External Sorting

Why Sort?

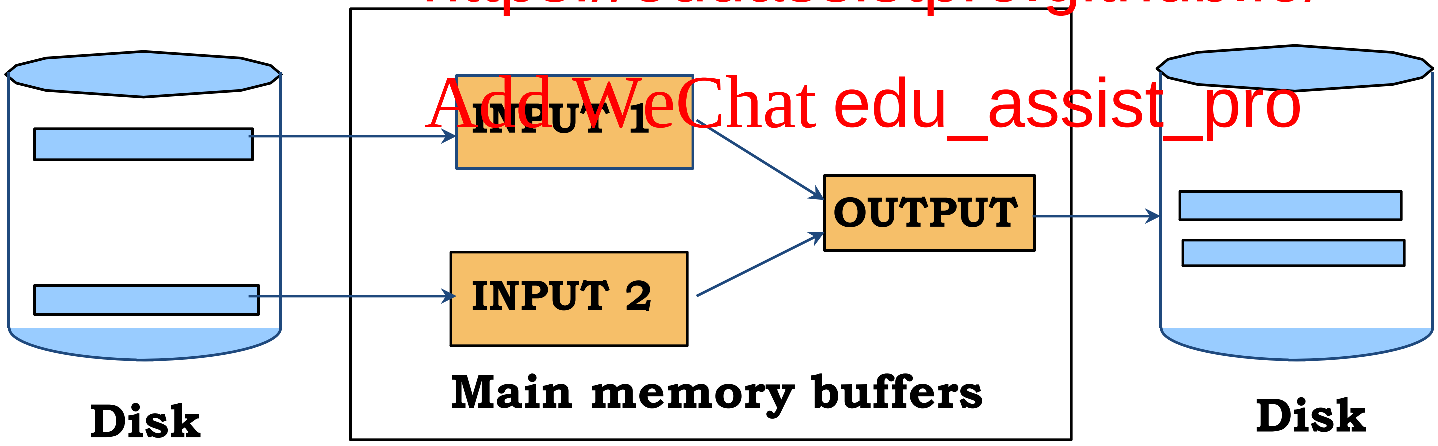
- A classic problem in computer science!
- Data requested in sorted order
  - e.g., find students in increasing *gpa* order

- Sorting is first step in *bulk loading* B+ tree index.
- Sorting useful *te copies* in a collection of records (Why

- *Sort-merge* join algorithm i rting.
- Problem: sort 1Gb of data with 1Mb of RAM.
- What is the minimum number of buffer pages needed to sort a file with arbitrary size?
  - Three.

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



Two-Way External Merge Sort

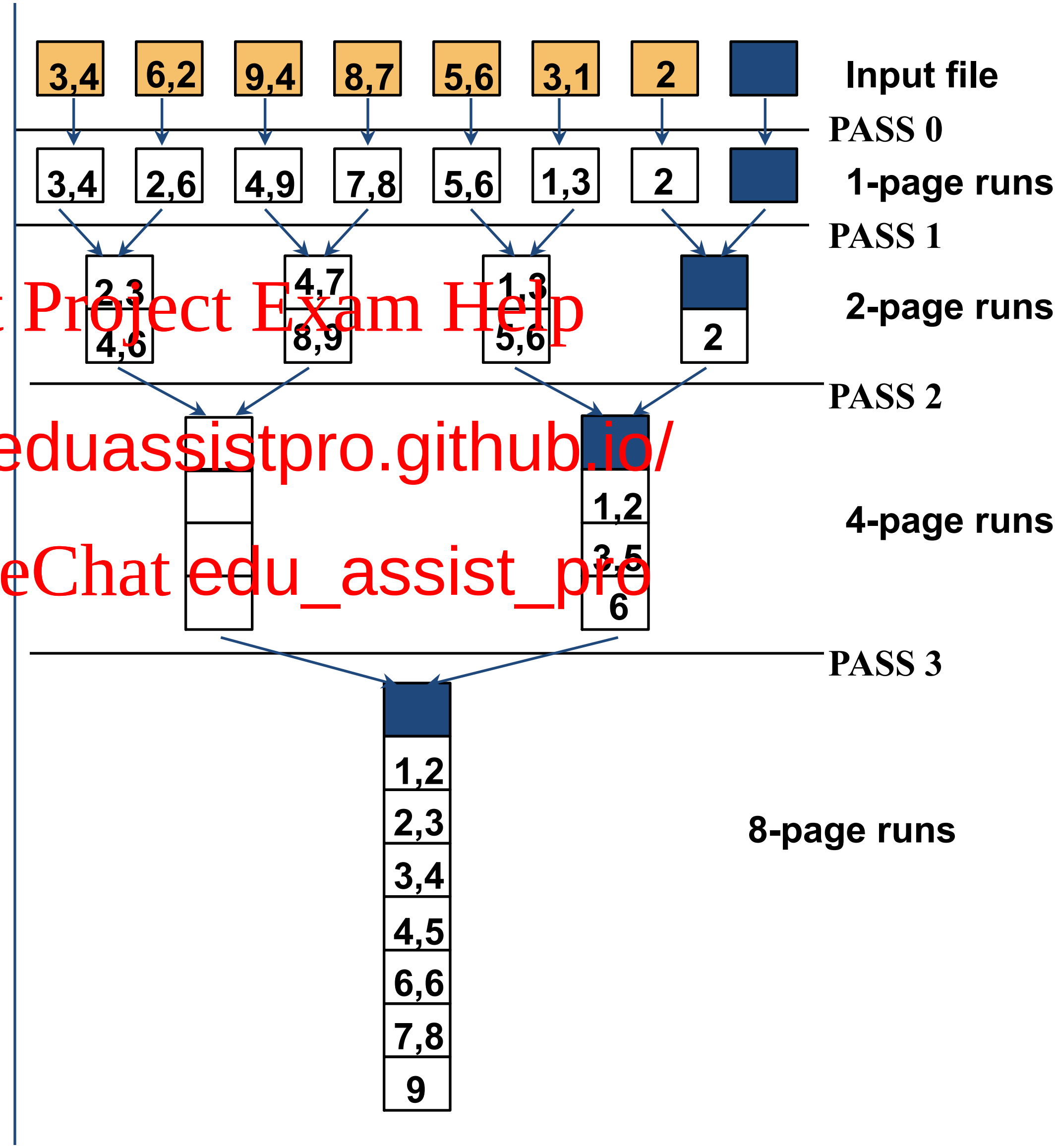
- Each pass we read + write each page in file.
- N pages in the file => the number of passes

$$=\lceil \log_2 N \rceil + 1$$

- So toal cost is:

$$2N\left(\lceil \log_2 N \rceil + 1\right)$$

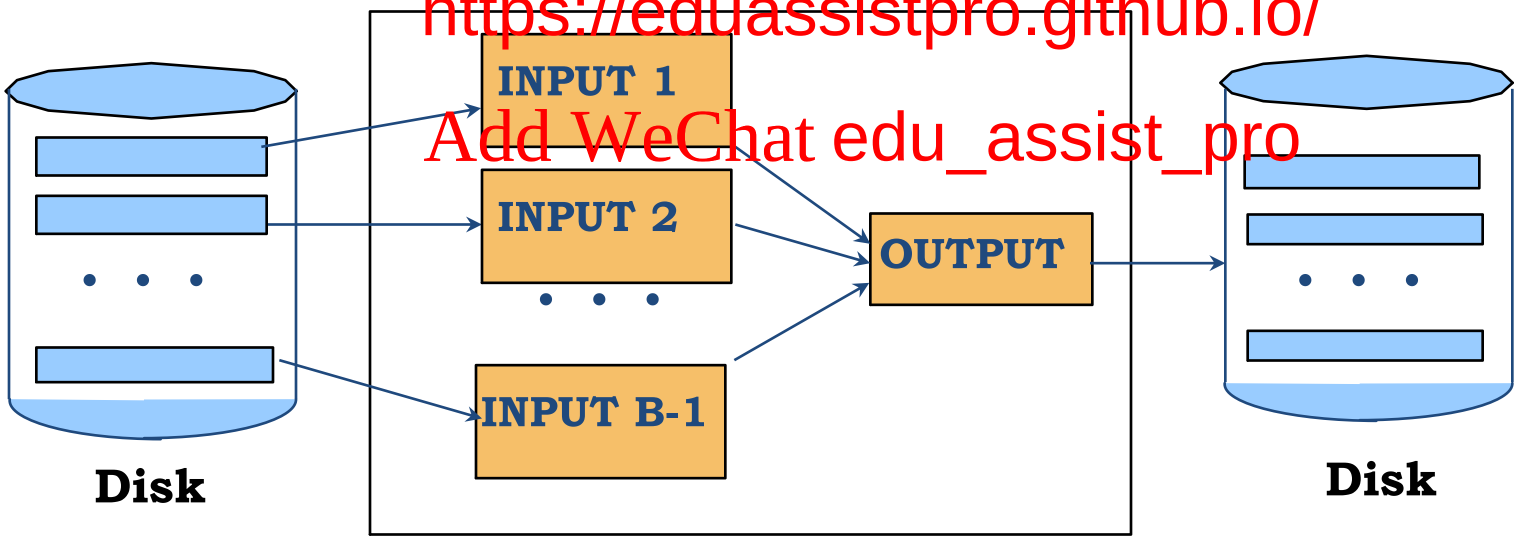
- _Idea:_ ***Divide and conquer:*** sort subfiles and merge



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.

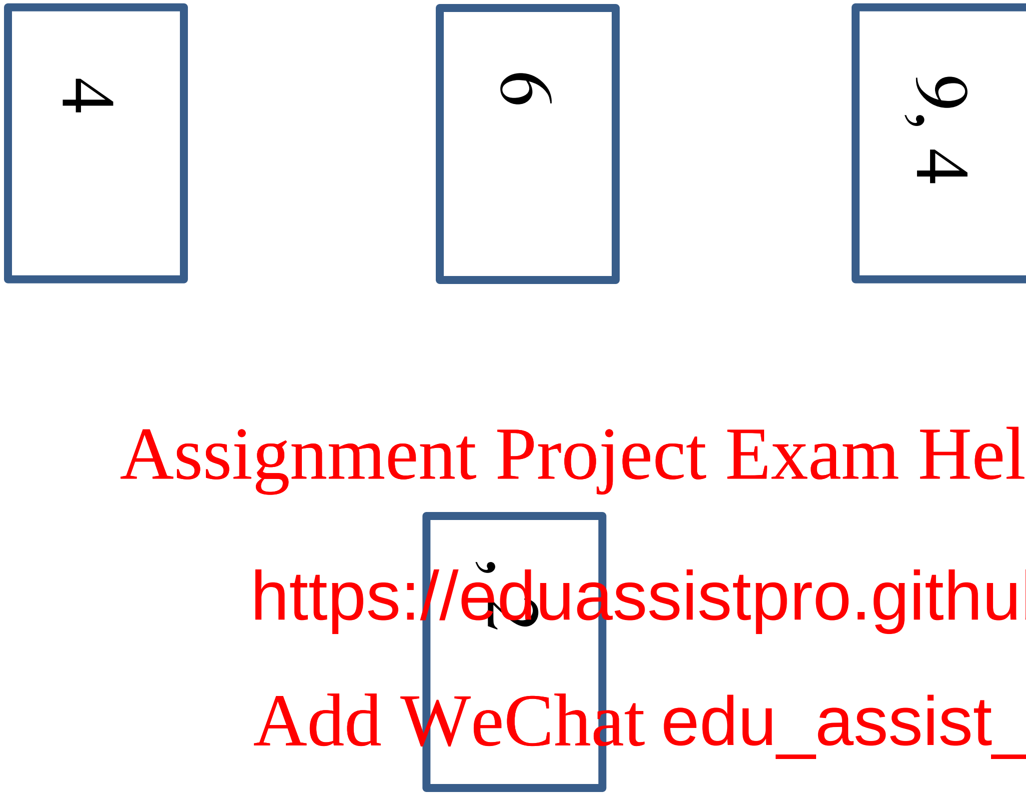


B Main memory buffers

4, 3

6, 2

9, 4



Cost of External Merge Sort

- Number of passes:
- Cost = 2N * (# of passes) $1+\lceil \log_{B-1} \lceil N / B \rceil \rceil$
- E.g., with 5 buffer pages, to sort 108 page file:

  – Pass 0: $\lceil 10$ pages each (last run is

  – Pass 1: $\lceil 22 / 4 \rceil$ = 6 sorted r

  ges 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					2	2
10,000					2	2
100,000	17	9			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

Speed-up: Internal Sort Algorithm

Quicksort is a fast way to sort in memory.

An alternative is “tournament sort” (a.k.a. “heapsort”): average run length is 2B.

- **Top:** Read in *B* blocks

  - **Output:** uffer
  - Read in a new

  - insert *r* into “
  - if *r* not smallest,

    - then **GOTO Output**
  - else
    - remove *r* from “heap”
    - output “heap” in order; **GOTO Top (next run)**

This can be only effectively used in the first pass. Virtually, make B be 2B.

I/O for External Merge Sort

- … longer runs often means fewer passes!
- Actually, do I/O a page at a time
- In fact, read a *block* of pages sequentially!

- Suggests we buffer (input/outp es.

  - But this will reduce fan-o merge passes!
  - In practice, most files still sorted in 2-3 passes.

Number of Passes of Optimized Sort

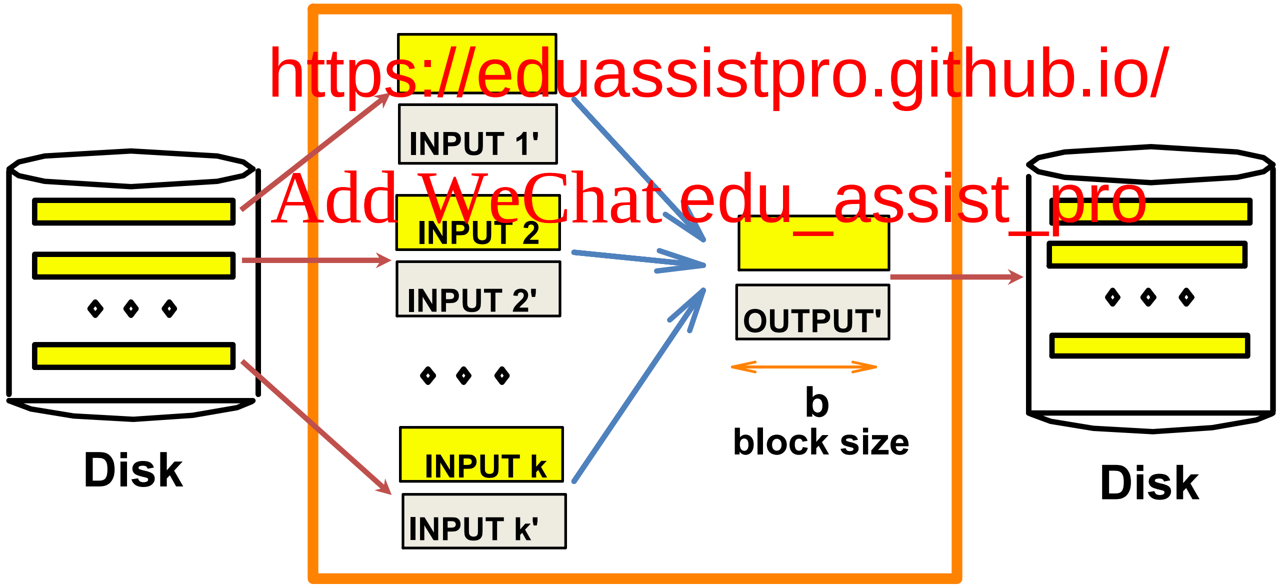
N	B=1,000	B=5,000	B=10,000
100	1	1	1
1,000	1	1	1
10,000	[illegible]	[illegible]	1
100,000	3	[illegible]	2
1,000,000	3	[illegible]	2
10,000,000	4	3	3
100,000,000	5	3	3
1,000,000,000	5	4	3

☛ *Block size = 32, initial pass produces runs of size 2B.*

Double Buffering

To reduce wait time for I/O request to complete, can *prefetch* into `shadow block'.

- Potentially, more passes; in practice, most files *still* sorted in 2-3 passes.



B main memory buffers, k-way merge

Sorting Records!

- Sorting has become a blood sport!
  - Parallel sorting is the name of the game ...
- Datamation: Sort 1M records of size 100 bytes

  - Typical DBMS

  - World record

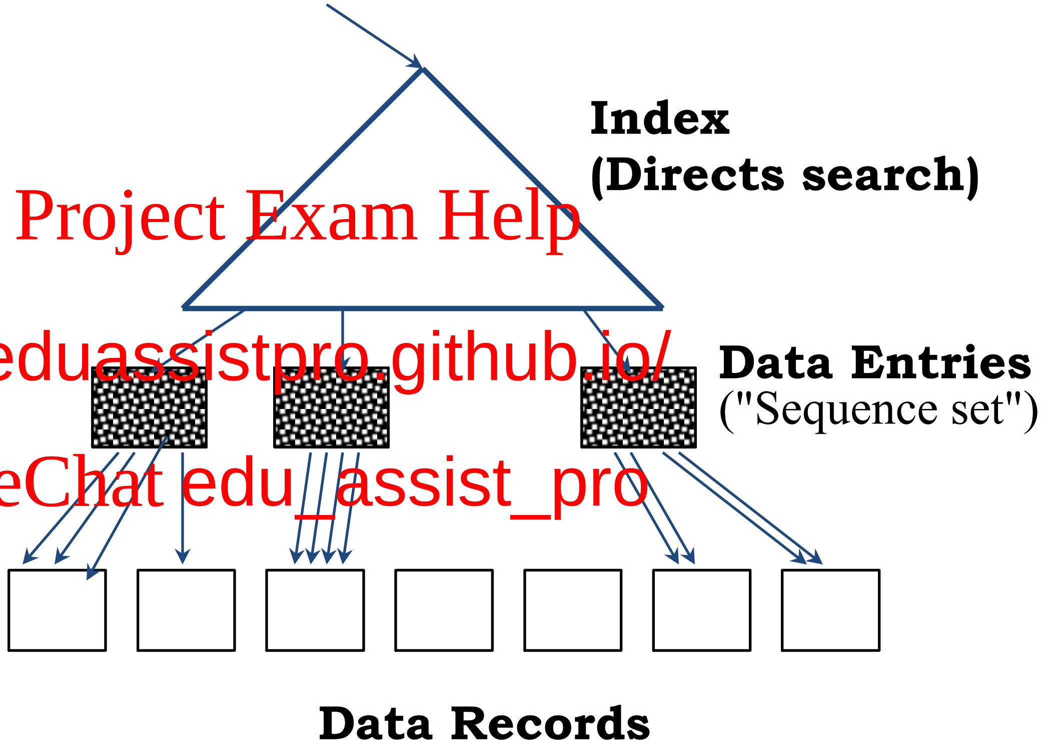
    - 12-CPU SGI machine, 96 RAM
- New benchmarks proposed:
  - Minute Sort: How many can you sort in 1 minute?

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***
- 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

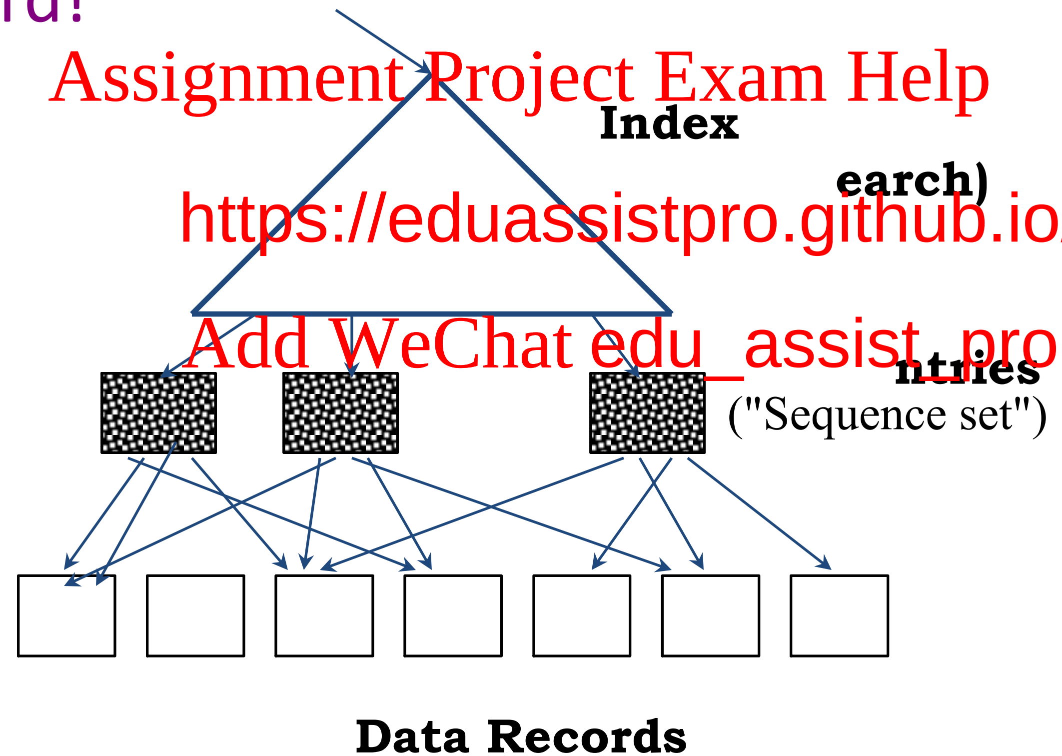
- Cost: root to the left-most leaf, then retrieve all leaf pages (Alternative 1)
- If Alternative 2 is Additional cost of retrieving data records: each page fetched just once.



☛ *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!



External Sorting vs. Unclustered Index

N	Sorting	p=1	p=10	p=100
100	200	100	1,000	10,000
1,000	2,000			100,000
10,000	40,000		0	1,000,000
100,000	600,000	100,000	0	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: Prod ze ***B*** (# buffer pages). Lat
  - # of runs merged at a ti s 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 passes rarely more than 2 or 3.

Summary, cont.

- Choice of internal sort algorithm may matter:
  - Quicksort: Quick!
  - Heap/tournament sort: slower (2x), longer runs

- The best sor

  - Despite 40 e’re still improving!

- Clustered B+ tree is good for sorting; unclustered tree is usually very bad.