# Join Algorithms II

## Hash Join Algorithms

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Fall 2022

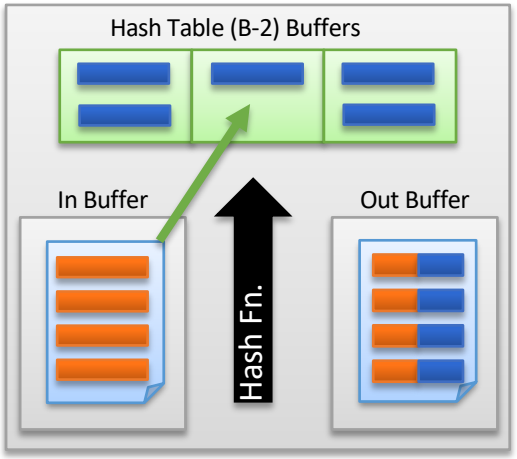
Reading: R & G Chapter 12 & 14

# Naïve in Memory Hash Join: R JOIN S


- Requires equality predicate:
  - Works for Equi-Joins & Natural Joins
- Assume R is smaller relation
  - Require R to fit in memory

- Simple algorithm:
  - Load all R into hash table
  - Scan S and probe R
- Memory requirements?
  - [R] <= (B-2) * hash_fill_factor
- What if R does not fit in memory?

What if R doesn't fit?



# Properties that help


- ```
  SELECT *
  FROM R AS r JOIN S AS s ON r.sid = s.sid
  WHERE r.sid = 4 OR r.sid = 6
  ```

- Is the same as

- ```
  SELECT *
  FROM R AS r JOIN S AS s ON r.sid = s.sid
  WHERE r.sid = 4
  UNION ALL
  SELECT *
  FROM R AS r JOIN S AS s ON r.sid = s.sid
  WHERE r.sid = 6
  ```

- i.e., we can decompose into smaller “partial joins”

# Properties that help


- `SELECT * FROM R AS r JOIN S AS s ON r.sid = s.sid`
- can be partitioned as

- ```
  SELECT *
  FROM R AS r JOIN S AS s ON r.sid = s.sid
  WHERE hash(r.sid) = 1

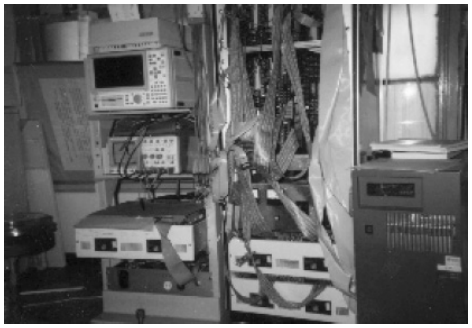
  UNION ALL

  SELECT *
  FROM R AS r JOIN S AS s ON r.sid = s.sid
  WHERE hash(r.sid) = 2

  UNION ALL
  …
  ```

- Just pick a hash function so that each `hash(r.sid)` fits in memory!
  ```

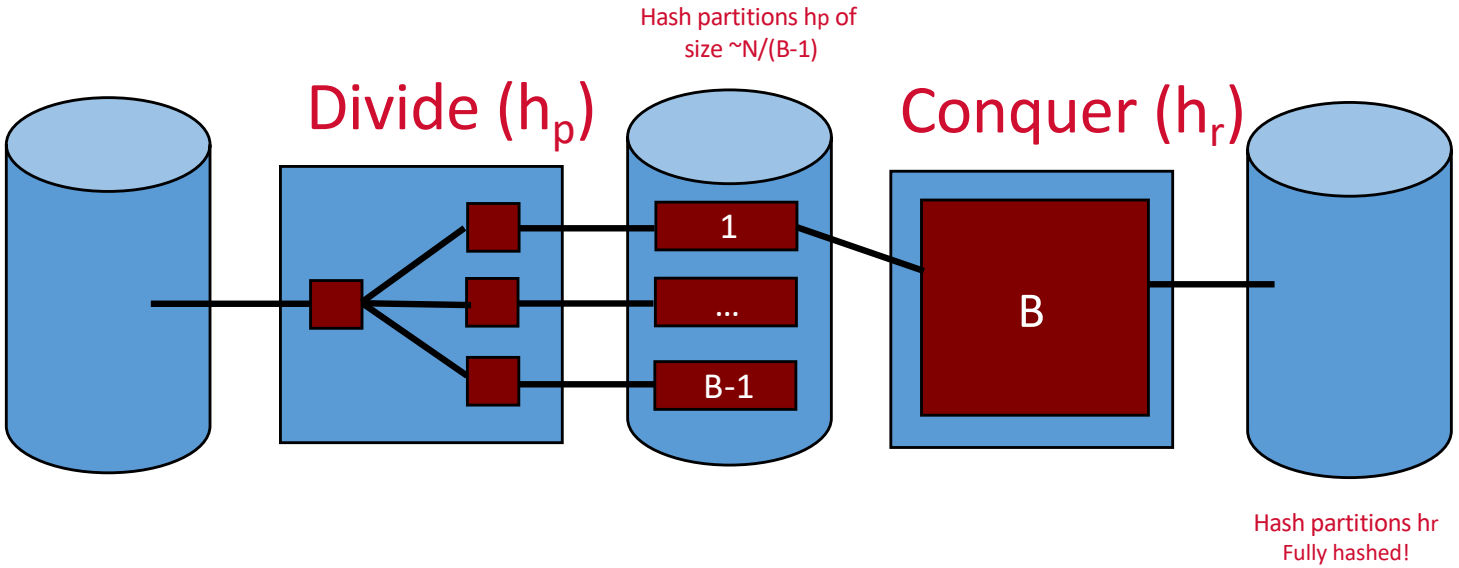
# Grace Hash Join



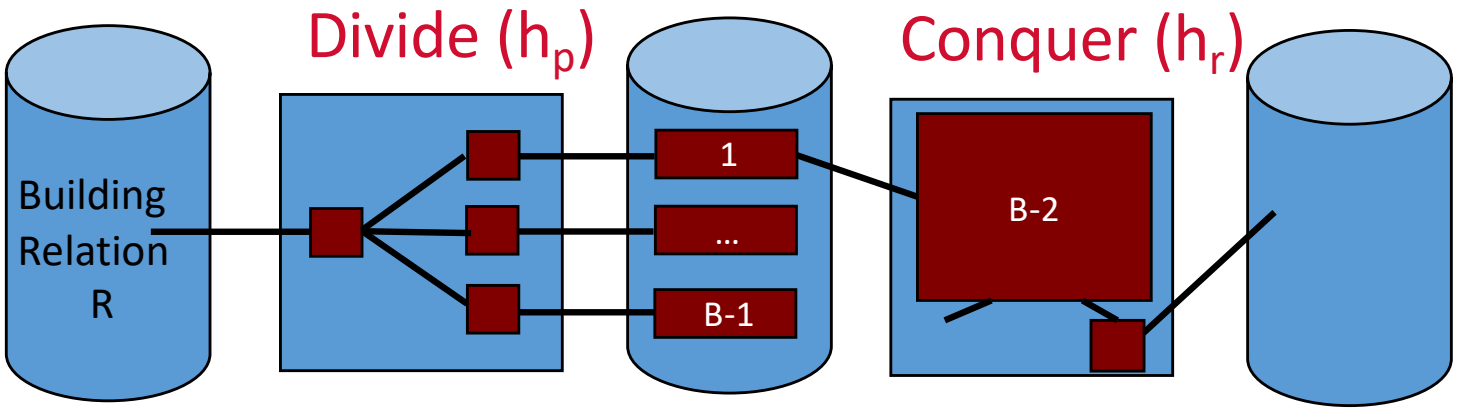
University of Tokyo's GRACE


- Requires equality predicate:
  - Equi-Joins & Natural Joins
- Two Stages:
  - **Partition** tuples from R and S by join key and store on disk
    - all tuples for a given key now reside in same partition
    - same partition might have tuples with different keys but same hash value
  - **Build & Probe** a separate hash table for each partition (like in Naïve Hash)
    - Assume **partition** of smaller relation fits in memory
      - Recurse if necessary…

# Remember External Hashing?

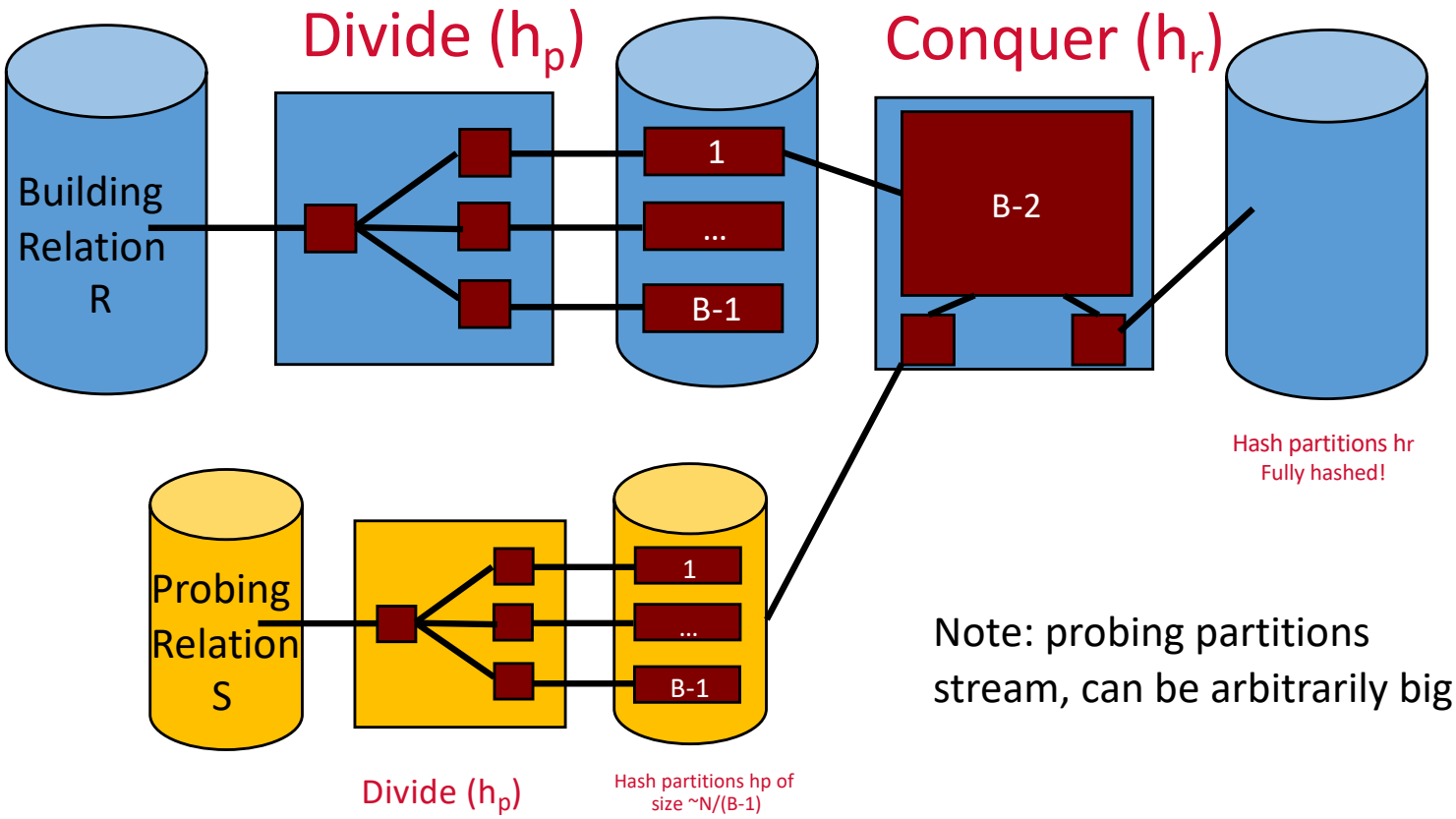


# Sketch of Grace Hash Join




Hash partitions hr
Fully hashed!

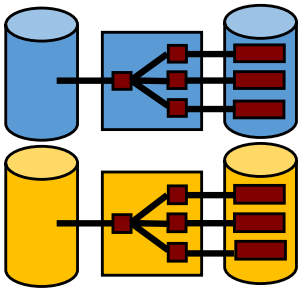
# Sketch of Grace Hash Join, cont.



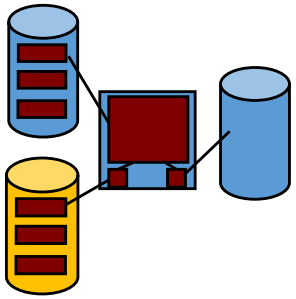

Note: probing partitions stream, can be arbitrarily big!

# PsuedoCode, Grace Hash

```
For Cur in {R, S}
   For page in Cur
      Read page into input buffer
      For tup on page
         Place tup in output buf hash_p(tup.joinkey)
         If output buf full then flush to disk partition
   Flush output bufs to disk partitions
```

# PsuedoCode, Grace Hash, cont.

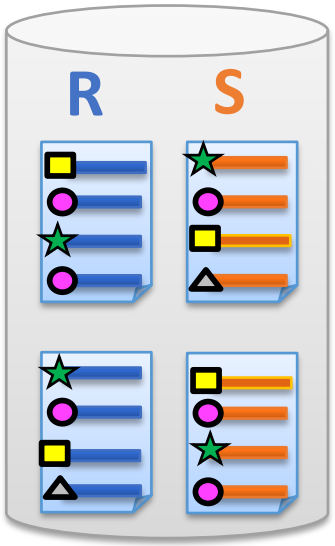



```
For Cur in {R, S}
   For page in Cur
      Read page into input buffer
      For tup on page
         Place tup in output buf hash_p(tup.joinkey)
         If output buf full then flush to disk partition
   Flush output bufs to disk partitions
For i in [0..(B-1))   // for each partition
   For page in R_i
      For tup on page
         Build tup into memory hash_r(tup.joinkey)
   For page in S_i
      Read page into input buffer
      For tup on page
         Probe memory hash_r(tup.joinkey) for matches
         Send all matches to output buffer
         Flush output buffer if full
```

# Grace Hash Join


- An animation
- Two phases:
  - Partition (divide)
  - Build & Probe hash tables (conquer)

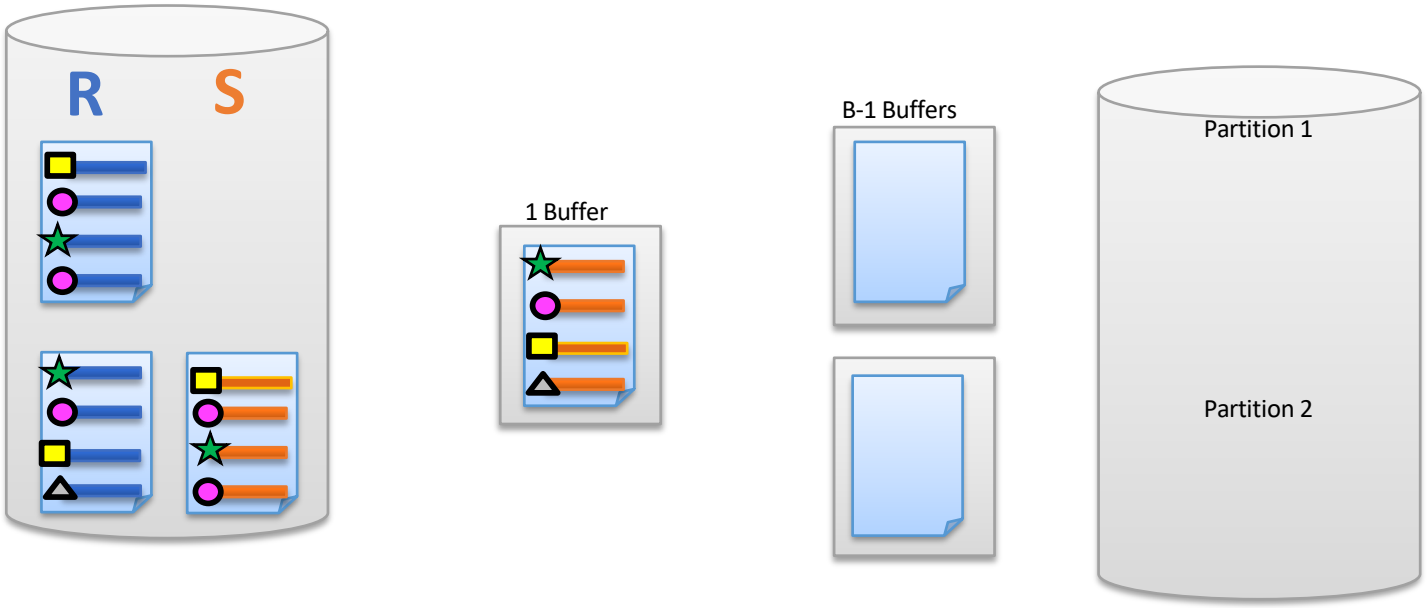
# Grace Hash Join: ***Partition***



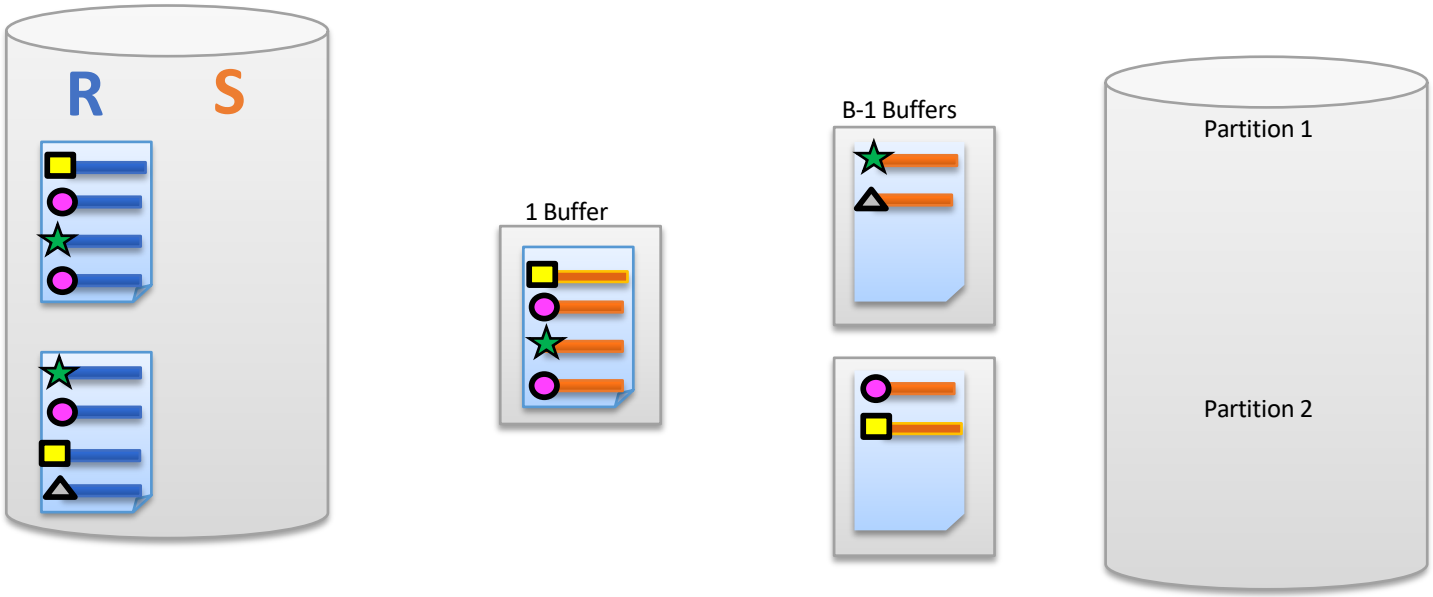




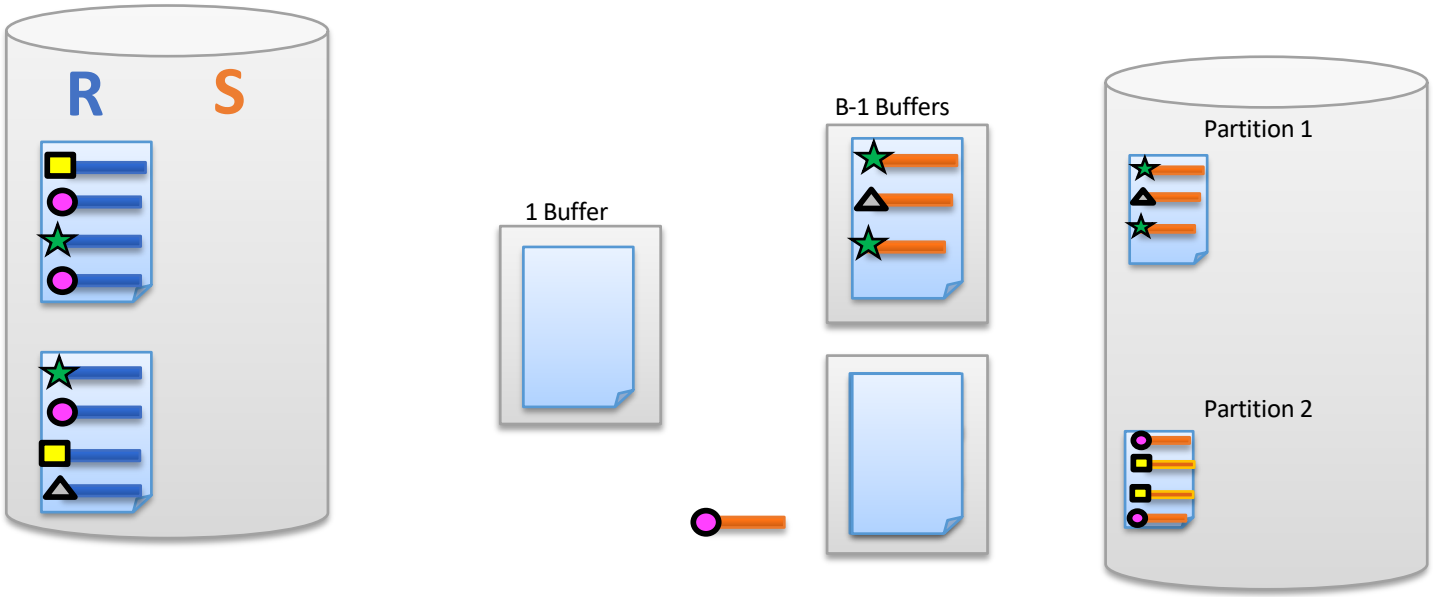
# Grace Hash Join: ***Partition Part 2***



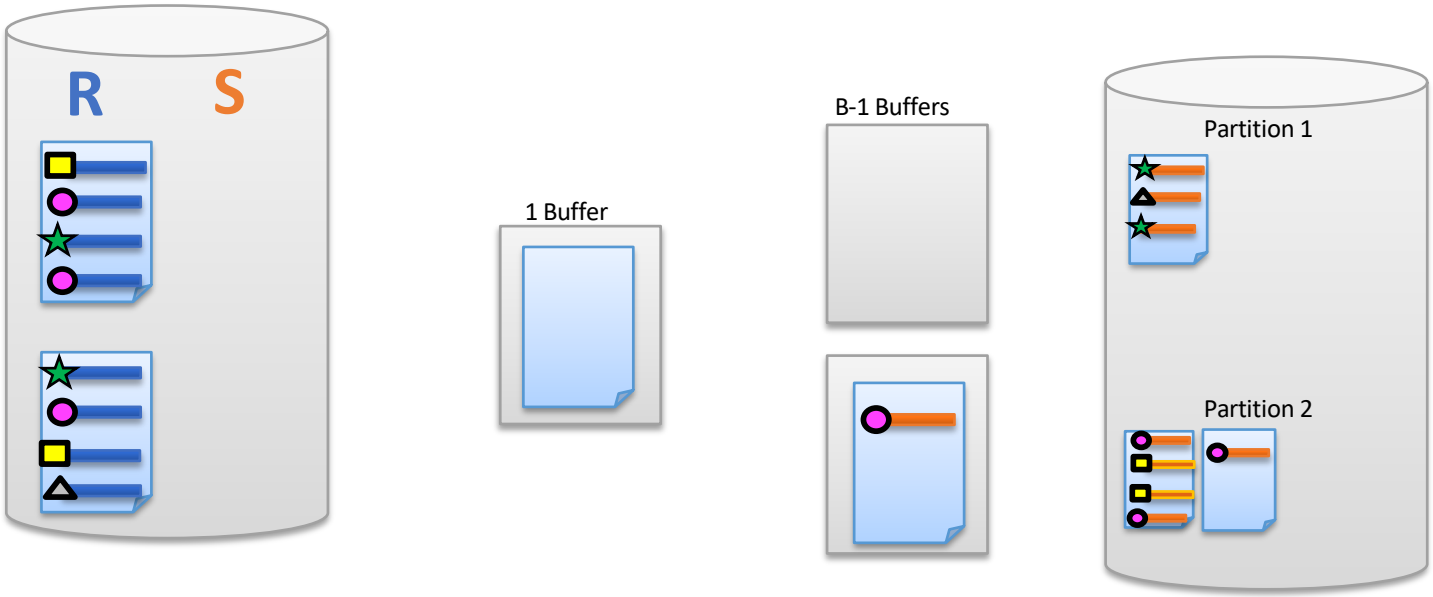
# Grace Hash Join: ***Partition Part 3***



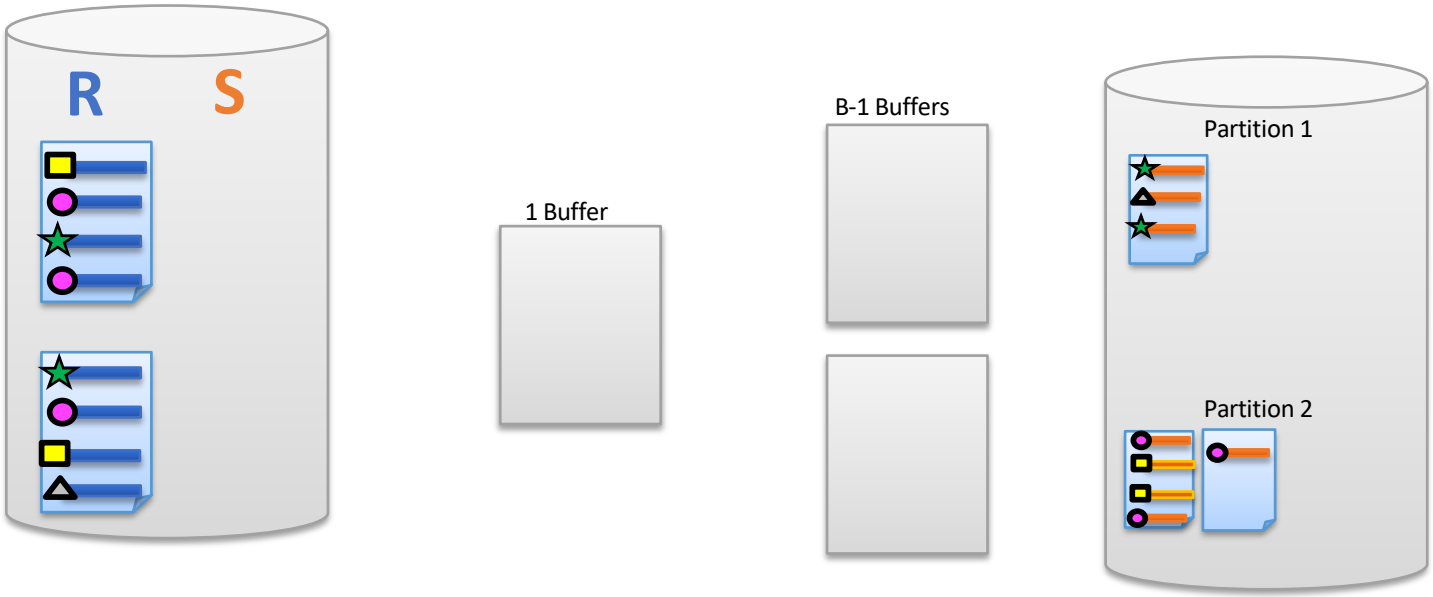
# Grace Hash Join: ***Partition Part 4***



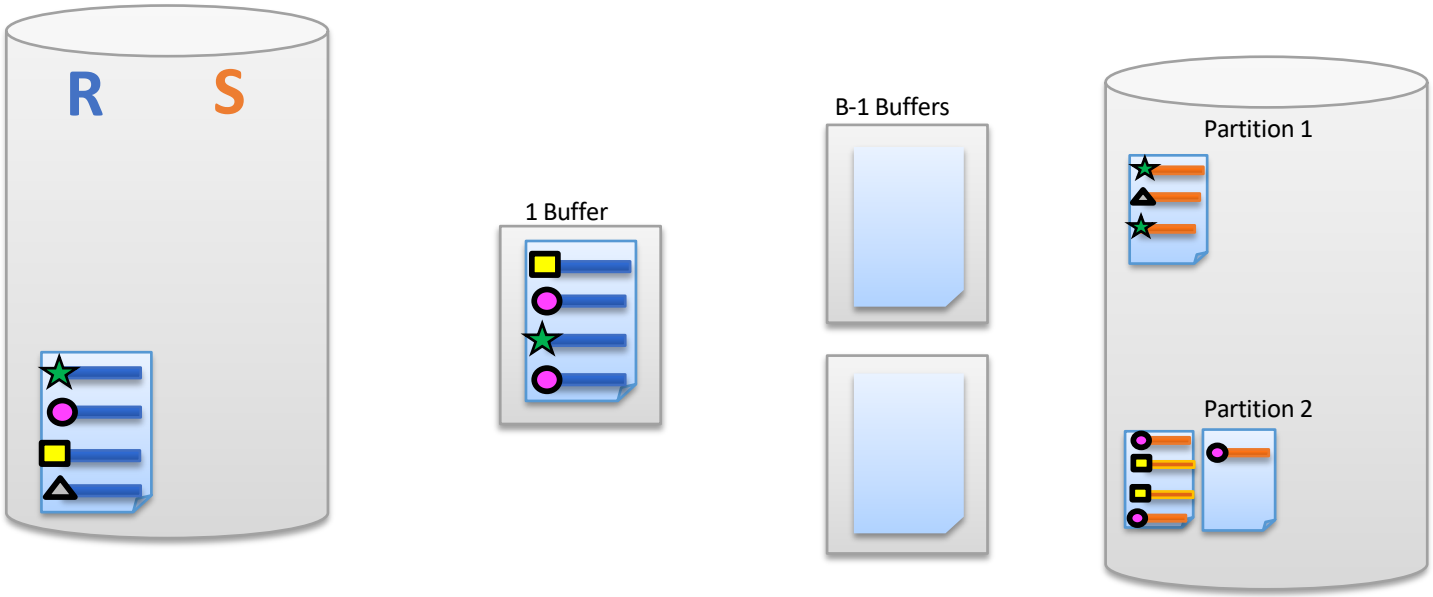
# Grace Hash Join: ***Partition Part 5***



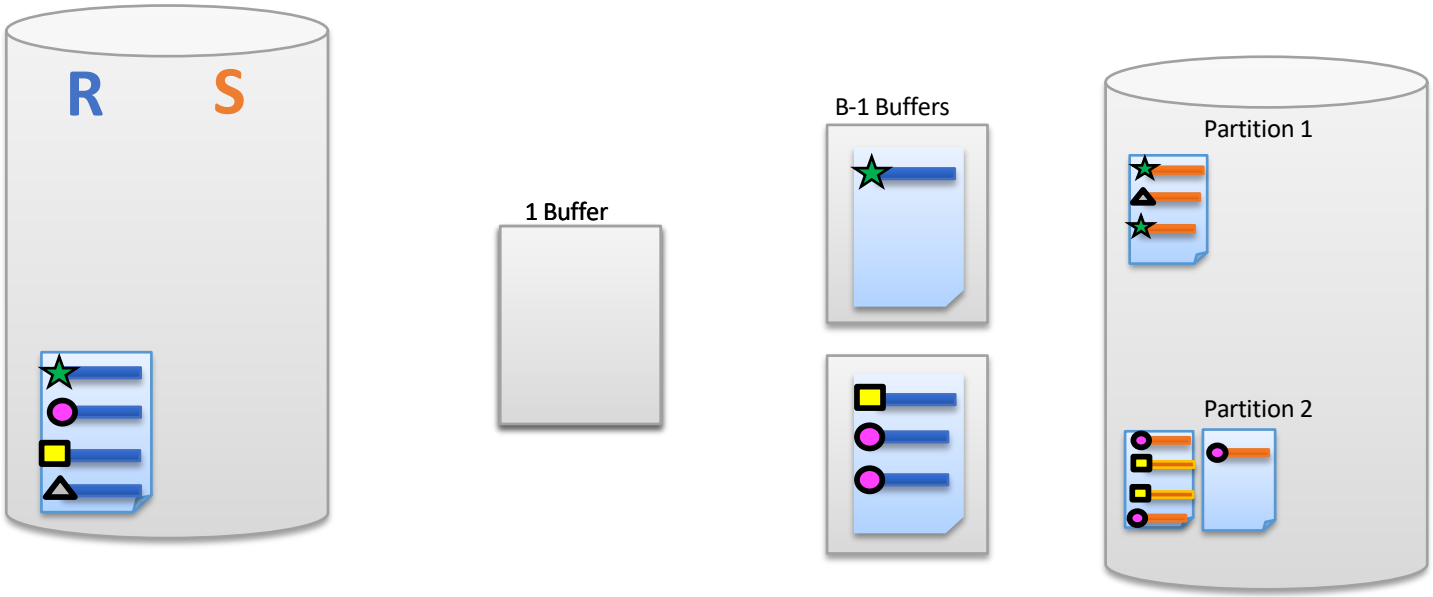
# Grace Hash Join: ***Partition Part 6***



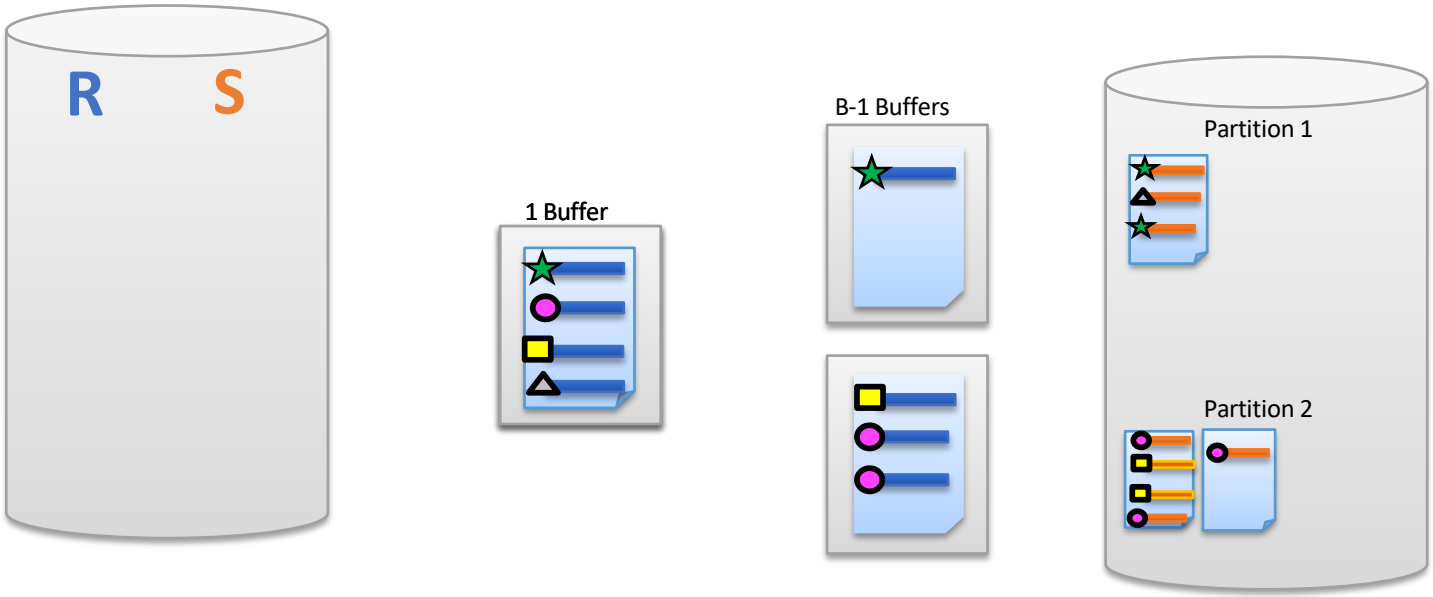
# Grace Hash Join: ***Partition Part 7***



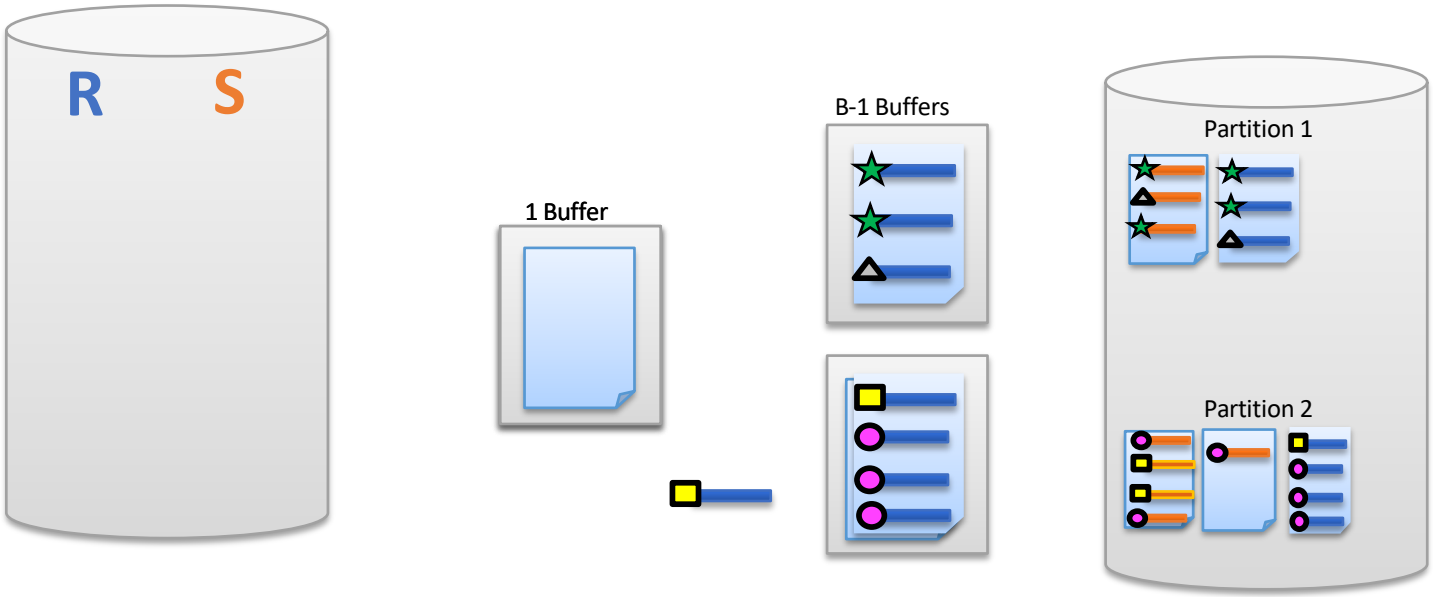
# Grace Hash Join: ***Partition Part 8***



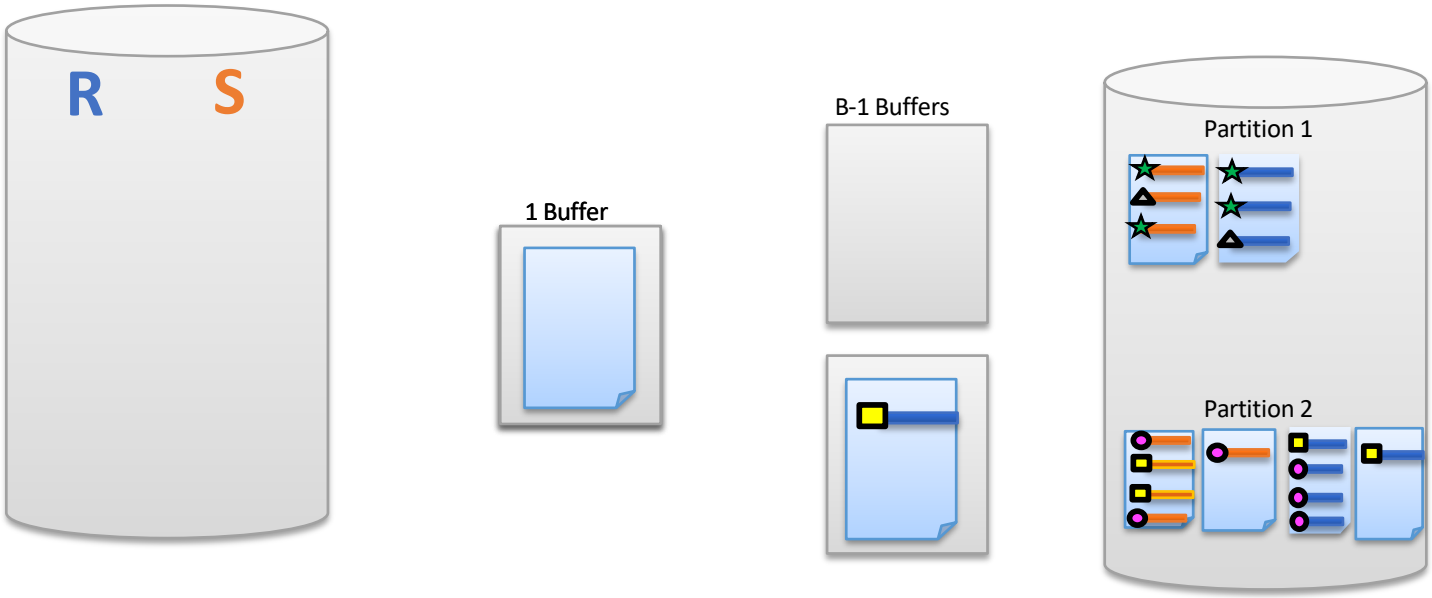

# Grace Hash Join: ***Partition 9***



# Grace Hash Join: ***Partition Part 10***

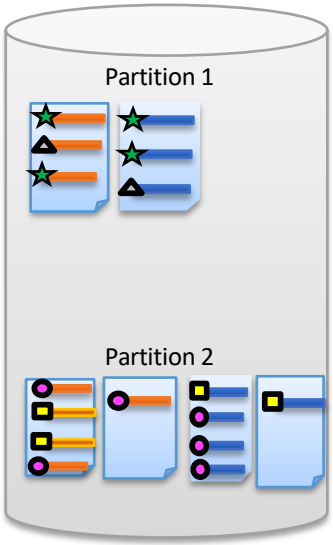


# Grace Hash Join: ***Partition Part 11***

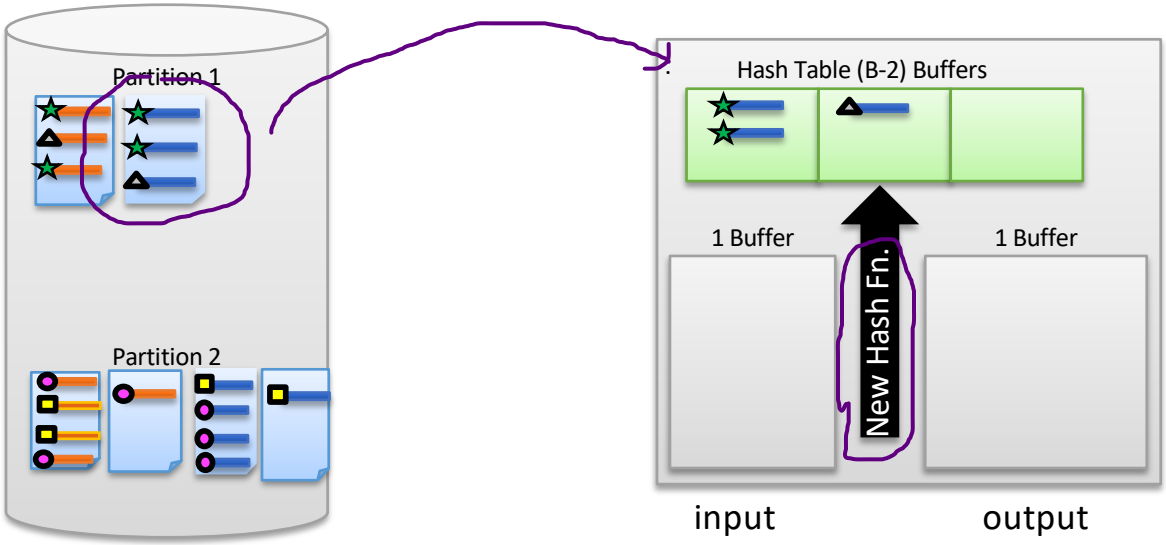


# Grace Hash Join: ***Partition Part 12***


- Each key is assigned to one partition
  - e.g., green star keys only in Partition 1
- Sensitive to key Skew
  - Purple circle key
- Each partition could be on a different disk or even different machine



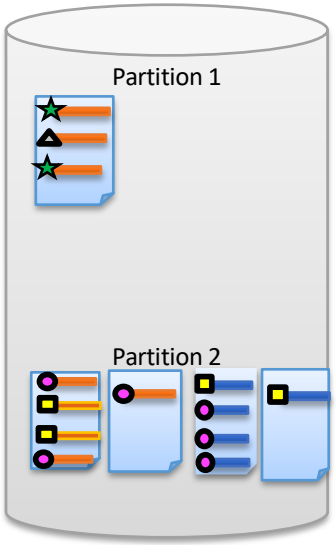
# Grace Hash Join: ***Build*** **&** *Probe*

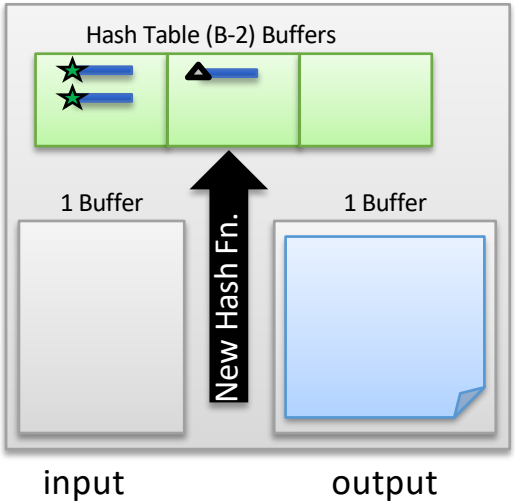




Blue tuples are from R

Orange tuples are from S

# Grace Hash Join: *Build* **& *Probe Part 2***

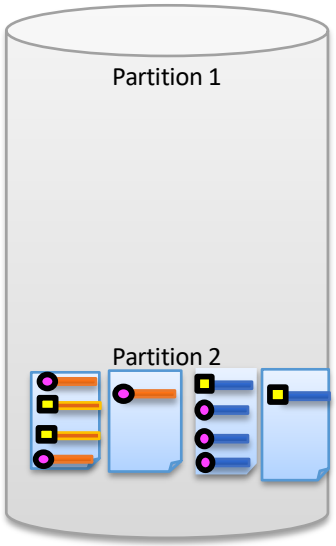



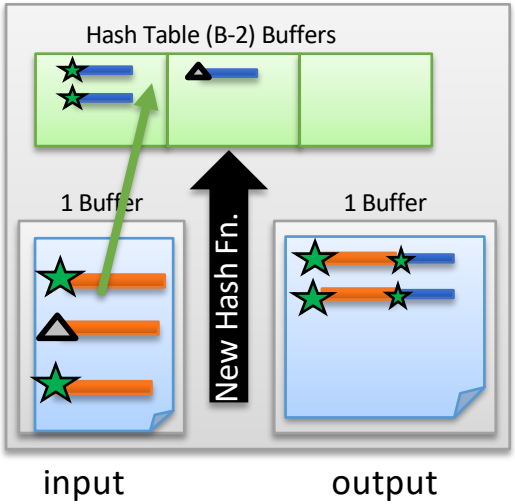




Blue tuples are from R

Orange tuples are from S

# Grace Hash Join: *Build* **& *Probe Part 3***

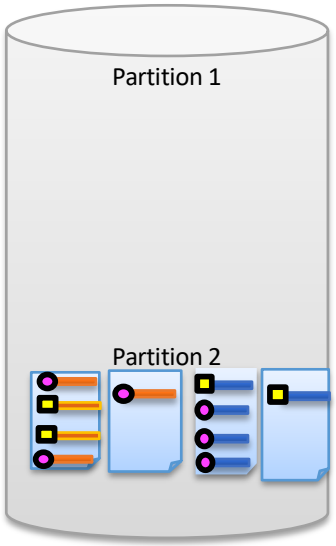



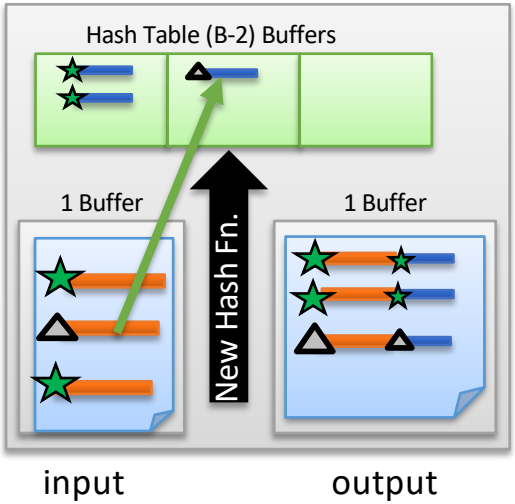




Blue tuples are from R

Orange tuples are from S

# Grace Hash Join: *Build* **& *Probe Part 4***

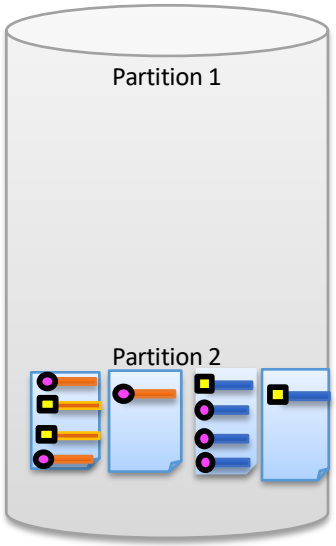



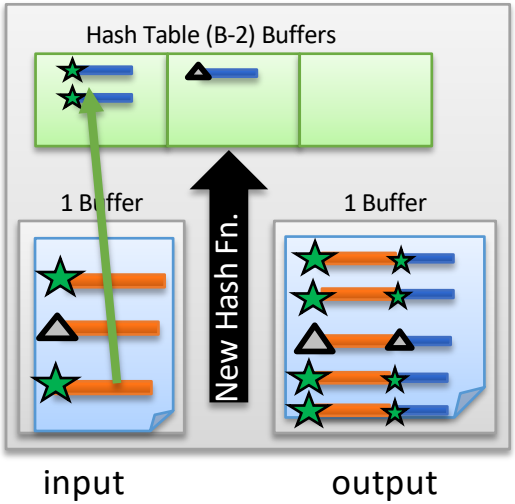




Blue tuples are from R

Orange tuples are from S

# Grace Hash Join: *Build* **& *Probe Part 5***

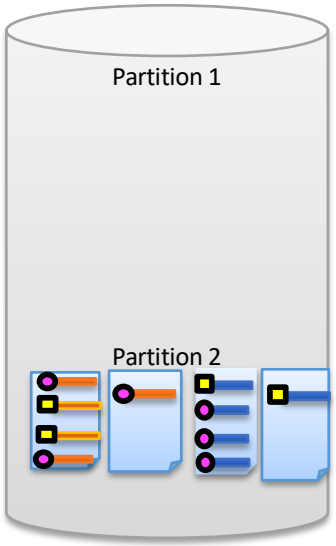



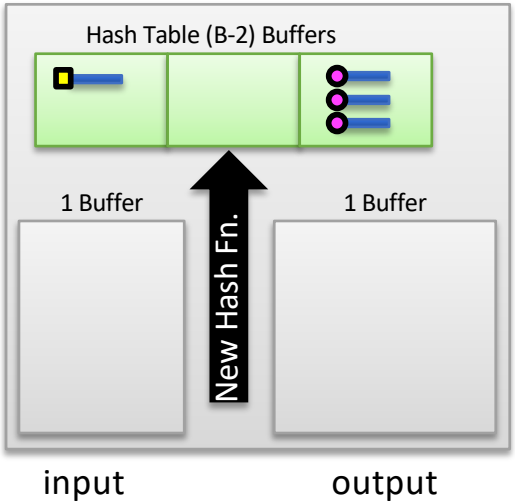




Blue tuples are from R

Orange tuples are from S

# Grace Hash Join: ***Build*** *& Probe Part 6*

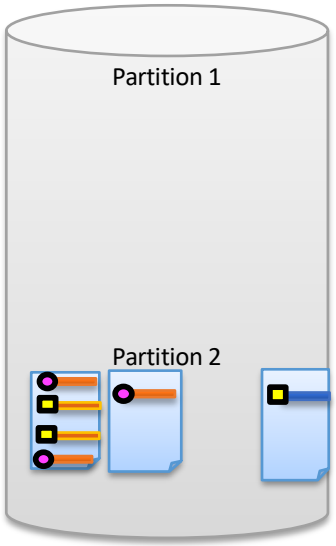


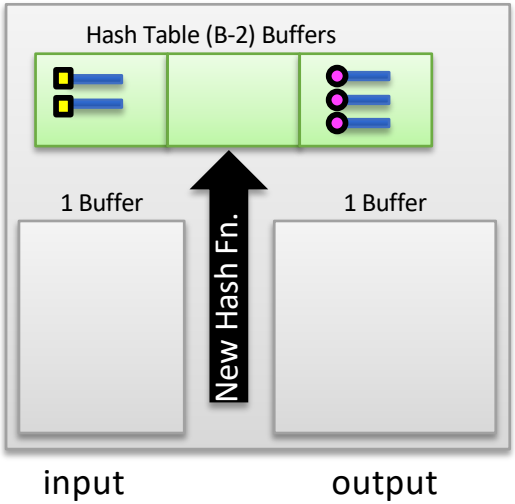




Blue tuples are from R

Orange tuples are from S

# Grace Hash Join: ***Build*** *& Probe Part 7*

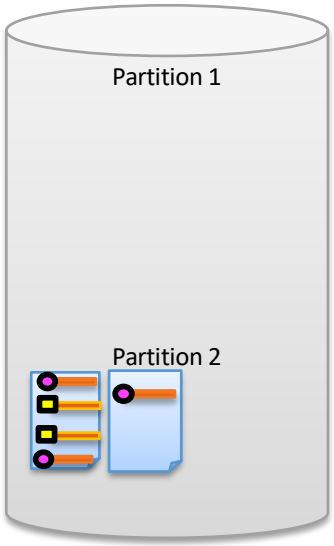



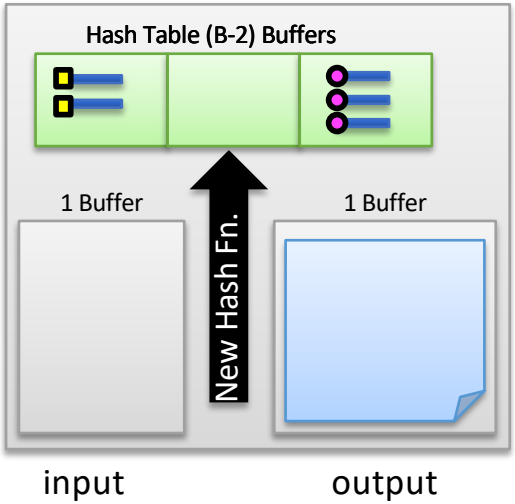




Blue tuples are from R

Orange tuples are from S

# Grace Hash Join: *Build* **& *Probe Part 8***

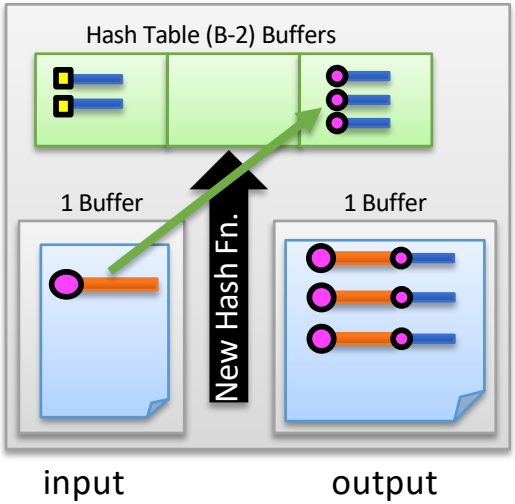




Blue tuples are from R

Orange tuples are from S

# Grace Hash Join: *Build* **& *Probe Part 9***



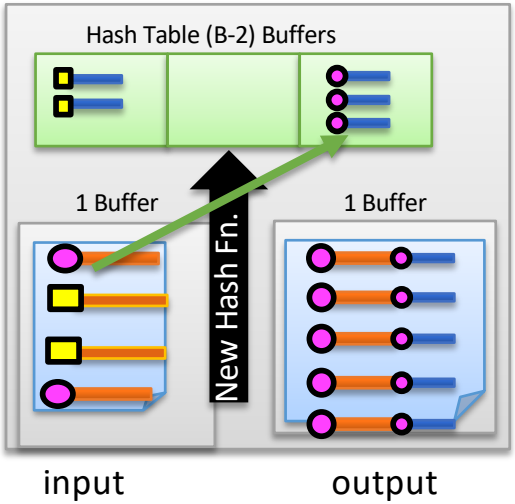



Blue tuples are from R

Orange tuples are from S

# Grace Hash Join: *Build* **& *Probe Part 10***



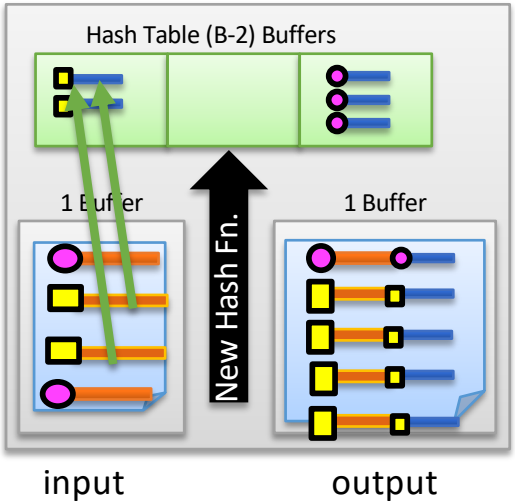



Blue tuples are from R

Orange tuples are from S

# Grace Hash Join: *Build* **& *Probe Part 11***



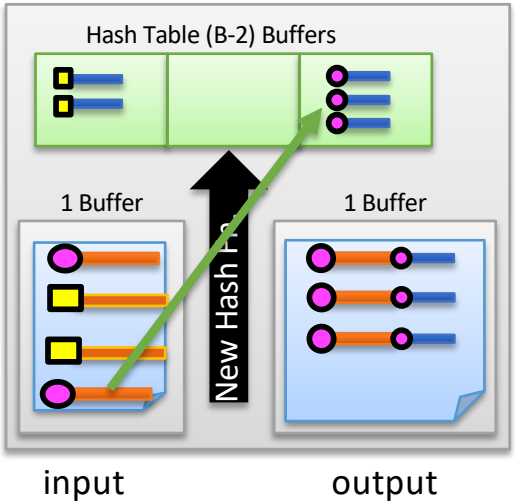



Blue tuples are from R

Orange tuples are from S

# Grace Hash Join: *Build* **& *Probe Part 12***

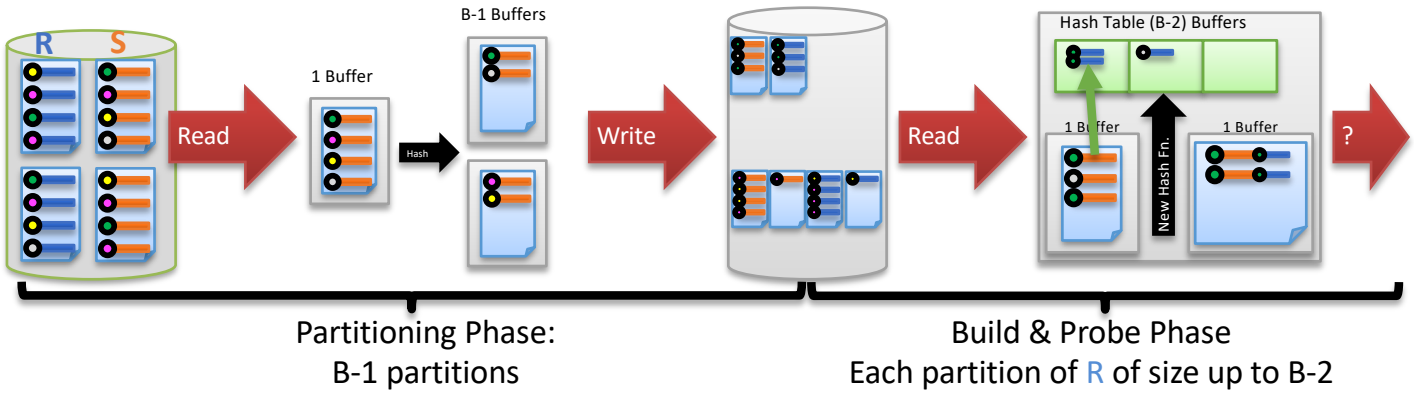





Blue tuples are from R

Orange tuples are from S

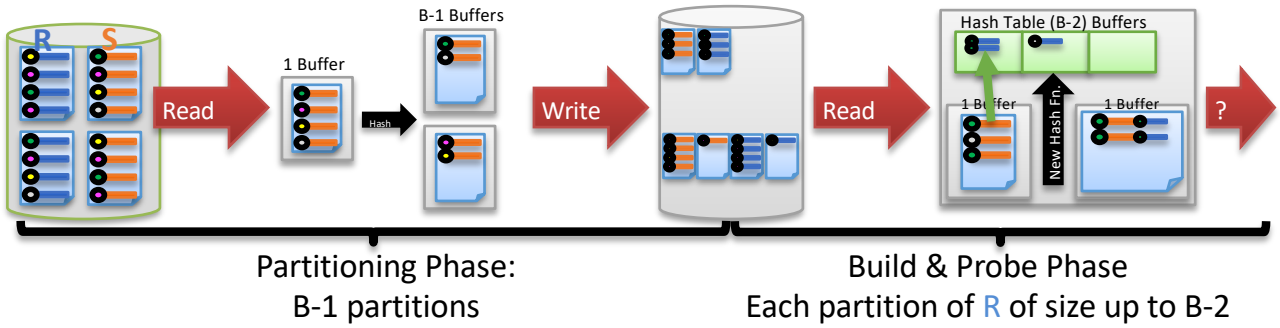
# Summary of Grace Hash Join




# What is the cost?

# Cost of Hash Join

[R]=1000, $p_R$=100, |R| = 100,000
[S]=500, $p_S$=80, |S| = 40,000

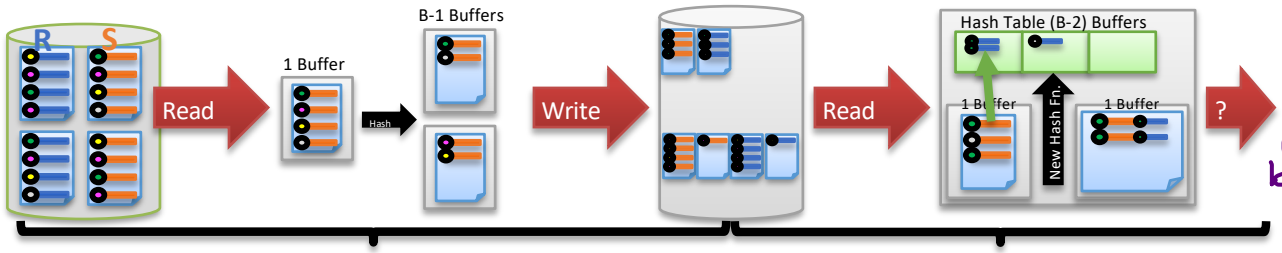



- Partitioning phase: read+write both relations
  ⇒ 2([R]+[S]) I/Os
- Matching phase: read both relations, forward output
  ⇒ [R]+[S]
- Total cost of 2-pass hash join = 3([R]+[S])
  - 3 * (1000 + 500) = 4500

No final write! We aren't actually writing into disk

# Cost of Hash Join Part 2

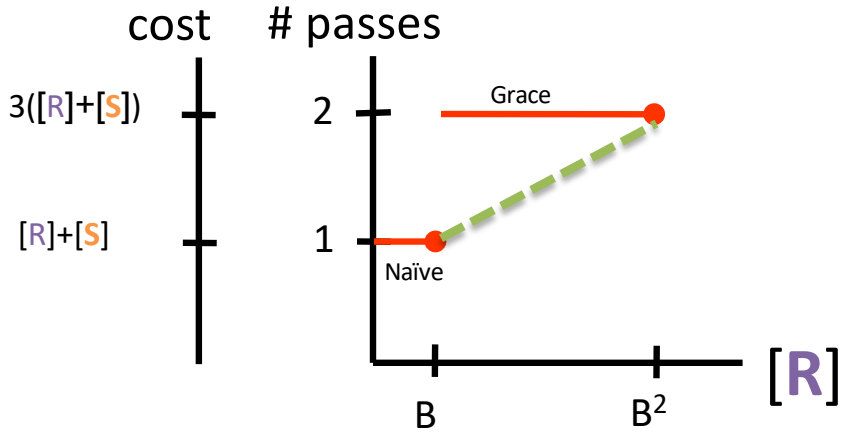
[R]=1000, $p_R$=100, |R| = 100,000
[S]=500, $p_S$=80, |S| = 40,000



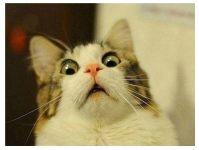

- **What's the max size of R that can be processed in 1 pass of build & probe?**
- Build hash table on **R** with uniform partitioning
  - **Partitioning Phase divides R into (B-1) runs of size [R] / (B-1)**
  - **Matching Phase requires each ([R] / (B-1)) <= (B-2)**
  - **Solving backwards gives R <= (B-1) (B-2) ≈ $B^2$**
- Note: no constraint on size of S (probing relation)!

# Cost of Hash Join Part 3

[R]=1000, $p_R$=100, |R| = 100,000
[S]=500, $p_S$=80, |S| = 40,000


- **Naïve Hash Join: *requires* [R] < B**
  - Put all of **R** in hash table
  - 1/3 the I/O cost of Grace!
- **Grace** Hash Join: 2-passes for [R] **< $B^2$**
- **Hybrid** Hash Join: an algorithm that adapts between the two
  - Tricky to tune



**TINSTAFL!!**

# Hash Join vs. Sort-Merge Join


- Sorting pros:
  - Good if input already sorted, or need output sorted
  - Not sensitive to data skew or bad hash functions
- Hashing pros:
  - For join: # passes depends on size of smaller relation
    - E.g. if smaller relation is < B, naïve/hybrid hashing is great
  - Good if input already hashed, or need output hashed

# Recap


- Nested Loops Join
  - Works for arbitrary Θ
  - Make sure to utilize memory in blocks
- Index Nested Loops
  - For equi-joins
  - When you already have an index on one side
- Sort/Hash
  - For equi-joins
  - No index required
  - Hash better if one relation is much smaller than other
- No clear winners – may want to implement them all
- Be sure you know the cost model for each
  - We will need it for query optimization!