ECS 165B: Database System Implementation
Lecture 12

UC Davis
April 23, 2010

Acknowledgements: portions based on slides by Raghu Ramakrishnan and Johannes Gehrke.

Class Agenda

- Last time:
  - Query evaluation techniques; external sorting
- Today:
  - Finish with external sorting
  - Physical query operators
- Reading
  - Chapters 13 and 14 of Ramakrishnan and Gehrke (or Chapter 13 of Silberschatz et al)

Announcements

Grades for Part 1: Monday

Quiz #1 in class next Wednesday (now reflected on web page); review session in class Monday

Quiz #2 (along with "Awards Ceremony") **will be during final exam slot**

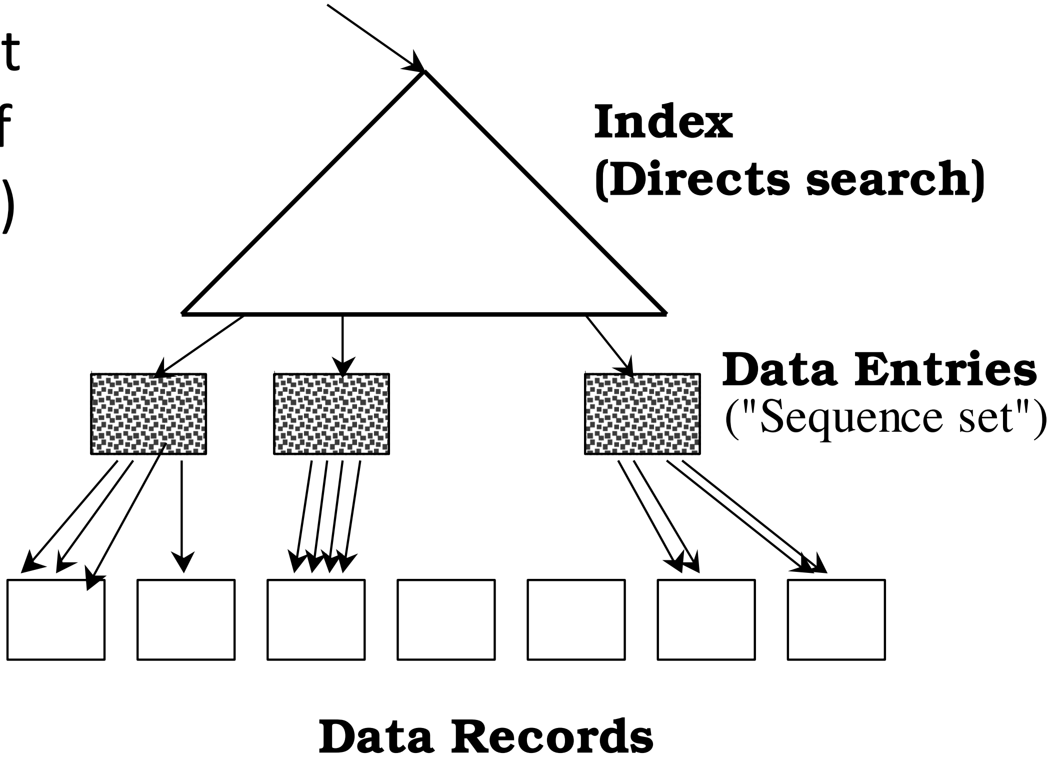
External Sorting, continued

Using B+ Trees for Sorting

- Scenario: table to be sorted has B+ tree index on sorting column(s)
- Idea: can retrieve records in order by traversing leaf pages
- Is this a good idea?
- Cases to consider:
  - B+ tree is clustered *Good idea!*
  - B+ tree is not clustered *Could be a very bad idea!*

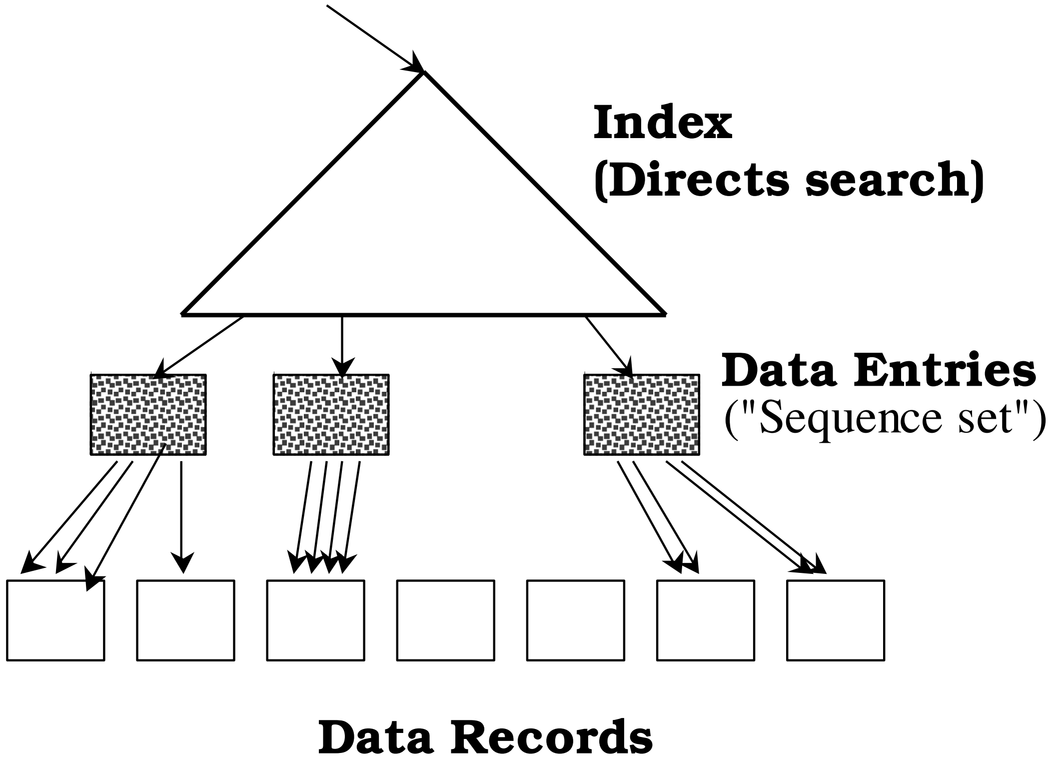
Clustered B+ Tree Used for Sorting

- Cost: root to the leftmost leaf, then retrieve all leaf pages (index is clustered)
- Each page fetched just once
- Always better than external sorting!



Unclustered B+ Tree Used for Sorting

- Leaves of tree have record ids, rather than records themselves
- In worst case, one I/O per data record!



External Sorting vs Unclustered Index

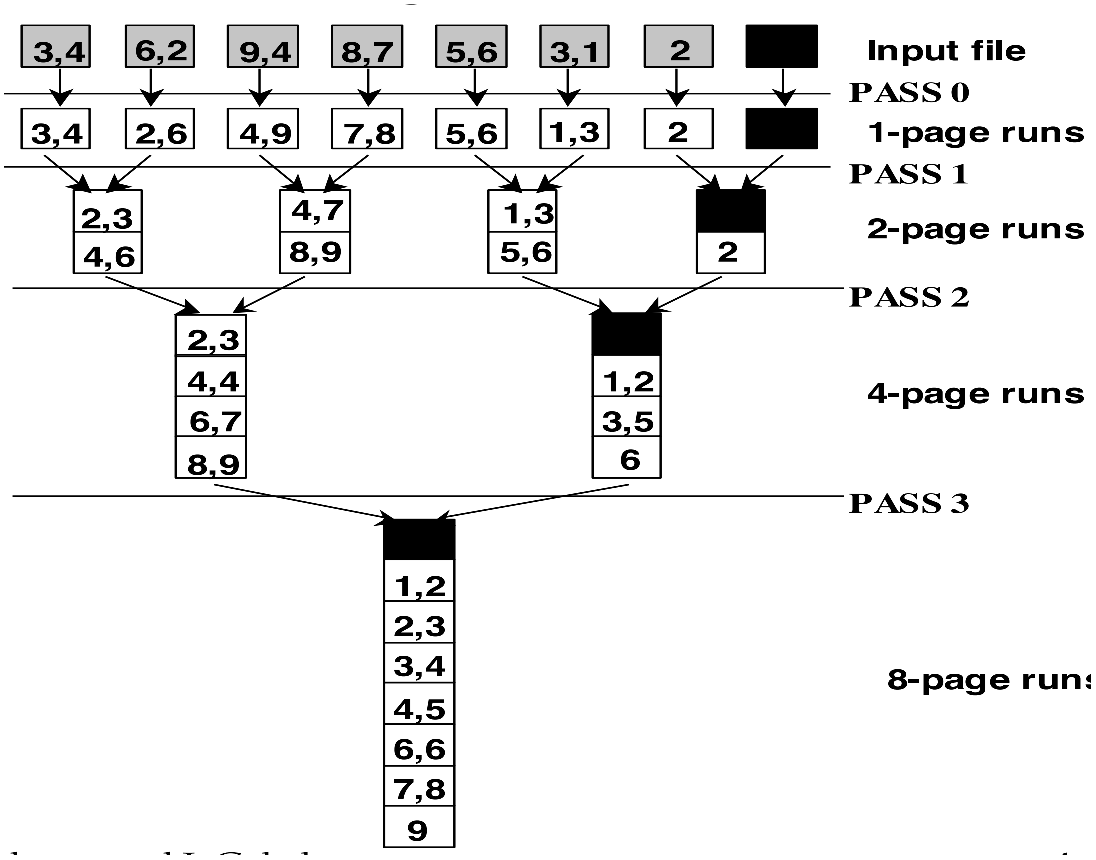
# of data pages		Unclustered index		
N	Sorting	p=1	p=10	p=100
100	200	100	1,000	10,000
1,000	2,000	1,000	10,000	100,000
10,000	40,000	10,000	100,000	1,000,000
100,000	600,000	100,000	1,000,000	10,000,000
1,000,000	8,000,000	1,000,000	10,000,000	100,000,000
10,000,000	80,000,000	10,000,000	100,000,000	1,000,000,000

- p = # of records per page
- B = 1000 and block size = 32 for external sorting
- p = 100 is the more realistic value

Summary of External Sorting

- External sorting is important; DBMS may dedicate part of buffer pool for sorting!
- External merge sort minimizes disk I/O cost
  - Pass 0: produces sorted **runs** of size *B* (# of buffer pages)
  - # of runs merged at a time depends on *B* and block size
  - Larger block size means less I/O cost per page
  - Larger block size means smaller # runs merged
  - In practice, # of runs rarely more than 2 or 3

Summary: External Merge Sort



- 2-way merge sort can be generalized to *n*-way merge sort, using as many interal buffer pages as we have available

Physical Relational Operators, Part 1: Joins

Relational Operations

- We will consider how to implement:

Selection (σ)	Selects a subset of rows from relation
Projection (π)	Deletes/reorders columns from relation
Join (&)	Allows us to combine two relations
Difference (−)	Tuples in one relation, but not the other
Union (U)	Tuples in either relation
Aggregation	SUM, MIN, etc. and GROUP BY

- Since each operation returns a relation, operations can be *composed*.
- After we cover the operations in isolation, we will discuss how to *optimize* queries formed by composing them

Schema for Running Examples

Sailors(*sid*: integer, *sname*: string, *rating*: integer, *age*: float)

Reserves(*sid*: integer, *bid*: integer, *day*: date, *rname*: string)

- Reserves: each tuple is 40 bytes long, 100 tuples per page, 1000 pages
- Sailors: each tuple is 50 bytes long, 80 tuples per page, 500 pages

Equality Joins With One Join Column

```
select *
from Reserves R, Sailors S
where R.sid = S.sid
```

R & S
(& is bowtie)

- Common! Must be carefully optimized. $R \times S$ is large, so $R \times S$ followed by selection is inefficient
- Assume: M tuples in R, p_R tuples per page, N tuples in S, p_S tuples per page
  - In our examples, *R* is Reserves and *S* is Sailors
- Will consider more complex join conditions later
- **Cost metric**: # of I/Os

Simple Nested Loops Join

```
for each tuple r in R do
    for each tuple s in S do
        if r and s agree on join attribute then
            add <r,s> to result
```

- For each tuple in the *outer* relation *R*, we can the entire *inner* relation *S*
  - Cost: $M + p_R * M * N = 1000 + 100*1000*500$ I/Os
- Page-oriented nested loops join: for each *page* of *R*, get each *page* of *S*, and write out matching pairs of tuples <*r*,*s*> where *r* is in *R*-page and *s* is in *S*-page
  - Cost: $M + M*N = 1000 + 1000*500$

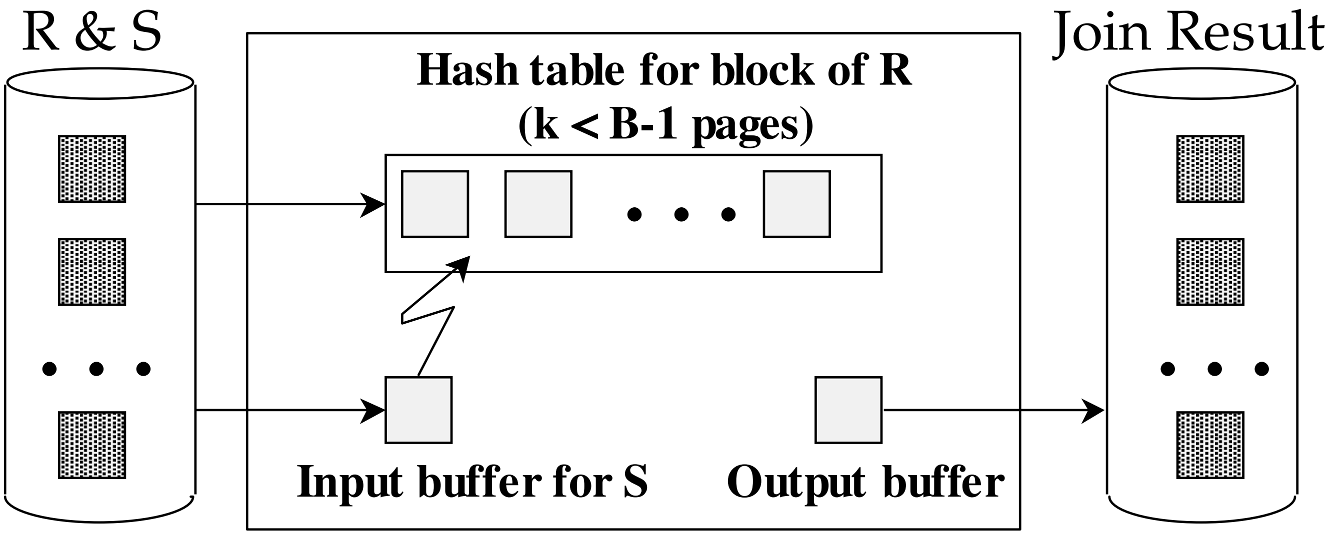
Index Nested Loops Join

```
for each tuple $r$ in $R$ do
    for each tuple $s$ in $S$ do
        if $r$ and $s$ agree on join attribute then
            add <$r$,$s$> to result
```

- If there is an index on the join attribute of one relation (say S), can make it the inner and exploit the index
    - Cost: $M + ((M * p_R) *$ cost of finding matching S tuples)
- For each R tuple, cost of probing S index is about 1.2 for hash index, 2-4 for B+ tree. Cost of then finding S tuples depends on clustering
    - Clustered index: usually 1 I/O per **group** of tuples with a given key; unclustered: up to 1 I/O per **tuple** in group of tuples with a given key

Block Nested Loops Join

- Use one page as an input buffer for scanning the inner *S*, one page as the output buffer, and all remaining pages to hold *block* of outer *R*
  - For each matching tuple *r* in *R*-block, *s* in *S*-page, add <*r*,*s*> to result. Then read next *R*-block, scan *S*, and repeat.



Sort-Merge Join

- Sort *R* and *S* on the join attribute, then scan them to do a *merge* (on join attribute), and output result tuples
  - Advance scan of *R* until current *R*-tuple ≥ current *S*-tuple, then advanced scan of *S* until current *S*-tuple ≥ current *R*-tuple; do this until current *R*-tuple = current *S*-tuple
  - At this point, *R*-tuple *matches* current *S*-tuple (and all following *S*-tuples with same value); output <*r*,*s*> for all pairs of such tuples
  - Then resume scanning *R* and *S*
- *R* is scanned once; each *S* "group" is scanned once per matching *R* tuple.

Example of Sort-Merge Join

sid	sname	rating	age
22	dustin	7	45.0
28	yuppy	9	35.0
31	lubber	8	55.5
44	guppy	5	35.0
58	rusty	10	35.0

sid	bid	day	rname
28	103	12/4/96	guppy
28	103	11/3/96	yuppy
31	101	10/10/96	dustin
31	102	10/12/96	lubber
31	101	10/11/96	lubber
58	103	11/12/96	dustin

- Cost: $M \log M + N \log N + {\sim}(M + N)$
  - In worst case $M + N$ could actually be $M*N$, but unlikely

Refinement of Sort-Merge Join

We can combine the merging phases in the *sorting* of R and S with the merging required for the join.

- With B > $\sqrt{L}$, where L is the size of the larger relation, using the sorting refinement that produces runs of length 2B in Pass 0, #runs of each relation is < B/2.
- Allocate 1 page per run of each relation, and `merge’ while checking the join condition.
- Cost: read+write each relation in Pass 0 + read each relation in (only) merging pass (+ writing of result tuples).
- In example, cost goes down from 7500 to 4500 I/Os.

In practice, cost of sort-merge join, like the cost of external sorting, is *linear*.

Hash Join

- Partition both relations using hash function *h*: *R* tuples in partition *i* will only match *S* tuples in partition *i*
- Read in a partition of *R*, hash it using *h'* (≠ *h*!). Scan matching partition of *S*, search for matches.