Query Optimization – Physical Query Plans

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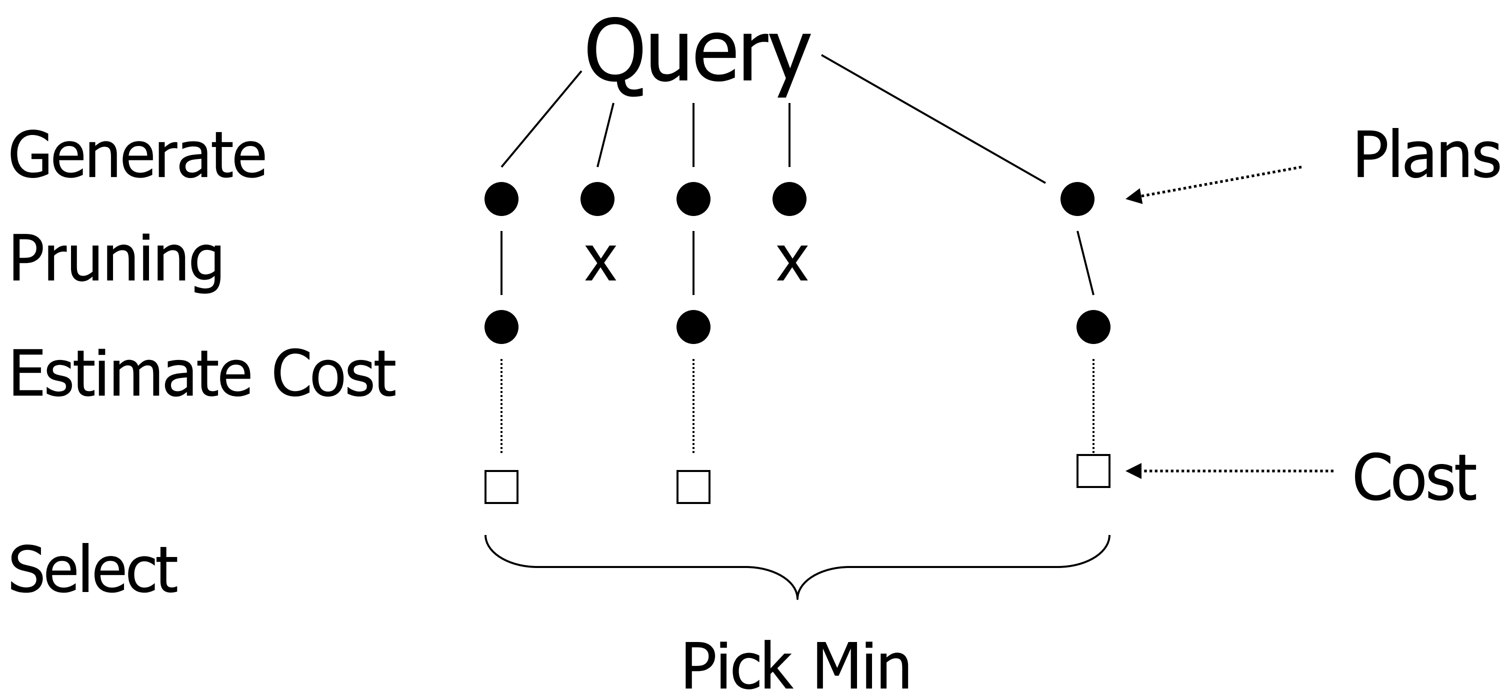
Query Optimization

--> 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

T(R) = # of tuples in a relation

T(R) > B(R)

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

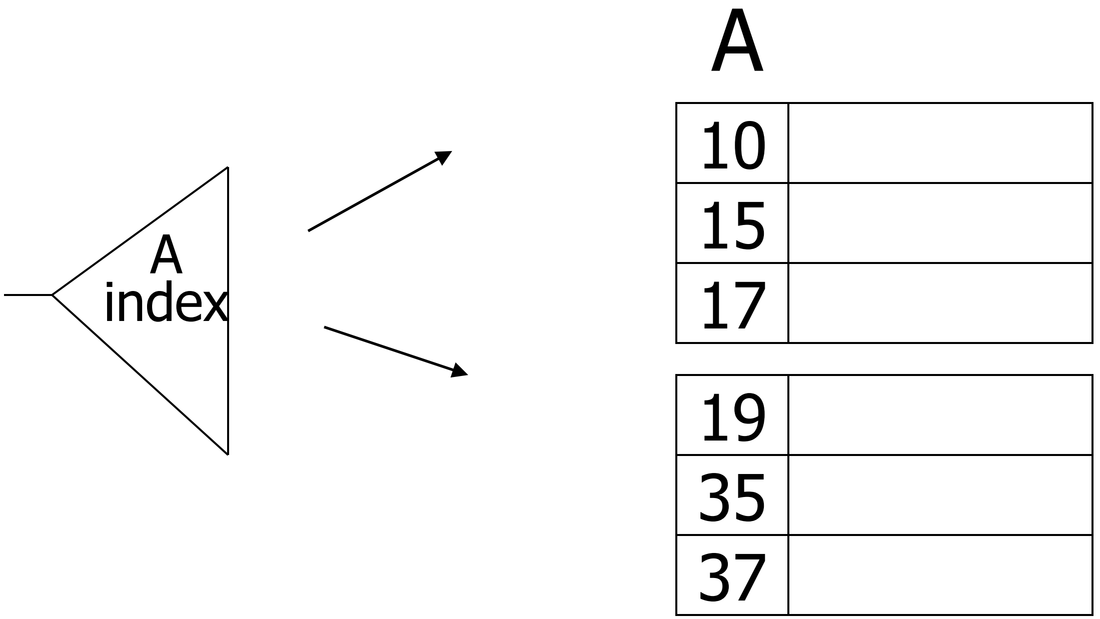
HT(i) = # levels in index i

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

Clustering index

index that follows the same ordering as the physical storing of the data

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

Numbers of tuples in relation R1

$T(R1) = 10,000$

$T(R2) = 5,000$

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

Memory available = 101 blocks

Size of the tuple

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

$\rightarrow$ Metric: # of IOs
(ignoring writing of result)

Options

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

Different algorithms that we can use

- Iteration join (conceptually)

  for each $r \in R1$ do

    for each $s \in R2$ do

      if $r.C = s.C$ then output r,s pair

Each block is read, not each tuple!

- Merge join (conceptually)

SORT the relations!

(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 $i \leftarrow i+1$

C = 2 in 4 tuples of R1 and C = 2 in 5 tuples of R2 --> 20 tuples to output

Procedure Output-Tuples

While (R1{ i }.C = R2{ j }.C) $\wedge$ (i $\leq$ T(R1)) do

[jj $\leftarrow$ j;

while (R1{ i }.C = R2{ jj }.C) $\wedge$ (jj $\leq$ T(R2)) do

[output pair R1{ i }, R2{ jj };

jj $\leftarrow$ jj+1]

i $\leftarrow$ 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

Hash function is a function that encrypts (with the same key) a value (give a number, receive a value).

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

	R1.C	R2.C
T1	100	100
T2	100	10
T3	1200	50
T4	1300	1300
T5	5000	4000
T6	5000	4000
T7	4000	4000

Buckets for R1	Bucket for R2
0 [T4 T5 T6]	0 [T3 T4]
1 [T1 T2 T3 T7]	1 [T1 T2 T5 T6 T7]

Faster because here we will only compare bucket by bucket.
Because comparing bucket 0 of R1 with bucket 1 of R2 will never give a match!

<u>Algorithm</u>

Here 6 computations for bucket 0 and 20 for bucket 1 --> 26 operations in total

49 otherwise (7x7)

(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?

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

- Relations not 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
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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

<u>Cost:</u> for each R1 chunk:

Read chunk: 1000 IOs

Read R2: $\underline{5000}$ 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

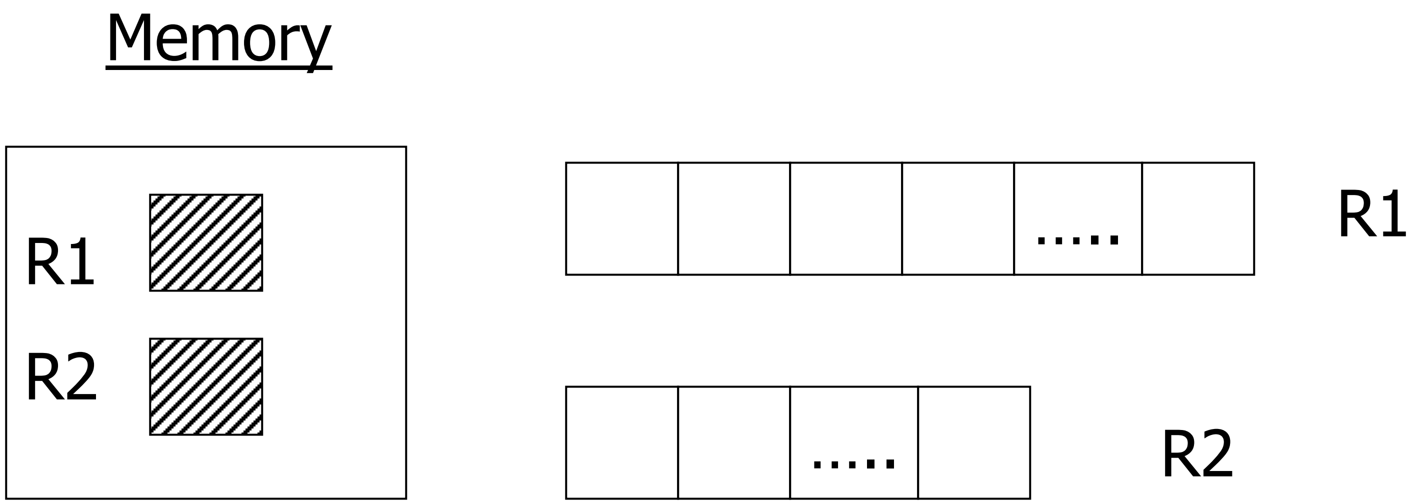
Read R1: $\underline{1000}$ IOs

1,100

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

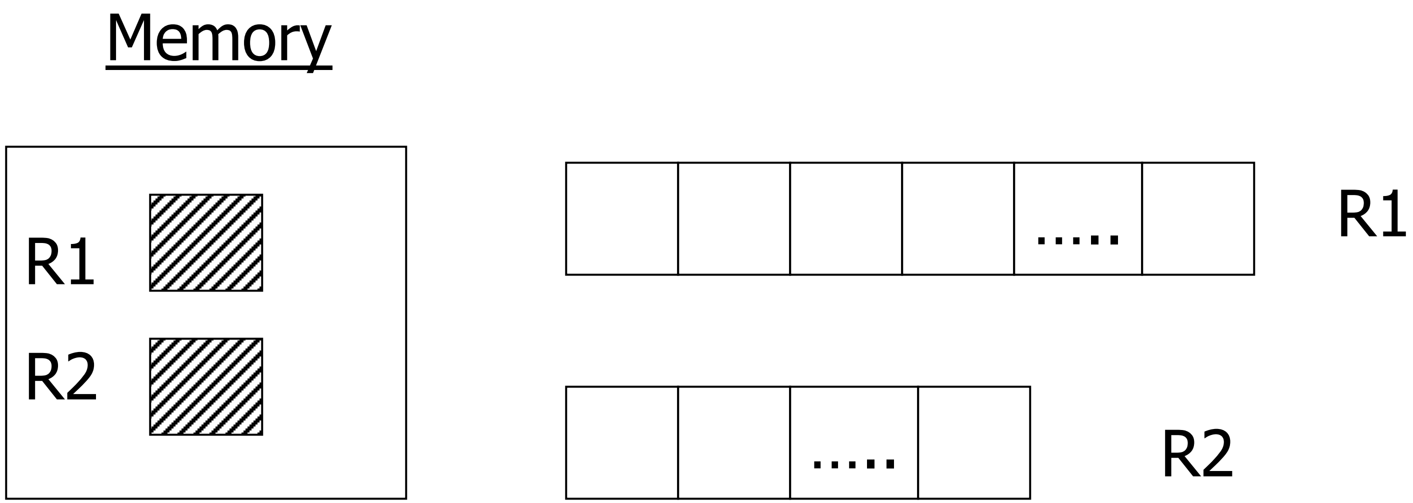
Example 1(c) Merge Join

- 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

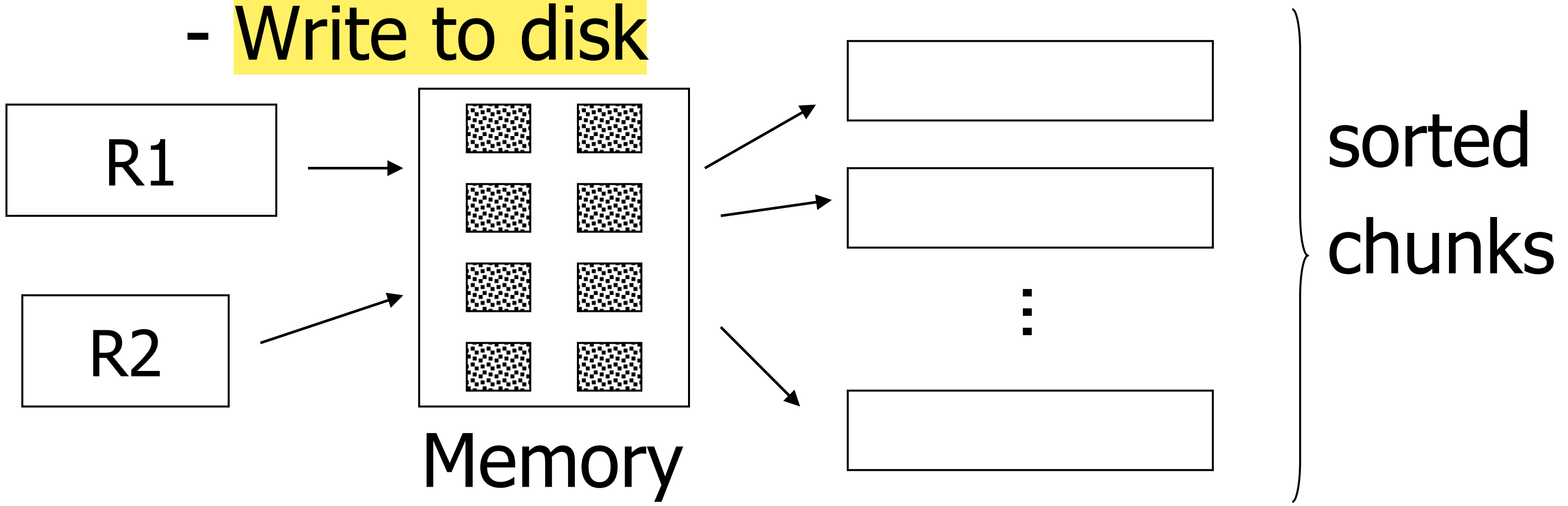
- R1, R2 not ordered, but contiguous

--> Need to sort R1, R2 first…. HOW?

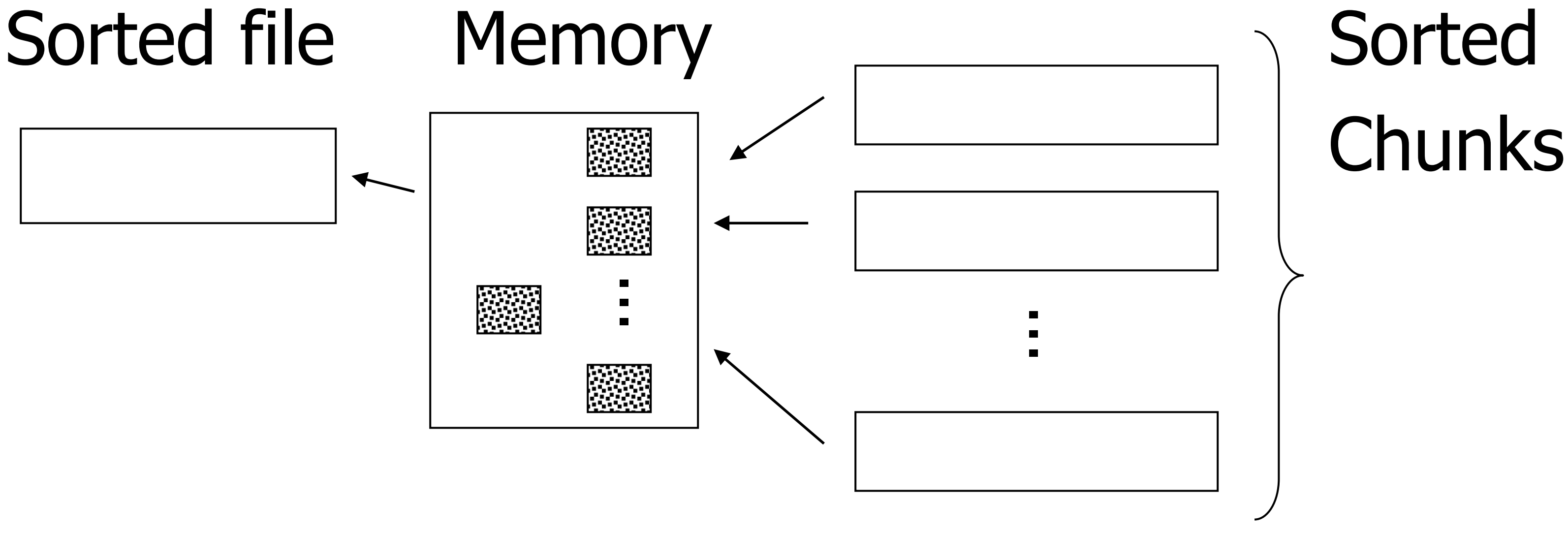
One way to sort: Merge Sort

(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

4x

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

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 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

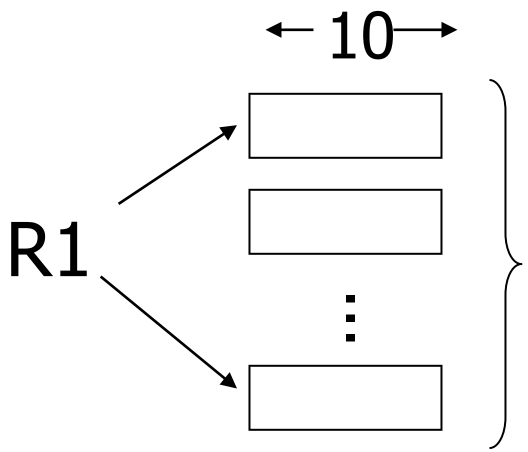
Merge join: $5(10{,}000+5{,}000) = 75{,}000$ IOs

Merge Join (with sort) WINS!

Merge Join better for BIG difference of size in the register.

How much memory do we need for merge sort?

E.g: Say I have 10 memory blocks



100 chunks $\Rightarrow$ 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 $\leq$ buffers available for merge

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Say k blocks in memory

x blocks for relation sort

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

\# chunks $\leq$ buffers available for merge

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

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

If not --> merge sort not interessant

In our example

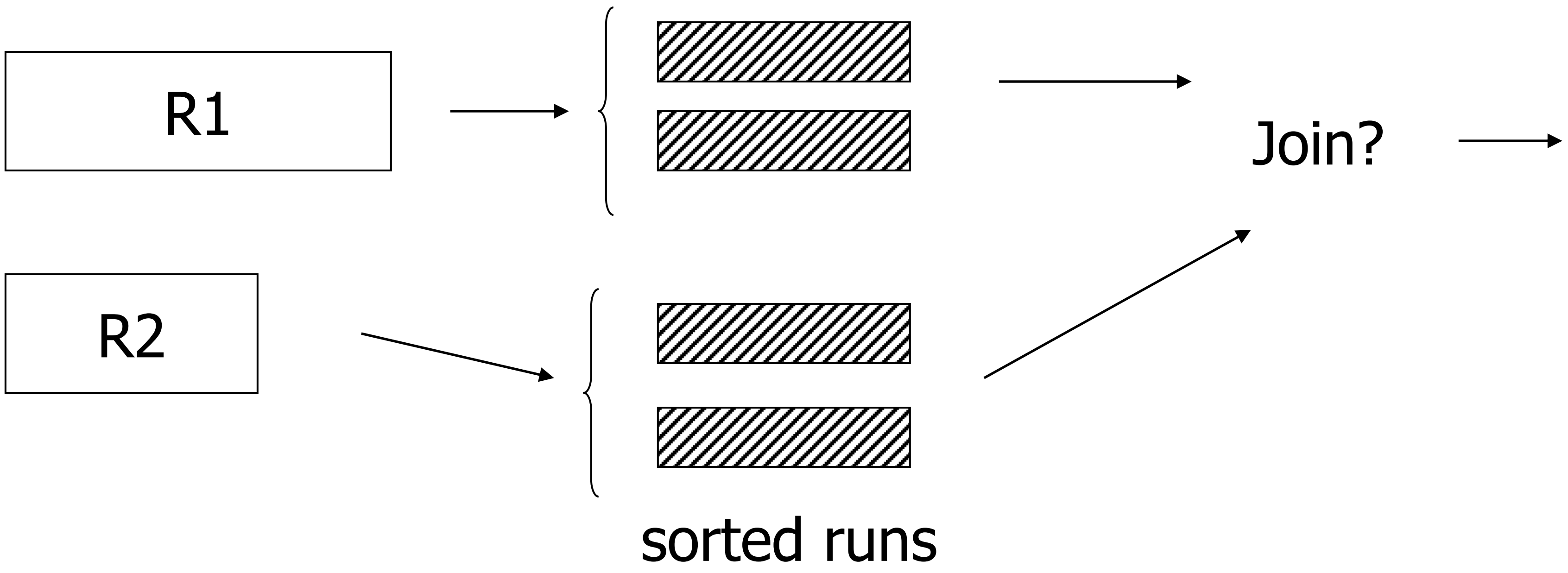
R1 is 1000 blocks, $k \geq 31.62$

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?



We can compare the heads, if one is lower than the other -> no join and pass to next block

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)

Total cost (including probes)

$= 500 + 5000$ [Probe + get records]

$= 500 + 5000\,[0.5 + 2]$ uniform assumption

$= 500 + 12{,}500 = 13{,}000$ (case b)

For case (c):

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

$= 500 + 2500 + 50 = 3050$ IOs

So far

not contiguous

Iterate R2 $\bowtie$ R1	55,000 (best)
Merge Join	________
Sort+ Merge Join	________
R1.C Index	________
R2.C Index	________

contiguous

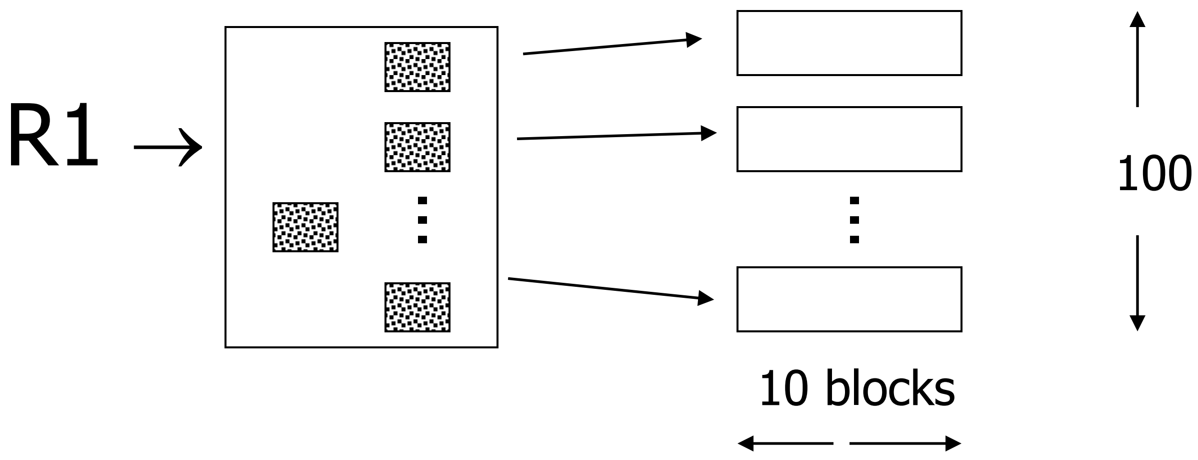
Iterate R2 $\bowtie$ R1	5500
Merge join	1500
Sort+Merge Join	7500 $\rightarrow$ 4500
R1.C Index	5500 $\rightarrow$ 3050 $\rightarrow$ 550
R2.C Index	________

Example 1(f) Hash Join

- R1, R2 contiguous (un-ordered)

→ Use 100 buckets

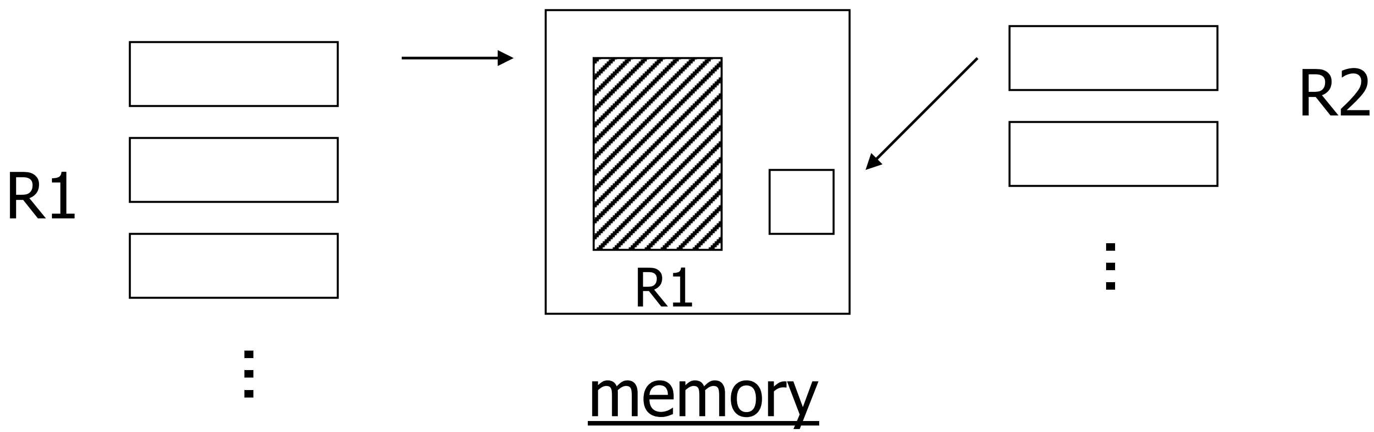
→ Read R1, hash, + write buckets



-> 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

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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

Readings

- DATABASE SYSTEMS - The Complete Book, Hector Garcia-Molina, Jeffrey D. Ullman, Jennifer Widom, Second Edition.
- Chapter 16.7.1, 16.7.2, and relevant sections in Chapter 15.