Example R1 $\bowtie$ R2 over common attribute C

T(R1) = 10,000 (Other notation: N_{R1})

T(R2) = 5,000

L(R1) = L(R2) = 1/10 block ($bf_{R1} = 10$)

Memory available = 101 blocks

→ Metric: # of IOs

(ignoring writing of result)

Options

- Transformations: R1 ⋈ R2, R2 ⋈ R1
- Join algorithms:
  - Iteration (nested loops)
  - Merge join
  - Join with index
  - Hash join

Example 1(a) Iteration Join R1 ⋈ R2

- Relations not contiguous (1 row/block)
- Recall : T(R1) = 10,000 T(R2) = 5,000
  L(R1) = L(R2) =1/10 block
  MEM=101 blocks

Cost: for each R1 tuple:

[Read tuple + Read R2]

Total =10,000*[1+5000]=50,010,000 Ios

-> T(R1)*B(R2)+B(R1) (B(R1)=T(R1) and B(R2)=T(R2) now)

- Can we do better?

Use our memory

(1) Read 100 blocks of R1 (M-1 blocks)

(2) Read all of R2 (using 1 block) + join

(3) Repeat until done

Cost: for each R1 chunk:

Read chunk: 100 IOs

Read R2: 5000 IOs

5100

-> B(R1)/(M-1)*B(R2)+B(R1)

Total = $\frac{10{,}000}{100}$ x 5100 = 510,000 IOs

- Can we do better?

☛ Reverse join order: R2 ⋈ R1

Total = $\frac{5000}{100}$ x (100 + 10,000) =

50 x 10,100 = 505,000 IOs

-> B(R2)/(M-1)*B(R1)+B(R2)

Example 1(b) Iteration Join ⋈ R2 R1

- Relations contiguous (10 rows/block)

  Cost

  For each R2 chunk:

  Read chunk: 100 IOs

  Read R1: 1000 IOs

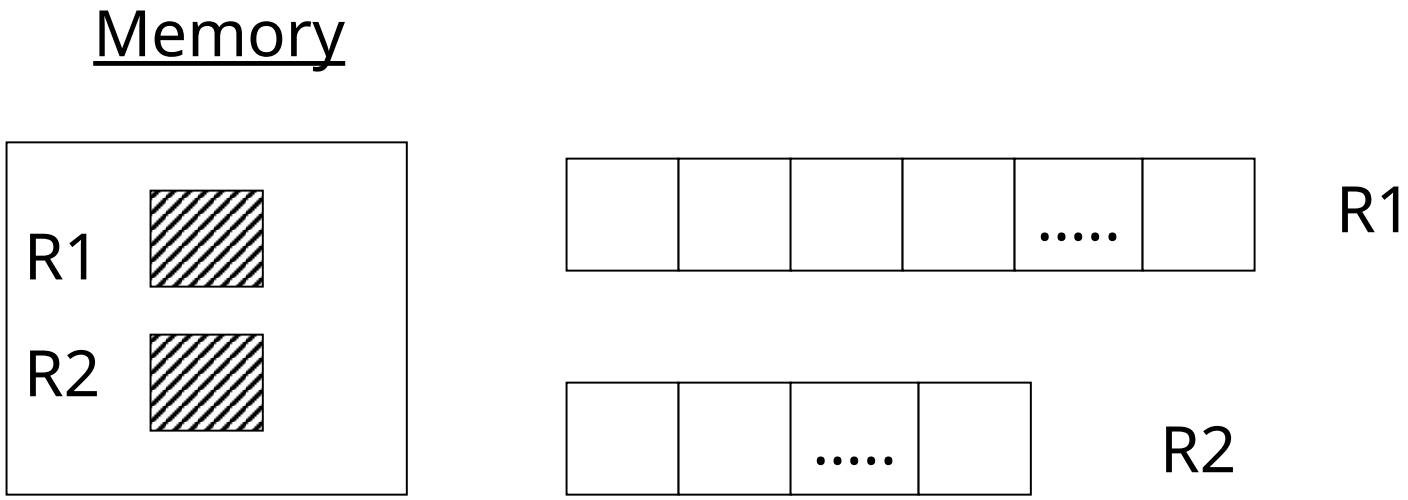
  1100

  Total= 5 chunks x 1100 = 5500 IOs

  -> B(R2)/(M-1)*B(R1)+B(R2)

Example 1(c) Merge Join

- Both R1, R2 ordered by C; relations contiguous



Total cost: Read R1 cost + read R2 cost

= 1000 + 500 = 1,500 IOs

Example 1(d) Merge Join

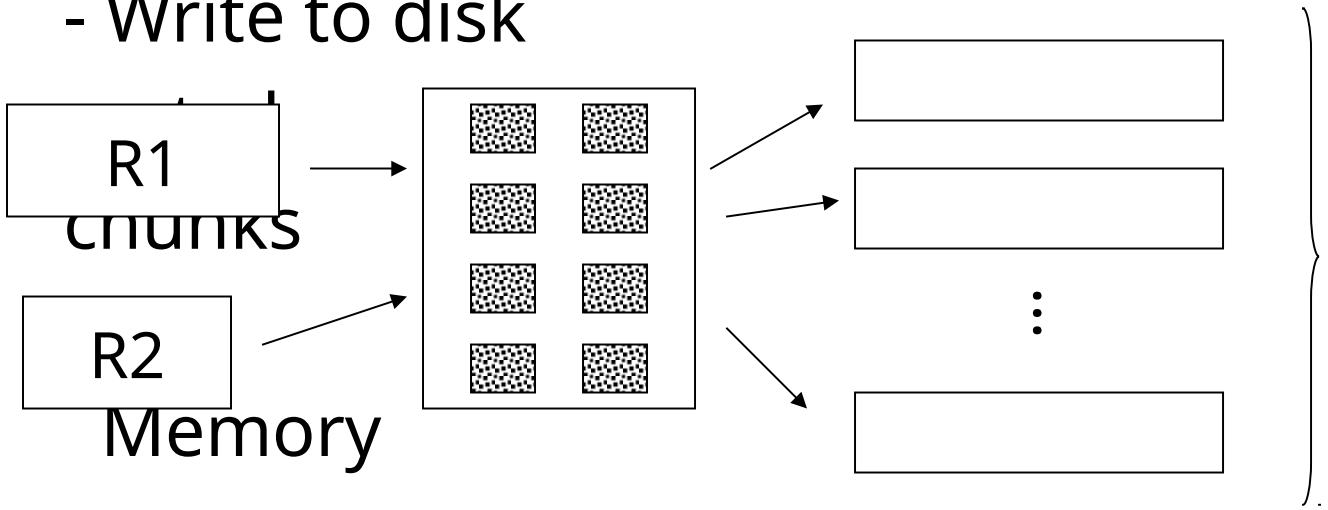
- R1, R2 not ordered, but contiguous

--> Need to sort R1, R2 first.... HOW?

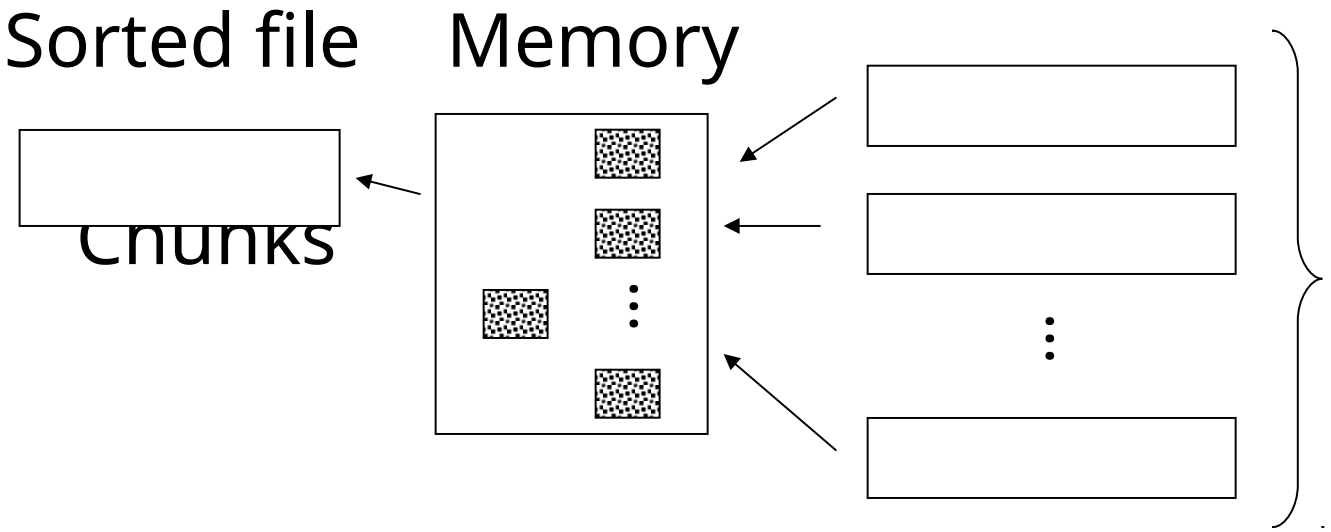
One way to sort: Merge Sort

(i) For each 100 blk chunk of R:

- Read chunk
- Sort in memory
- Write to disk



(ii) Read all chunks + merge + write out



Cost: Sort

Each tuple is read,written,
read, written

so...

Sort cost R1: 4 x 1,000 = 4,000

Sort cost R2: 4 x 500 = 2,000

Example 1(d) Merge Join (continued)

R1,R2 contiguous, but unordered

Total cost = sort cost + join cost

= 6,000 + 1,500 = 7,500 IOs

But: Iteration cost = 5,500

so merge join does not pay off!

But say R1 = 10,000 blocks contiguous

R2 = 5,000 blocks not ordered

Iterate: $\frac{5000}{100}$ x (100+10,000) = 50 x 10,100

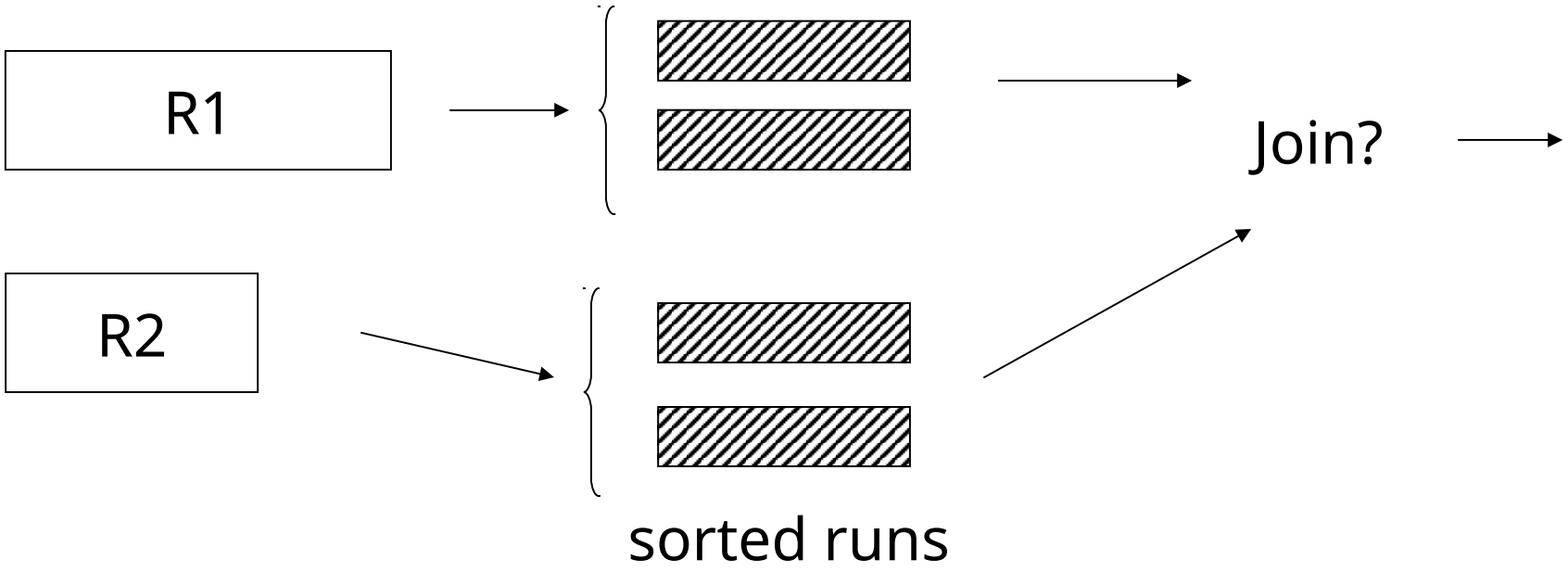
= 505,000 IOs

Merge join: 5(10,000+5,000) = 75,000 IOs

Merge Join (with sort) WINS!

Can we improve on merge join?

Hint: do we really need the fully sorted files?



Cost of improved merge join:

C = Read R1 + write R1 into runs

+ read R2 + write R2 into runs

+ join

= 2000 + 1000 + 1500 = 4500

Example 1(e) Index Join

- Assume R1.C index exists; 2 levels
- Assume R2 contiguous, unordered

- Assume R1.C index fits in memory

Cost: Reads: 500 IOs

for each R2 tuple:

- probe index - free
- if match, read R1 tuple: 1 IO

What is expected # of matching tuples?

(a) say R1.C is key, R2.C is foreign key

then expect = 1

(b) say V(R1,C) = 5000, T(R1) = 10,000

with uniform assumption

expect = 10,000/5,000 = 2

What is expected # of matching tuples?

(c) Say DOM(R1, C)=1,000,000

T(R1) = 10,000

with alternate assumption

$$\text{Expect} = \frac{10{,}000}{1{,}000{,}000} = \frac{1}{100}$$

Total cost with index join

(a) Total cost = 500+5000*(1)*1 = 5,500

(b) Total cost = 500+5000*(2)*1 = 10,500

(c)Total cost = 500+5000*(1/100)*1=550

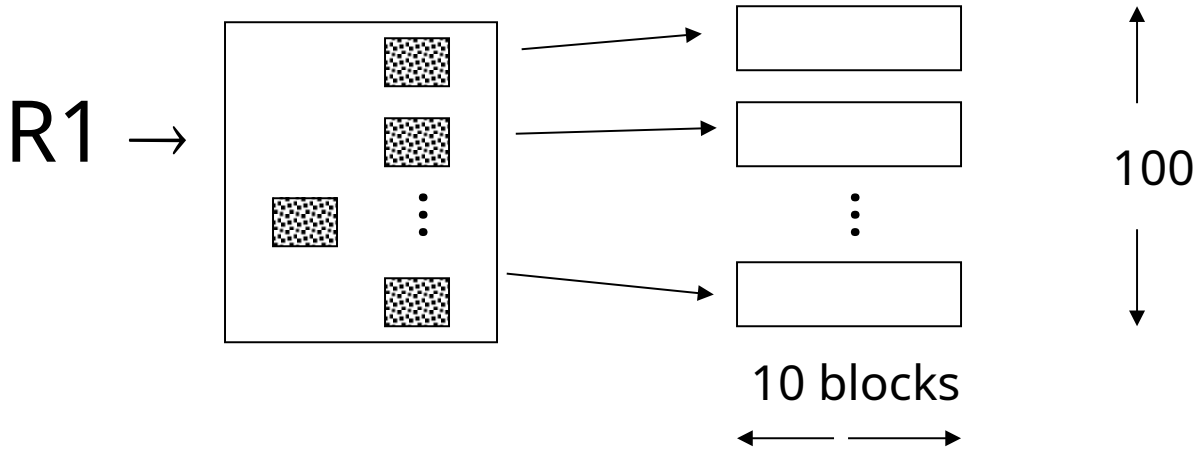
-> B(R2)+T(R2)*T(R1)/V(R1,C)

Example 1(f) Hash Join

- R1, R2 contiguous (un-ordered)

→ Use 100 buckets

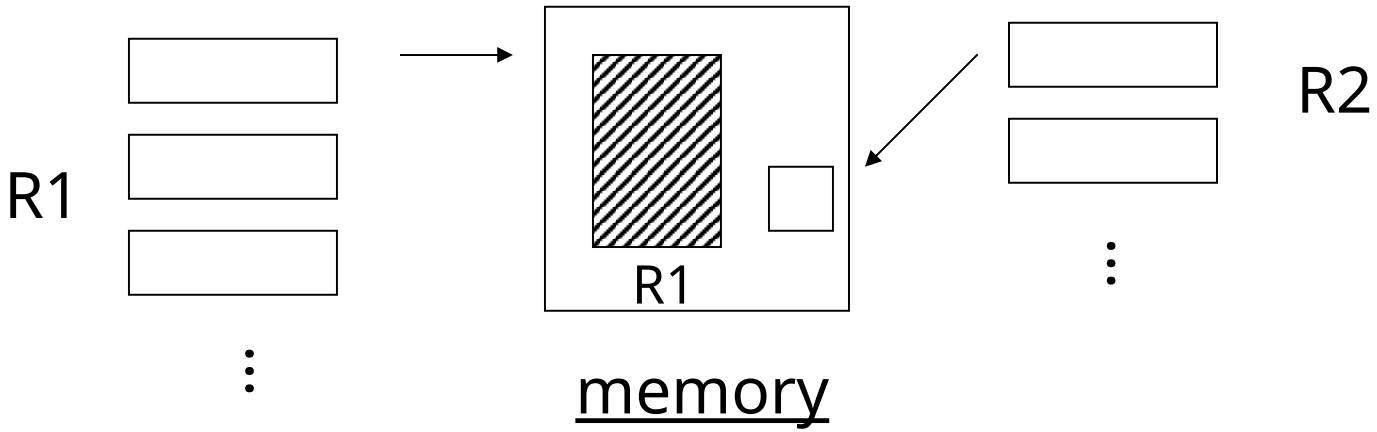
→ Read R1, hash, + write buckets



-> Same for R2

-> Read one R1 bucket; build memory hash table

-> Read corresponding R2 bucket + hash probe



✎ Then repeat for all buckets

Cost:

"Bucketize:" Read R1 + write

Read R2 + write

Join: Read R1, R2

Total cost = 3 x [1000+500] = 4500

-> 3*[B(R1)+B(R2)]

Note: this is an approximation since buckets will vary in size and we have to round up to blocks

A hash join trick:

- Only write into buckets
  <val,ptr> pairs
- When we get a match in join phase,
  must fetch tuples

- To illustrate cost computation, assume:
  - 100 <val,ptr> pairs/block
  - expected number of result tuples is 100

- Build hash table for R2 in memory (no outp)
  5000 tuples → 5000/100 = 50 blocks
- Read R1 and match
- Read ~ 100 R2 tuples

Total cost =	Read R2:	500
	Read R1:	1000
	Get tuples:	100
		1600

Summary

- Iteration ok for “small” relations (relative to memory size)
- For equi-join, where relations not sorted and no indexes exist, hash join usually best

- Sort + merge join good for non-equi-join (e.g., R1.C > R2.C)
- If relations already sorted, use merge join
- If index exists, it could be useful

  (depends on expected result size)