Signal Processing on Databases

Jeremy Kepner

Lecture 3: Entity Analysis in Unstructured Data

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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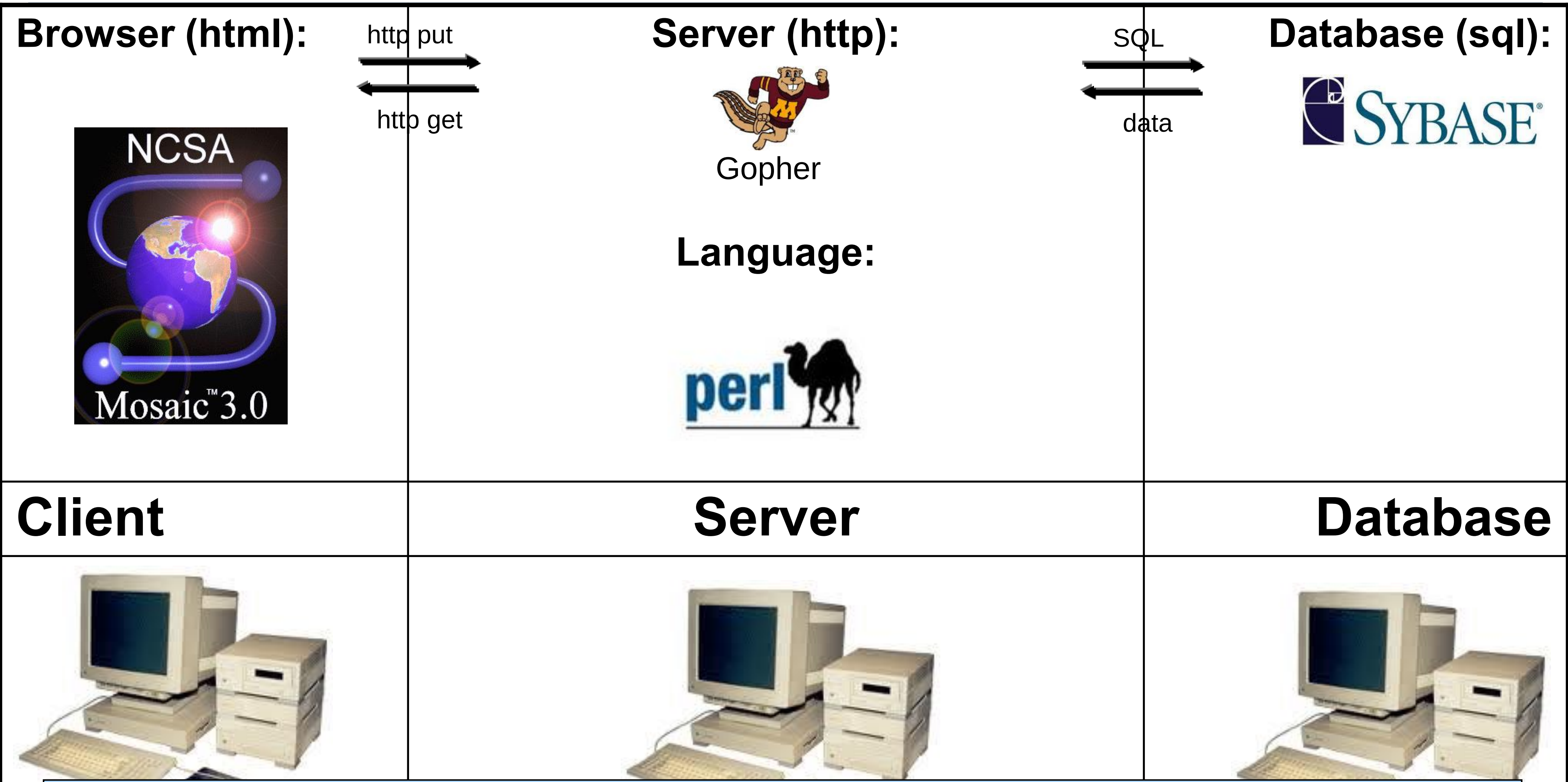
Outline

- 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):

http put

http get

Server (http):

Gopher

Language:

SQL

data

Database (sql):

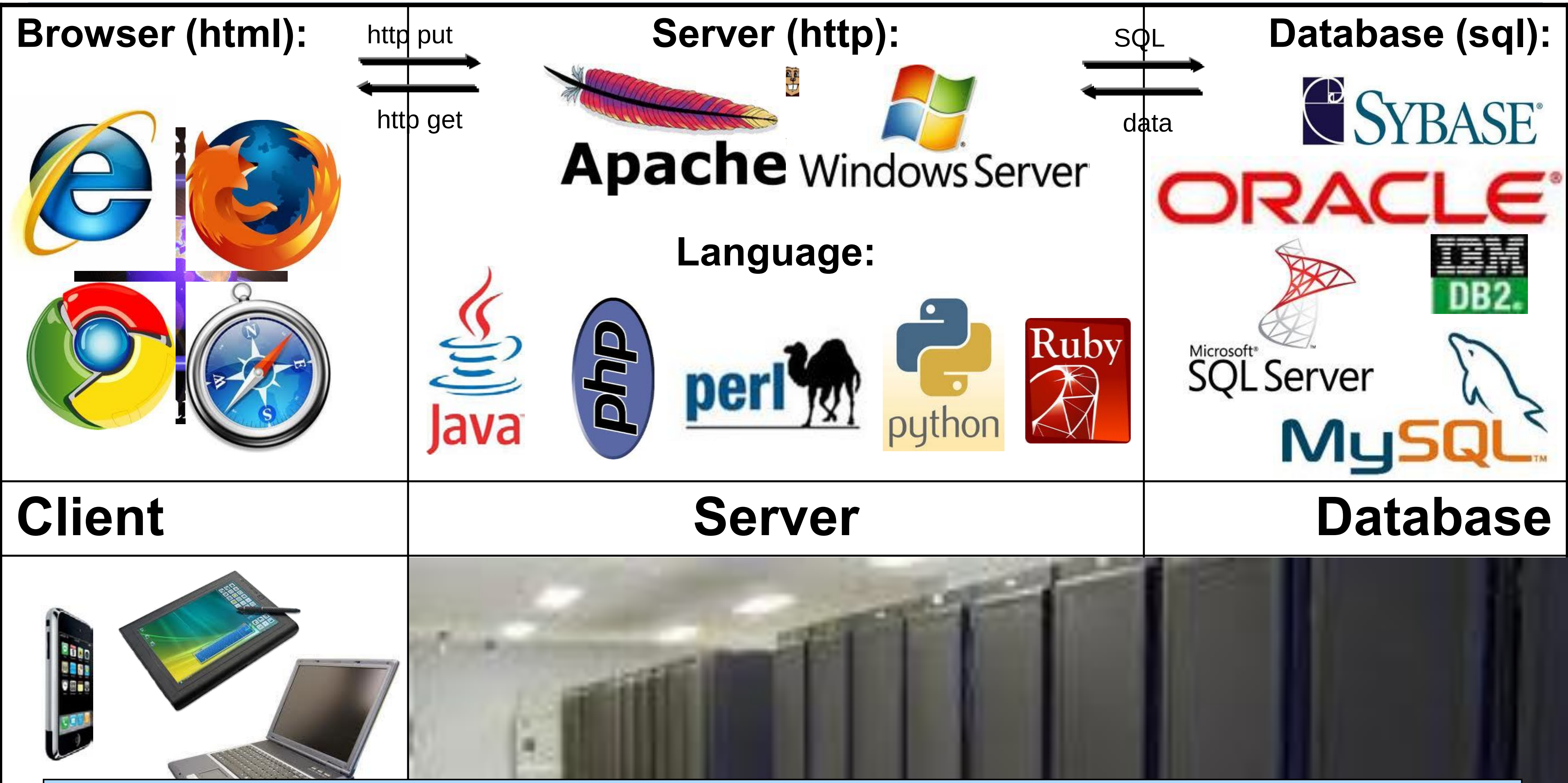
Client

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):

http put

http get

Server (http):

SQL

data

Database (sql):

Language:

Client

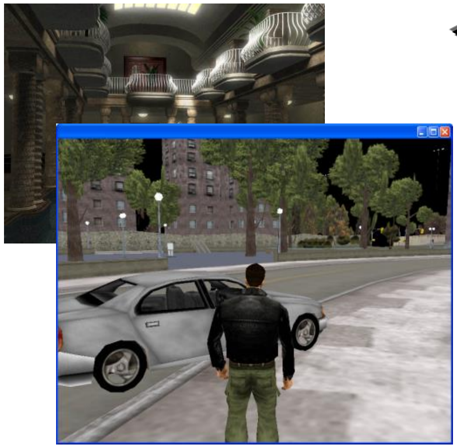
Server

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

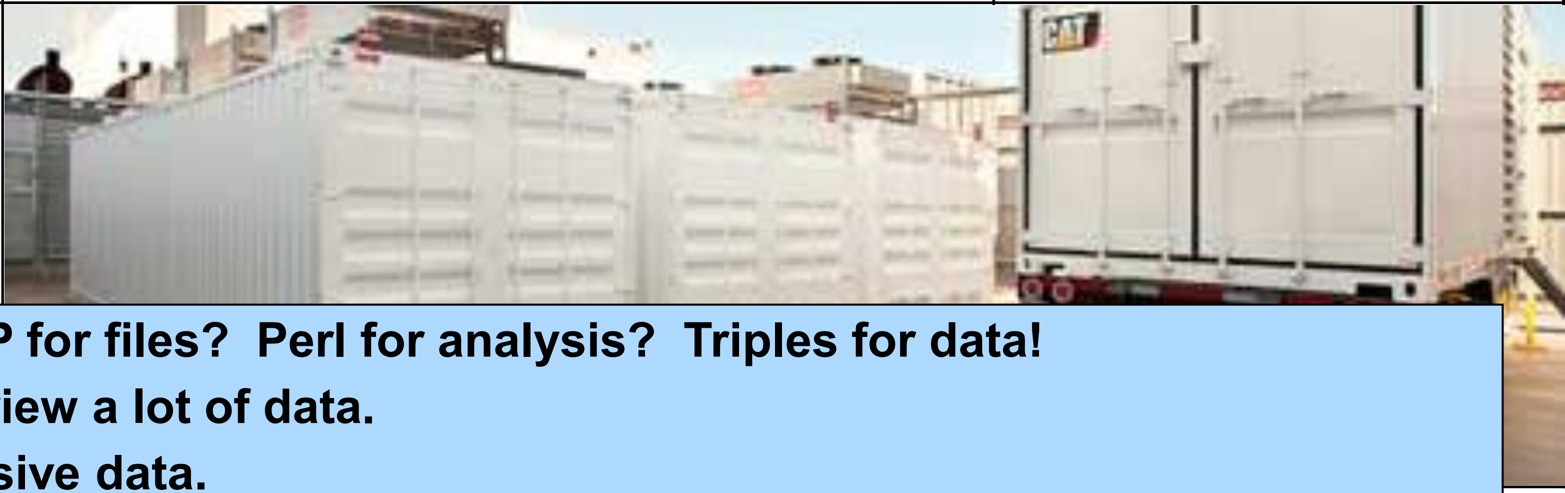
riak

Cassandra

H·BASE

Client

Server

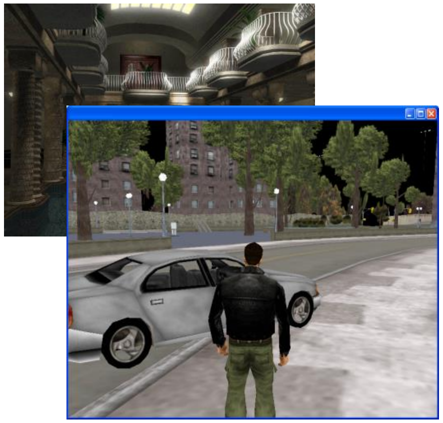


Database

- 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):



http put →

← http get

Server (http):

Apache Windows Server

Language:

Java php perl python Ruby

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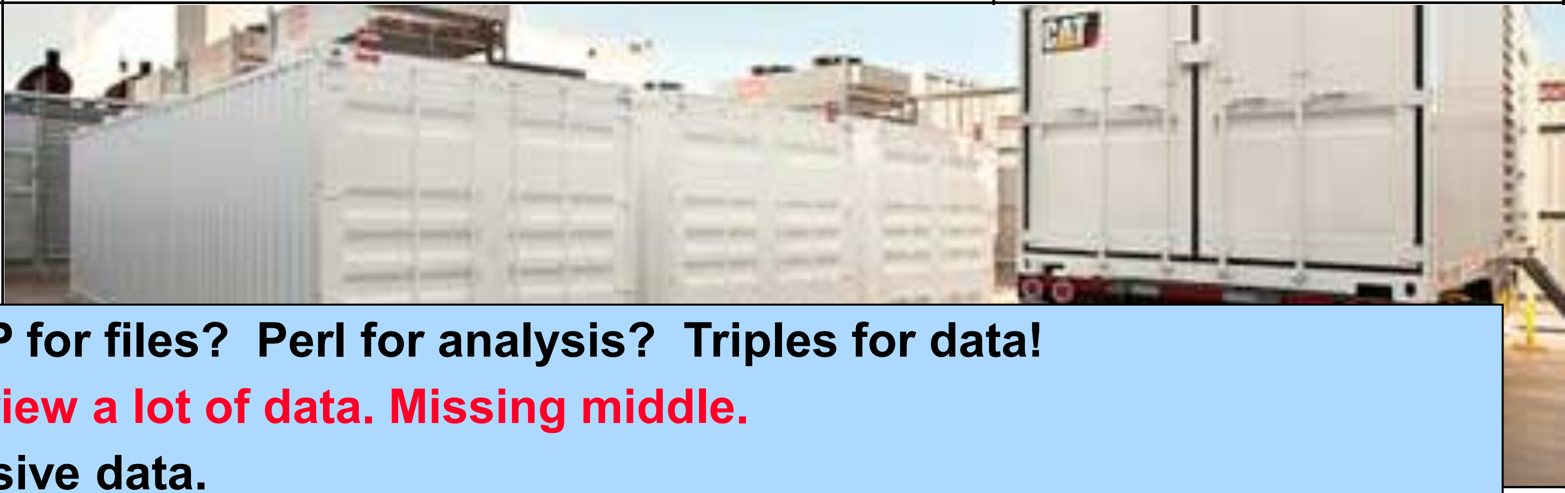
← data

Database (triples):

BigTable riak Cassandra HBASE

Client

Server

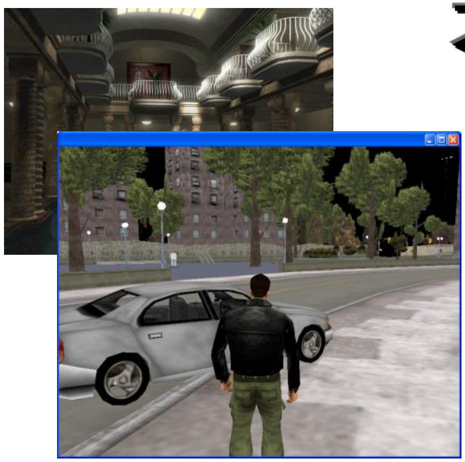


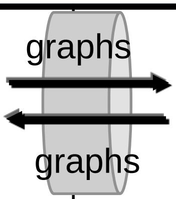
Database

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

Future Web?

Game (data):





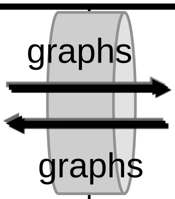
portal

Server (files):

lustre

Language:

D4M



portal

Database (triples):

BigTable

riak

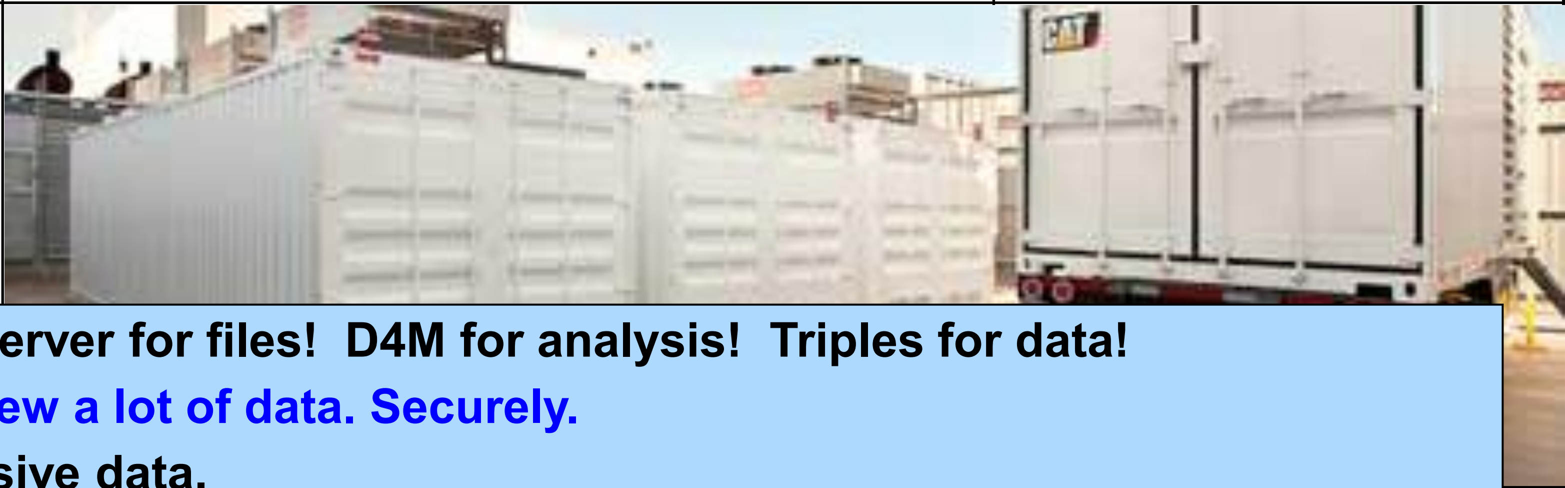
Cassandra

H·BASE

Client

Server

Database

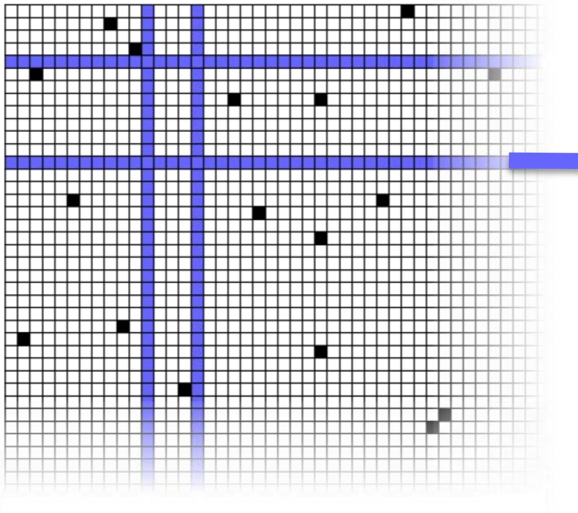


- Game GUI! Fileserver for files! D4M for analysis! Triples for data!
- A little work to view a lot of data. Securely.
- Great view. Massive data.

D4M: “Databases for Matlab”

Triple Store

Distributed Database



Triple store are high performance distributed databases for heterogeneous data

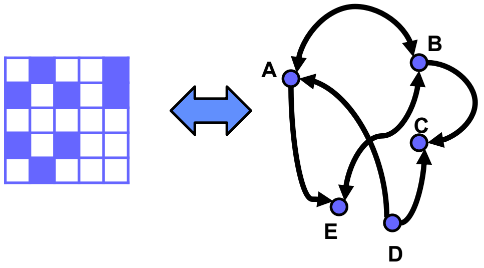
D4M

Dynamic
Distributed
Dimensional
Data
Model

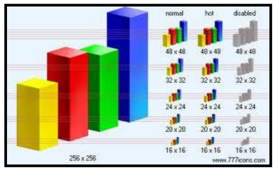
Query:
Alice
Bob
Cathy
David
Earl

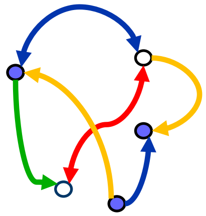
Associative Arrays

Numerical Computing Environment



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





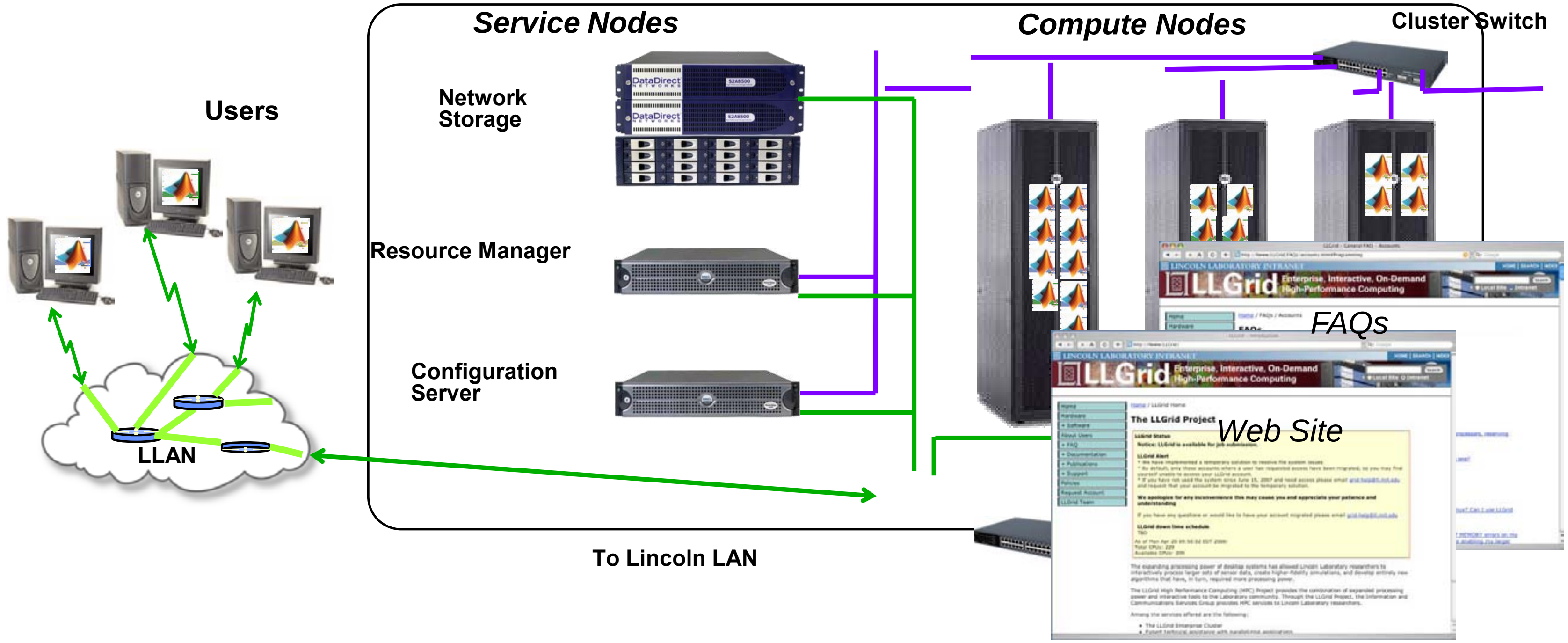
…for statistical signal processing or graph analysis in MATLAB

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

Outline

- Introduction
- ➡ Technologies
  - Hardware
  - Cloud software
  - Associative Arrays
- Results
- Demo
- Summary

What is LL Grid?



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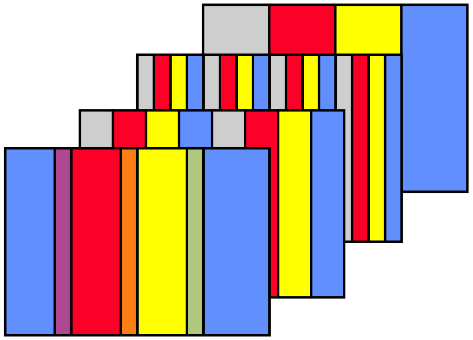
- **LLGrid is a ~500 user ~2000 processor system**
- **World's only desktop interactive supercomputer**
  - **Dramatically easier to use than any other supercomputer**
  - **Highest fraction of staff using (20%) supercomputing of any organization on the planet**
- **Foundation of Supercomputing in Massachusetts**

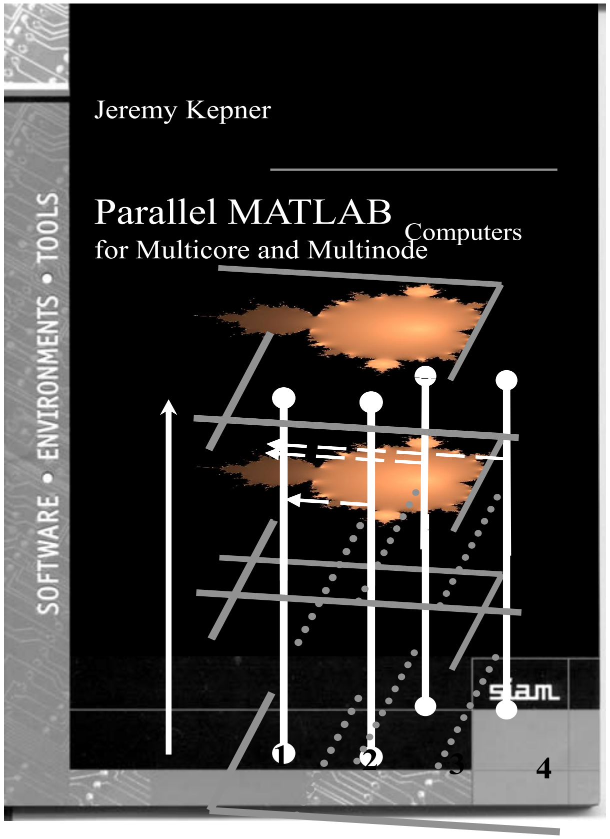
Why is LLGrid easier to use?

Universal Parallel Matlab programming →

```
Amap = map([Np 1],{},0:Np-1);
Bmap = map([1 Np],{},0:Np-1);
A = rand(M,N,Amap);
B = zeros(M,N,Bmap);
B(:,:) = fft(A);
```

- **pMatlab runs in all parallel Matlab environments**
- **Only a few functions are needed**
  - **Np**
  - **Pid**
  - **map**
  - **local**
  - **put_local**
  - **global_index**
  - **agg**
  - **SendMsg/RecvMsg**





Jeremy Kepner
Parallel MATLAB for Multicore and Multinode Computers
SOFTWARE • ENVIRONMENTS • TOOLS
siam
1
2
3
4

- **Distributed arrays have been recognized as the easiest way to program a parallel computers since the 1970s**
  - **Only a small number of distributed array functions are necessary to write nearly all parallel programs**
- **LLGrid is the first system to deploy interactive distributed arrays**

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:

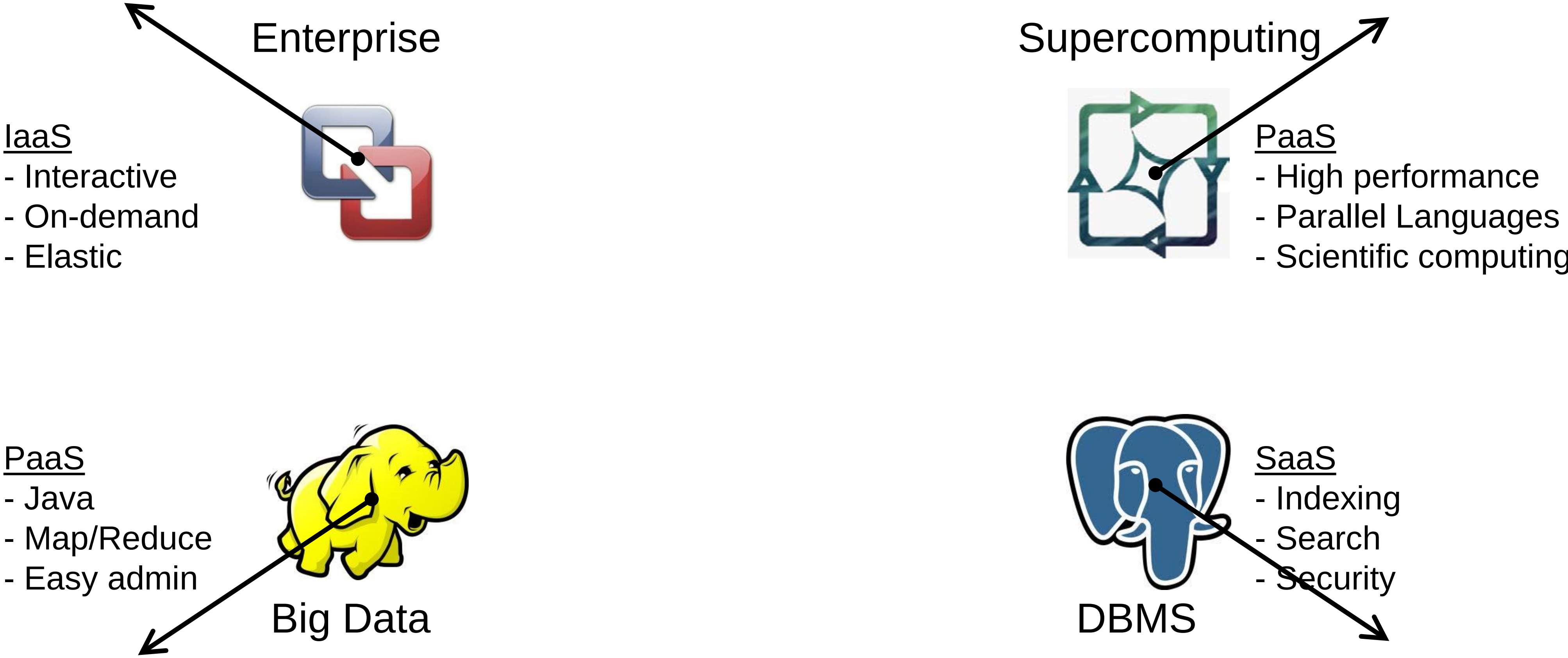
YAHOO!
Windows Live Search
Google
facebook
cloudera
APACHE

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:

Google Apps
salesforce.com
amazon web services
Windows Azure
cloudnine HOSTING
iTricity

The Big Four Cloud Ecosystems



Enterprise

IaaS
- Interactive
- On-demand
- Elastic

Supercomputing

PaaS
- High performance
- Parallel Languages
- Scientific computing

PaaS
- Java
- Map/Reduce
- Easy admin

Big Data

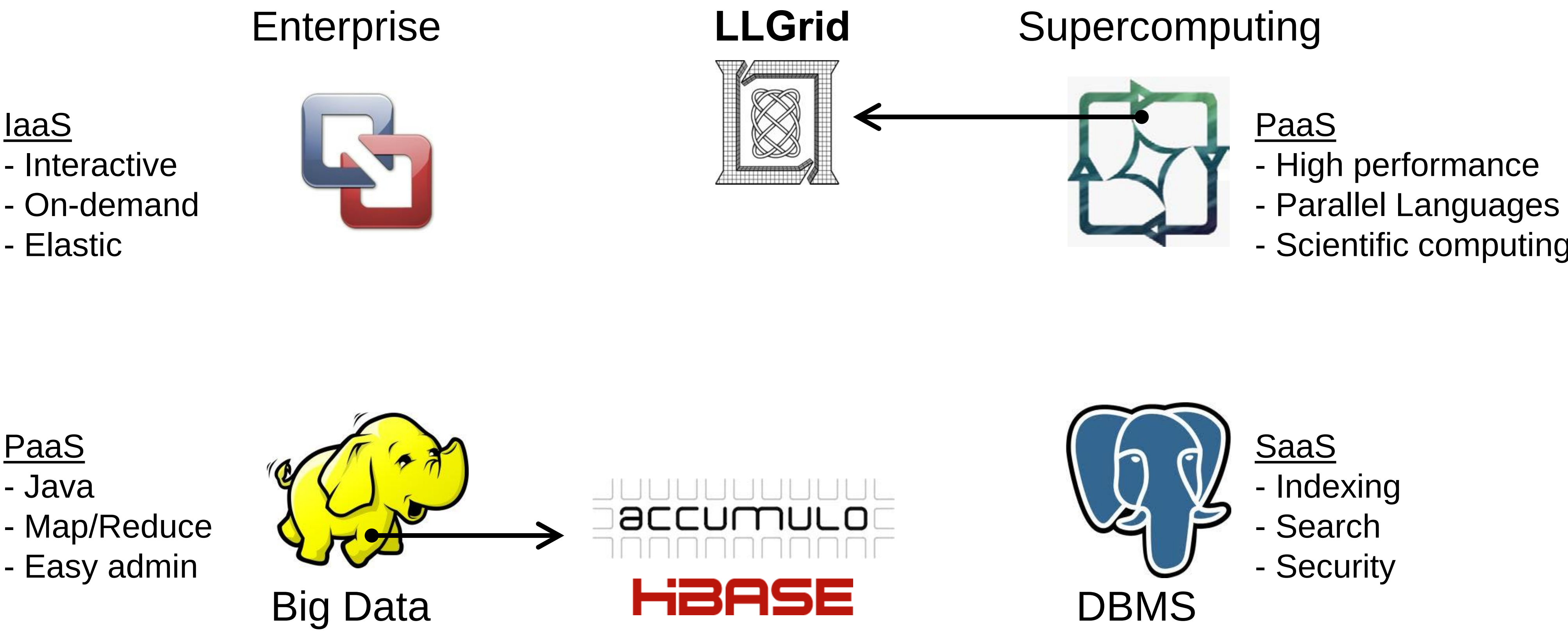
SaaS
- Indexing
- Search
- Security

DBMS

- **Each ecosystem is at the center of a multi-$B market**
- **Pros/cons of each are numerous; diverging hardware/software**
- **Some missions can exist wholly in one ecosystem; some can't**

IaaS: Infrastructure as Service
PaaS: Platform as a Service
SaaS: Software as a Service

The Big Four Cloud Ecosystems



Enterprise

LLGrid

Supercomputing

IaaS
- Interactive
- On-demand
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PaaS
- High performance
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PaaS
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Big Data

DBMS

SaaS
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- **LLGrid provides interactive, on-demand supercomputing**
- **Accumulo database provides high performance indexing, search, and authorizations within a Hadoop environment**

IaaS: Infrastructure as Service
PaaS: Platform as a Service
SaaS: Software as a Service

The Big Four Cloud Ecosystems

Enterprise

LLGrid

Supercomputing

IaaS
- Interactive
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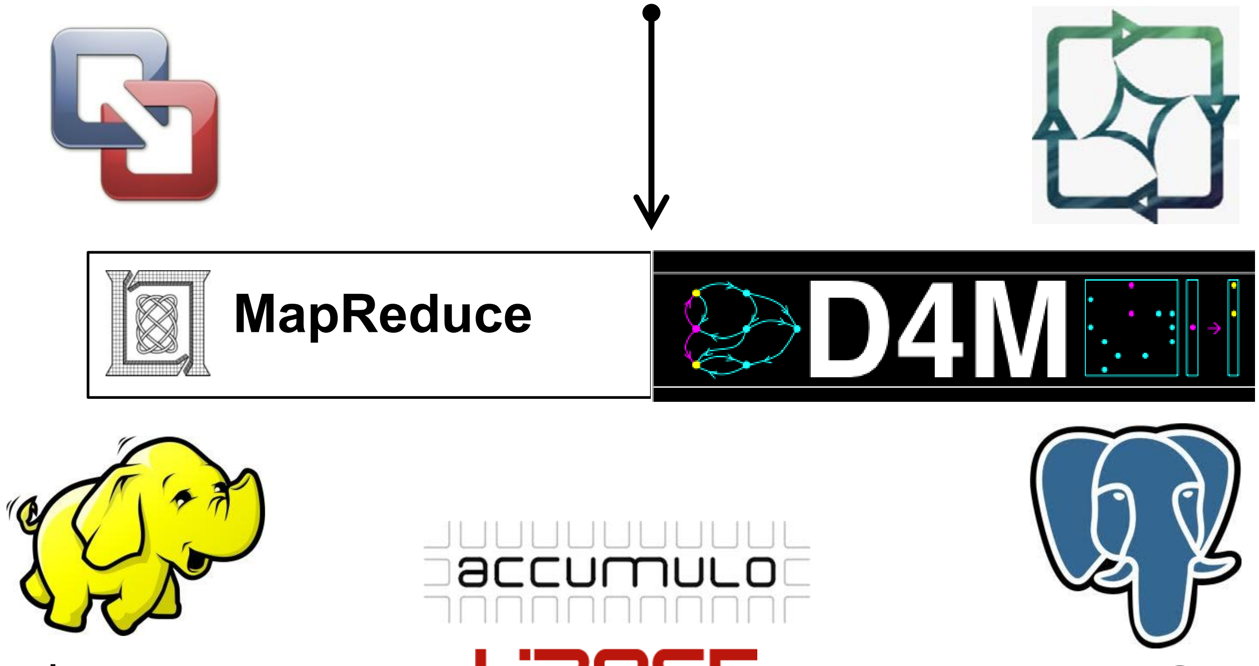


PaaS
- Java
- Map/Reduce
- Easy admin

Big Data

DBMS

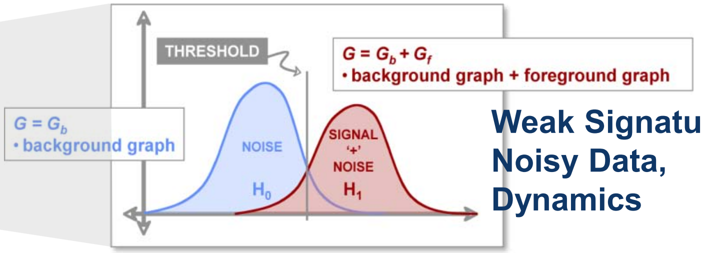
SaaS
- Indexing
- Search
- Security

- **LLGrid MapReduce provides map/reduce interface to supercomputing**
- **D4M provides an interactive parallel scientific computing environment to databases**

IaaS: Infrastructure as Service
PaaS: Platform as a Service
SaaS: Software as a Service

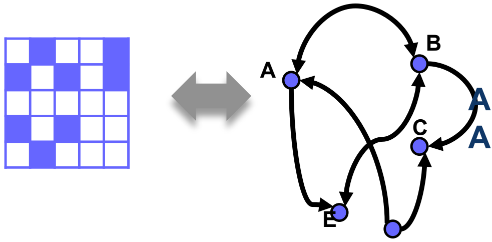
Big Compute + Big Data Stack

Novel Analytics for:
Text, Cyber, Bio



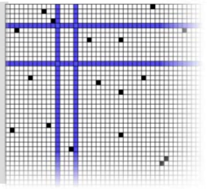
Weak Signatures, Noisy Data, Dynamics

High Level Composable API:
D4M ("Databases for Matlab")



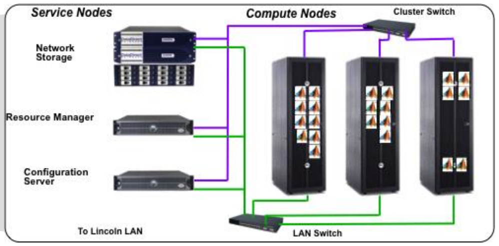
Array Algebra

Distributed Database:
Accumulo/HBase (triple store)



Distributed Database/ Distributed File System

High Performance Computing:
LLGrid + Hadoop



Interactive Super-

computing

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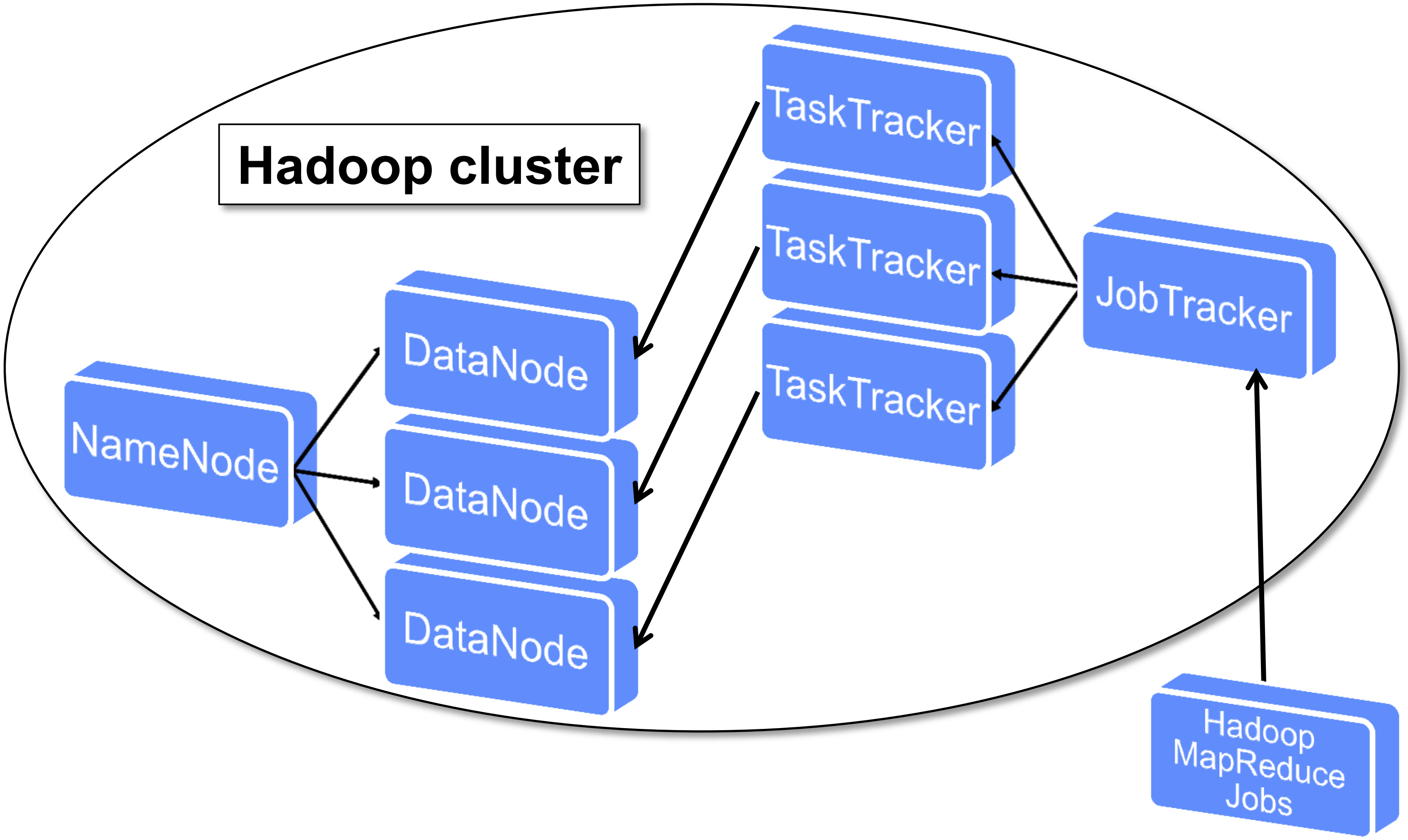
- **Combining Big Compute and Big Data enables entirely new domains**

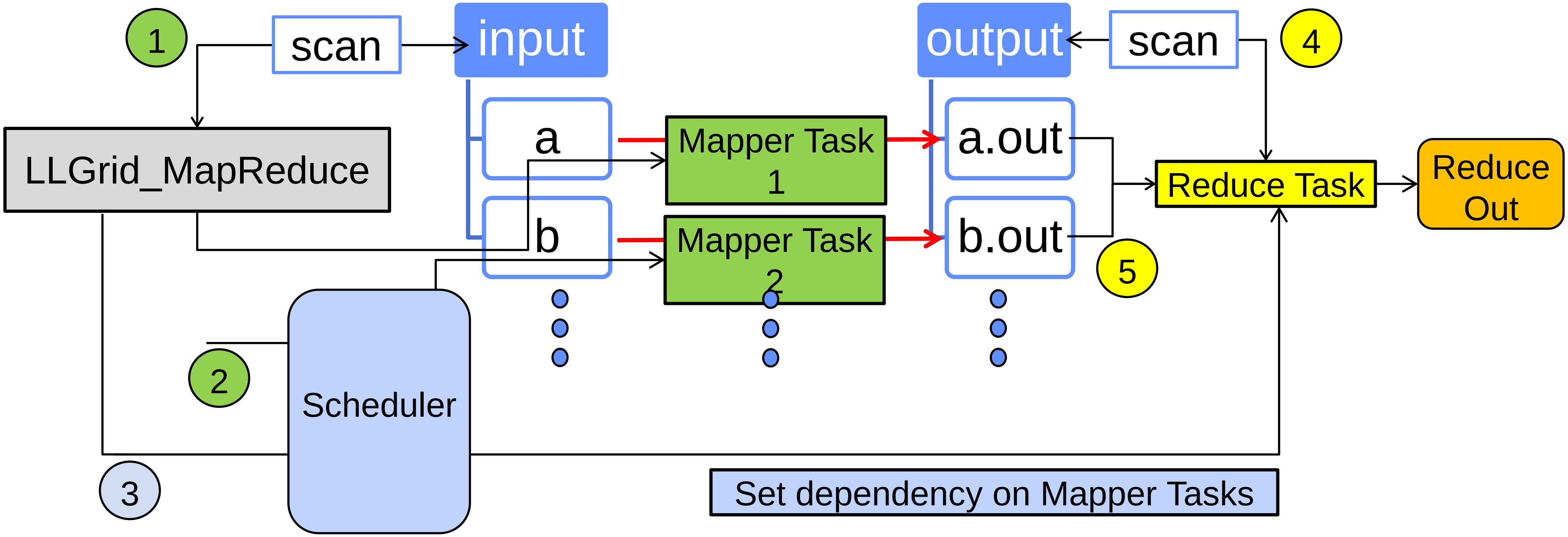
Hadoop Architecture Overview



Hadoop: Strengths and Weaknesses

- What works well
  - Distributed processing of large data
    - Indexing log files
    - Sorting data
  - Scale up from single servers to thousands of machines
    - Local computation and storage
  - Detect and handle failures at the application layer
    - Highly-available service on top of a cluster of computers
- Some difficulties are
  - Controlling compute resources for a given job
    - Full blown, greedy scheduling
  - Multi-user environments
    - Not easy to provide fair-share control on their use of Hadoop cluster
  - Non-Java programmers
    - Takes time to learn the parallel programming API for Java

LLGrid_MapReduce Architecture



- **LLGrid MapReduce provides a language agnostic and scheduler agnostic map/reduce interface in a supercomputing environment**

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Multi-Dimensional Associative Arrays

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

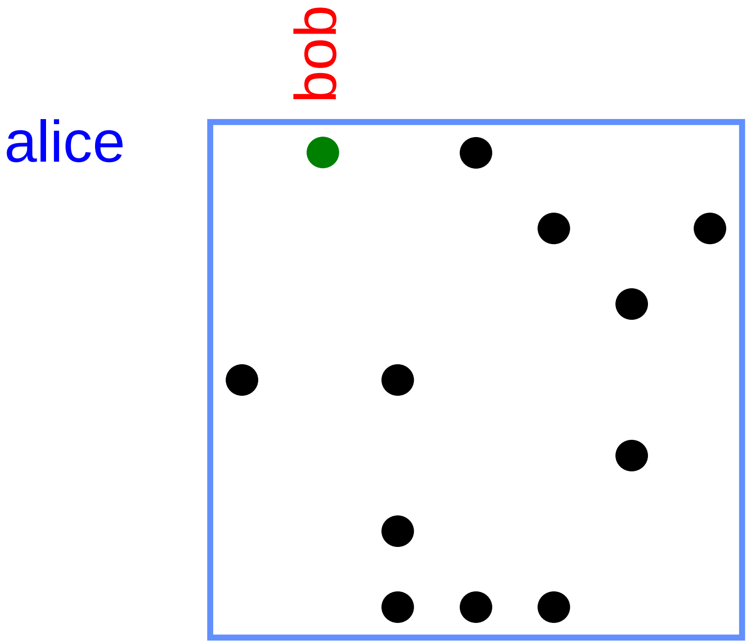
  A('alice ','bob ') = 'cited '

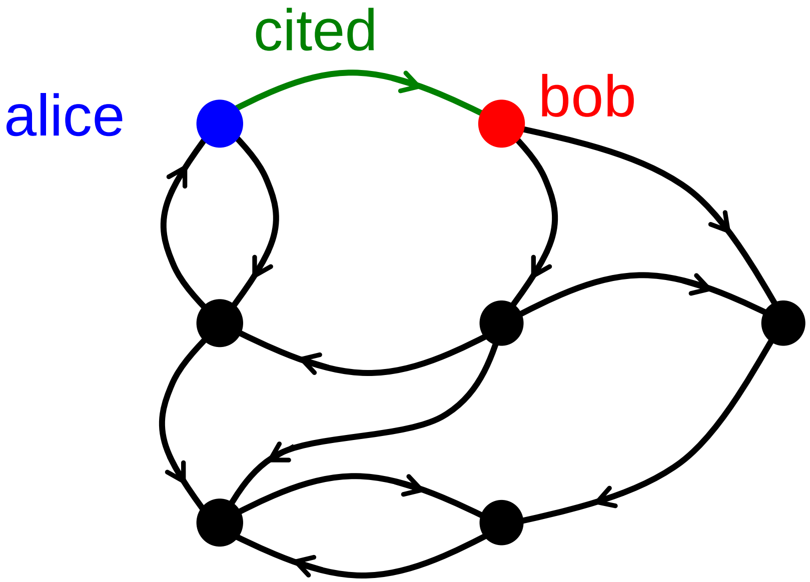
  or A('alice ','bob ') = 47.0

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

  ('alice ','bob ','cited ')

  or ('alice ','bob ',47.0)





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**

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

	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

Triple Store Table: T

Key Innovations

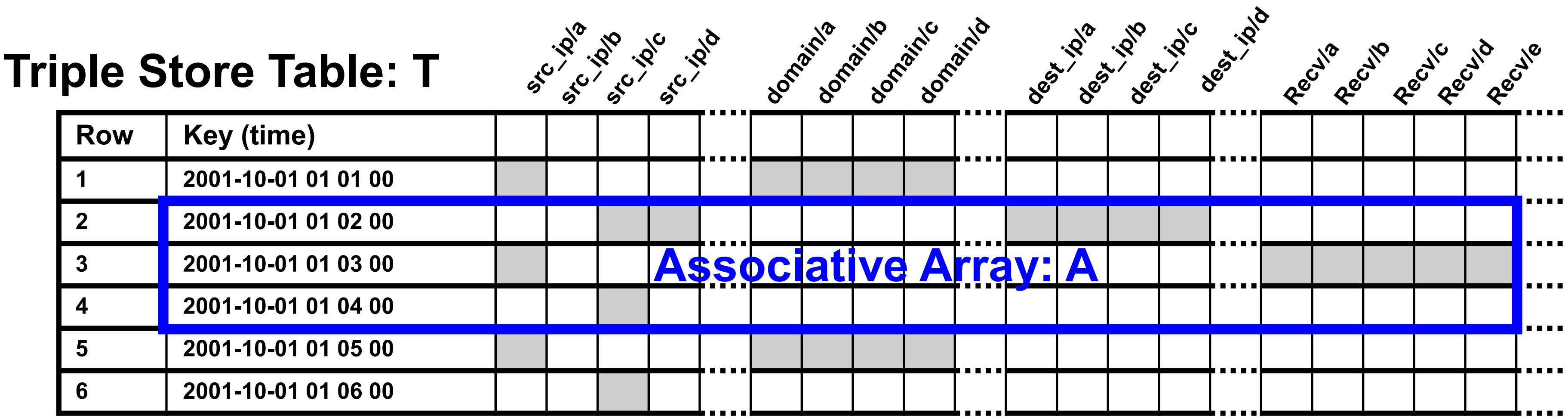
- Handles all data into a *single* table representation
- Transpose pairs allows quick look up of *either* row or column

Outline

- Introduction
- Technologies
- ➡ Results
  - Benchmark performance
  - Facet search
  - Management and monitoring
- Demo
- Summary

Stats Diagram

Triple Store Table: T



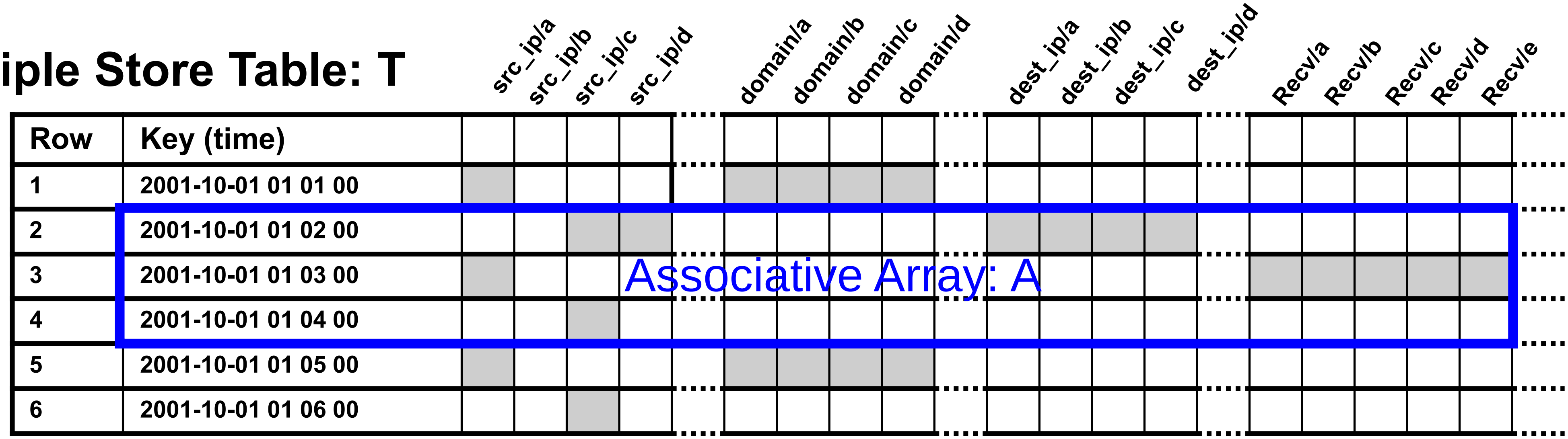
Row	Key (time)	src_ip/a	src_ip/b	src_ip/c	src_ip/d	....	domain/a	domain/b	domain/c	domain/d	....	dest_ip/a	dest_ip/b	dest_ip/c	dest_ip/d	....	Recv/a	Recv/b	Recv/c	Recv/d	Recv/e	....
1	2001-10-01 01 01 00	▨				....	▨	▨	▨	▨	....					....						....
2	2001-10-01 01 02 00			▨	▨	....					....	▨	▨	▨	▨	....						....
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			▨		....					....					....						....

- 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 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
```

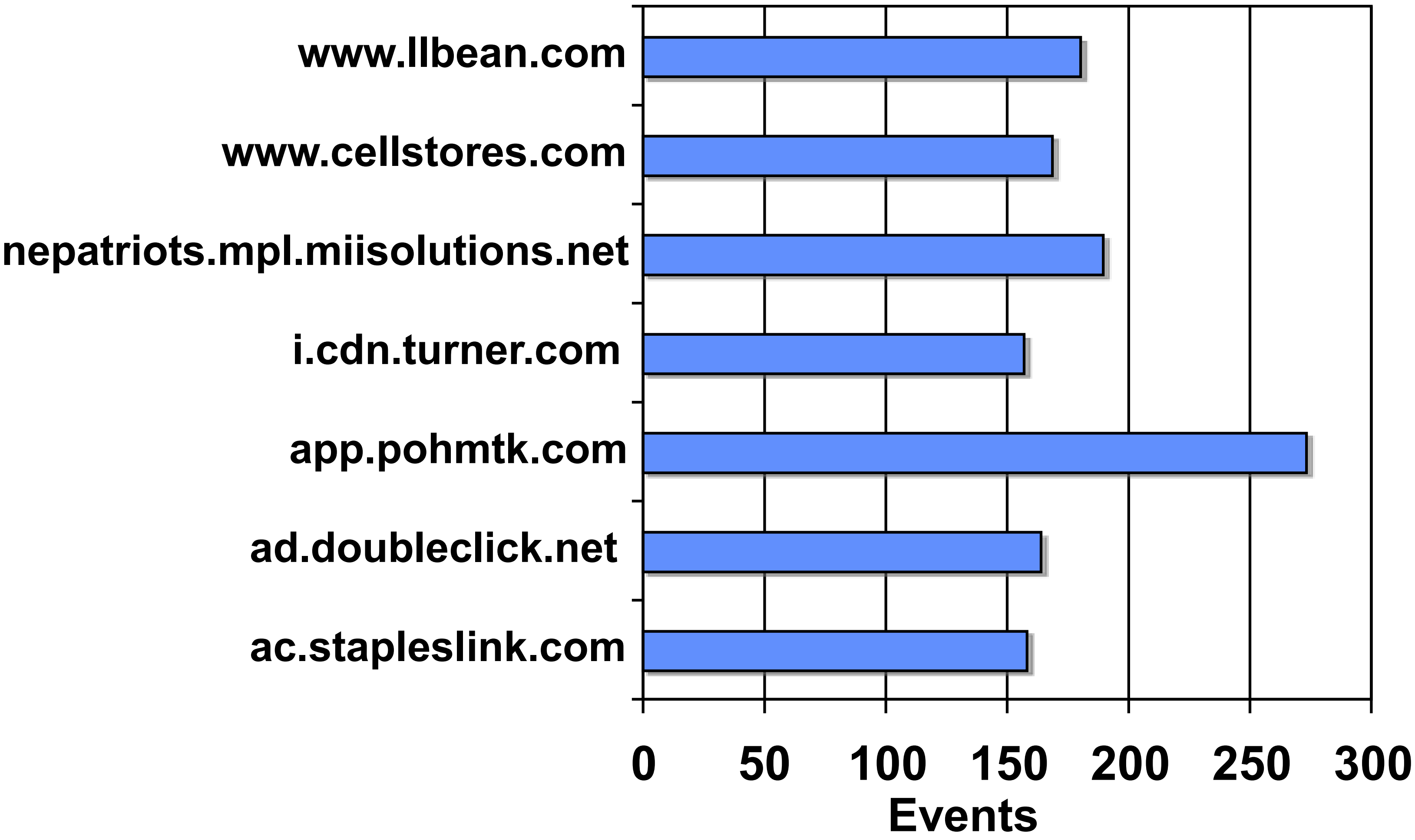
- **Find popular pairs**

A’ * A > 200 **or** sqIn(A) > 200

- **Find domains with many dest IPs**

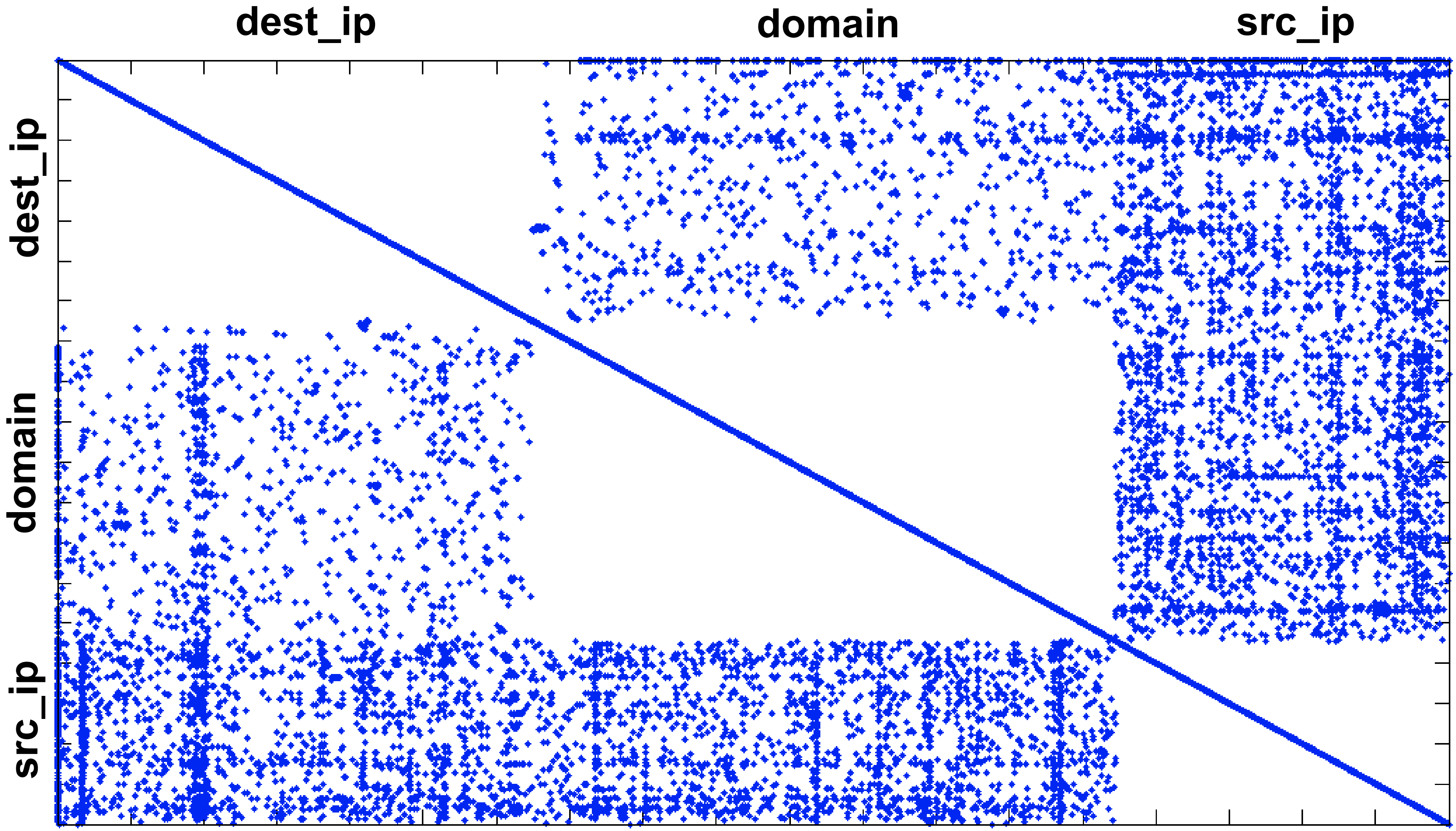
```
sum(double(logical(sqIn(A))),2) > 3
```

Count



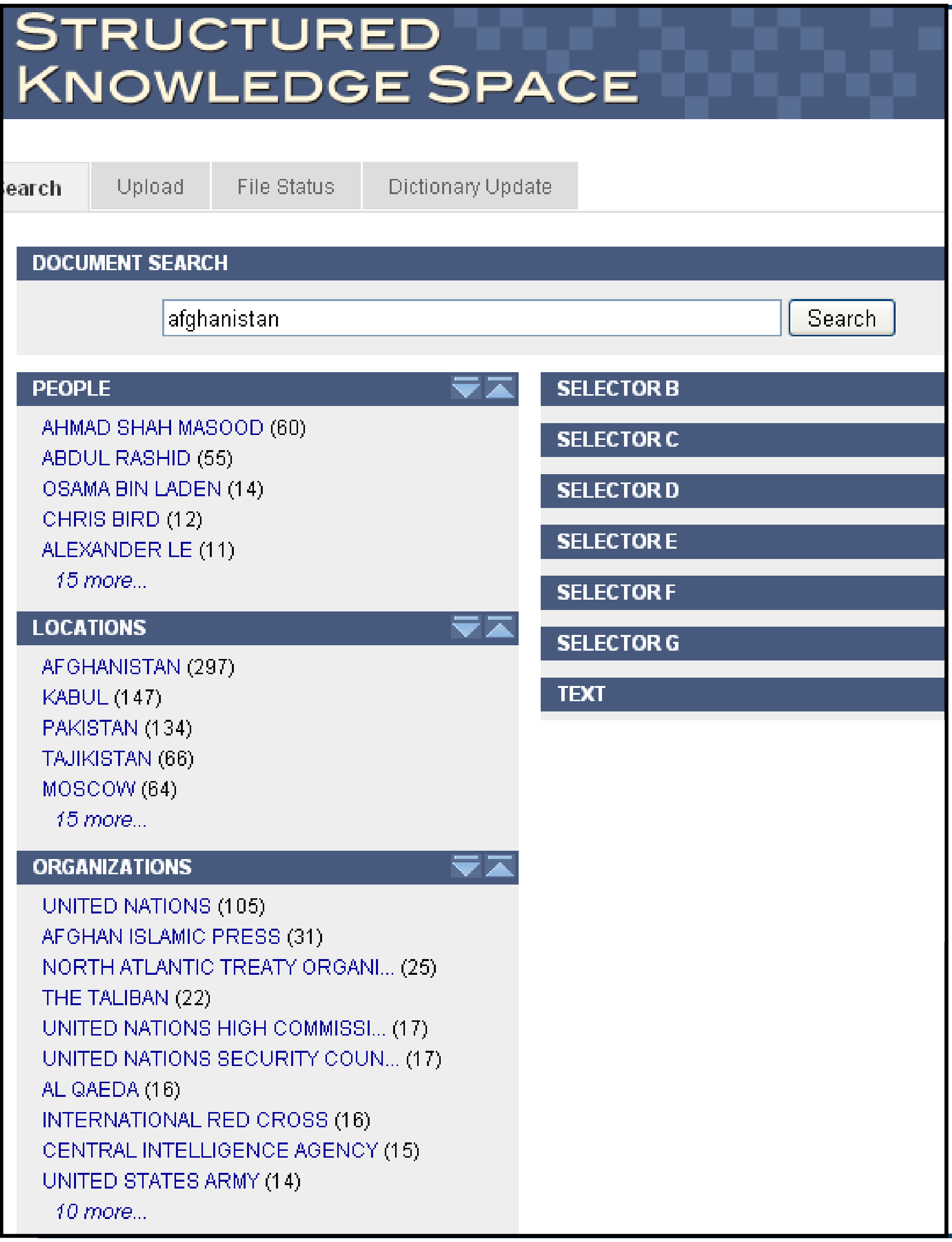
- Very easy to get elementary count info necessary for finding clutter and anomalies

Covariance



- **Adjacency matrix a natural result of covariance calculation**

Facet Search



DOCUMENT SEARCH

afghanistan

PEOPLE

AHMAD SHAH MASOOD (60)
ABDUL RASHID (55)
OSAMA BIN LADEN (14)
CHRIS BIRD (12)
ALEXANDER LE (11)
15 more...

LOCATIONS

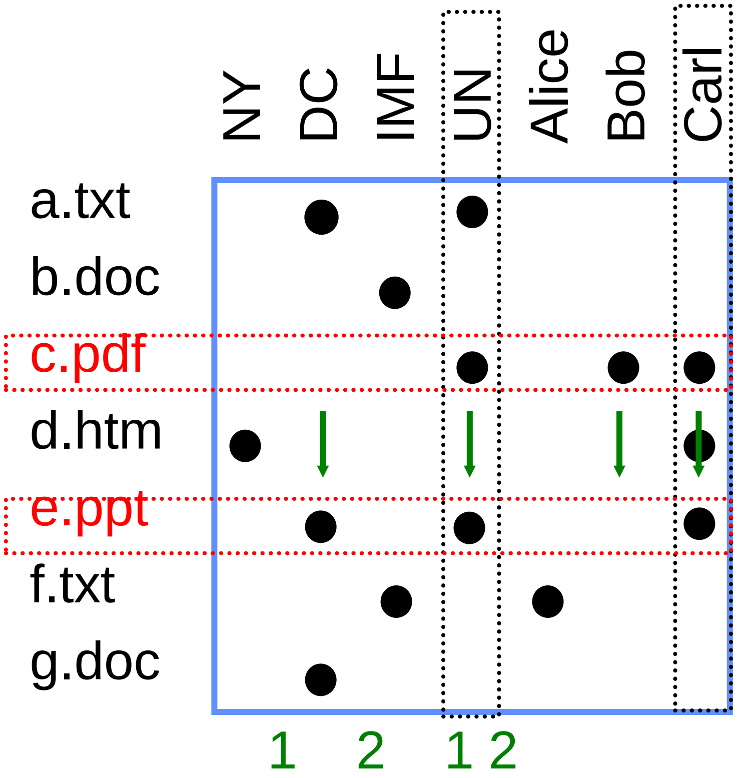
AFGHANISTAN (297)
KABUL (147)
PAKISTAN (134)
TAJIKISTAN (66)
MOSCOW (64)
15 more...

ORGANIZATIONS

UNITED NATIONS (105)
AFGHAN ISLAMIC PRESS (31)
NORTH ATLANTIC TREATY ORGANI... (25)
THE TALIBAN (22)
UNITED NATIONS HIGH COMMISSI... (17)
UNITED NATIONS SECURITY COUN... (17)
AL QAEDA (16)
INTERNATIONAL RED CROSS (16)
CENTRAL INTELLIGENCE AGENCY (15)
UNITED STATES ARMY (14)
10 more...

- **Core analytic of SKS**
- **Give 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



	NY	DC	IMF	UN	Alice	Bob	Carl
a.txt		●		●			
b.doc			●				
c.pdf				●		●	●
d.htm	●						●
e.ppt		●		●			●
f.txt			●		●		
g.doc		●					

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

$$A(x,y) : S^{N\mathrm{x}M} \rightarrow R$$

- 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

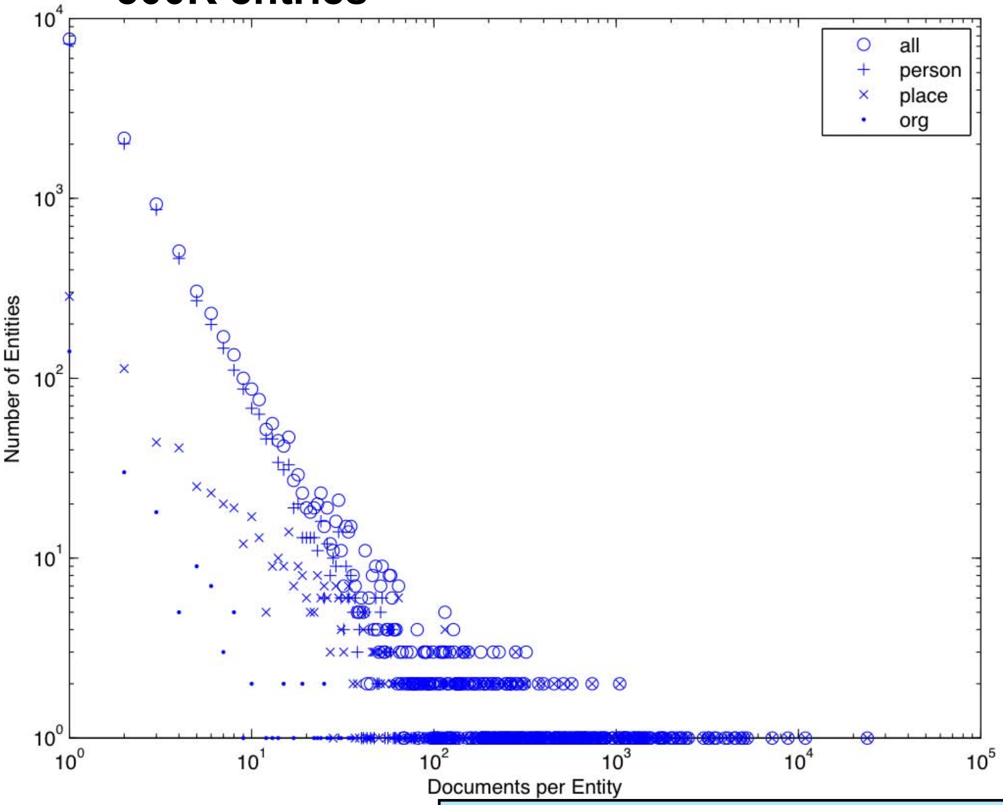
$$(\ \underline{A}(:,y_1)\ \&\ \underline{A}(:,y_2)\ )^t\ \ A$$

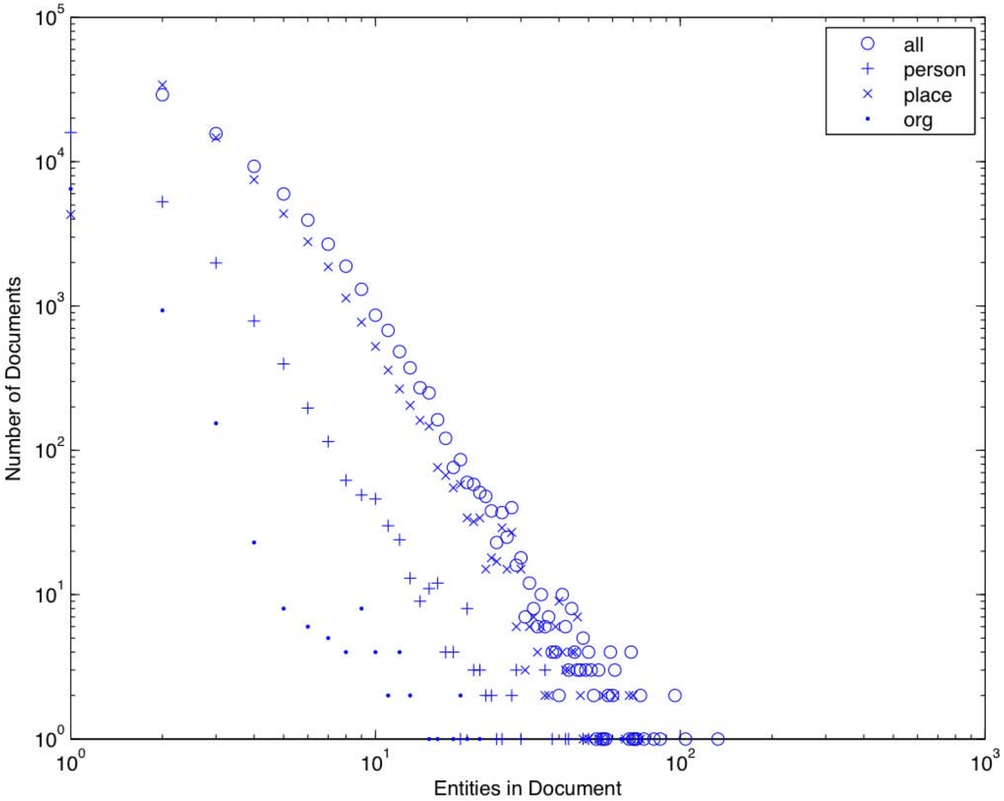
Outline

- Introduction
- Technologies
- Results
- ➡ Demo
- Summary

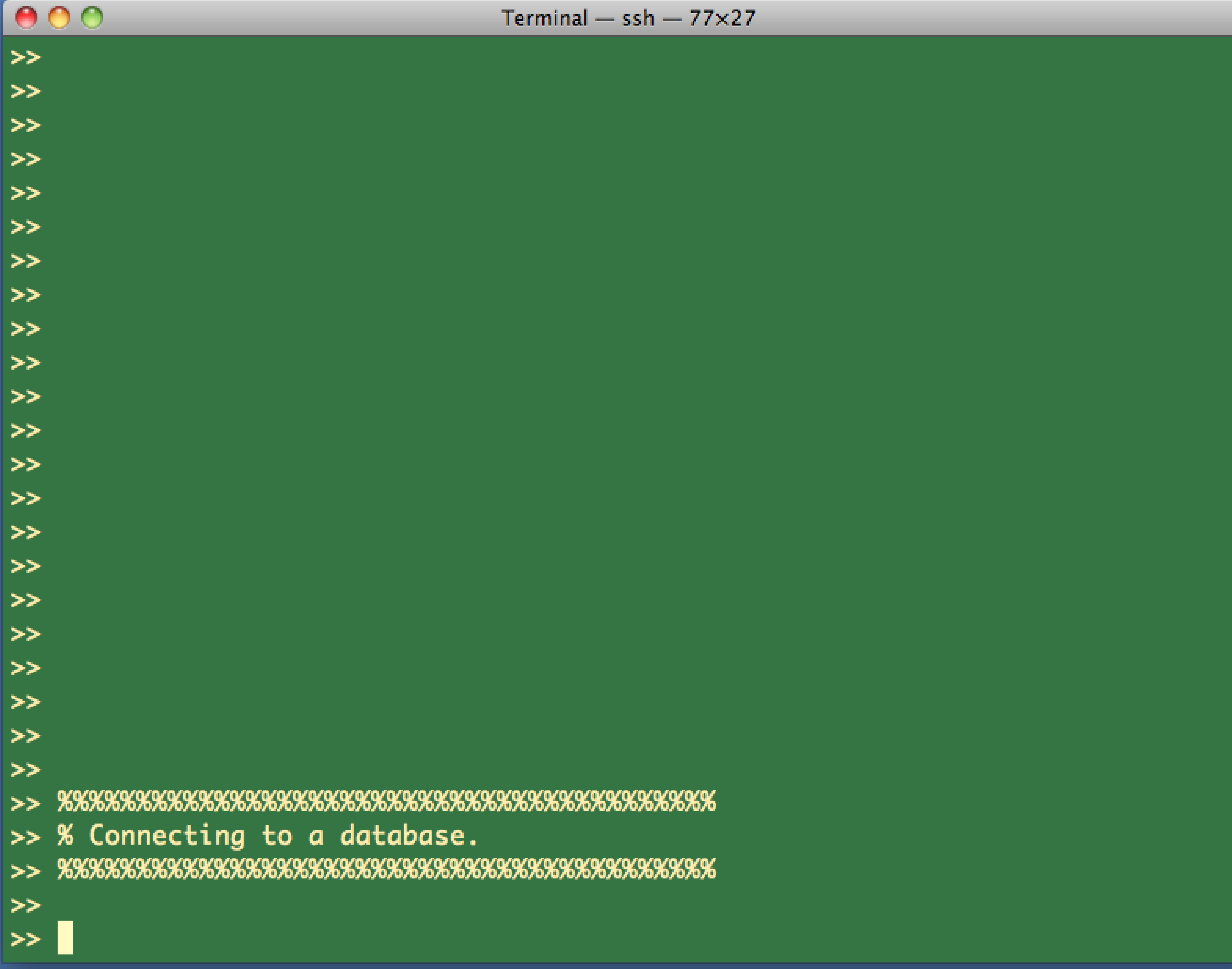
Reuters Corpus V1 (NIST)
1996-08-20 to 1997-08-19 (Released 2000-11-03

- 810,000 Reuters news blurbs
- Picked 70,000 and found 13,000 entities
- A is a 70Kx13K associative array with 500K entries





- Power laws everywhere
- Number of persons >> number of places
- Number of document/places>> number of document/person



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>> % Connecting to a database.
>> %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
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>> 
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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 than traditional approaches
- D4M is built on composable associative arrays which admit linear algebraic manipulation

Example Code & Assignment

- Example Code (end of Lecture 3 and start of lecture 4)
  - – d4m_api/examples/2Apps/1EntityAnalysis
  - – d4m_api/examples/2Apps/2TrackAnalysis

- Assignment
  - – None

RES-LL.005 D4M: Signal Processing on Databases
Fall 2012