Evaluation of Relational Operations

CMPSCI 445

Fall 2008

Relational Operations

- We will consider how to implement:
  - *Selection* (σ) Selects a subset of rows from relation.
  - *Projection* (π) Deletes unwanted columns from relation.
  - *Join* ($\bowtie$) Allows us to combine two relations.
  - *Set-difference* ($-$) Tuples in reln. 1, but not in reln. 2.
  - *Union* ($\cup$) Tuples in reln. 1 and in reln. 2.
  - *Aggregation* (SUM, MIN, etc.) and GROUP BY
  - *Order By* Returns tuples in specified order.
- After we cover the operations, we will discuss how to *optimize* queries formed by composing them.

Outline

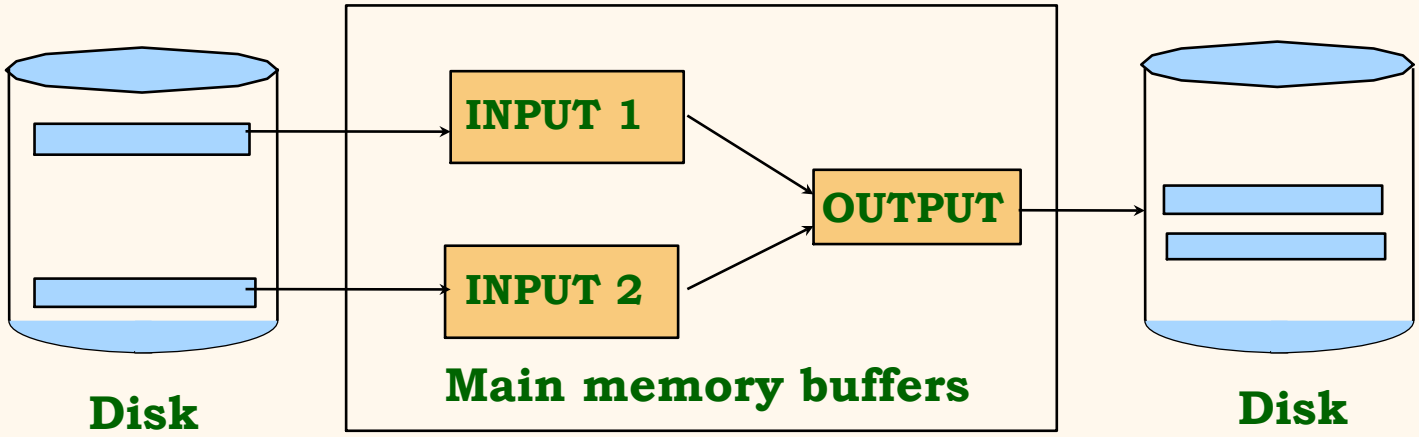
- Sorting
- Evaluation of joins
- Evaluation of other operations

Why Sort?

- A classic problem in computer science!
- Important utility in DBMS:
  - Data requested in sorted order (e.g., ORDER BY)
    - e.g., find students in increasing *gpa* order
  - Sorting useful for eliminating *duplicates* (e.g., SELECT DISTINCT)
  - *Sort-merge* join algorithm involves sorting.
  - Sorting is first step in *bulk loading* B+ tree index.
- Problem: sort 1Gb of data with 1Mb of RAM.

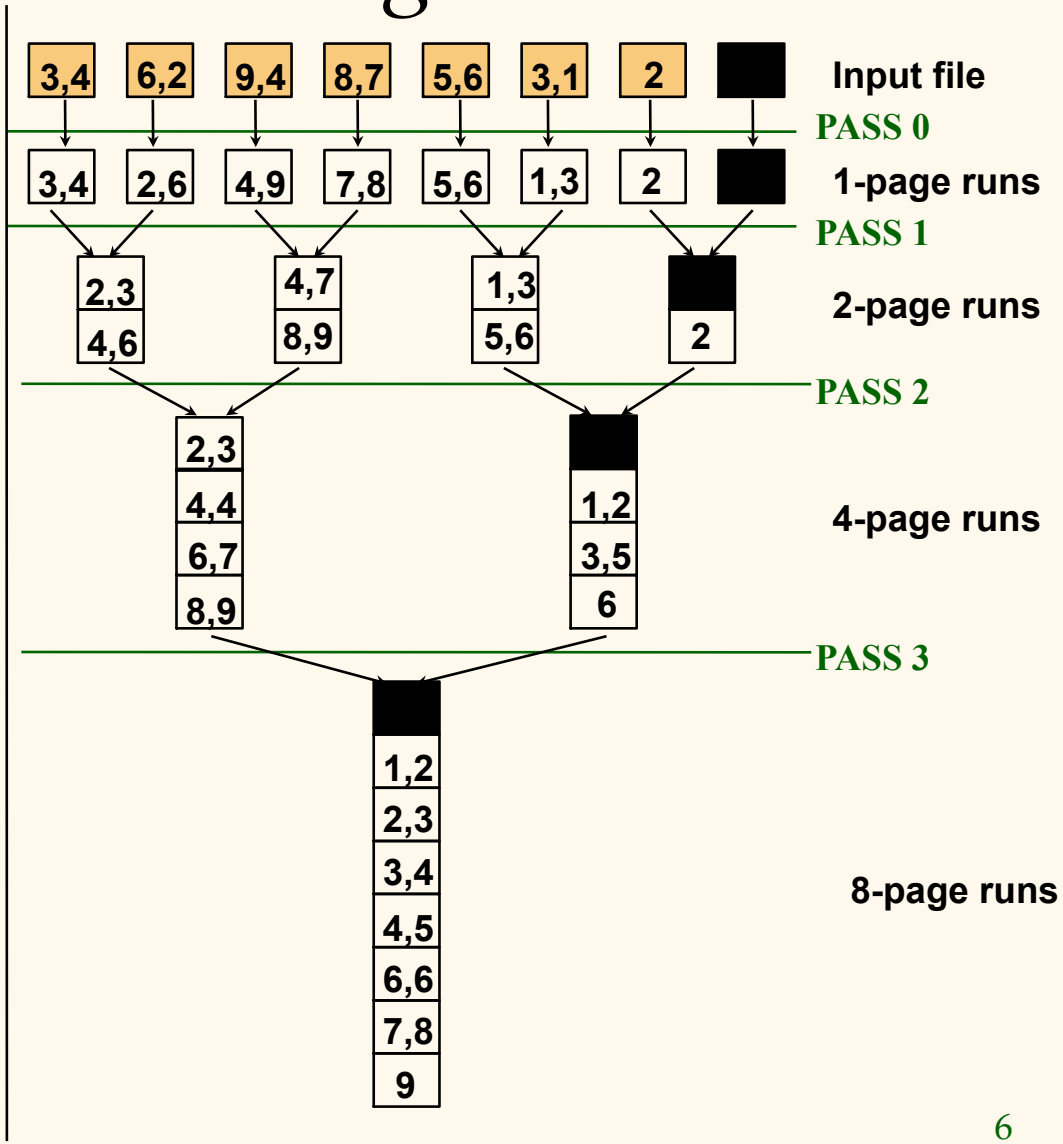
2-Way Sort: Requires 3 Buffers

- Pass 1: Read a page, sort it, write it.
  - only one buffer page is used
- Pass 2, 3, …, etc.:
  - three buffer pages used.



Two-Way External Merge Sort

- Each pass we read + write each page in file: 2N.
- N pages in the file => the number of passes
$$= \lceil \log_2 N \rceil + 1$$
- So total cost is:
$$2N\left(\lceil \log_2 N \rceil + 1\right)$$
- *Idea:* ***Divide and conquer:*** sort subfiles and merge

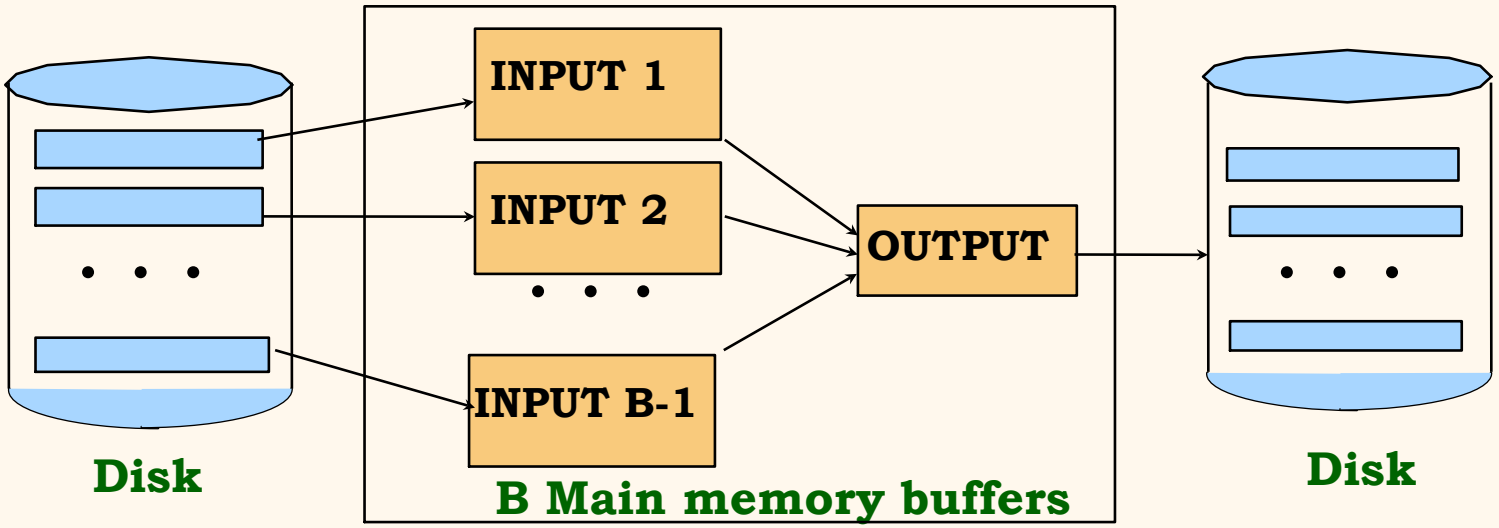


General External Merge Sort

☛ ***More than 3 buffer pages. How can we utilize them?***

❖ To sort a file with N pages using B buffer pages:

- Pass 0: use B buffer pages. Produce $\lceil N / B \rceil$ sorted runs of B pages each.
- Pass 2, …, etc.: merge B-1 runs.



Cost of External Merge Sort

- Number of passes: $1 + \lceil \log_{B-1} \lceil N / B \rceil \rceil$
- Cost = 2N * (# of passes)
- E.g., with 5 buffer pages, to sort 108 page file:
  - Pass 0: $\lceil 108 / 5 \rceil$ = 22 sorted runs of 5 pages each (last run is only 3 pages)
  - Pass 1: $\lceil 22 / 4 \rceil$ = 6 sorted runs of 20 pages each (last run is only 8 pages)
  - Pass 2: 2 sorted runs, 80 pages and 28 pages
  - Pass 3: Sorted file of 108 pages

Number of Passes of External Sort

N	B=3	B=5	B=9	B=17	B=129	B=257
100	7	4	3	2	1	1
1,000	10	5	4	3	2	2
10,000	13	7	5	4	2	2
100,000	17	9	6	5	3	3
1,000,000	20	10	7	5	3	3
10,000,000	23	12	8	6	4	3
100,000,000	26	14	9	7	4	4
1,000,000,000	30	15	10	8	5	4

Blocked I/O for External Merge Sort

- … longer runs often means fewer passes!
- Actually, we don't do I/O a page at a time
- In fact, read a *block* of pages sequentially!
- Suggests we should make each buffer (input/output) be a *block* of pages.
  - But this will reduce fan-out during merge passes!
  - In practice, most files still sorted in 2-3 passes.

Sorting Records!

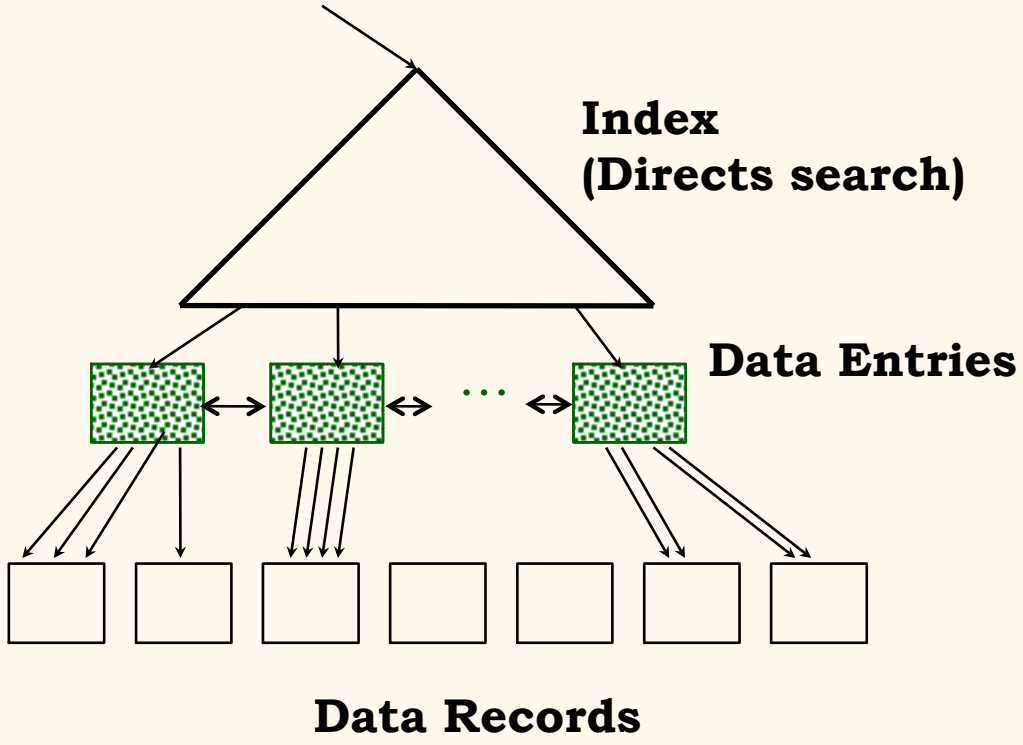
- Sorting has become highly competitive!
  - Parallel sorting is the name of the game ...
- Datamation sort benchmark: Sort 1M records of size 100 bytes
  - in 1985: 15 minutes
  - World records: 1.18 ***seconds*** (1998 record)
    - 16 off-the-shelf PC, each with 2 Pentium processor, tow hard disks, running NT4.0.
- New benchmarks proposed:
  - Minute Sort: How many can you sort in 1 minute?
  - Dollar Sort: How many can you sort for $1.00?

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 left-most leaf, then retrieve all leaf pages (Alternative 1)
- If Alternative 2 is used? Additional cost of retrieving data records: each page fetched just once.

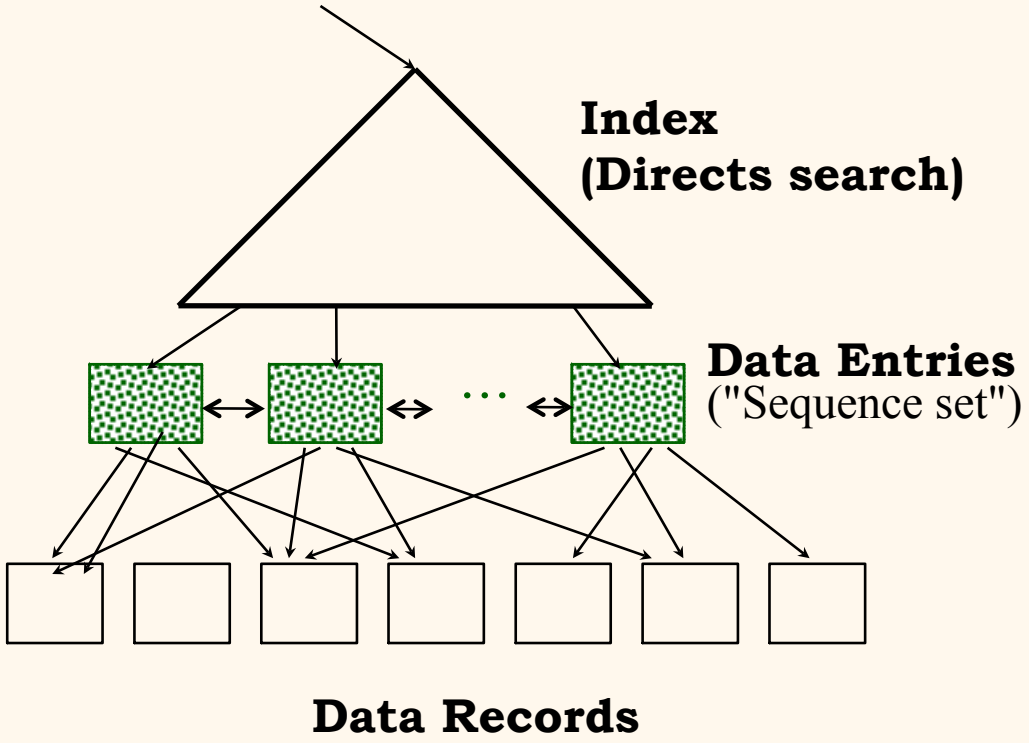


☛ *Always better than external sorting!*

Unclustered B+ Tree Used for Sorting

- Alternative (2) for data entries; each data entry contains *rid* of a data record. In general, one I/O per data record!

Worse case I/O: *pN*
p: # records per page
N: # pages in file



External Sorting vs. 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=1,000 and block size=32 for sorting***
- ***p=100 is the more realistic value.***

Summary

- 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*** (# buffer pages). Later passes: ***merge*** runs.
  - # 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.
- Clustered B+ tree is good for sorting; unclustered tree is usually very bad.