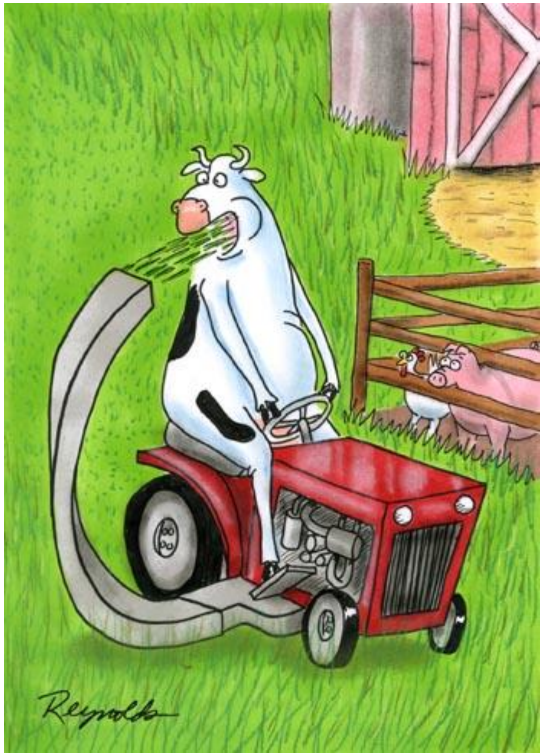
# *External Sorting*

Chapter 13

(I will be out of town on Wednesday, 2016-10-26. No class will be held.)

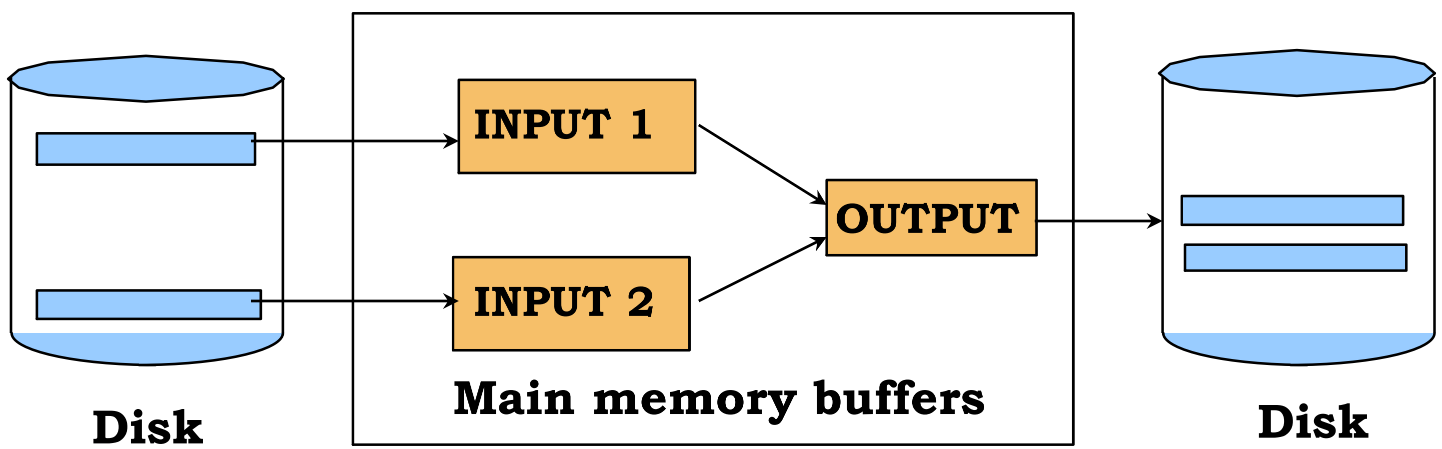


# *Why Sort?*

- A classic problem in computer science!
- Advantages of requesting data in sorted order
  - gathers duplicates
  - allows for efficient searches
- Sorting is first step in *bulk loading* B+ tree index.
- *Sort-merge* join algorithm involves sorting.
- Problem: sort 20Gb of data with 1Gb of RAM.
  - why not let the OS handle it with virtual memory?

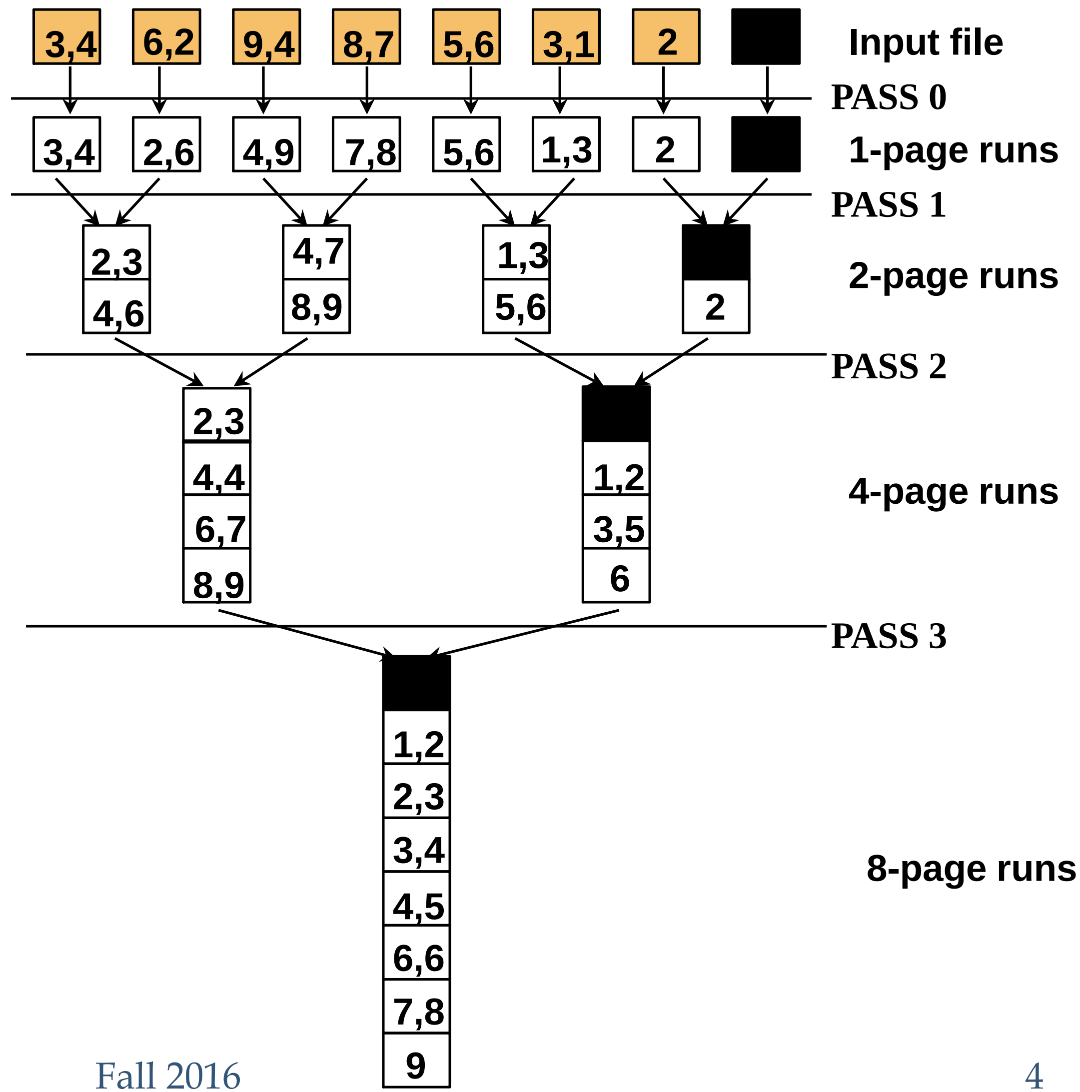
# 2-Way Sort: Requires 3 Buffers

- Pass 1: Read a page, sort it, write it.
  - only one buffer page is used
- Pass 2, 3, …, N etc.:
  - Read two pages, merge them, and write merged page
  - Requires three buffer pages.



# Two-Way External Merge Sort

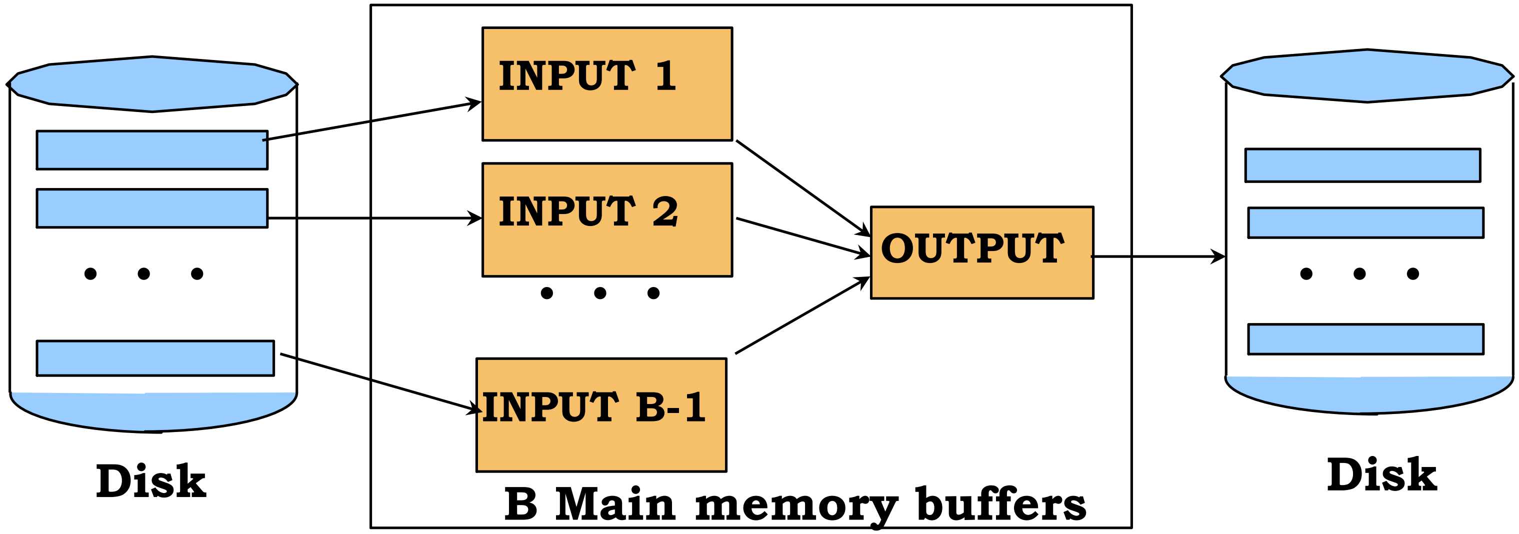
- Each pass we read + write each page in file.
- N pages in the file => the number of passes
  $$=\lceil \log_2 N \rceil + 1$$
- So toal cost is:
  $$2N\left(\lceil \log_2 N \rceil + 1\right)$$
- <u>*Idea:*</u> ***Divide and conquer:*** sort pages and merge



# *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.



# General External Merge Sort

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

- Key Insight #1: We can merge more than 2 input buffers at a time… affects fanout → base of log!
- Key Insight #2: The output buffer is generated incrementally, so only one buffer page is needed for any size of run!
- 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, leaving one page for output.

# 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: $\lceil 6/4 \rceil$ = 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 |

# *Internal Sort Algorithm*

- Quicksort is a fast way to sort in memory.
  - Very fast on average
  - Worse case $N^2$ (i.e. bad pivots)
- Alternatives
  - Heap Sort, stable and always O(NlogN)
  - Merge Sort, basic "out-of-core" sort applied recursively
  - Selection sort variants "Replacement Sort"
    - fill buffers in order from smallest
    - allows one to write sorted "top of list" before all buffers are entirely sorted
    - prefetch the next buffer while processing (streaming)

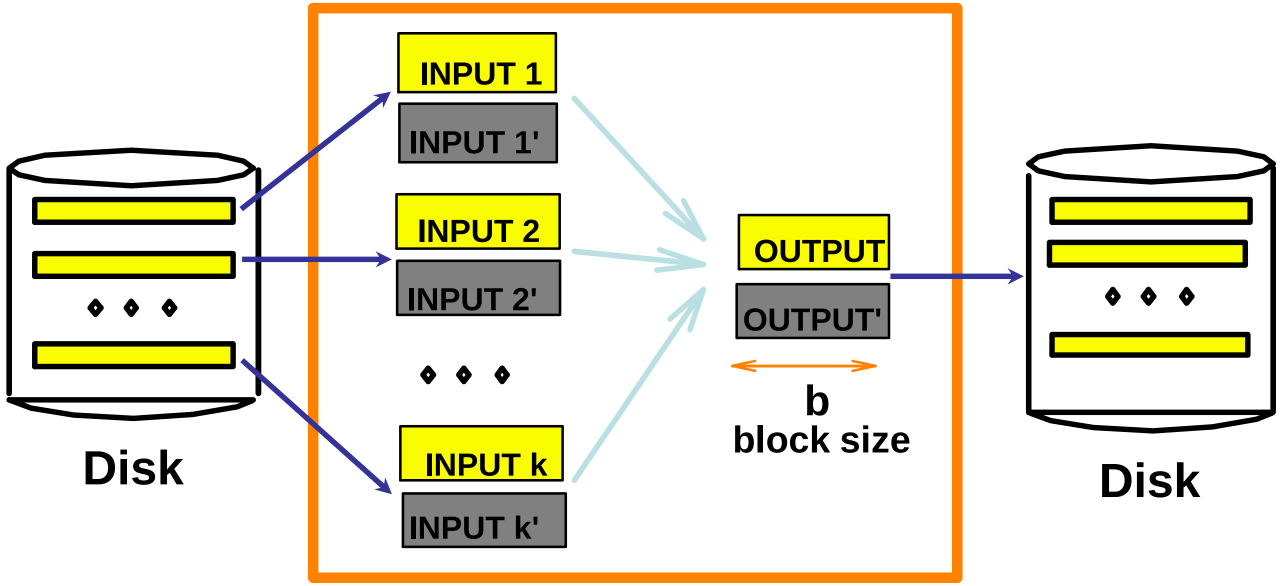
# *Number of Passes of Optimized Sort*

| N | B=1,000 | B=5,000 | B=10,000 |
|---|---|---|---|
| 100 | 1 | 1 | 1 |
| 1,000 | 1 | 1 | 1 |
| 10,000 | 2 | 2 | 1 |
| 100,000 | 3 | 2 | 2 |
| 1,000,000 | 3 | 2 | 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 a "shadow block".
- Potentially, more passes; in practice, most files *still* sorted in 2-3 passes.




B main memory buffers, k-way merge

# *Sorting Records!*

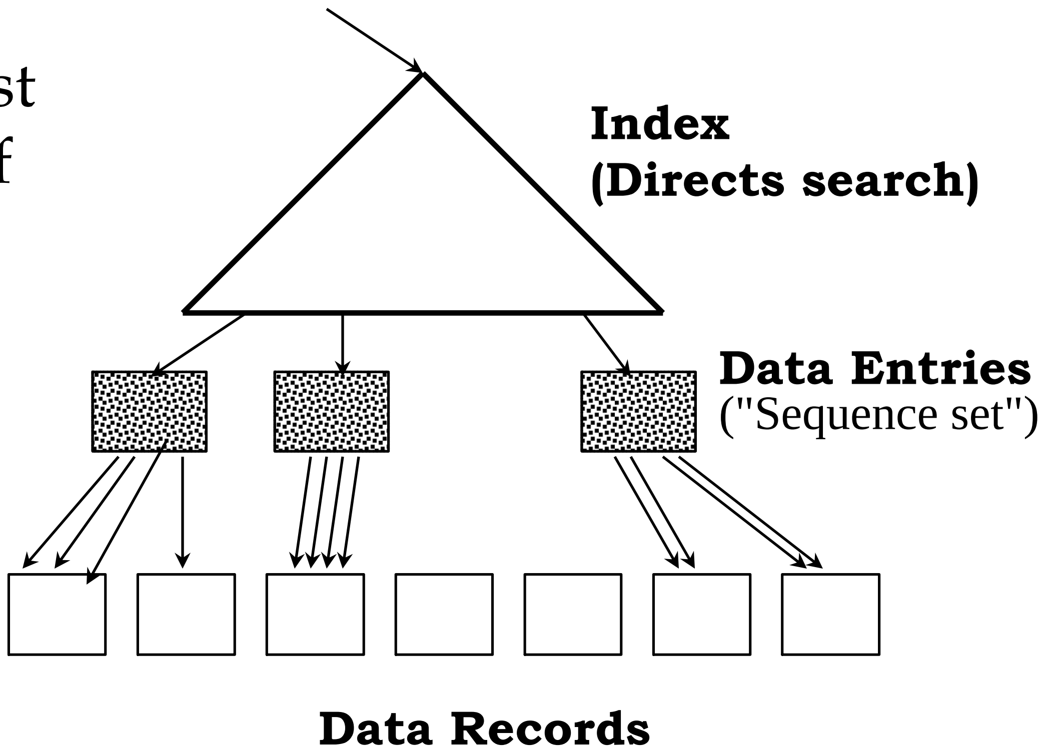
- Sorting has become a blood sport!
  - Parallel external sorting is the name of the game …
- 2005 IBM Almaden
  - Sort 1Tbyte of 100 byte records
  - Typical DBMS: > 5 days
  - World record: ***17 min, 37 seconds***
    - RS/6000 SP with 488 nodes
    - Each node: 4, 332MHz 604 processors, 1.5GB of RAM, and a 9GB SCSI disk
- 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.

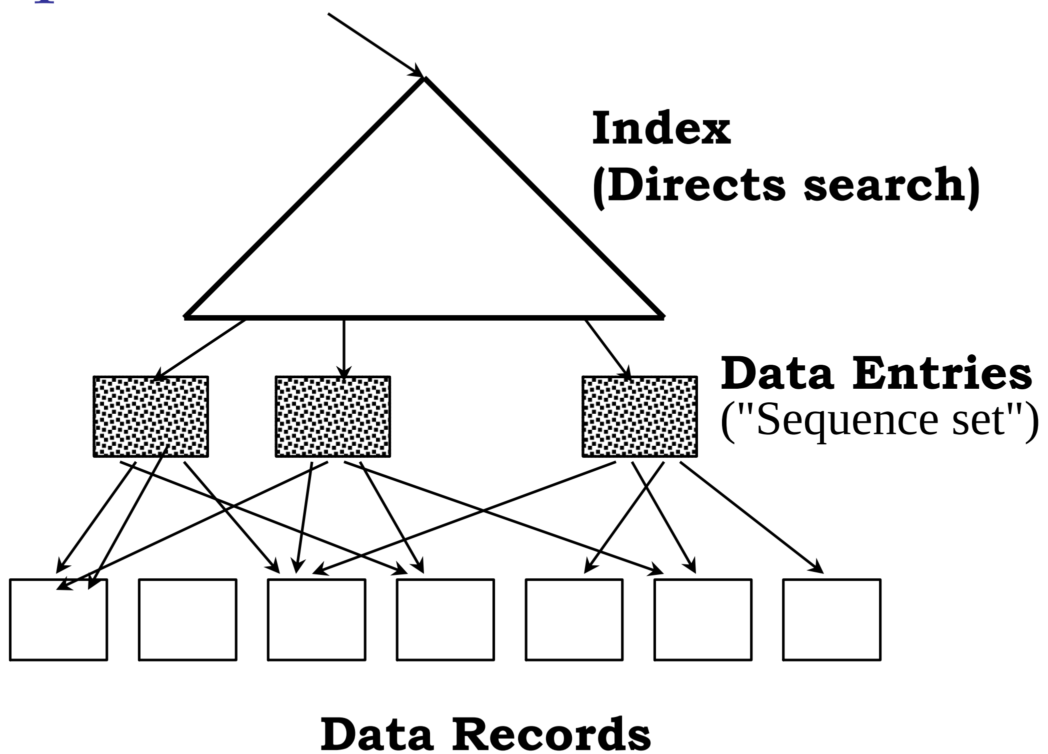



- Fill factor of < 100% introduces a small overhead extra pages fetched

☒ *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 | 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 just 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.

# Summary, cont.

- Choice of internal sort algorithm may matter:
  - Quicksort: Quick!
  - Alternative sorts
    - guaranteed N logN on worst case data
    - stable (ties retain their original order)
- The best sorts are wildly fast:
  - Despite 40+ years of research, we're still improving!
- Clustered B+ tree is good for sorting; unclustered tree is usually very bad.