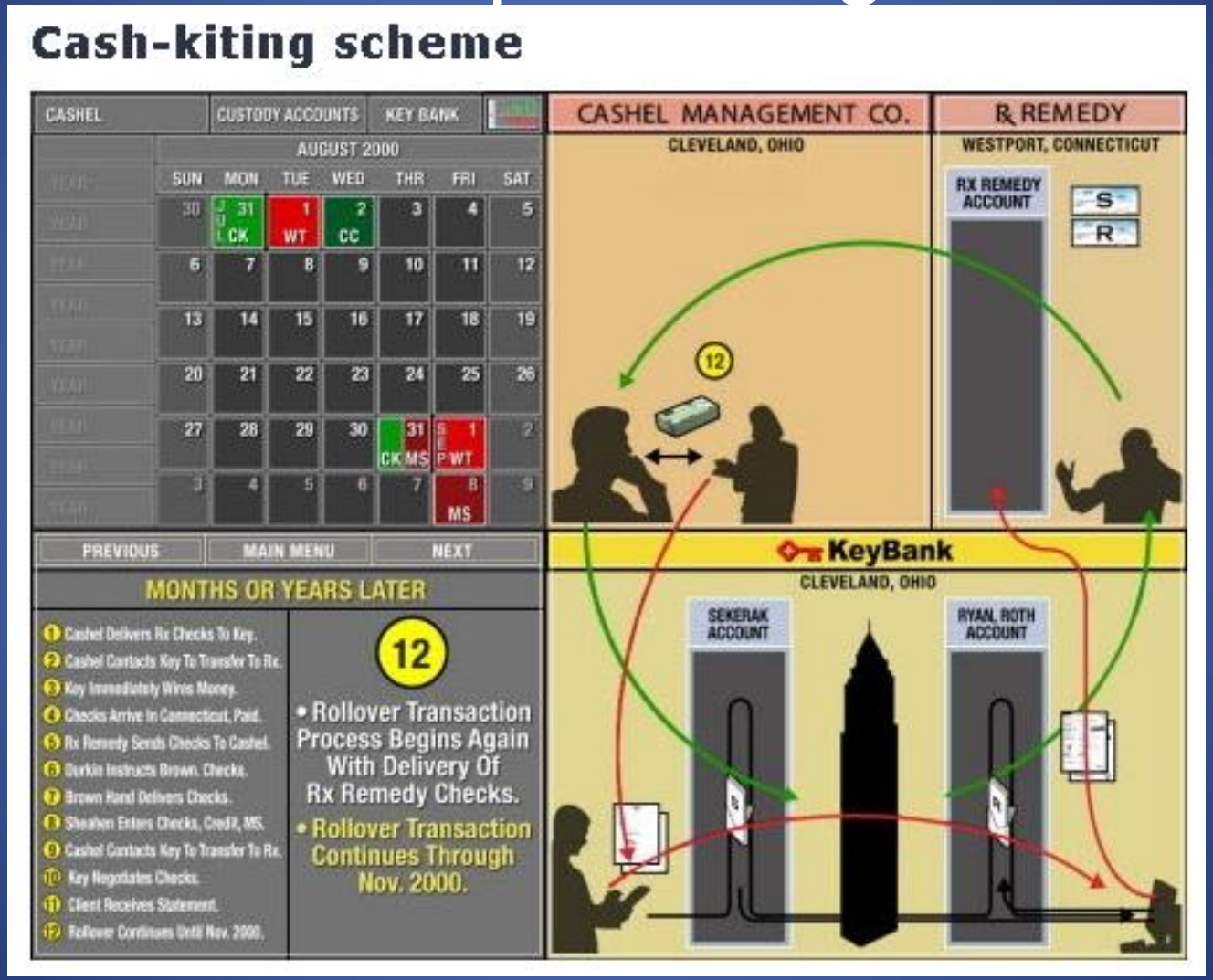
- Largest supercomputer installations do not have enough memory to process the Brain Graph (3 PB)!

- Electrical power cost
- At 10 cents per kilowatt-hour — $7 million per year

Class	Scale	Storage
Toy	26	17 GB
Mini	29	140 GB
Small	32	1 TB
Medium	36	17 TB
Large	39	140 TB
Huge	42	1.1 PB

http://gigaom.com/2013/06/06/heres-how-the-nsa-analyzes-all-that-call-data/
http://www.pdl.cmu.edu/SDI/2013/slides/big_graph_nsa_rd_2013_56002v1.pdf

Fraud – Cheque Kiting Scheme



http://photos.cleveland.com/plain-dealer/2012/02/19fvisualejpg.html

Bernie Madoff Corporate Network

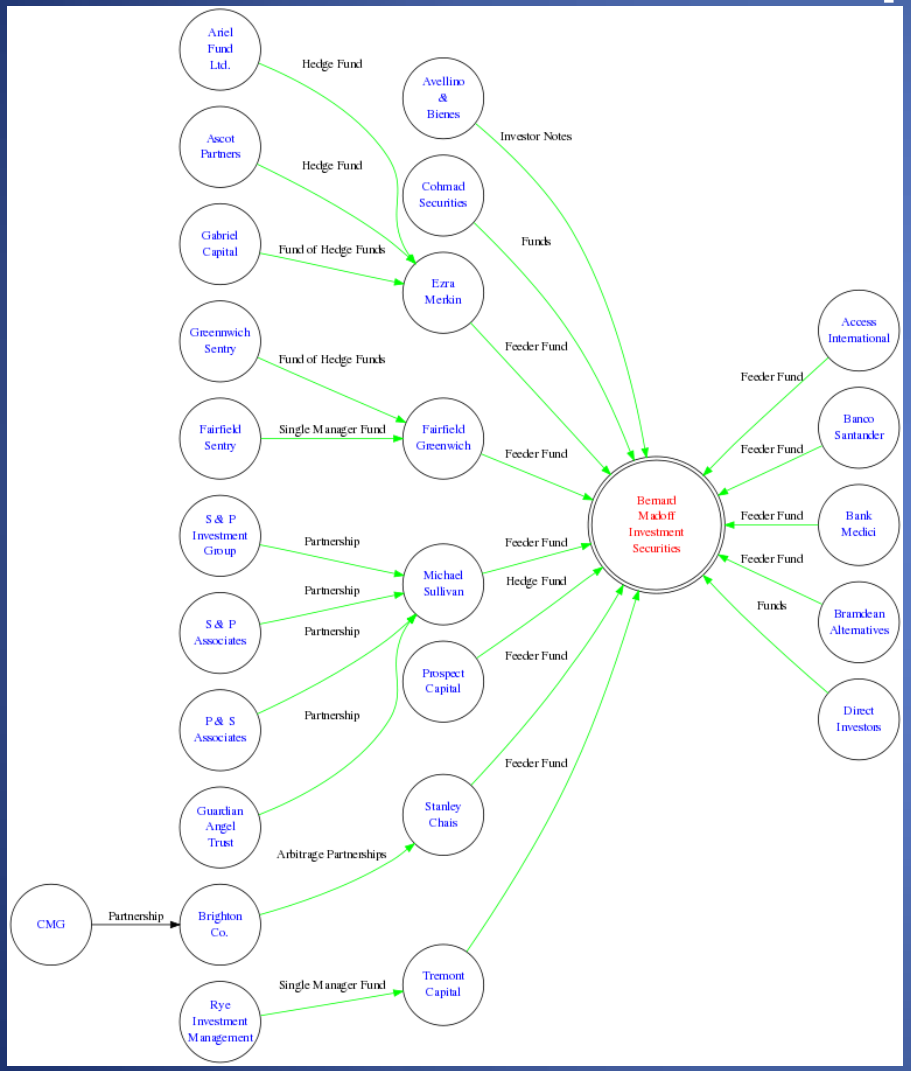


Diagram of companies feeding money to Bernie Madoff

Shortest Paths - Trains

- “In 2007, a colleague and I used Java with Oracle 9i to implement Dijkstra’s Algorithm. Our “MapQuest for Trains” application would route a rail train over various right-of-ways while minimizing cost. The cost was a function of distance, fuel surcharge, and obstacles. The task to route a train from Los Angeles to Chicago had a grotesquely long response time. Nobody wanted their applications deployed on our nodes because we spiked the servers!”

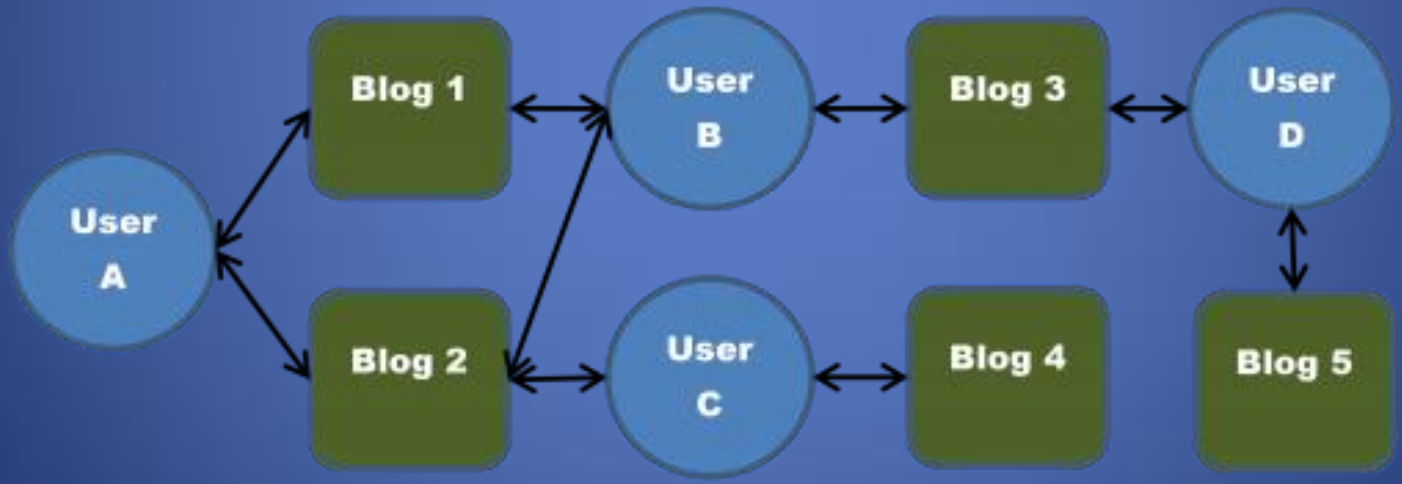
- Solved by using a Neo4J graph database as the underlying storage

http://keyholesoftware.com/2013/01/28/mapping-shortest-routes-using-a-graph-database/
http://myjavaneo4j.herokuapp.com/

Shortest Paths - Trains

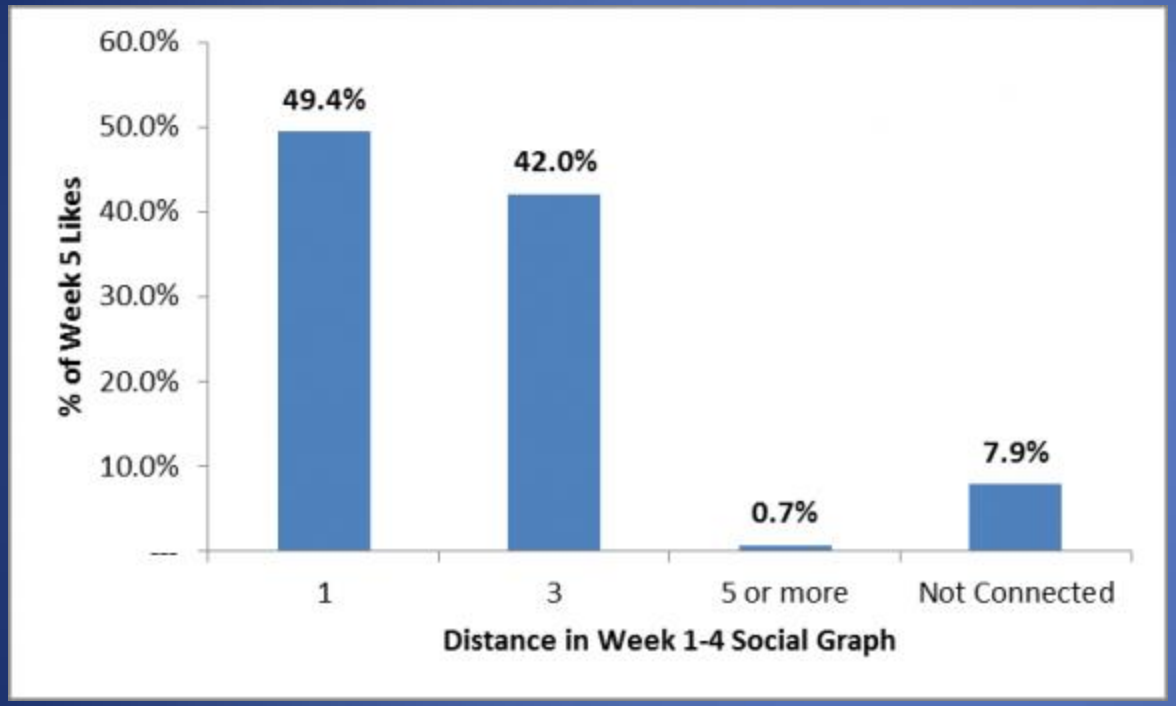
Social Network Prediction Engine

- Problem: predict which blog posts a WordPress user would ‘like’ based on prior user activity and blog content



http://www.overkillanalytics.net/kaggles-wordpress-challenge-the-like-graph/

Social Network Prediction Engine



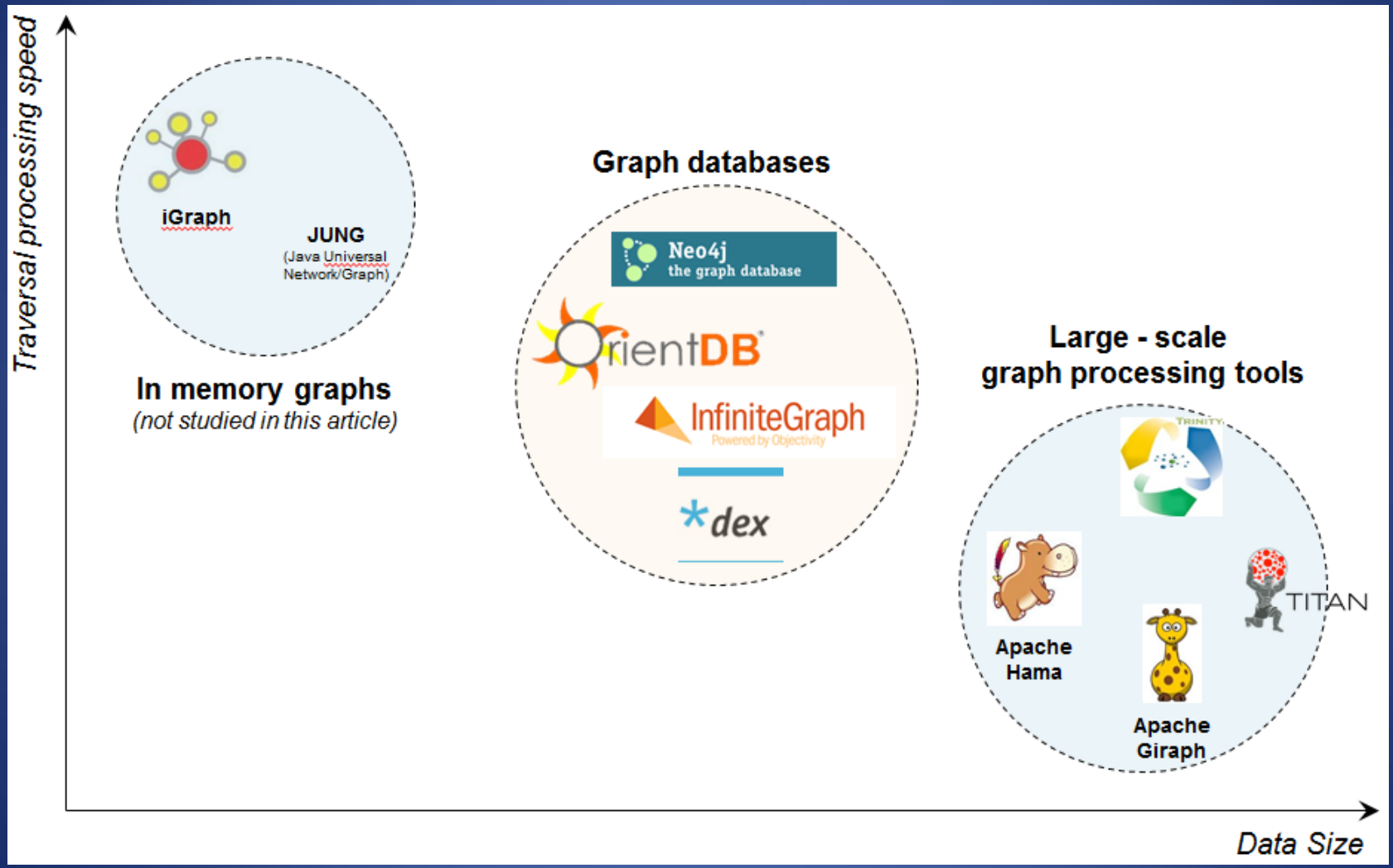
Results:

Nearly 50% of all new likes are from blogs one ‘edge’ from the user

A distance of 3 edges/likes traversed – encompasses 90% of all new likes.

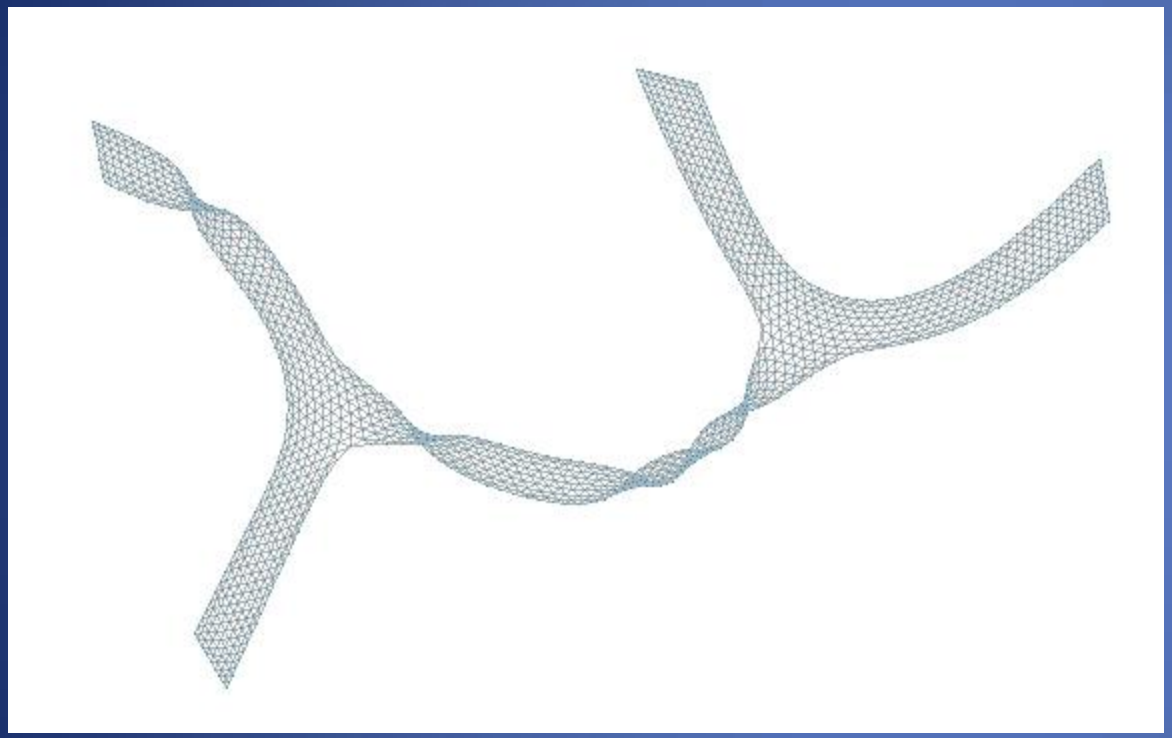
http://www.overkillanalytics.net/kaggles-wordpress-challenge-the-like-graph/

Graph DB on the Market



http://blog.octo.com/en/graph-databases-an-overview/

Visualization



Andrei Kashcha:

Uses VivaGraphJS, google app engine, U of F sparse matrices

http://www.yasiv.com/graphs

Visualization

- Tools in the browser (Neo4J, Linkurious, D3, Keylines)
- Gephi, on the desktop
- With Excel: nodexl.codeplex.com

- Nathan Yau, Flowing Data (more for R)

Job Trends

Slowing demand in

Oracle

Java

From 3% to 2% in about 7 years

http://www.indeed.com/jobtrends?q=java&l=New+York%2C+NY

Job Trends

Strong demand growth in

"Data Science"
"Big Data"
"R statistics"

Although, fewer jobs overall

http://www.indeed.com/jobtrends?q=%22Data+Science%22&l=New+York%2C+NY

Data Science

- New profession
- Expertise involves:
- Computer and software
- Math and Statistics
- Data (often Big Data)
- Subject Matter Domain Knowledge

- Find significant inferences, trends
- Add value to the organization
- Jingjing's thesis

Canadian Universities

- Queen's
- Master's Degree in Management Analytics (Business)

- University of Toronto
- Certificate: Management of Enterprise Data Analytics

- York University, Toronto, Ontario
- Master of Science in Business Analytics

- University of Ottawa
- Master in Electronic Business Technologies

- Simon Fraser:
- Master's program in Big Data

http://www.informationweek.com/big-data/big-data-analytics/big-data-analytics-masters-degrees-20-top-programs/d/d-id/1108042?page_number=19
http://www.kdnuggets.com/education/usa-canada.html

US Universities

- Arizona State University
- Bentley University, Waltham, Mass.
- Carnegie Mellon University, Pittsburgh, Pa.
- Columbia University, New York, N.Y.
- DePaul University, Chicago, Ill.
- Drexel University, Philadelphia, Pa.
- Fordham University, New York, N.Y.
- Harvard University, Cambridge, Mass.
- Louisiana State University, Baton Rouge, La.
- Massachusetts Institute of Technology, Cambridge, Mass.
- New York University, New York, N.Y.
- North Carolina State University, Raleigh, N.C.
- Northwestern University, Evanston, Ill.
- Purdue University, Lafayette, Ind.
- Rutgers University, New Brunswick, N.J.
- University of San Francisco, San Francisco, Cal.
- Stanford University, Stanford, Calif.
- University of California at Berkeley, Berkeley, California
- University of Southern California, Los Angeles, California
- University of Cincinnati, Cincinnati, Ohio
- University of Connecticut, Graduate Learning Center, Hartford, Conn.
- University of Illinois, Champaign, Ill.
- University of Tennessee, Knoxville, Tenn.

http://www.informationweek.com/big-data/big-data-analytics/big-data-analytics-masters-degrees-20-top-programs/d/d-id/1108042

US University Degrees

- Master of Business Administration
- Master of Business Administration, Business Analytics
- Master of Business Administration, specialization In Business Analytics
- Master of Business And Science degree in Operations Research and Business Analytics
- Master of Engineering
- Master of Information and Data Science
- Master of Information Systems Management, Business Intelligence and Data Analytics.
- Master of Science (MS), Applied Urban Science and Informatics
- Master of Science In Analytics
- Master of Science in Business Analytics
- Master of Science in Business Analytics and Project Management
- Master of Science in Computer Science - Data Science
- Master of Science In Computer Science, Specialization in Information Management and Analytics
- Master of Science In Marketing Analytics
- Master of Science in Predictive Analytics
- Master of Science in Statistics: Analytics Concentration
- Masters of Science in Computational Science and Engineering
- Masters of Science in Computer Science, Machine Learning

http://www.informationweek.com/big-data/big-data-analytics/big-data-analytics-masters-degrees-20-top-programs/d/d-id/1108042

MOOC

- Massive Open Online Courses

- Coursera.com
- MIT
- Code Academy
- Khan Academy

https://en.wikipedia.org/wiki/Massive_Open_Online_Course

Coursera

- Johns Hopkins: Data Science Specialization
- The Data Scientist's Toolbox
- R Programming
- Getting and Cleaning Data
- Exploratory Data Analysis
- Reproducible Research
- Statistical Inference
- Regression Models
- Practical Machine Learning
- Developing Data Products
- Capstone Project

https://www.coursera.org/specialization/jhudatascience/1?utm_medium=courseDescripTop

Coursera

- Core concepts in data analysis: getting started
- National Research University - Higher School of Economics (HSE), Russia

- Duke University:
- Irrational Behavior – Dan Ariely

Questions