Query Operators

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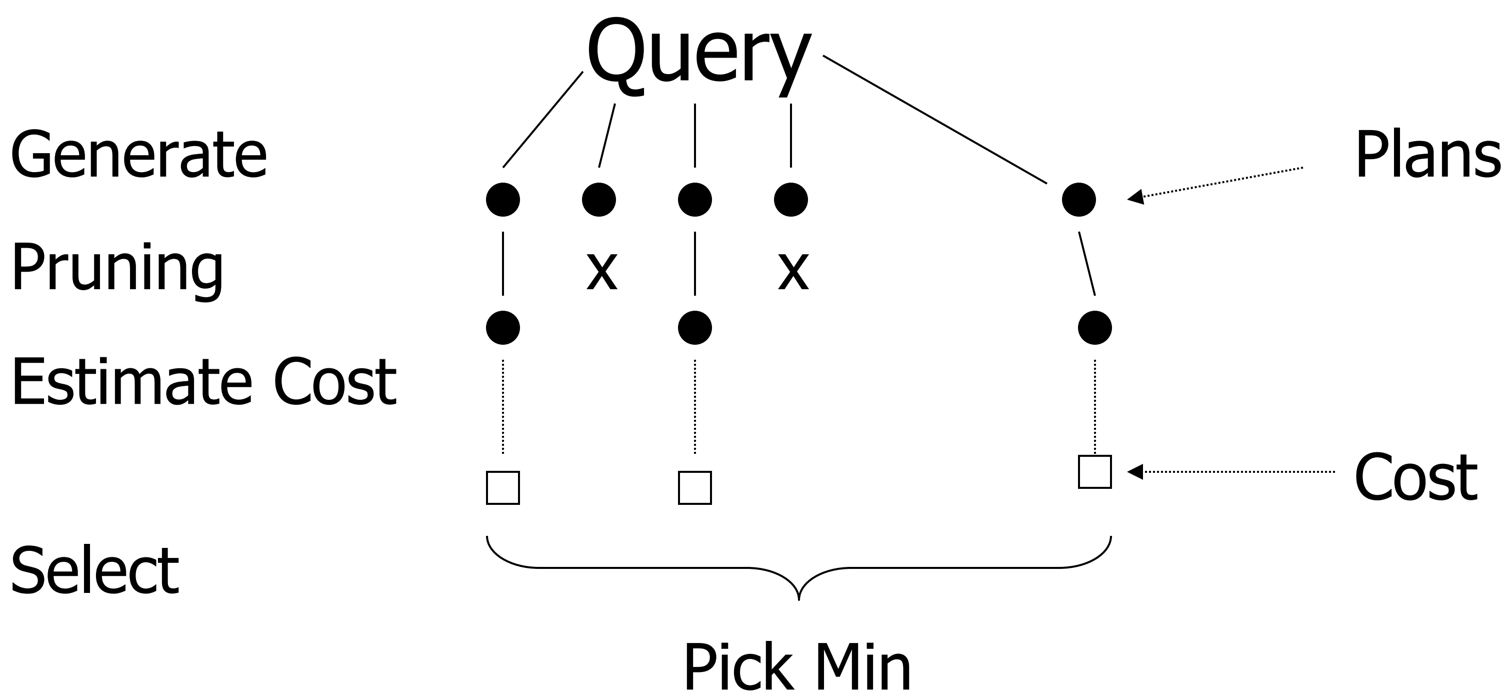
Query Optimization

--> Generating and comparing plans



To generate plans consider:

- Transforming relational algebra expression
  (e.g. order of joins)
- Use of existing indexes
- Building indexes or sorting on the fly

- Implementation details:

  e.g. - Join algorithm

  - Memory management
  - Parallel processing

Estimating IOs:

- Count # of disk blocks that must be read (or written) to execute query plan

To estimate costs, we may have additional parameters:

B(R) = # of blocks containing R tuples

f(R) = max # of tuples of R per block

M = # memory blocks available

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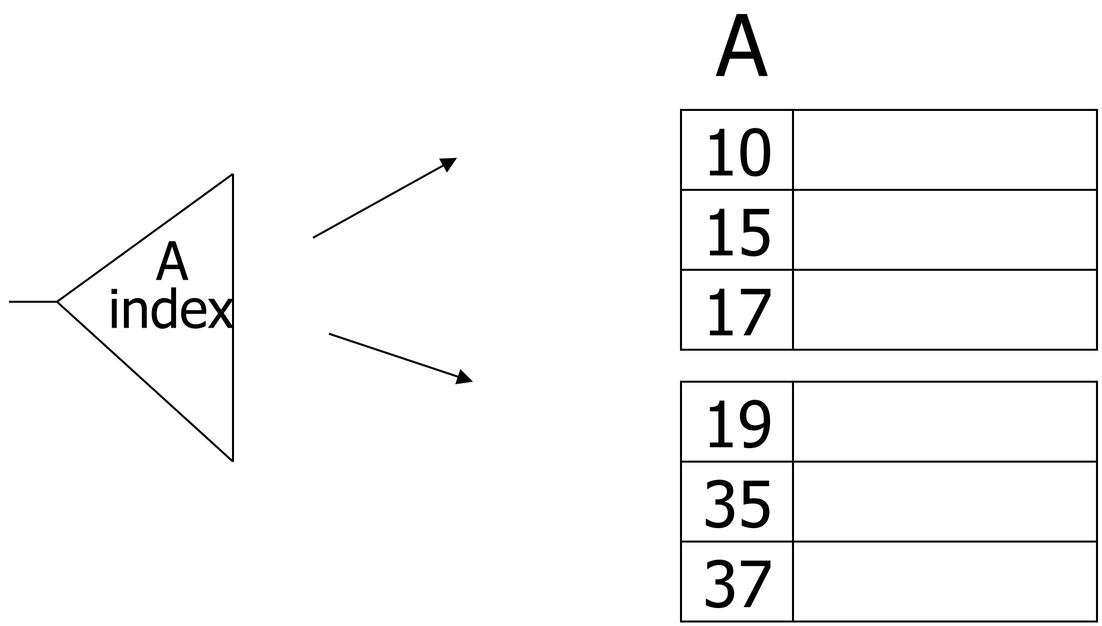
M = # memory blocks available

HT(i) = # levels in index i

LB(i) = # of leaf blocks in index i

Clustering index

Index that allows tuples to be read in an order that corresponds to physical order



Notions of clustering

- Clustered file organization

R1 R2 S1 S2	R3 R4 S3 S4	…..

- Clustered relation

R1 R2 R3 R4	R5 R5 R7 R8	…..

- Clustering index

Example R1 $\bowtie$ R2 over common attribute C

T(R1) = 10,000

T(R2) = 5,000

S(R1) = S(R2) = 1/10 block

Memory available = 101 blocks

Example   R1 $\bowtie$ R2 over common attribute C

T(R1) = 10,000

T(R2) = 5,000

S(R1) = S(R2) = 1/10 block

Memory available = 101 blocks

→ Metric: # of IOs

(ignoring writing of result)

Caution!

This may not be the best way to compare

- ignoring CPU costs
- ignoring timing
- ignoring double buffering requirements

Options

- Transformations: R1 $\bowtie$ R2, R2 $\bowtie$ R1
- Joint algorithms:
  - Iteration (nested loops)
  - Merge join
  - Join with index
  - Hash join

- Iteration join (conceptually)

```
for each r ∈ R1 do
    for each s ∈ R2 do
        if r.C = s.C then output r,s pair
```

- Merge join (conceptually)

  (1) if R1 and R2 not sorted, sort them

  (2) $i \leftarrow 1$; $j \leftarrow 1$;

  While $(i \leq T(R1)) \wedge (j \leq T(R2))$ do

  if R1{ i }.C = R2{ j }.C then outputTuples

  else if R1{ i }.C > R2{ j }.C then $j \leftarrow j+1$

  else if R1{ i }.C < R2{ j }.C then $i \leftarrow i+1$

Procedure Output-Tuples

```
While (R1{ i }.C = R2{ j }.C) ∧ (i ≤ T(R1)) do
    [jj ← j;
     while (R1{ i }.C = R2{ jj }.C) ∧ (jj ≤ T(R2)) do
              [output pair R1{ i }, R2{ jj };
               jj ← jj+1  ]
     i ← i+1  ]
```

Example

i	R1{i}.C	R2{j}.C	j
1	10	5	1
2	20	20	2
3	20	20	3
4	30	30	4
5	40	30	5
		50	6
		52	7

- Join with index (Conceptually)

Assume R2.C index

For each $r \in R1$ do

  [$X \leftarrow$ index (R2, C, r.C)

    for each $s \in X$ do

      output r,s pair]

Note: $X \leftarrow$ index(rel, attr, value)

then X = set of rel tuples with attr = value

- Hash join (conceptual)
  - Hash function h, range 0 $\rightarrow$ k
  - Buckets for R1: G0, G1, ... Gk
  - Buckets for R2: H0, H1, ... Hk

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<u>Algorithm</u>

(1) Hash R1 tuples into G buckets

(2) Hash R2 tuples into H buckets

(3) For i = 0 to k do

    match tuples in Gi, Hi buckets

Simple example   hash: even/odd

R1	R2
2	5
4	4
3	12
5	3
8	13
9	8
	11
	14

Buckets

	R1	R2
Even	2 4 8	4 12 8 14
Odd:	3 5 9	5 3 13 11

Factors that affect performance

(1) Tuples of relation stored
physically together?

(2) Relations sorted by join attribute?

(3) Indexes exist?

<u>Example 1(a)</u> Iteration Join R1 $\bowtie$ R2

- Relations <u>not</u> contiguous
- Recall $\left\{ \begin{array}{l} T(R1) = 10{,}000 \quad T(R2) = 5{,}000 \\ S(R1) = S(R2) = 1/10 \text{ block} \\ MEM = 101 \text{ blocks} \end{array} \right.$

Example 1(a) Iteration Join R1 $\bowtie$ R2

- Relations not contiguous
- Recall $\begin{cases} T(R1) = 10{,}000 \quad T(R2) = 5{,}000 \\ S(R1) = S(R2) = 1/10 \text{ block} \\ MEM = 101 \text{ blocks} \end{cases}$

Cost: for each R1 tuple:

[Read tuple + Read R2]

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

- Can we do better?

- Can we do better?

Use our memory

(1) Read 100 blocks of R1

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

(3) Repeat until done

Cost: for each R1 chunk:

Read chunk: 1000 IOs

Read R2: 5000 IOs

6000

Cost: for each R1 chunk:

Read chunk: 1000 IOs

Read R2: 5000 IOs

6000

$$\text{Total} = \frac{10{,}000}{1{,}000} \times 6000 = 60{,}000 \text{ IOs}$$

- Can we do better?

- Can we do better?

☛ Reverse join order: R2 $\bowtie$ R1

$$\text{Total} = \frac{5000}{1000} \times (1000 + 10{,}000) =$$

$$5 \times 11{,}000 = 55{,}000 \text{ IOs}$$

Example 1(b) Iteration Join R2 $\bowtie$ R1

- Relations contiguous

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- Relations contiguous

Cost

For each R2 chunk:

Read chunk: 100 IOs

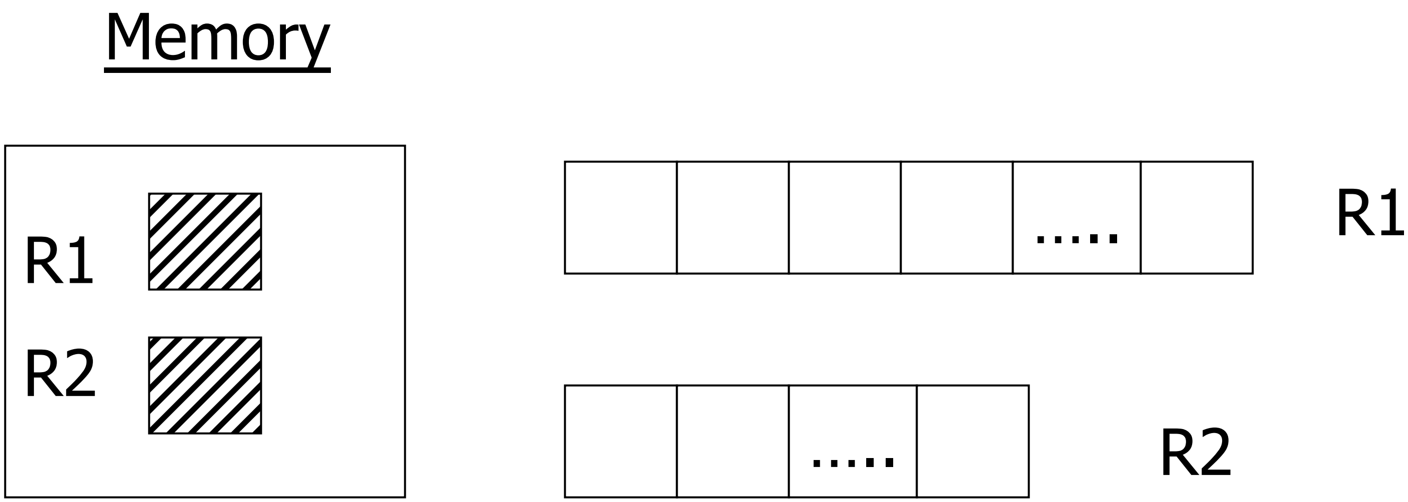
Read R1: 1000 IOs

1,100

Total= 5 chunks x 1,100 = 5,500 IOs

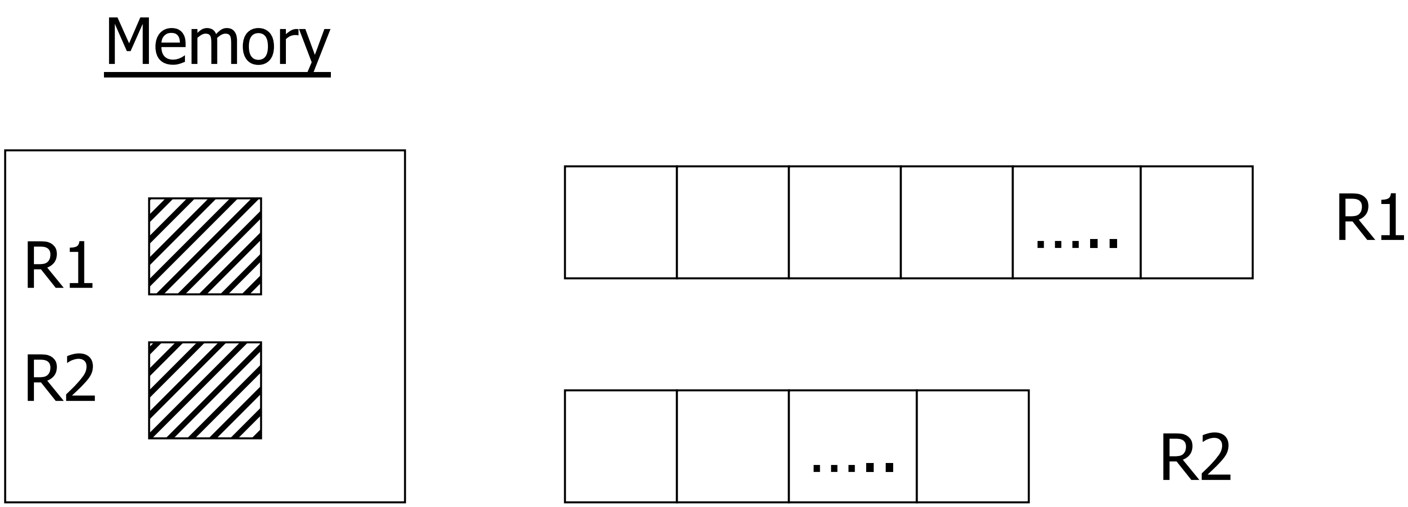
Example 1(c) Merge Join

- Both R1, R2 ordered by C; relations contiguous



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

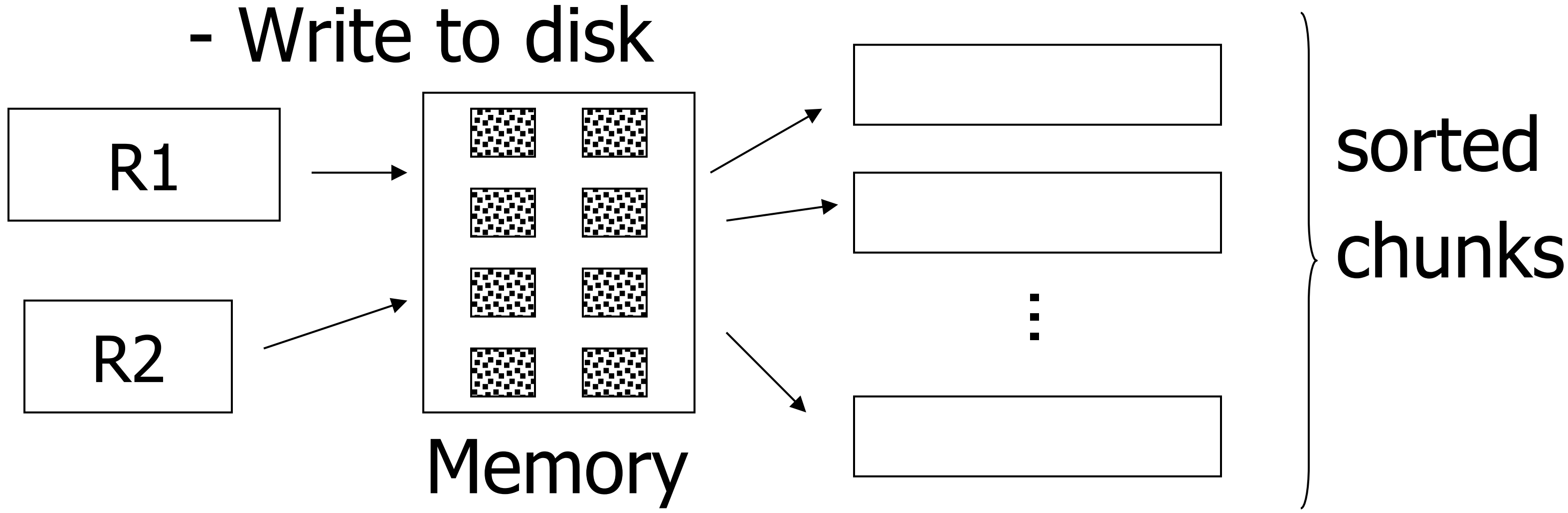
- R1, R2 not ordered, but contiguous

--> Need to sort R1, R2 first…. HOW?

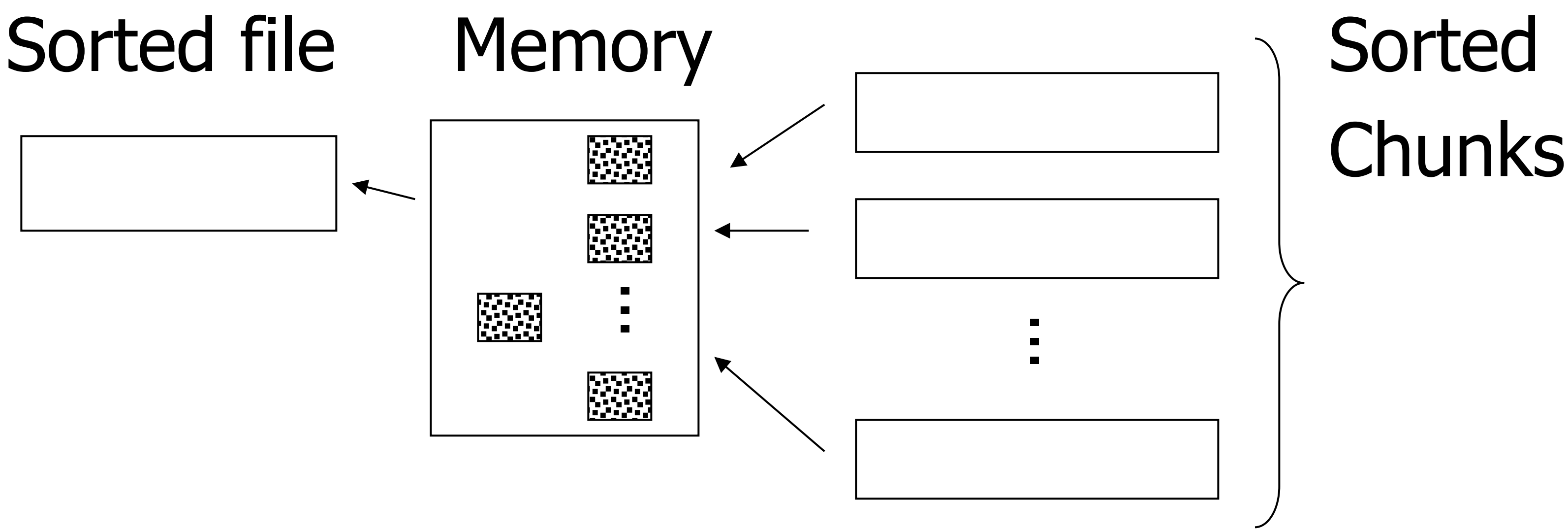
One way to sort: Merge Sort

(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

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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 joint does not pay off!

But say R1 = 10,000 blocks contiguous
R2 = 5,000 blocks not ordered

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

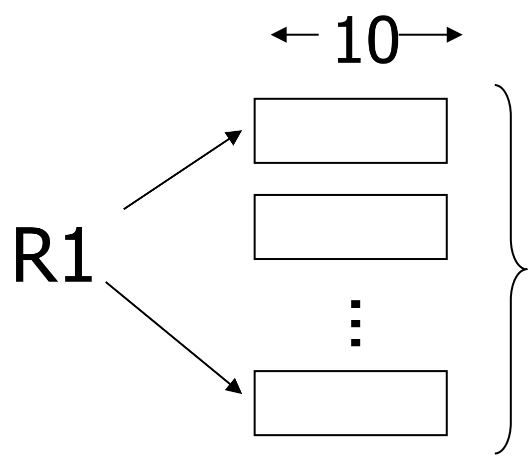
$= 505{,}000$ IOs

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

Merge Join (with sort) WINS!

How much memory do we need for merge sort?

E.g: Say I have 10 memory blocks



100 chunks ⇒ to merge, need 100 blocks!

In general:

Say k blocks in memory

x blocks for relation sort

chunks = (x/k)   size of chunk = k

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chunks = (x/k) size of chunk = k

chunks ≤ buffers available for merge

so... $(x/k) \leq k$

or $k^2 \geq x$ or $k \geq \sqrt{x}$

In our example

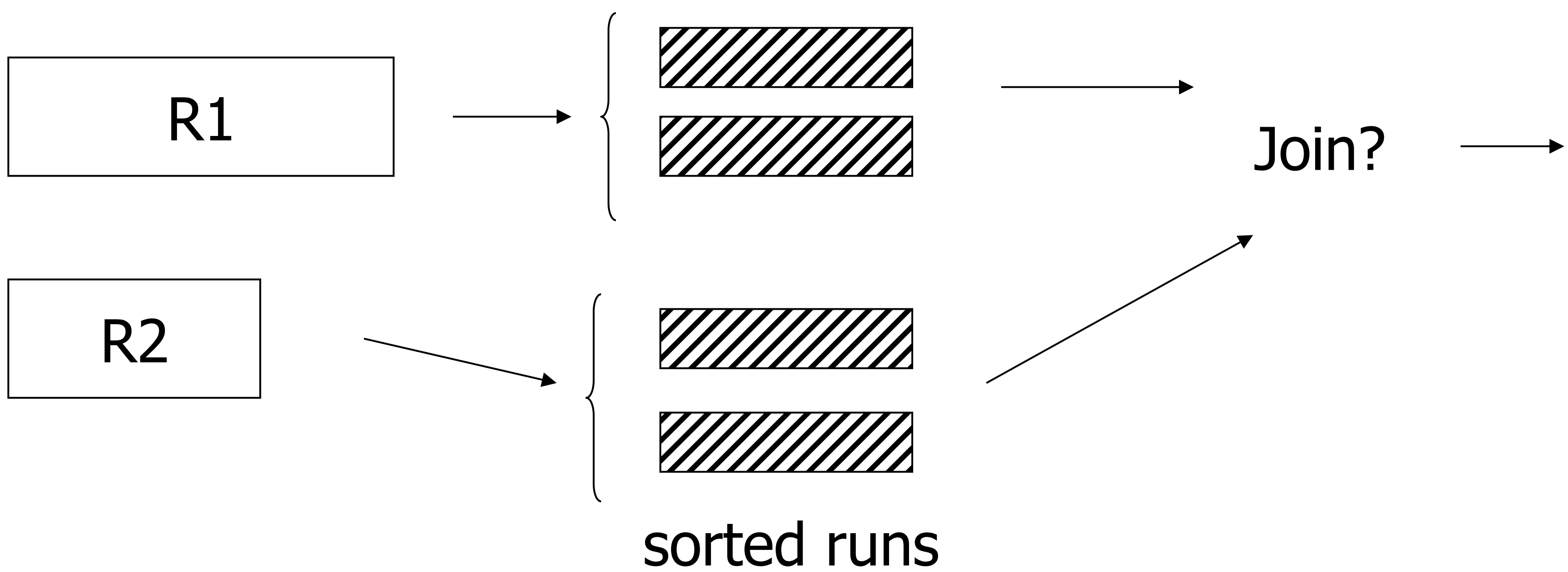
R1 is 1000 blocks, $k \geq 31.62$

R2 is 500 blocks, $k \geq 22.36$

Need at least 32 buffers

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

--> Memory requirement?

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

What if index does not fit in memory?

Example: say R1.C index is 201 blocks

- Keep root + 99 leaf nodes in memory
- Expected cost of each probe is

$$E = (0)\frac{99}{200} + (1)\frac{101}{200} \approx 0.5$$

Total cost (including probes)

= 500+5000 [Probe + get records]

= 500+5000 [0.5+2]   uniform assumption

= 500+12,500 = 13,000   (case b)

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= 500+5000 [Probe + get records]

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= 500+12,500 = 13,000 (case b)

For case (c):

$= 500+5000[0.5 \times 1 + (1/100) \times 1]$

= 500+2500+50 = 3050 IOs

So far

	Method	Cost
not contiguous	Iterate R2 $\bowtie$ R1	55,000 (best)
	Merge Join	________
	Sort+ Merge Join	________
	R1.C Index	________
	R2.C Index	________
contiguous	Iterate R2 $\bowtie$ R1	5500
	Merge join	1500
	Sort+Merge Join	7500 $\rightarrow$ 4500
	R1.C Index	5500 $\rightarrow$ 3050 $\rightarrow$ 550
	R2.C Index	________

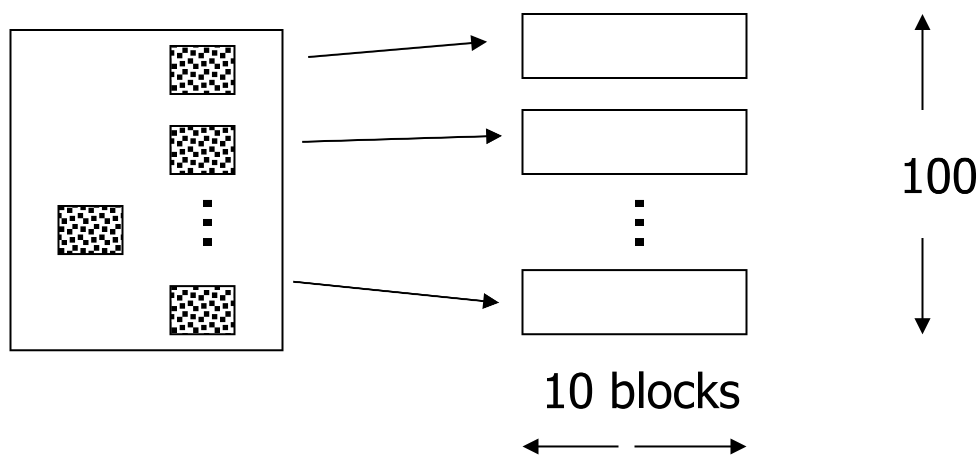
Example 1(f) Hash Join

- R1, R2 contiguous (un-ordered)

→ Use 100 buckets

→ Read R1, hash, + write buckets

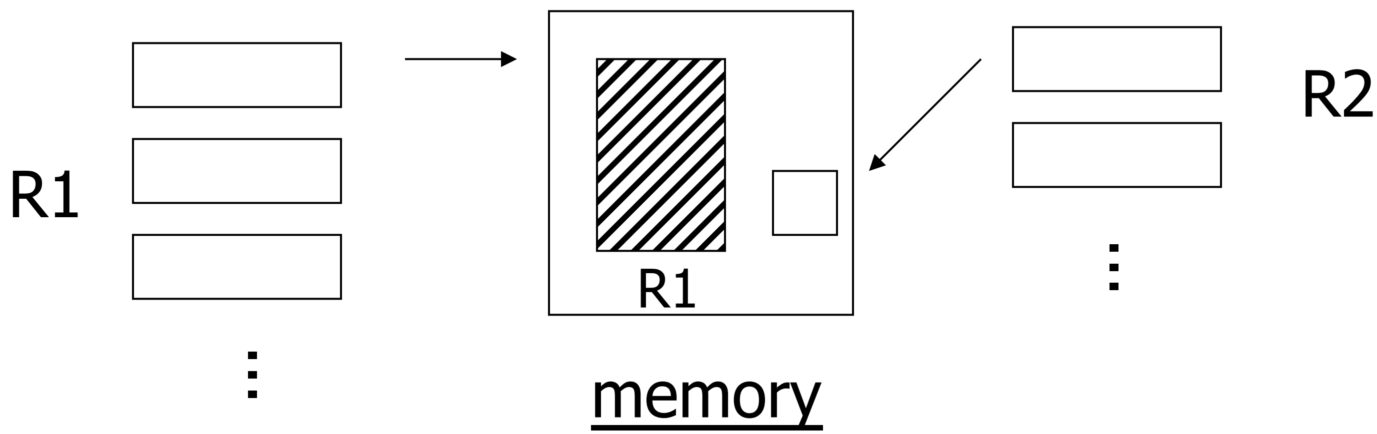
R1 →



-> 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

Cost:

"Bucketize:" Read R1 + write

Read R2 + write

Join: Read R1, R2

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

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

Minimum memory requirements:

Size of R1 bucket = (x/k)

k = number of memory buffers

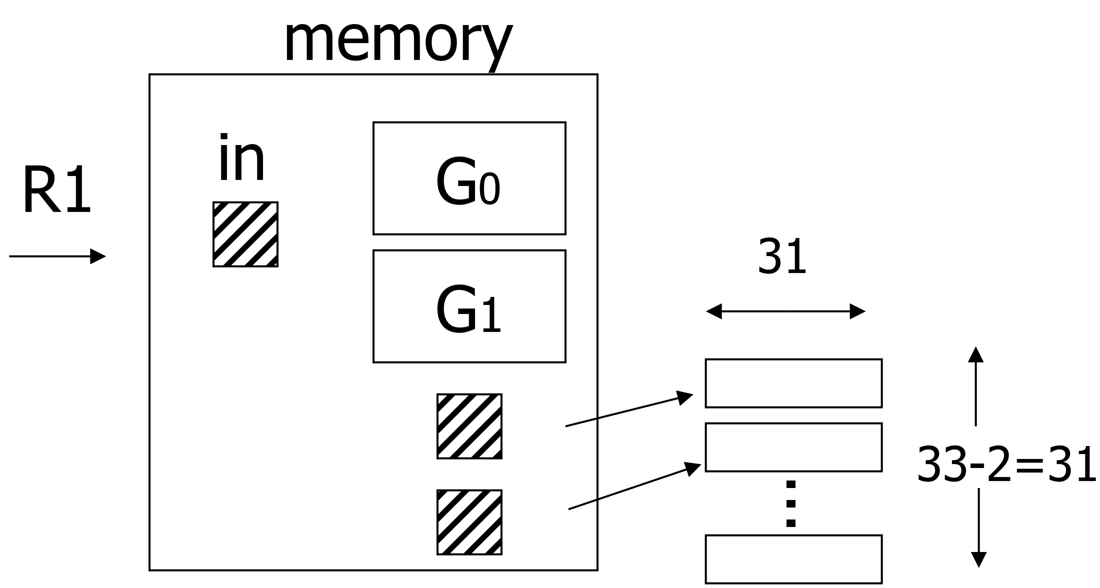
x = number of R1 blocks

So... $(x/k) < k$

$k > \sqrt{x}$ need: k+1 total memory buffers

Trick: keep some buckets in memory

E.g., k' =33 R1 buckets = 31 blocks
keep 2 in memory



called hybrid hash-join

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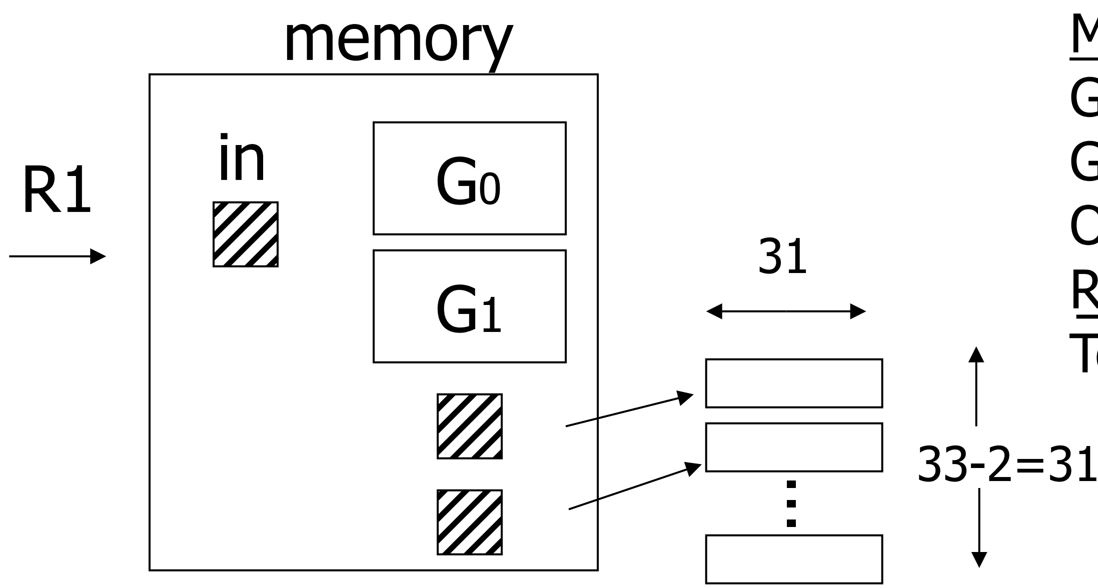


Memory use:

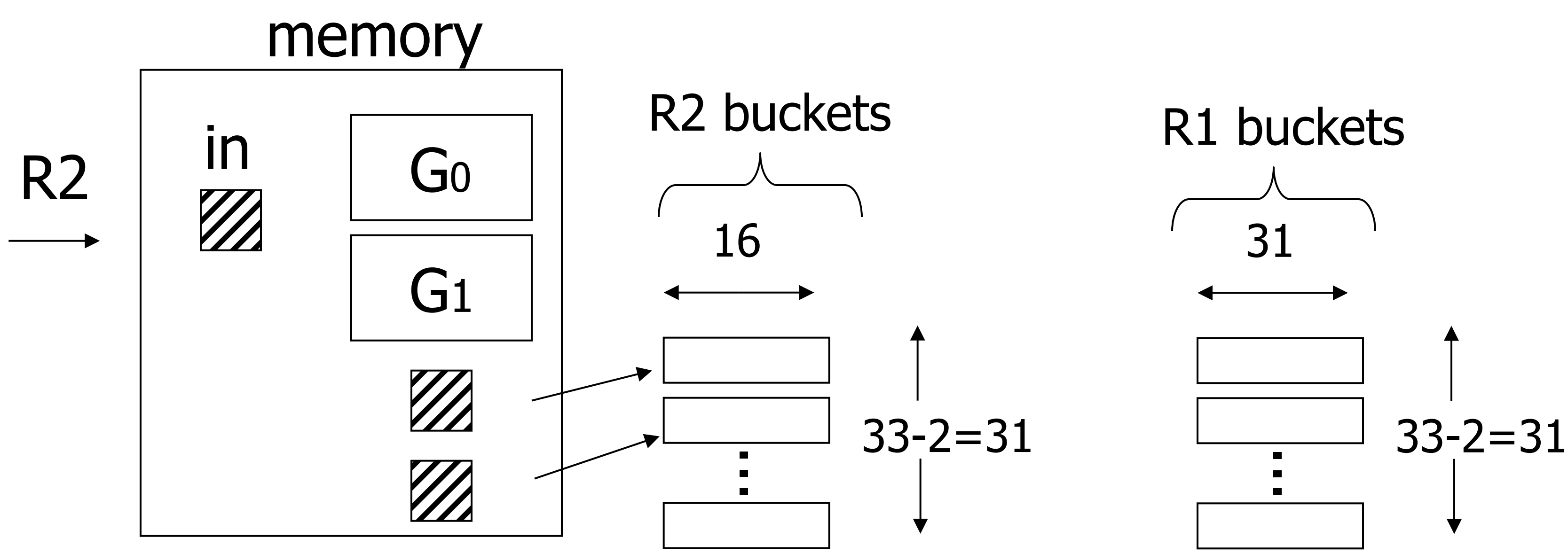
G0	31 buffers
G1	31 buffers
Output	33-2 buffers
R1 input	1
Total	94 buffers

6 buffers to spare!!

called hybrid hash-join

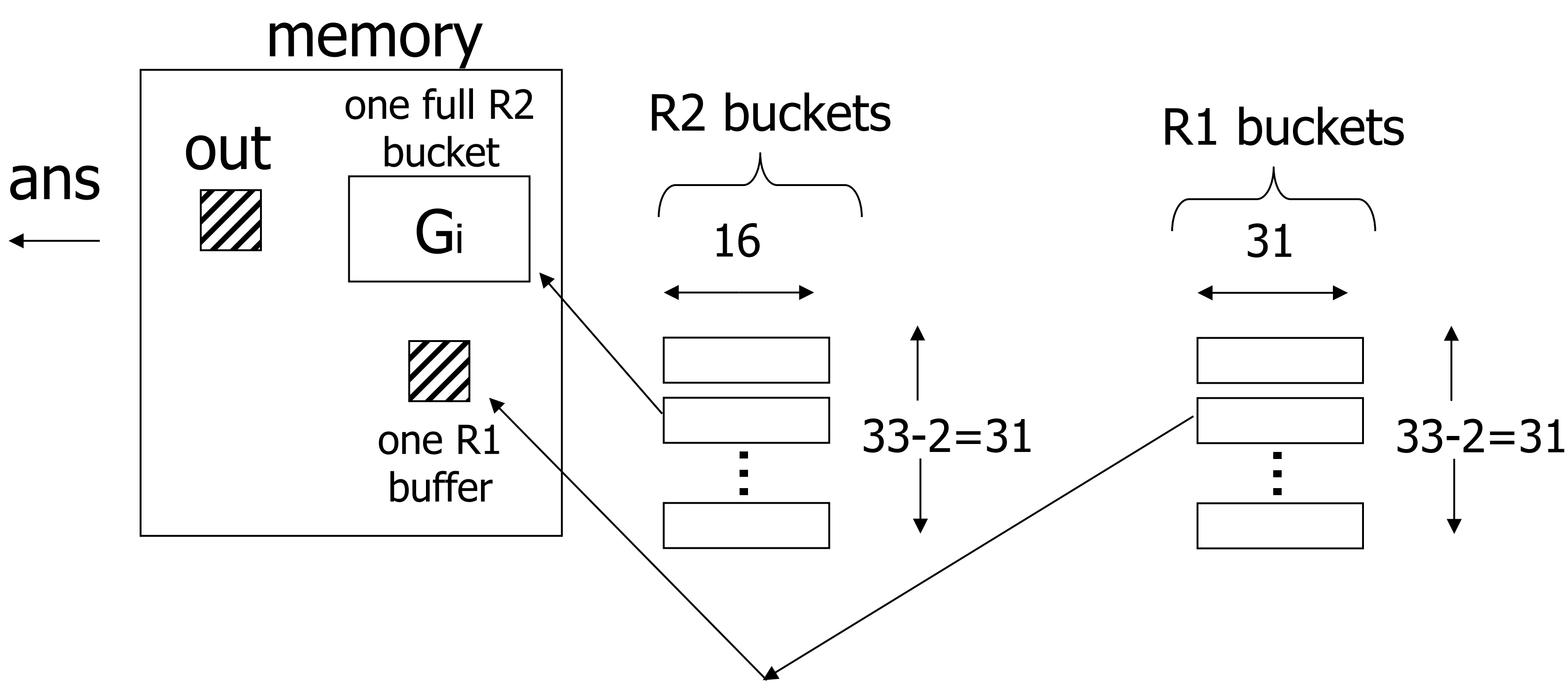
Next: Bucketize R2

- R2 buckets =500/33= 16 blocks
- Two of the R2 buckets joined immediately with G0,G1



Finally: Join remaining buckets

- for each bucket pair:
  - read one of the buckets into memory
  - join with second bucket

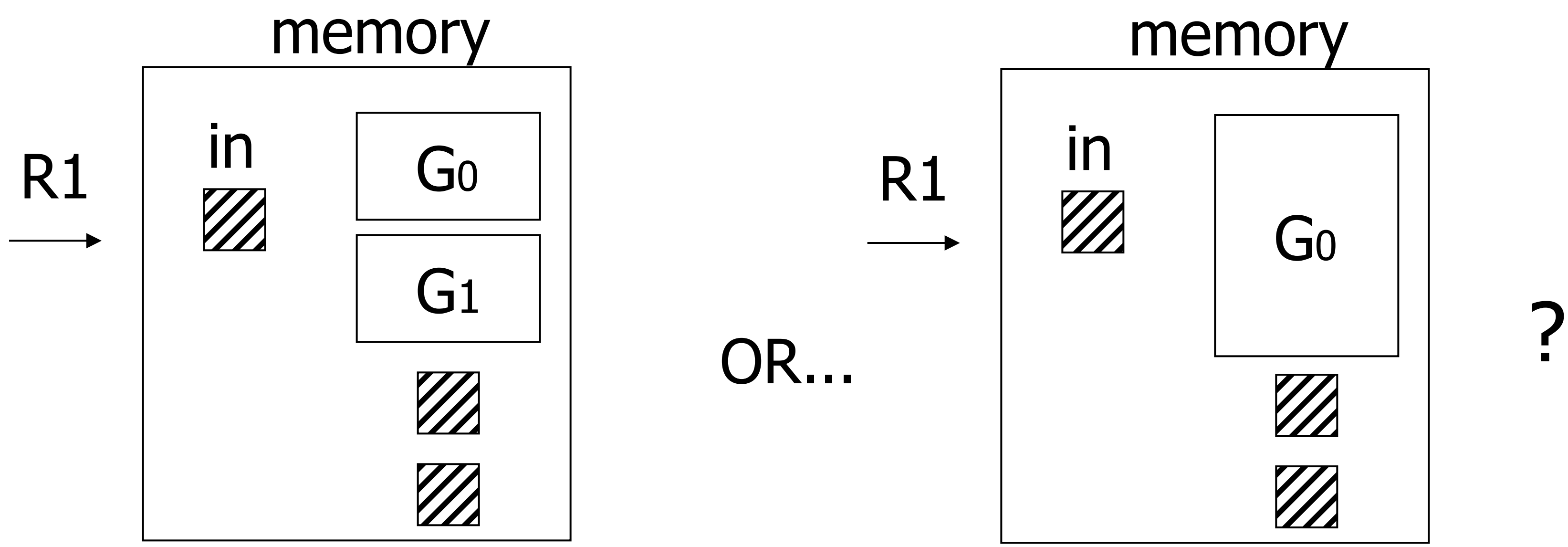


Cost

- Bucketize R1 = $1000+31\times31=1961$
- To bucketize R2, only write 31 buckets:
  so, cost = $500+31\times16=996$
- To compare join (2 buckets already done)
  read $31\times31+31\times16=1457$

Total cost = $1961+996+1457 = 4414$

- How many buckets in memory?



☛ See textbook for answer...

Another 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

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  5000 tuples → 5000/100 = 50 blocks
- Read R1 and match
- Read ~ 100 R2 tuples

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  - 100 <val,ptr> pairs/block
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- Read ~ 100 R2 tuples

<u>Total cost</u> =	Read R2:	500
	Read R1:	1000
	Get tuples:	100
		1600

So far:

contiguous

Iterate	5500
Merge join	1500
Sort+merge joint	7500
R1.C index	5500 → 550
R2.C index	_____
Build R.C index	_____
Build S.C index	_____
Hash join	4500+
with trick,R1 first	4414
with trick,R2 first	_____
Hash join, pointers	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)

Join strategies for parallel processors

Later on….

Chapter 16 [16] summary

- Relational algebra level
- Detailed query plan level
  - Estimate costs
  - Generate plans
    - Join algorithms
  - Compare costs