Using R for Iterative and Incremental Processing

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UC Berkeley and HP Labs

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Big Data, Complex Algorithms

PageRank
(Dominant eigenvector)

Recommendations
(Matrix factorization)

Anomaly detection
(Top-K eigenvalues)

User Importance
(Vertex Centrality)

Big Data, Complex Algorithms

PageRank
(Dominant eigenvector)

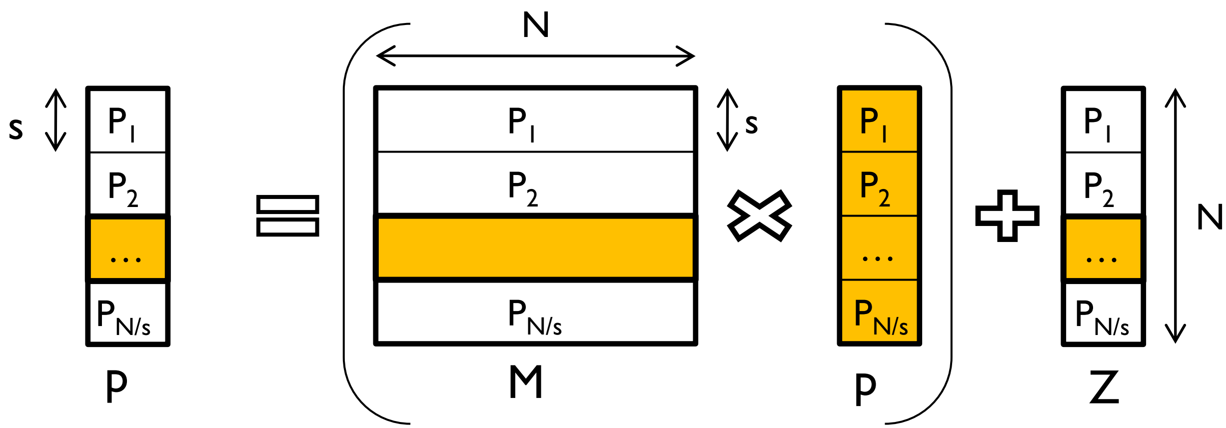
Machine learning + Graph algorithms

Iterative Linear Algebra Operations

Anomaly detection
(Top-K eigenvalues)

User Importance
(Vertex Centrality)

PageRank Using Matrices



Dominant eigenvector

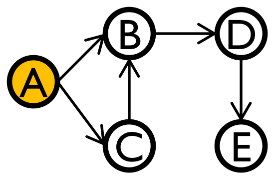
M = modified web graph matrix

p = PageRank vector

Simplified algorithm:

repeat { p = M*p + Z}

Breadth-first Search Using Matrices



X					
	1	0	0	0	0

	A	B	C	D	E
A	1	1	1	0	0
B	0	1	0	1	0
C	0	1	1	0	0
D	0	0	0	1	1
E	0	0	0	0	1

← G

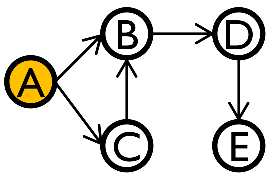
G = adjacency matrix

X = BFS vector

Simplified algorithm:

repeat { X = G*X }

Breadth-first Search Using Matrices



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	A	B	C	D	E
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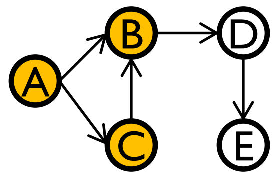

*	*	*	0	0
A	**B**	**C**	**D**	**E**

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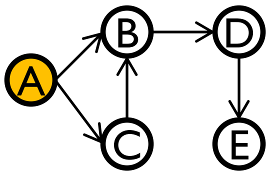
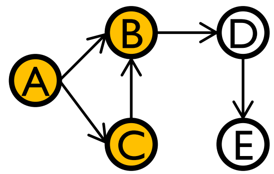
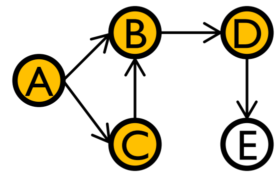
Breadth-first Search Using Matrices







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	A	B	C	D	E
A	1	1	1	0	0
B	0	1	0	1	0
C	0	1	1	0	0
D	0	0	0	1	1
E	0	0	0	0	1

← G

*	*	*	0	0
A	**B**	**C**	**D**	**E**

*	*	*	*	0
A	**B**	**C**	**D**	**E**

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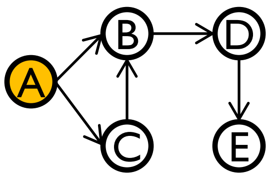
Breadth-first Search Using Matrices



X	1	0	0	0	0

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A	1	1	1	0	0
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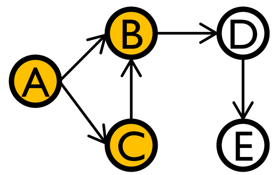
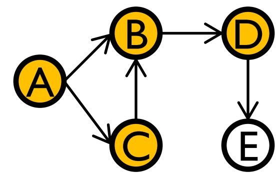
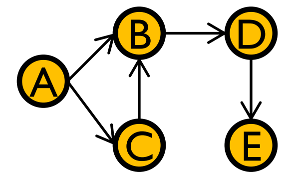
← G



*	*	*	0	0
A	**B**	**C**	**D**	**E**



*	*	*	*	0
A	**B**	**C**	**D**	**E**



*	*	*	*	*
A	**B**	**C**	**D**	**E**

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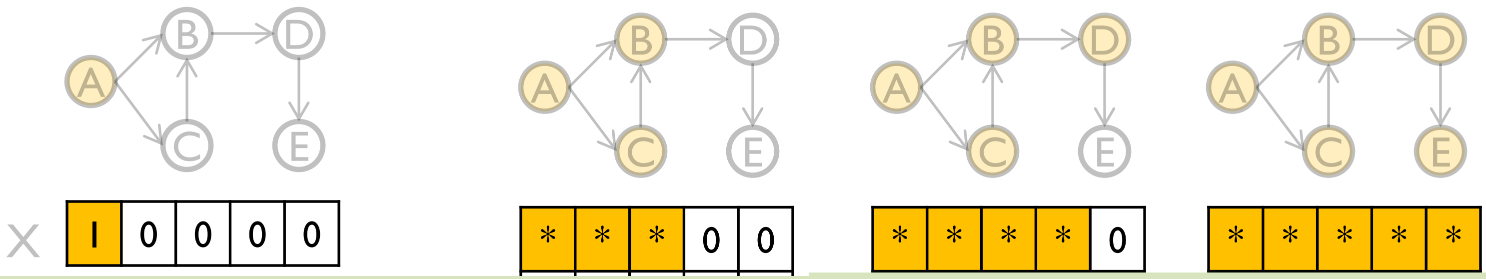
Breadth-first Search Using Matrices



Matrix operations

Easy to express

Efficient to implement

E	0	0	0	0	1

G = adjacency matrix

X = BFS vector

Simplified algorithm:

repeat { X = G*X }

Linear Algebra on Existing Frameworks

Matrix Operations: *Structured*, coarse grained

Need global state

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Data-parallel frameworks – MapReduce/Dryad

– Process each *record* in parallel

– Use case: Computing sufficient statistics

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Matrix Operations: *Structured*, coarse grained

Need global state

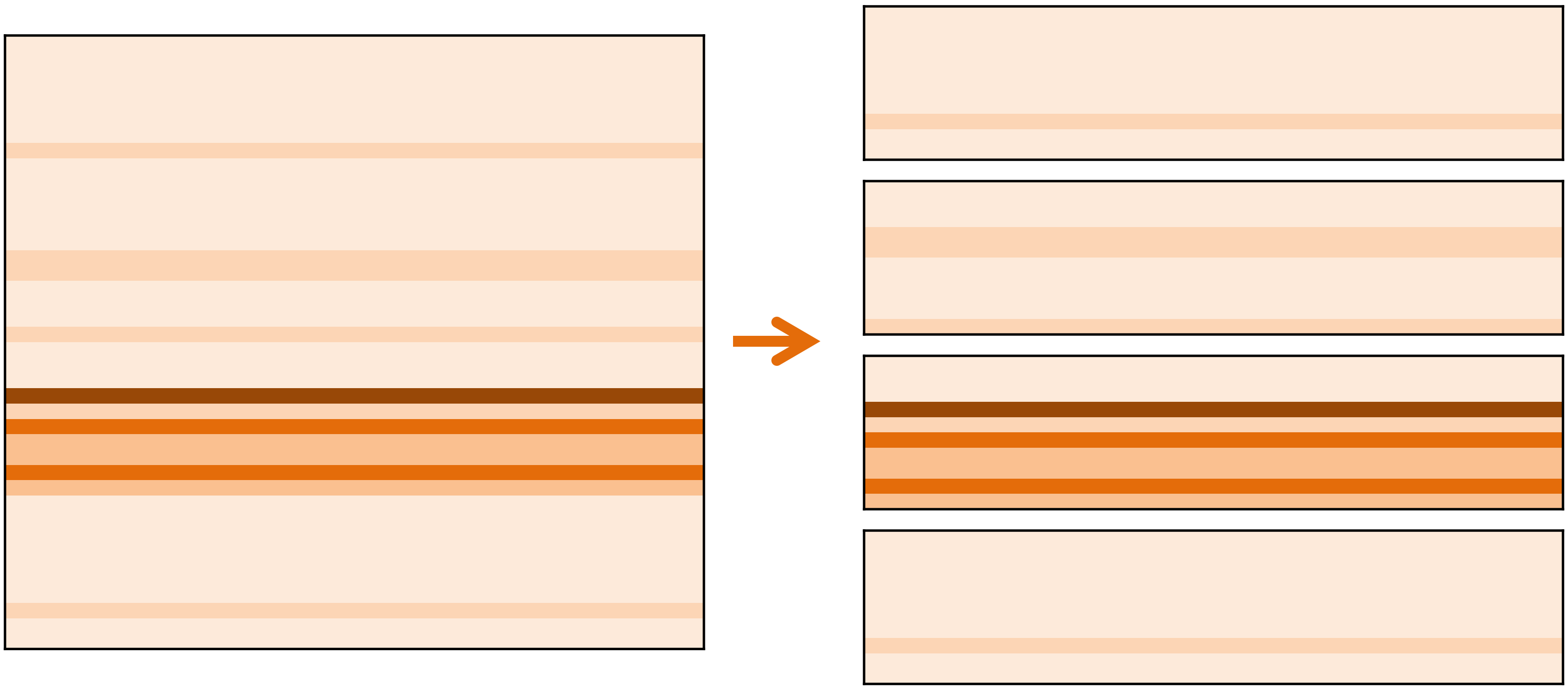
Data-parallel frameworks – MapReduce/Dryad

- – Process each *record* in parallel
- – Use case: Computing sufficient statistics

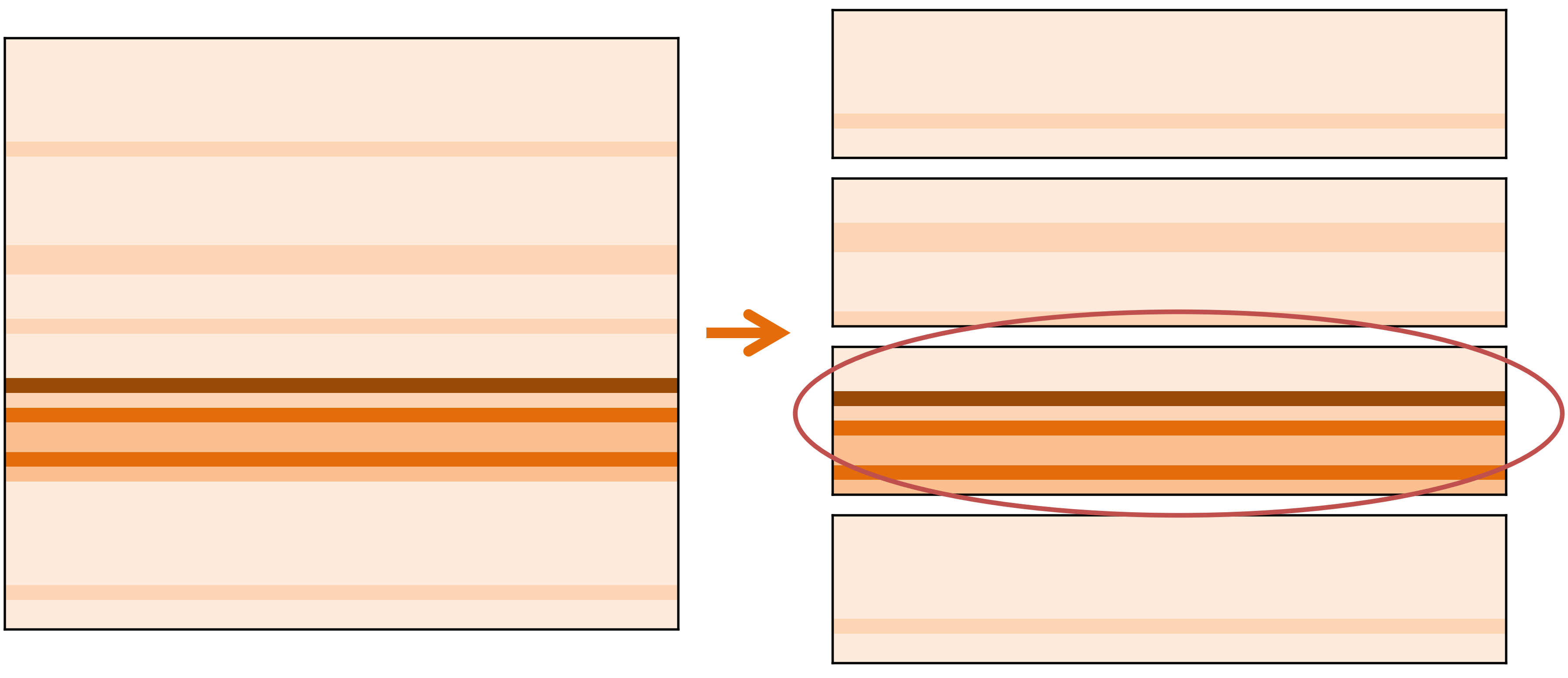
Graph-centric frameworks – Pregel/GraphLab

- – Process each *vertex* in parallel
- – Use case: Graph models

Challenge 1 – Sparse Matrices



Challenge 1 – Sparse Matrices



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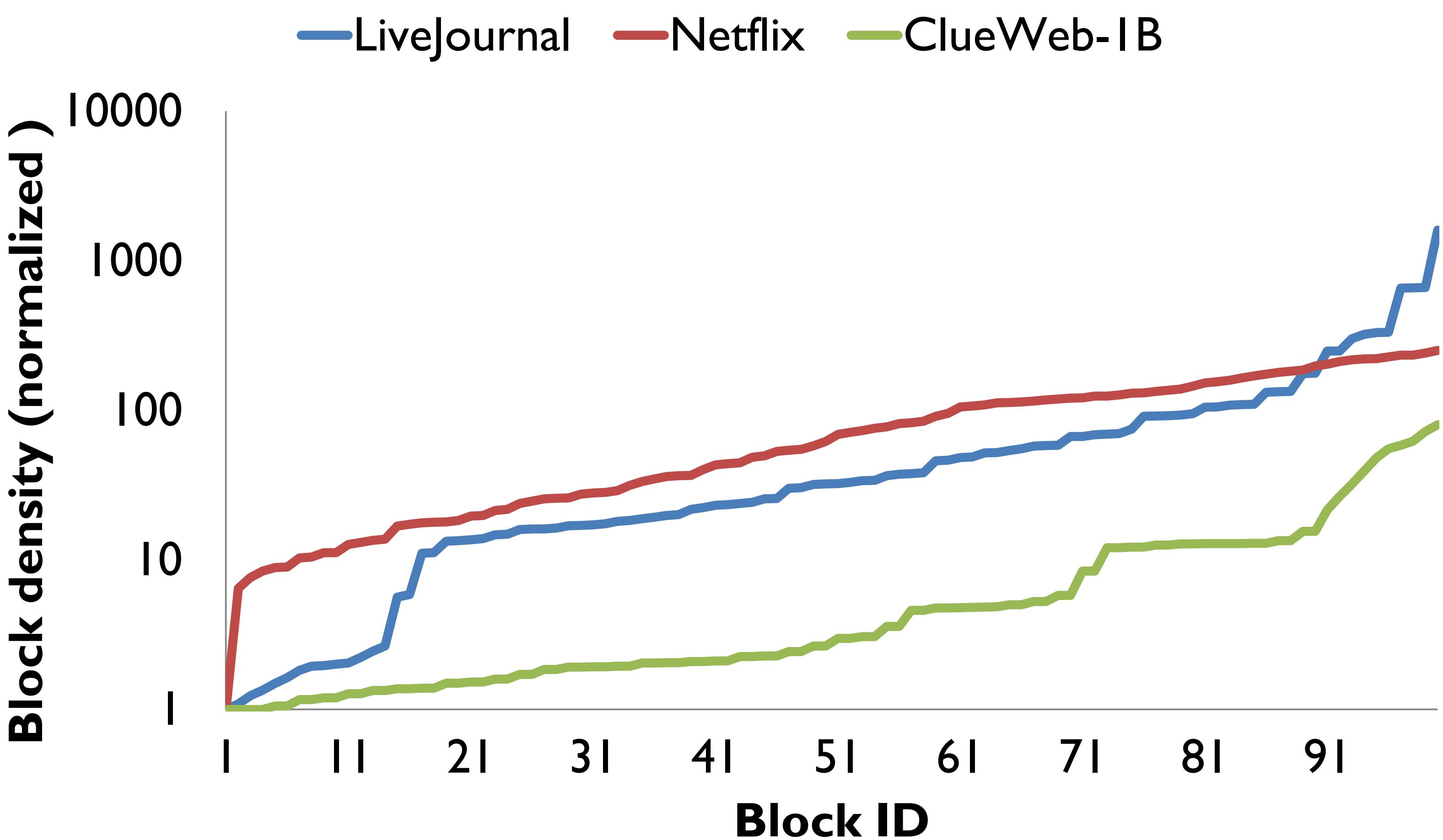

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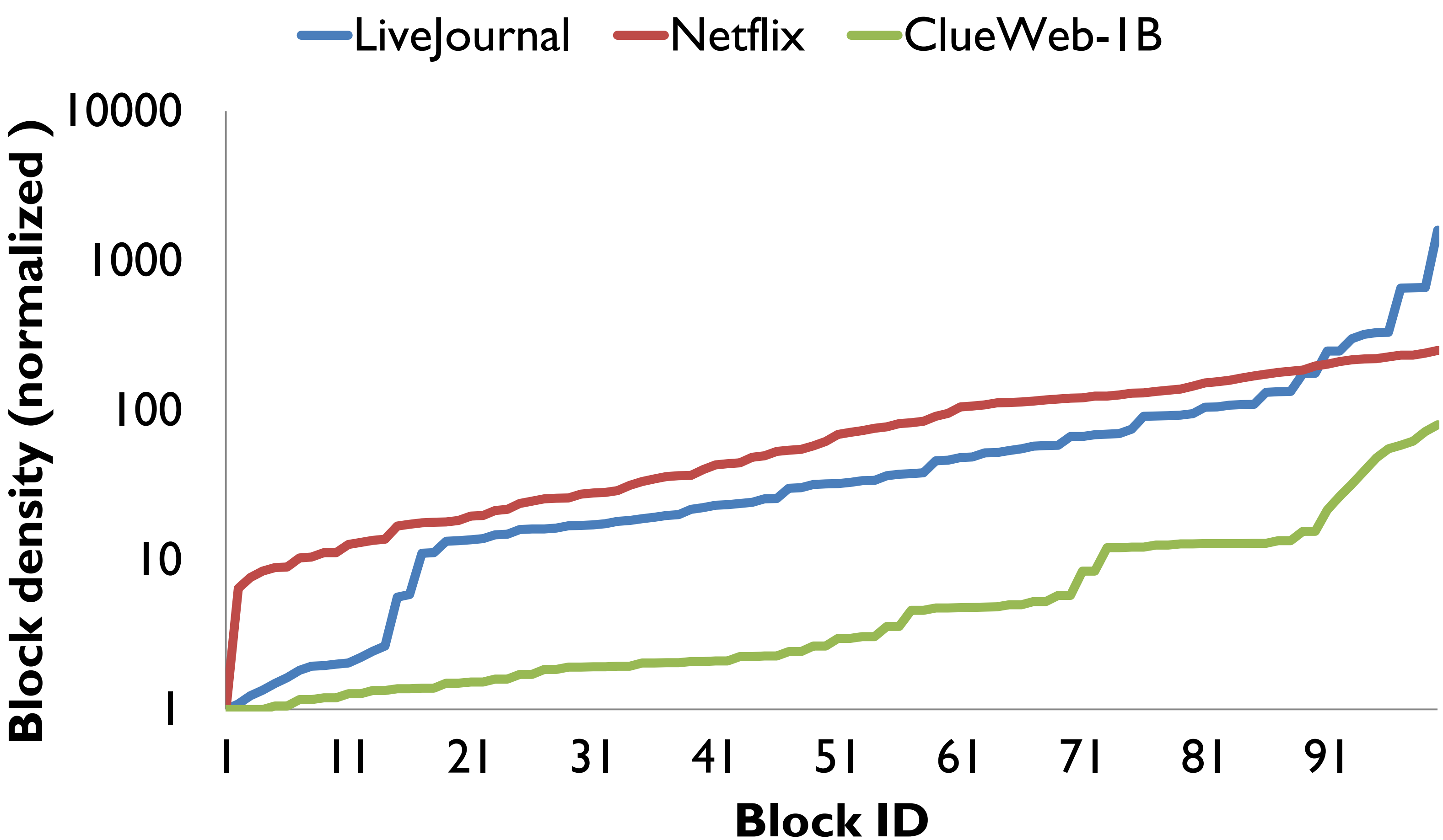

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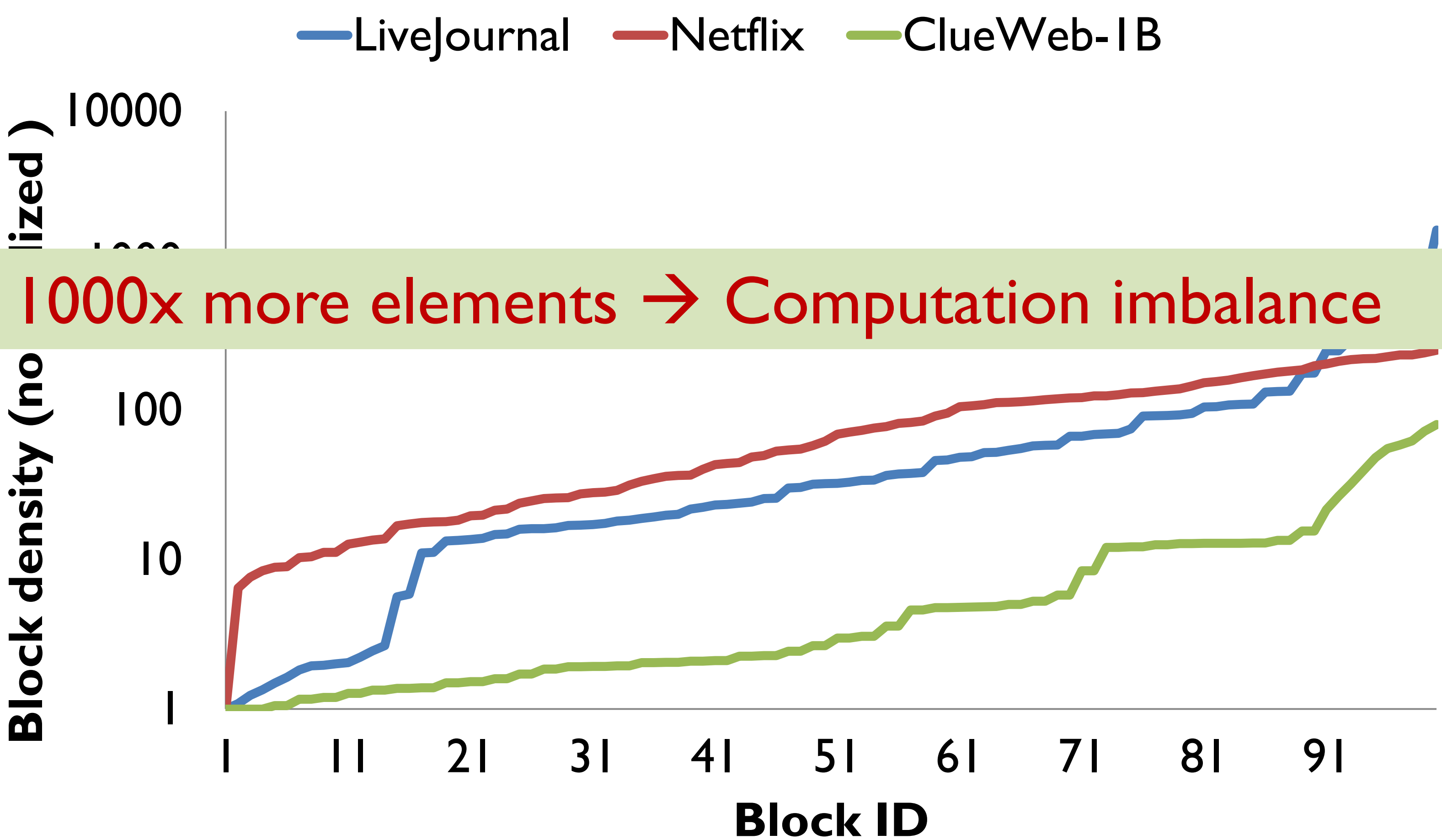
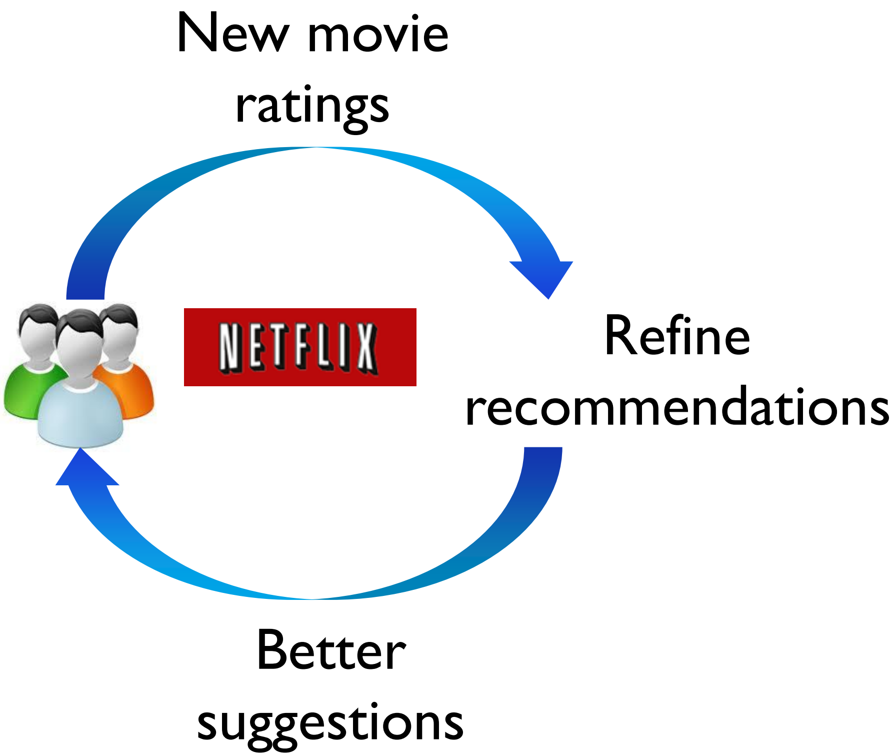


1000x more elements → Computation imbalance

Challenge 2 – Incremental Updates



Incremental computation on consistent view of data

Presto

Framework for large-scale iterative linear algebra

Extend R for scalability and incremental updates

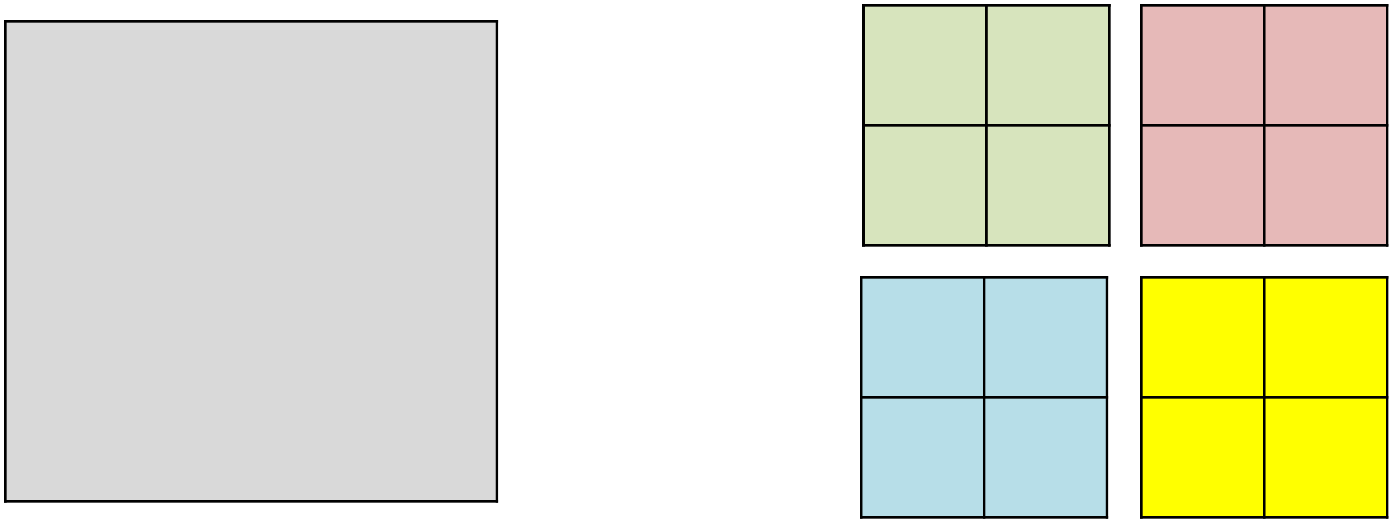
Outline

- Motivation
- Programming model
- Design
- Applications and Results

Programming Model

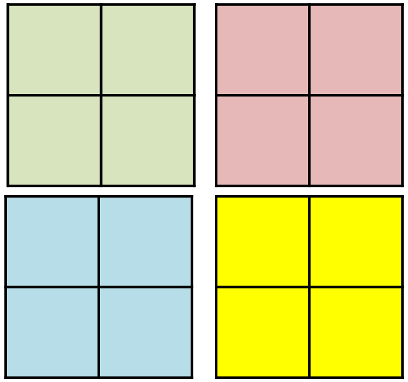
One data structure: Distributed Array

A ← *darray*(…)



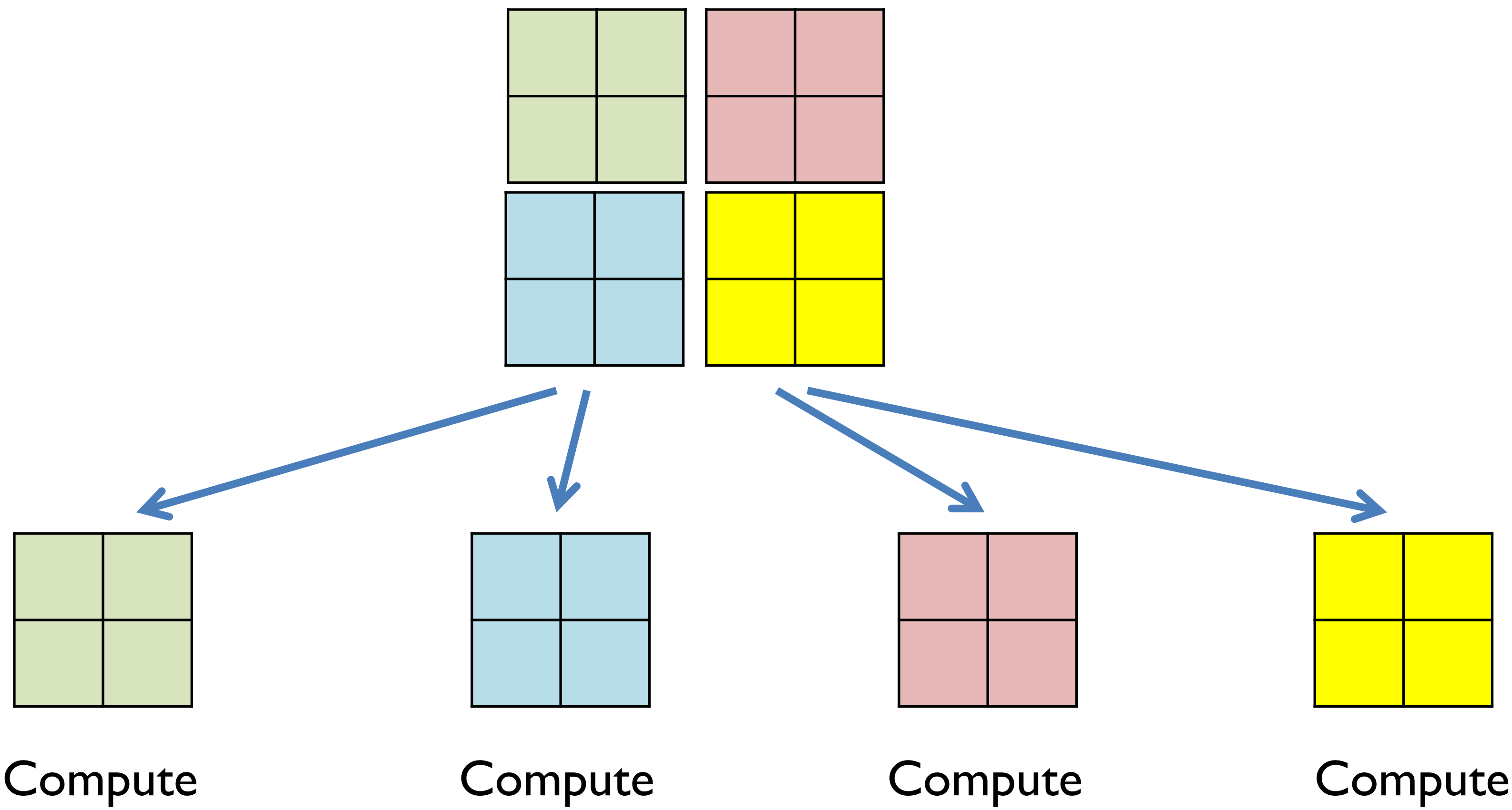
Programming Model

Iteration: foreach



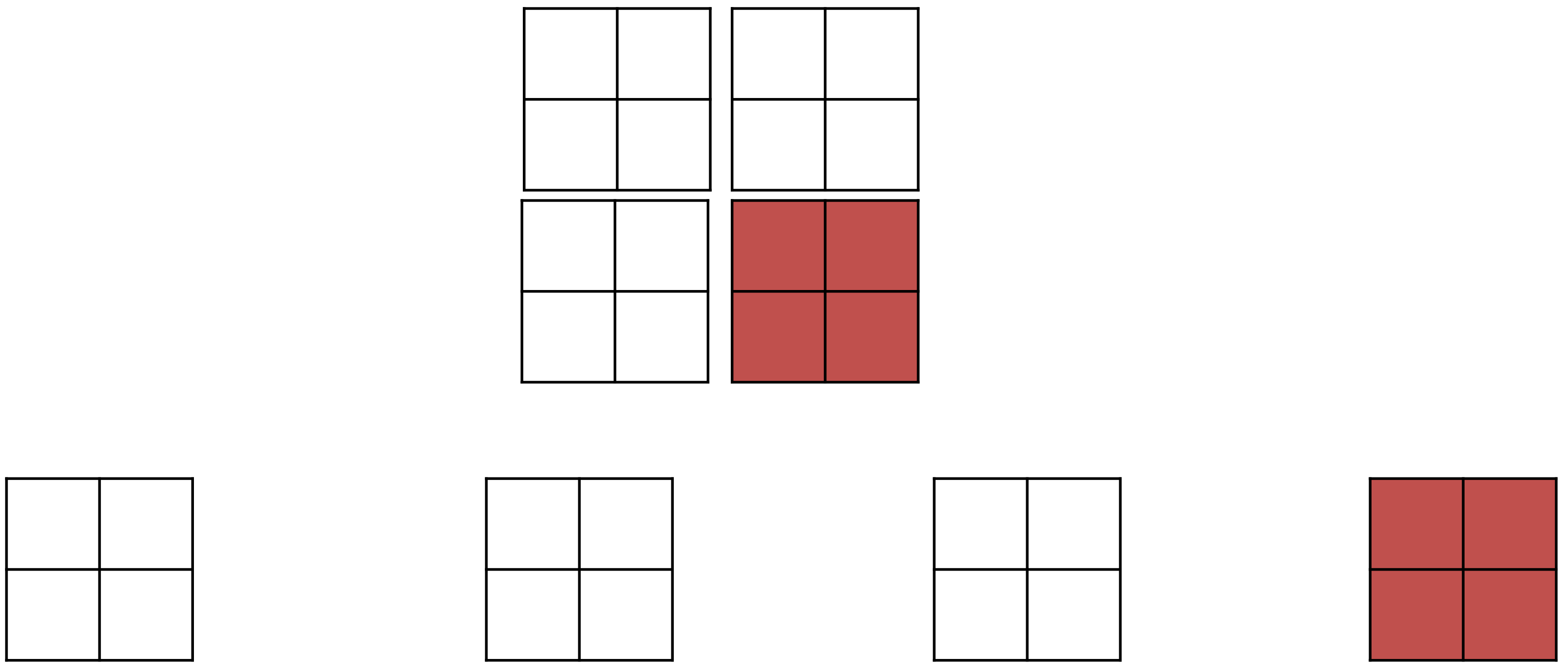
Programming Model

Iteration: foreach



Programming Model

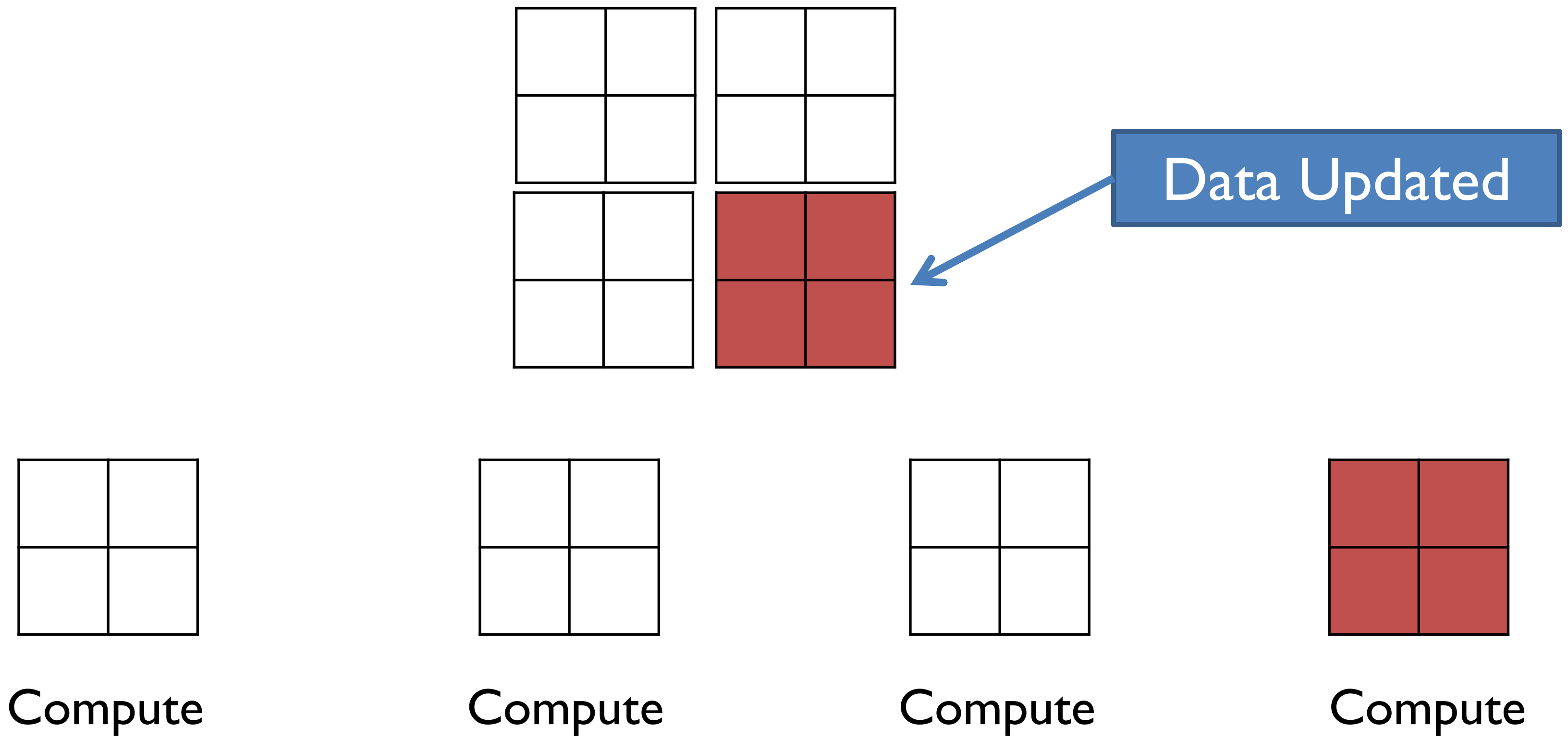
Incremental updates: onchange, update



Compute Compute Compute Compute

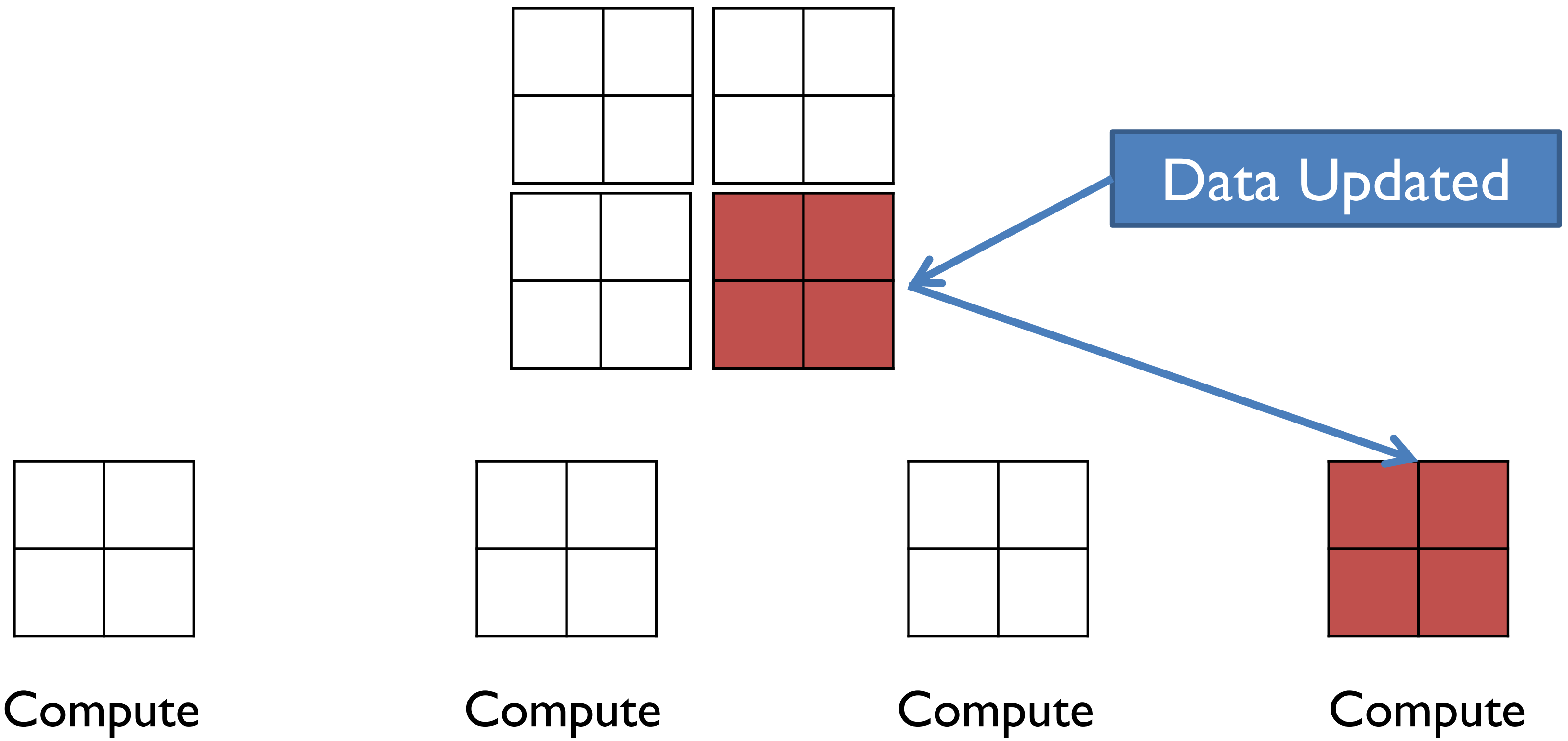
Programming Model

Incremental updates: onchange, update

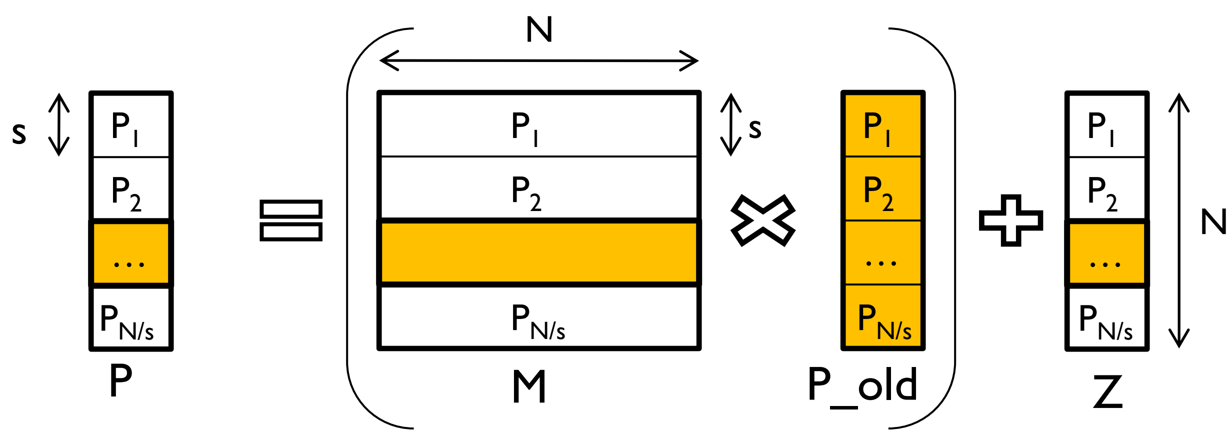


Programming Model

Incremental updates: onchange, update

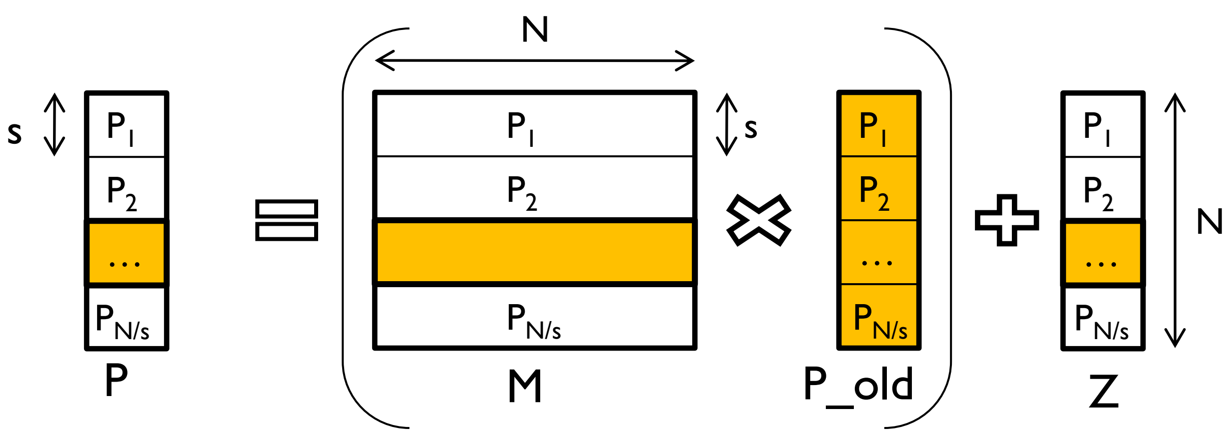


PageRank Using Presto




```
M ← darray(dim=c(N,N),blocks=(s,N))
P ← darray(dim=c(N,1),blocks=(s,1))
while(..){
  foreach(i,1:len,
     calculate(p=splits(P,i),m=splits(M,i),
               x=splits(P_old),z=splits(Z,i)) {
        p ← (m*x)+z
     }
  )
  P_old ← P
}
```

PageRank Using Presto

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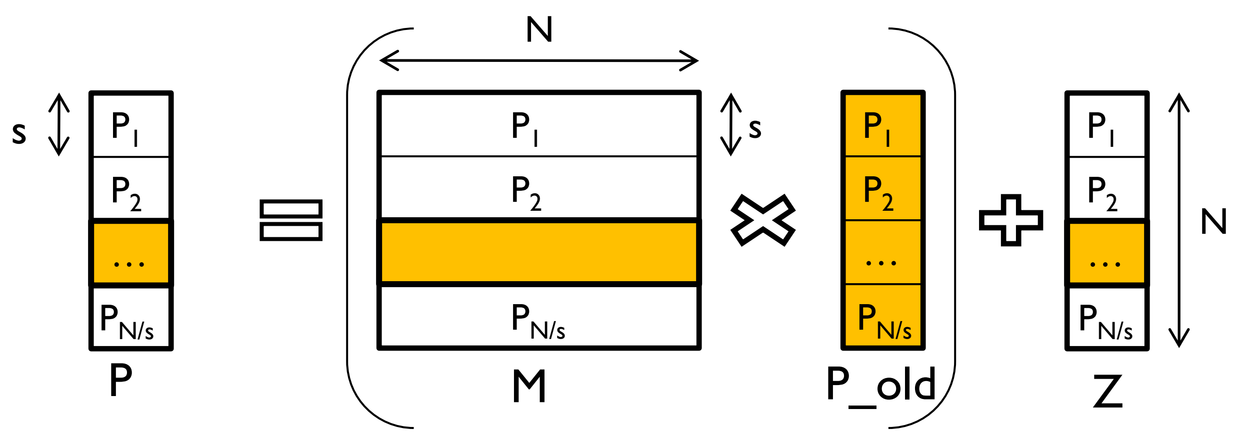
```

Create Distributed Array

PageRank Using Presto

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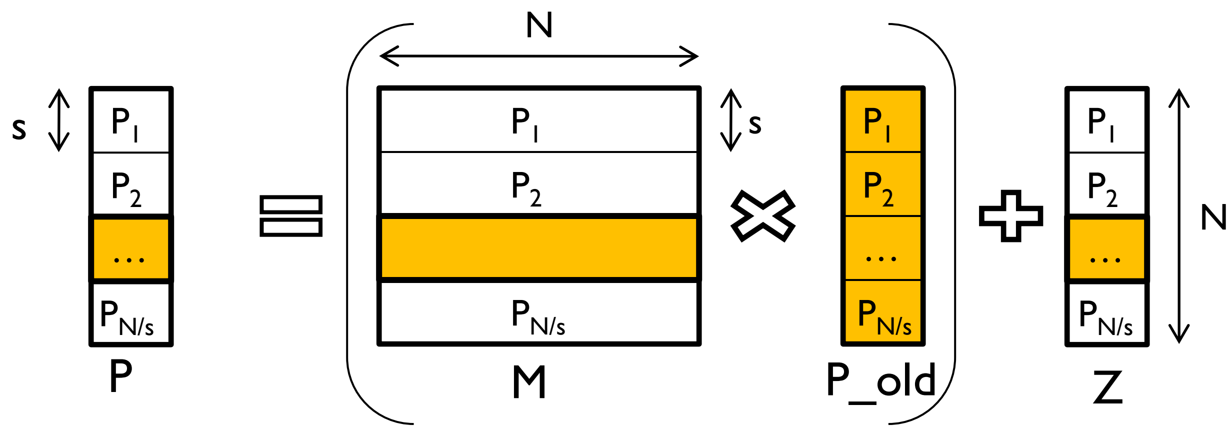
PageRank Using Presto

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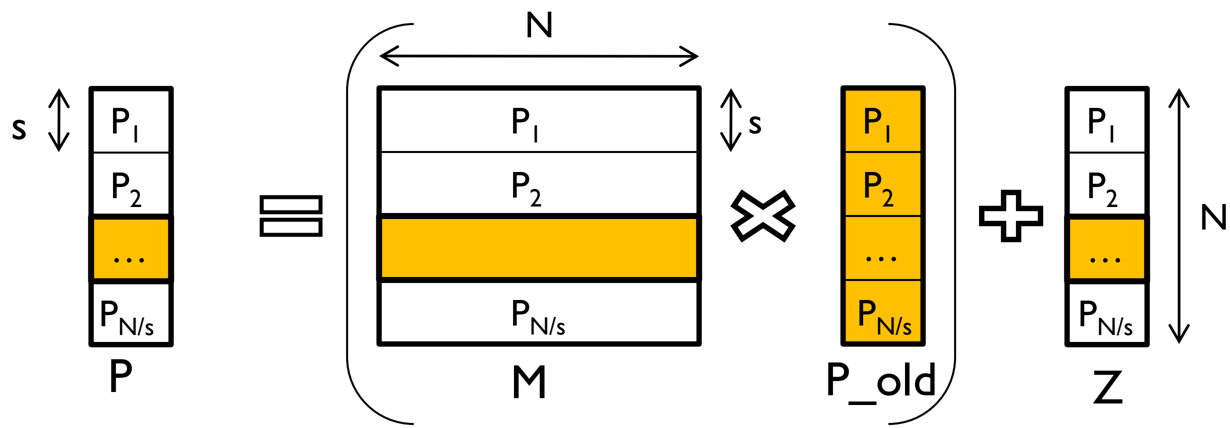
Execute function in a cluster

PageRank Using Presto

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}
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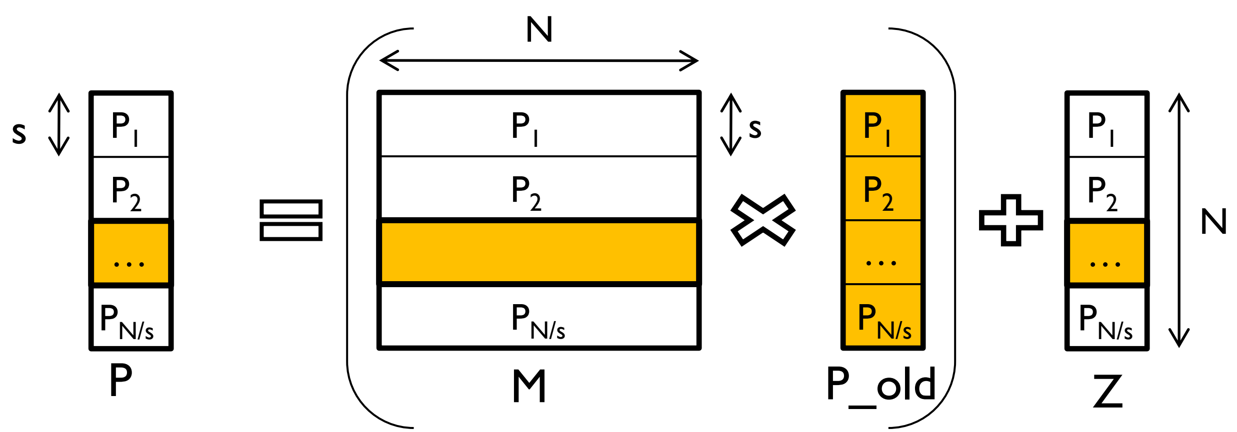
Execute function in a cluster

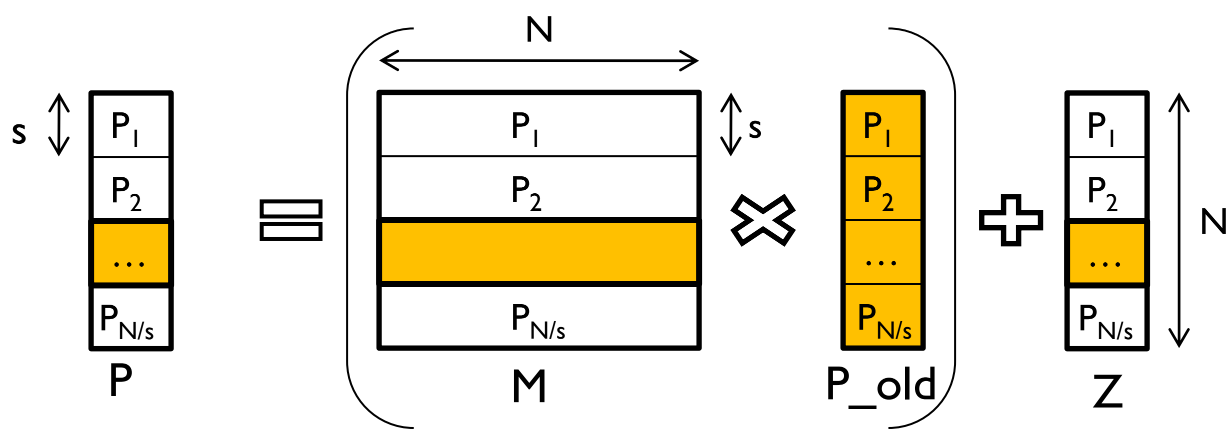
Pass array partitions

Incremental PageRank




```
M ← darray(dim=c(N,N),blocks=(s,N))
P ← darray(dim=c(N,1),blocks=(s1))
onchange(M) {
  while(..){
    foreach(i,1:len,
       calculate(p=splits(P,i), m=splits(M,i),
                 x=splits(P_old), z=splits(Z,i)) {
         p ← (m*x)+z
         update(p)
      })
    P_old ← P
  }}
```

Incremental PageRank

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          p ← (m*x)+z
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      })
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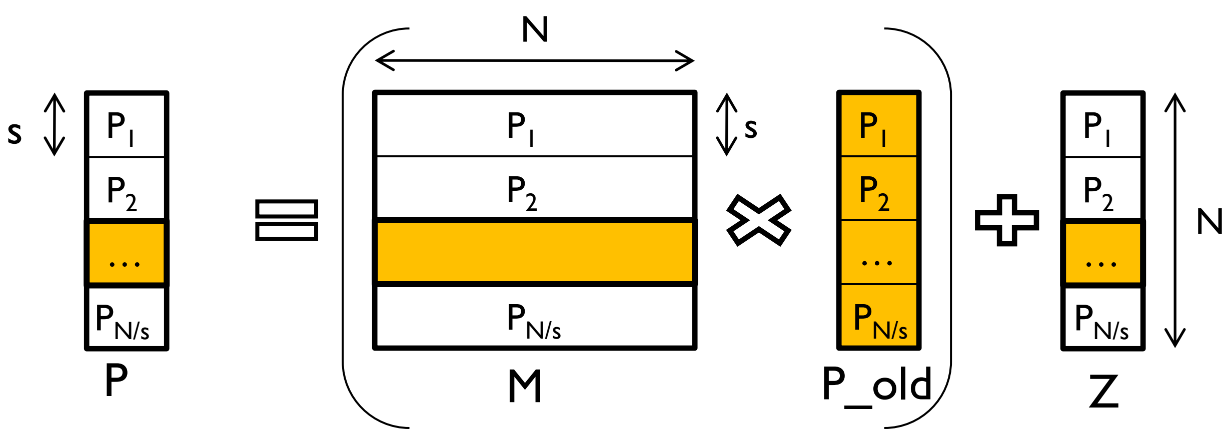
}}
```

Execute when data changes

Incremental PageRank

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      })
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```

Execute when data changes

Update page rank vector

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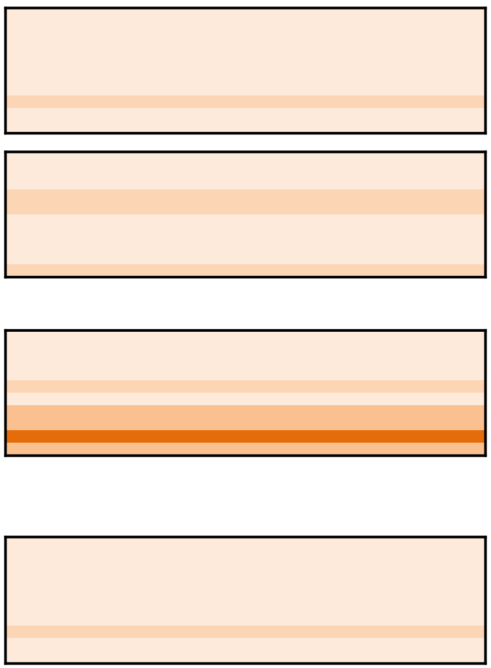
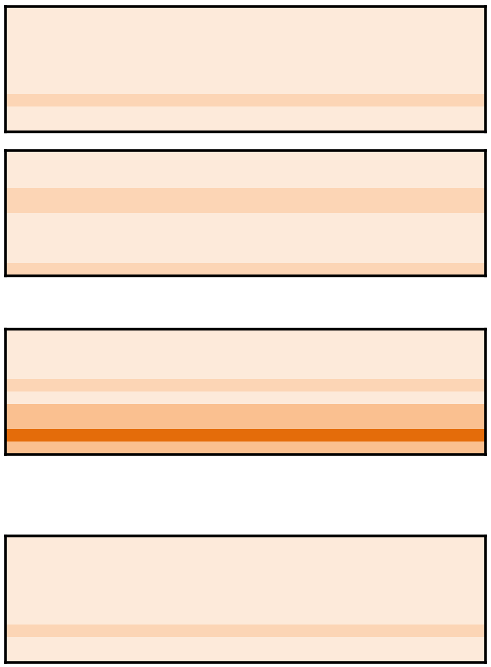
- Design
- Applications and Results

Dynamic Partitioning of Matrices

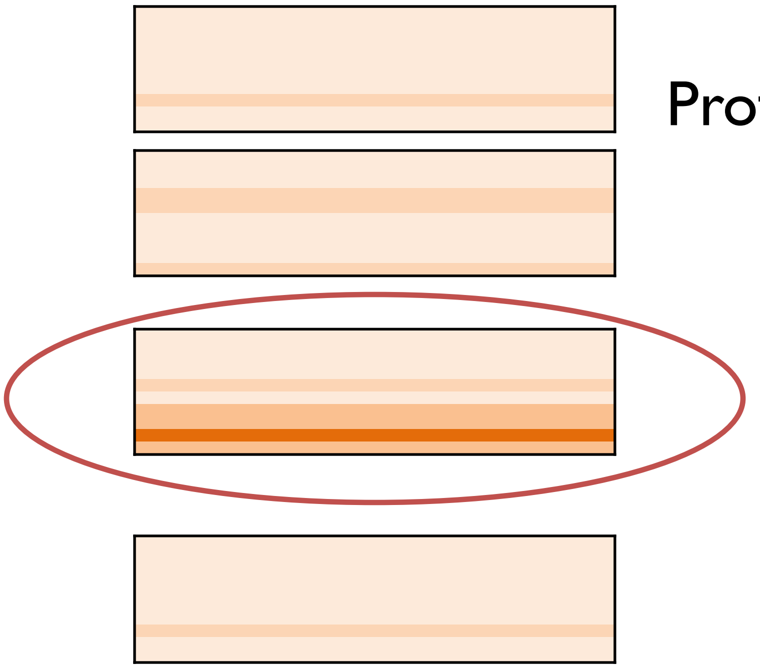


Dynamic Partitioning of Matrices



Profile execution

Dynamic Partitioning of Matrices



Profile execution

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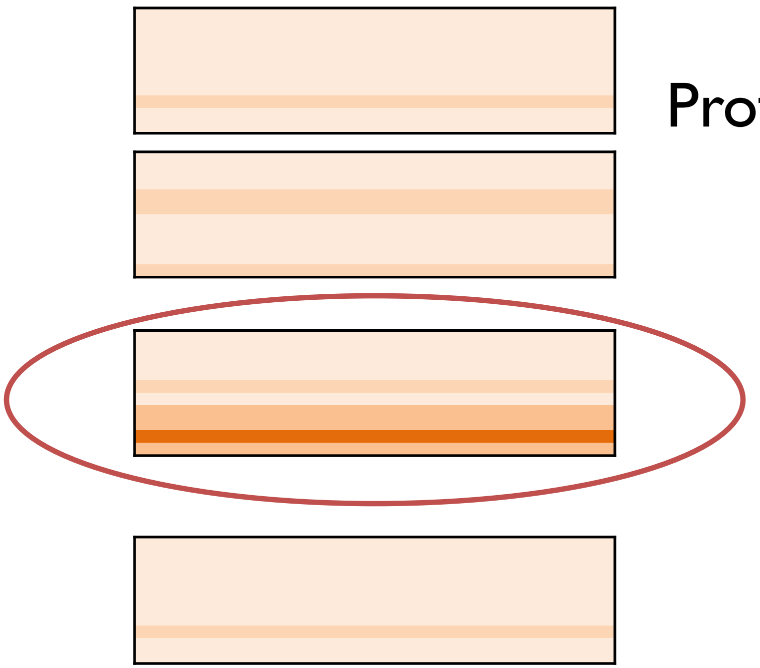
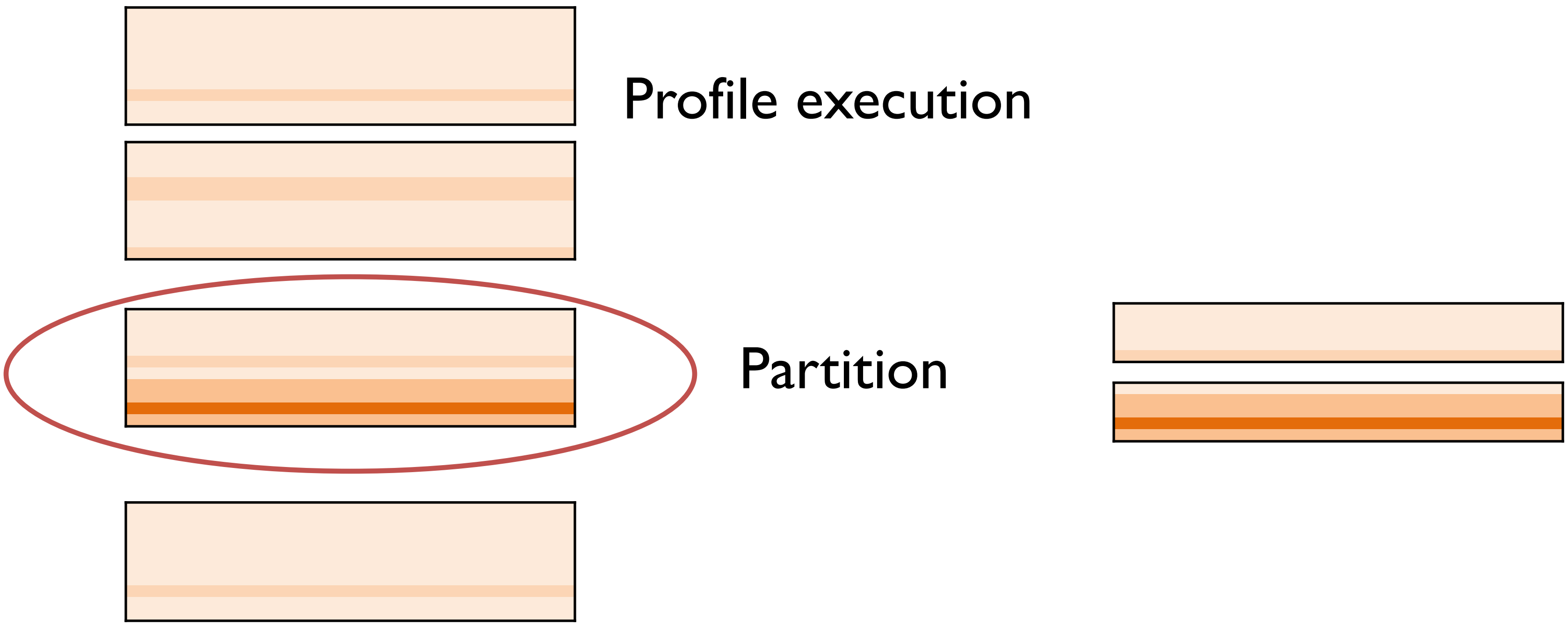


Profile execution

Partition

Dynamic Partitioning of Matrices



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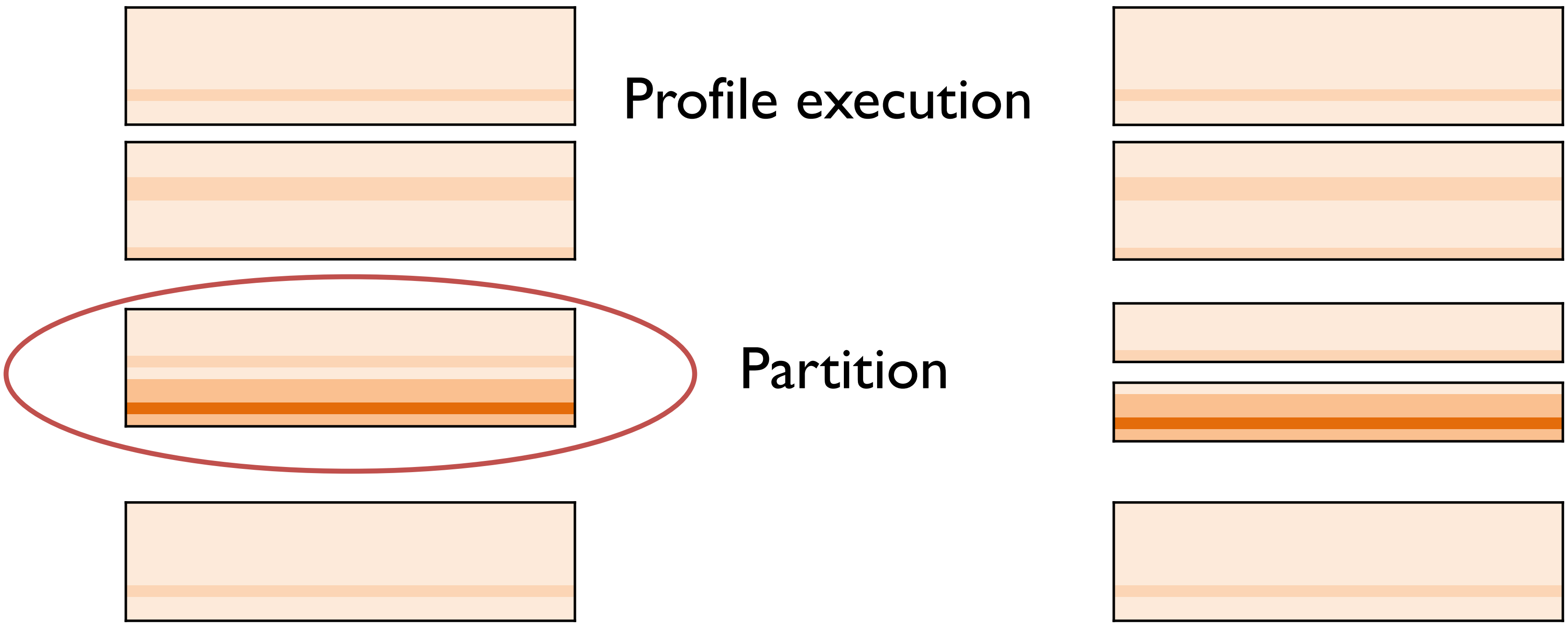
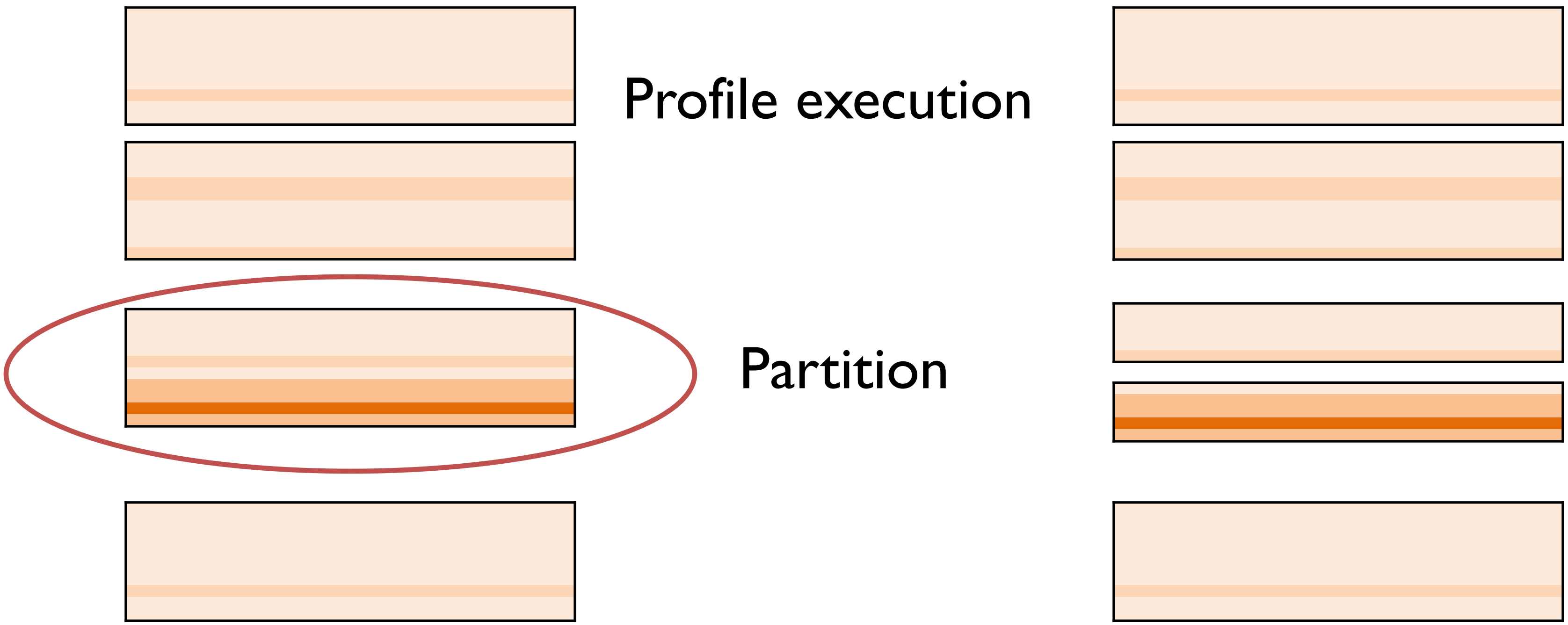
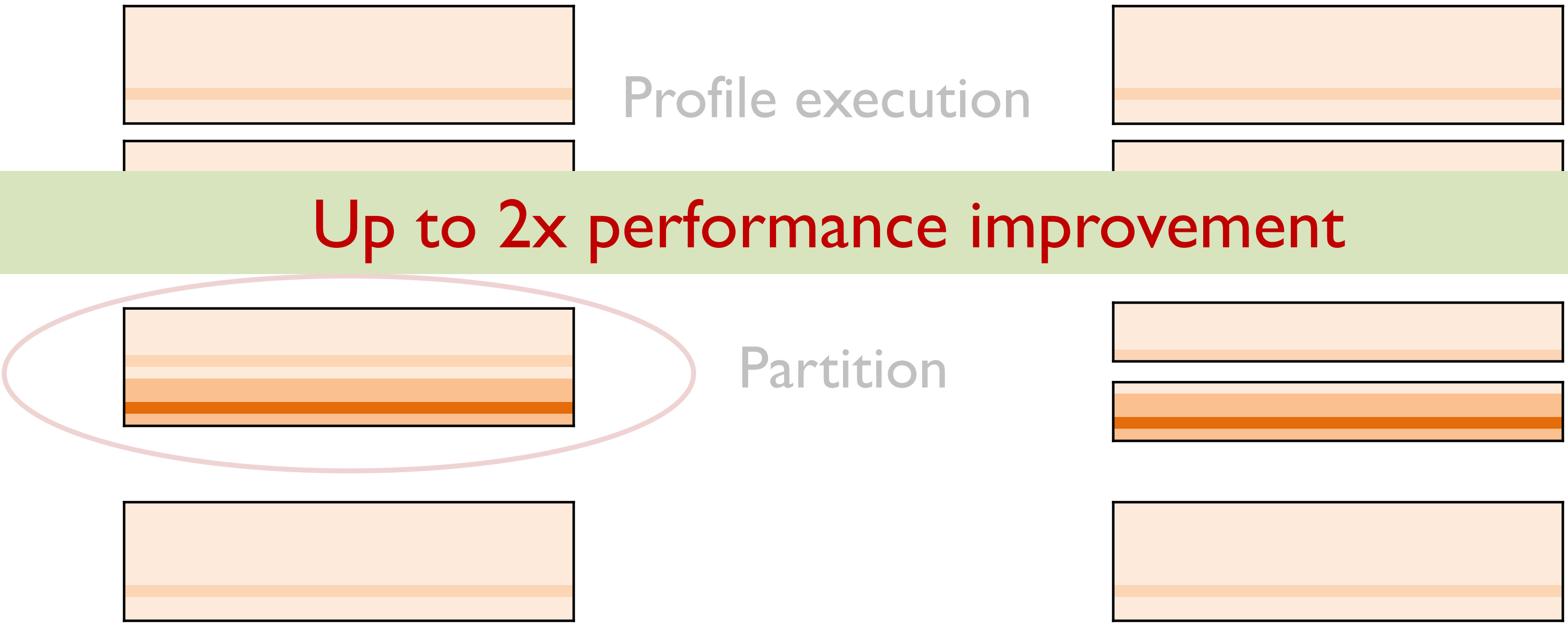


Dynamic Partitioning of Matrices



Programmers specify **size invariants**.

Dynamic Partitioning of Matrices

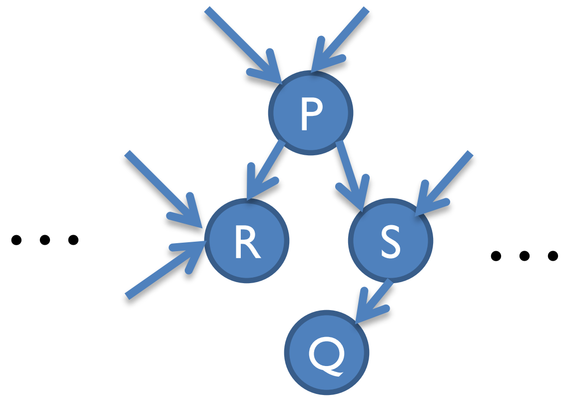


Up to 2x performance improvement

Programmers specify size invariants.

Incremental Updates Using Consistent Snapshots

Web Graph

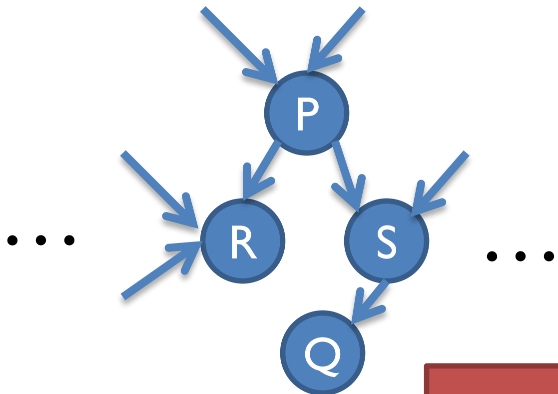


Adjacency Matrix

$$\begin{pmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ & & \cdots & \end{pmatrix}$$

Incremental Updates Using Consistent Snapshots

Web Graph



Adjacency Matrix

$$\begin{pmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ & \cdots & & \end{pmatrix}$$

onchange(M_1)

Incremental Updates Using Consistent Snapshots

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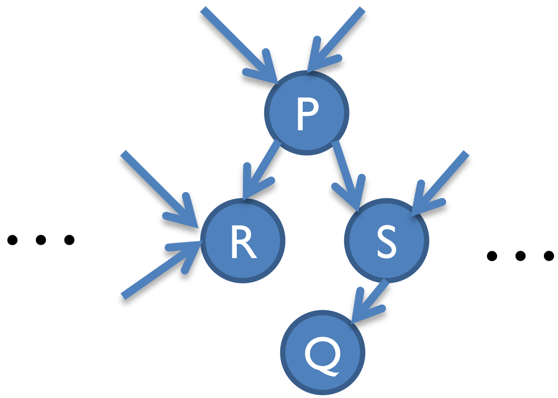


Adjacency Matrix

$$\begin{pmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ & \multicolumn{2}{c}{\cdots} & \end{pmatrix}$$

Page Rank

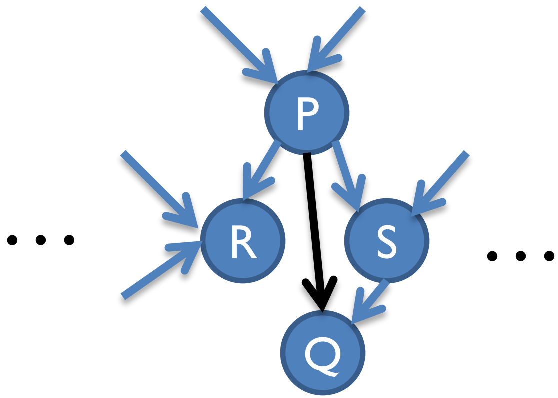
$$\begin{pmatrix} 0.035 \\ 0.006 \\ 0.008 \\ 0.032 \end{pmatrix}$$

…

update → P_1

Incremental Updates Using Consistent Snapshots

Web Graph



Adjacency Matrix

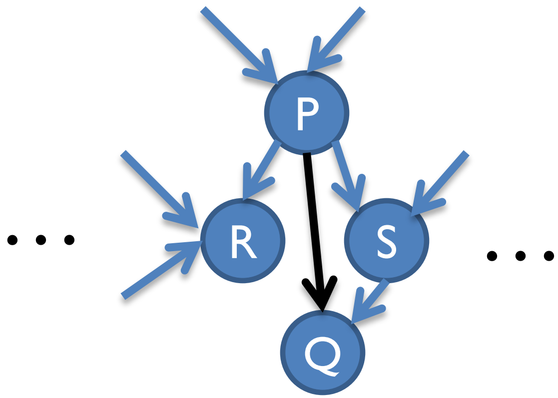
$$\begin{pmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ & \cdots & & \end{pmatrix}$$

Page Rank

$$\begin{pmatrix} 0.035 \\ 0.006 \\ 0.008 \\ 0.032 \end{pmatrix}$$
$$\cdots$$

Incremental Updates Using Consistent Snapshots

Web Graph



Adjacency Matrix

$$\begin{pmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ & \cdots & & \end{pmatrix}$$

Page Rank

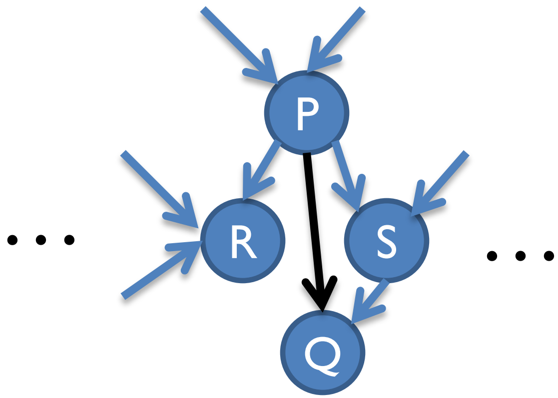
$$\begin{pmatrix} 0.035 \\ 0.006 \\ 0.008 \\ 0.032 \end{pmatrix} \cdots$$

onchange(M_2)

$$\begin{pmatrix} 0 & \color{red}{1} & 1 & 1 \\ 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}$$

Incremental Updates Using Consistent Snapshots

Web Graph



Adjacency Matrix

$$\begin{pmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & \\ & \cdots & & \end{pmatrix}$$

Page Rank

$$\begin{pmatrix} 0.035 \\ 0.006 \\ 0.008 \\ .032 \end{pmatrix} \cdots$$

update → P_2

$$\begin{pmatrix} 0 & \color{red}{1} & 1 & 1 \\ 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}$$

$$\begin{pmatrix} 0.035 \\ \color{red}{0.028} \\ 0.008 \\ 0.032 \end{pmatrix}$$

Versioned Distributed Arrays

Mechanics of versioning

- *update*: Increment version number
- *onchange*: Bind a version number for the array before executing the handler

Outline

- Motivation
- Programming model
- Design
- Applications and Results

Applications Implemented in Presto

Application	Algorithm	Presto LOC
PageRank	Eigenvector calculation	41
Triangle counting	Top-K eigenvalues	121
Netflix recommendation	Matrix factorization	130
Centrality measure	Graph algorithm	132
k-path connectivity	Graph algorithm	30
k-means	Clustering	71
Sequence alignment	Smith-Waterman	64

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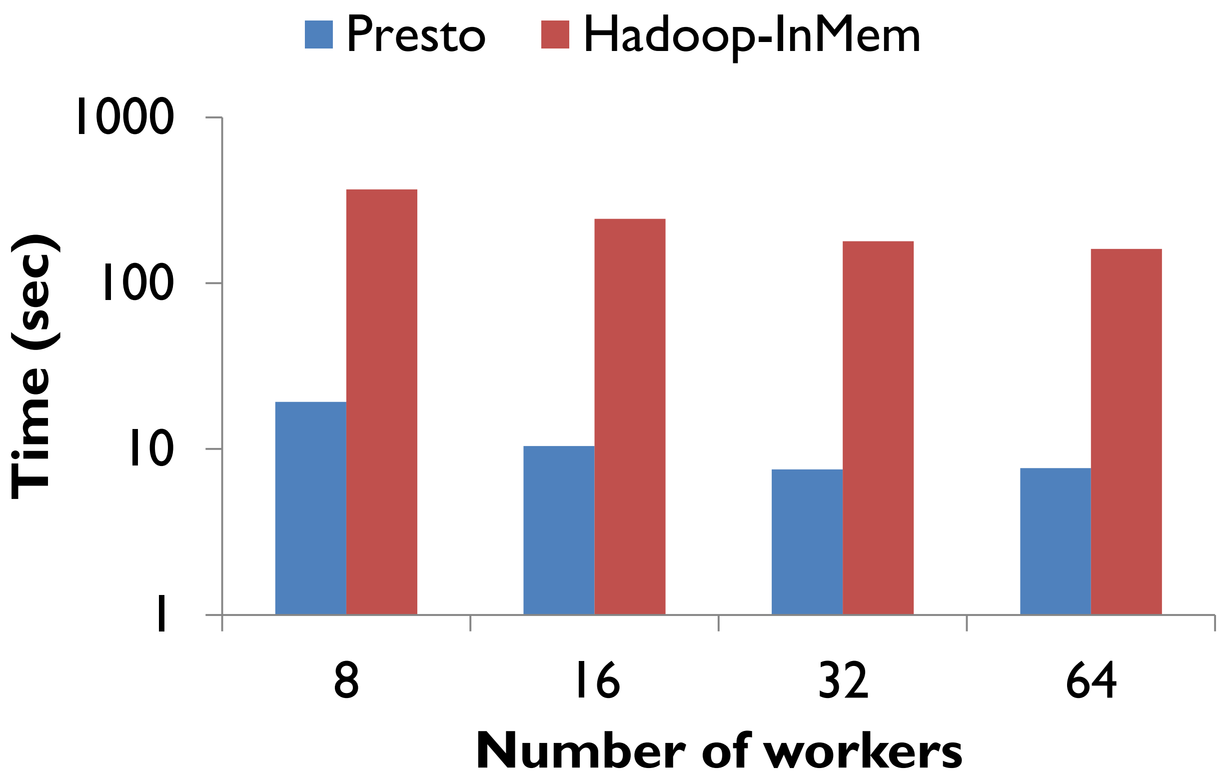
Fewer than 140 lines of code

Presto is Fast !

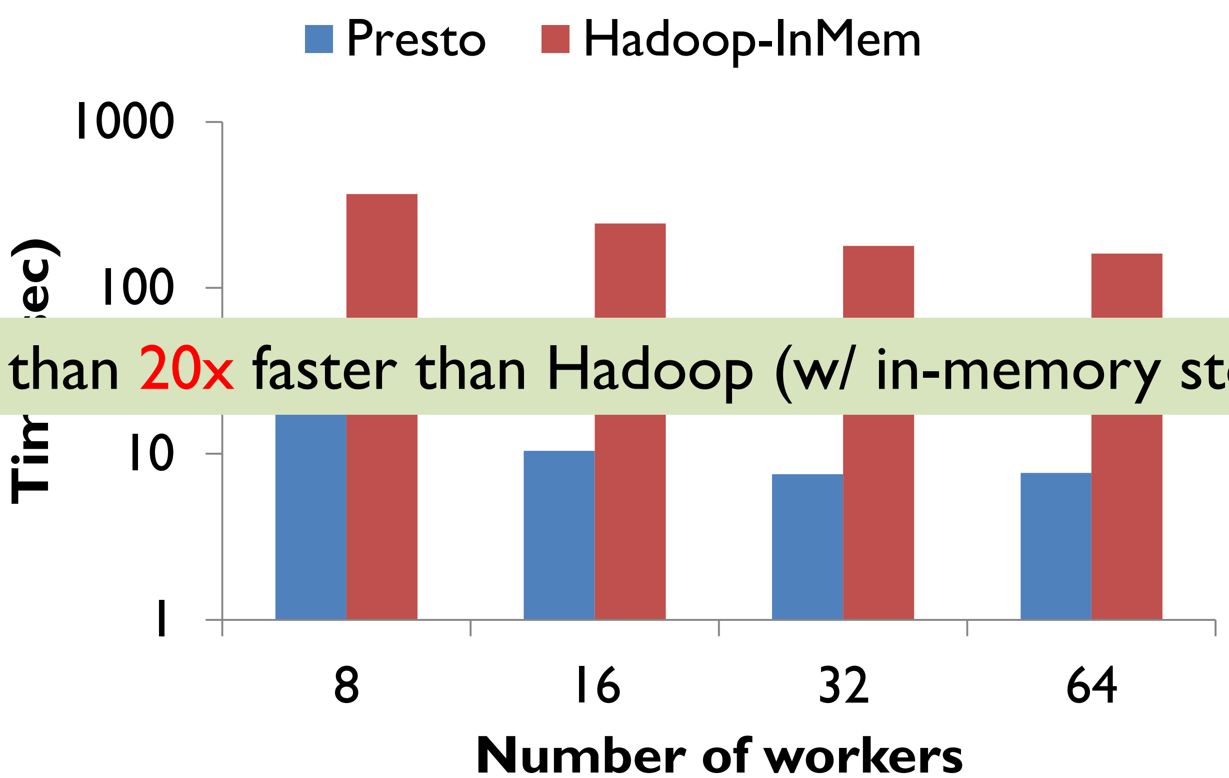
PageRank per-iteration execution time



Data: 100M nodes, 1.2B edges. Setup: 10G network. 12 cores, 96GB RAM.

Presto is Fast !

PageRank per-iteration execution time



More than 20x faster than Hadoop (w/ in-memory storage)

Data: 100M nodes, 1.2B edges. Setup: 10G network. 12 cores, 96GB RAM.

More in the Paper

- Memory management, caching of partitions
- Scheduling operations
- Storage driver interface to HBase
- Fault tolerance

Conclusion

Linear Algebra is a powerful abstraction

Easily express machine learning, graph algorithms

Challenges: Sparse matrices, Incremental data

Presto – prototype extends R

Open source version soon !