

CS 245: Database System Principles

Notes 7: Query Optimization

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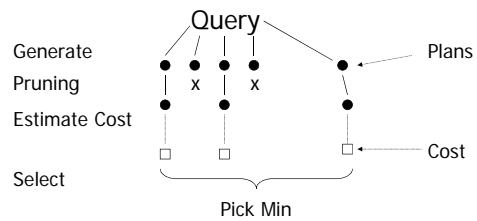
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Query Optimization

--> Generating and comparing plans



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To generate plans consider:

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

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- Implementation details:
 - e.g. - Join algorithm
 - Memory management
 - Parallel processing

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Estimating IOs:

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

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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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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

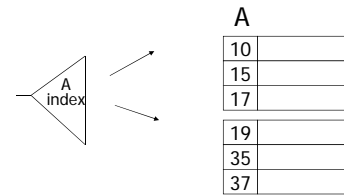
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Clustering index

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



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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

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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

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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)

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Caution!

This may not be the best way to compare

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

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Options

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

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- 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

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- 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 $i \leftarrow i+1$

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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  $R1\{i\}, R2\{jj\}$ ;
      $jj \leftarrow jj+1$  ]
   $i \leftarrow i+1$  ]
```

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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

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- Join with index (Conceptually)

```
For each  $r \in R1$  do
  [  $X \leftarrow \text{index}(R2, C, r.C)$ 
    for each  $s \in X$  do
      output  $r,s$  pair ]
```

Note: $X \leftarrow \text{index}(\text{rel}, \text{attr}, \text{value})$
then X = set of rel tuples with attr = value

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- Hash join (conceptual)
 - Hash function h , range $0 \rightarrow k$
 - Buckets for R1: G_0, G_1, \dots, G_k
 - Buckets for R2: H_0, H_1, \dots, H_k

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- Hash join (conceptual)
 - Hash function h , range $0 \rightarrow k$
 - Buckets for R1: G_0, G_1, \dots, G_k
 - Buckets for R2: H_0, H_1, \dots, H_k

Algorithm

- (1) Hash R1 tuples into G buckets
- (2) Hash R2 tuples into H buckets
- (3) For $i = 0$ to k do
 - match tuples in G_i, H_i buckets

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Simple example hash: even/odd

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

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Factors that affect performance

- (1) Tuples of relation stored physically together?
- (2) Relations sorted by join attribute?
- (3) Indexes exist?

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Example 1(a) Iteration Join $R_1 \bowtie R_2$

- Relations not contiguous
- Recall
 - $T(R_1) = 10,000$ $T(R_2) = 5,000$
 - $S(R_1) = S(R_2) = 1/10$ block
 - MEM=101 blocks

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Example 1(a) Iteration Join $R_1 \bowtie R_2$

- Relations not contiguous
- Recall
 - $T(R_1) = 10,000$ $T(R_2) = 5,000$
 - $S(R_1) = S(R_2) = 1/10$ block
 - MEM=101 blocks

Cost: for each R1 tuple:

[Read tuple + Read R2]

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

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- Can we do better?

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- 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

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Cost: for each R1 chunk:

Read chunk: 1000 IOs
Read R2: $\frac{5000}{6000}$ IOs

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Cost: for each R1 chunk:

Read chunk: 1000 IOs
Read R2: $\frac{5000}{6000}$ IOs

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

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- Can we do better?

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- Can we do better?

• Reverse join order: $R2 \bowtie R1$

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

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

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

- Relations contiguous

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

- Relations contiguous

Cost

For each R2 chunk:

Read chunk: 100 IOs

Read R1: $\frac{1000}{1,100}$ IOs

Total = 5 chunks \times 1,100 = 5,500 IOs

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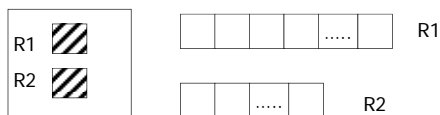
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Example 1(c) Merge Join

- Both R1, R2 ordered by C; relations contiguous

Memory



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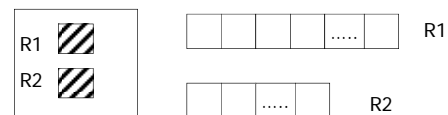
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Example 1(c) Merge Join

- Both R1, R2 ordered by C; relations contiguous

Memory



Total cost: Read R1 cost + read R2 cost
= 1000 + 500 = 1,500 IOs

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Example 1(d) Merge Join

- R1, R2 not ordered, but contiguous
- > Need to sort R1, R2 first.... HOW?

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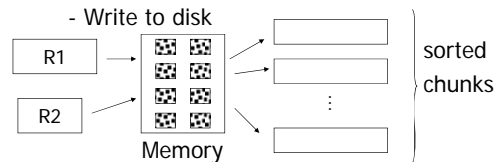
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One way to sort: Merge Sort

(i) For each 100 blk chunk of R:

- Read chunk
- Sort in memory
- Write to disk

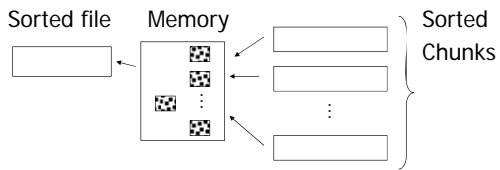


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(ii) Read all chunks + merge + write out



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Cost: Sort

Each tuple is read, written,
read, written

so...

Sort cost R1: $4 \times 1,000 = 4,000$

Sort cost R2: $4 \times 500 = 2,000$

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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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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!

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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!

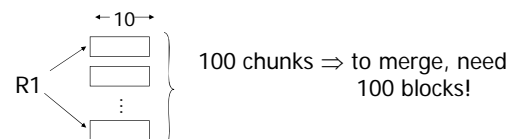
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How much memory do we need for
merge sort?

E.g: Say I have 10 memory blocks



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In general:

Say k blocks in memory
 x blocks for relation sort
chunks = (x/k) size of chunk = k

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In general:

Say k blocks in memory
 x blocks for relation sort
chunks = (x/k) size of chunk = k

chunks \leq buffers available for merge

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In general:

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 $k \geq \sqrt{x}$

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In our example

R1 is 1000 blocks, $k \geq 31.62$
R2 is 500 blocks, $k \geq 22.36$

Need at least 32 buffers

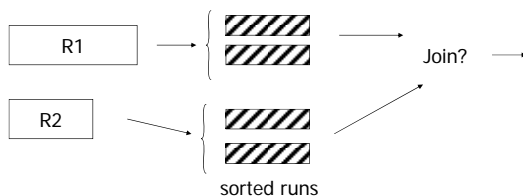
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Can we improve on merge join?

Hint: do we really need the fully sorted files?



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Cost of improved merge join:

$C = \text{Read R1} + \text{write R1 into runs}$
 $+ \text{read R2} + \text{write R2 into runs}$
 $+ \text{join}$
 $= 2000 + 1000 + 1500 = 4500$

--> Memory requirement?

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Example 1(e) Index Join

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

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Cost: Reads: 500 IOs

for each R2 tuple:

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

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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 = $10,000/5,000 = 2$

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What is expected # of matching tuples?

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

$$T(R1) = 10,000$$

with alternate assumption

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

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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 = $500 + 5000(1/100)1 = 550$

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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

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

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Total cost (including probes)

$$\begin{aligned}
 &= 500 + 5000 \text{ [Probe + get records]} \\
 &= 500 + 5000 [0.5 + 2] \quad \text{uniform assumption} \\
 &= 500 + 12,500 = 13,000 \quad (\text{case b})
 \end{aligned}$$

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Total cost (including probes)

$$\begin{aligned}
 &= 500 + 5000 \text{ [Probe + get records]} \\
 &= 500 + 5000 [0.5 + 2] \quad \text{uniform assumption} \\
 &= 500 + 12,500 = 13,000 \quad (\text{case b})
 \end{aligned}$$

For case (c):

$$\begin{aligned}
 &= 500 + 5000 [0.5 \times 1 + (1/100) \times 1] \\
 &= 500 + 2500 + 50 = 3050 \text{ IOs}
 \end{aligned}$$

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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	_____

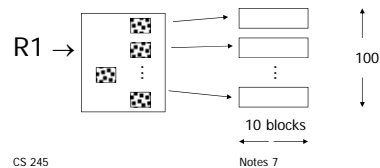
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Example 1(f) Hash Join

- R1, R2 contiguous (un-ordered)
- \rightarrow Use 100 buckets
- \rightarrow Read R1, hash, + write buckets

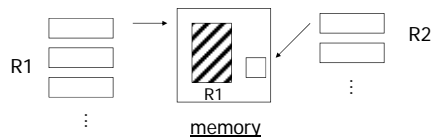


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- \rightarrow Same for R2
- \rightarrow Read one R1 bucket; build memory hash table
- \rightarrow Read corresponding R2 bucket + hash probe



Then repeat for all buckets

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Cost:

"Bucketize:" Read R1 + write
Read R2 + write

Join: Read R1, R2

$$\text{Total cost} = 3 \times [1000 + 500] = 4500$$

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Cost:

"Bucketize:" Read R1 + write

Read R2 + write

Join: Read R1, R2

$$\text{Total cost} = 3 \times [1000 + 500] = 4500$$

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

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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

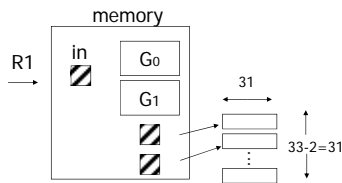
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Trick: keep some buckets in memory

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



called hybrid hash-join

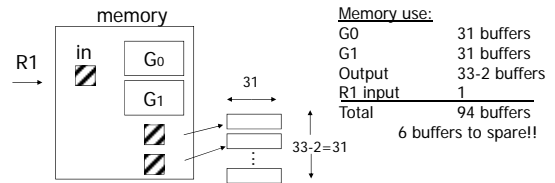
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Trick: keep some buckets in memory

E.g., $k'=33$ R1 buckets = 31 blocks
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called hybrid hash-join

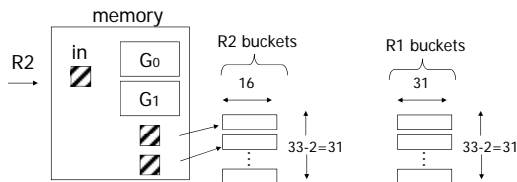
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Next: Bucketize R2

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



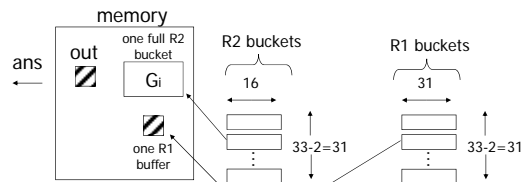
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Finally: Join remaining buckets

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



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Cost

- Bucketize R1 = $1000 + 31 \times 31 = 1961$
- To bucketize R2, only write 31 buckets:
so, cost = $500 + 31 \times 16 = 996$
- To compare join (2 buckets already done)
read $31 \times 31 + 31 \times 16 = 1457$

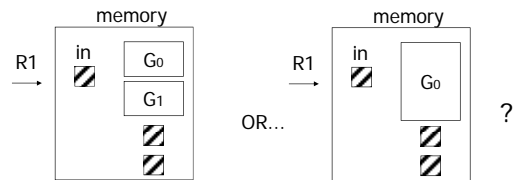
Total cost = $1961 + 996 + 1457 = 4414$

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• How many buckets in memory?



☒ See textbook for answer...

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Another hash join trick:

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

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

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- To illustrate cost computation, assume:
 - 100 <val,ptr> pairs/block
 - expected number of result tuples is 100
- Build hash table for R2 in memory
 5000 tuples $\rightarrow 5000/100 = 50$ blocks
- Read R1 and match
- Read ~ 100 R2 tuples

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- To illustrate cost computation, assume:
 - 100 <val,ptr> pairs/block
 - expected number of result tuples is 100
- Build hash table for R2 in memory
 5000 tuples $\rightarrow 5000/100 = 50$ blocks
- Read R1 and match
- Read ~ 100 R2 tuples

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

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So far:

contiguous	Iterate	5500
	Merge join	1500
	Sort+merge join	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

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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

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- 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)

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Join strategies for parallel processors

Later on....

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Chapter 16 [16] summary

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

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