# CSE 444: Database Internals

Lecture 8

Operator Algorithms (part 2)

# Announcements

- Lab 2 / part 1 due on Friday
- Paper review for master’s due on Wednesday
- Homework 2 due next week on Monday

# Outline

- **Join operator algorithms**
  – One-pass algorithms (Sec. 15.2 and 15.3)
  – Index-based algorithms (Sec 15.6)
  – Two-pass algorithms (Sec 15.4 and 15.5)

# Index Based Selection

Selection on equality: $\sigma_{a=v}(R)$

- B(R)= size of R in blocks
- T(R) = number of tuples in R
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Note: we ignore I/O cost for index pages

# Index Based Selection

- Example:

  B(R) = 2000
  T(R) = 100,000
  V(R, a) = 20

  cost of $\sigma_{a=v}(R) = ?$

- Table scan:
- Index based selection:

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Lesson: Don't build unclustered indexes when V(R,a) is small !

# Index Nested Loop Join

$R \bowtie S$

- Assume S has an index on the join attribute
- Iterate over R, for each tuple fetch corresponding tuple(s) from S

- Cost:
  - If index on S is clustered: $B(R) + T(R)B(S)/V(S,a)$
  - If index on S is unclustered: $B(R) + T(R)T(S)/V(S,a)$

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  - Index-based algorithms (Sec 15.6)
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# Two-Pass Algorithms

- What if data does not fit in memory?
- Need to process it in multiple passes

- Two key techniques
  - Sorting
  - Hashing

# Basic Terminology

- A run in a sequence is an increasing subsequence

- What are the runs?

  2, 4, 99, 103, 88, 77, 3, 79, 100, 2, 50

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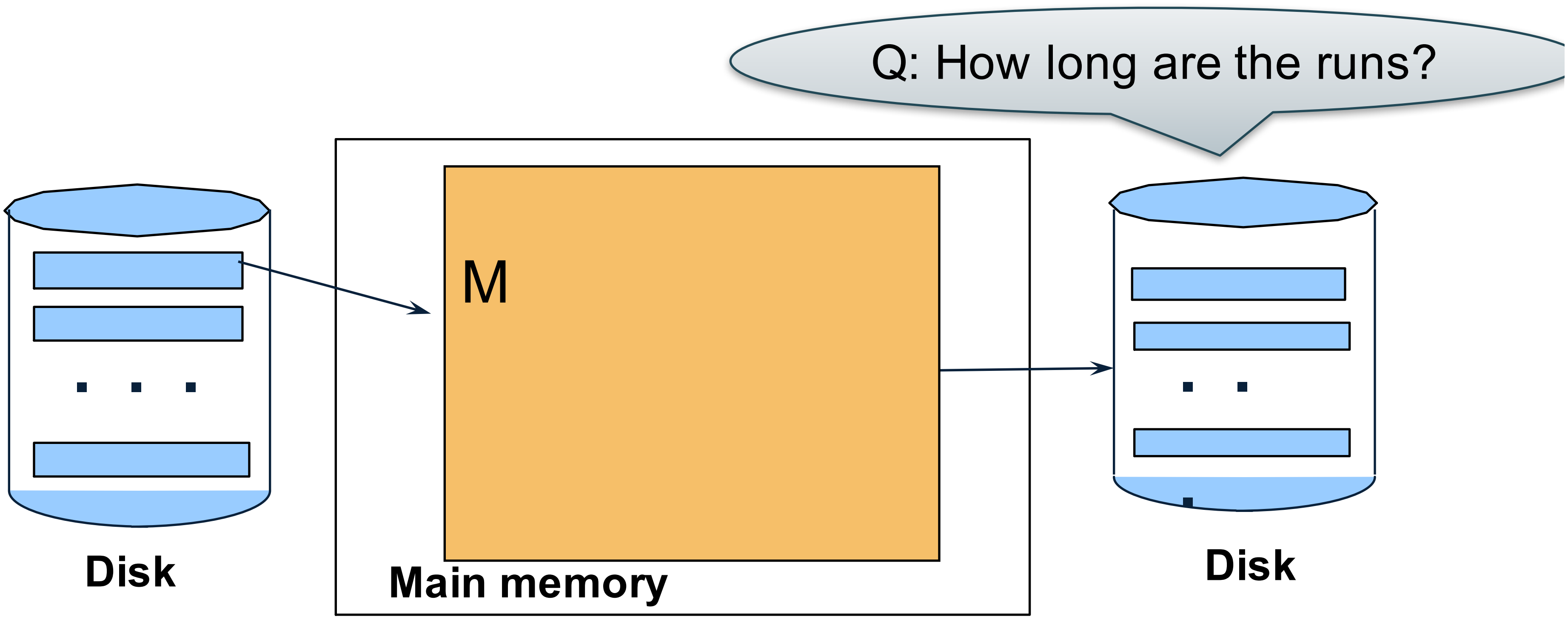

# External Merge-Sort: Step 1

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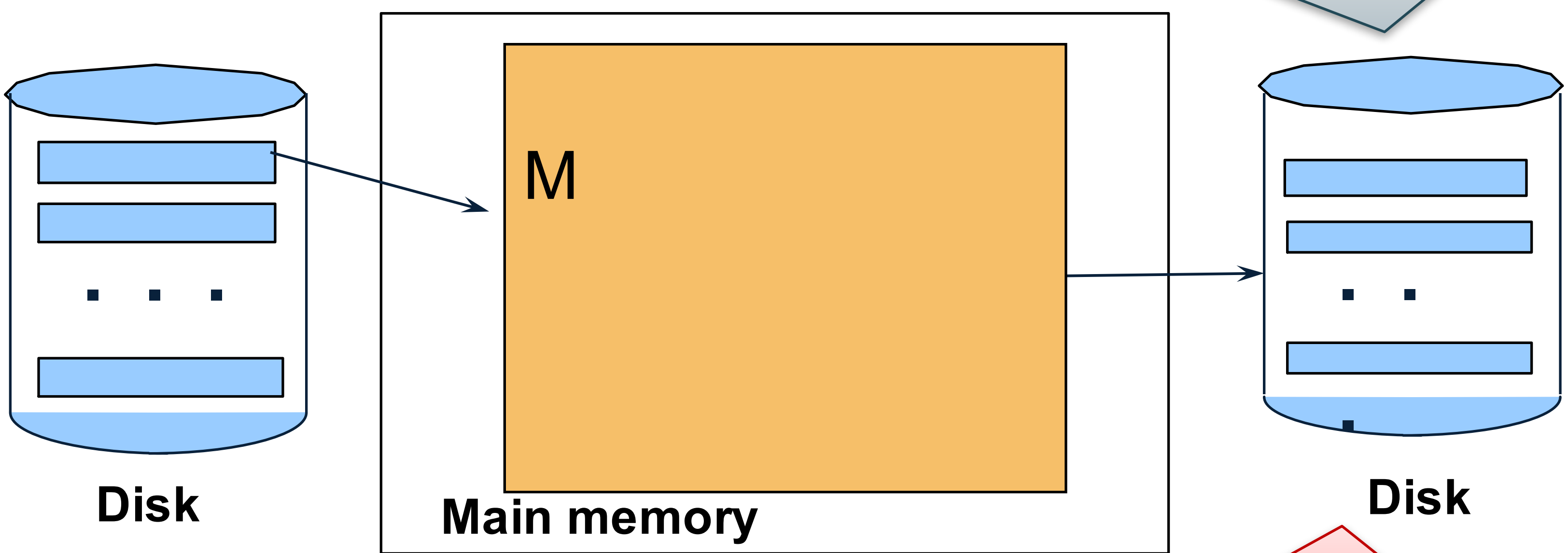
Q: How long are the runs?




A: Length = M blocks

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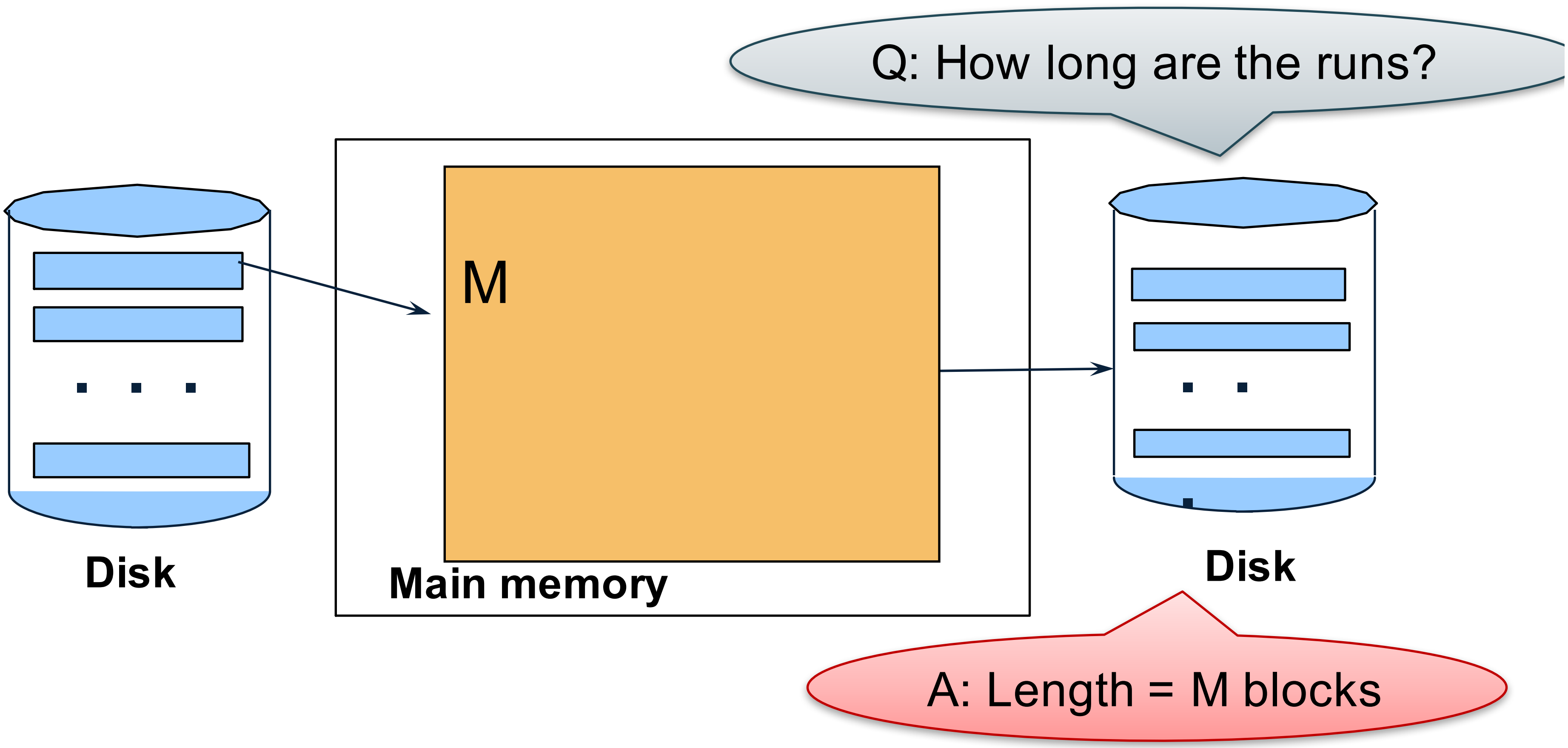
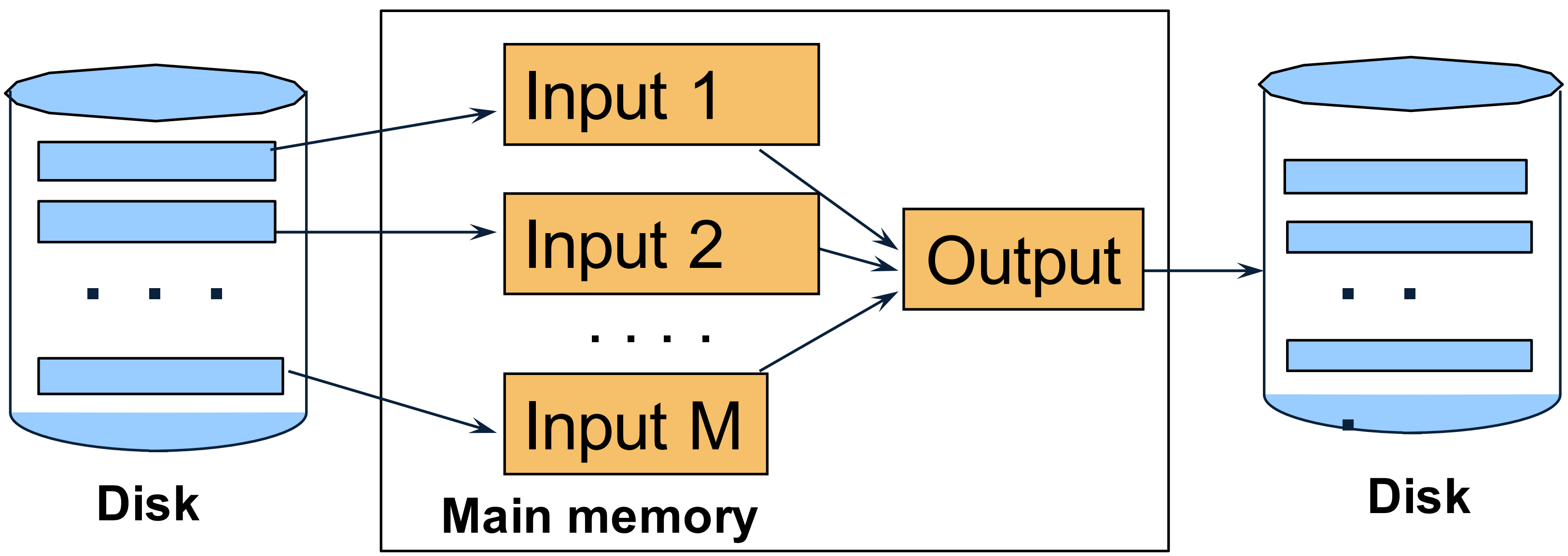



Can increase to length 2M using "replacement selection"

# External Merge-Sort: Step 2

Phase two: merge M runs into a bigger run

- Merge M – 1 runs into a new run
- Result: runs of length M (M – 1) ≈ $M^2$




If B <= $M^2$ then we are done

# Example

- Merging three runs to produce a longer run:

**0, 14, 33, 88, 92, 192, 322**
**2, 4, 7, 43, 78, 103, 523**
**1, 6, 9, 12, 33, 52, 88, 320**

Output:
**0**

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Output:
**0, 1, 2, 4, 6, 7, ?**

# Cost of External Merge Sort

- Read+write+read = 3B(R)
- Assumption: B(R) <= $M^2$

# Discussion

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  - Page size = 32KB
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- R can be as large as $10^{12}$-pages
  - $32 \times 10^{15}$ Bytes = 32 PB

# Merge-Join

Join R $\bowtie$ S

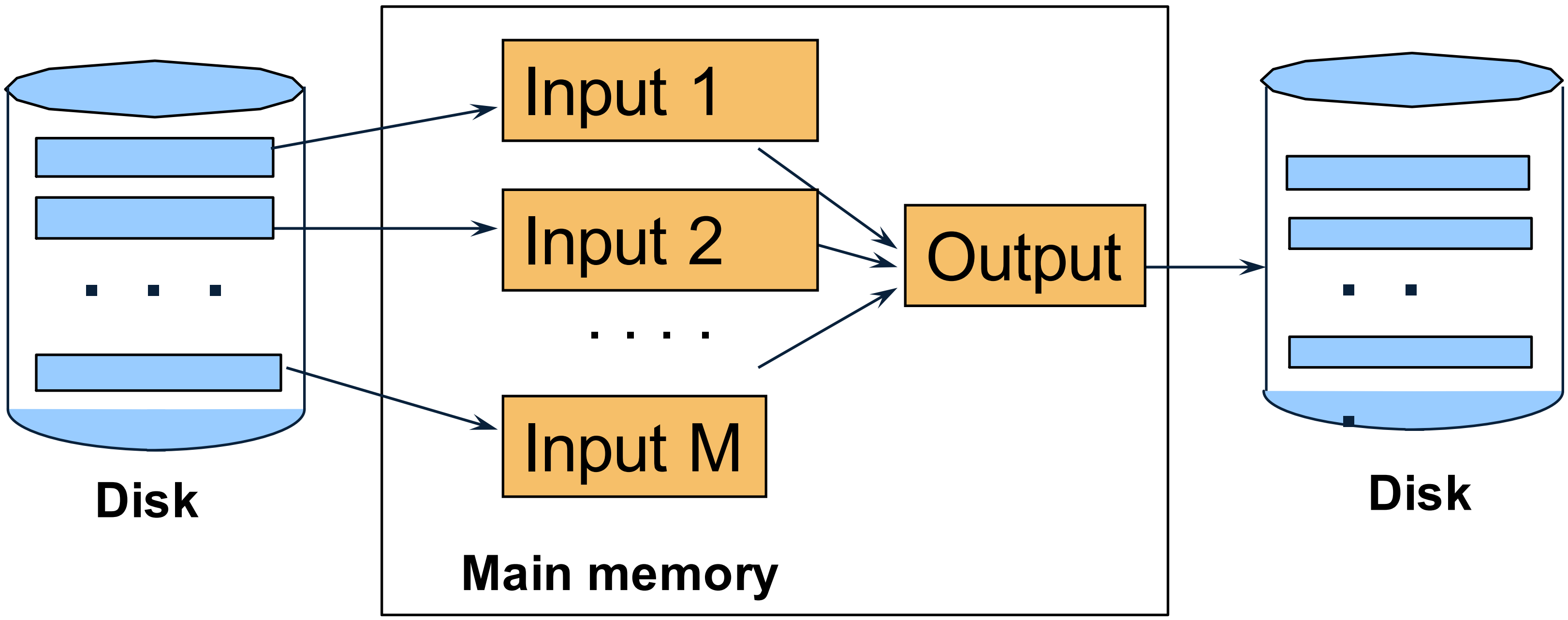
- How?....

# Merge-Join

Join R $\bowtie$ S

- Step 1a: initial runs for R
- Step 1b: initial runs for S
- Step 2: merge and join

# Merge-Join




$M_1 = B(R)/M$ runs for R

$M_2 = B(S)/M$ runs for S

Merge-join $M_1 + M_2$ runs;

need $M_1 + M_2 <= M$

# Partitioned Hash Algorithms

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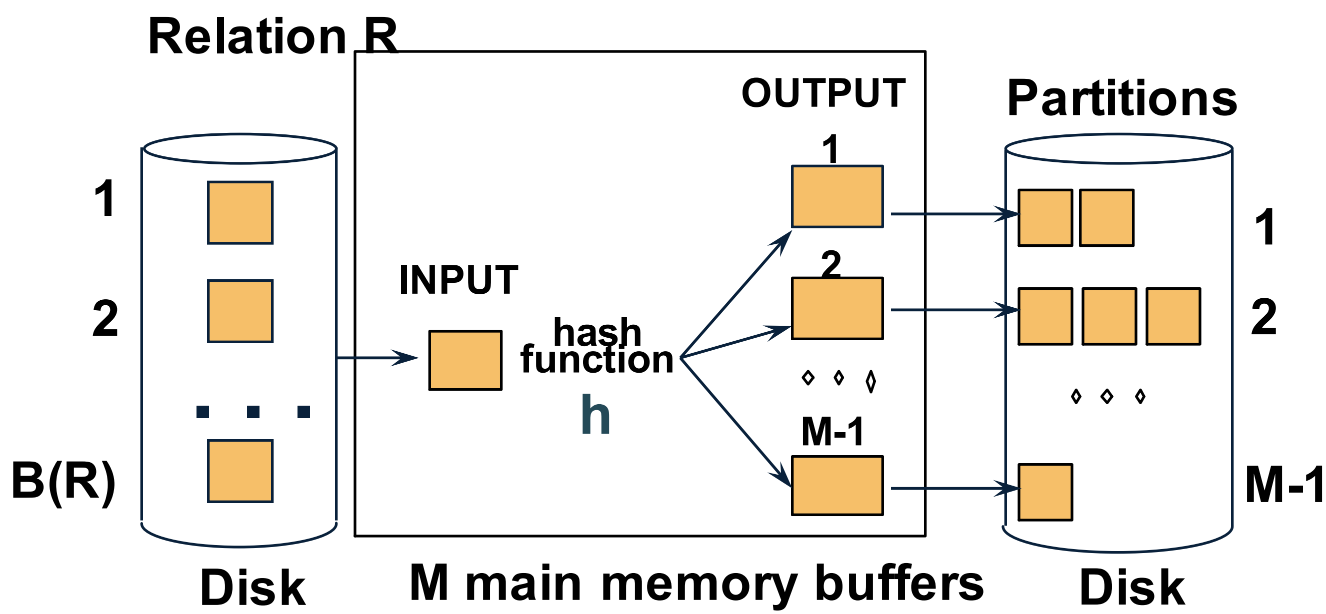
How do we choose k?

# Partitioned Hash Algorithms

- We choose k = M-1 Each bucket has size approx. B(R)/(M-1) ≈ B(R)/M




Assumption: $B(R)/M \leq M$, i.e. $B(R) \leq M^2$

# Grace-Join

$R \bowtie S$

Note: grace-join is also called *partitioned hash-join*

# Grace-Join

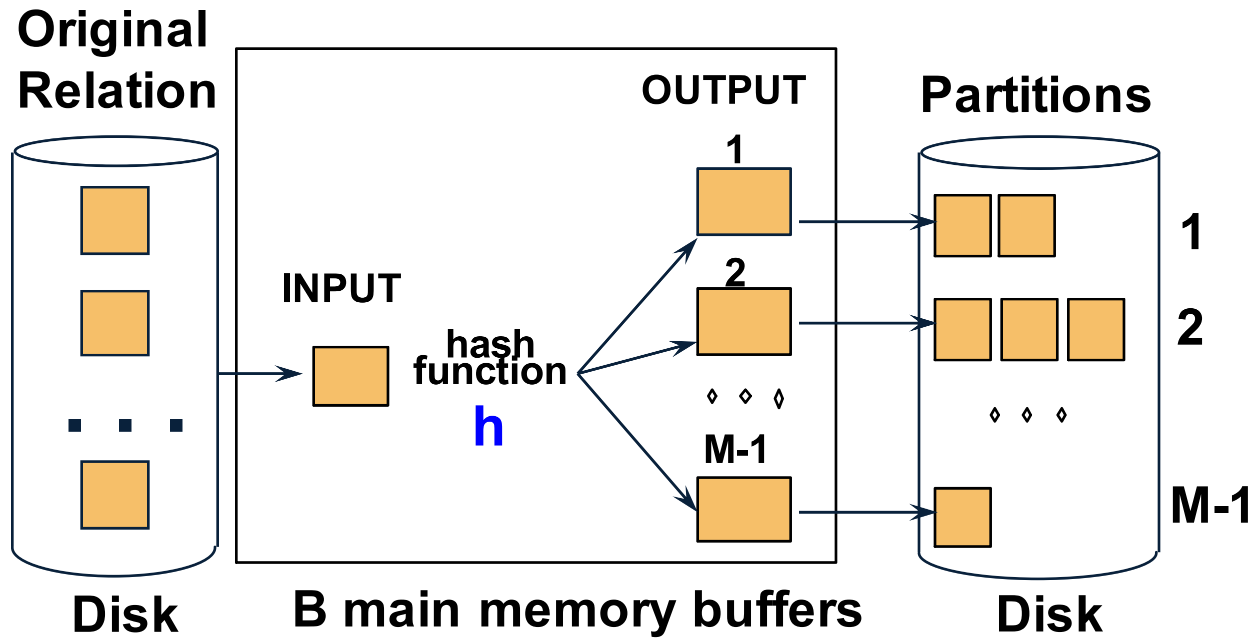
$R \bowtie S$

- Step 1:
  - Hash S into M buckets
  - Send all buckets to disk
- Step 2
  - Hash R into M buckets
  - Send all buckets to disk
- Step 3
  - Join every pair of buckets

Note: grace-join is also called *partitioned hash-join*

# Grace-Join

- Partition both relations using hash fn **h**: R tuples in partition i will only match S tuples in partition i.



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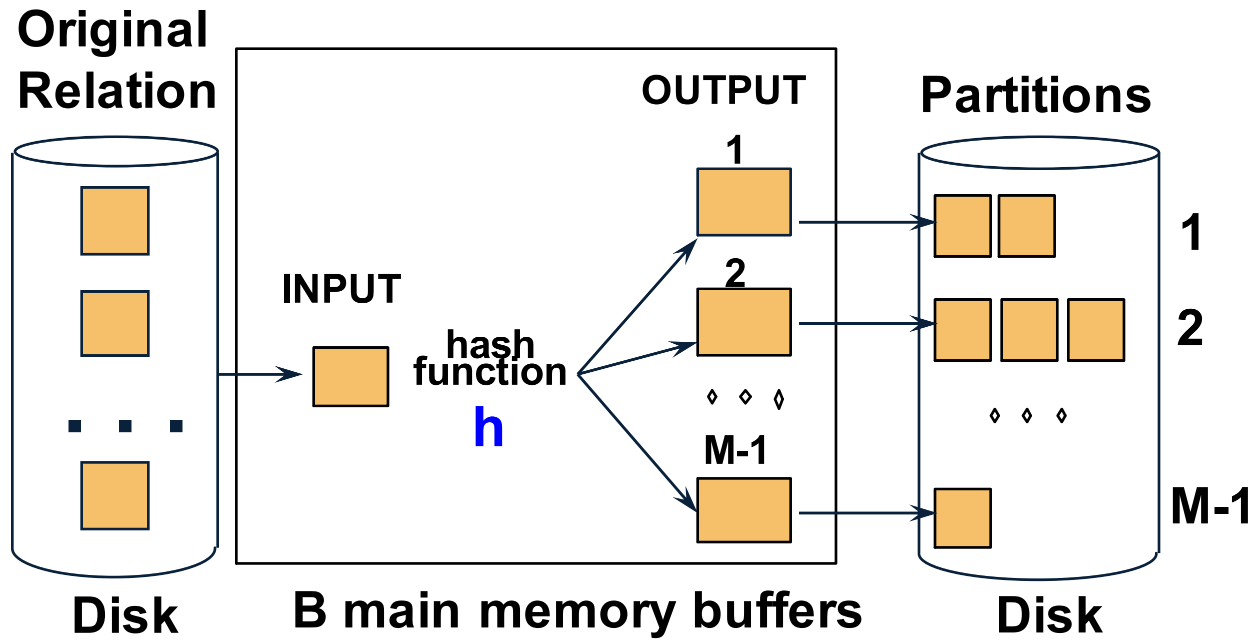
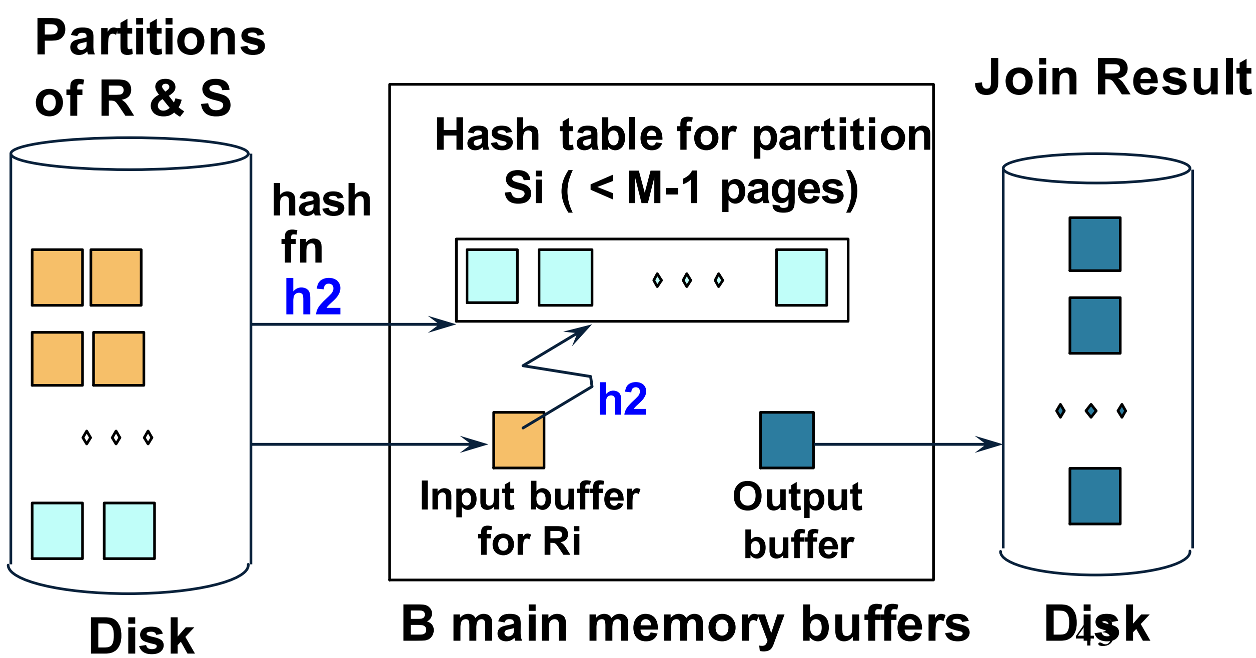



❖ Read in a partition of R, hash it using **h2 (<> h!)**. Scan matching partition of S, search for matches.



# Grace Join

- Cost: 3B(R) + 3B(S)
- Assumption: min(B(R), B(S)) <= $M^2$

# Hybrid Hash Join Algorithm

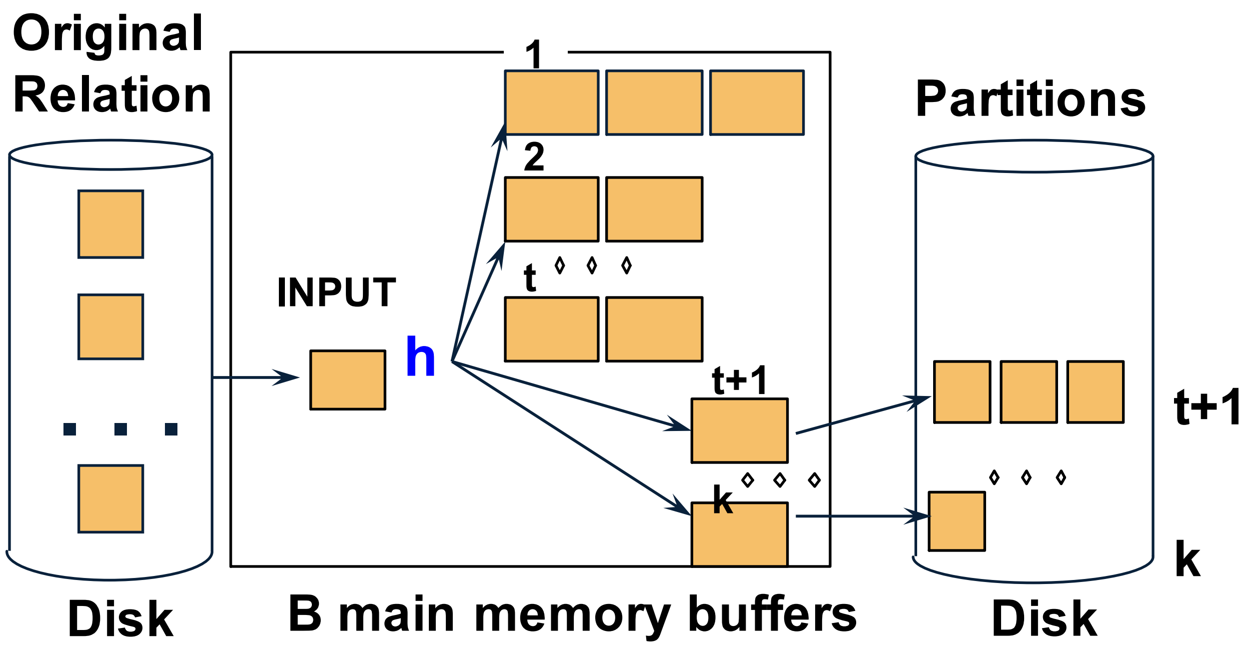
- Partition S into k buckets

  t buckets $S_1$ , …, $S_t$ stay in memory

  k-t buckets $S_{t+1}$, …, $S_k$ to disk
- Partition R into k buckets
  – First t buckets join immediately with S
  – Rest k-t buckets go to disk
- Finally, join k-t pairs of buckets:

  $(R_{t+1},S_{t+1})$, $(R_{t+2},S_{t+2})$, …, $(R_k,S_k)$

# Hybrid Hash Join Algorithm



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  – Choose t/k large but s.t. t/k * B(S) <= M

# Hybrid Join Algorithm

- How to choose k and t?

  – Choose k large but s.t. $k <= M$ (One block/bucket in memory)

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  - Choose k large but s.t. $k <= M$ (One block/bucket in memory)
  - Choose t/k large but s.t. $t/k * B(S) <= M$ (First t buckets in memory)
  - Together: $t/k * B(S) + k-t <= M$

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- Assuming $t/k * B(S) \gg k\text{-}t$: $t/k = M/B(S)$

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  – Choose t/k large but s.t. $t/k * B(S) <= M$

  – Together: $t/k * B(S) + k\text{-}t <= M$

- Assuming $t/k * B(S) >> k\text{-}t$: $t/k = M/B(S)$

Total size of first t buckets

Number of remaining buckets

# Hybrid Join Algorithm

Even better: adjust t dynamically

- Start with t = k:  all buckets are in main memory
- Read blocks from S, insert tuples into buckets
- When out of memory:
  - Send one bucket to disk
  - t := t-1
- Worst case:
  - All buckets are sent to disk (t=0)
  - Hybrid join becomes grace join

# Hybrid Join Algorithm

Cost of Hybrid Join:

- Grace join: $3B(R) + 3B(S)$
- Hybrid join:
  - Saves 2 I/Os for t/k fraction of buckets
  - Saves $2t/k(B(R) + B(S))$ I/Os
  - Cost:
    $(3-2t/k)(B(R) + B(S)) = (3-2M/B(S))(B(R) + B(S))$

# Hybrid Join Algorithm

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# Hybrid Join Algorithm

- What is the advantage of the hybrid algorithm?

It degrades gracefully when S larger than M:

- When B(S) <= M
  - Main memory hash-join has cost B(R) + B(S)
- When B(S) > M
  - Grace-join has cost 3B(R) + 3B(S)
  - Hybrid join has cost (3-2t/k)(B(R) + B(S))

# Summary of External Join Algorithms

- Block Nested Loop: B(S) + B(R)*B(S)/M
- Index Join: B(R) + T(R)B(S)/V(S,a)
- Partitioned Hash: 3B(R)+3B(S);
  – $\min(B(R),B(S)) <= M^2$
- Merge Join: 3B(R)+3B(S)
  – $B(R)+B(S) <= M^2$

# Summary of Query Execution

- For each logical query plan
  - There exist many physical query plans
  - Each plan has a different cost
  - Cost depends on the data
- Additionally, for each query
  - There exist several logical plans
- Next lecture: query optimization
  - How to compute the cost of a complete plan?
  - How to pick a good query plan for a query?