How does Hash Join work in PostgreSQL and its derivates

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Hash join in PostgreSQL

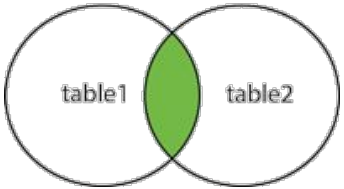
What is JOIN

An SQL join clause - corresponding to a join operation in relational algebra - combines columns from one or more tables in a relational database.

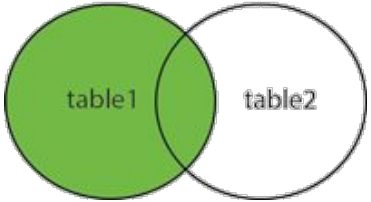
-- Wikipedia

JOIN Types

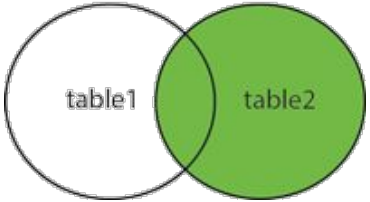
INNER JOIN



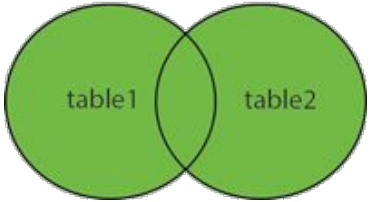
LEFT JOIN



RIGHT JOIN

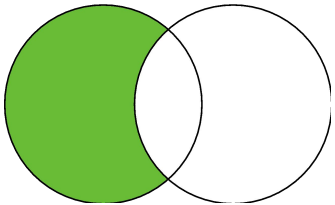


FULL OUTER JOIN



SEMI JOIN

ANTI JOIN



Examples

student table

id	name	age
10	Jack	25
12	Tom	26
13	Ariel	25

score table

id	stu_id	subject	score
1	10	math	95
2	10	history	98
3	12	math	97
4	15	history	92

```
CREATE TABLE student(id int, name text, age int);
CREATE TABLE score(id int, stu_id int, subject text, score int);
INSERT INTO student VALUES (10, 'Jack', 25), (12, 'Tom', 26), (13, 'Ariel', 25);
INSERT INTO score VALUES (1, 10, 'math', 95), (2, 10, 'history', 98), (3, 12, 'math', 97), (4, 15, 'history', 92);
```

JOIN Examples

GREENPLUM DATABASE

```
set enable_mergejoin to off;
set enable_hashagg to off;
```

JOIN Types	Examples
Inner JOIN	SELECT name, score FROM student st **INNER JOIN** score s ON st.id = s.stu_id
Left JOIN	SELECT name, score FROM student st **LEFT JOIN** score s ON st.id = s.stu_id
Right JOIN	SELECT name, score FROM student st **RIGHT JOIN** score s ON st.id = s.stu_id
Full JOIN	SELECT name, score FROM student st **FULL JOIN** score s ON st.id = s.stu_id
Semi JOIN	SELECT id, name FROM student st WHERE **EXISTS** (SELECT id FROM score WHERE stu_id = st.id)
Anti JOIN	SELECT name FROM student st WHERE **NOT EXISTS** (SELECT stu_id FROM score where score.stu_id = st.id)

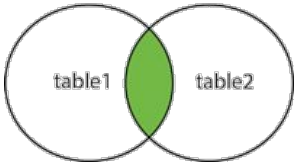
Explain shows join type

JOIN Examples

```
# SELECT * FROM student;
 id | name  | age
----+-------+-----
 10 | Jack  |  25
 13 | Ariel |  25
 12 | Tom   |  26
```

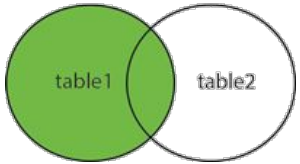
```
# SELECT * FROM score;
 id | stu_id | subject | score
----+--------+---------+-------
  1 |     10 | math    |    95
  2 |     10 | history |    98
  3 |     12 | math    |    97
  4 |     15 | history |    92
```

INNER JOIN



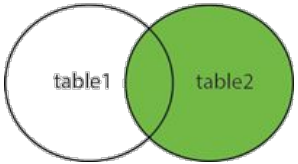

```
 name | score
------+-------
 Tom  |    97
 Jack |    95
 Jack |    98
(3 rows)
```

LEFT JOIN



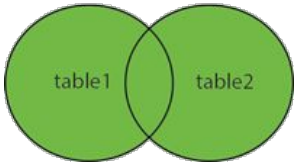

```
 name  | score
-------+-------
 Tom   |    97
 Jack  |    95
 Jack  |    98
 Ariel |
(4 rows)
```

RIGHT JOIN



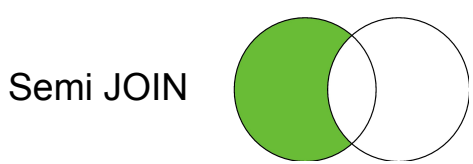

```
 name | score
------+-------
 Tom  |    97
      |    92
 Jack |    95
 Jack |    98
(4 rows)
```

FULL OUTER JOIN




```
 name  | score
-------+-------
 Tom   |    97
       |    92
 Jack  |    95
 Jack  |    98
 Ariel |
(5 rows)
```

Semi JOIN




```
 id | name
----+------
 10 | Jack
 12 | Tom
(2 rows)
```

```
 name
-------
 Ariel
(1 row)
```

JOIN implementation algorithms

- Nested Loop
- Merge Join
- Hash Join

Hash join has two phases

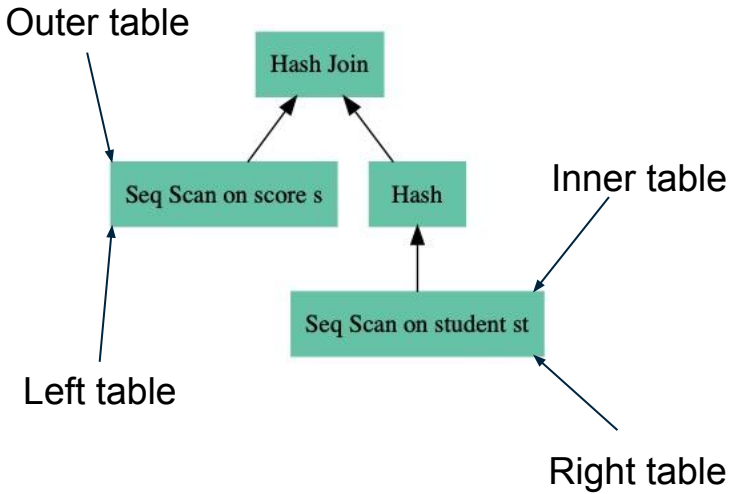
- **Build phase**: build hash table on the smaller table after applying possible local predicates, which is called **inner** table.

- **Probe phase**: scan tuple from another table and probe hash table for matches based on criteria, this ‘another’ table is called **outer** table

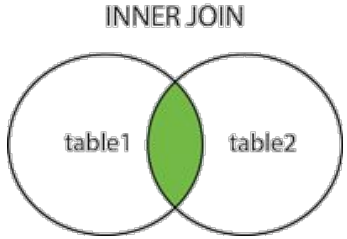
Let us start from inner join

SELECT name, subject, score FROM student st INNER JOIN score s ON st.id = s.stu_id

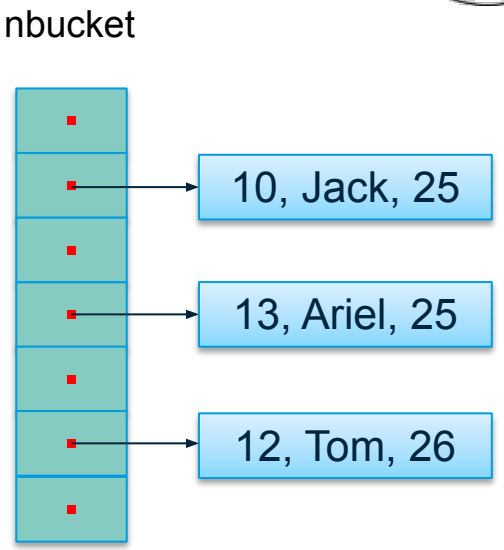
```
QUERY PLAN
-----------------------------------------------------
Hash Join  (cost=35.42..297.73 …)
   Hash Cond: (st.id = s.stu_id)
   ->  Seq Scan on student st  (cost=0.00..22.00)
   ->  Hash  (cost=21.30..21.30 rows=1130 width=8)
         ->  Seq Scan on score s  (cost=0.00..21.30)
(5 rows)
```



Inner join: build phase

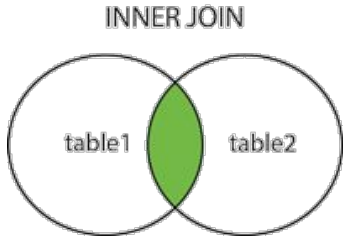



```
SELECT * FROM student;
 id | name  | age
----+-------+-----
 10 | Jack  |  25
 13 | Ariel |  25
 12 | Tom   |  26
```



SELECT name, subject, score FROM student st INNER JOIN score s ON st.id = s.stu_id

Inner join: probe phase

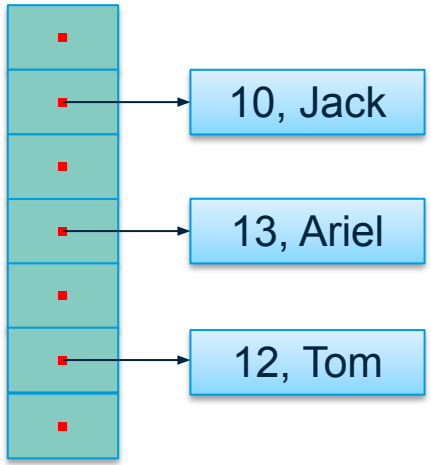


Score table

id	stu_id	subject	score
1	10	math	95
2	10	history	98
3	12	math	97
4	15	history	92

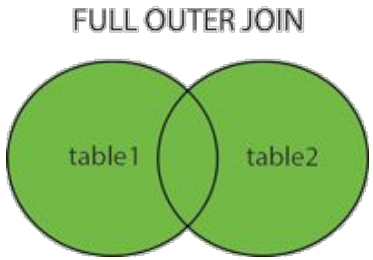
Jack	math	95
Jack	hist	98
Tom	math	97

Hash table for student



SELECT name, subject, score FROM student st INNER JOIN score s ON st.id = s.stu_id

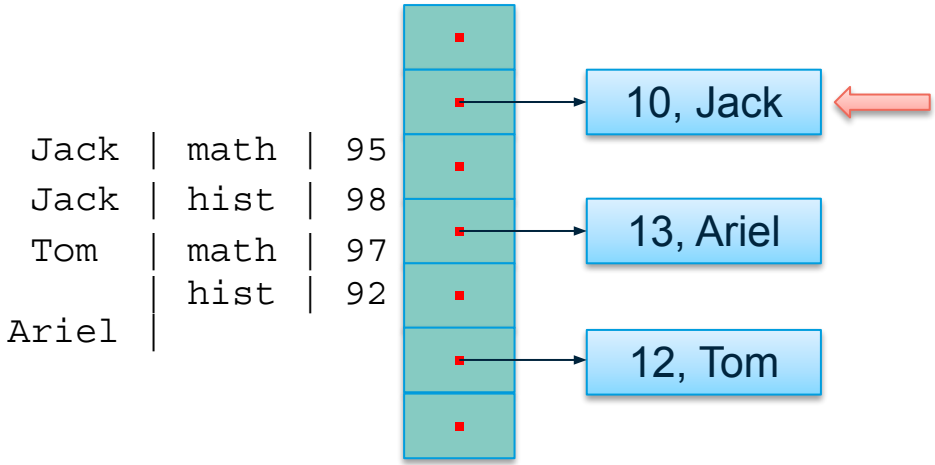
Full outer join



Score table

id	stu_id	subject	score
1	10	math	95
2	10	history	98
3	12	math	97
4	15	history	92

Hash table for student



SELECT name, subject, score FROM student st INNER JOIN score s ON st.id = s.stu_id

JOIN SQL semantics vs. JOIN imp types

```
explain SELECT * FROM bigger_table LEFT JOIN smaller_table ON …
Hash Left Join
   Hash Cond: (b.id = s.id)
   ->  Seq Scan on bigger_table b
   ->  Hash
         ->  Seq Scan on smaller_table s
(5 rows)

explain SELECT * FROM smaller_table LEFT JOIN bigger_table ON …
Hash Right Join
   Hash Cond: (s.id = b.id)
   ->  Seq Scan on bigger_table s
   ->  Hash
         ->  Seq Scan on smaller_table b
(5 rows)
```

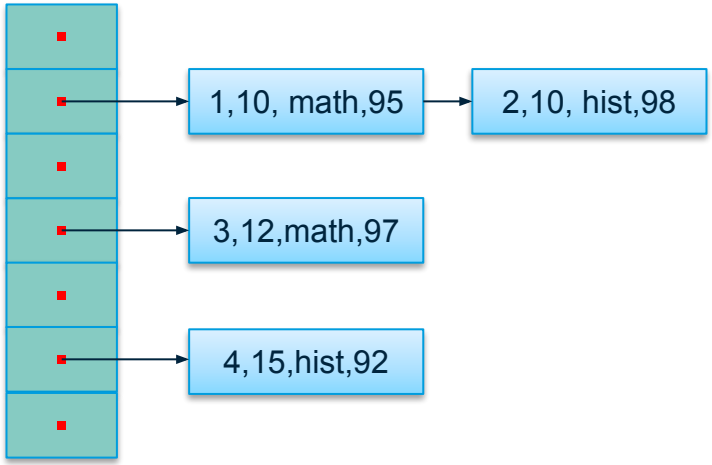
Semi join: stop with first match

student table

id	name	age
10	Jack	25
13	Ariel	25
12	Tom	26

10	Jack
12	Tom

Hash table for score on stu_id




```
SELECT id, name FROM student st
WHERE EXISTS (SELECT id FROM score WHERE stu_id = st.id)
```

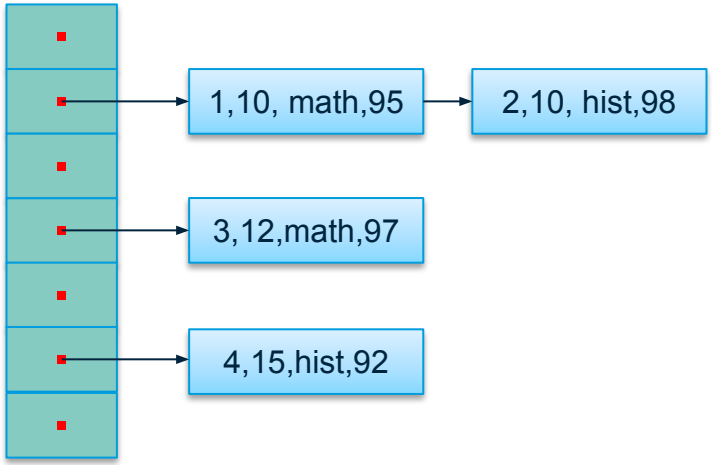
Anti join: emit tuple when there is no match

student table

id	name	age
10	Jack	25
13	Ariel	25
12	Tom	26

13 | Ariel

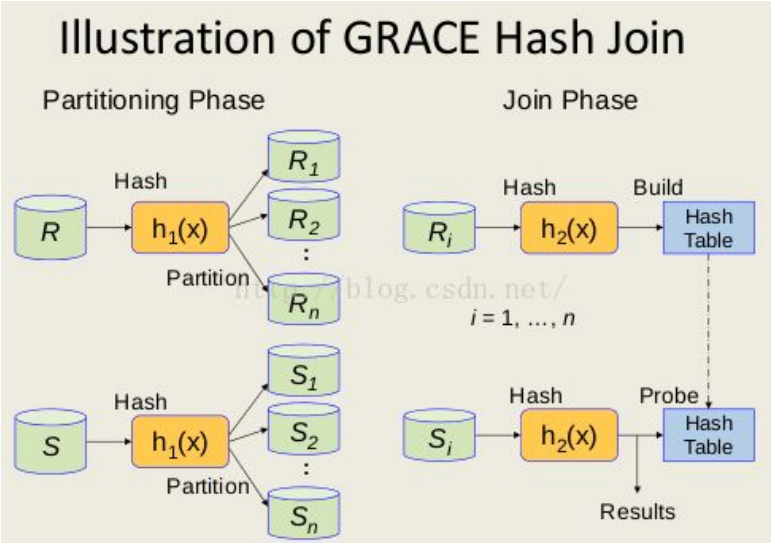
Hash table for score on stu_id



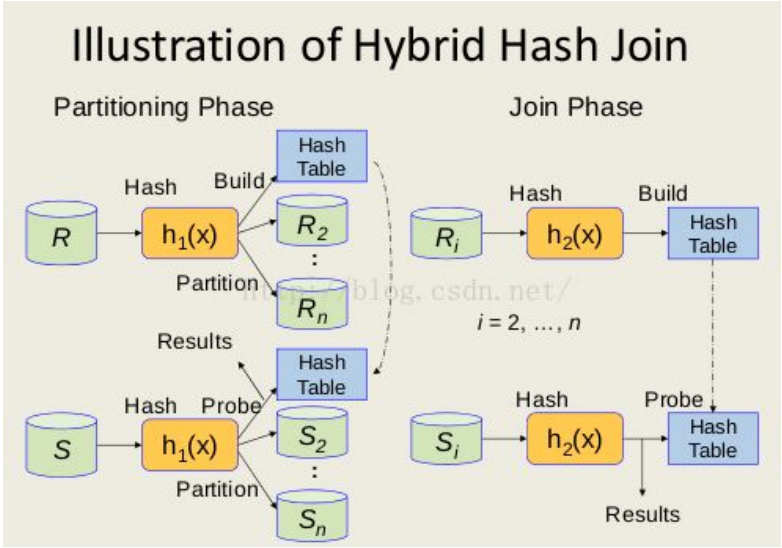

```
SELECT id, name FROM student st
WHERE id NOT EXISTS (SELECT stu_id FROM score)
```

What about if inner table is too big to fit into memory?

Grace Hash Join

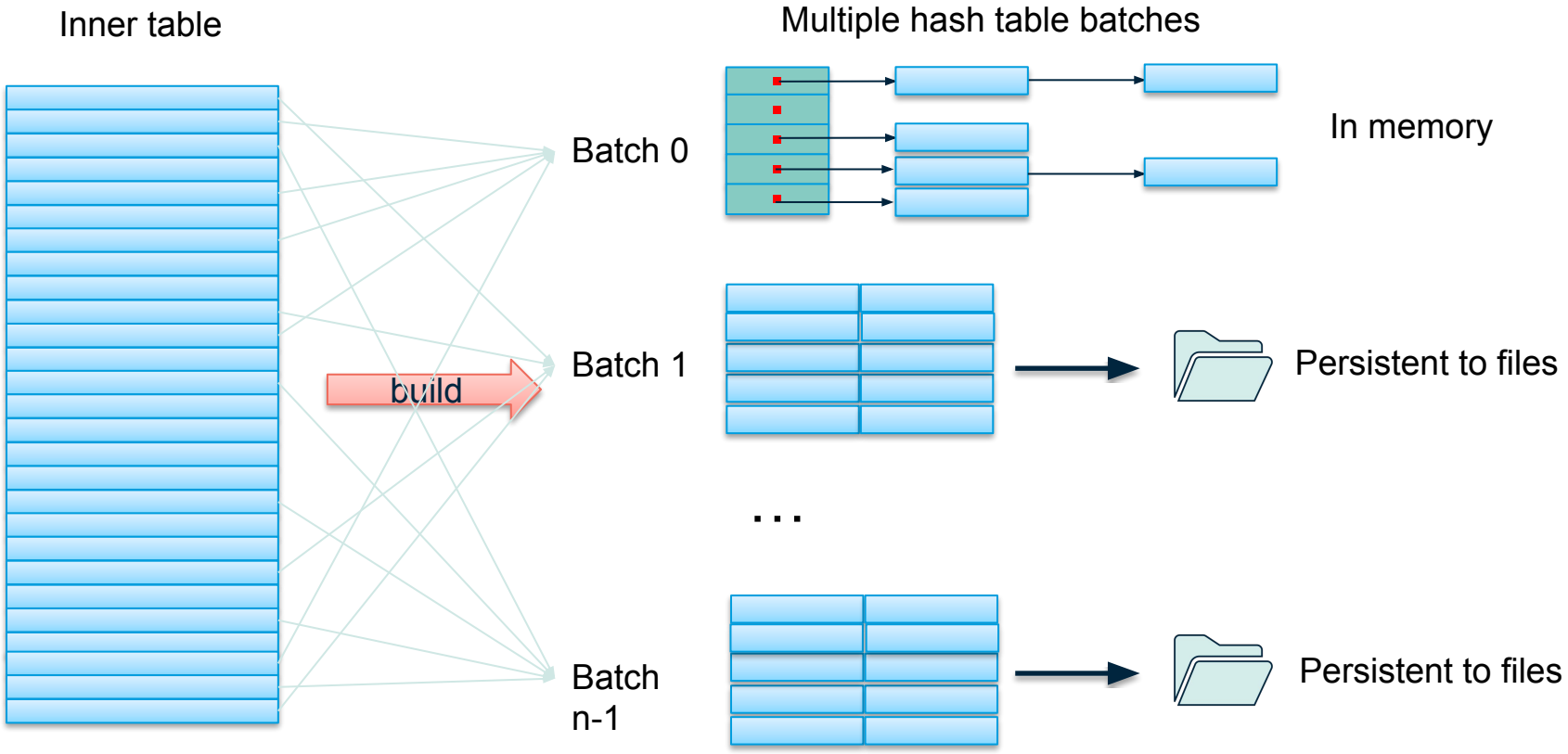


Hybrid Hash Join

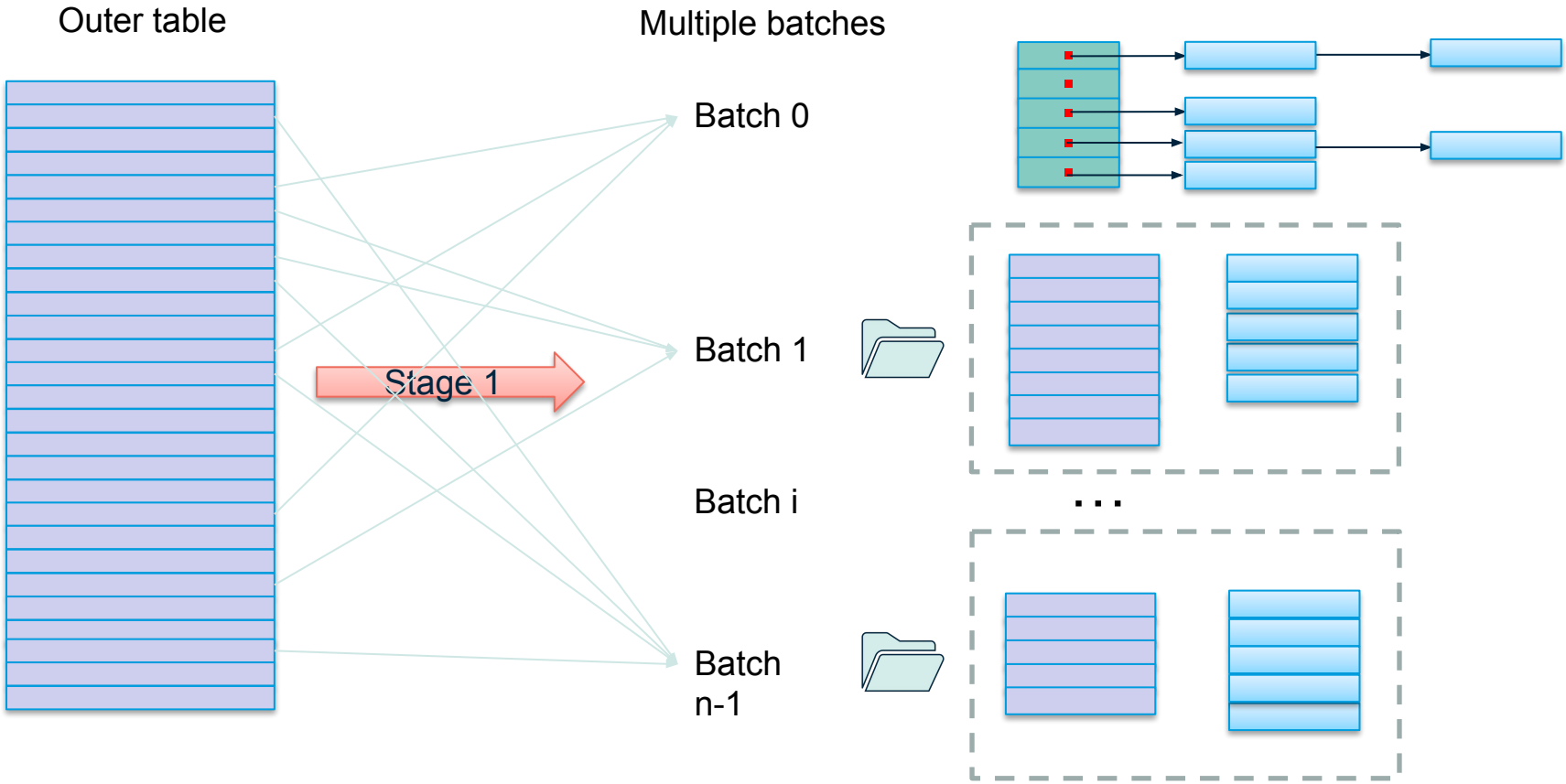


https://blog.csdn.net/apsvvfb/article/details/50456178

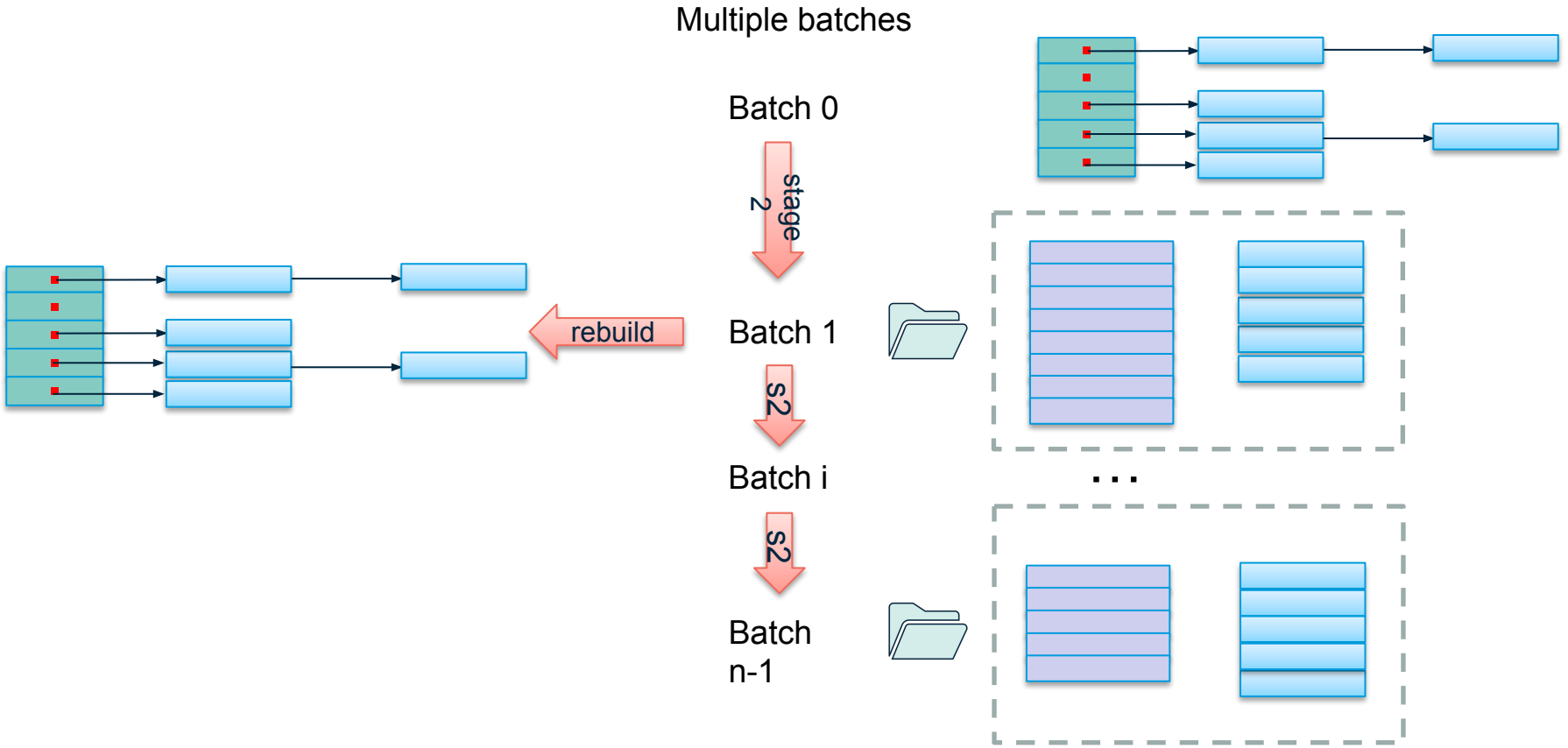
Partition phase for inner table of hybrid hash join



Partition phase for outer table of Hybrid hash join

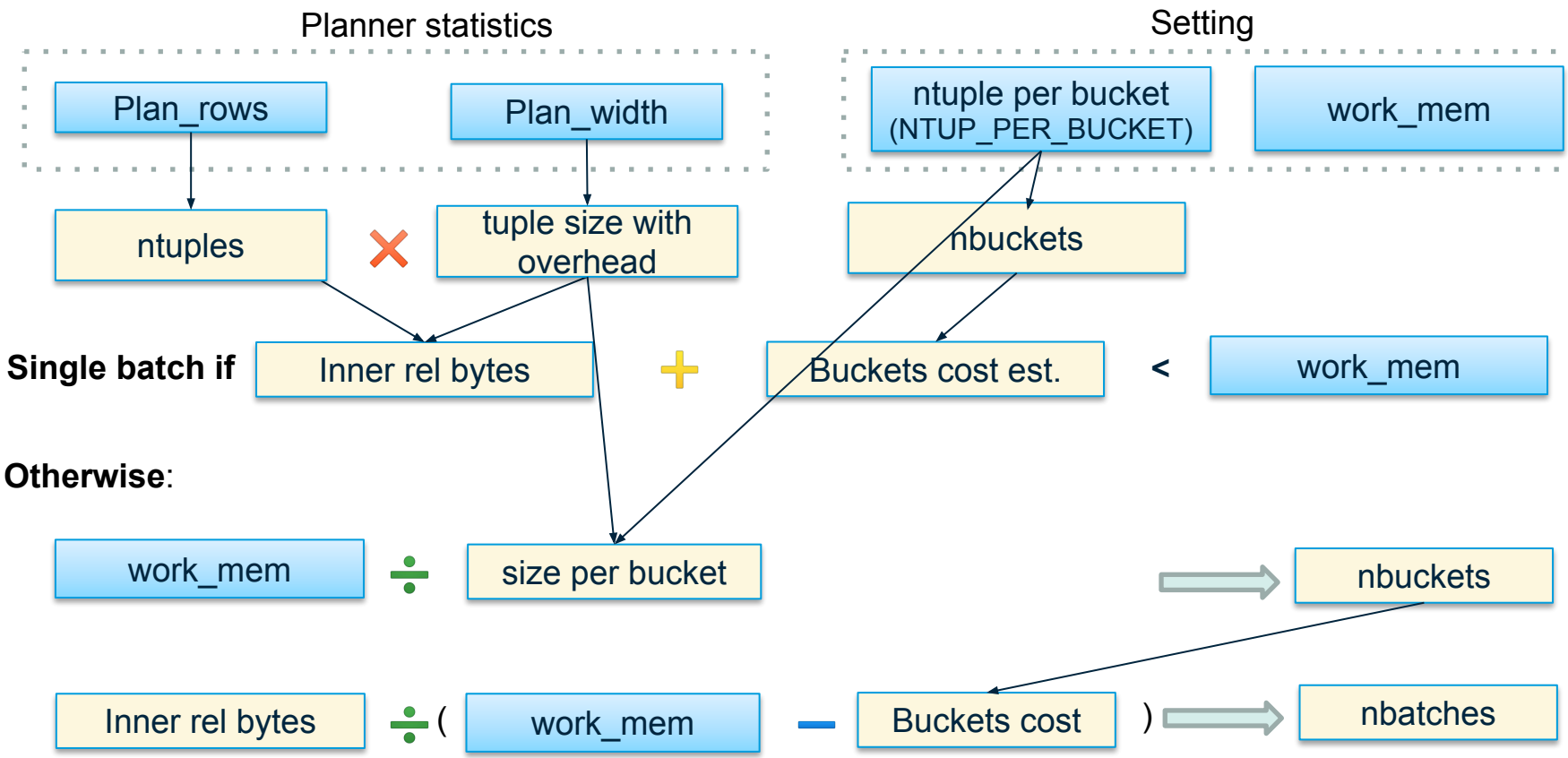


Join phase of Hybrid hash join: for later batches

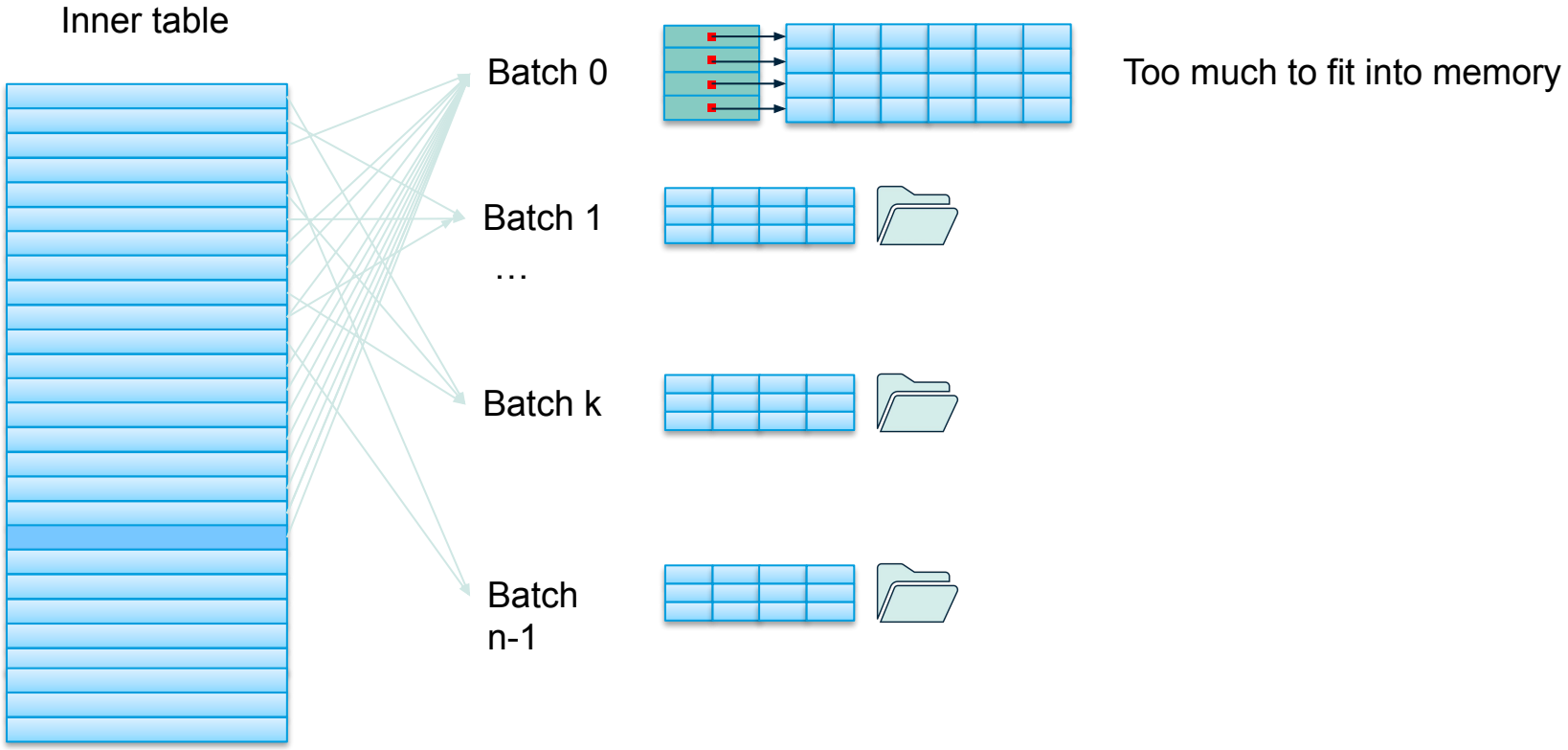


GREENPLUM DATABASE

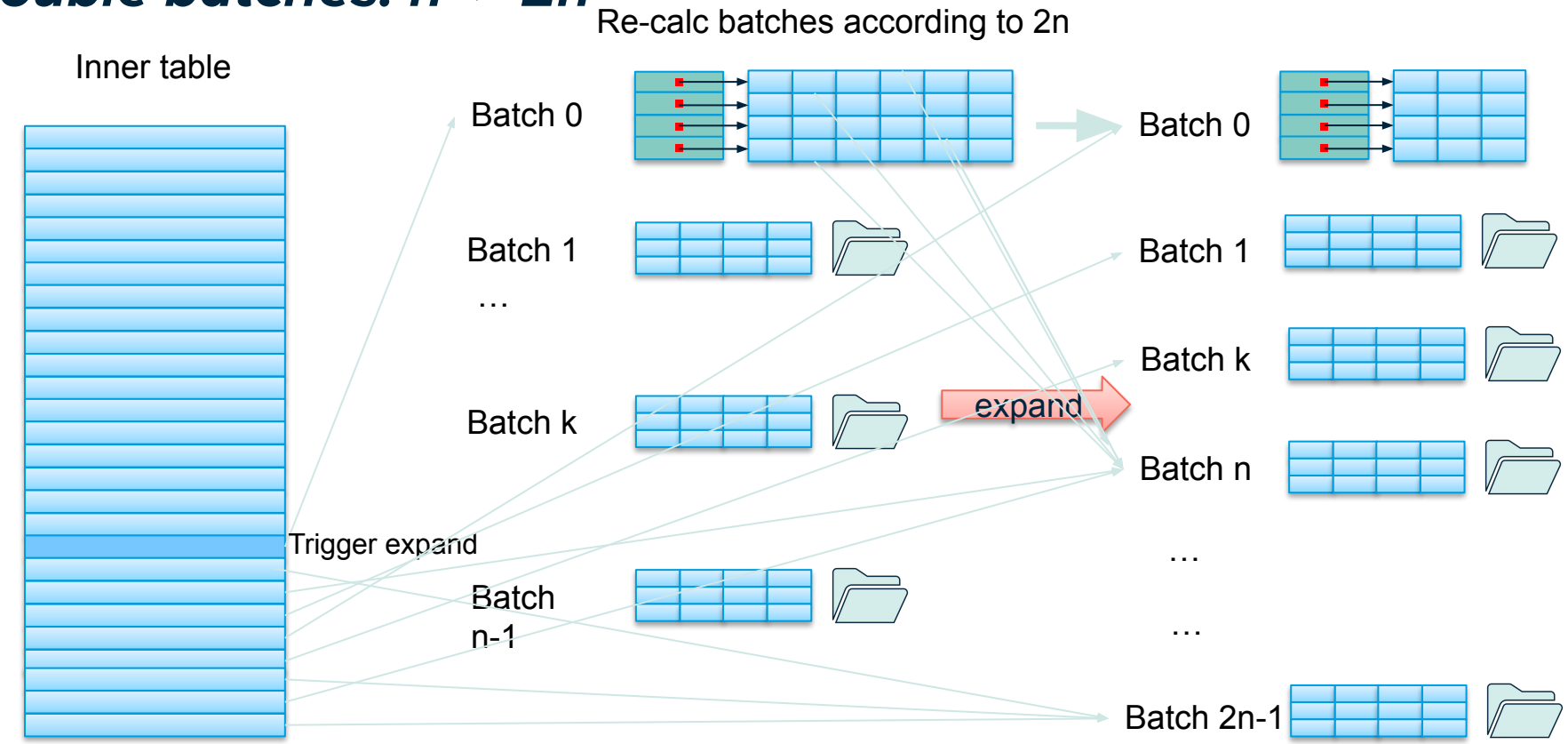
How to determine number of buckets & batches



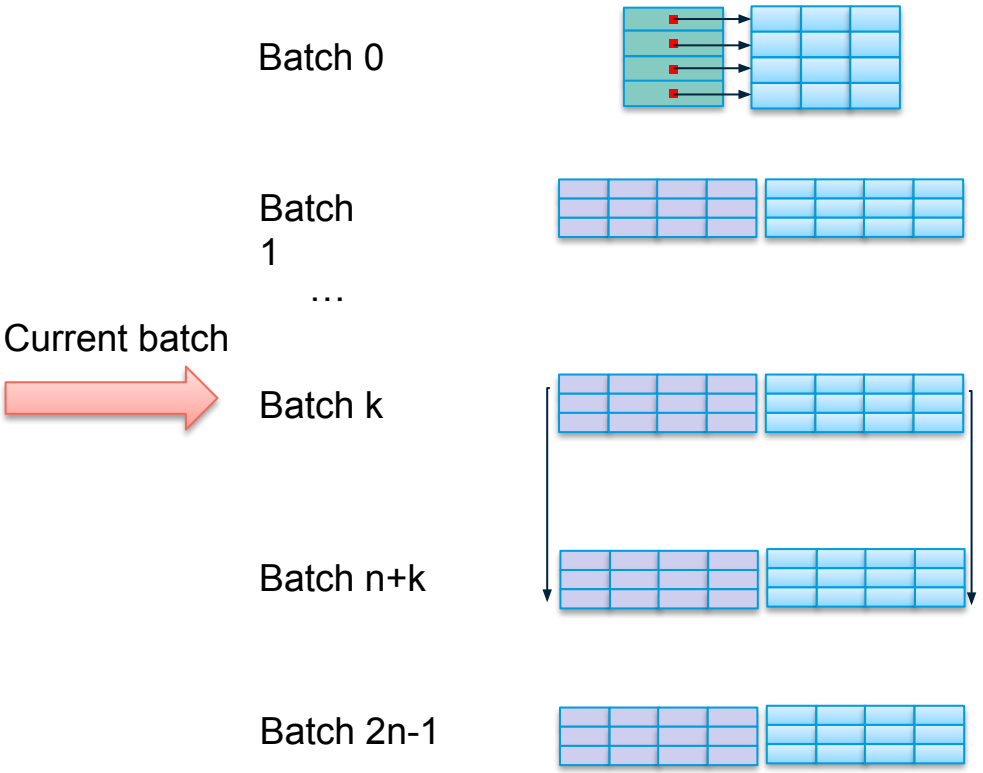
How about if batch 0 is too big?



Double batches: n -> 2n

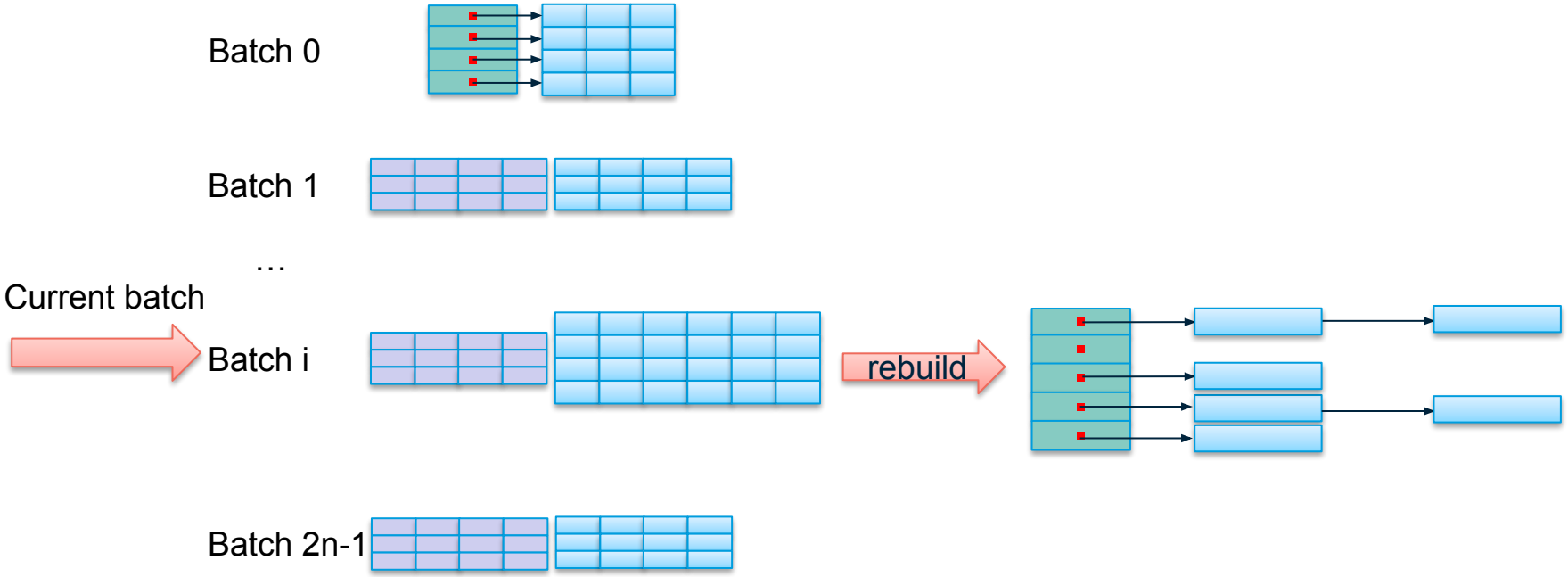


Observation: batch expands result in tuple movement

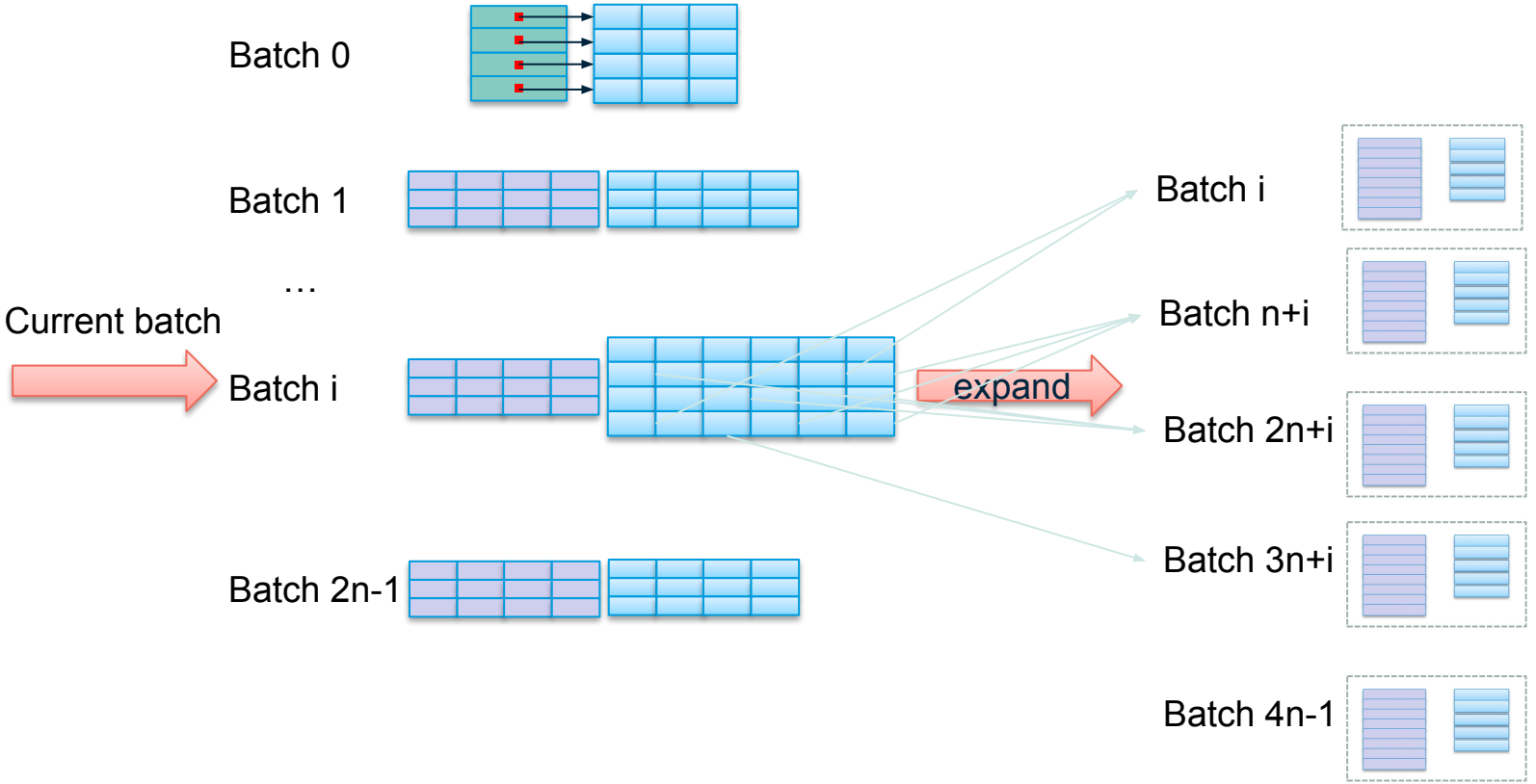


So tuples might move to later batches, as we build hash table from inner batch file, and scan outer batch file.

Batch i might result in batch expand again



Then expand batches again, and more tuple movements



Skew optimization overview

- Optimization if outer table has ***non uniform distribution***, so that most common values (MCV) will be processed in batch 0

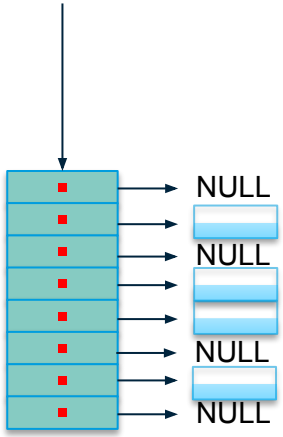
Skew optimization: prepare skew hash table

$$\frac{work\_mem * 0.02}{tupsize + exta\_cost}$$

Number of MCVs
memory allowed

1. Determine size

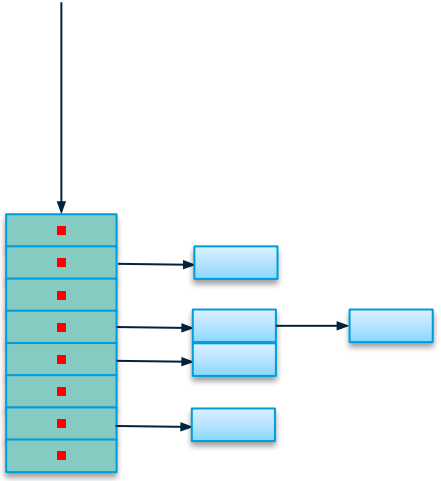
pg_statistic of outer table
MVC stats



Skew hash table

2. Create empty table with hash value

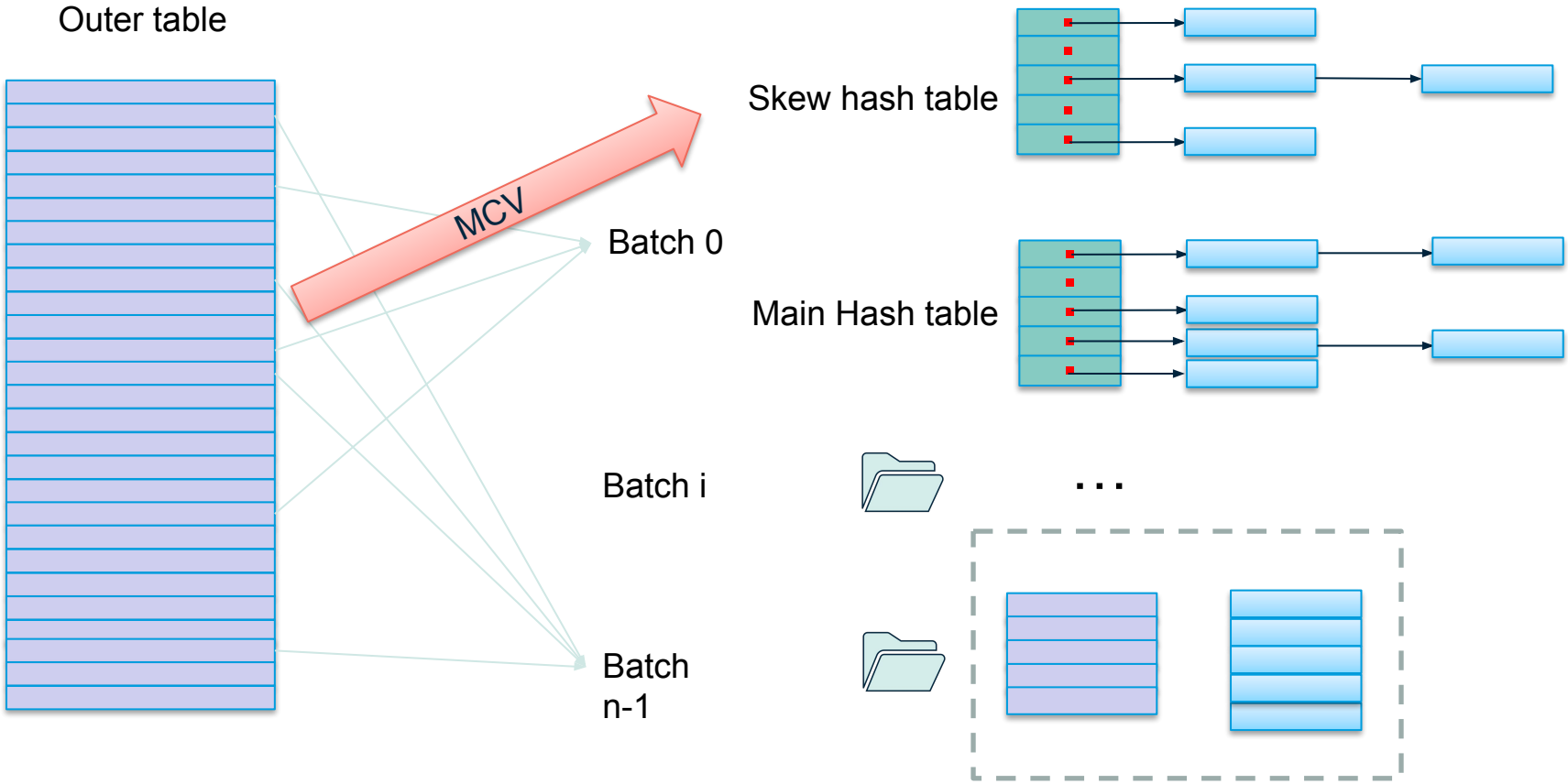
Inner table



Skew hash table

3. Populate skew hash table

Skew optimization: probe skew hash table

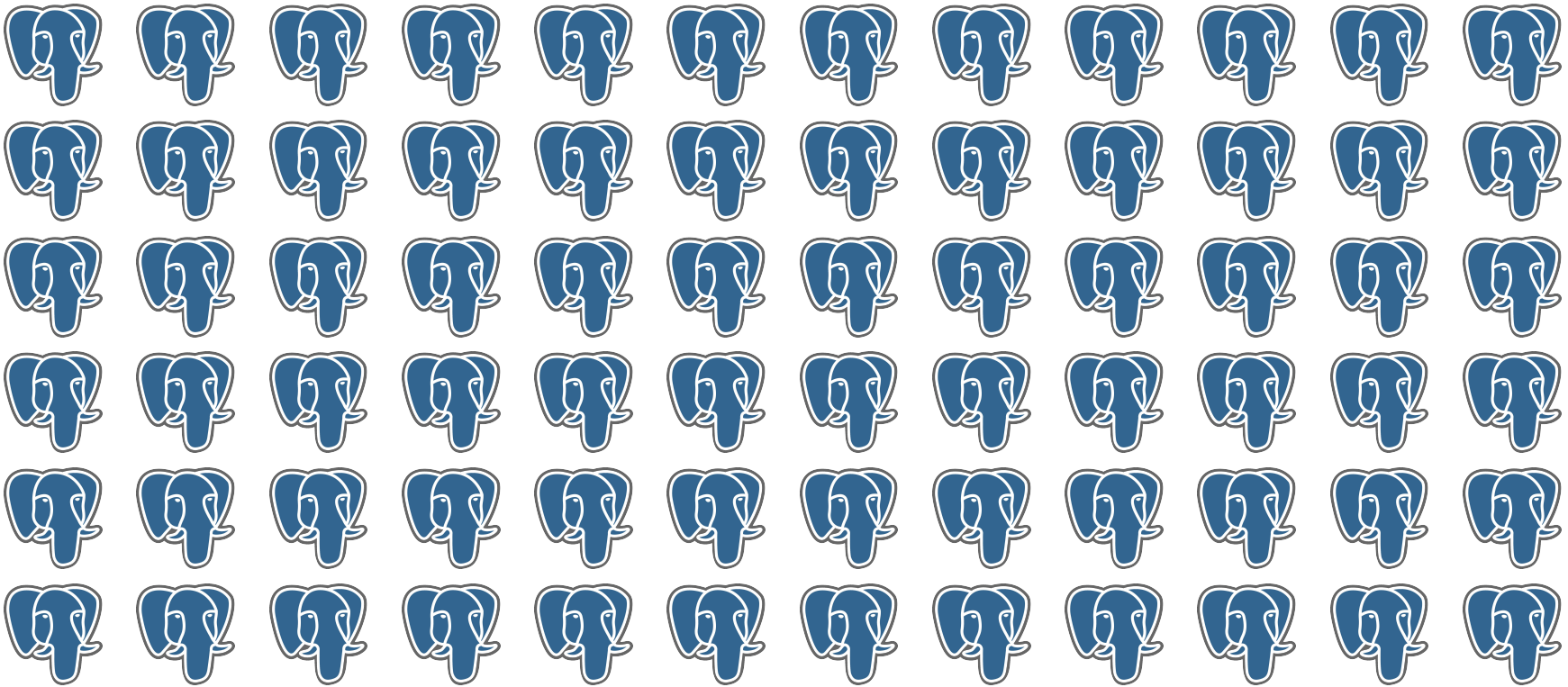


Parallel Join

Hash join in Greenplum

GREENPLUM DATABASE®

Basically many PostgreSQL nodes



GREENPLUM DATABASE®

A transparent distributed database with ACID

MPP shared nothing arch

GREENPLUM DATABASE®

Key Greenplum concepts

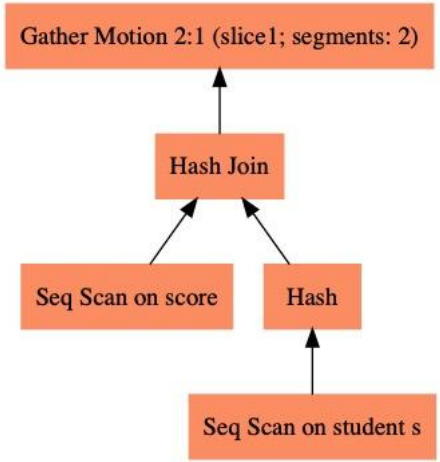
- **Distribution** policy: controls how to distribute tuples to each segments
  - Hash distribution
  - Random distribution
  - Replicated tables
  - Customized hash function
- **Motion**: transfer data between different segments
  - Gather
  - Redistribution
  - Broadcast

Hash join for tables with 'same' distribution

CREATE TABLE student(id int, name text, age int) **distributed by (id);**

CREATE TABLE score(id int, stu_id int, subject text, score int) **distributed by (stu_id);**

SELECT name, subject, score FROM student s INNER JOIN score ON **s.id = score.stu_id**;

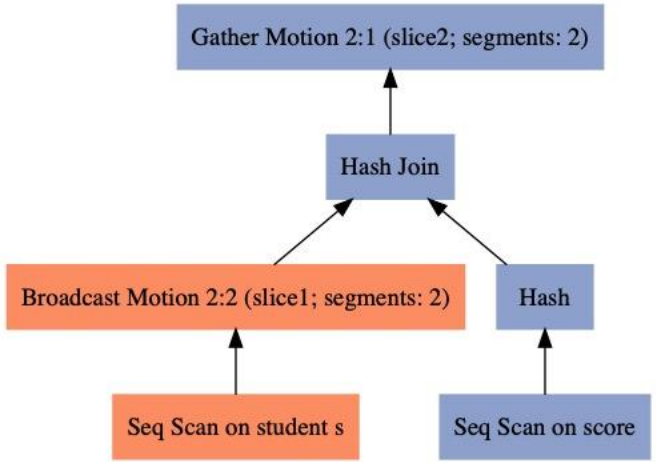


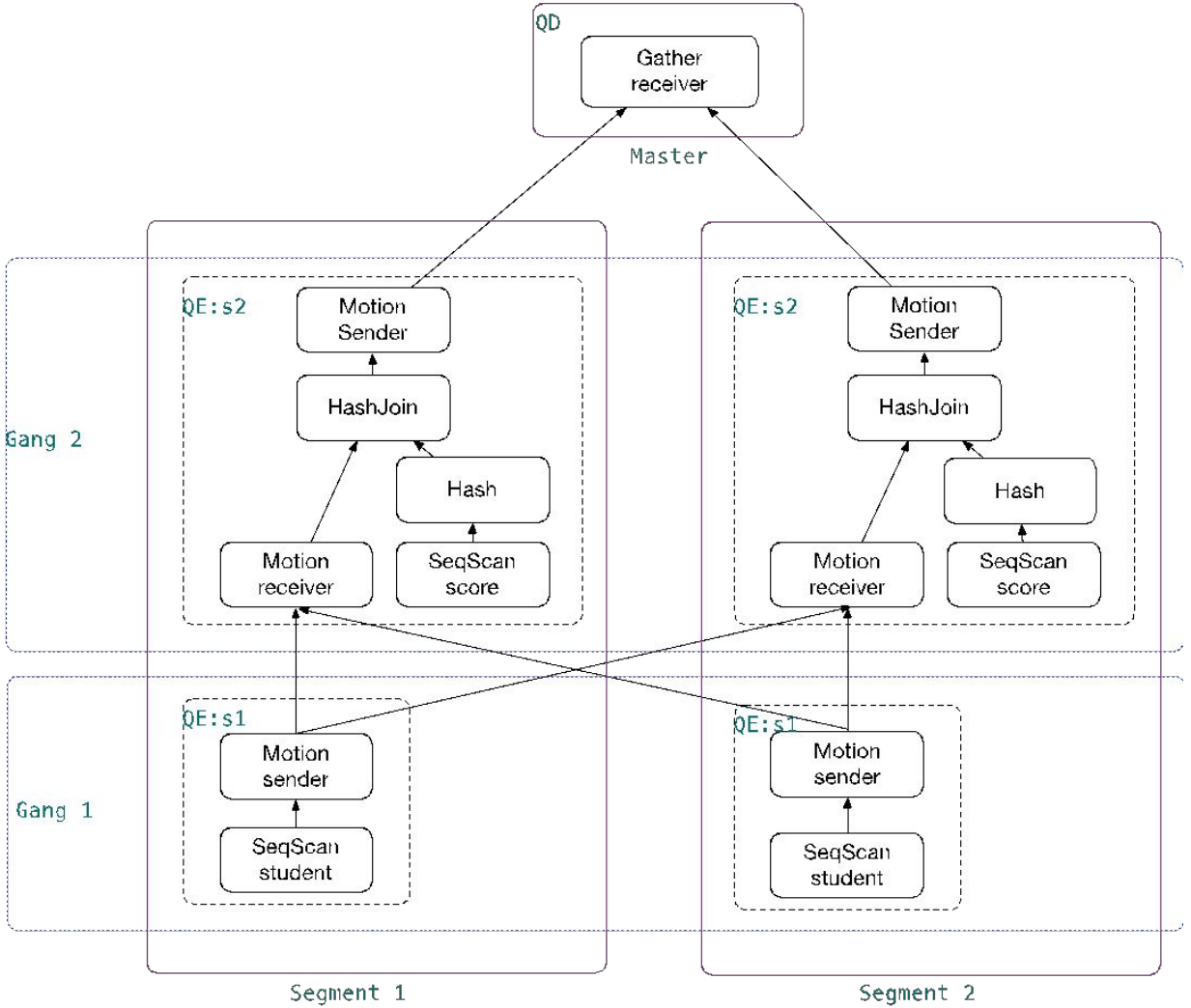
Hash join for tables with different distribution

CREATE TABLE student(id int, name text, age int) **distributed by (id);**

CREATE TABLE score(id int, stu_id int, subject text, score int) **distributed by (id);**

SELECT name, subject, score FROM student s INNER JOIN score ON **s.id** = **score.stu_id**;




QD
Gather receiver
Master
Gang 2
QE:s2
Motion Sender
HashJoin
Hash
Motion receiver
SeqScan score
QE:s2
Motion Sender
HashJoin
Hash
Motion receiver
SeqScan score
Gang 1
QE:s1
Motion sender
SeqScan student
QE:s1
Motion sender
SeqScan student
Segment 1
Segment 2

Greenplum enhancements

- Batch file compression using zstd
- *Left anti semi join to optimize 'NOT IN'*

```
# explain SELECT name FROM student st WHERE id NOT IN (SELECT stu_id FROM score);
QUERY PLAN
------------------------------------------------------------------------------------------------
 Gather Motion 2:1  (slice2; segments: 2)  (cost=2.26..4.35 rows=4 width=5)
   ->  Hash Left Anti Semi (Not-In) Join  (cost=2.26..4.35 rows=2 width=5)
         Hash Cond: (st.id = score.stu_id)
         ->  Seq Scan on student st  (cost=0.00..2.03 rows=2 width=9)
         ->  Hash  (cost=2.16..2.16 rows=4 width=4)
               ->  Broadcast Motion 2:2  (slice1; segments: 2)  (cost=0.00..2.16 rows=4 width=4)
                     ->  Seq Scan on score  (cost=0.00..2.04 rows=2 width=4)
 Optimizer: Postgres query optimizer
```

Hash join state machine

Hash join state machine

- HJ_BUILD_HASHTABLE
- HJ_NEED_NEW_OUTER
- HJ_SCAN_BUCKET
- HJ_FILL_OUTER_TUPLE
- HJ_FILL_INNER_TUPLES
- HJ_NEED_NEW_BATCH