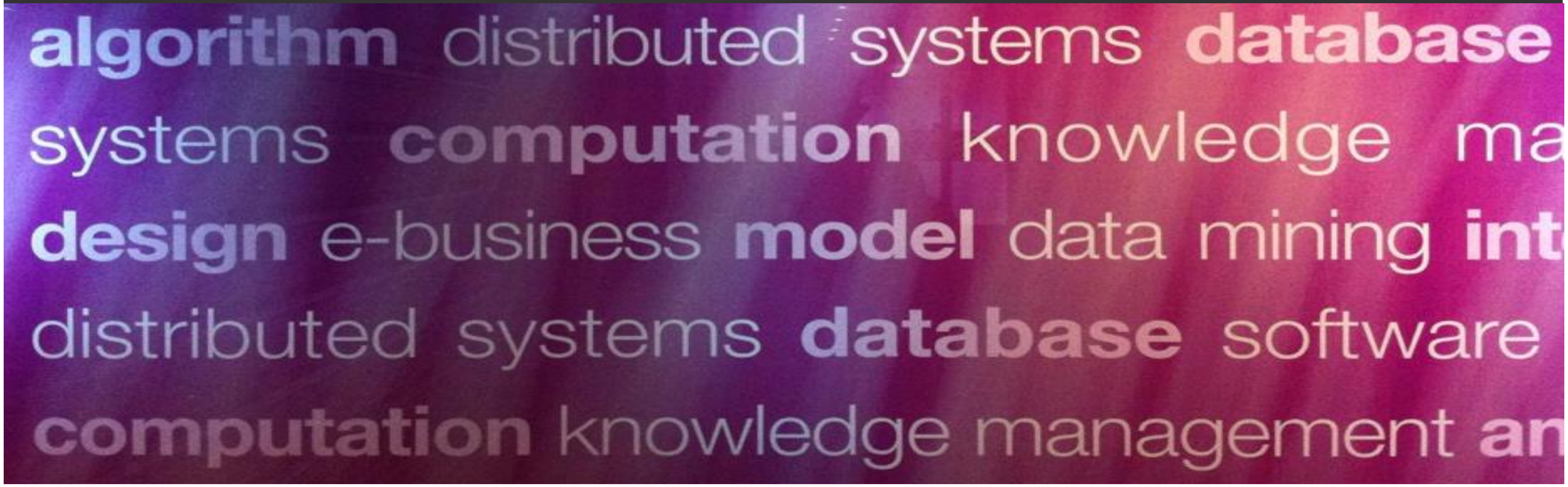
MONASH University

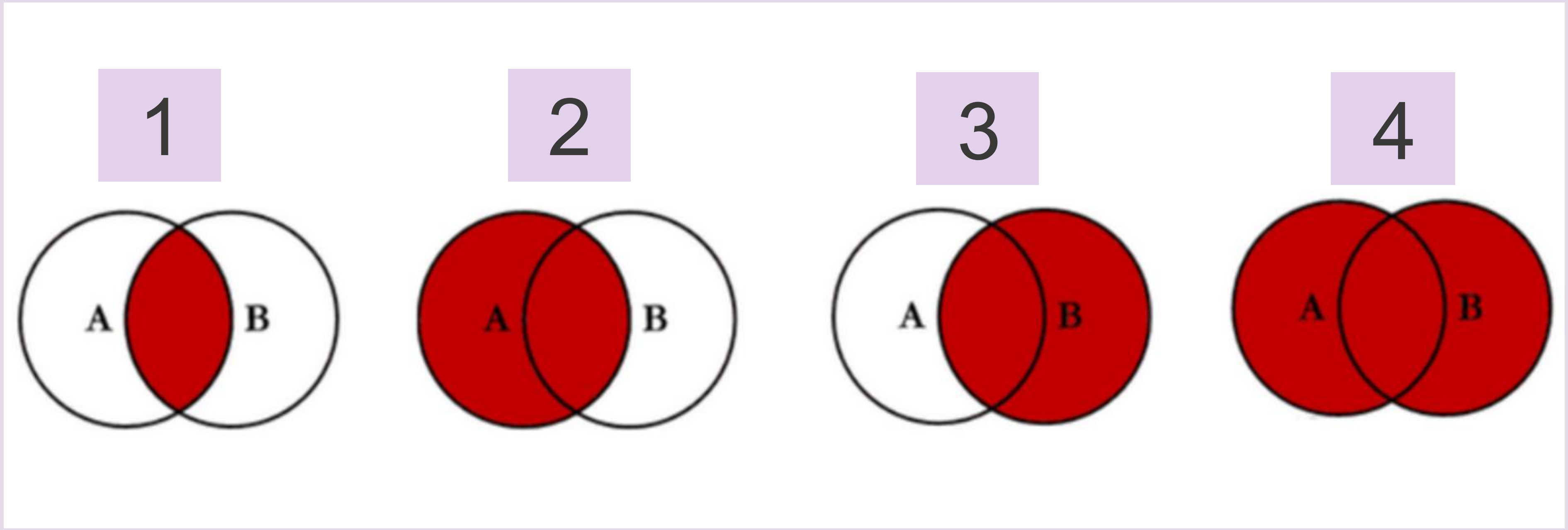
Information Technology

FIT5202 (Volume III - Join)

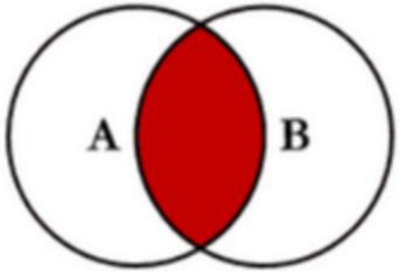
Week 3b – Parallel Outer Join


algorithm distributed systems database
systems computation knowledge
design e-business model data mining
distributed systems database software
computation knowledge management

- **Exercise 1**
  - Identify the LEFT OUTER JOIN?



Join Queries



- **Inner Join**

  Select R.x, R.a, S.y, S.b

  From R, S

  Where R.a = S.b;

R

x	a
0	1
1	2
2	3

S

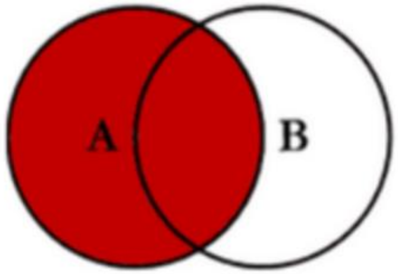
y	b
0	6
0	4
3	1
6	2
1	6
4	2
7	2
7	1
2	1
5	5
5	6
8	9

Results

x	a	y	b
0	1	3	1
0	1	7	1
0	1	2	1
1	2	6	2
1	2	4	2
1	2	7	2

Return results when there is a match

Join Queries



- **Outer Join**

  Select R.x, R.a, S.y, S.b

  From R left outer join S

  On R.a = S.b;

R

x	a
0	1
1	2
2	3

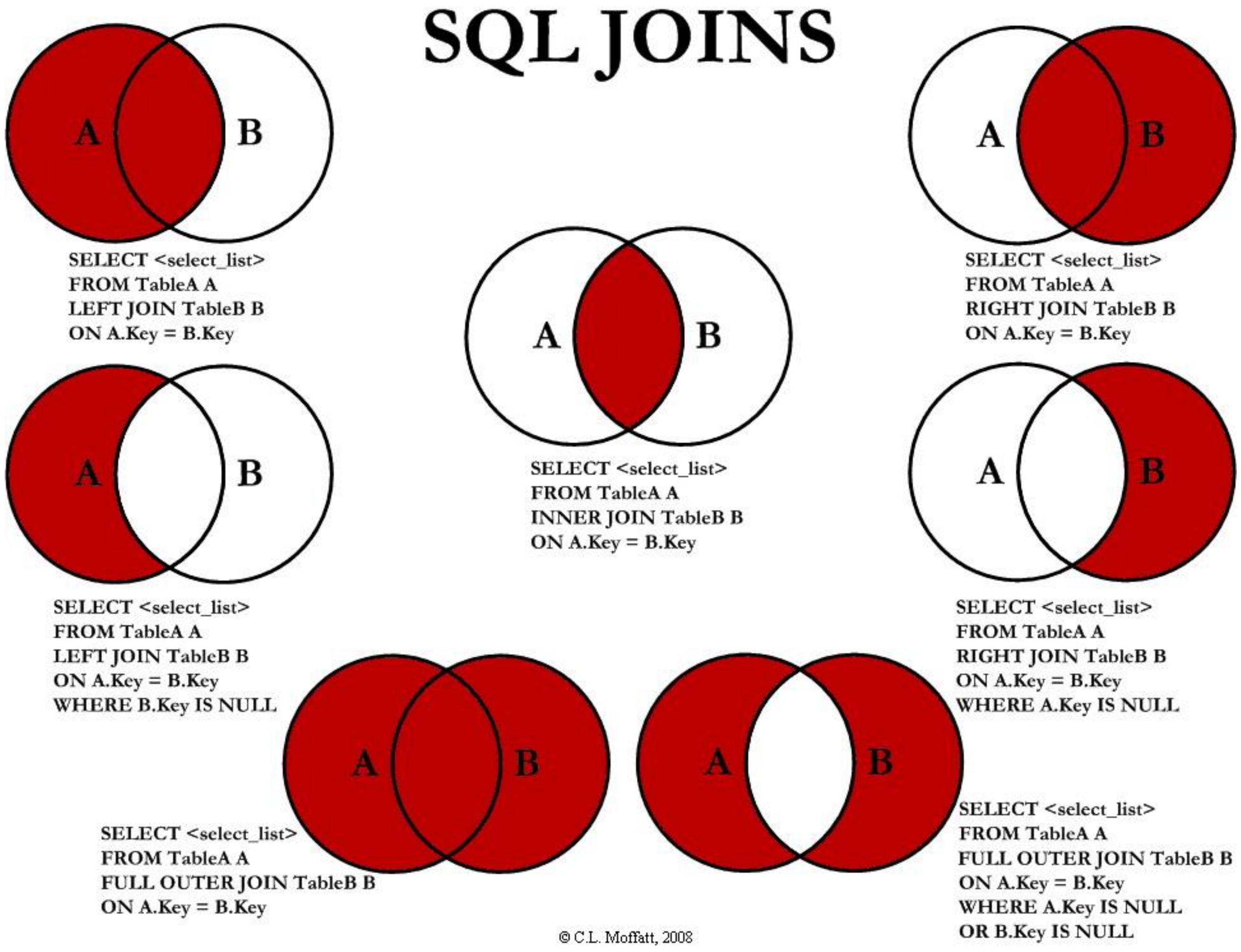
S

y	b
0	6
0	4
3	1
6	2
1	6
4	2
7	2
7	1
2	1
5	5
5	6
8	9

Results

x	a	y	b
0	1	3	1
0	1	7	1
0	1	2	1
1	2	6	2
1	2	4	2
1	2	7	2
2	3	Null	Null

Return all records from left table, and matched records from both tables



```
SELECT <select_list>
FROM TableA A
LEFT JOIN TableB B
ON A.Key = B.Key
```

```
SELECT <select_list>
FROM TableA A
INNER JOIN TableB B
ON A.Key = B.Key
```

```
SELECT <select_list>
FROM TableA A
RIGHT JOIN TableB B
ON A.Key = B.Key
```

```
SELECT <select_list>
FROM TableA A
LEFT JOIN TableB B
ON A.Key = B.Key
WHERE B.Key IS NULL
```

```
SELECT <select_list>
FROM TableA A
RIGHT JOIN TableB B
ON A.Key = B.Key
WHERE A.Key IS NULL
```

```
SELECT <select_list>
FROM TableA A
FULL OUTER JOIN TableB B
ON A.Key = B.Key
```

```
SELECT <select_list>
FROM TableA A
FULL OUTER JOIN TableB B
ON A.Key = B.Key
WHERE A.Key IS NULL
OR B.Key IS NULL
```

https://www.codeproject.com/Articles/33052/Visual-Representation-of-SQL-Joins

Parallel Join Query Processing

- Parallel Inner Join components
  - **Data Partitioning**
    - Divide and Broadcast
    - Disjoint Partitioning
  - **Local Join**
    - Nested-Loop Join
    - Sort-Merge Join
    - Hash Join

- Example of a Parallel Inner Join Algorithm
  - **Divide and Broadcast, plus Hash Join**

Parallel Join Query Processing

- Parallel Outer Join processing methods
  - **ROJA** (Redistribution Outer Join Algorithm)
  - **DOJA** (Duplication Outer Join Algorithm)
  - **DER** (Duplication & Efficient Redistribution)

$\Big\}$ Outer join of two tables

- Load Balancing
  - **OJSO** (Outer Join Skew Optimization)

$\Big\}$ Outer join of three tables

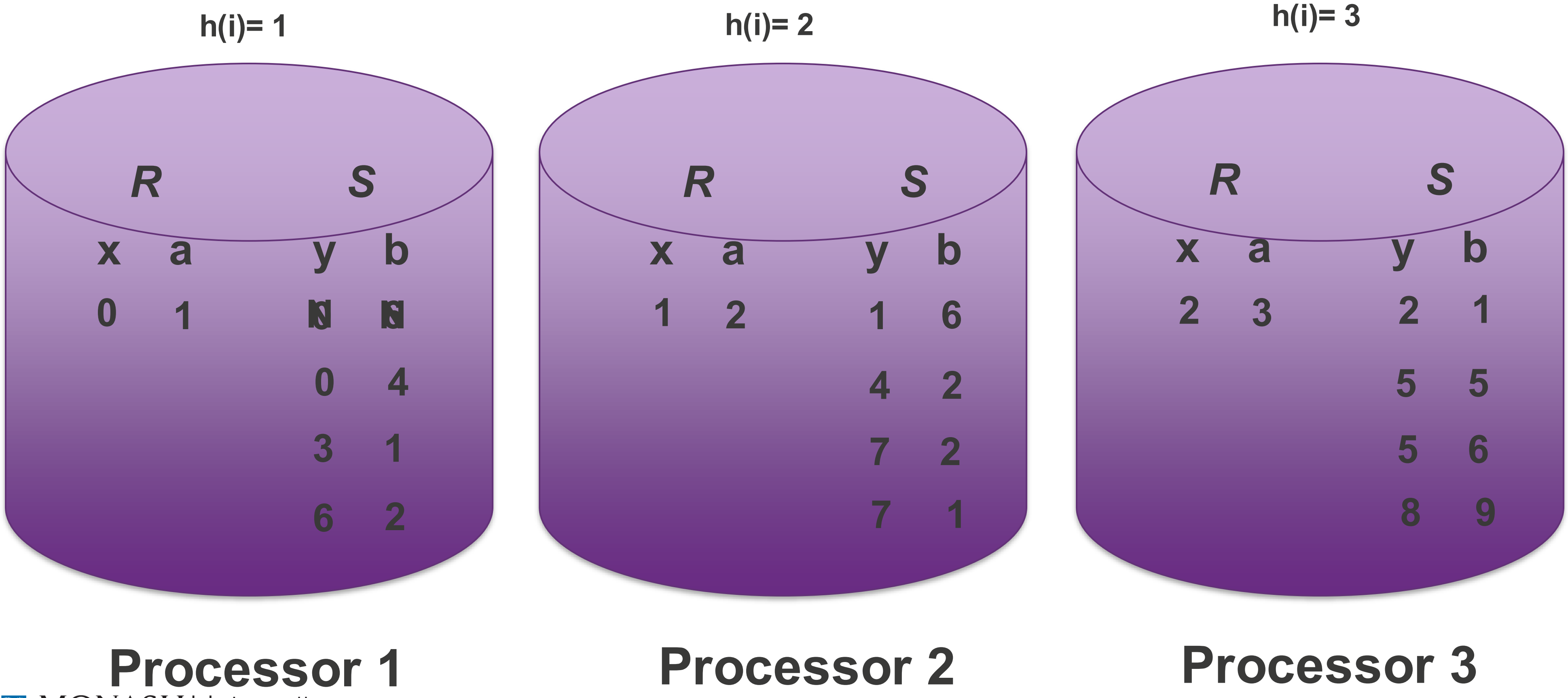
1. ROJA

- Hash-based algorithm

Step 1: Distribute or reshuffle data based on join attribute.
Step 2: Each processor performs local outer Join.

SELECT R.x, R.a, S.y, S.b
FROM R left outer join S on R.a = S.b

Eg. Using hash func h(i) = i mod 3 + 1



h(i)= 1 — **Processor 1**

R x	R a	S y	S b
0	1	N	N
		0	4
		3	1
		6	2

h(i)= 2 — **Processor 2**

R x	R a	S y	S b
1	2	1	6
		4	2
		7	2
		7	1

h(i)= 3 — **Processor 3**

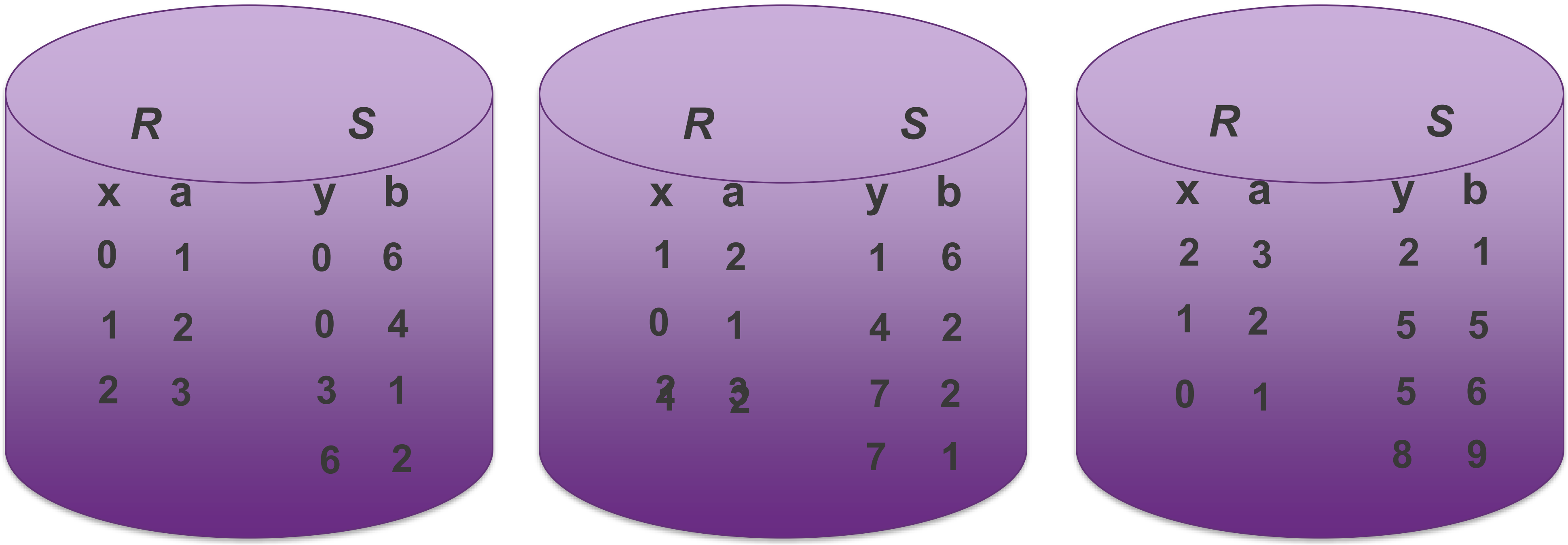
R x	R a	S y	S b
2	3	2	1
		5	5
		5	6
		8	9

2. DOJA

SELECT R.x, R.a, S.y, S.b
FROM R left outer join S on R.a = S.b

Step 1: Replicate small table.
Step 2: Local Inner Join
Step 3: Hash redistribute inner join result (temporary) based on attribute x.

Note: data initially partitioned using hash partitioning using non-join key x & y



Processor 1

R x	R a	S y	S b
0	1	0	6
1	2	0	4
2	3	3	1
		6	2

Processor 2

R x	R a	S y	S b
1	2	1	6
0	1	4	2
2 4	3 2	7	2
		7	1

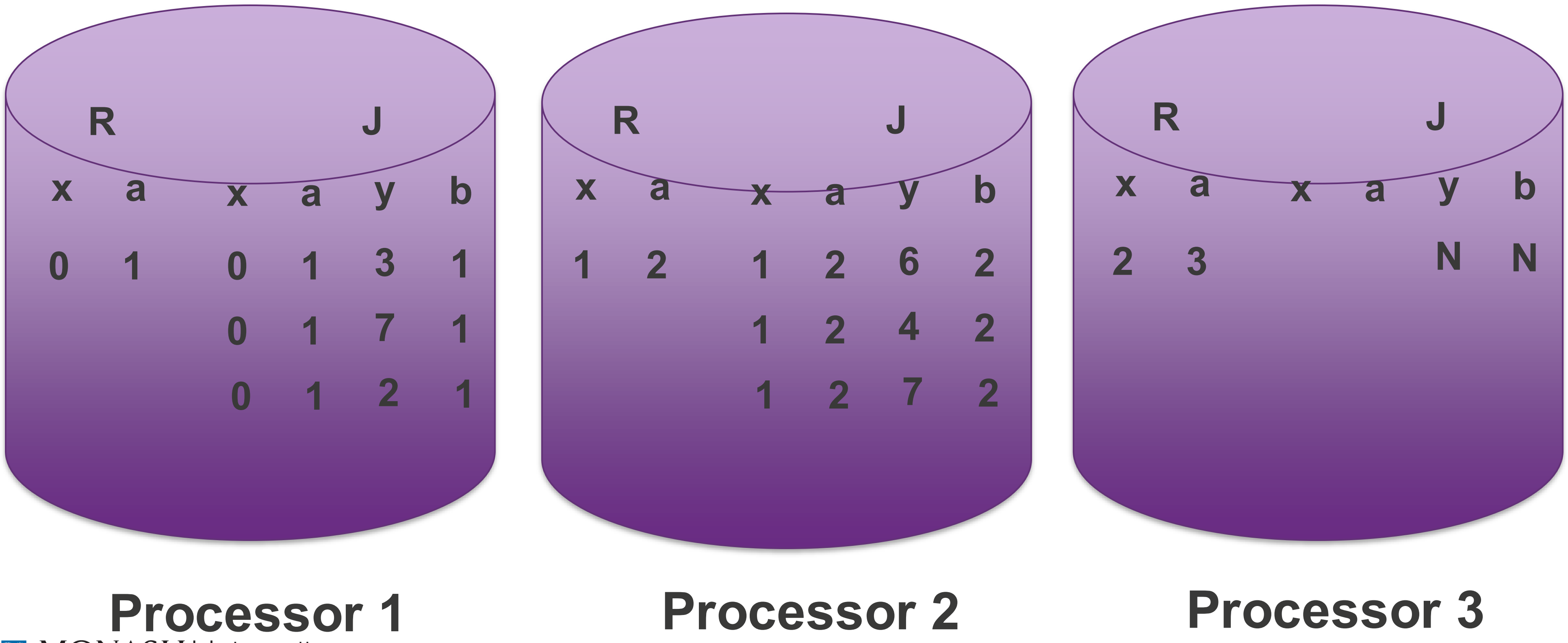
Processor 3

R x	R a	S y	S b
2	3	2	1
1	2	5	5
0	1	5	6
		8	9

2. DOJA

Step 4: Local outer join

SELECT R.x, R.a, S.y, S.b
FROM R left outer join S on R.a = S.b



Processor 1

R

x	a
0	1

J

x	a	y	b
0	1	3	1
0	1	7	1
0	1	2	1

Processor 2

R

x	a
1	2

J

x	a	y	b
1	2	6	2
1	2	4	2
1	2	7	2

Processor 3

R

x	a
2	3

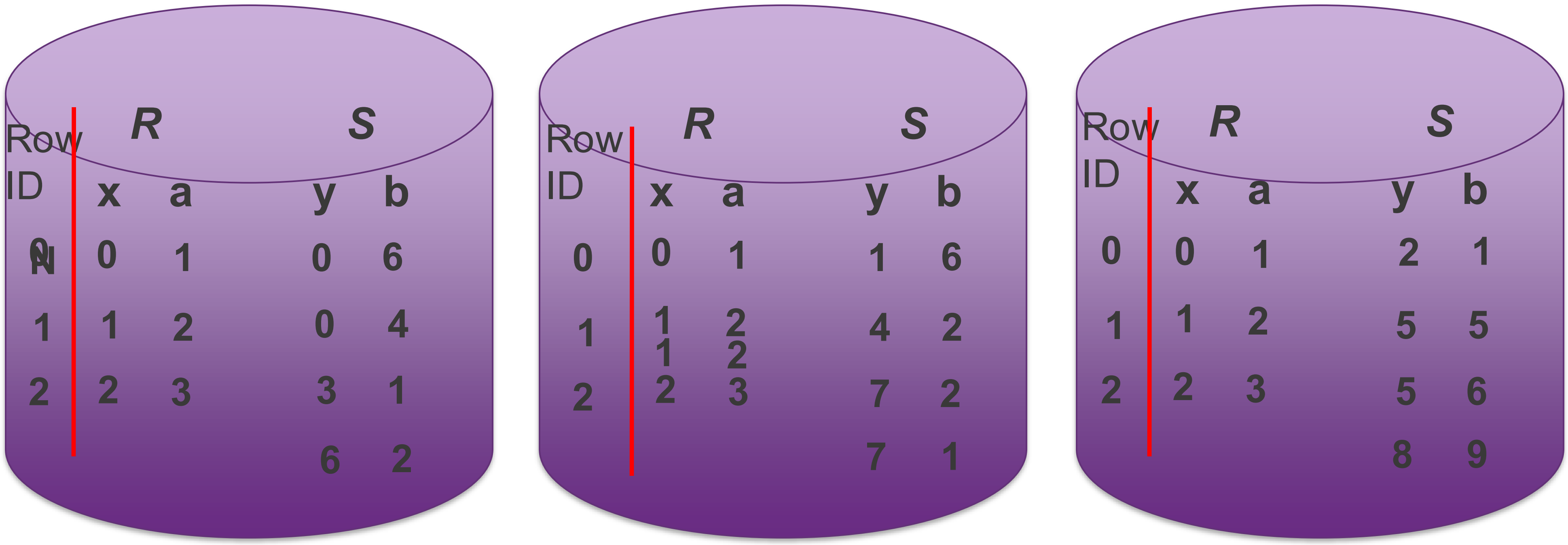
J

x	a	y	b
		N	N

3. DER

SELECT R.x, R.a, S.y, S.b
FROM R left outer join S on R.a = S.b

Step 1: Replicate small table (left)
Step 2: Local Inner Join
Step 3: Select ROW ID of left table with no matches.
Step 4: Redistribute the ROW ID.
Step 5: Store the ROW ID that appears as many times as the number of processors



Processor 1

Row ID	*R*		*S*	
	x	a	y	b
0 N	0	1	0	6
1	1	2	0	4
2	2	3	3	1
			6	2

Processor 2

Row ID	*R*		*S*	
	x	a	y	b
0	0	1	1	6
1	1 1	2 2	4	2
2	2	3	7	2
			7	1

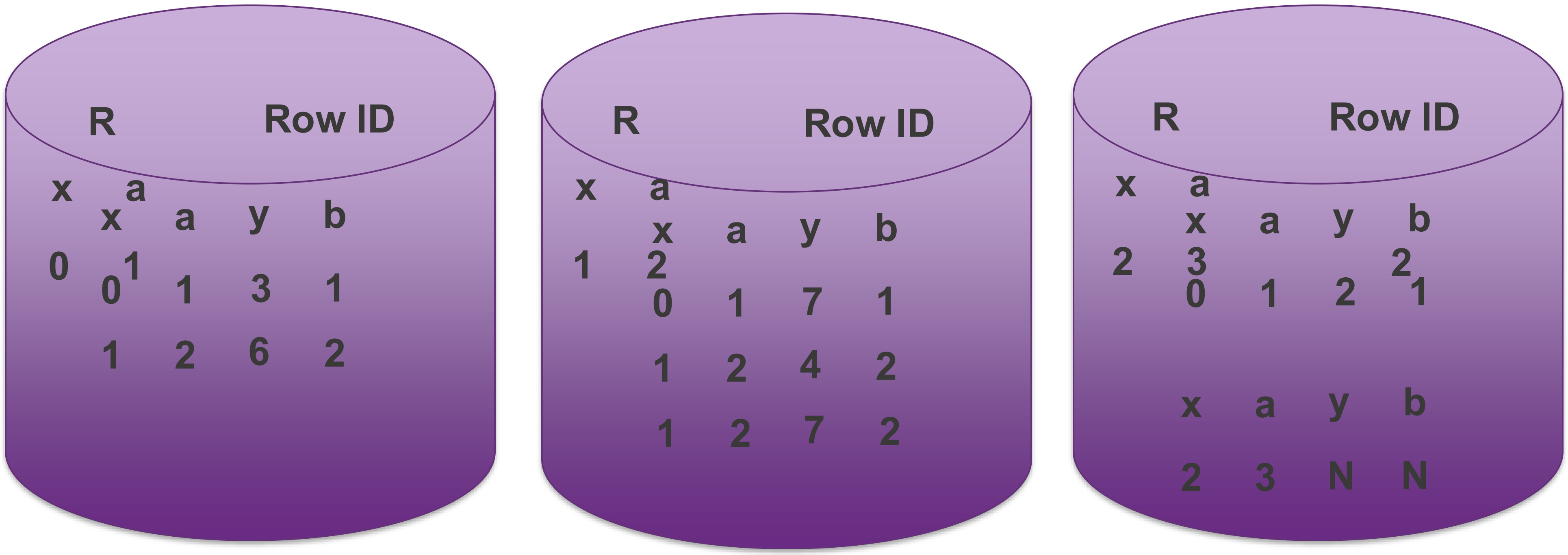
Processor 3

Row ID	*R*		*S*	
	x	a	y	b
0	0	1	2	1
1	1	2	5	5
2	2	3	5	6
			8	9

3. DER

SELECT R.x, R.a, S.y, S.b
FROM R left outer join S on R.a = S.b

Step 6: show Inner join (in step 2) plus records of R without any matches



Processor 1 **Processor 2** **Processor 3**

Parallel Join Query Processing

- Parallel Outer Join processing methods
  - **ROJA** (Redistribution Outer Join Algorithm)
  - **DOJA** (Duplication Outer Join Algorithm)
  - **DER** (Duplication & Efficient Redistribution)

- Load Balancing
  - **OJSO** (Outer Join Skew Optimization)

Question from student:

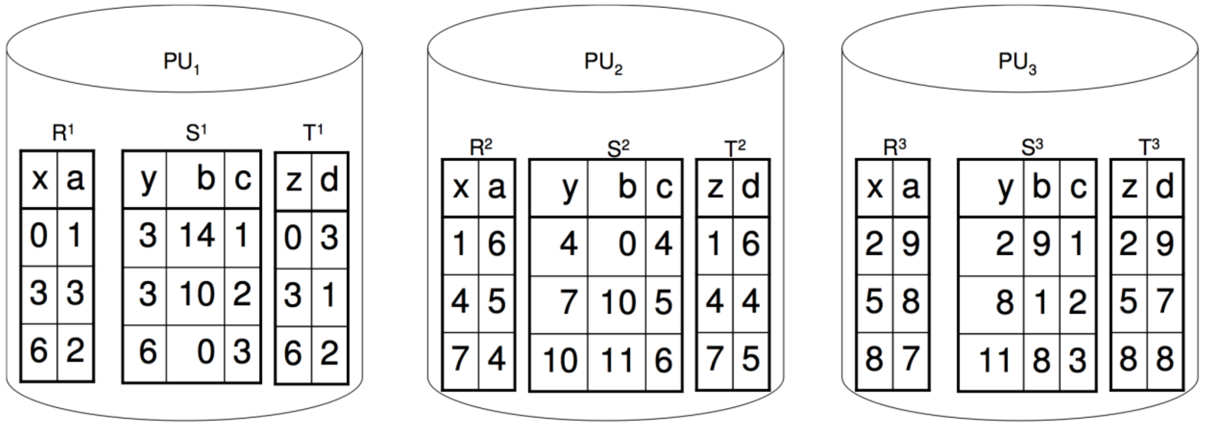
What's the point of DOJA, it seems to be a more costly and less efficient version of ROJA?

	ROJA	DOJA	DER
Steps	**Step 1:** Distribute or reshuffle the data based on the join attribute. **Step 2:** Each processor performs the Local outer Join.	**Step 1:** Replication. We duplicate the small table. **Step 2:** Local Inner Join **Step 3:** Hash redistribute the inner join result based on attribute X. **Step 4:** Local outer join	**Step 1:** Replication. We broadcast the left table. **Step 2:** Local Inner Join **Step 3:** Select the ROW ID of left table with no matches. **Step 4:** Redistribute the ROW ID. **Step 5:** Store the ROW ID that appears as many times as the number of processors. **Step 6:** Inner join
Pros	fast performance, only two steps	None. ROJA is faster than DOJA.	Redistributes dangling row IDs instead of actual records.
Cons	redistribution of data -> data skew, communication cost	In the replication step, if the table is large, the replication cost is expensive. In the distribution step, data skew and communication cost similar to ROJA	In the replication step, if the table is large, the replication cost is expensive.

Another example…

```
Select x, y, z, a, c
From R left outer join S on R.a=S.b
       left outer join T on S.c=T.d;
```

- Initial Data Placement



R^1

x	a
0	1
3	3
6	2

S^1

y	b	c
3	14	1
3	10	2
6	0	3

T^1

z	d
0	3
3	1
6	2

R^2

x	a
1	6
4	5
7	4

S^2

y	b	c
4	0	4
7	10	5
10	11	6

T^2

z	d
1	6
4	4
7	5

R^3

x	a
2	9
5	8
8	7

S^3

y	b	c
2	9	1
8	1	2
11	8	3

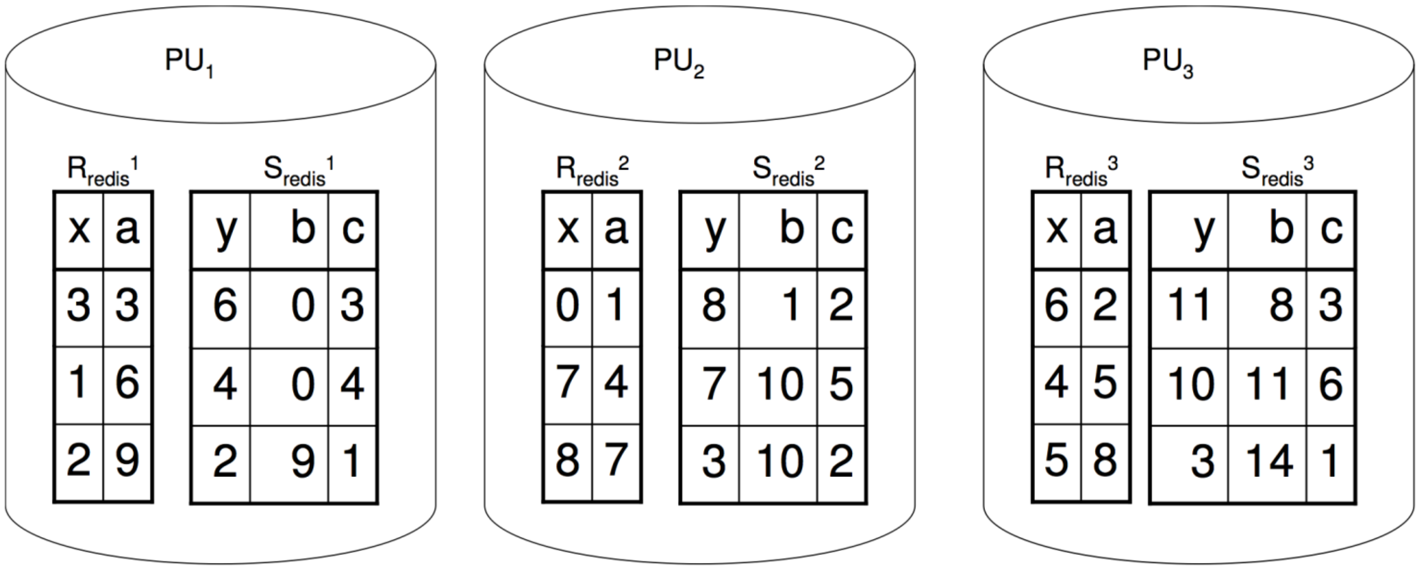
T^3

z	d
2	9
5	7
8	8

Figure 1: Three relations R, S and T are hash partitioned on a three parallel-unit system. The partitioning columns are $R.x$, $S.y$ and $T.z$ respectively. The hash function, $h(i) = i \ mod\ 3 + 1$, places a tuple with value i in the partitioning column on the $h(i)$-th PU.

Another example…

- Step 1: Redistribution of R and S (**why do we need to redistribute?**)



R_{redis}^1

x	a
3	3
1	6
2	9

S_{redis}^1

y	b	c
6	0	3
4	0	4
2	9	1

R_{redis}^2

x	a
0	1
7	4
8	7

S_{redis}^2

y	b	c
8	1	2
7	10	5
3	10	2

R_{redis}^3

x	a
6	2
4	5
5	8

S_{redis}^3

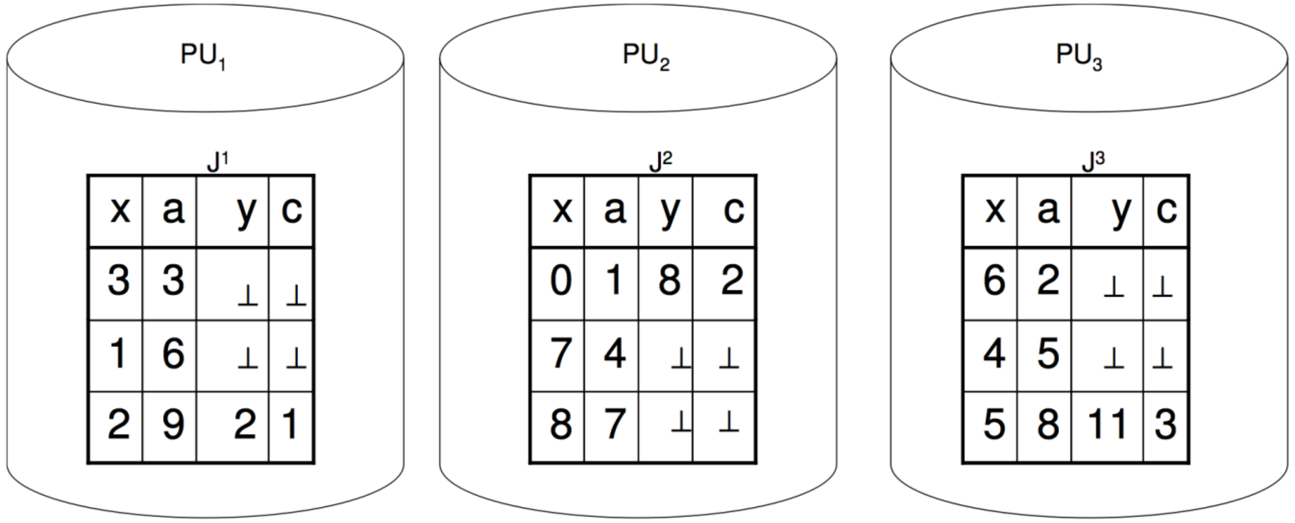
y	b	c
11	8	3
10	11	6
3	14	1

Figure 2: The result of hash redistributing R and S on their join attributes ($R.a$ and $S.b$) to two temporary tables R_{redis} and S_{redis}.

Values of R.a & S.b share the same hash key in the same processor

Another example…

- Step 2: (a) Outer Join R and S, and store in J



J^1 (PU$_1$)

x	a	y	c
3	3	⊥	⊥
1	6	⊥	⊥
2	9	2	1

J^2 (PU$_2$)

x	a	y	c
0	1	8	2
7	4	⊥	⊥
8	7	⊥	⊥

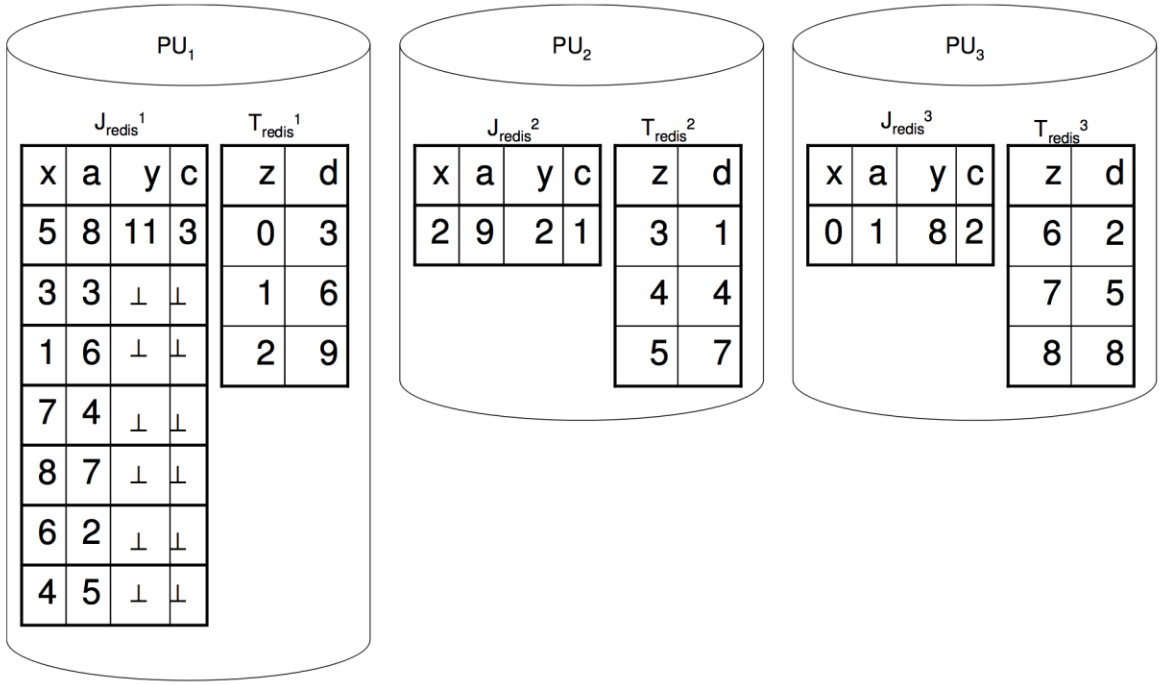
J^3 (PU$_3$)

x	a	y	c
6	2	⊥	⊥
4	5	⊥	⊥
5	8	11	3

Figure 3: The results of left outer joining R_{redis} and S_{redis} (R_{redis} and S_{redis} are shown in Figure 2) are stored in a temporary table J.

Another example…

- Step 2: (b) Redistribute J and T



PU1, J_{redis}^1:

x	a	y	c
5	8	11	3
3	3	⊥	⊥
1	6	⊥	⊥
7	4	⊥	⊥
8	7	⊥	⊥
6	2	⊥	⊥
4	5	⊥	⊥

PU1, T_{redis}^1:

z	d
0	3
1	6
2	9

PU2, J_{redis}^2:

x	a	y	c
2	9	2	1

PU2, T_{redis}^2:

z	d
3	1
4	4
5	7

PU3, J_{redis}^3:

x	a	y	c
0	1	8	2

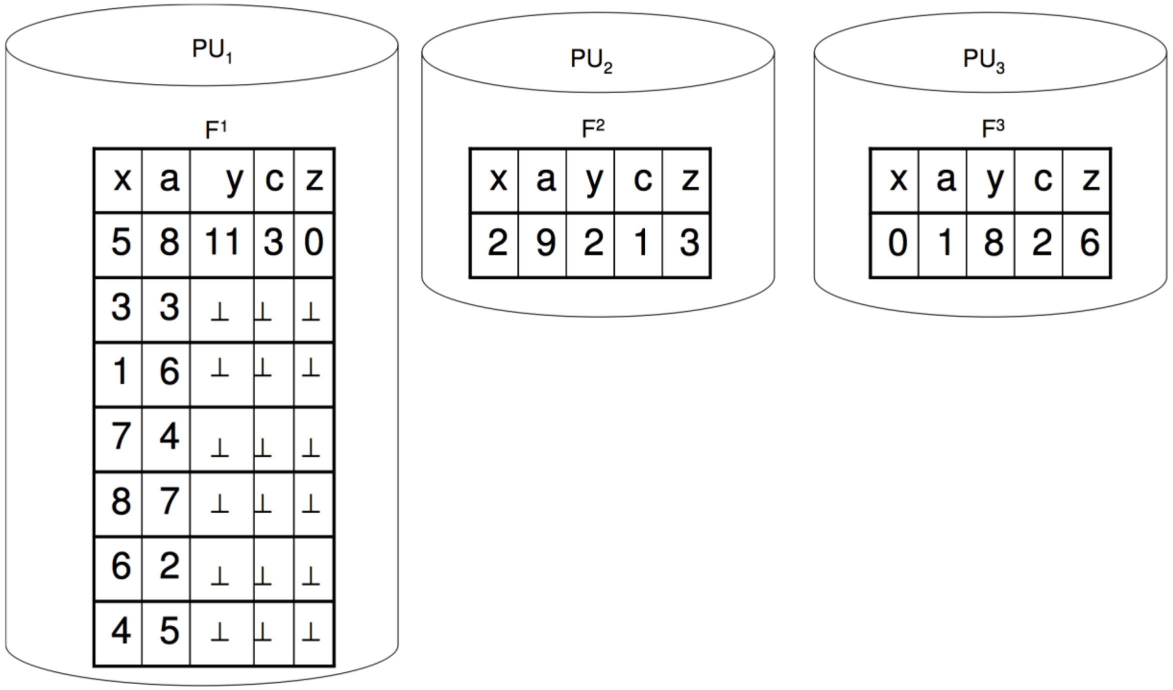
PU3, T_{redis}^3:

z	d
6	2
7	5
8	8

Figure 4: The result of hash redistributing J (shown in Figure 3) and T (shown in Figure 1) on their join attributes ($J.c$ and $T.d$) to two temporary tables J_{redis} and T_{redis}.

Another example…

- Step 3: Outer Join J and T ➔ Final Results



F^1

x	a	y	c	z
5	8	11	3	0
3	3	$\perp$	$\perp$	$\perp$
1	6	$\perp$	$\perp$	$\perp$
7	4	$\perp$	$\perp$	$\perp$
8	7	$\perp$	$\perp$	$\perp$
6	2	$\perp$	$\perp$	$\perp$
4	5	$\perp$	$\perp$	$\perp$

F^2

x	a	y	c	z
2	9	2	1	3

F^3

x	a	y	c	z
0	1	8	2	6

Figure 5: The final results of the two outer joins in Query 1 are stored in a temporary table F.

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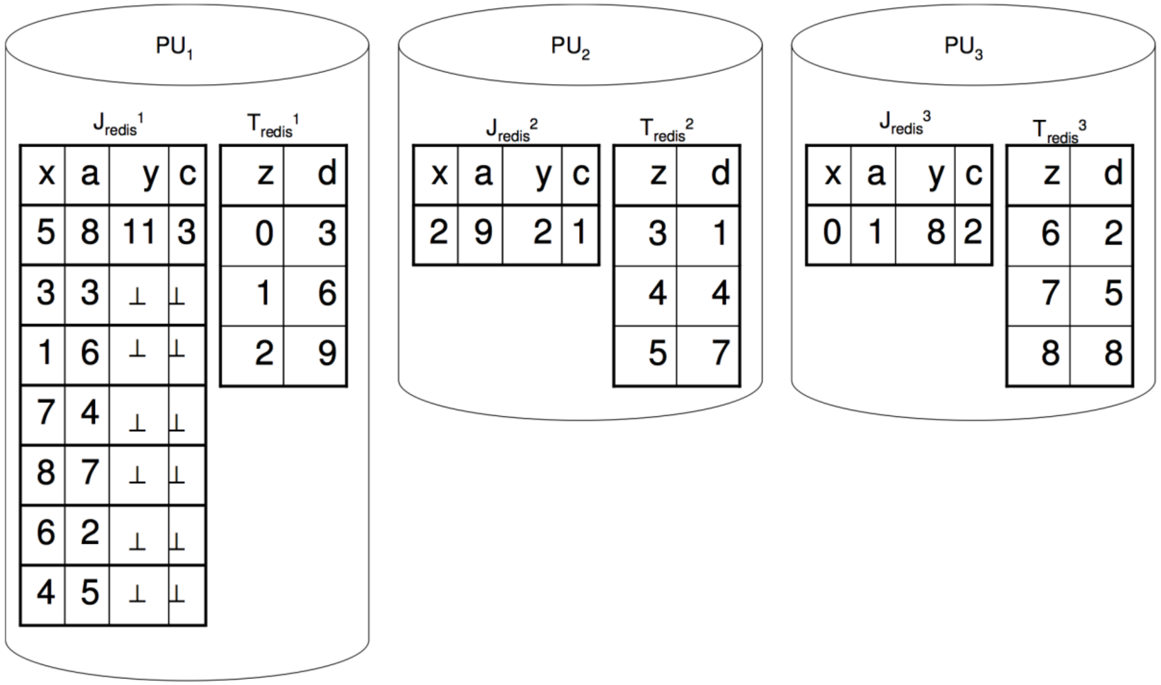
Conclusion…

- Skew can easily happen easily in Outer Join queries



PU_1

J_{redis}^1

x	a	y	c
5	8	11	3
3	3	⊥	⊥
1	6	⊥	⊥
7	4	⊥	⊥
8	7	⊥	⊥
6	2	⊥	⊥
4	5	⊥	⊥

T_{redis}^1

z	d
0	3
1	6
2	9

PU_2

J_{redis}^2

x	a	y	c
2	9	2	1

T_{redis}^2

z	d
3	1
4	4
5	7

PU_3

J_{redis}^3

x	a	y	c
0	1	8	2

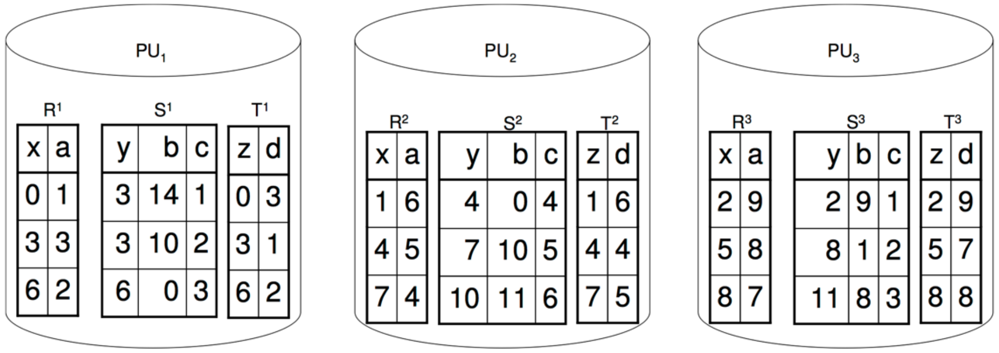
T_{redis}^3

z	d
6	2
7	5
8	8

Figure 4: The result of hash redistributing J (shown in Figure 3) and T (shown in Figure 1) on their join attributes ($J.c$ and $T.d$) to two temporary tables J_{redis} and T_{redis}.

A better solution… OJSO (Extra Reading)

- Step 1: Redistribute R and S (same as the previous example)



PU$_1$

R^1

x	a
0	1
3	3
6	2

S^1

y	b	c
3	14	1
3	10	2
6	0	3

T^1

z	d
0	3
3	1
6	2

PU$_2$

R^2

x	a
1	6
4	5
7	4

S^2

y	b	c
4	0	4
7	10	5
10	11	6

T^2

z	d
1	6
4	4
7	5

PU$_3$

R^3

x	a
2	9
5	8
8	7

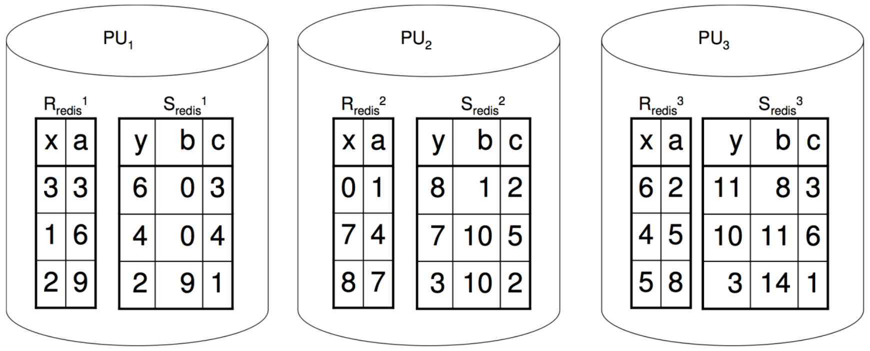
S^3

y	b	c
2	9	1
8	1	2
11	8	3

T^3

z	d
2	9
5	7
8	8

Figure 1: Three relations R, S and T are hash partitioned on a three parallel-unit system. The partitioning columns are $R.x$, $S.y$ and $T.z$ respectively. The hash function, $h(i) = i \ mod \ 3 + 1$, places a tuple with value i in the partitioning column on the $h(i)$-th PU.



PU$_1$

$R_{redis}{}^1$

x	a
3	3
1	6
2	9

$S_{redis}{}^1$

y	b	c
6	0	3
4	0	4
2	9	1

PU$_2$

$R_{redis}{}^2$

x	a
0	1
7	4
8	7

$S_{redis}{}^2$

y	b	c
8	1	2
7	10	5
3	10	2

PU$_3$

$R_{redis}{}^3$

x	a
6	2
4	5
5	8

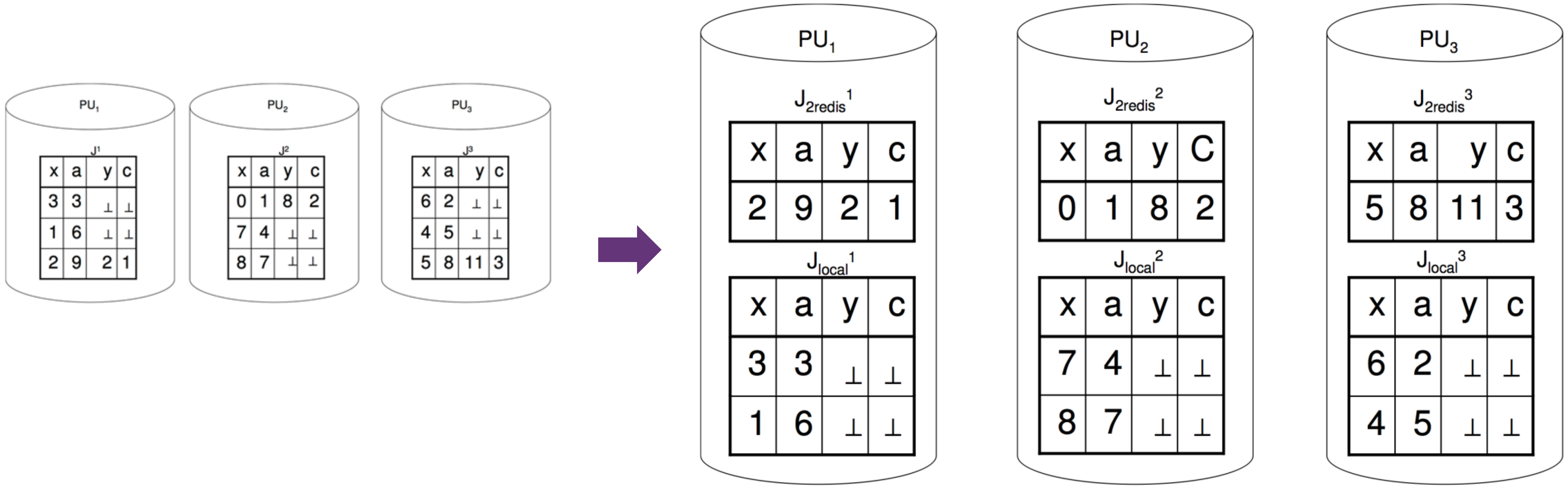
$S_{redis}{}^3$

y	b	c
11	8	3
10	11	6
3	14	1

Figure 2: The result of hash redistributing R and S on their join attributes ($R.a$ and $S.b$) to two temporary tables R_{redis} and S_{redis}.

A better solution… OJSO (Extra Reading)

- Step 2: (a) Outer Join R and S, but the results (J) are divided into J_{2redis} and J_{local}



PU_1, J^1

x	a	y	c
3	3	⊥	⊥
1	6	⊥	⊥
2	9	2	1

PU_2, J^2

x	a	y	c
0	1	8	2
7	4	⊥	⊥
8	7	⊥	⊥

PU_3, J^3

x	a	y	c
6	2	⊥	⊥
4	5	⊥	⊥
5	8	11	3

PU_1, J_{2redis}^1

x	a	y	c
2	9	2	1

J_{local}^1

x	a	y	c
3	3	⊥	⊥
1	6	⊥	⊥

PU_2, J_{2redis}^2

x	a	y	C
0	1	8	2

J_{local}^2

x	a	y	c
7	4	⊥	⊥
8	7	⊥	⊥

PU_3, J_{2redis}^3

x	a	y	c
5	8	11	3

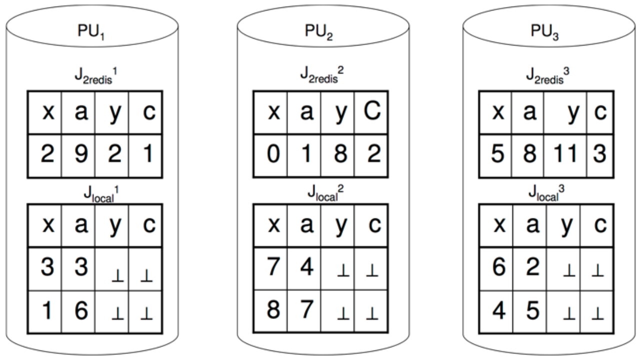
J_{local}^3

x	a	y	c
6	2	⊥	⊥
4	5	⊥	⊥

Figure 9: The results of left outer joining R_{redis} and S_{redis} are split into two temporary tables J_{2redis} and J_{local}.

A better solution… OJSO (Extra Reading)

- Step 2: (b) Redistribute J_{2redis} and T; and do an outer join



PU$_1$

J_{2redis}^1

x	a	y	c
2	9	2	1

J_{local}^1

x	a	y	c
3	3	⊥	⊥
1	6	⊥	⊥

PU$_2$

J_{2redis}^2

x	a	y	C
0	1	8	2

J_{local}^2

x	a	y	c
7	4	⊥	⊥
8	7	⊥	⊥

PU$_3$

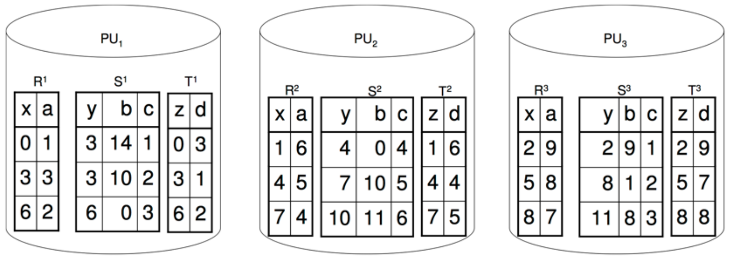
J_{2redis}^3

x	a	y	c
5	8	11	3

J_{local}^3

x	a	y	c
6	2	⊥	⊥
4	5	⊥	⊥

Fig 9



PU$_1$

R^1

x	a
0	1
3	3
6	2

S^1

y	b	c
3	14	1
3	10	2
6	0	3

T^1

z	d
0	3
3	1
6	2

PU$_2$

R^2

x	a
1	6
4	5
7	4

S^2

y	b	c
4	0	4
7	10	5
10	11	6

T^2

z	d
1	6
4	4
7	5

PU$_3$

R^3

x	a
2	9
5	8
8	7

S^3

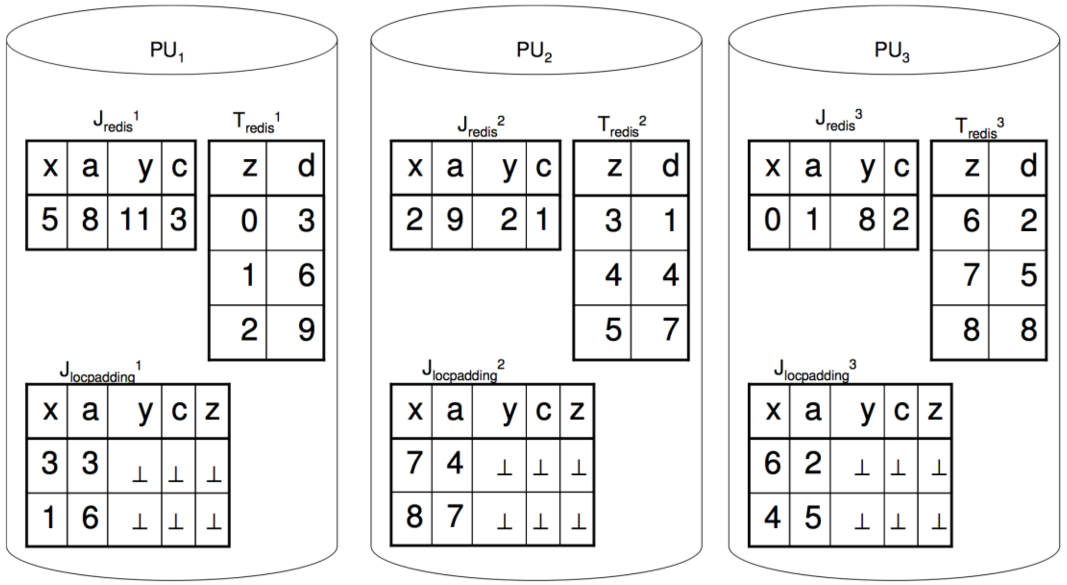
y	b	c
2	9	1
8	1	2
11	8	3

T^3

z	d
2	9
5	7
8	8

Fig 1

hash func h(i) = i mod 3 + 1



PU$_1$

J_{redis}^1

x	a	y	c
5	8	11	3

T_{redis}^1

z	d
0	3
1	6
2	9

$J_{locpadding}^1$

x	a	y	c	z
3	3	⊥	⊥	⊥
1	6	⊥	⊥	⊥

PU$_2$

J_{redis}^2

x	a	y	c
2	9	2	1

T_{redis}^2

z	d
3	1
4	4
5	7

$J_{locpadding}^2$

x	a	y	c	z
7	4	⊥	⊥	⊥
8	7	⊥	⊥	⊥

PU$_3$

J_{redis}^3

x	a	y	c
0	1	8	2

T_{redis}^3

z	d
6	2
7	5
8	8

$J_{locpadding}^3$

x	a	y	c	z
6	2	⊥	⊥	⊥
4	5	⊥	⊥	⊥

Figure 10: The result of hash redistributing J_{2redis} (shown in Figure 9) and T (shown in Figure 1) on their join attributes to two temporary tables J_{redis} and T_{redis}. $J_{locpadding}$ is created from J_{local} (shown in Figure 9) with padded nulls.

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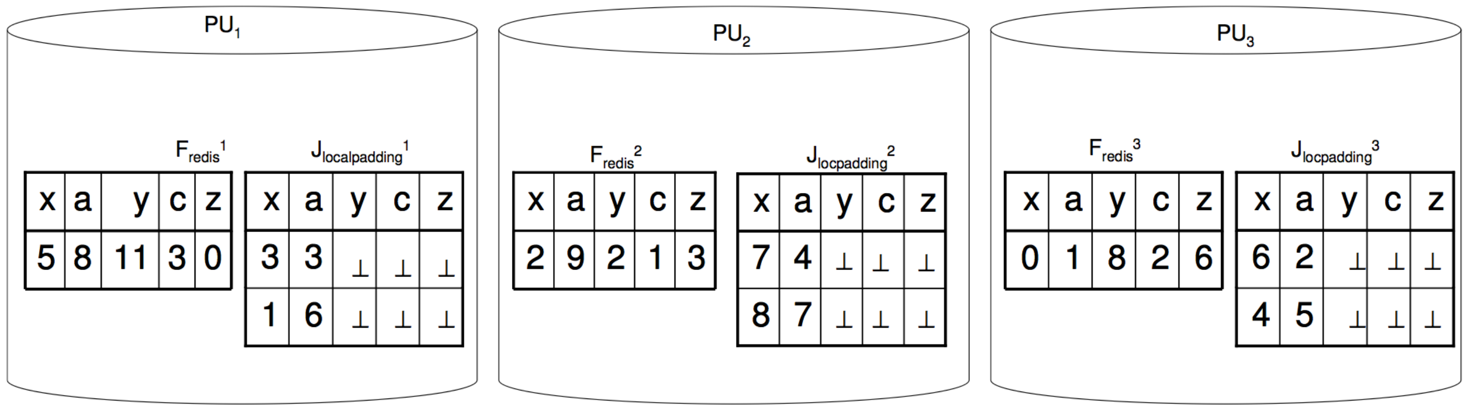
A better solution… OJSO (Extra Reading)

- Step 3: Union the final results in each processor



F_{redis}^1

x	a	y	c	z
5	8	11	3	0

$J_{localpadding}^1$

x	a	y	c	z
3	3	⊥	⊥	⊥
1	6	⊥	⊥	⊥

F_{redis}^2

x	a	y	c	z
2	9	2	1	3

$J_{locpadding}^2$

x	a	y	c	z
7	4	⊥	⊥	⊥
8	7	⊥	⊥	⊥

F_{redis}^3

x	a	y	c	z
0	1	8	2	6

$J_{locpadding}^3$

x	a	y	c	z
6	2	⊥	⊥	⊥
4	5	⊥	⊥	⊥

Figure 11: The results of the second outer join in Query 1 are stored in a temporary table F. The final result for Query 1 is the union of F and $J_{locpadding}$.

Summary…

- Parallel Outer Join processing methods
  - **ROJA** (Redistribution Outer Join Algorithm)
  - **DOJA** (Duplication Outer Join Algorithm)
  - **DER** (Duplication & Efficient Redistribution)

- Load Balancing
  - **OJSO** (Outer Join Skew Optimization)

Parallel Join Demo in Apache Spark

References

- Xu, Y. & Kostamaa, P. (2010). A new algorithm for small-large table outer joins in parallel DBMS. In *Proceedings of the 26th Intl Conference on Data Engineering (ICDE'2010)* (pp. 1018-1024), IEEE Comp Society Press.
- Xu,Y. & Kostamaa, P. (2009). Efficient Outer Join Data Skew Handling in Parallel DBMS. In *Proceedings of the 35th International Conference on Very Large Data Bases (VLDB'2009)* (pp. 1390-1396), VLDB Endowment.