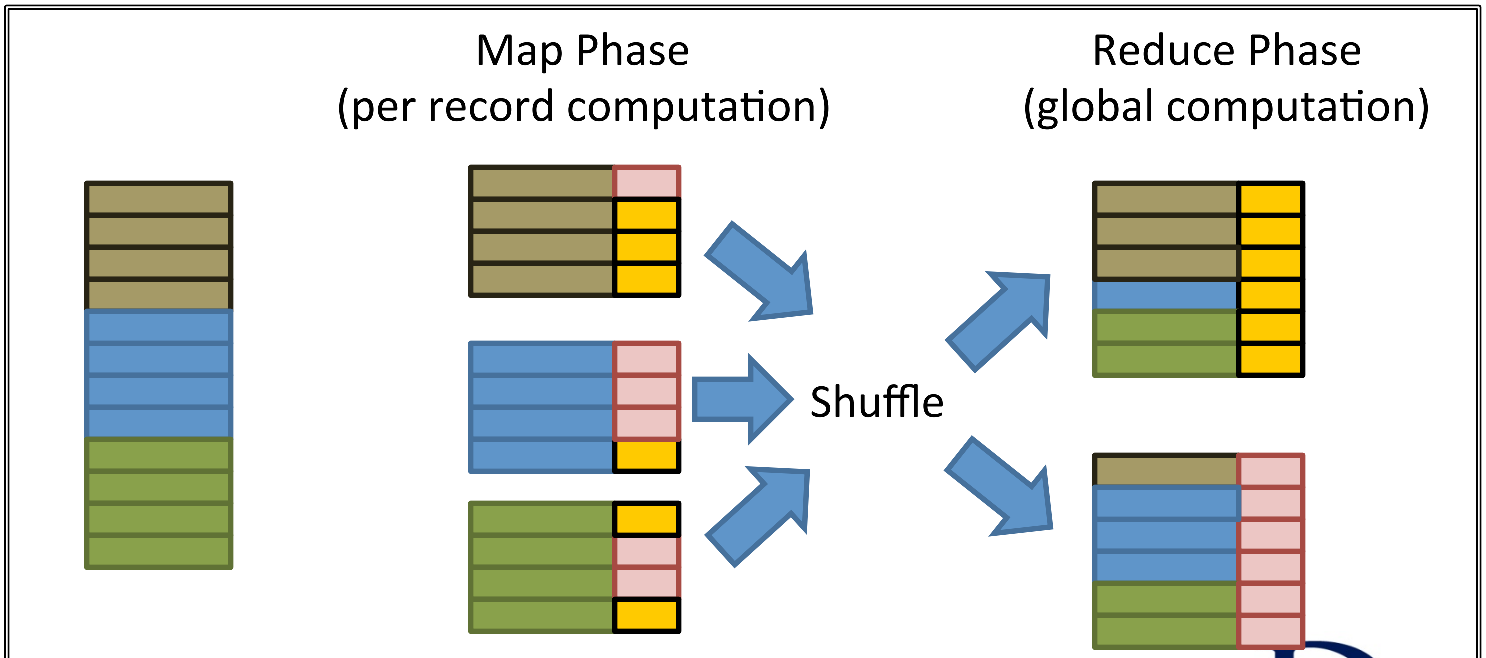
Map Reduce (contd.)

CompSci 590.03
Instructor: Ashwin Machanavajjhala

Recap: Map-Reduce

```
map     (k1,v1)        → list(k2,v2);
reduce  (k2,list(v2))  → list(k3,v3).
```



Duke UNIVERSITY

This Class

- High Level Languages for Map Reduce
- Join Processing

HIGH LEVEL LANGUAGES

Word Count in **Pig**

Load A = 'documents' USING PigStorage('\t') AS (id, docstring)

// load the data using a built in loader assuming data is (id, document string) delimited by tabs

B = FOREACH A GENERATE FLATTEN(Tokenize(docstring)) AS word

// Mapper UDF Tokenize generates a set of words
// FLATTEN: flattens a set into multiple records.

C = GROUP B BY word

// groups the data by word

D = FOREACH C GENERATE group, COUNT(B)

// Built in reduce function counts the number of times each word appears in B

STORE D

GROUP

```
A = load 'student' AS (name:chararray,age:int,gpa:float);

DESCRIBE A;
A: {name: chararray,age: int,gpa: float}

DUMP A;
(John,18,4.0F)
(Mary,19,3.8F)
(Bill,20,3.9F)
(Joe,18,3.8F)
```

```
B = GROUP A BY age;

DESCRIBE B;
B: {group: int, A: {name: chararray,age: int,gpa: float}}

ILLUSTRATE B;
etc …
----------------------------------------------------------------------
| B       | group: int | A: bag({name: chararray,age: int,gpa: float}) |
----------------------------------------------------------------------
|         | 18         | {(John, 18, 4.0), (Joe, 18, 3.8)}             |
|         | 20         | {(Bill, 20, 3.9)}                             |
----------------------------------------------------------------------

DUMP B;
(18,{(John,18,4.0F),(Joe,18,3.8F)})
(19,{(Mary,19,3.8F)})
(20,{(Bill,20,3.9F)})
```

Duke UNIVERSITY

Pig UDFs

- All user defined functions are written in java.

```
package myudfs;
import java.io.IOException;
import org.apache.pig.EvalFunc;
import org.apache.pig.data.Tuple;
import org.apache.pig.impl.util.WrappedIOException;

public class UPPER extends EvalFunc<String>
{
    public String exec(Tuple input) throws IOException {
        if (input == null || input.size() == 0)
            return null;
        try{
            String str = (String)input.get(0);
            return str.toUpperCase();
        }catch(Exception e){
            throw WrappedIOException.wrap("Caught exception processing input row ", e);
        }
    }
}
```

- See http://wiki.apache.org/pig/UDFManual

Algebraic UDFs

- Aggregate functions take a bag and return a scalar value
- Some aggregate functions (e.g., associative and commutative operations) can be computed incrementally in a distributed fashion.

```java
public interface Algebraic{
    public String getInitial();
    public String getIntermed();
    public String getFinal();
}
```


Duke UNIVERSITY

Other functions

- COGROUP // group multiple tables on the same value
- FILTER // discard records that do not satisfy some property
- UNION // union of two tables
- SAMPLE // randomly sample each record with probability p
- DISTINCT // remove duplicates
- LIMIT // return a subset of n (not random)

- See http://pig.apache.org/docs/r0.7.0/piglatin_ref2.html

COGROUP

```
A = LOAD 'data1' AS (owner:chararray,pet:chararray);

DUMP A;
(Alice,turtle)
(Alice,goldfish)
(Alice,cat)
(Bob,dog)
(Bob,cat)

B = LOAD 'data2' AS (friend1:chararray,friend2:chararray);

DUMP B;
(Cindy,Alice)
(Mark,Alice)
(Paul,Bob)
(Paul,Jane)
```

```
X = COGROUP A BY owner, B BY friend2;
```

```
(Alice,{(Alice,turtle),(Alice,goldfish),(Alice,cat)},{(Cindy,Alice),(Mark,Alice)})
(Bob,{(Bob,dog),(Bob,cat)},{(Paul,Bob)})
(Jane,{},{(Paul,Jane)})
```

JOIN

```
A = LOAD 'data1' AS (a1:int,a2:int,a3:int);

DUMP A;
(1,2,3)
(4,2,1)
(8,3,4)
(4,3,3)
(7,2,5)
(8,4,3)

B = LOAD 'data2' AS (b1:int,b2:int);

DUMP B;
(2,4)
(8,9)
(1,3)
(2,7)
(2,9)
(4,6)
(4,9)
```

```
X = JOIN A BY a1, B BY b1;

DUMP X;
(1,2,3,1,3)
(4,2,1,4,6)
(4,3,3,4,6)
(4,2,1,4,9)
(4,3,3,4,9)
(8,3,4,8,9)
(8,4,3,8,9)
```

JOIN PROCESSING

JOINs

- A = JOIN B BY fieldB, C BY fieldC PARALLEL 20
  - Specify the number of reduce tasks

- A = JOIN B BY fieldB, C BY fieldC USING 'replicated'
  - Can ask the system to use one of three ways to do join.

Duke UNIVERSITY

Join Types

Fragment Replicated Join:

- When one of the tables is small enough to fit in memory.
- Replicate the "small" table to all mappers containing the other "large" table.

Skewed Join:

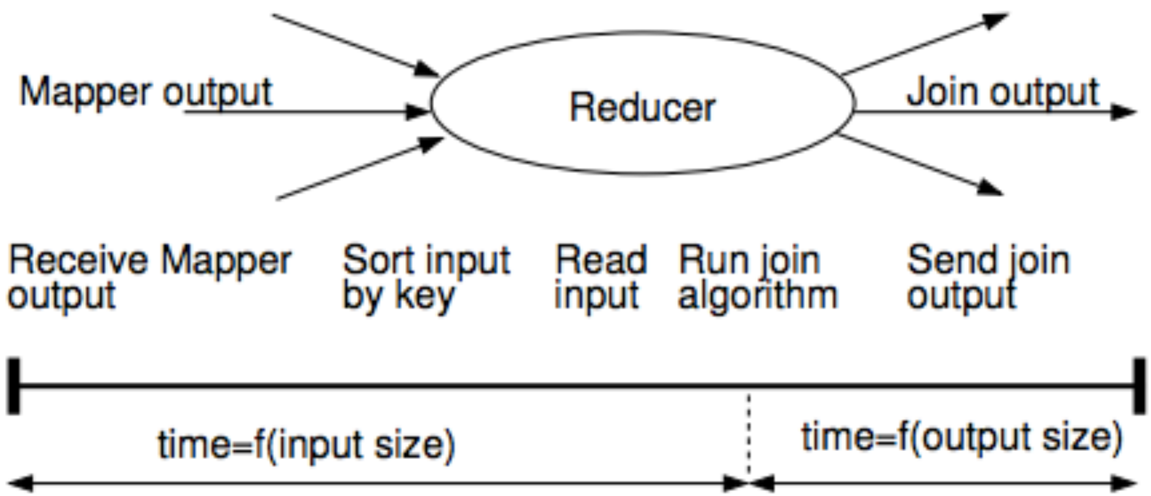
- When one of the join attributes is very skewed.
- Keys with large number of keys are split into multiple reducers.

Merge Join:

- When two datasets are already sorted on the join key
- Use sort merge join.

Join as an Optimization Problem

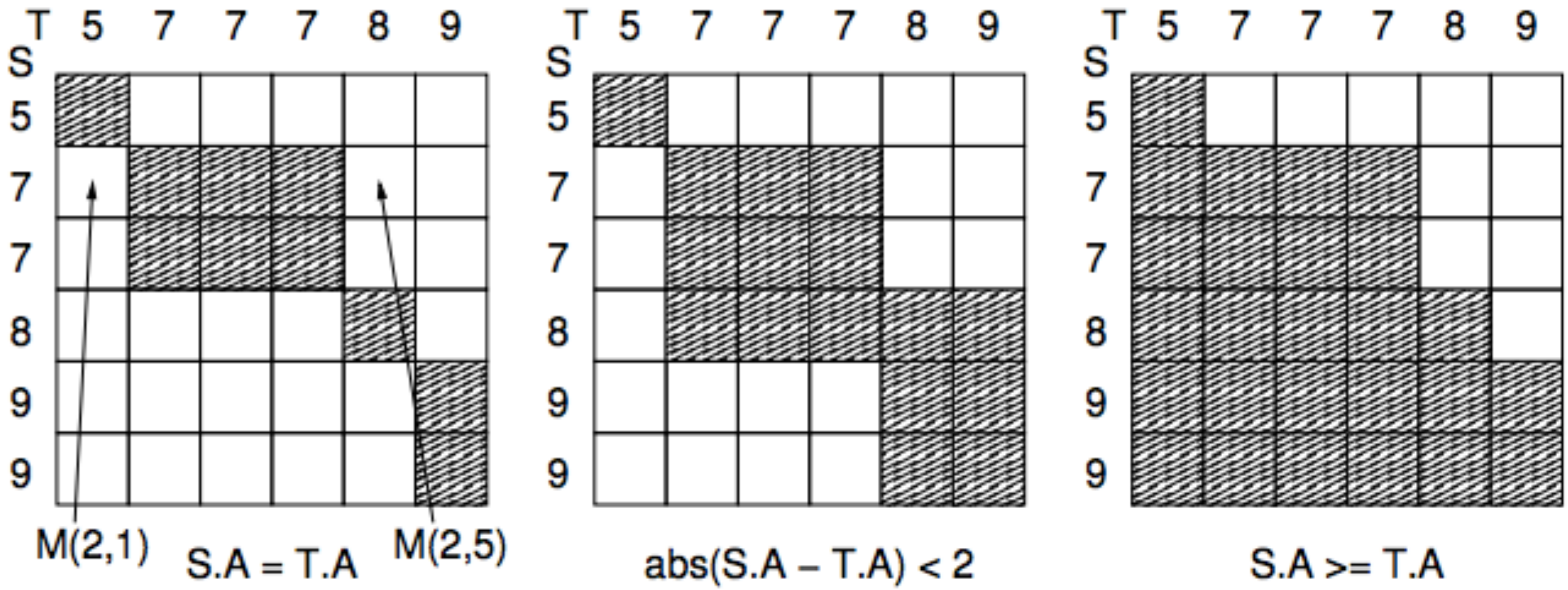
- Objective: minimize job completion time
- Cost at a reducer:



- Input-size dominated: Reducer input processing time is large
- Output-size dominated: Reducer output processing time is large

Join-Matrix

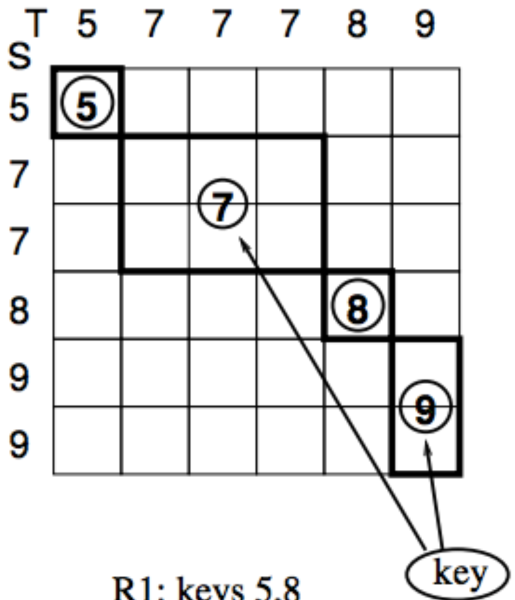
M_{ij} = pair of tuples that have S.key = i and T.key = j
M_{ij} is shaded if corresponding tuples appear in the join output.



Goal: find a mapping between join matrix cells to reducers that minimizes completion time.

Duke UNIVERSITY

Join Alternatives



R1: keys 5,8
Input: S1,S4
T1,T5
Output: 2 tuples

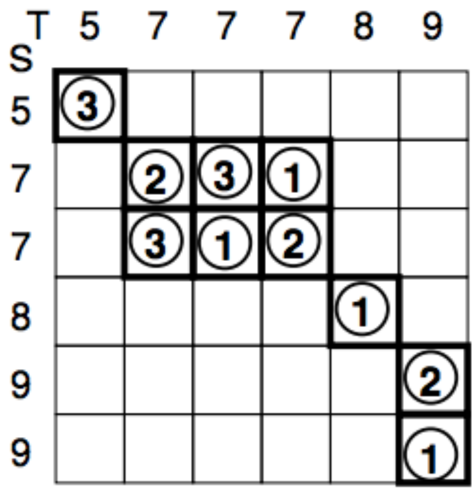
R2: key 7
Input: S2,S3
T2,T3,T4
Output: 6 tuples

R3: key 9
Input: S5,S6
T6
Output: 2 tuples

max–reducer–input = 5
max–reducer–output = 6

- Standard join algorithm
- Group both tables by key, send all tuples with the same key to a single reducer
- Skew in 7 leads to skewed execution times in reducers.

Join Alternatives



R1: key 1
Input: S2,S3,S4,S6
T3,T4,T5,T6
Output: 4 tuples

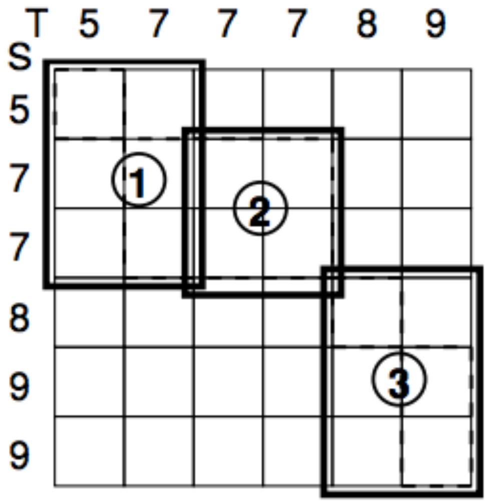
R2: key 2
Input: S2,S3,S5
T2,T4,T6
Output: 3 tuples

R3: key 3
Input: S1,S2,S3
T1,T2,T3
Output: 3 tuples

max–reducer–input = 8
max–reducer–output = 4

- Fine grained load balancing
  - Divide the cells in the join matrix equally amongst the reducers
- Leads to replication of tuples to multiple reducers
  - S2, S3 are sent to all reducers.

Join Alternatives



R1: key 1
  Input: S1,S2,S3
  T1,T2
  Output: 3 tuples

R2: key 2
  Input: S2,S3
  T3,T4
  Output: 4 tuples

R3: key 3
  Input: S4,S5,S6
  T5,T6
  Output: 3 tuples

max–reducer–input = 5
max–reducer–output = 4

- Best of both worlds
- 7 is broken down into two reducers
- Limits replication of input as well as reduces output skew.

Computing a join

- Identify the regions in the join matrix that appear in the join.
  - Sufficient to identify a superset of the shaded cells in the join matrix
- Map regions of the join matrix to reducers such that each shaded cell is covered by a reducer.
- Develop a Map-reduce algorithm to assign tuples to the corresponding reducers.

Approach 1: Cross Product

- Cross Product: all cells in the join matrix are shaded
  - Superset of any join condition

Cross Product

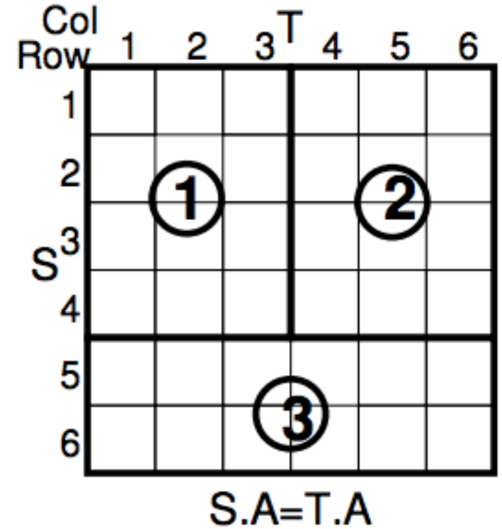
How to cover the cross product by r reducers?

- Need to cover all |S| |T| cells using r reducers
  - **Max reducer output size >= |S||T|/r**
  - **Therefore, Max reducer input size >= 2 sqrt(|S||T|/r)**

- We can match these lower bounds by assigning square regions from the join matrix of side = sqrt(|S| |T| / r) cells.
  - |S| and |T| must be multiples of sqrt(|S| |T| / r)

- Algorithms in the paper for optimal mapping to reducers for any given |S|, |T|, r.
  - **At most 4 sqrt(|S| |T| / r) max reducer input and max reducer output.**

Join Algorithm



- Assign row ids from {1, 2, …, |S|} and {1, 2, …, |T|} to all rows in S and T, resp.

- Map phase:
  For x ε S, let R = {r1, …, rk} be the regions intersecting row x.id.
  Generate tuples: one tuple (r,x) for each r ε R
  Similarly generate tuples for y ε T.

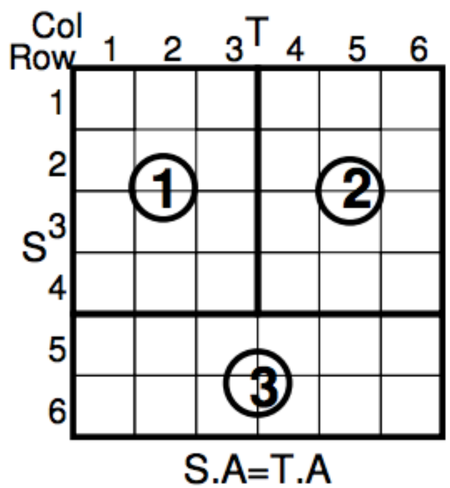
- Reduce phase:
  Perform the join (or cross product) of all the tuples input to the reducer.

Duke UNIVERSITY

Join Algorithm: 1-Bucket-Theta

- Problem: Need a new map step to assign ids to rows in S and T

- Instead, on seeing a new tuple in S or T, assign a random row id.



Map:

Input tuple	Random row/col	Output
S1.A=5	3	(1,S1),(2,S1)
S2.A=7	5	(3,S2)
S3.A=7	1	(1,S3),(2,S3)
S4.A=8	5	(3,S4)
S5.A=9	1	(1,S5),(2,S5)
S6.A=9	2	(1,S6),(2,S6)
T1.A=5	6	(2,T1),(3,T1)
T2.A=7	2	(1,T2),(3,T2)
T3.A=7	2	(1,T3),(3,T3)
T4.A=7	3	(1,T4),(3,T4)
T5.A=8	6	(2,T5),(3,T5)
T6.A=9	4	(2,T6),(3,T6)

Reduce:

Reducer X: key 1
Input: S1, S3, S5 ,S6 T2, T3, T4
Output: (S3,T2),(S3,T3) (S3,T4)

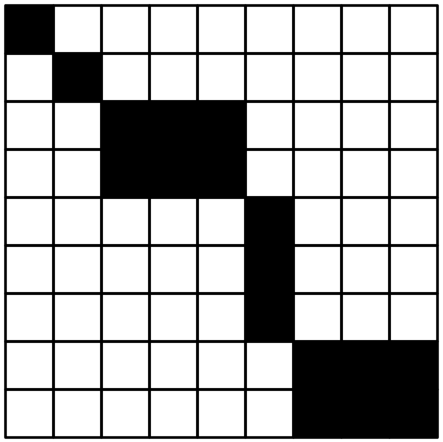
Reducer Y: key 2
Input: S1, S3, S5, S6 T1, T5, T6
Output: (S1,T1),(S5,T6) (S6,T6)

Reducer Z: key 3
Input: S2, S4 T1, T2, T3, T4, T5, T6
Output: (S2,T2),(S2,T3) (S2,T4),(S4,T5)

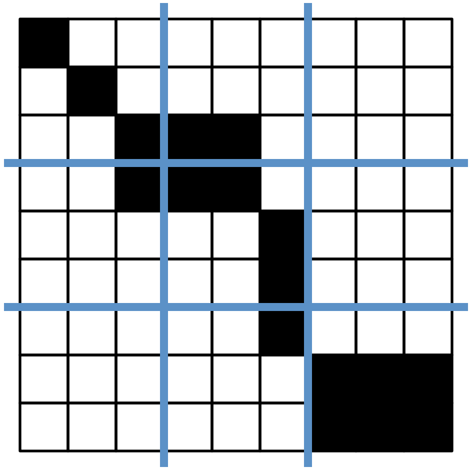
1-Bucket-Theta

- Since every cell in the entire cross product is sent to some reducer, any join algorithm can be implemented
  - By applying the appropriate join condition.
- If evaluating a join requires at least an x fraction of all cells in the join matrix, then max reducer input >= 2 sqrt(x|S||T|/r).
- 1-Bucket-Theta has max reducer input <= 4 sqrt(|S| |T|/r)
- Hence, at most a factor of 2/sqrt(x) off
  - Works well as long as x is large (at least 50%)

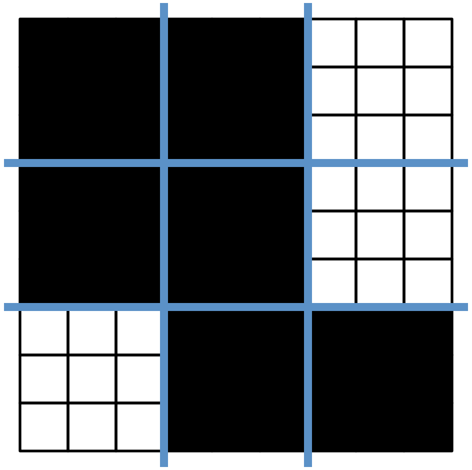
Approach 2: Approximate the Join Matrix



True join matrix



Histogram boundaries



Candidate cells to be covered by algorithm

Approach 2

- Need more detailed statistics about |S| and |T|
- Need to know something about the join predicate
  - Doesn't work for black-box join operators
  - Need to identify which blocks contain 0 cells that appear in the join
  - Equijoins, band-joins, inequality joins …
- Paper shows a heuristic technique to divide candidate cells into reducers.

Duke UNIVERSITY

Summary

- High level languages help write complex programs without thinking about map and reduce

- Join operations can be optimized by dividing the join matrix into regions.