Massive Database Analysis on the Cloud with D4M

Jeremy Kepner

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Outline

- **Introduction**
  - *Webolution*
  - *As is, is OK*
  - *D4M*
- Technologies
- Results
- Demo
- Summary

Primordial Web

Kepner & Beaudry 1992, Visual Intelligence Corp (now GE Intelligent Platforms)

Browser (html):		Server (http):		Database (sql):
NCSA Mosaic™ 3.0	http put ⇄ http get	Gopher Language: perl	SQL ⇄ data	SYBASE
Client		**Server**		**Database**
				

- Browser GUI? HTTP for files? Perl for analysis? SQL for data?
- A lot of work just to view data.
- Won't catch on.

Cambrian Web

Browser (html): | **Server (http):** | **Database (sql):**

http put / http get

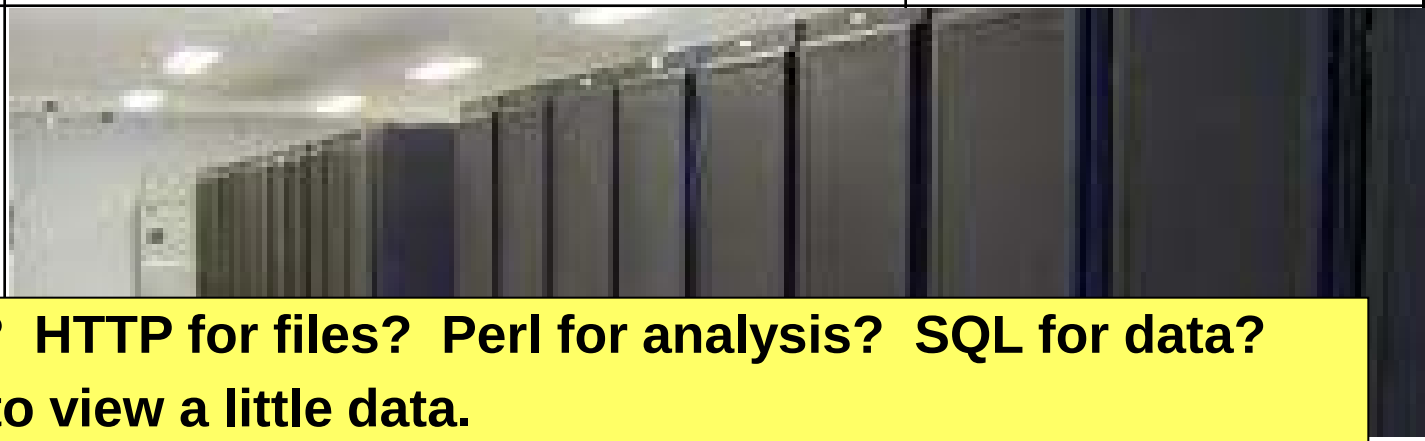
SQL / data

Apache Windows Server

Language: Java, php, perl, python, Ruby

SYBASE, ORACLE, IBM DB2, Microsoft SQL Server, MySQL

Client | **Server** | **Database**



- Browser GUI? HTTP for files? Perl for analysis? SQL for data?
- A lot of work to view a little data.
- ~~Won't catch on.~~

Modern Web

Game (data):

http put

http get

Server (http):

Apache Windows Server

Language:

Java php perl python Ruby

java

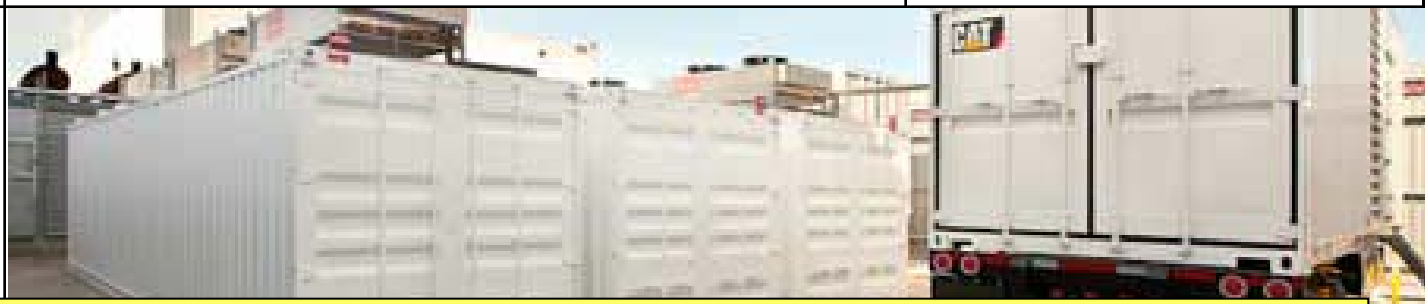
data

Database (triples):

BigTable riak Cassandra HBASE

Client

Server

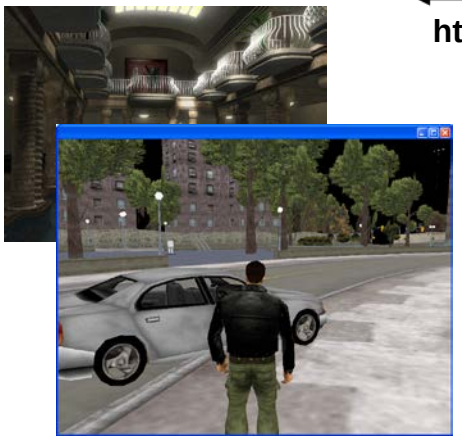


Database

- Game GUI! HTTP for files? Perl for analysis? Triples for data!
- A lot of work to view a lot of data.
- Great view. Massive data.

Modern Web

Game (data):



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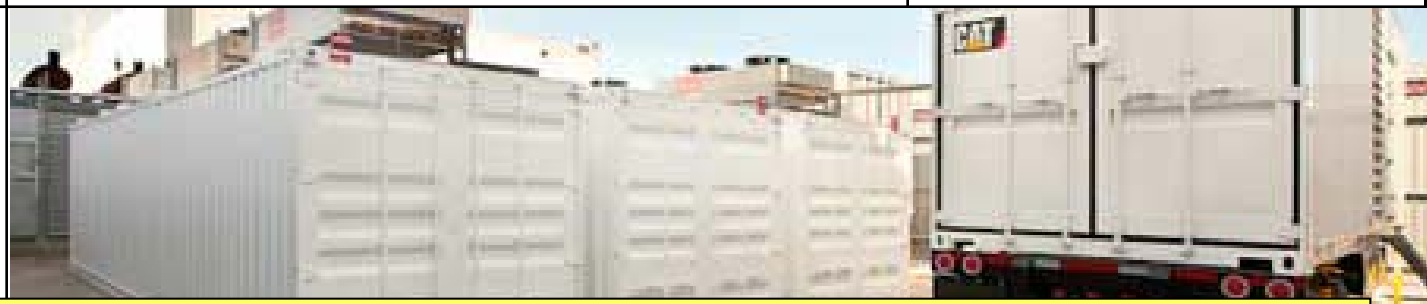
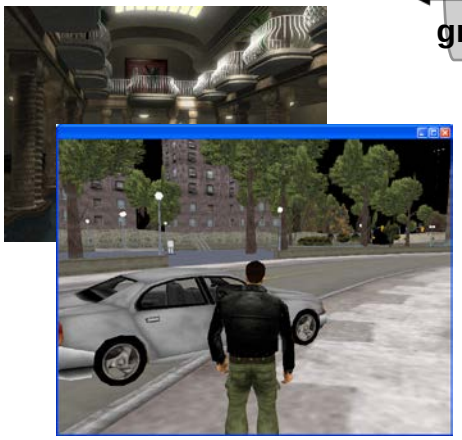


Database

- Game GUI! HTTP for files? Perl for analysis? Triples for data!
- A lot of work to view a lot of data. Missing middle.
- Great view. Massive data.

Future Web?

Game (data):



graphs

graphs

portal

Server (files):

lustre®

Language:

graphs

graphs

portal

Database (triples):

BigTable

riak

Cassandra

HBASE

Client

Server

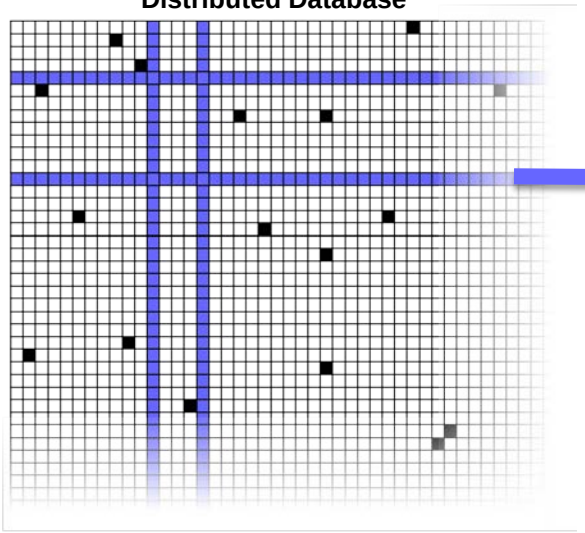
Database

- Game GUI! Fileserver for files! D4M for analysis! Triples for data!
- A little work to view a lot of data. Securely.
- Great view. Massive data.

D4M: "Databases For Matlab"

Triple Store

Distributed Database



Triple store are high performance distributed databases for heterogeneous data

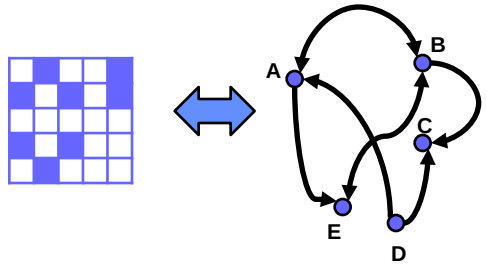
D4M

Dynamic Distributed Dimensional Data Model

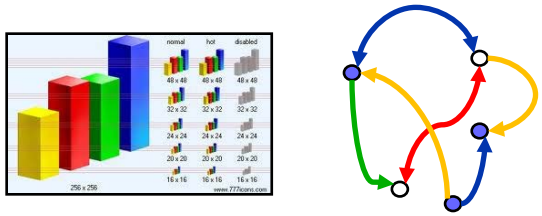
Query:
Alice
Bob
Cathy
David
Earl

Associative Arrays

Numerical Computing Environment



A D4M query returns a sparse matrix or graph from Cloudbase…



…for statistical signal processing or graph analysis in MATLAB

D4M binds Associative Arrays to Triple Store, enabling rapid prototyping of data-intensive cloud analytics and visualization

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  - ***Cloud Software***
  - *D4M*
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Recap: Cloud Computing Concepts

Data Intensive Computing

- Compute architecture for large scale data analysis
  - Billions of records/day, trillions of stored records, petabytes of storage
    - Google File System 2003
    - Google MapReduce 2004
    - Google BigTable 2006
- Design Parameters
  - Performance and scale
  - Optimized for ingest, query and analysis
  - Co-mingled data
  - Relaxed data model
  - Simplified programming
- Community:

Utility Computing

- Compute services for outsourcing IT
  - Concurrent, independent users operating across millions of records and terabytes of data
    - IT as a Service
    - Infrastructure as a Service (IaaS)
    - Platform as a Service (PaaS)
    - Software as a Service (SaaS)
- Design Parameters
  - Isolation of user data and computation
  - Portability of data with applications
  - Hosting traditional applications
  - Lower cost of ownership
  - Capacity on demand
- Community:

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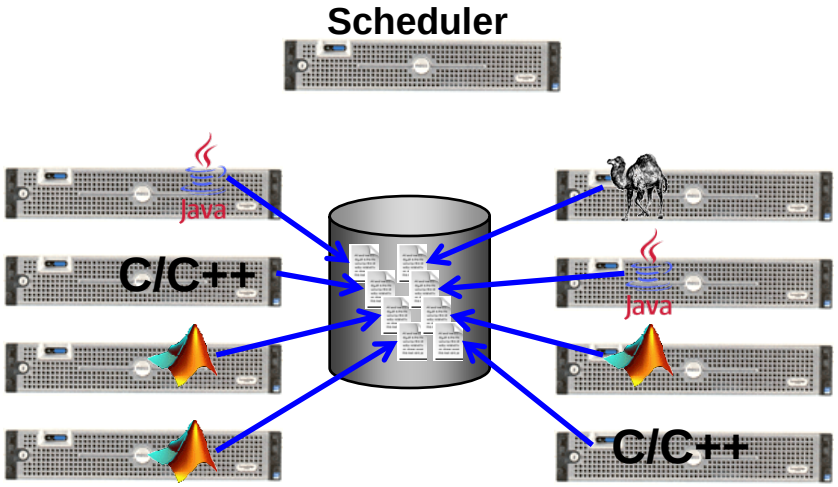
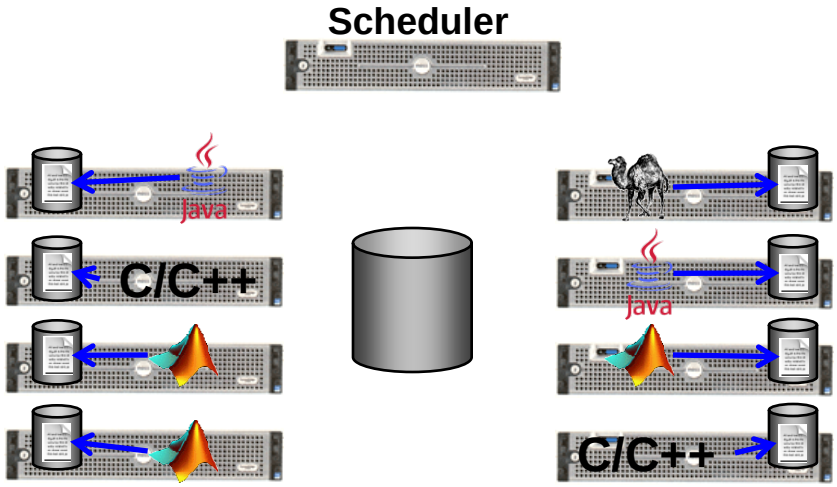
Advantages of Data Intensive Cloud

Traditional:
Data from central store to compute nodes

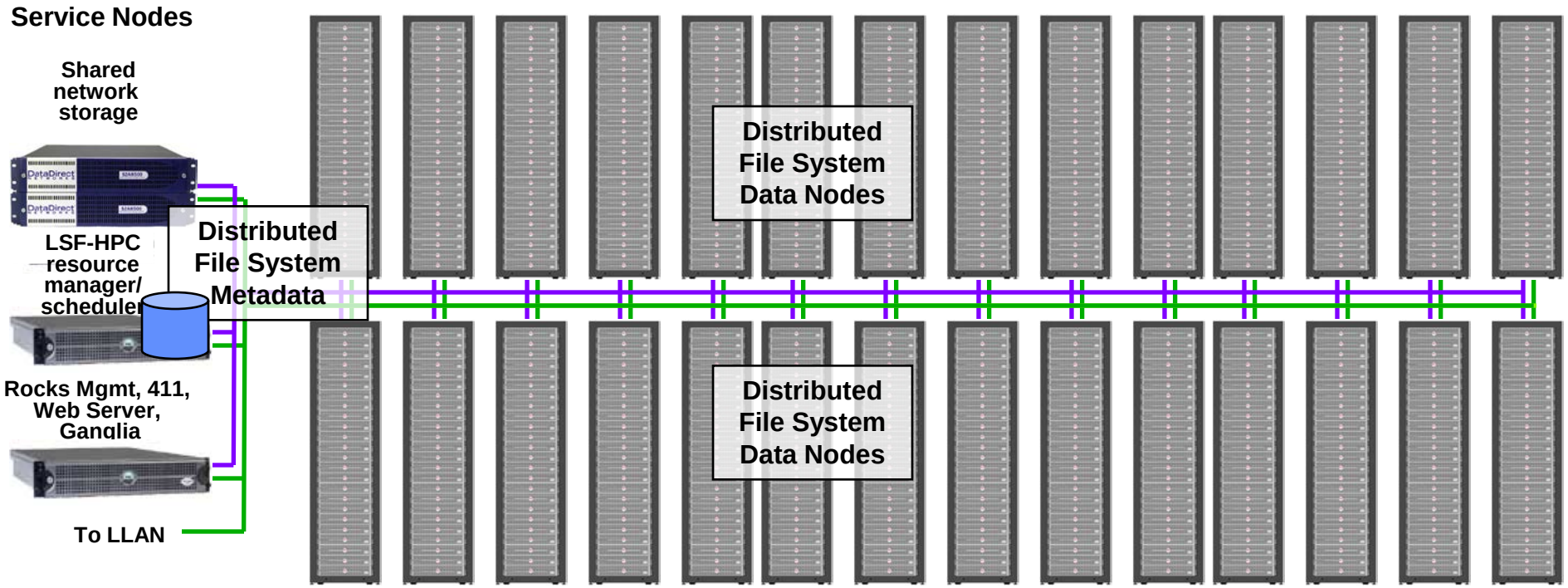


Cloud:
Data replicated on nodes, computation sent to nodes



- Cloud computing moves computation to data
  - Good for applications where time is dominated by reading from disk
- Replaces expensive shared memory hardware and proprietary database software with cheap clusters and open source
  - Scalable to hundreds of nodes

Distributed Cloud File Systems on TX-2500 Cluster



432 DELL PowerEdge 2850

Dual 3.2 GHz EM64-T Xeon (P4)
8 GB RAM memory
Two Gig-E Intel interfaces
Infiniband interface
Six 300-GB disk drives

- 432+5 Nodes
- 864+10 CPUs
- 3.4 TB RAM
- 0.78 PB of Disk
- 28 Racks

MIT-LL Cloud	Hadoop DFS	Sector
Number of nodes used	350	350
File system size	298.9 TB	452.7 TB
Replication factor	3	2

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Multi-Dimensional Associative Arrays

- **Extends associative arrays to 2D and mixed data types**

```
A('alice ','bob ') = 'talked '
```

or

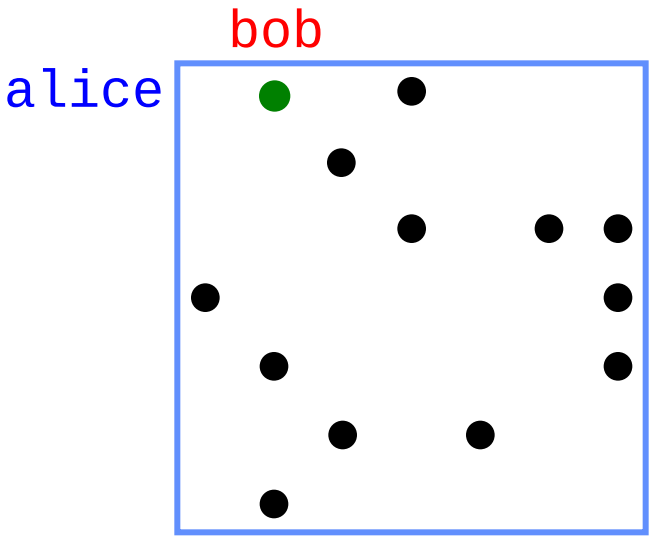
```
A('alice ','bob ') = 47.0
```

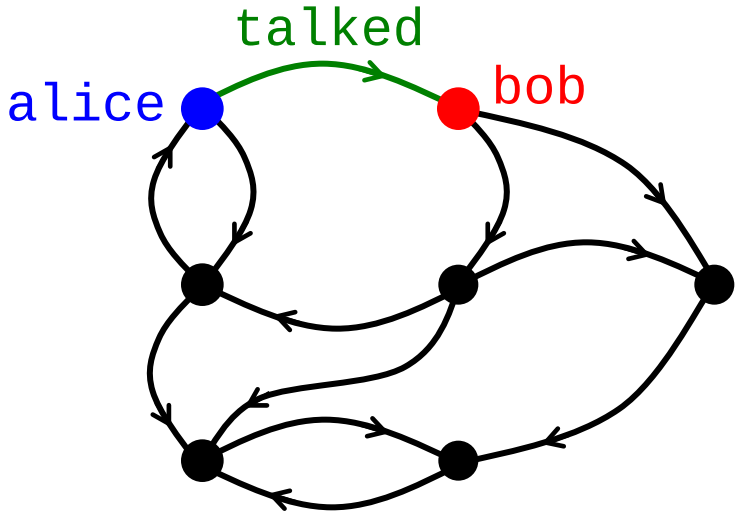
- **Key innovation: 2D is 1-to-1 with triple store**

```
('alice ','bob ','talked ')
```

or

```
('alice ','bob ',47.0)
```





- **Associative arrays unify four viewpoints into one concept**

Composable Associative Arrays

- **Key innovation: mathematical closure**
  - **all associative array operations return associative arrays**

- **Enables composable mathematical operations**

```
A + B      A - B      A & B      A|B      A*B
```

- **Enables composable query operations via array indexing**

```
A('alice bob ',:)    A('alice ',:)   A('al* ',:)
A('alice : bob ',:)  A(1:2,:)        A == 47.0
```

- **Simple to implement in a library (~2000 lines) in programming environments with: 1st class support of 2D arrays, operator overloading, sparse linear algebra**

- **Complex queries with ~50x less effort than Java/SQL**
- **Naturally leads to high performance parallel implementation**

Associative Array Algebra

- Keys and values are from the infinite strict totally ordered set $\mathbb{S}$
- Associative array $A(\mathbf{k}) : \mathbb{S}^d \rightarrow \mathbb{S}$, $\mathbf{k}=(k^1,\ldots,k^d)$, is a partial function from d keys (typically 2) to 1 value, where

  $A(\mathbf{k}_i) = v_i$ and $\varnothing$ otherwise
- Binary operations on associative arrays $A_3 = A_1 \oplus A_2$, where $\oplus = \cup_{f()}$ or $\cap_{f()}$, have the properties
  - If $A_1(\mathbf{k}_i) = v_1$ and $A_2(\mathbf{k}_i) = v_2$, then $A_3(\mathbf{k}_i)$ is

    $v_1 \cup_{f()} v_2 = f(v_1,v_2)$ or $v_1 \cap_{f()} v_2 = f(v_1,v_2)$
  - If $A_1(\mathbf{k}_i) = v$ or $\varnothing$ and $A_2(\mathbf{k}_i) = \varnothing$ or v, then $A_3(\mathbf{k}_i)$ is

    $v \cup_{f()} \varnothing = v$ or $v \cap_{f()} \varnothing = \varnothing$

- **High level usage dictated by these definitions**
- **Deeper algebraic properties set by the collision function f()**
- **Frequent switching between "algebras"**

Universal "Exploded" Schema

Input Data

Time	src_ip	domain	dest_ip
2001-01-01	a		a
2001-01-02	b	b	
2001-01-03		c	c

Triple Store Table: Ttranspose

	2001-01-01	2001-01-02	2001-01-03
src_ip/a	1		
src_ip/b		1	
domain/b		1	
domain/c			1
dest_ip/a	1		
dest_ip/c			1

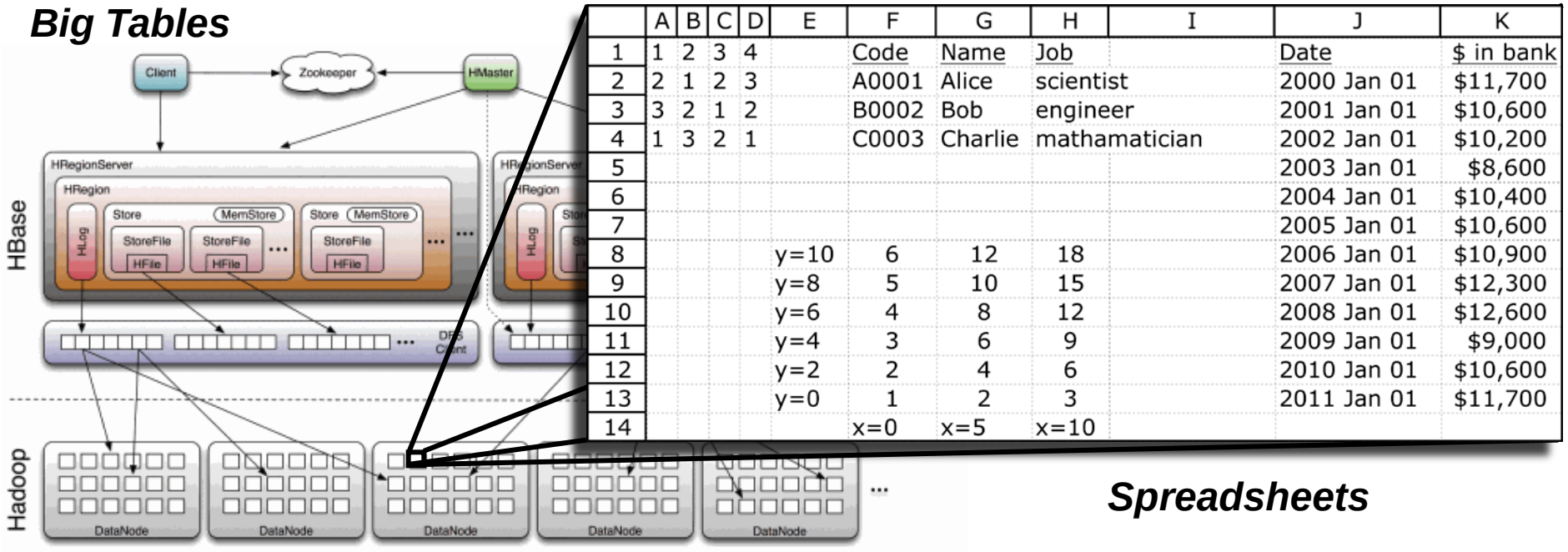
Triple Store Table: T

	src_ip/a	src_ip/b	domain/b	domain/c	dest_ip/a	dest_ip/c
2001-01-01	1				1	
2001-01-02		1	1			
2001-01-03				1		1

Key Innovations

- Handles all data into a *single* table representation
- Transpose pairs allows quick look up of *either* row or column

Unifies Spreadsheets and Big Tables



	A	B	C	D	E	F	G	H	I	J	K
1	1	2	3	4		Code	Name	Job		Date	$ in bank
2	2	1	2	3		A0001	Alice	scientist		2000 Jan 01	$11,700
3	3	2	1	2		B0002	Bob	engineer		2001 Jan 01	$10,600
4	1	3	2	1		C0003	Charlie	mathamatician		2002 Jan 01	$10,200
5										2003 Jan 01	$8,600
6										2004 Jan 01	$10,400
7										2005 Jan 01	$10,600
8					y=10	6	12	18		2006 Jan 01	$10,900
9					y=8	5	10	15		2007 Jan 01	$12,300
10					y=6	4	8	12		2008 Jan 01	$12,600
11					y=4	3	6	9		2009 Jan 01	$9,000
12					y=2	2	4	6		2010 Jan 01	$10,600
13					y=0	1	2	3		2011 Jan 01	$11,700
14						x=0	x=5	x=10			

- ***Spreadsheets*** **are the most commonly used analytical structure on Earth (100M users/day?)**
- **Big Tables (Google, Amazon, Facebook, …) store most of the analyzed data in the world (Exabytes?)**
- **Simultaneous diverse data: strings, dates, integers, reals, …**
- **Simultaneous diverse uses: matrices, functions, hash tables, databases, …**

Outline

- Introduction
- Technologies
- **Results**
  - ***Network Monitoring***
  - ***Text Query***
  - ***Insert Performance***
- Demo
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Stats Diagram

Triple Store Table: T

Row	Key (time)	src_ip/a	src_ip/b	src_ip/c	src_ip/d	domain/a	domain/b	domain/c	domain/d	dest_ip/a	dest_ip/b	dest_ip/c	dest_ip/d	Recv/a	Recv/b	Recv/c	Recv/d	Recv/e
1	2001-10-01 01 01 00	■				■	■	■	■									
2	2001-10-01 01 02 00			■	■					■	■	■	■					
3	2001-10-01 01 03 00	■												■	■	■	■	■
4	2001-10-01 01 04 00			■														
5	2001-10-01 01 05 00	■				■	■	■	■									
6	2001-10-01 01 06 00			■														

Associative Array: A

- Copy a set of rows from T into associative array A
- Perform the following statistical calculations on A
  - Column count: how many times each column appears in A
  - Column type count: how many times each column type appears in A
  - Column covariance: how many times a each pair of columns in A appear in the same row together
  - Column covariance: how many times a each pair of column types in A appear in the same row together

- Good for identifying column types, gaps, clutter, and correlations

Stats Implementation

- **Define a set of rows**

```
r = '2001-01-01 01 02 00,2001-01-01 01 03 00, 2001-01-01 01 04 00,'
```

- **Copy rows from table to associative array and convert `'1'` to `1`**

```
A = double(logical(T(r,:)))
A = A(:,'src_ip/ *,domain/ *,dest_ip/ *,')
```

- **Find popular columns counts**

```
sum(A,1) > 200
```

- **Find popular pairs**

```
A' * A > 200
```

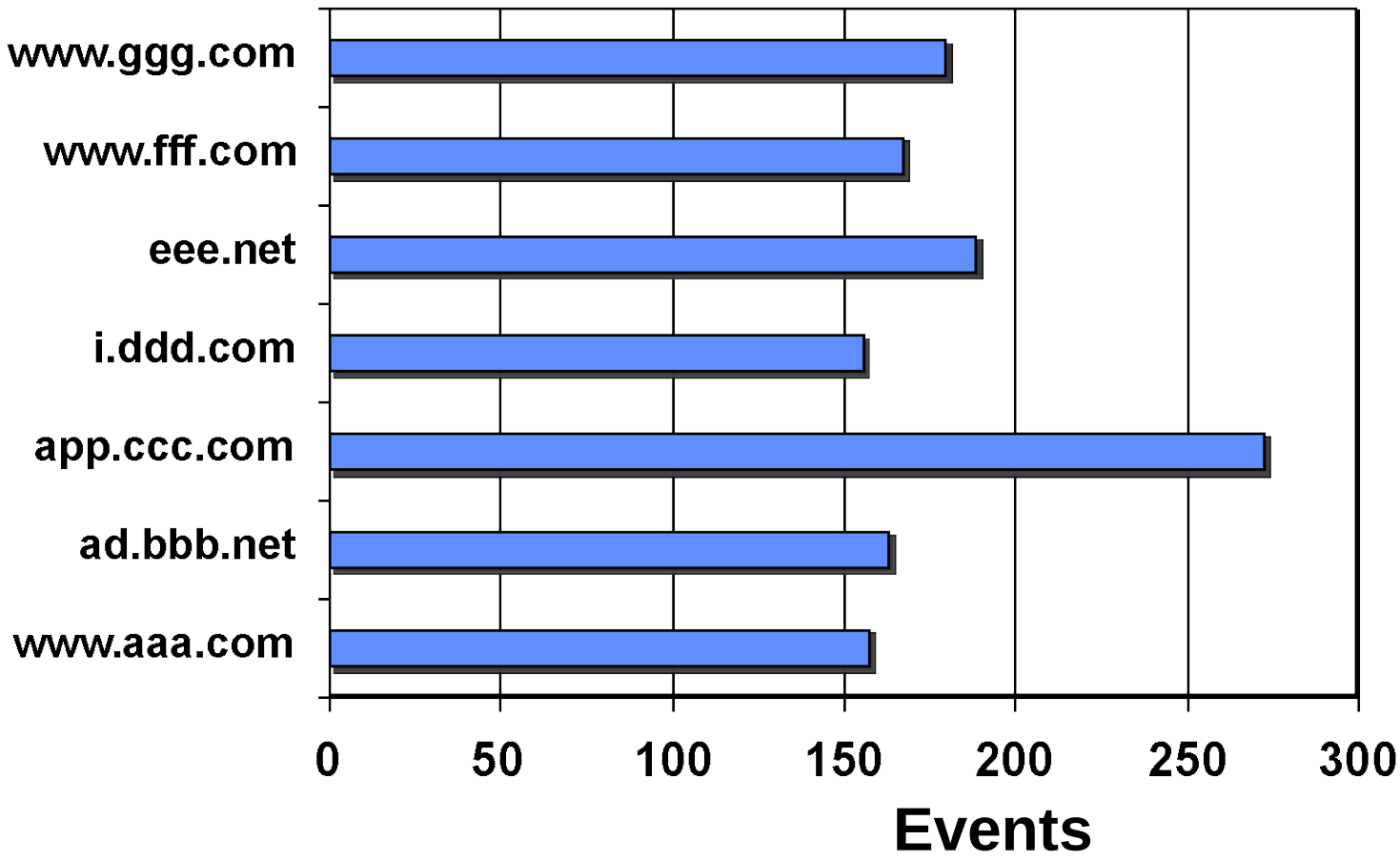
or

```
sqIn(A) > 200
```

- **Find domains with many dest IPs**

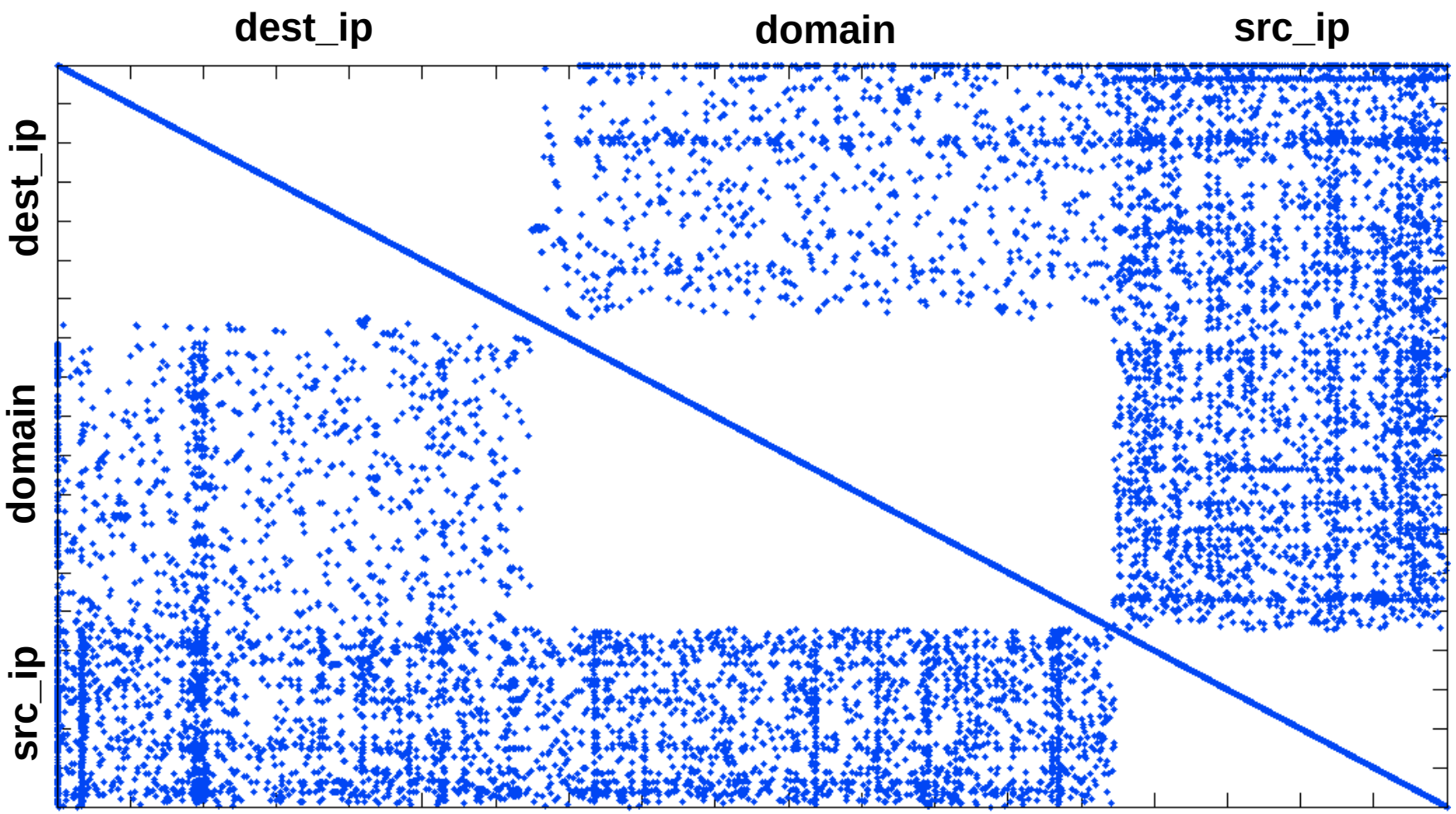
```
sum(double(logical(sqIn(A))),2) > 3
```

Count



- Very easy to get elementary count info necessary for finding clutter and anomalies

Covariance

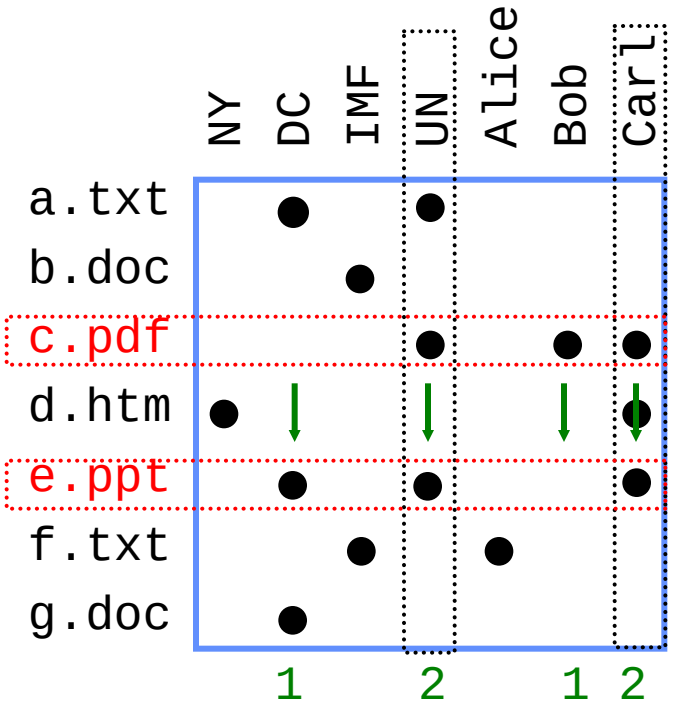


- Adjacency matrix a natural result of covariance calculation

Facet Search

- Core analytic of SKS
- Gives keyword distribution of a set of documents that share a common keyword(s)
  - Provides useful guide to what keyword to select next
- Currently implemented with several hundreds of lines of Java/SQL
- Associative array implementation has 1 line

Facet Search Algorithm



- Associative array relates documents to place, org and person entities

$$A(x,y) : \mathbf{S}^{NxM} \rightarrow \mathbf{R}$$

- Facets y_1=UN, y_2=Carl
- Documents that contain both

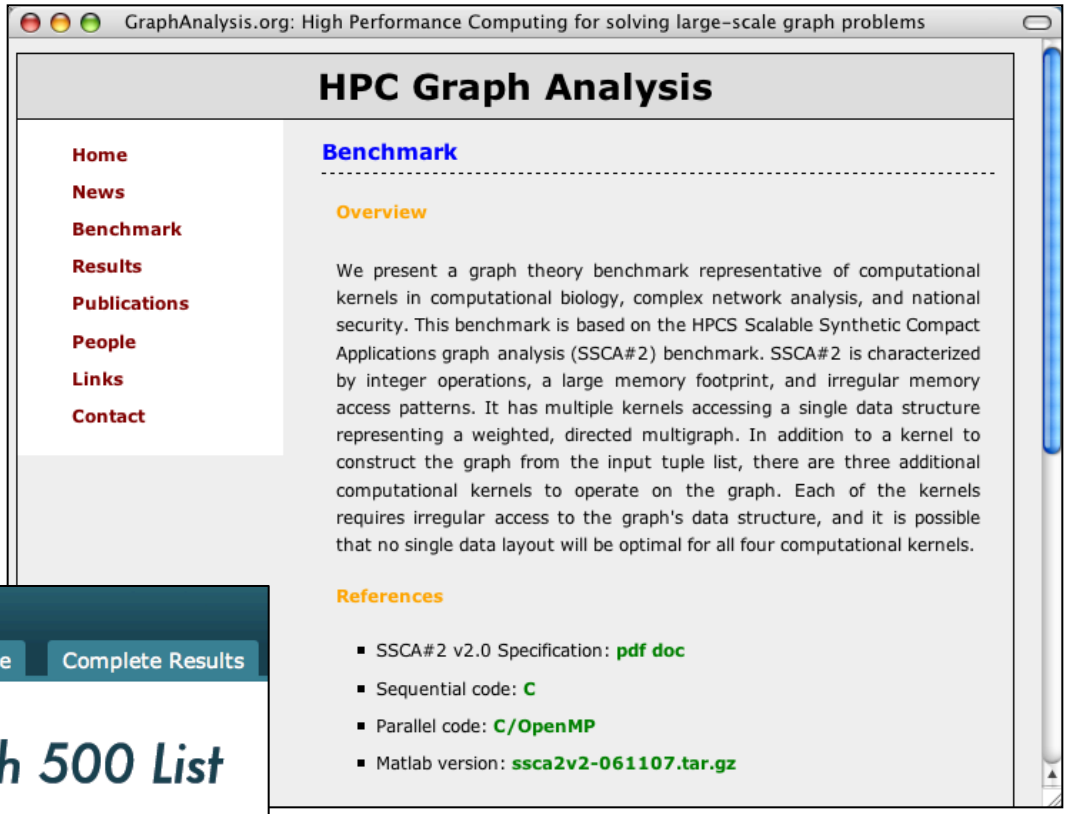
$$\underline{A}(:,y_1) \;\&\; \underline{A}(:,y_2)$$

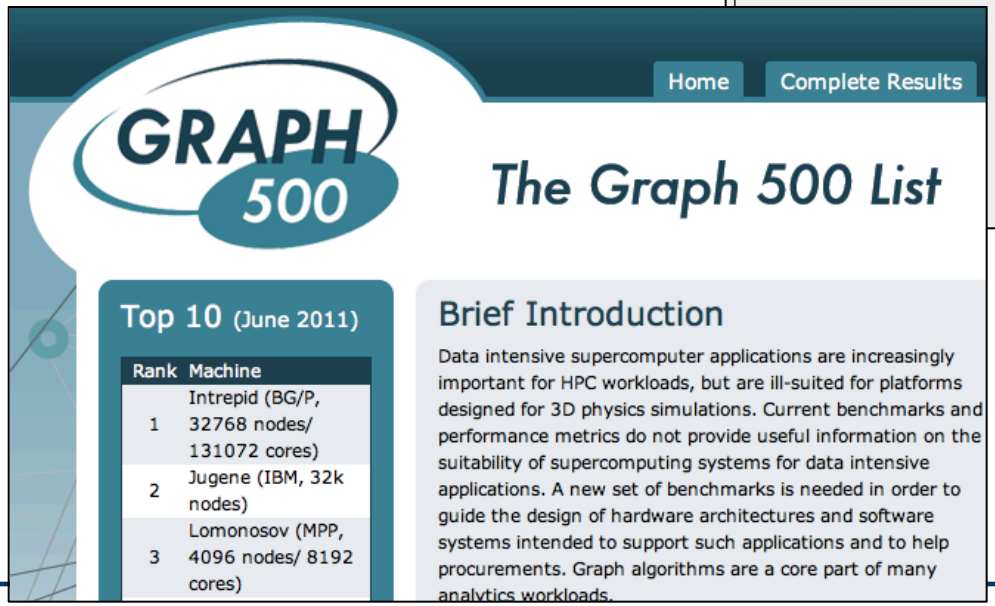
- Entity counts in the above set of documents obtained via matrix multiply

$$(\underline{A}(:,y_1) \;\&\; \underline{A}(:,y_2))^t \; A$$

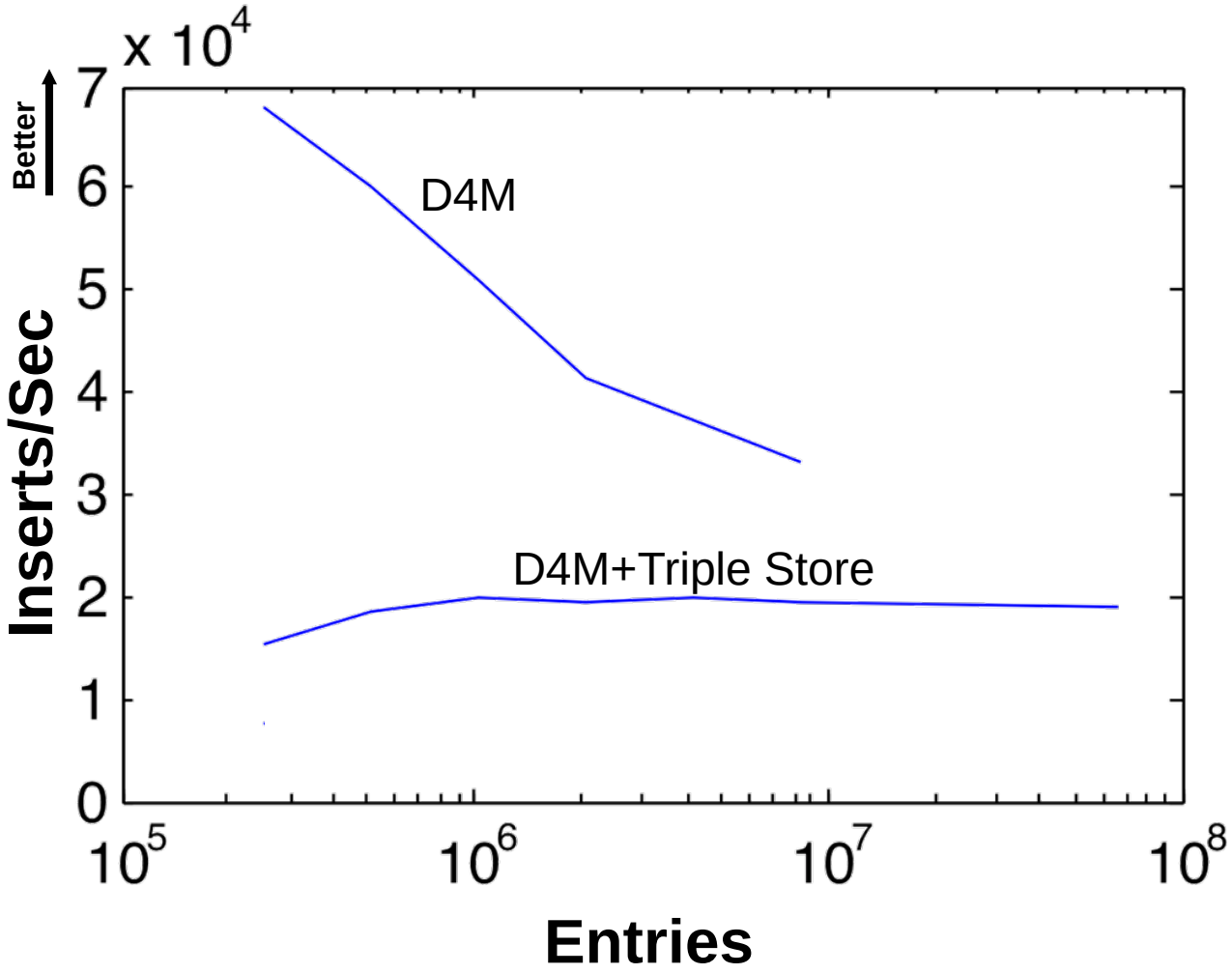
Graph Analysis/Graph500 Benchmark

- **Scalable benchmark specified by graph community**
- **Goal**
  - **Stress parallel computer architecture**
- **Key data**
  - **Very large Power law graph**
- **Kernels**
  - **Data Generator**
  - **Ingest**

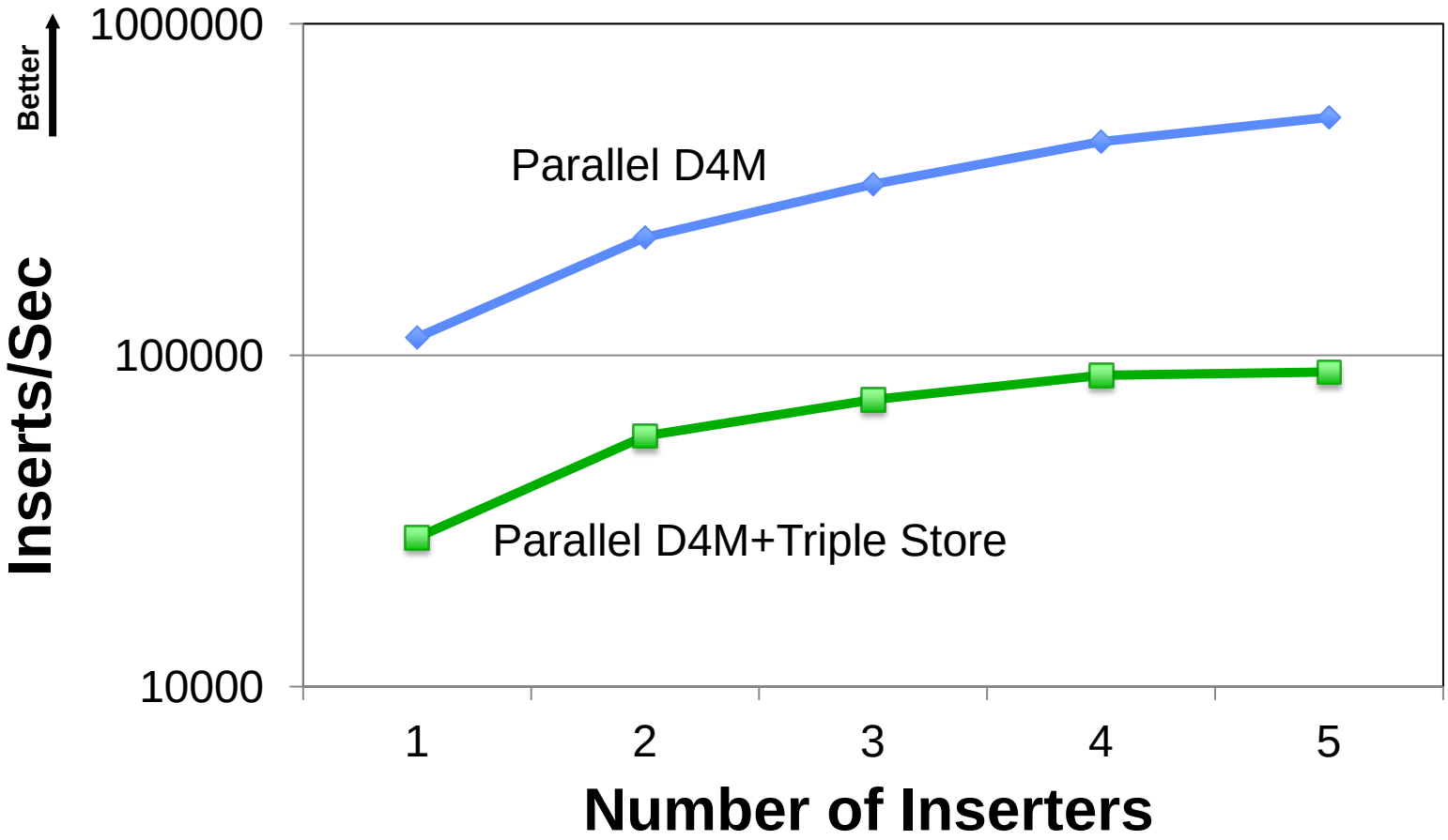




Single Node Insert Rate



Parallel D4M + Single Node Triple Store Graph500 insert rate



- **Parallel D4M provides 500K memory inserts/sec on 1 node**
- **Parallel D4M + Triple Store provides 100K disk inserts/sec on 1 node**
- **Parallel D4M enables exploiting full power of Triple Store from D4M**

Reference

- **Book: "Graph Algorithms in the Language of Linear Algebra"**
- **Editors: Kepner (MIT-LL) and Gilbert (UCSB)**
- **Contributors**
  - **Bader (Ga Tech)**
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  - **Gilbert (UCSB)**
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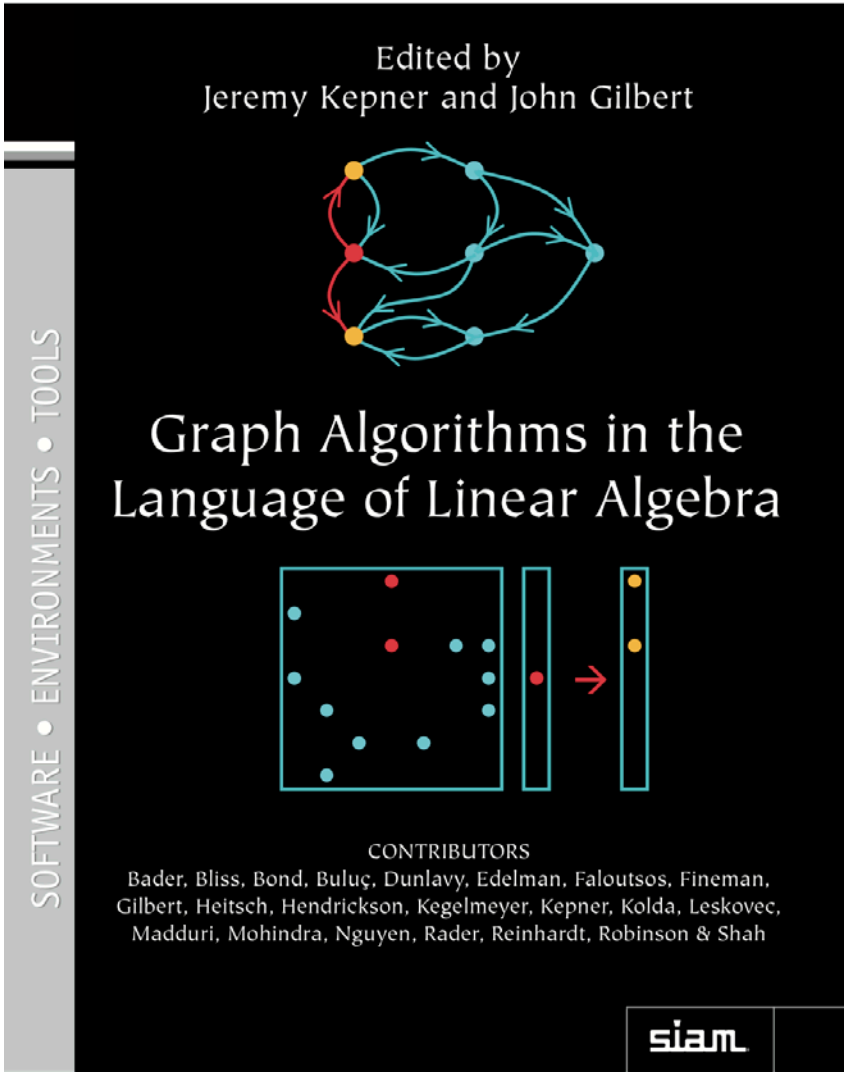

Summary

- Web evolution has resulted in a new class of technologies for
  - Display (game interfaces)
  - Analysis (D4M)
  - Storage (triple stores)

- D4M is a novel technology that allows complex analytics to be implement with significantly less effort that traditional approaches

- D4M is built on composable associative arrays which admit linear algebraic manipulation