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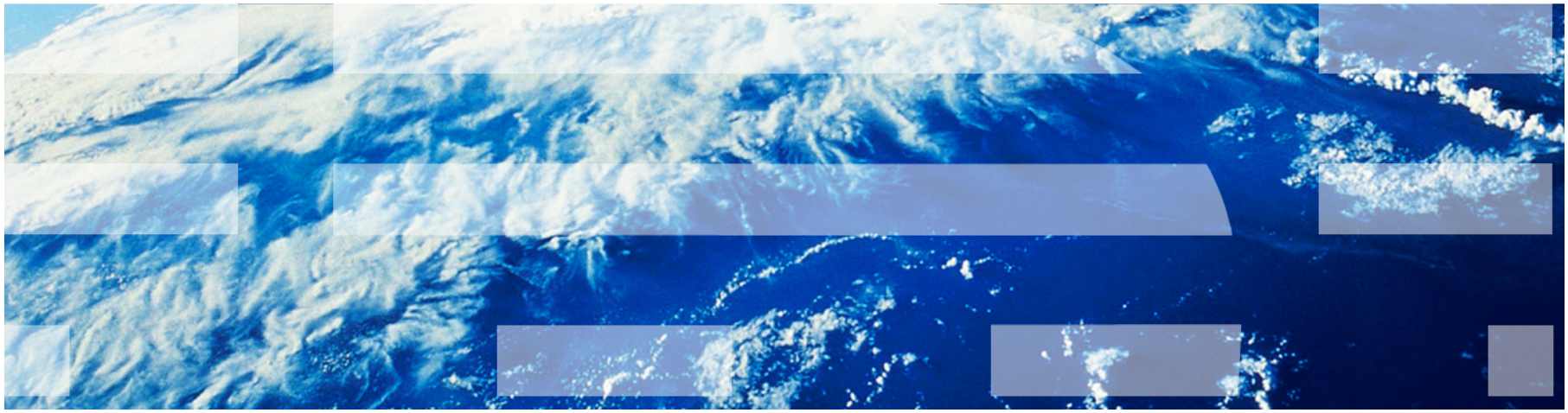
EECS E6893 Big Data Analytics Lecture 1:

Overview of Big Data Analytics

Ching-Yung Lin, Ph.D.

Adjunct Professor, Depts. of Electrical Engineering and Computer Science

IEEE Fellow



September 8th, 2023

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Definition and Characteristics of Big Data

"*Big data is high-**volume**, high-**velocity** and high-**variety** information assets that demand **cost-effective**, **innovative** forms of information processing for **enhanced insight and decision making**.*" -- Gartner

which was derived from:

"*While enterprises struggle to consolidate systems and collapse redundant databases to enable greater operational, analytical, and collaborative consistencies, changing economic conditions have made this job more difficult. E-commerce, in particular, has exploded data management challenges along three dimensions: **volumes, velocity and variety**. In 2001/02, IT organizations much compile a variety of approaches to have at their disposal for dealing each.*" – Doug Laney

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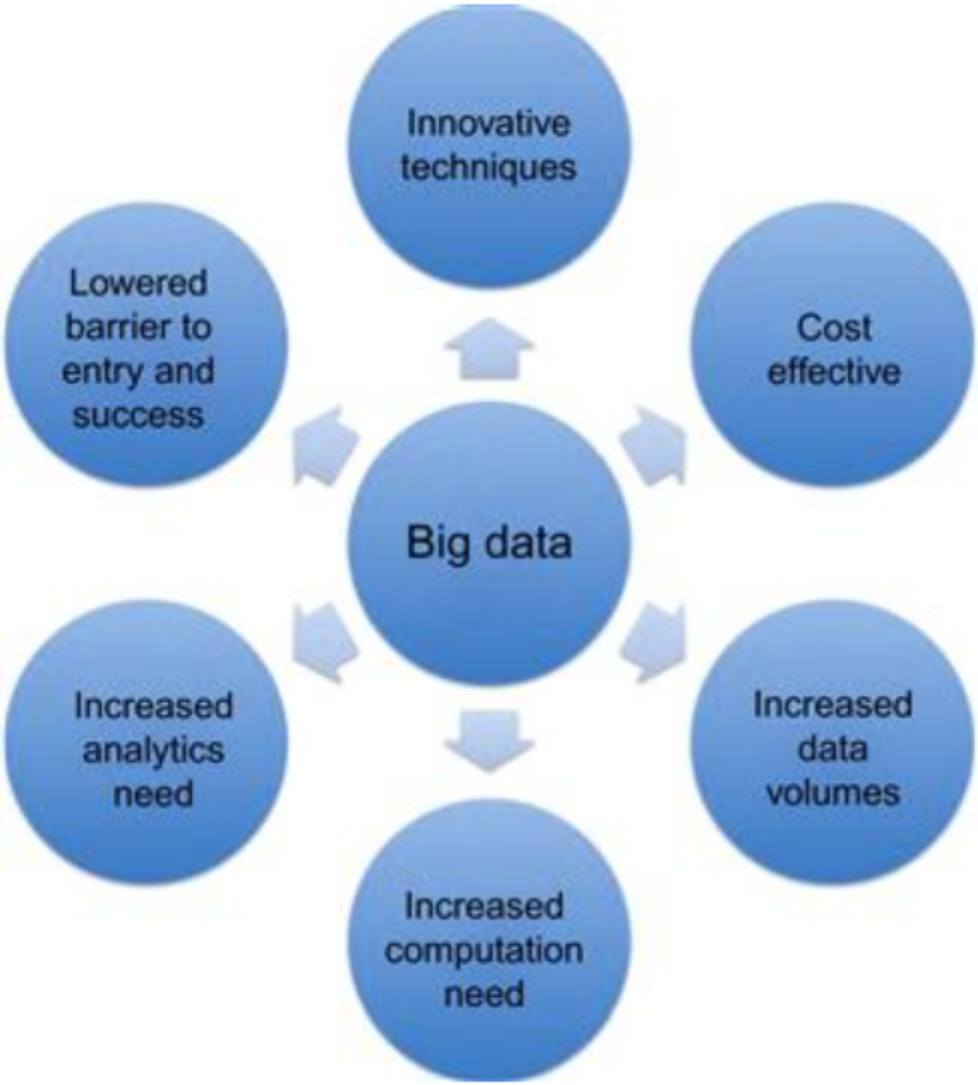
What made Big Data needed?



"Big Data Analytics", David Loshin

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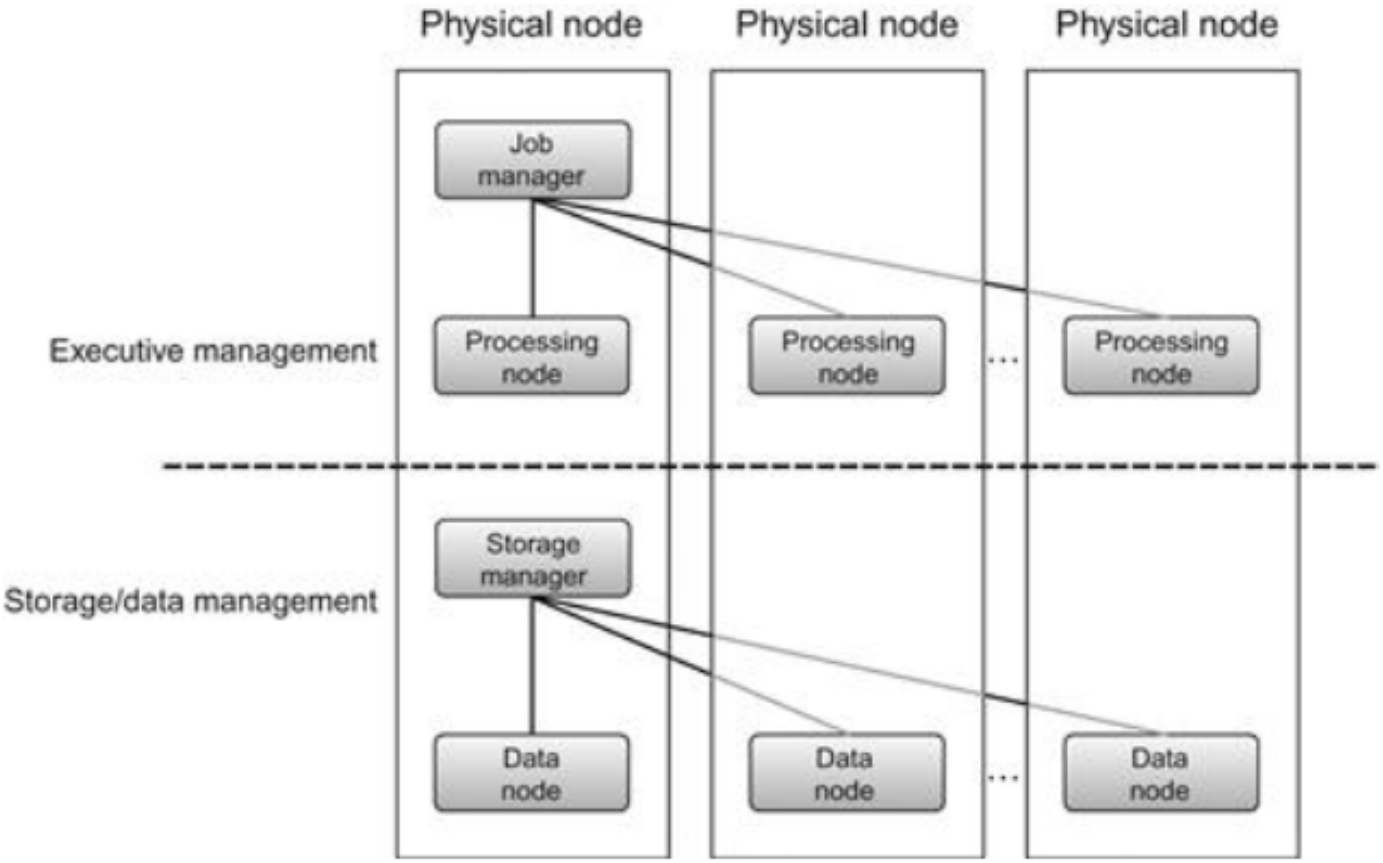
Key Computing Resources for Big Data

- Processing capability: CPU, processor, or node.
- Memory
- Storage
- Network



"Big Data Analytics", David Loshin

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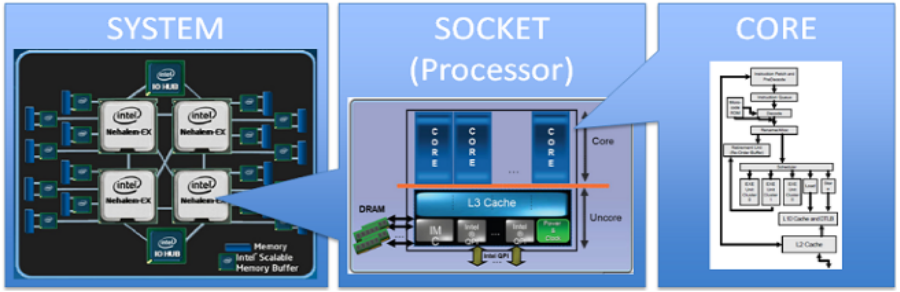
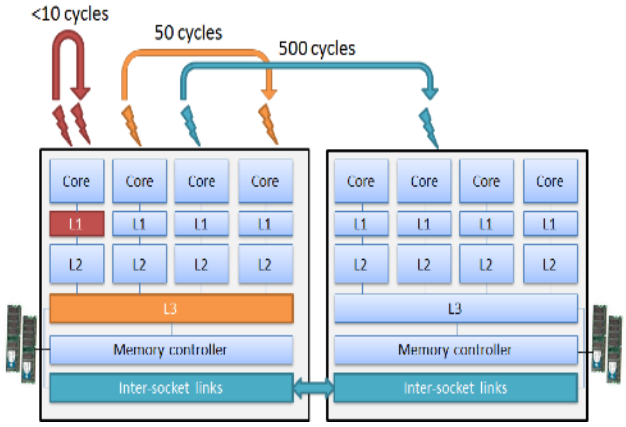
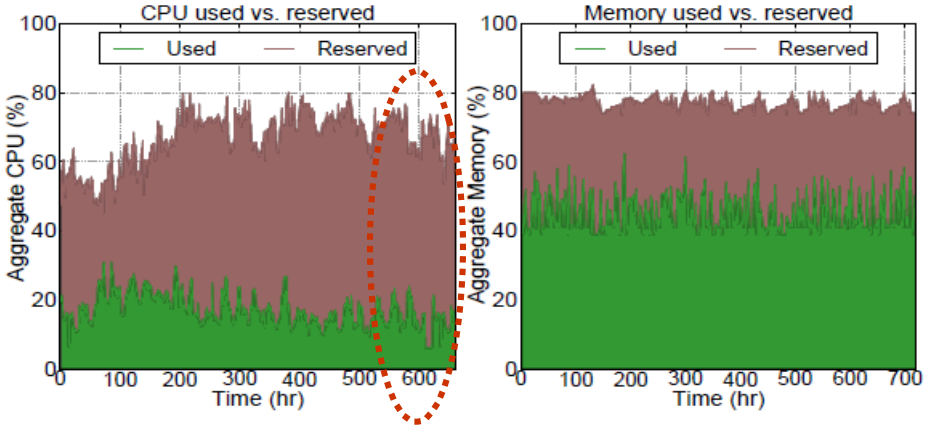
Scalability — Scale Up & Scale Out

- Scale out
  - Use more resources to distribute workload in parallel
  - Higher data access latency is typically incurred
- Scale up
  - Efficiently use the resources
  - Architecture-aware algorithm design





Example: Resource utilization for a large production cluster at Twitter data center



www.stanford.edu/~cdel/2014.asplos.quasar.pdf

- For independent data ==> scale up may not have obvious advantage than scale out
- For linked data ==> utilizing scale up as much as possible before scale out

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Contrasting Approaches in Adopting High-Performance Capabilities

Aspect	Typical Scenario	Big Data
Application development	Applications that take advantage of massive parallelism developed by specialized developers skilled in high-performance computing, performance optimization, and code tuning	A simplified application execution model encompassing a distributed file system, application programming model, distributed database, and program scheduling is packaged within Hadoop, an open source framework for reliable, scalable, distributed, and parallel computing
Platform	Uses high-cost massively parallel processing (MPP) computers, utilizing high-bandwidth networks, and massive I/O devices	Innovative methods of creating scalable and yet elastic virtualized platforms take advantage of clusters of commodity hardware components (either cycle harvesting from local resources or through cloud-based utility computing services) coupled with open source tools and technology
Data management	Limited to file-based or relational database management systems (RDBMS) using standard row-oriented data layouts	Alternate models for data management (often referred to as NoSQL or "Not Only SQL") provide a variety of methods for managing information to best suit specific business process needs, such as in-memory data management (for rapid access), columnar layouts to speed query response, and graph databases (for social network analytics)
Resources	Requires large capital investment in purchasing high-end hardware to be installed and managed in-house	The ability to deploy systems like Hadoop on virtualized platforms allows small and medium businesses to utilize cloud-based environments that, from both a cost accounting and a practical perspective, are much friendlier to the bottom line

"Big Data Analytics", David Loshin

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Techniques towards Big Data

- Massive Parallelism
- Huge Data Volumes Storage
- Data Distribution
- High-Speed Networks
- High-Performance Computing
- Task and Thread Management
- Data Mining and Analytics
- Data Retrieval
- Machine Learning
- Data Visualization

➔ Techniques exist for years to decades. Why is Big Data hot?

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Why Big Data now?

- More data are being collected and stored
- Open source code
- Commodity hardware / Cloud

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Why Big Data now?

- More data are being collected and stored
- Open source code
- Commodity hardware / Cloud

→
- High-Volume
- High-Velocity
- High-Variety

→ Artificial Intelligence

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https://www.youtube.com/watch?v=BV8qFeZxZPE

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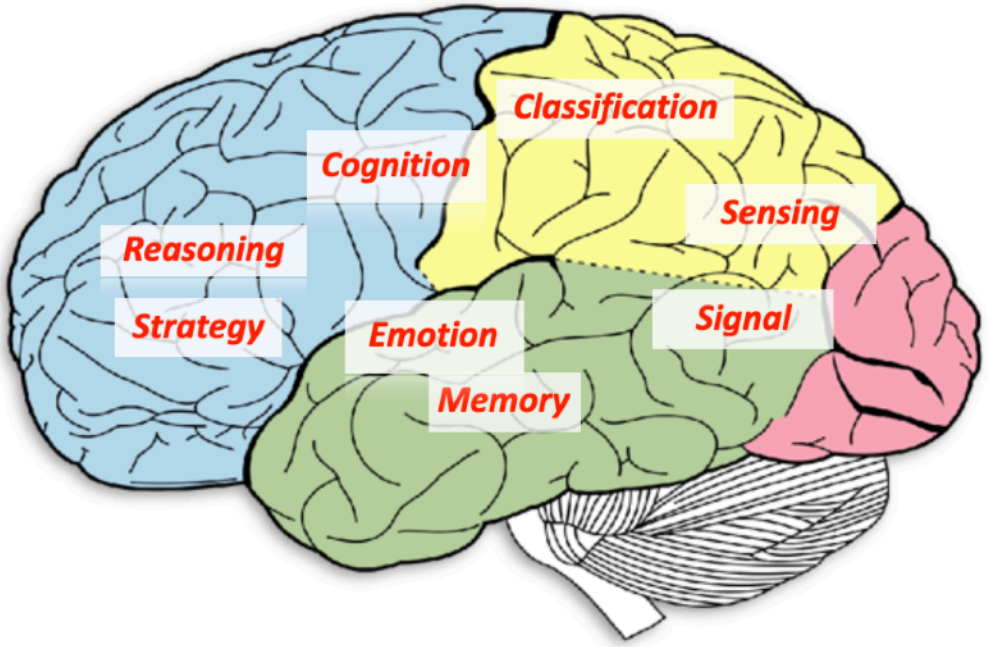
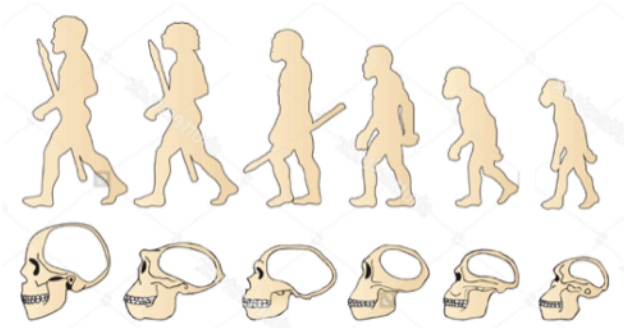
Evolution of Intelligence

Direction of the Evolution of Intelligence





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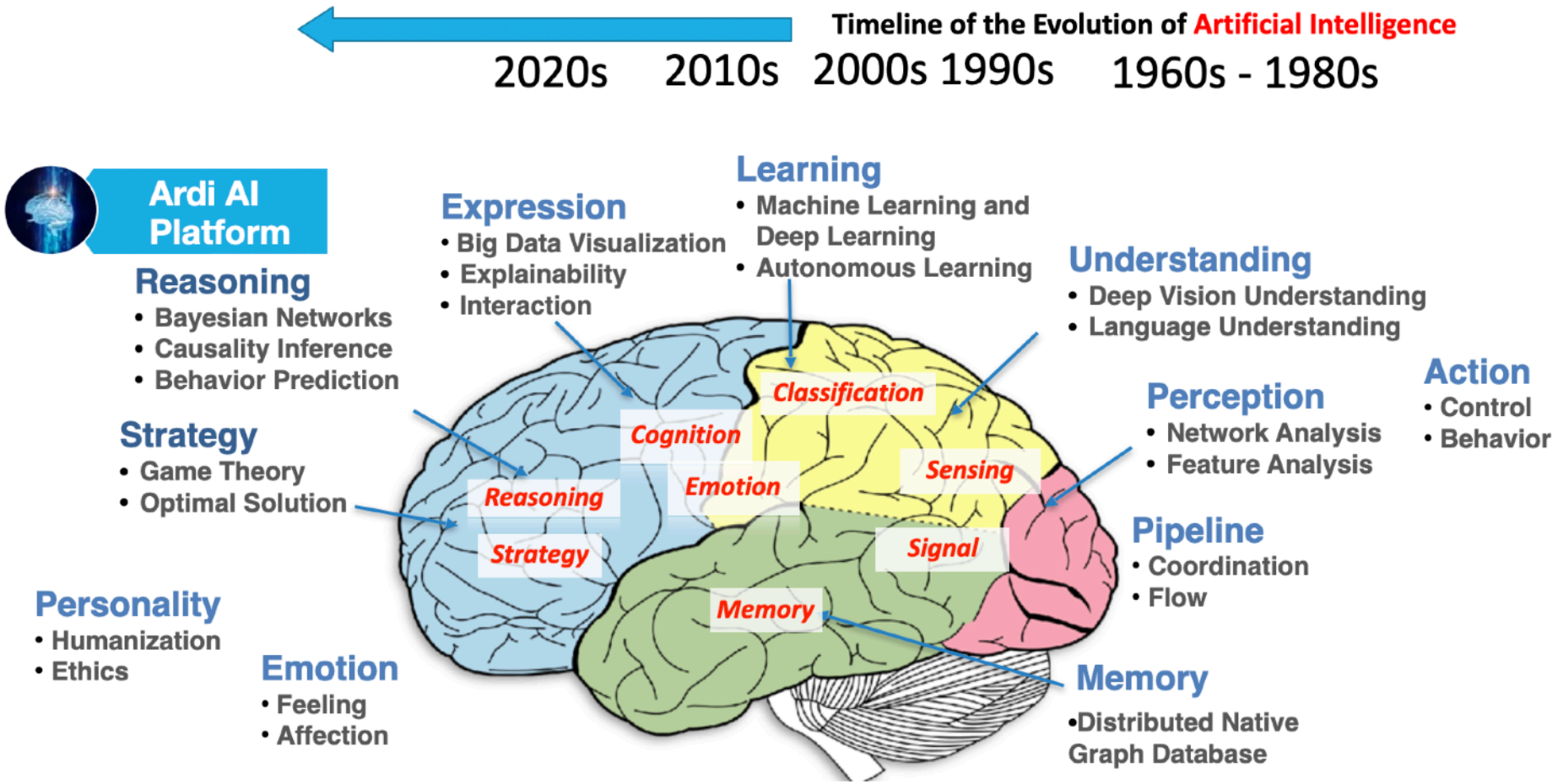
Evolution of Artificial Intelligence is similar, but much faster



https://www.graphen.ai/products/ardi.html

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Course Main Thrust 1: Apache Hadoop and Big Data

The Apache™ Hadoop® project develops open-source software for reliable, scalable, distributed computing.

The Apache Hadoop software library is a framework that allows for the distributed processing of large data sets across clusters of computers using simple programming models. It is designed to scale up from single servers to thousands of machines, each offering local computation and storage. Rather than rely on hardware to deliver high-availability, the library itself is designed to detect and handle failures at the application layer, so delivering a highly-available service on top of a cluster of computers, each of which may be prone to failures.

The project includes these modules:

- **Hadoop Common**: The common utilities that support the other Hadoop modules.
- **Hadoop Distributed File System (HDFS™)**: A distributed file system that provides high-throughput access to application data.
- **Hadoop YARN**: A framework for job scheduling and cluster resource management.
- **Hadoop MapReduce**: A YARN-based system for parallel processing of large data sets.

http://hadoop.apache.org

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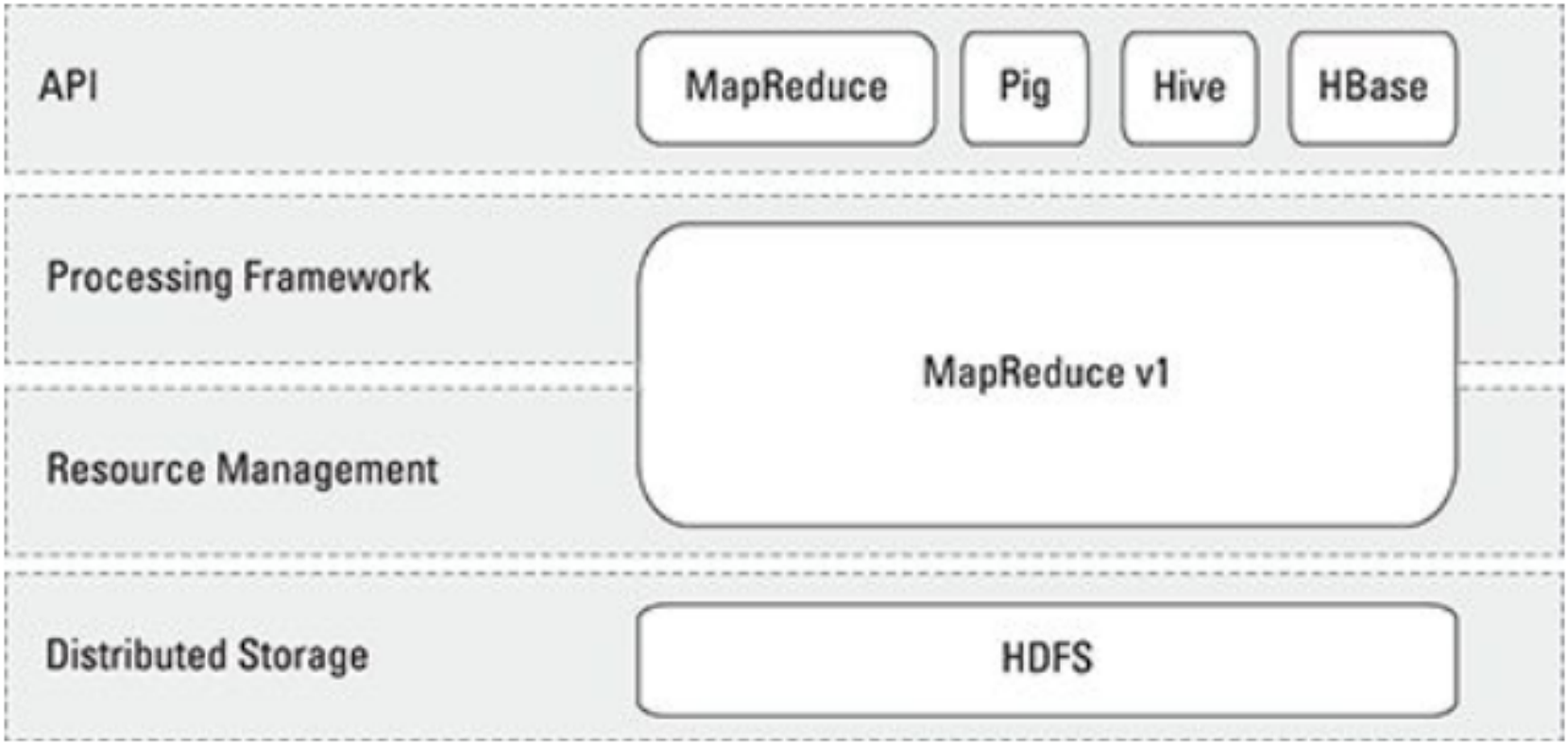
Four distinctive layers of Hadoop



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Course Main Thrust 2: Apache Spark and ML Library

Columbia University

APACHE Spark™ *Lightning-fast unified analytics engine*

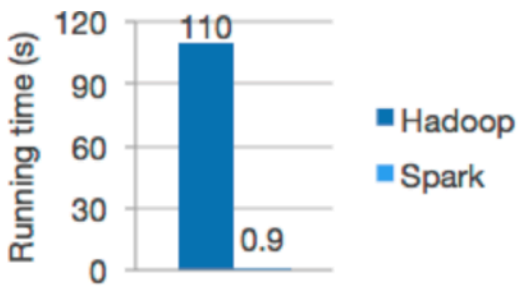
Download | Libraries | Documentation | Examples | Community | Developers

Apache Spark™ is a unified analytics engine for large-scale data processing.

Speed

Run workloads 100x faster.

Apache Spark achieves high performance for both batch and streaming data, using a state-of-the-art DAG scheduler, a query optimizer, and a physical execution engine.



Logistic regression in Hadoop and Spark

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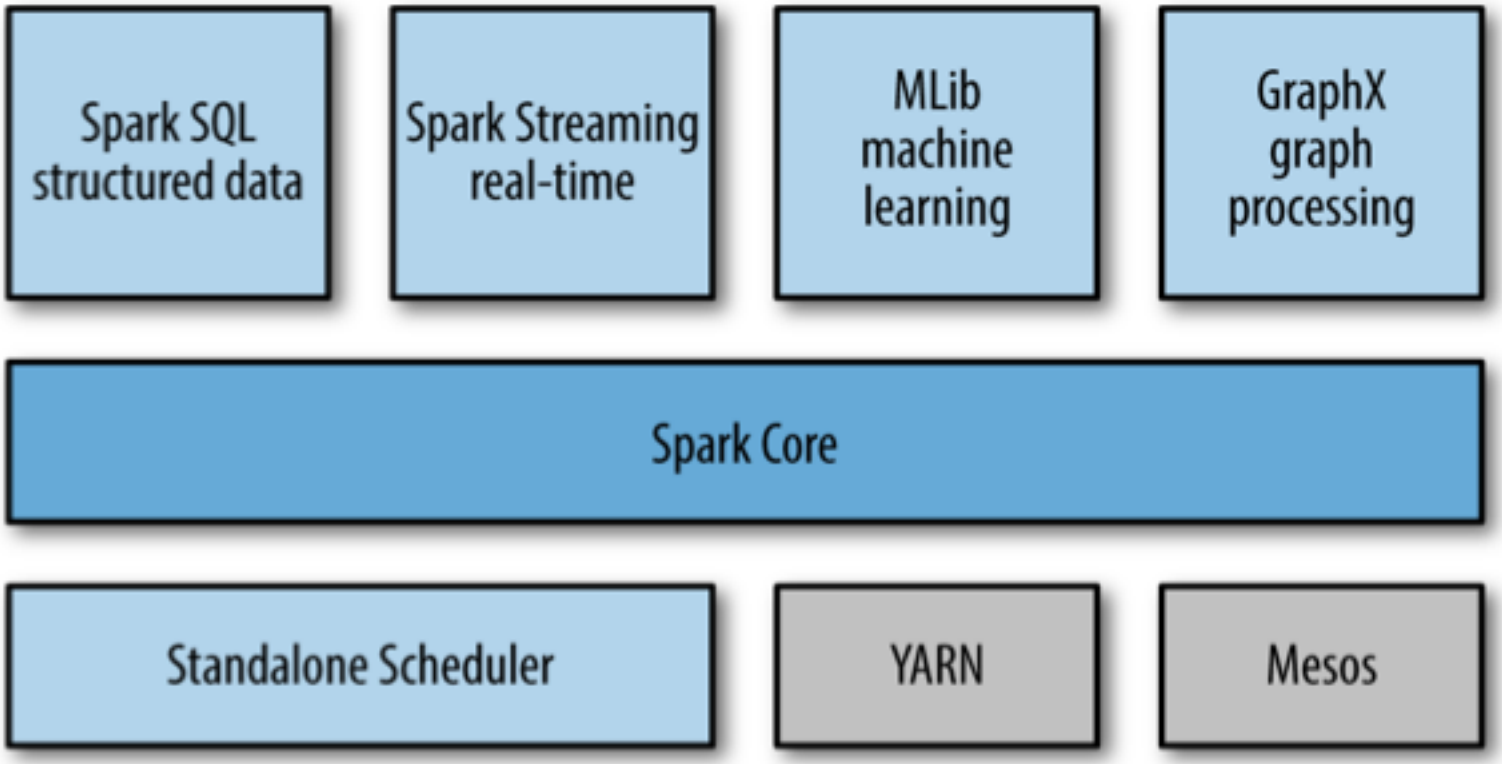
Main Spark Stack



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Course Main Thrust 3: Streaming and Linked Big Data Analytics

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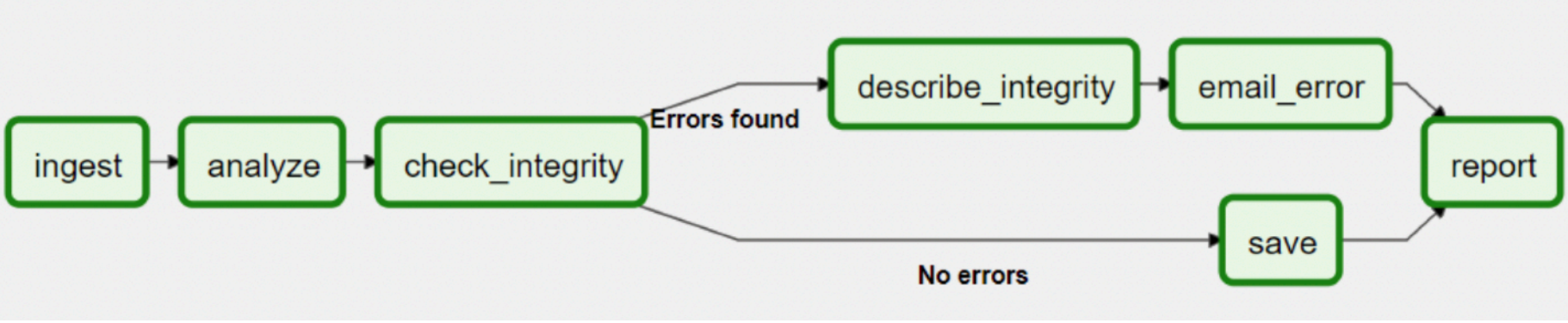
Course Main Thrust 3: Workflow and Analytics Pipeline



- A scheduler, which handles both triggering scheduled workflows, and submitting Tasks to the executor to run.
- An executor, which handles running tasks. In the default Airflow installation, this runs everything *inside* the scheduler, but most production-suitable executors actually push task execution out to *workers*.
- A *webserver*, which presents a handy user interface to inspect, trigger and debug the behaviour of DAGs and tasks.
- A folder of *DAG files*, read by the scheduler and executor (and any workers the executor has)
- A *metadata database*, used by the scheduler, executor and webserver to store state.

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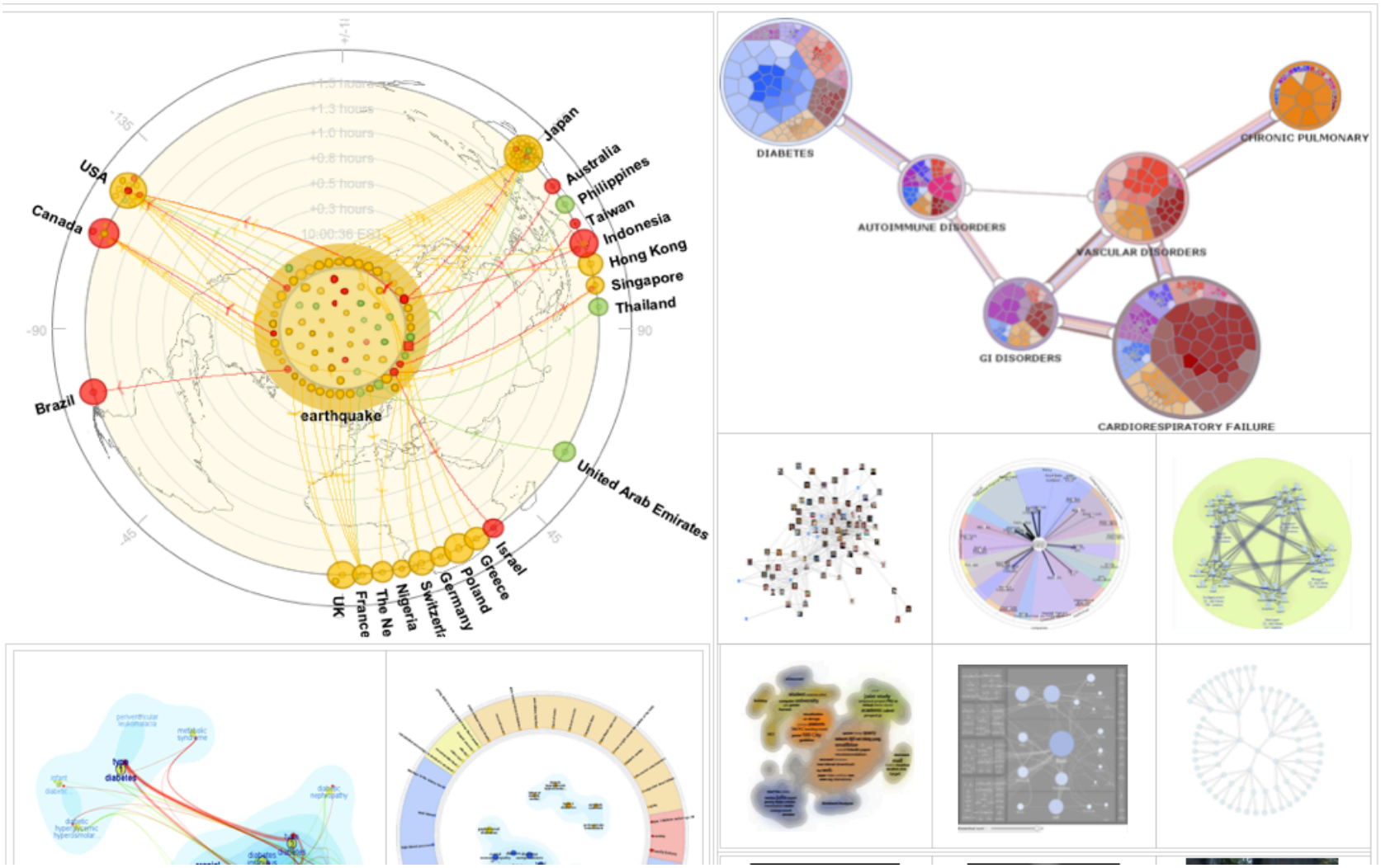
Course Main Thrust 4: Big Data Visualization



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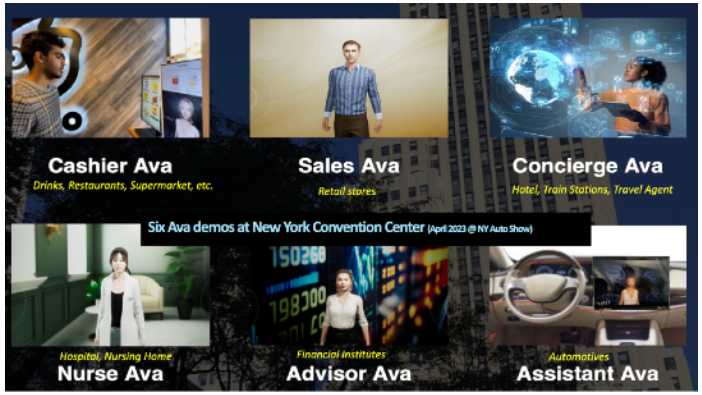
Course Main Thrust 5: Generative AI and Large Language Model



Graphen Ava — World's First AI Digital Human for Daily Life

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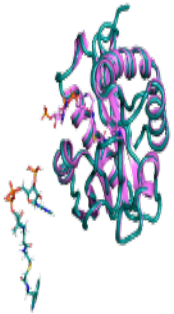
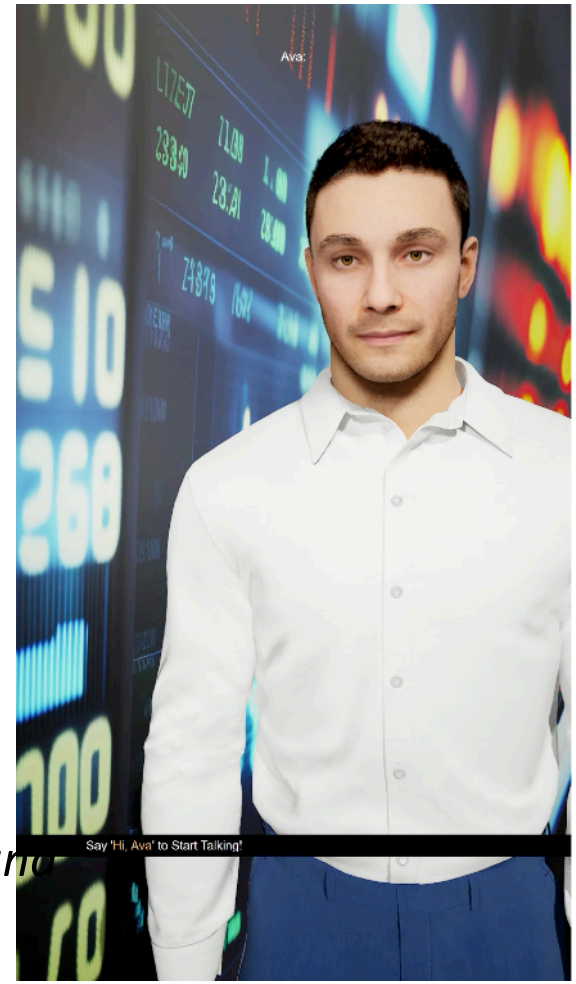
Course Main Thrust 6: Big Data AI Solutions

- **Big Data and AI for Finance**
- **Big Data and AI for Healthcare**

Graphen Small Mole Drug Dev ➔ 1/27 of the Time;
1/9000 of the Cost, comparing to traditional methods





*"Tools from established companies like **Google**, startups like **Graphen**, and AI chipsets from vendors like **NVIDIA** and **Intel** will help accelerate the speed of drug discovery, development, and testing, allowing pharmaceutical companies and healthcare authorities to combat the pandemic." – ABI research, May 2020*

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Why you want to take this class

- **Key Differentiator of this class:** Focusing on building a full-spectrum understanding of the latest Big Data Analytics technologies and using them to build real industry real-world solutions.

- **Sapphire Big Data Analytics Open Source Applications:** Create a Big Data open source toolsets for various industries (and disciplines)

- **Dataset and Use Cases:** Welcome!!

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Course Grading

- **5 Homeworks: 50%**
  - -- **Individual work**; Language Requirement: Python, JavaScript; Get familiar with Linux
  - -- **Report (including description of the work, discussions, experiments, etc) and source code**
    - **HW #0: Big Data Environment Setup and Testing**
    - **HW #1: Analytic Algorithms and System Monitoring**
    - **HW #2: Streaming Big Data and Analytics Pipeline**
    - **HW #3: Big Data Analytics Visualization and Linked Big Data**
    - **HW #4: Big Data and Generative AI**

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Course Grading

- **Final Project: 50%**

  -- Teamwork: 2 - 3 students per team (on campus); 1 - 3 students per team for CVN

  - **Proposal** (slides — short presentation in the class)
  - **Progress Presentation** (slides — short presentation in the class)
  - **Progress Report** (report)
  - **Final Report** (paper, up to 10 pages)
  - **Workshop Presentation** (Oral and Demo)
  - **Open Source Codes**
  - **Video Presentation** (on YouTube)

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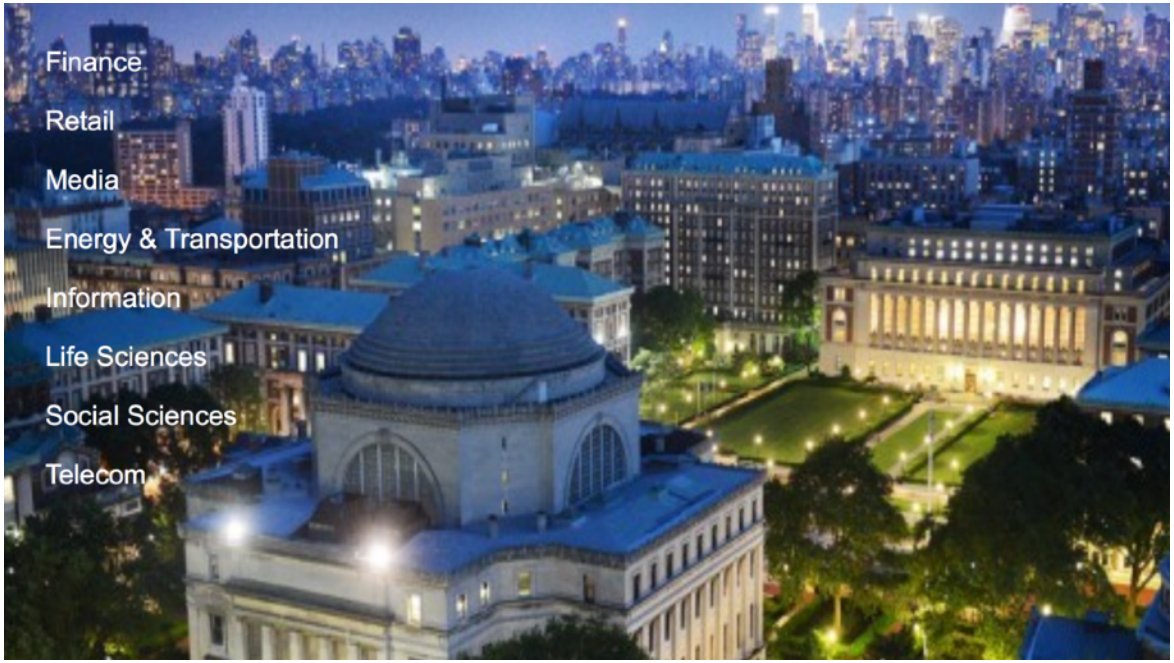
Course Information

- Website:

  http://www.ee.columbia.edu/~cylin/course/bigdata/

- Textbook:

  -- None, but reference book(s) and/or articles/papers will be provided each lecture.



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Course Outline

Class Date	Class Number	Topics Covered
09/08/23	1	Introduction of Big Data Analytics
09/15/23	2	Big Data Platforms
09/22/23	3	Big Data Analytics Algorithms
09/29/23	4	Real-Time Stream Analysis
10/06/23	5	End-to-End System Workflow
10/13/23	6	Linked Big Data Analysis
10/20/23	7	Big Data Visualization
10/27/23	8	Big Data and Generative AI
11/03/23	9	Final Project Proposal Presentation
11/10/23	10	Large Language Models
11/17/23	11	Final Project Progress Presentation
11/24/23		Thanksgiving Holiday
12/01/23	12	Big Data Analytics Applications -- AI Finance
12/08/23	13	Big Data Analytics Applications -- AI Medical
12/15/23	14	Big Data Analytics Workshop

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Assignments and Submissions

Class Date	Class Number	Assignment	Due
09/08/23	1	HW #0 Big Data Environment Setup and Testing [assignment][tutorial]	
09/15/23	2	HW #0 Tutorial II	
09/22/23	3	HW #1 Analytics Algorithms and System Monitoring [assignment][tutorial]	HW #0
09/29/23	4	HW #1 Tutorial II	
10/06/23	5	HW #2 Streaming Big Data Analytics and Pipeline [assignment][tutorial]	HW #1
10/13/23	6	HW #2 Tutorial II	
10/20/23	7	HW #3 Big Data Visualization [assignment][tutorial]	HW #2
10/27/23	8	HW#3 Tutorial II	
11/03/23	9		Proposal Slides
11/10/23	10	HW #4 Big Data and Generative AI [assignment][tutorial]	HW #3
11/17/23	11		Progress Slides
11/24/23			
12/01/23	12		HW #4 & Progress Report
12/08/23	13		
12/15/23	14		Final Project Slides and Other Materials

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Other Issues

- Professor Lin:
  - Office Hours:
    By appointment
  - Contact: c.lin@columbia.edu

- TA (CA/IA/Grader) —
  - Qingcheng Yu: TBD (onsite) and TBD (onsite)
  - Gudmundur Jonasson: TBD (online) and TBD (onsite)
  - Ajinkeya Chitrey (tentative): TBD (online) and TBD (onsite)

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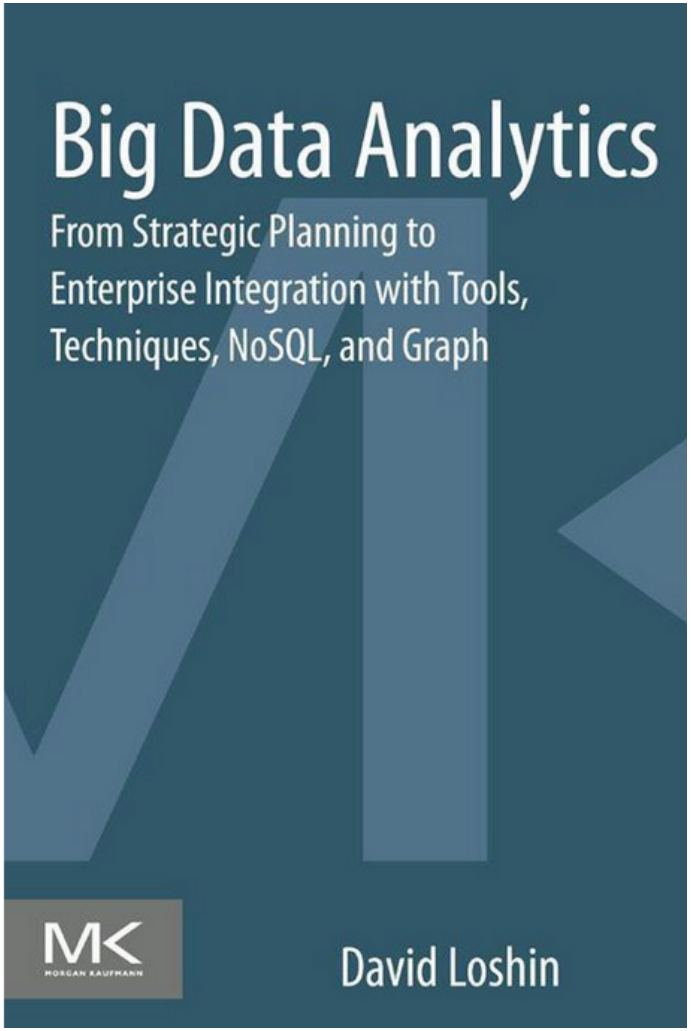
Reading Reference for Lecture 1



Chapter 1: Market and Business Drivers for Big Data Analysis

Chapter 2: Business Problems Suited to Big Data Analytics

Chapter 3: Achieving Organizational Alignment for Big Data Analytics

Chapter 4: Developing a Strategy for Integrating Big Data Analytics into the Enterprise

Chapter 5: Data Governance for Big Data Analytics: Considerations for Data Policies and Processes

Chapter 6: Introduction to High-Performance Appliances for Big Data Management

Chapter 7: Big Data Tools and Techniques

Chapter 8: Developing Big Data Applications

Chapter 9: NoSQL Data Management for Big Data

Chapter 10: Using Graph Analytics for Big Data

Chapter 11: Developing the Big Data Roadmap

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5 Example Big Data Use Case Categories

Big Data Exploration
Find, visualize, understand all big data to improve decision making

Enhanced 360º View of the Customer
Extend existing customer views (MDM, CRM, etc) by incorporating additional internal and external information sources

Security/Intelligence Extension
Lower risk, detect fraud and monitor cyber security in real-time

Operations Analysis
Analyze a variety of machine data for improved business results

Data Warehouse Augmentation
Integrate big data and data warehouse capabilities to increase operational efficiency

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Big Data Examples -- Application Use Cases

1. Expertise Location
2. Recommendation
3. Commerce
4. Financial Analysis
5. Social Media Monitoring
6. Telco Customer Analysis
7. Healthcare Analysis
8. Data Exploration and Visualization
9. Personalized Search
10. Anomaly Detection
11. Fraud Detection
12. Cybersecurity
13. Sensor Monitoring (Smarter another Planet)
14. Cellular Network Monitoring
15. Cloud Monitoring
16. Code Life Cycle Management
17. Traffic Navigation
18. Image and Video Semantic Understanding
19. Genomic Medicine
20. Brain Network Analysis
21. Data Curation
22. Near Earth Object Analysis

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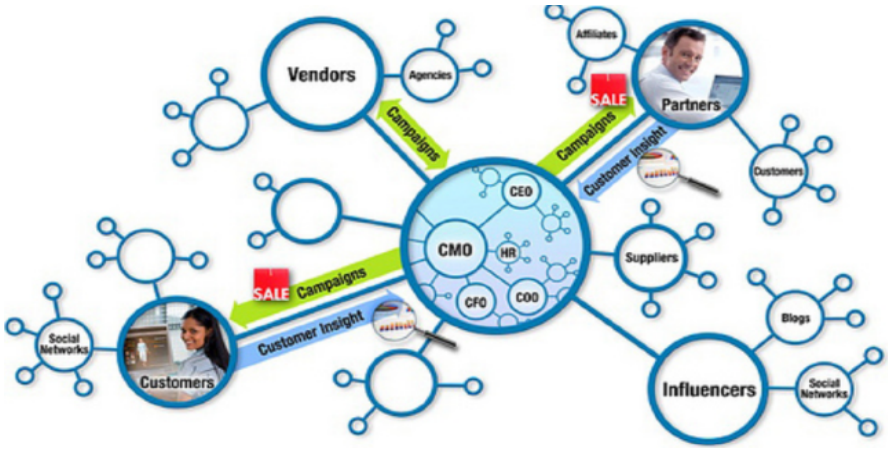
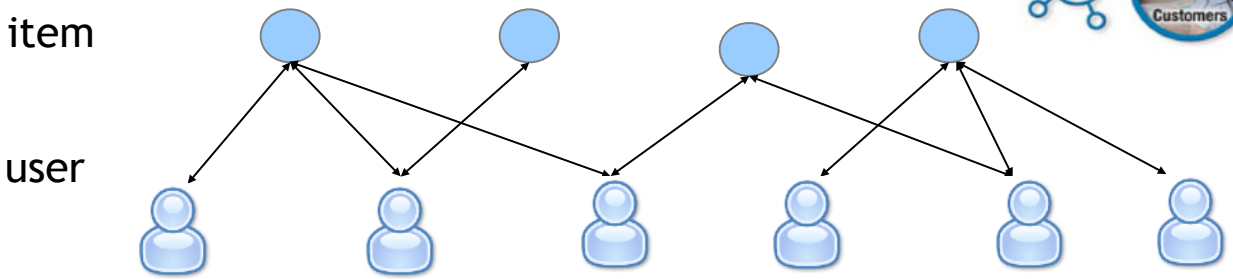
Category 1: 360° View

Recommendation





Enhancing:

Coremetrics An IBM Company

unica

Graph Visualizations

Communities	Graph Search	Network Info Flow	Bayesian Networks
Centralities	Graph Query	Shortest Paths	Latent Net Inference
Ego Net Features	Graph Matching	Graph Sampling	Markov Networks

Middleware and Database

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Use Case 1: Social Network Analysis in Enterprise for Productivity

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Production Live System used by IBM GBS since 2009 – verified ~$100M contribution

15,000 contributors in 76 countries; 92,000 annual unique IBM users

25,000,000+ emails & SameTime messages (incl. Content features)

1,000,000+ Learning clicks; 14M KnowledgeView, SalesOne, …, access d

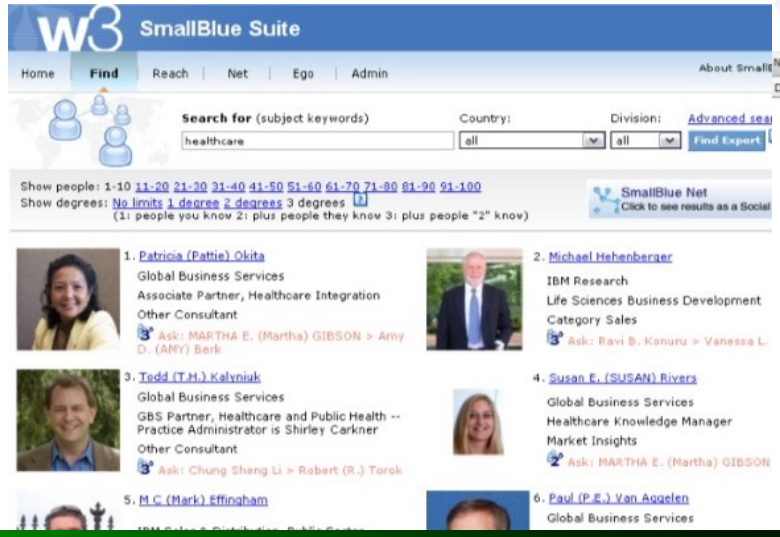
1,000,000+ Lotus Connections (blogs, file sharing, bookmark) data

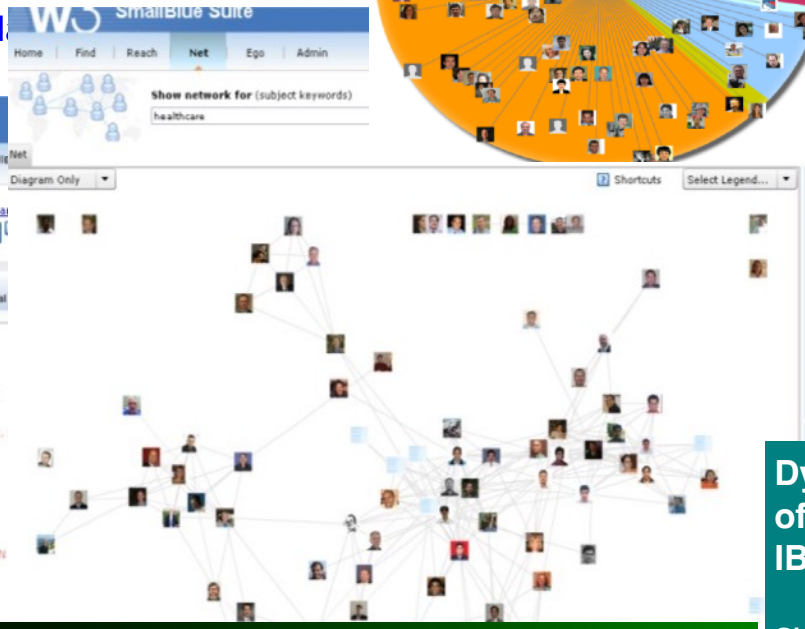
200,000 people's consulting project & earning d

Shortest Paths

Centralities

Graph Search





Dynamic networks of 400,000+ IBMers:

Shortest Paths
Social Capital
Bridges
Hubs
Expertise Search
Graph Search
Graph Recomm.

- On BusinessWeek four times, including being the Top Story of Week, April 2009
- Help IBM earned the 2012 Most Admired Knowledge Enterprise Award
- Wharton School study: $7,010 gain per user per year using the tool
- In 2012, contributing about 1/3 of GBS Practitioner Portal $228.5 million savings an
- APQC (WW leader in Knowledge Practice) April 2013:
  "The Industry Leader and Best Practice in Expertise Location"

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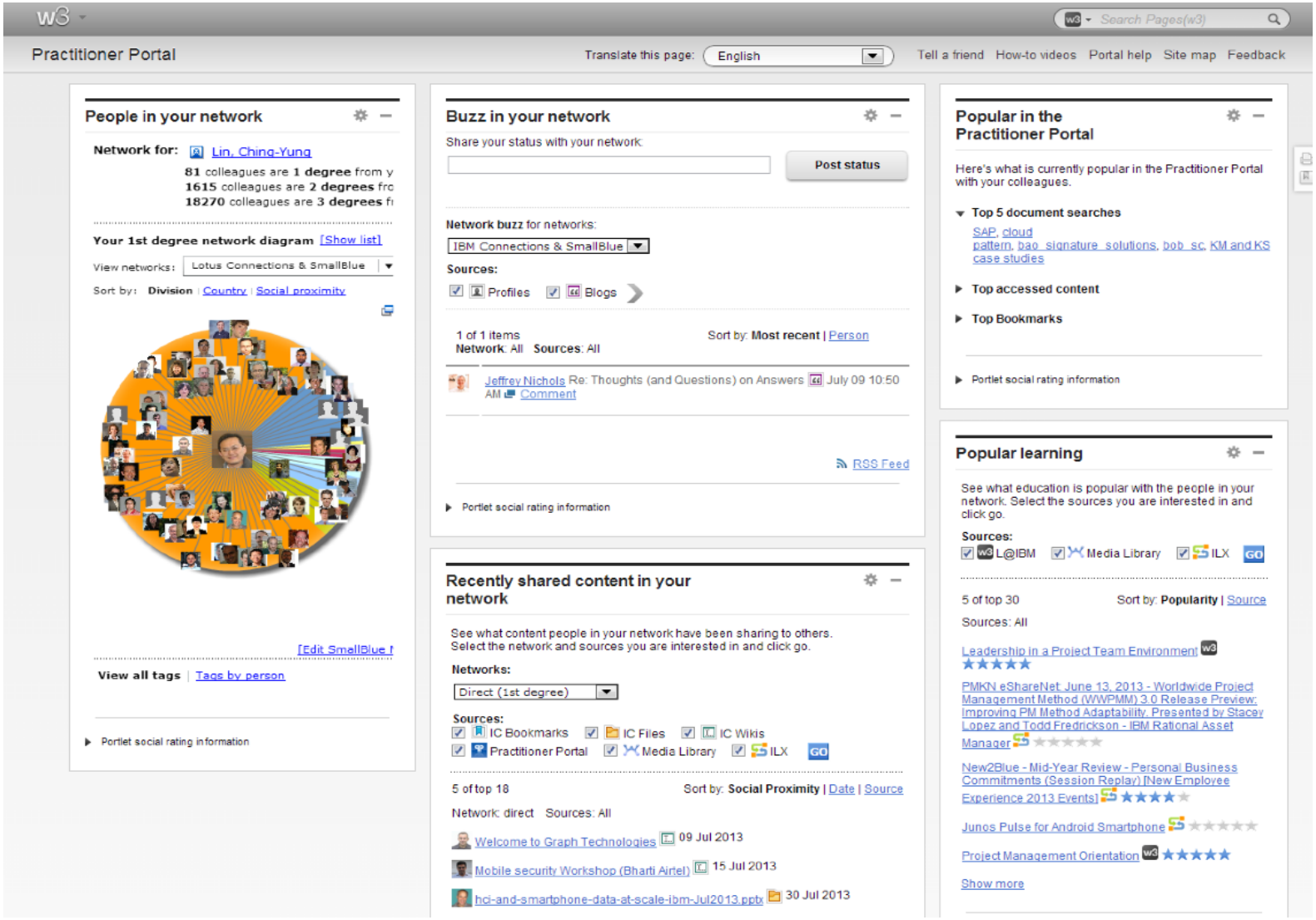
Use Case 2: Personalized Recommendation



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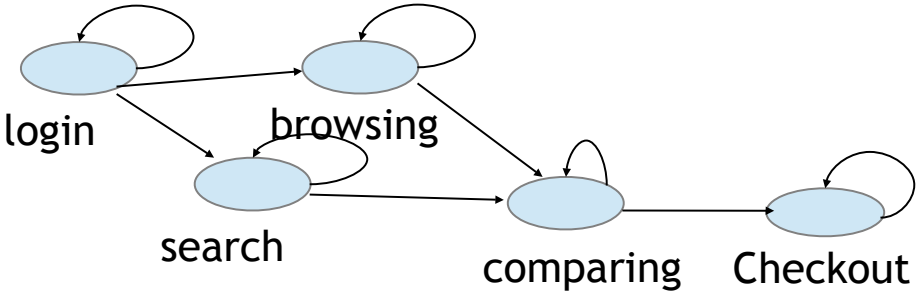
Use Case 3: Customer Behavior Sequence Analytics

Markov Network | Latent Network | Bayesian Network



- Behavior Pattern Detection
- Help Needed Detection

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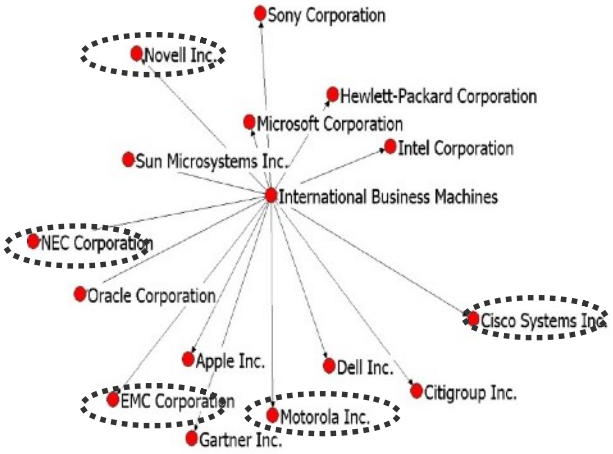
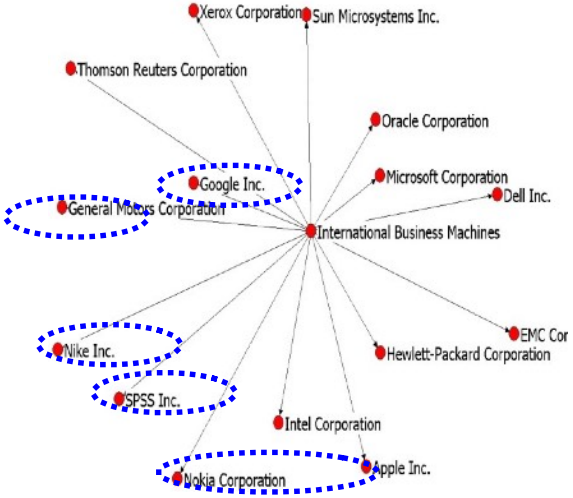
Use Case 4: Graph Analytics for Financial Analysis

Goal: *Injecting Network Graph Effects for Financial Analysis. Estimating company performance considering correlated companies, network properties and evolutions, causal parameter analysis, etc.*

- IBM 2003



- IBM 2009

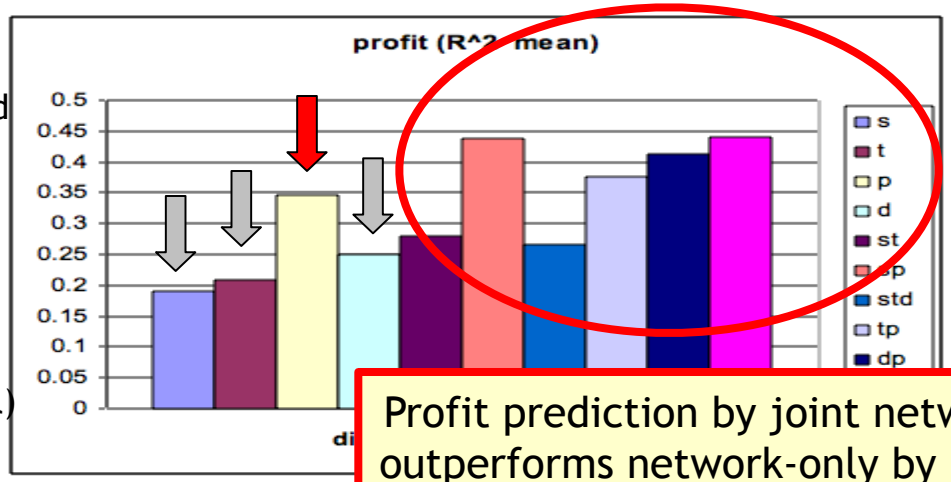


- Data Source:
  - Relationships among 7594 companies, data mining from NYT 1981 ~ 2009

Targets: 20 Fortune companies' normalized Profits

Goal: Learn from previous 5 years, and predict next year

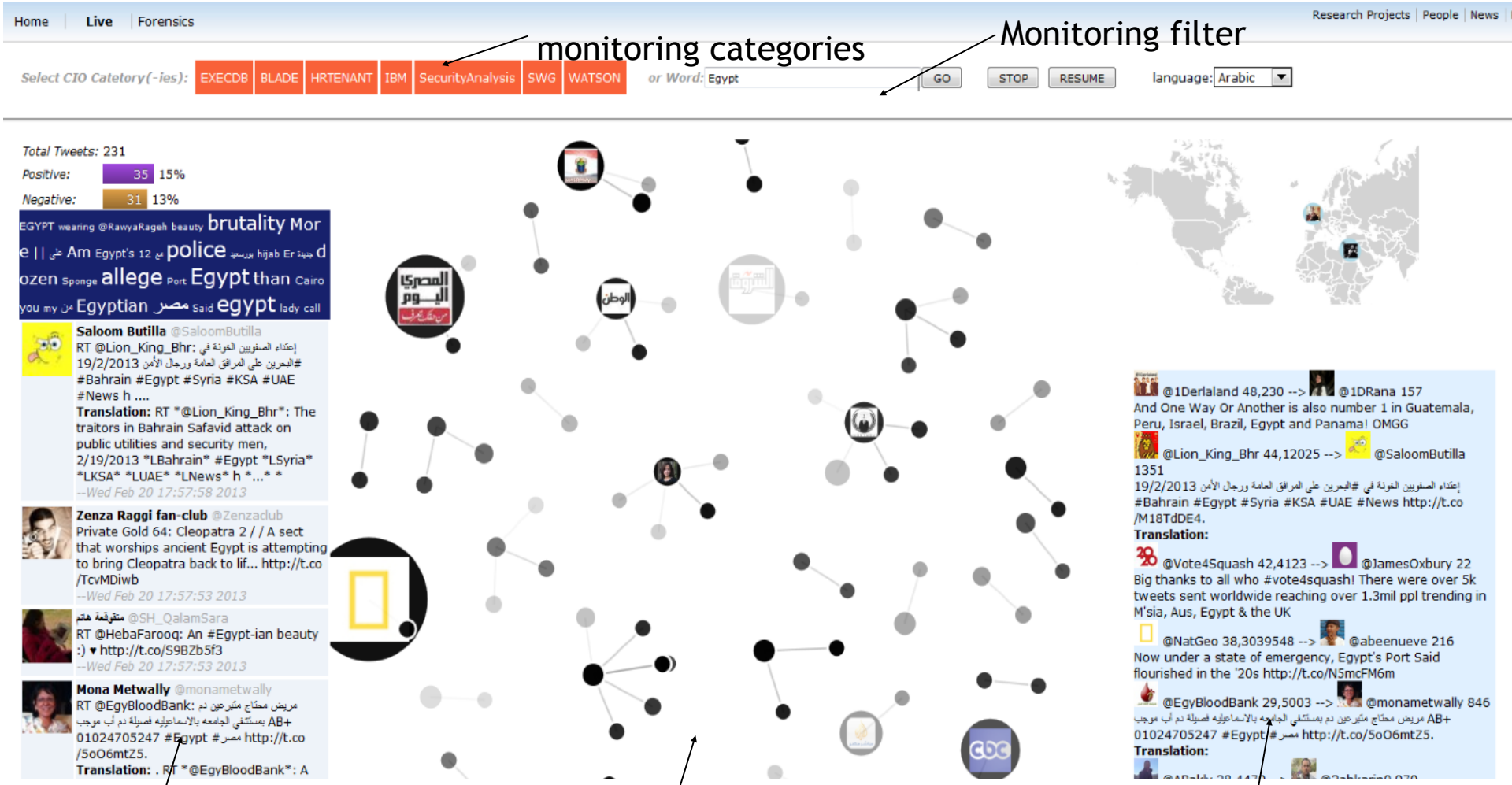
Model: Support Vector Regression (RBF kernel)



Network feature:
s (current year network feature),
t (temporal network feature),
d (delta value of network feature)
Financial feature:
p (historical profits and

Profit prediction by joint network and financial analysis outperforms network-only by 130% and financial-only by 33%.

Use Case 5: Social Media Monitoring



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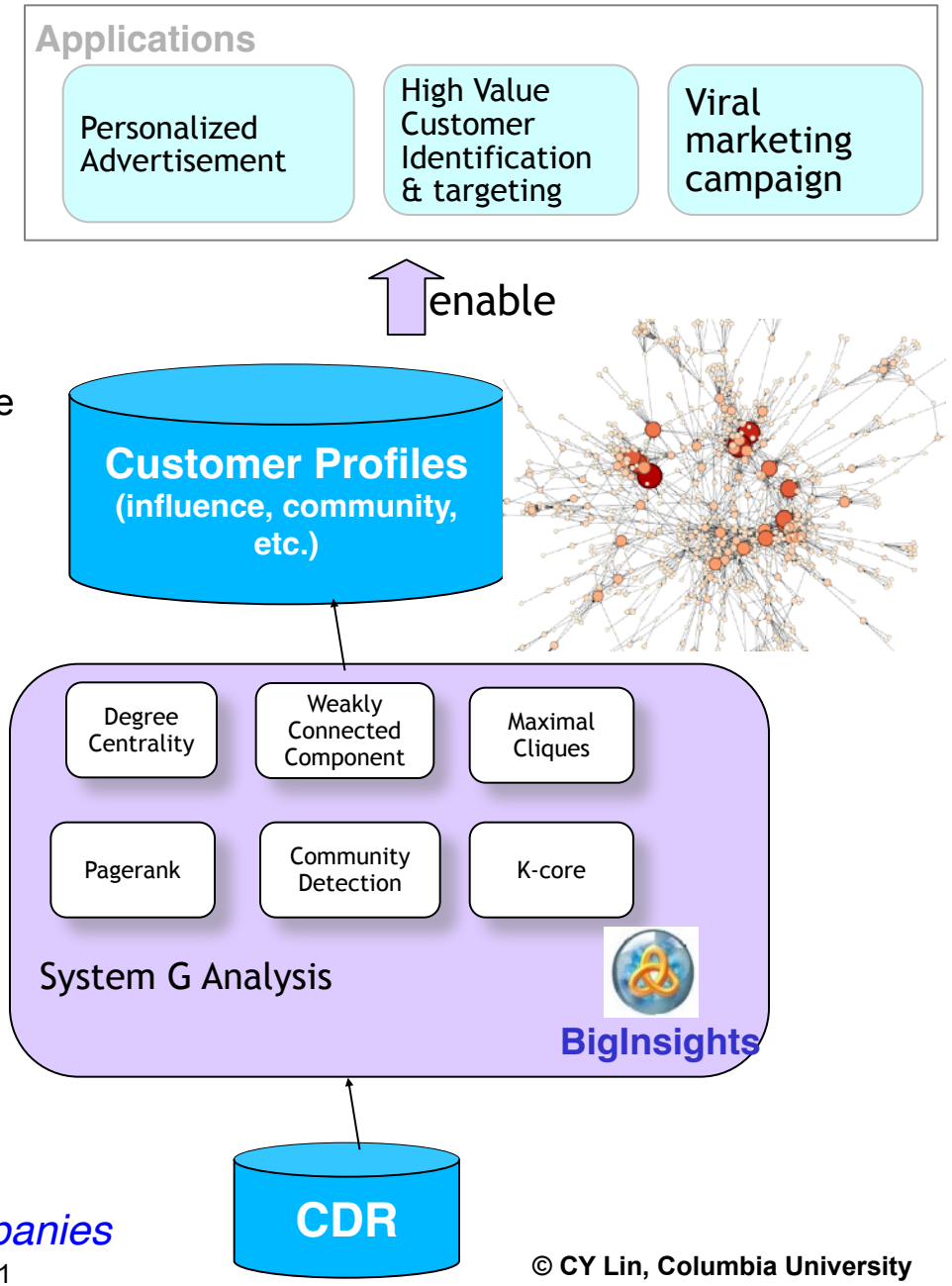
Use Case 6: Customer Social Analysis for Telco

Goal: Extract customer social network behaviors to enable Call Detail Records (CDRs) data monetization for Telco.

- Applications based on the extracted social profiles
  - Personalized advertisement (beyond the scope of traditional campaign in Telco)
  - High value customer identification and targeting
  - Viral marketing campaign
- Approach
  - Construct social graphs from CDRs based on {caller, callee, call time, call duration}
  - Extract customer social features (e.g. influence, communities, etc.) from the constructed social graph as customer social profiles
  - Build analytics applications (e.g. personalized advertisement) based on the extracted customer social profiles



PoCs with Chinese and Indian Telecomm companies

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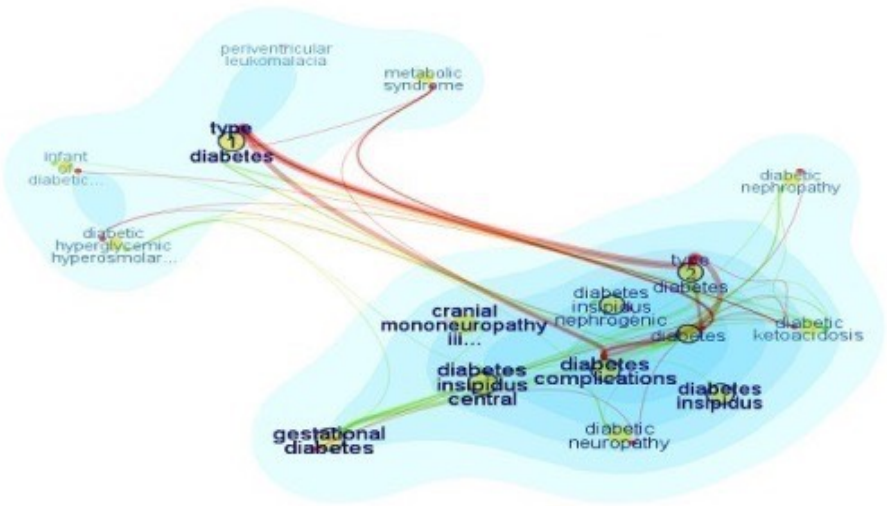
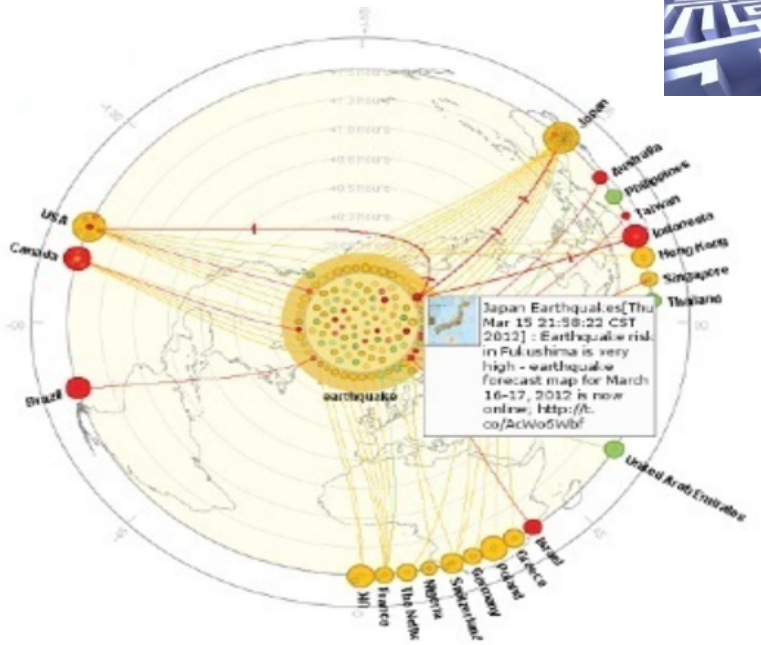
Category 2: Data Exploration





Enhancing:

Vivisimo

CÚRAM SOFTWARE

Huge Network Visualization | Network Propagation | I2 3D Network Visualization | Geo Network Visualization | Graphical Model

Communities | Graph Search | Network Info Flow | Bayesian Networks

Centralities | Graph Query | Shortest Paths | Latent Net Inference

Ego Net Features | Graph Matching | Graph Sampling | Markov Networks

Middleware and Database

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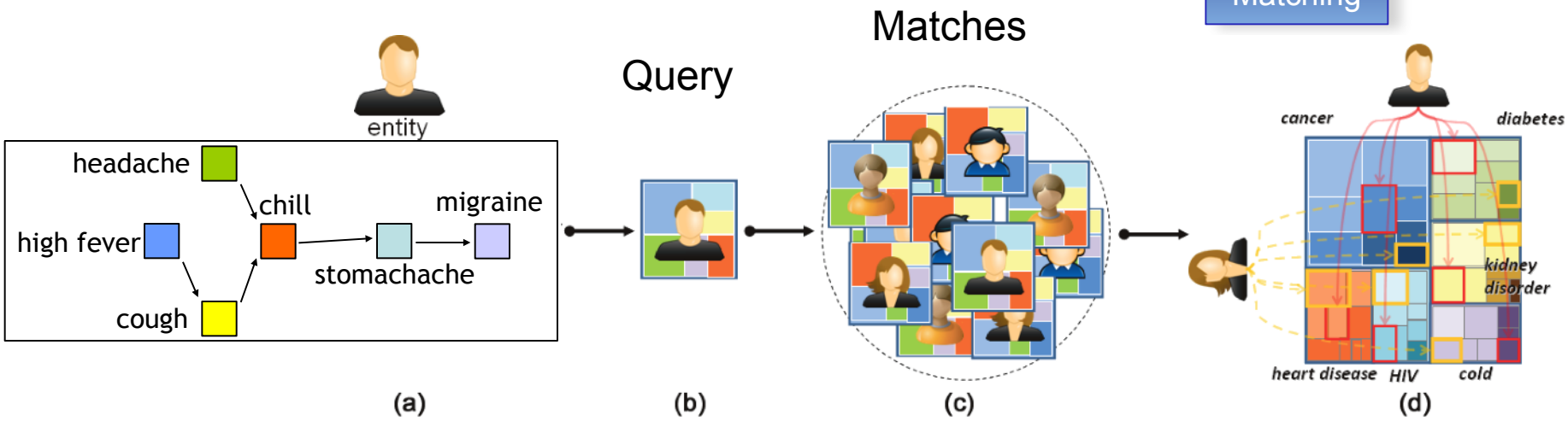
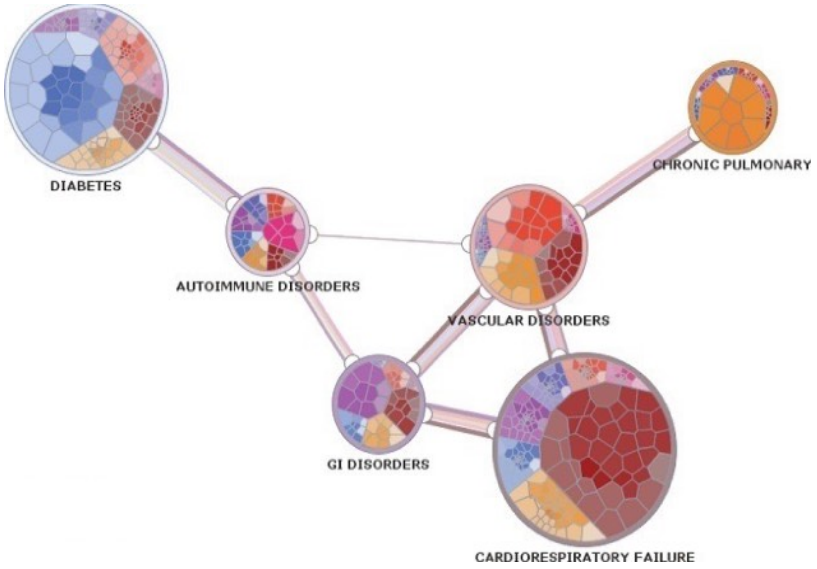
Use Case 7: Graph Analytics and Visualization

Columbia University

Graph Matching



Graph Communities



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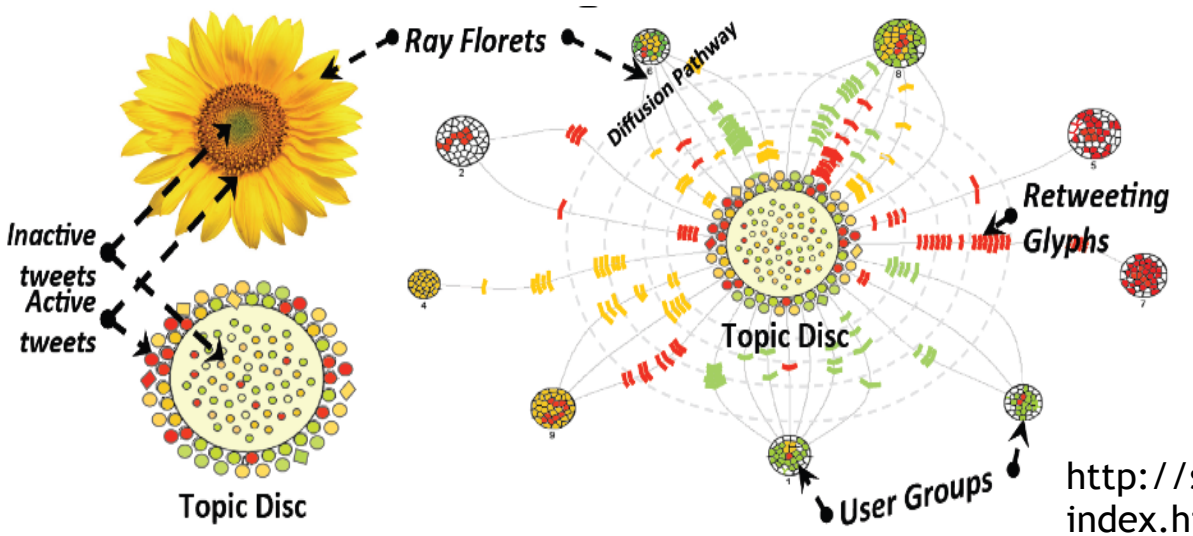
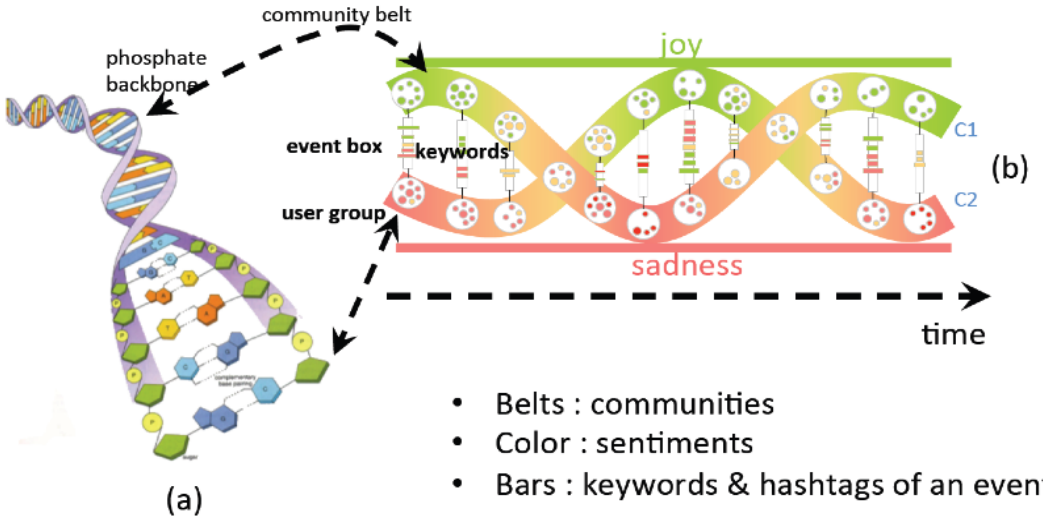
User Case 8: Visualization for Navigation and Exploration



Whisper : Tracing the information diffusion in Social Media

http://systemg.ibm.com/apps/whisper/index.html

SocialHelix: Visualizaiton of Sentiment Divergence in Social Media



- Belts : communities
- Color : sentiments
- Bars : keywords & hashtags of an event

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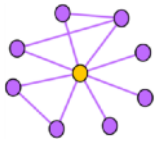
Use Case 9: Graph Search

Graph Search

existing search engine

query



Info-Socio networks

index

ranking

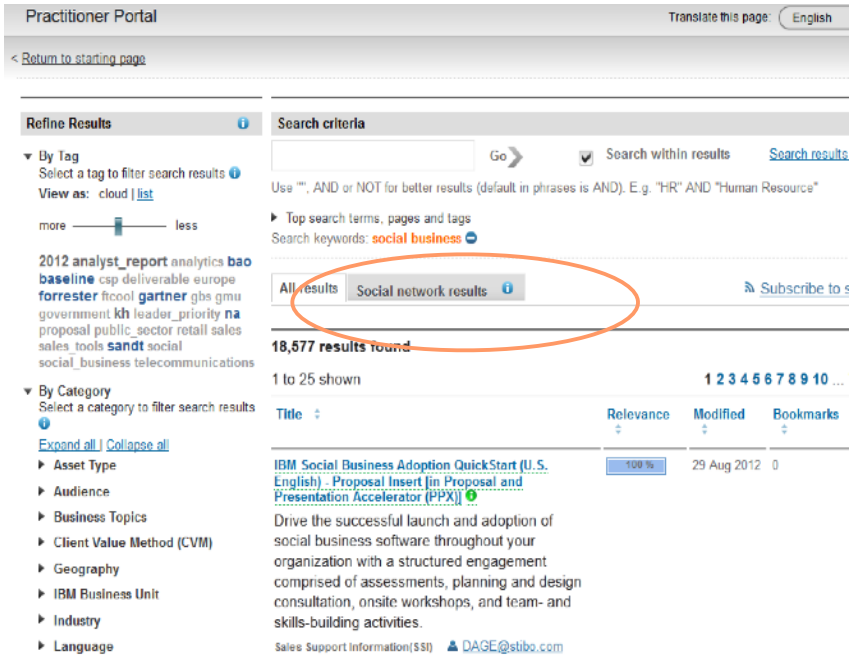
re-ranking

Improved search results

Interest / social network based content recommendations

Graph analysis

query context



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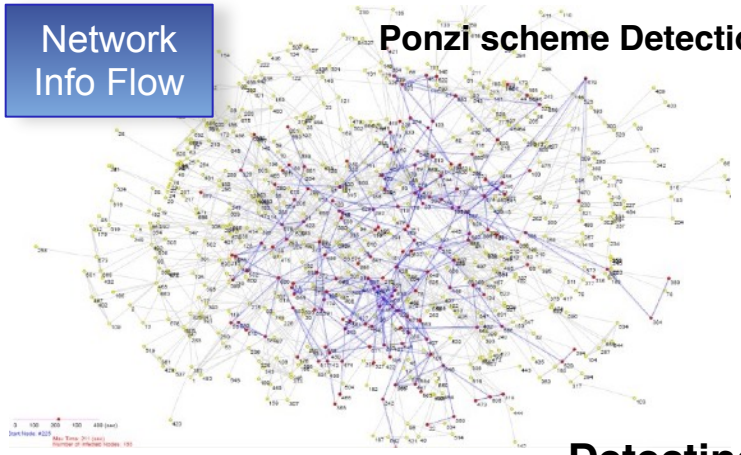
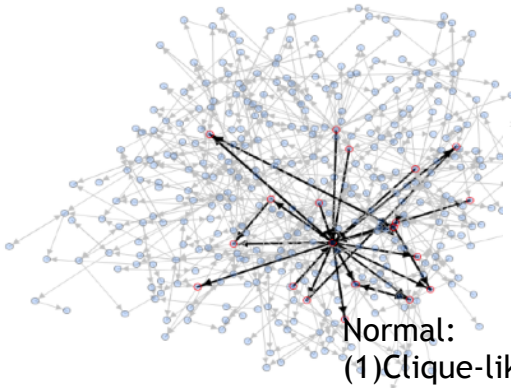
Category 3: Security

Network Info Flow

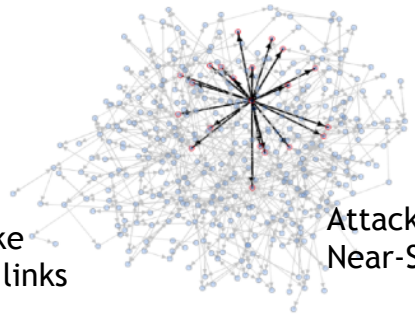
Ponzi scheme Detection



Ego Net Features

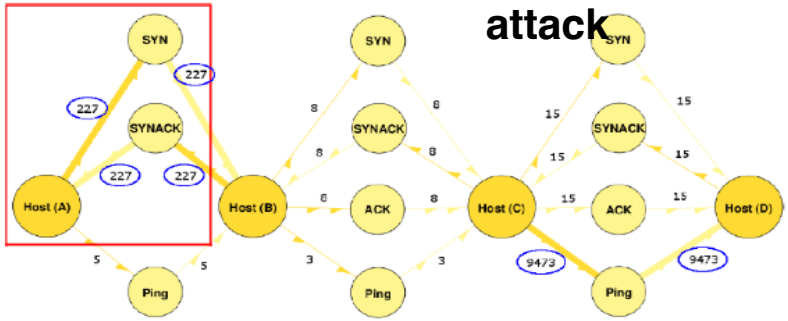


Normal:
(1)Clique-like
(2)Two-way links

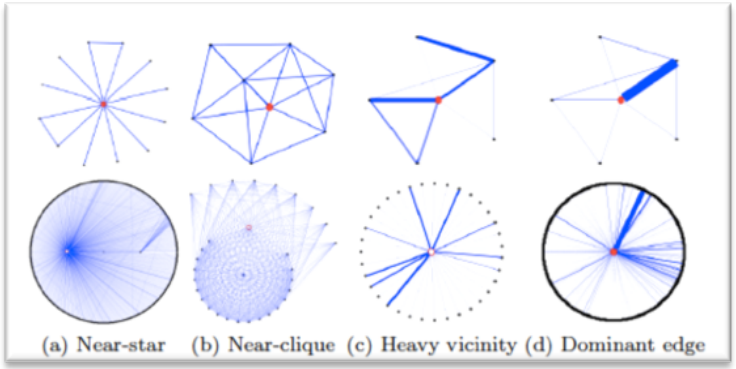


Attacker:
Near-Star

Detecting DoS attack



(a) Single large graph representing TCP SYN and ICMP PING network traffic, with two Denial of Service (DoS) attacks taking place.



(a) Near-star (b) Near-clique (c) Heavy vicinity (d) Dominant edge

Graph Visualizations

Communities	Graph Search	Network Info Flow	Bayesian Networks
Centralities	Graph Query	Shortest Paths	Latent Net Inference
Ego Net Features	Graph Matching	Graph Sampling	Markov Networks

Middleware and Database

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Use Case 10: Anomaly Detection at Multiple Scales

Based on President Executive Order 13587

Goal: System for Detecting and Predicting Abnormal Behaviors in Organization, through large-scale social network & cognitive analytics and data mining, to decrease insider threats such as espionage, sabotage, colleague-shooting, suicide, etc.

"Enterprise Information Leakage Impacted economy and jobs" Feb 2013

"What's emerged is a multibillion dollar detective industry"
npr Jan 10, 2013

Emails
Instant Messaging
Web Access
Executed Processes
Printing
Copying
Log On/Off

→ **Social sensors** | **Click streams capturer** | **Feed subscription** | **Database access**

→ ***Graph analysis*** | ***Behavior analysis*** | **Semantics analysis** | **Psychological analysis**

→ Multimodality Analysis →

Detection, Prediction & Exploration Interface

Infrastructure + ~ 490 Analytics

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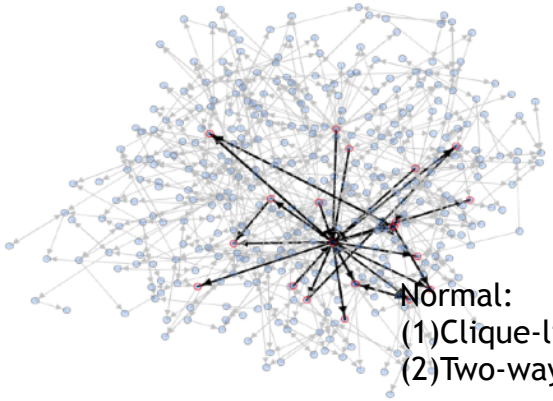
Use Case 11: Fraud Detection for Bank

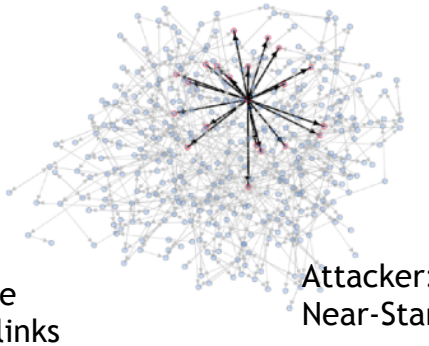
Network Info Flow

Ego Net Features

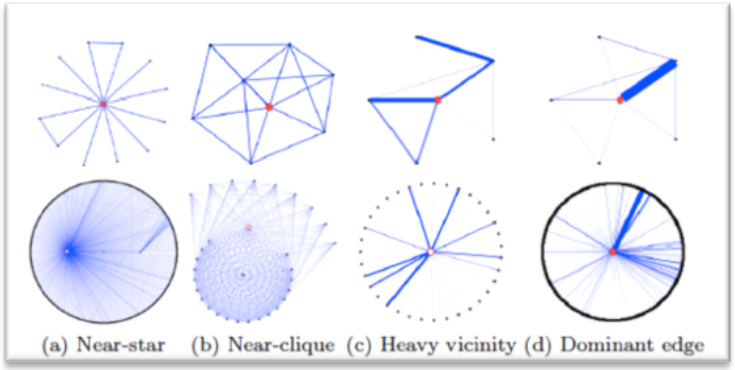
Ponzi scheme Detection



Normal:
(1)Clique-like
(2)Two-way links



Attacker:
Near-Star



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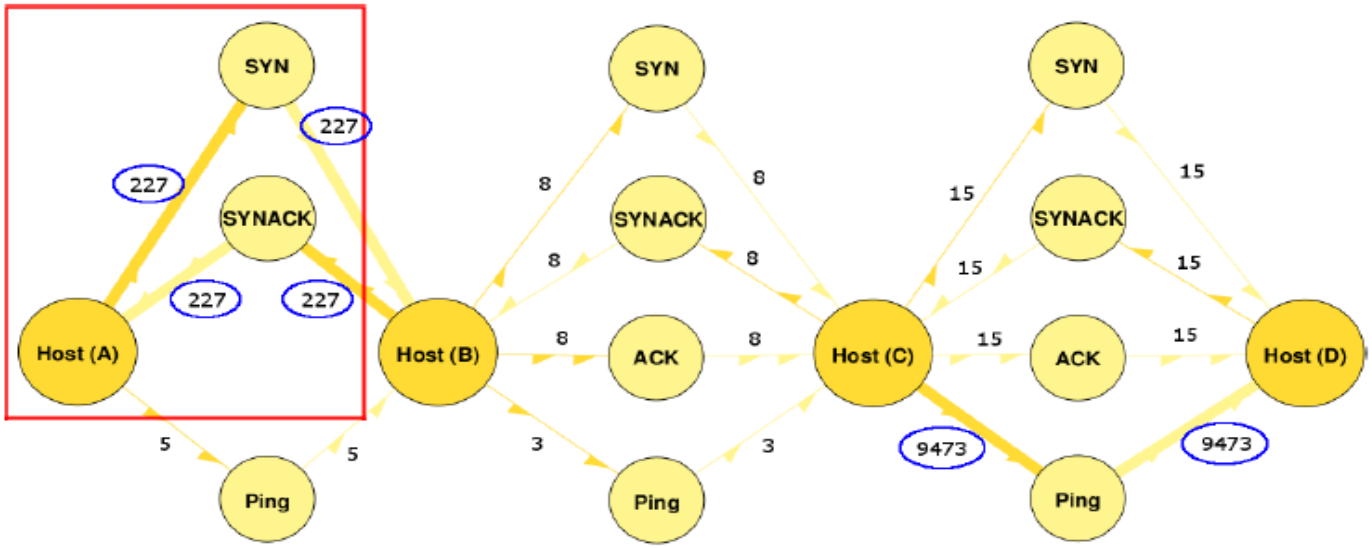
Use Case 12: Detecting Cyber Attacks

Network Info Flow

Ego Net Features

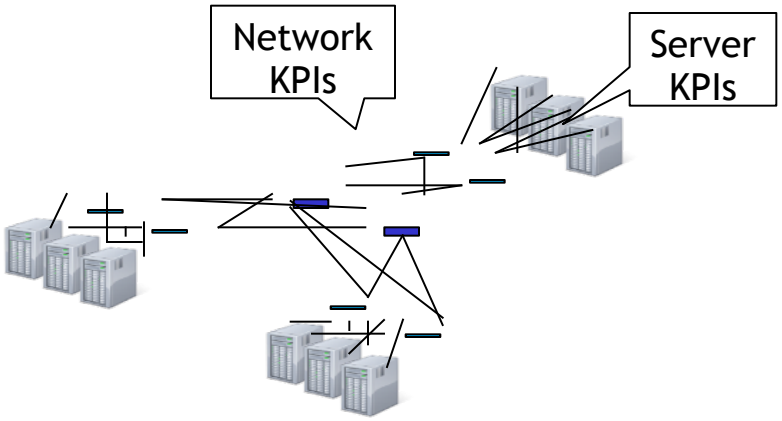
Detecting DoS attack



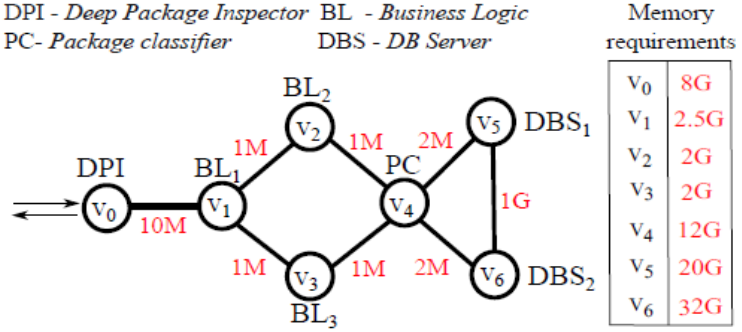
(a) Single large graph representing TCP SYN and ICMP PING network traffic, with two Denial of Service (DoS) attacks taking place.

© CY Lin, Columbia University

Category 4: Operations Analysis



Cloud Service Placement

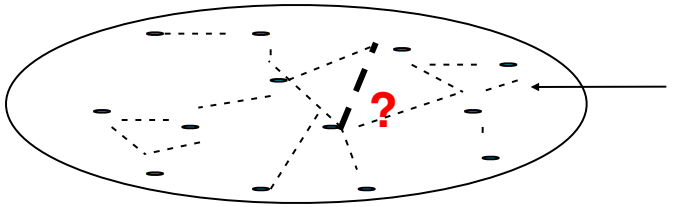


Graph Matching

Bayesian Network

KPI time series (e.g., server performance/ load, network performance/load)

Causality analyzer



Varying over time

– KPI (a time series)

--- (potential) pairwise relationship (e.g., causality)

Graph Visualizations

Communities	Graph Search	Network Info Flow	Bayesian Networks
Centralities	Graph Query	Shortest Paths	Latent Net Inference
Ego Net Features	Graph Matching	Graph Sampling	Markov Networks

Middleware and Database

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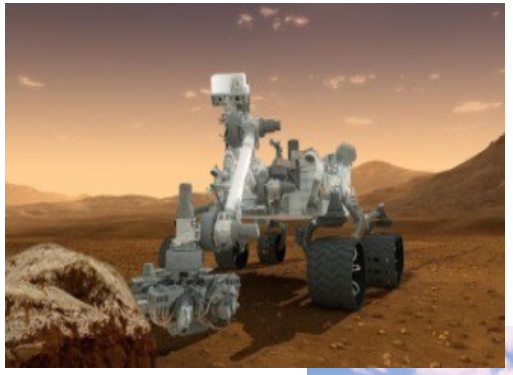
Use Case 13: Smarter *another* Planet

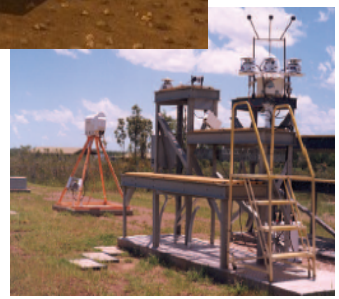
Columbia University

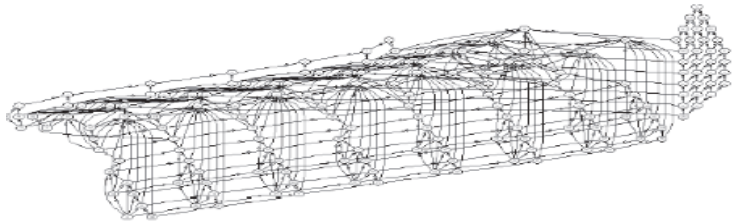
Bayesian Network

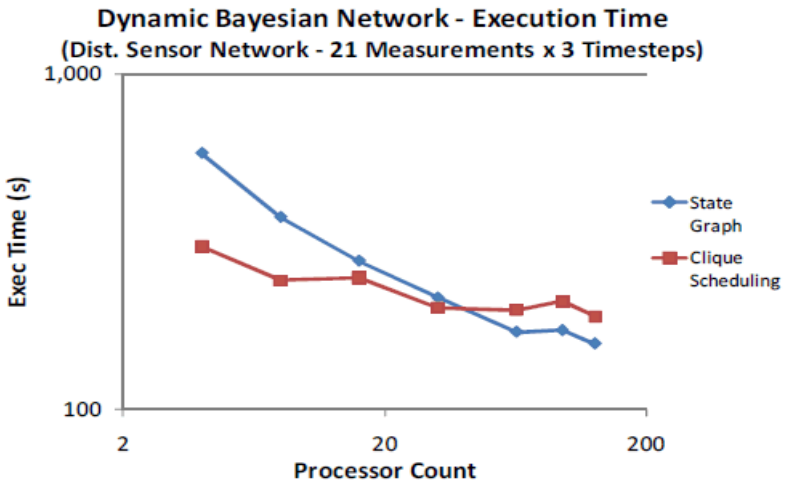
Goal: Atmospheric Radiation Measurement (ARM) climate research facility provides *24x7 continuous field observations* of cloud, aerosol and radiative processes. **Graphical models** can automate the validation with improvement efficiency and performance.



Approach: BN is built to represent the dependence among sensors and replicated across timesteps. BN parameters are learned from over *15 years* of ARM climate data to support distributed climate sensor validation. Inference validates sensors in the connected instruments.







Bayesian Network

* 3 timesteps * 63 variables
* 3.9 avg states * 4.0 avg indegree
* 16,858 CPT entries

Junction Tree

* 67 cliques
* 873,064 PT entries in cliques

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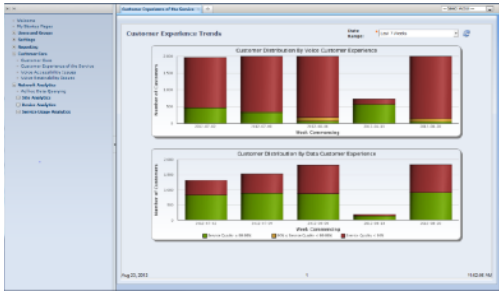
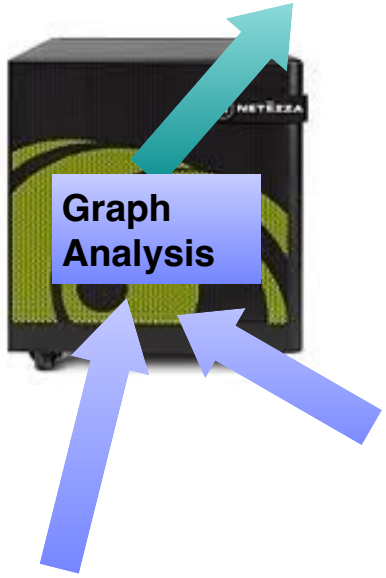
Use Case 14: Cellular Network Analytics in Telco Operation

Goal: Efficiently and uniquely identify *internal* state of Cellular/Telco networks (e.g., performance and load of network elements/links) using probes between monitors placed at selected network elements & endhosts

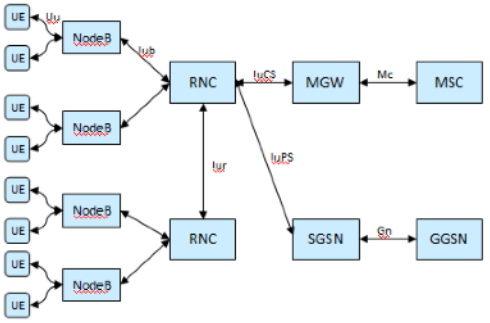


Network load level report

- Applied Graph Analytics to telco network analytics based on CDRs (call detail records): estimate traffic load on CSP network with low monitoring overhead
  - (1)CDRs, already collected for billing purposes, contain information about voice/data calls
  - (2)Traditional NMS* and EMS** typically lack of end-to-end visibility and topology across vendors
  - (3)Employ graph algorithms to analyze network elements which are not reported by the usage data from CDR information
- Approach
  - Cellular network comprises a hierarchy of network elements
  - Map CDR onto network topology and infer load on each network element using graph analysis
  - Estimate network load and localize potential problems



Network topology



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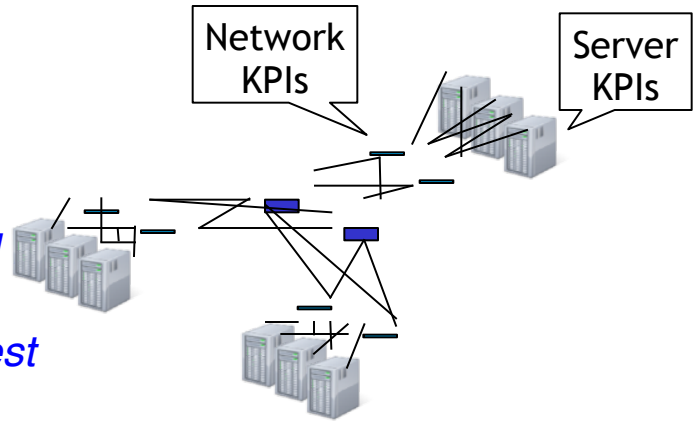
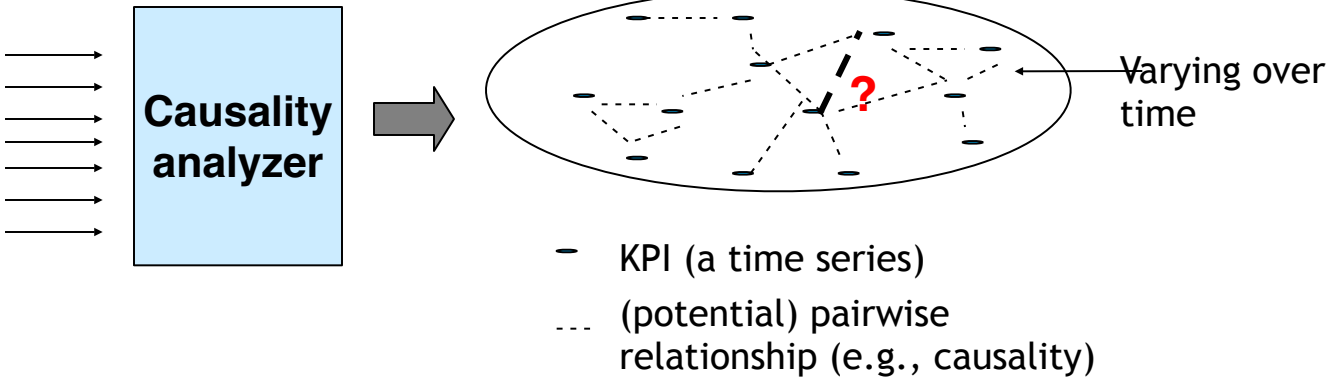
Use Case 15: Monitoring Large Cloud

Goal: *M*onitoring technology that can track the time-varying state (e.g., causality relationships between KPIs) of a large Cloud when the processing power of monitoring system cannot keep up with the scale of the system & the rate of change

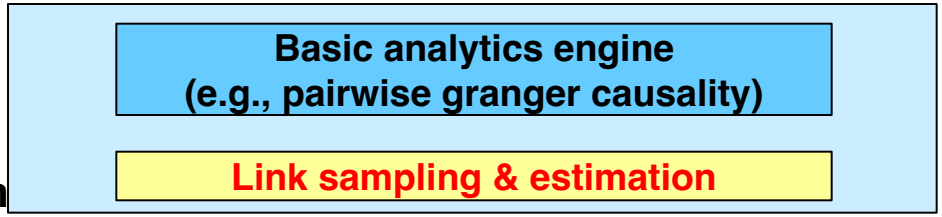
- *Causality relationships (e.g., Granger causality) are crucial performance monitoring & root cause analysis*
- *Challenge: easy to test pairwise relationship, but hard to test multi-variate relationship (e.g., a large number of KPIs)*



KPI time series (e.g., server performance/load, network performance/load)



Our approach: Probabilistic monitoring via sampling & estimation



Select KPI pairs (sampling) → *Test link existence* → *Estimate unsampled links based on history* → *Overall graph*

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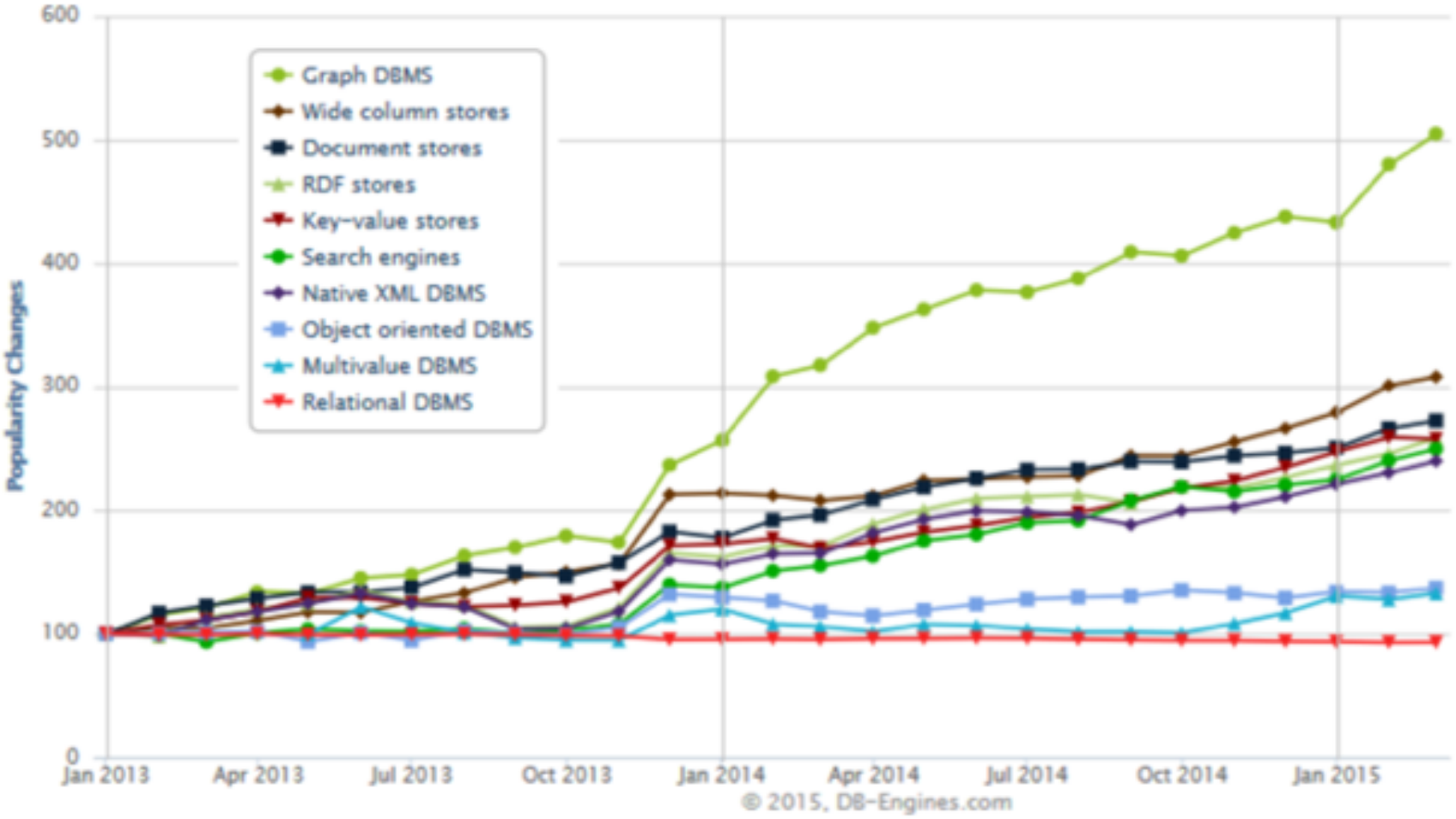
Category 5: Data Warehouse Augmentation



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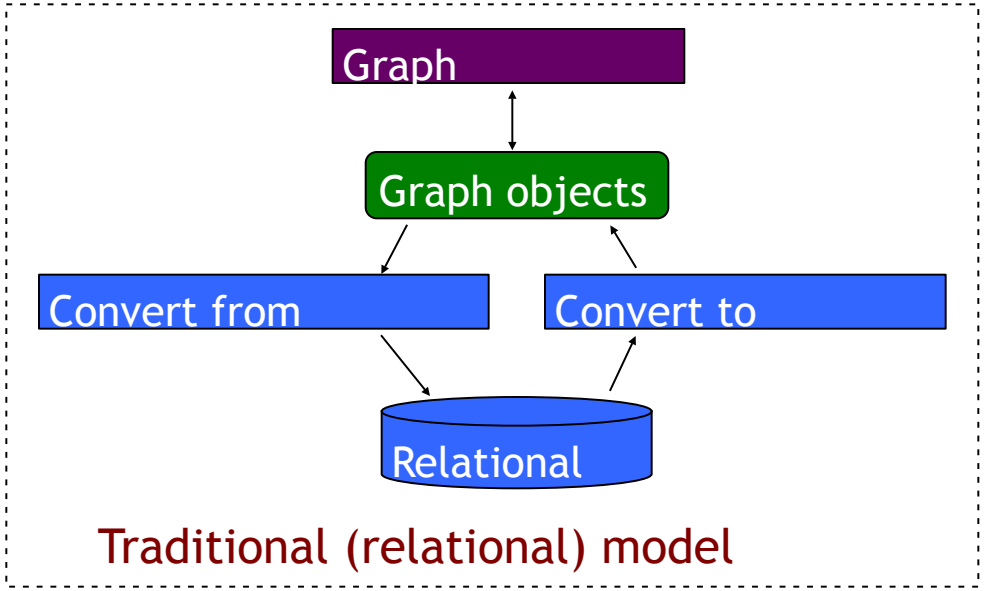
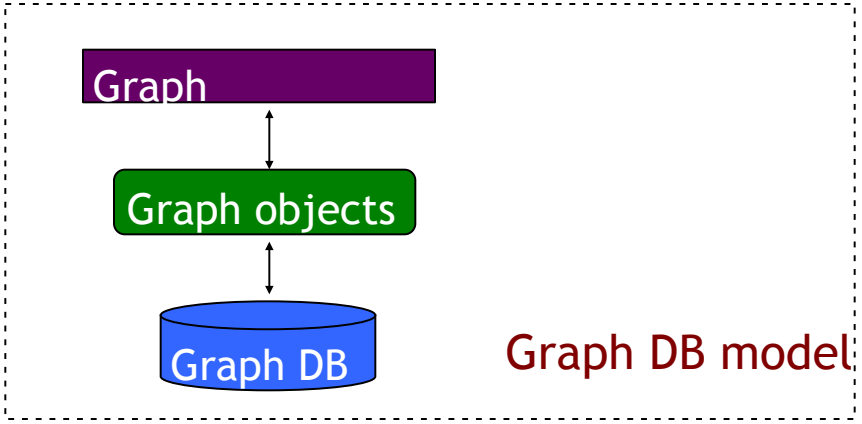
Use Case 16: Code Life Cycle Improvement





- Advantages of working directly with graph DB for graph applications
  - (1) Smaller and simpler code
  - (2) Flexible schema → easy schema evolution
  - (3) Code is easier and faster to write, debug and manage
  - (4) Code and Data is easier to transfer and maintain

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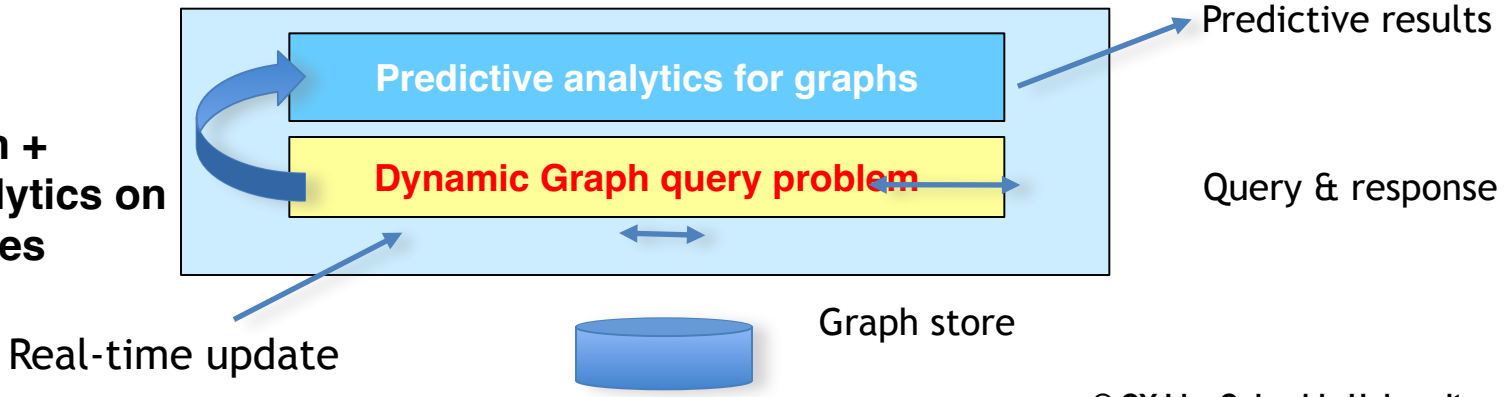
Use Case 17: Smart Navigation Utilizing Real-time Road Information

Goal: *Enable unprecedented level of accuracy in **traffic scheduling** (for a fleet of transportation vehicles) and navigation of individual cars utilizing the **dynamic real-time information** of changing road condition and predictive analysis on the data*

- *Dynamic graph algorithms implemented in System G provide **highly efficient graph query computation** (e.g. shorted path computation) on time-varying graphs (order of magnitudes improvement over existing solutions)*

- *High-throughput **real-time predictive analytics** on graph makes it possible to estimate the future traffic condition on the route to make sure that the decision taken now is optimal overall*

Our approach: Querying over dynamic graph + predictive analytics on graph properties



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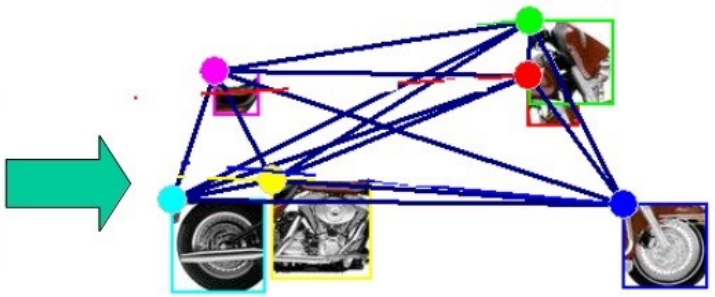
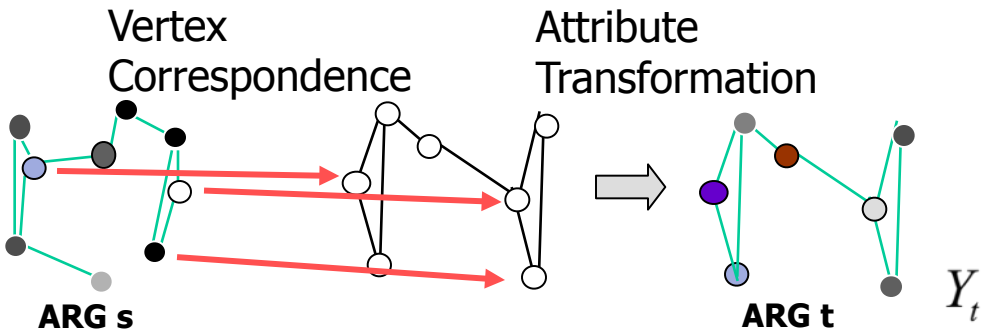
Use Case 18: Graph Analysis for Image and Video Analysis





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Use Case 19: Graph Matching for Genomic Medicine

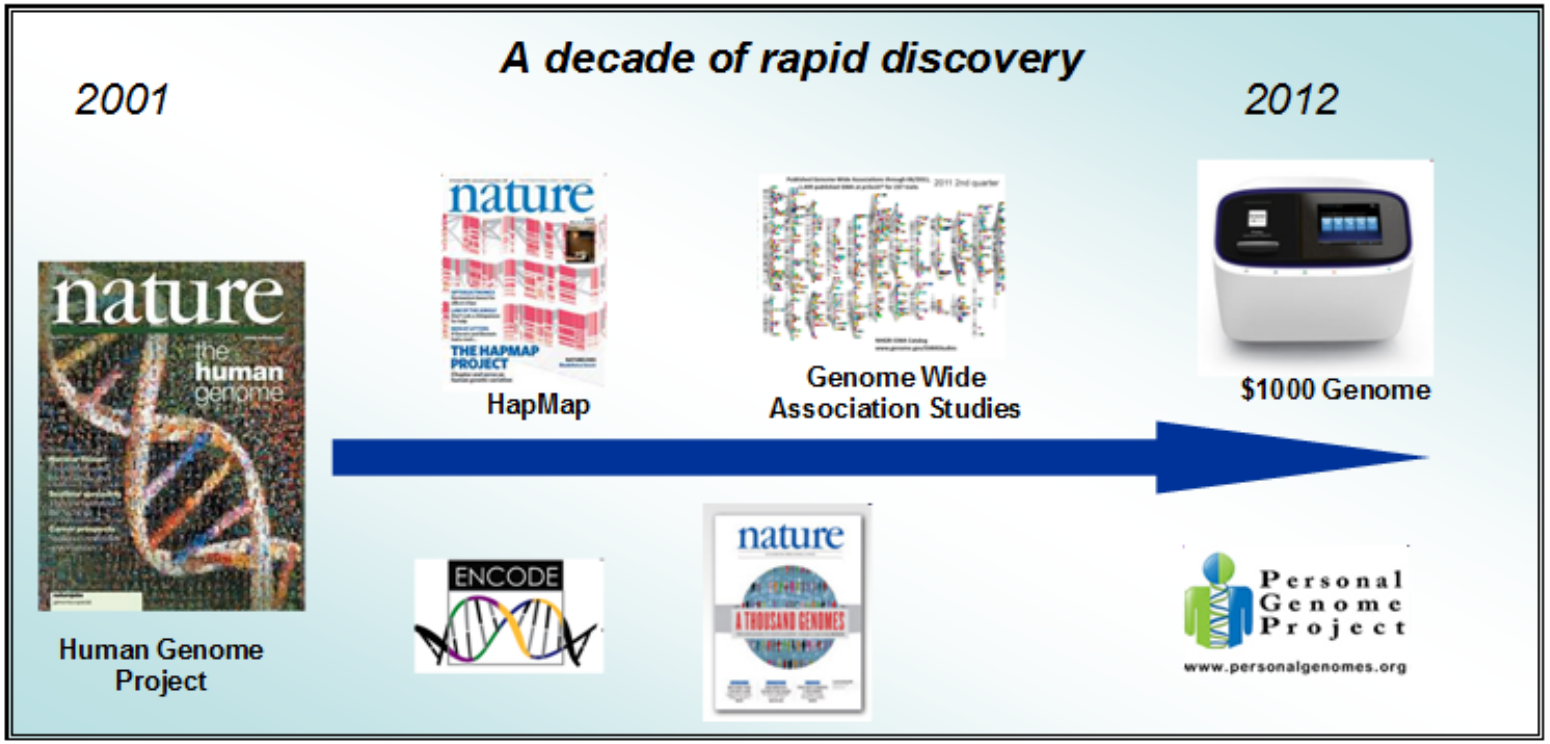

Figure 1: Since the Human Genome Project, various projects have started to reveal the mysteries of genomes and the $1000 Genome is almost reality.

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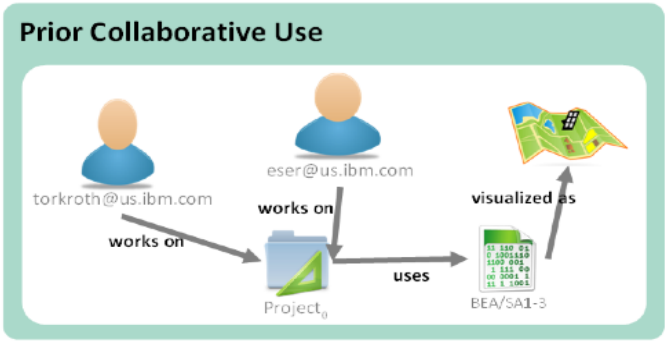
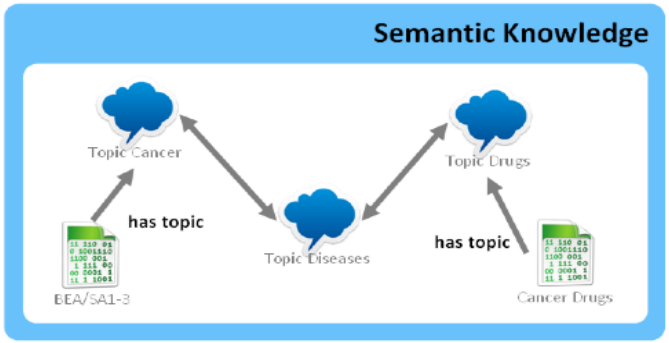
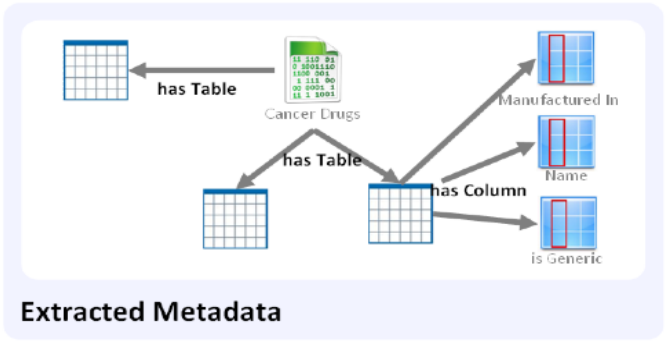
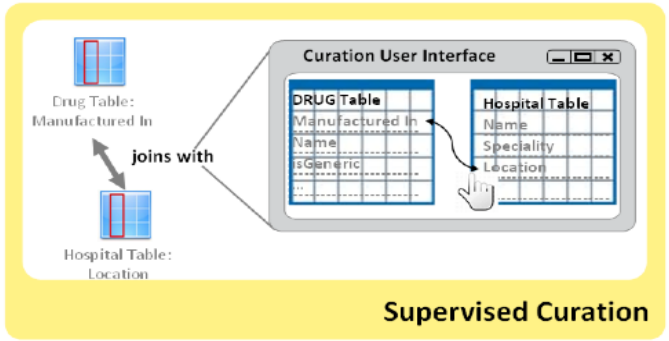
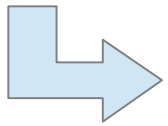
Use Case 20: Data Curation for Enterprise Data Management

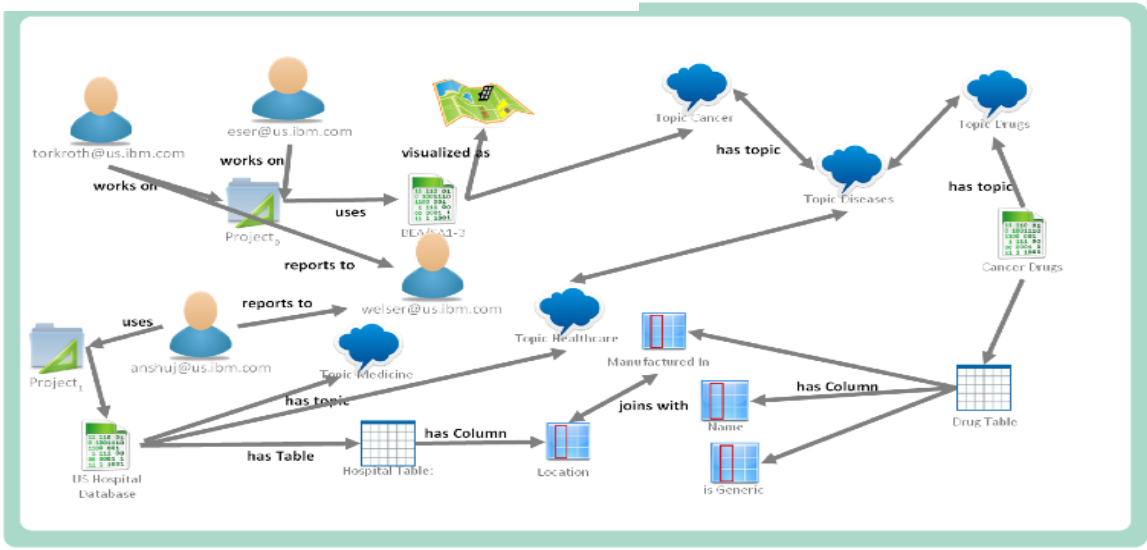












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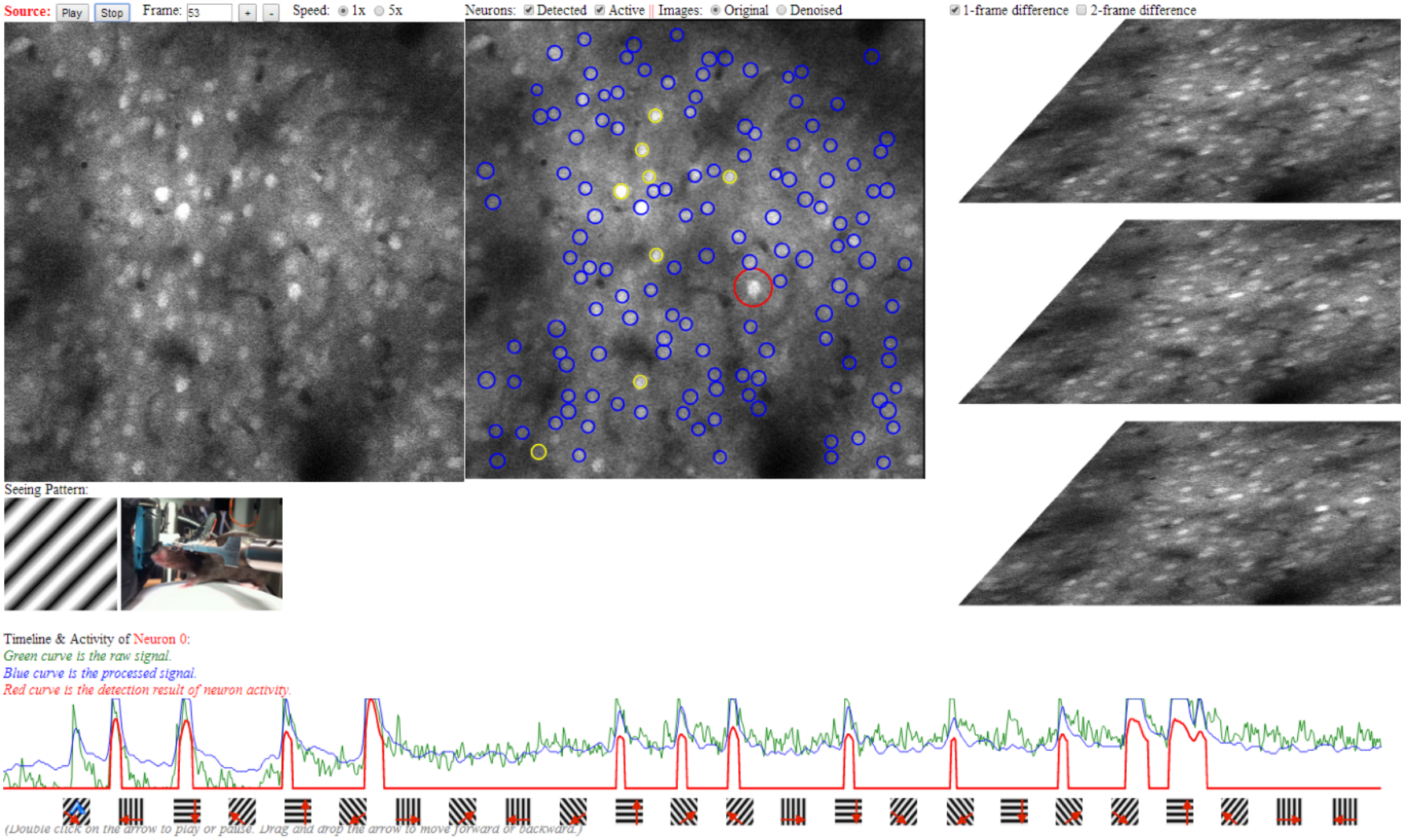
Use Case 21: Understanding Brain Network



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Use Case 22: Planet Security

- Big Data on Large-Scale Sky Monitoring

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Homework #0: Big Data Environment Setup and Test (due September 22, 5pm)

1. Warm-Up Exercises:
   - Setup Google Cloud account and environment
   - Install Google Cloud SDK
   - Create a Spark cluster
   - Word Count using Google Cloud Storage and Spark
   - Hive and BigQuery

2. Data Analysis — NYC Bike Expert:
   - Load data to a Cloud Storage
   - Simple Analyses through BigQuery

3. Data Analysis — Understanding Shakespeare:
   - Load data to a Cloud Storage
   - Simple Analyses through Word Counts
   - Analyses after running Natural Language Toolkit

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Homework Late Submission Policy

5pm: submission deadline
Next Day midnight: 10% penalty
Two Days late midnight: 20% penalty
Three Days late midnight: 30% penalty
Any late submission more than 3 days will not be accepted.

Please do your each homework as early as possible!! They are all quite 'heavy'.

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