Spring 2017

EXTERNAL SORTING

(CH. 13 IN THE COW BOOK)

Motivation for External Sort

- Often have a large (size greater than the available main memory) that we need to sort.
- Why are we sorting:
  - Query processing: e.g. there are sort-based join and aggregate algorithms
  - Bulkload B+-tree: recall you had to sort the data entries in the leaf level for this.
  - One can specify ORDER BY in SQL, which sorts the output of the query
  - …

Problem Statement

- Given **M** memory pages, and a relation of size **N** pages, where N > M, sort R on a **sort key**, to produce an output relation R' that is sorted on the sort key.
- Example: Sort the following table on zipcode

```
CREATE TABLE Tweets (
   uniqueMsgID INTEGER,       -- unique message id
   tstamp      TIMESTAMP,     -- when was the tweet posted
   uid         INTEGER,       -- unique id of the user
   msg         VARCHAR (140), -- the actual message
   zip         INTEGER,       -- zipcode when posted
   retweet     BOOLEAN        -- retweeted?
   );
```

- Another example: SELECT * FROM Tweets WHERE tstamp = TODAY ORDER BY zip

Note the sort key can be composite

Goal of a good sort algorithm

- Sort efficiently!
- Sort well!
  - Able to sort large relations with “small” amounts of main memory

Where does the memory come from?

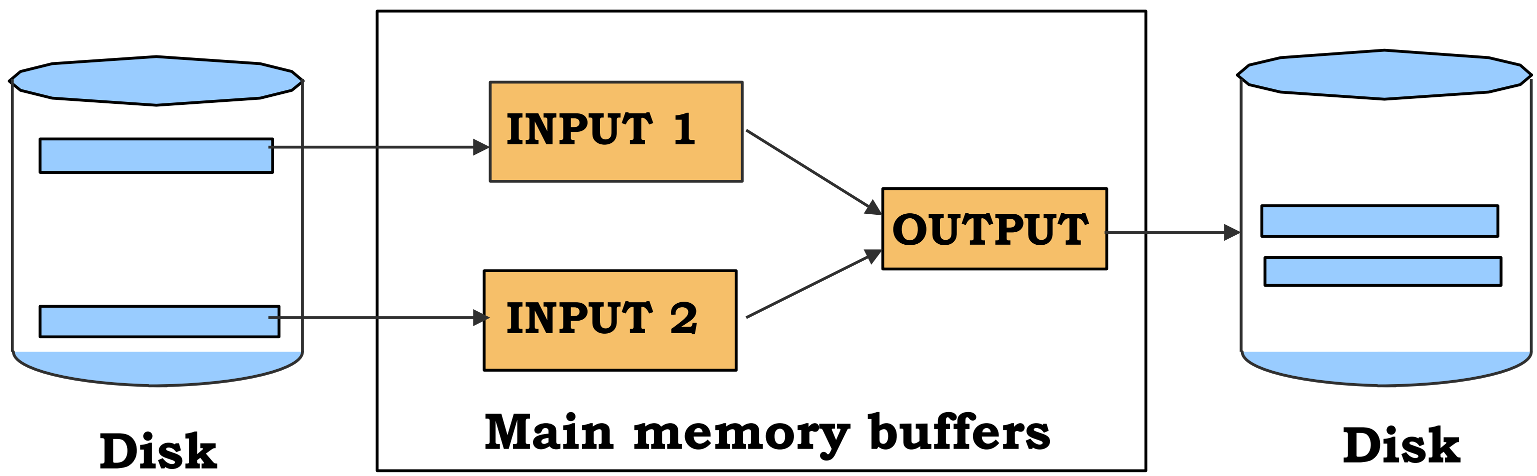
- What does sort efficiently mean:
  - Minimize the number of disk I/Os
  - Try using sequential I/Os rather than random I/Os
  - Minimize the CPU costs
  - Overlap I/O operations with CPU operations

Quick note: Sorting is very important in MapReduce. The reducer expects data to arrive in sorted order from the mappers.

2-Way Sort: Requires 3 Buffers

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

Algorithms for sorting in memory?



Two-Way External Merge Sort

- Read & write entire file in each pass
- N pages, # passes =

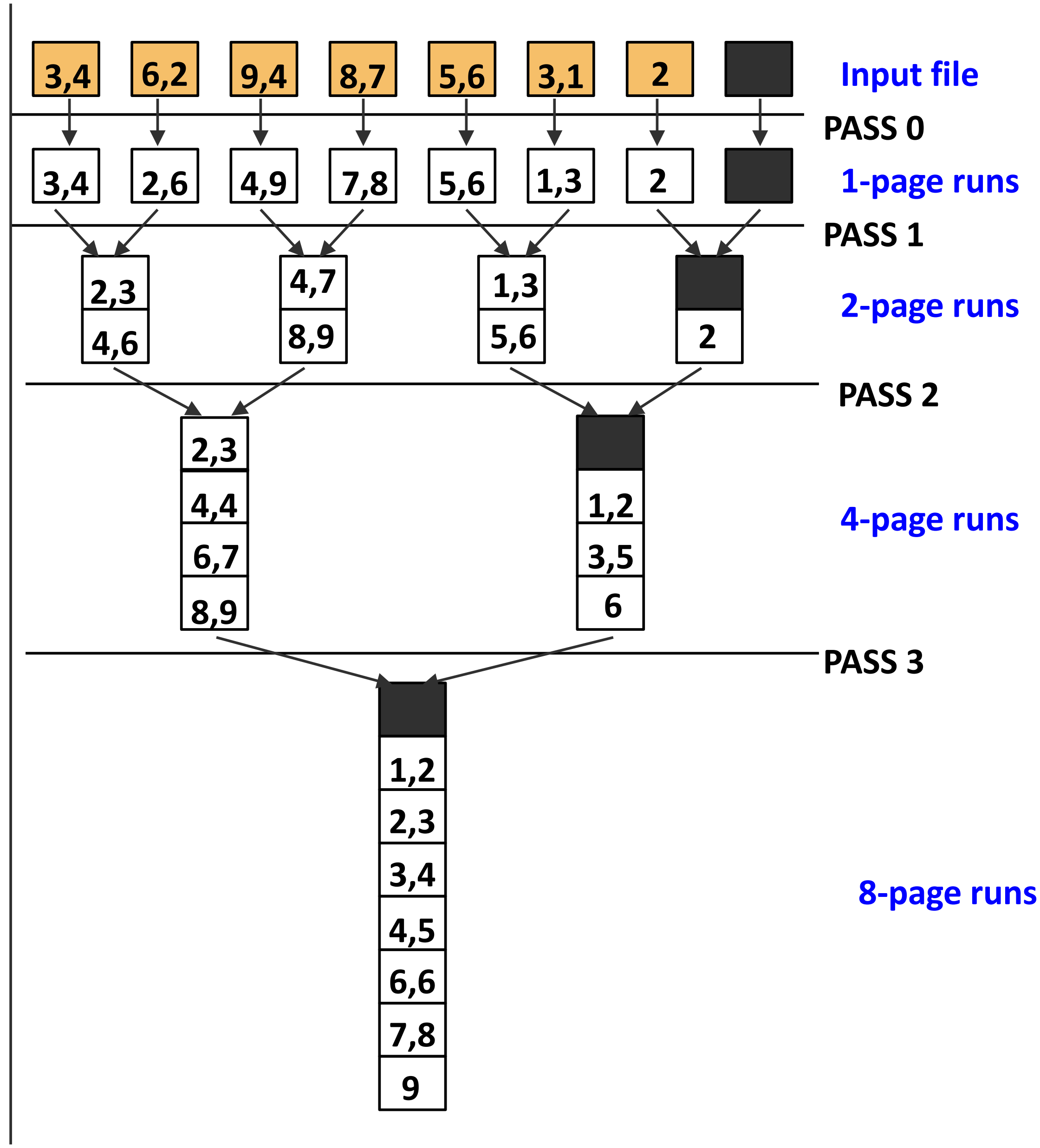
$$\lceil \log_2 N \rceil + 1$$

- So total cost is:

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

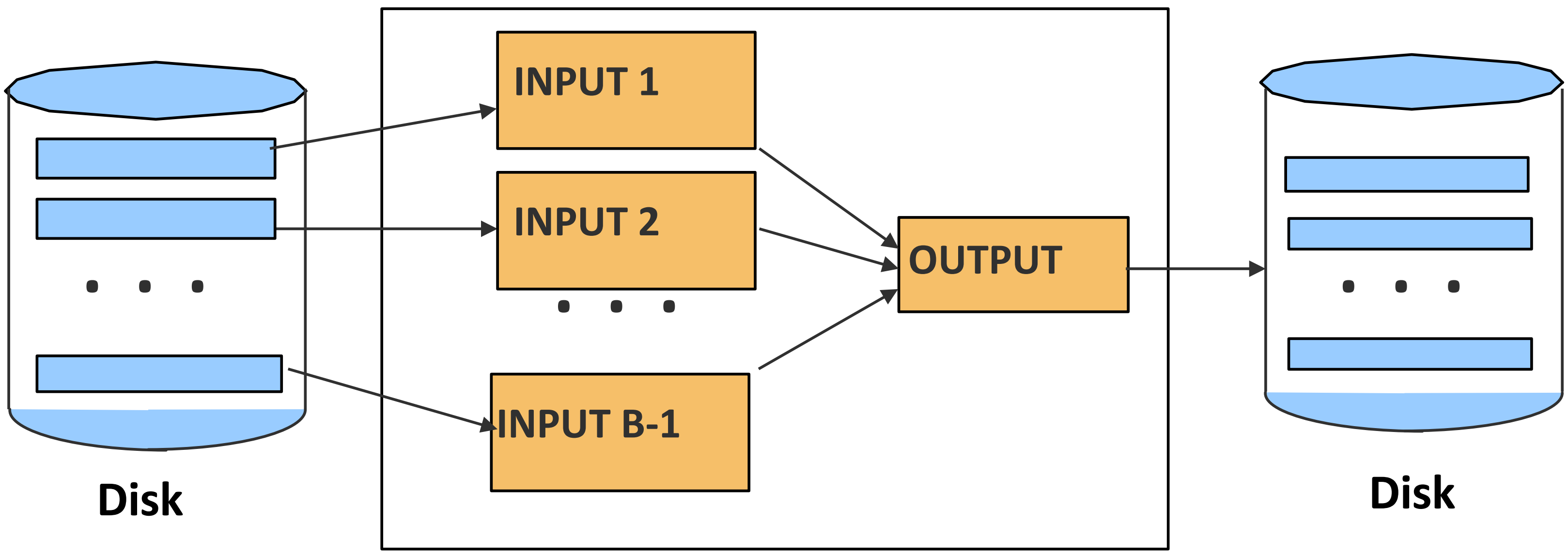
- **Divide and conquer**

How can we utilize more than three buffer pages?



General External Merge Sort

- Sort a file with *N* pages using *B* buffer pages:
  - Pass 0: use *B* buffer pages (run size = B pgs). Produce $\lceil N/B \rceil$ sorted runs of *B* pages each.
  - Pass 2, 3, …: merge ***B-1*** runs.



B-1 way merge.
Total buffer pages: B

Where are the main memory buffer pages allocated?

Cost of External Sort Merge

- # passes =
- I/O Cost = # passes * 2 N
- Consider sorting a file with a 1000 pages, using 11 buffer pages.
  - At the end of the first pass, we have runs of size pages
  - Next pass produces runs of size pages each
  - The next pass

Number of Passes of External Sort

N (# of pages)	B=3	B=17	B=257
100	7	2	1
10,000	13	4	2
1,000,000	20	5	3
10,000,000	23	6	3
100,000,000	26	7	4
1,000,000,000	30	8	4

32K pg size, 32TB relation

@1ms per read, 1111 hours = **46 days!**

Internal Sort Algorithm: Replacement Sort

Size of the buffer pool?

Example: M = 2 pages, 2 tuples per page.
Input Sequence: 10, 20, 30, 40, 25, 35, 9, 8, 7, 6, 5, …

1. In-memory 10, 20, 30, 40
2. Read 25, Output 10. In-memory: 20, 25, 30, 40
3. Read 35, Output 20. In-memory : 25, 30, 35, 40
4. Read 9, Output 25. In-memory : 9, 30, 35, 40
5. Read 8, Output 30. In-memory : 8, 9, 35, 40
6. Read 7, Output 35. In-memory : 7, 8, 9, 40
7. Read 6, Output 40. In-memory : 6, 7, 8, 9
8. Read 5, Flush output, Start new run. In-memory …

   On Disk: 10, 20, 25, 30, 35, 40

Average length of a run in replacement sort is *2M*

Internal Sort Algorithm

- Quicksort is a fast way to sort in memory.
- An alternative is **replacement sort**, which is also called tournament sort or heapsort
  - `Top:` Read in ***M*** pages of the relation R
  - `Output:` move smallest record to output buffer
  - Read in a new record *r*
  - insert *r* into "sorted heap"
  - if *r* not smallest, then `GOTO Output`
  - else remove *r* from "heap"
  - output "heap" in order; `GOTO Top`
- Worst-Case: What is min length of a run? How does this arise?
- Best-Case: What is max length of a run? How does this arise?
- Quicksort is faster, but longer runs often means fewer passes!

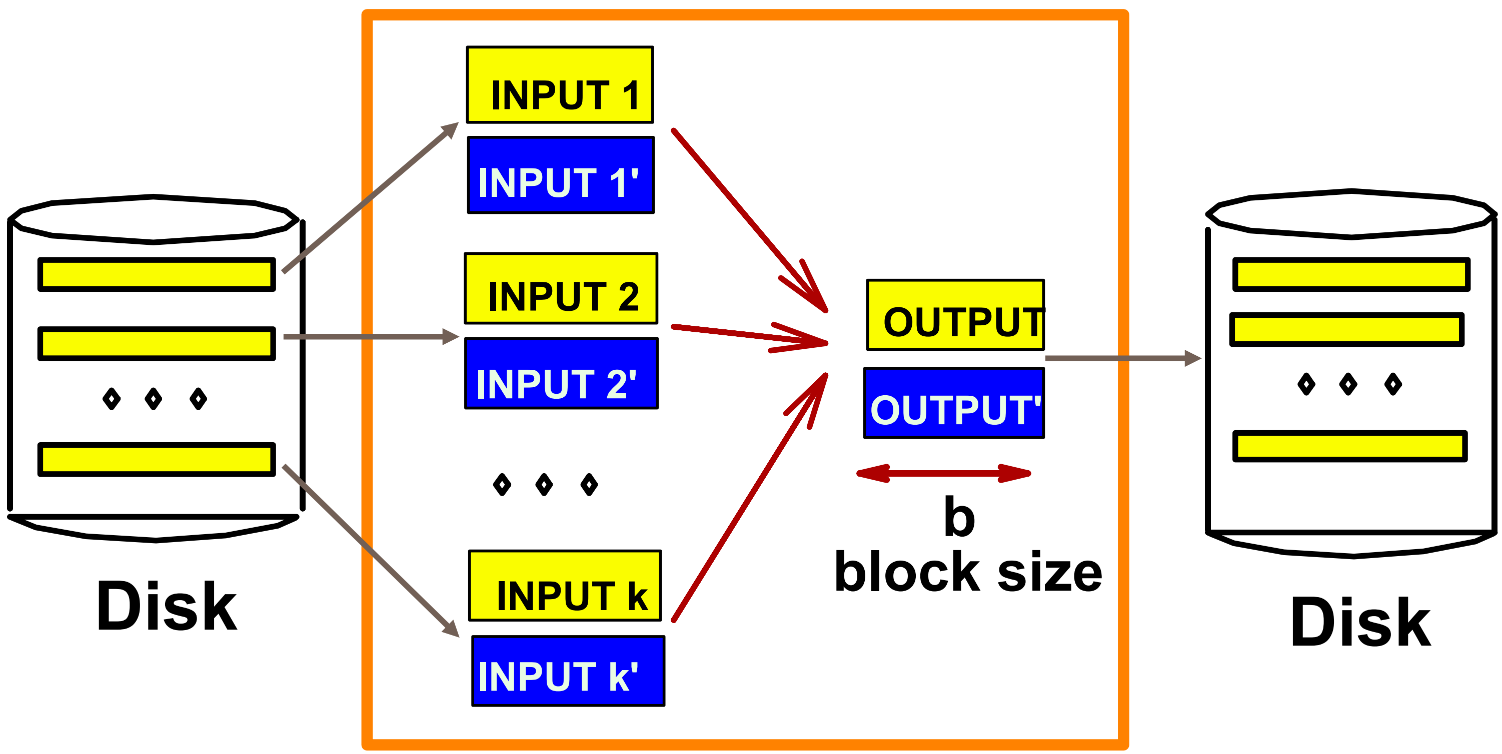
Blocked I/Os

- So far we reading/writing one page at a time, but we know that reading a **block** of pages sequentially is faster.
- Make each buffer (input/output) be a block of pgs.
  - Will reduce fan-out during merge passes! Side-effect?
  - Reduces per page I/O cost.
  - First Pass: Each run **2B** pages, $\lceil N/2B \rceil$ runs (where **B** is the size of the buffer pool in #pages)
    - Which internal sort algorithm are we using?
  - Merge Tree Fanout: $F = \lfloor B/b \rfloor - 1$, b is block size
  - # passes: $\lceil \log_F \ldots \rceil + 1$
  - In practice, buffer pools are large, so most files are sorted in 2-3 passes

Double Buffering

Reduces response time.
What about throughput?

- Overlap CPU and IO processing
- *Prefetch* into shadow block.
  - Potentially, more passes; in practice, 2-3 passes.



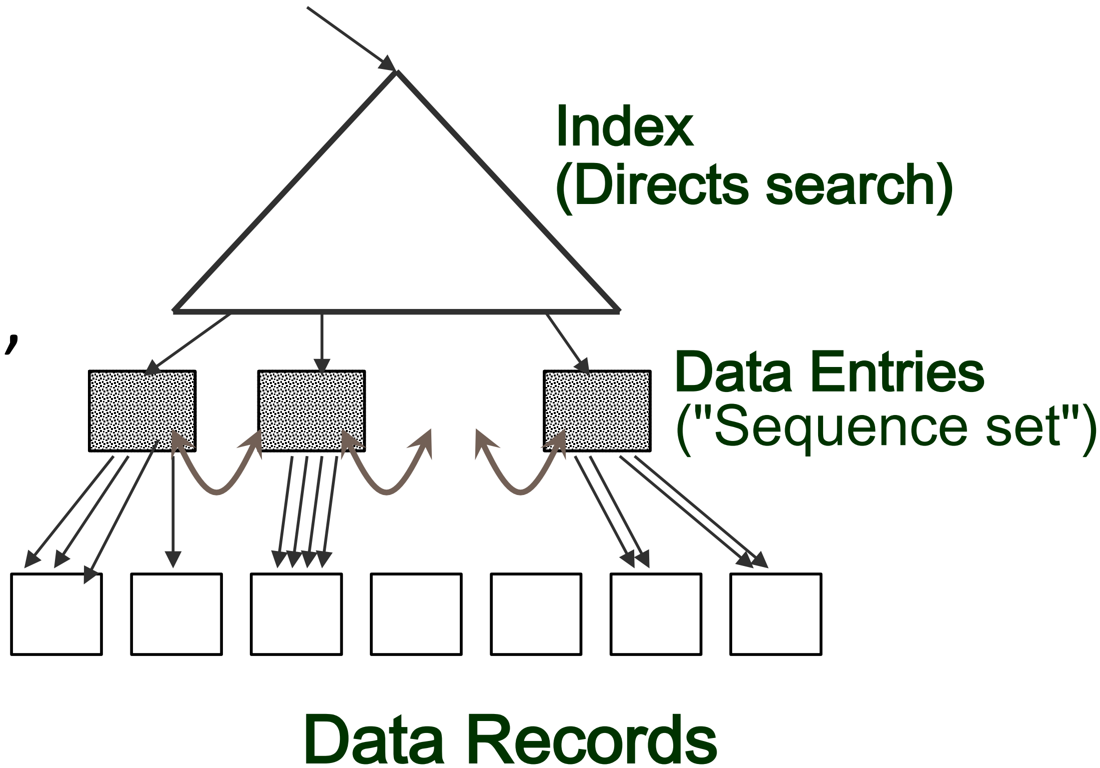
B main memory buffers, k-way merge

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

- Go to the left-most leaf, then retrieve all leaf pages
- If data entry has records, then we are done!
- If the data entries have **rid**s, each data page is fetched just once (since this is a clustered index)



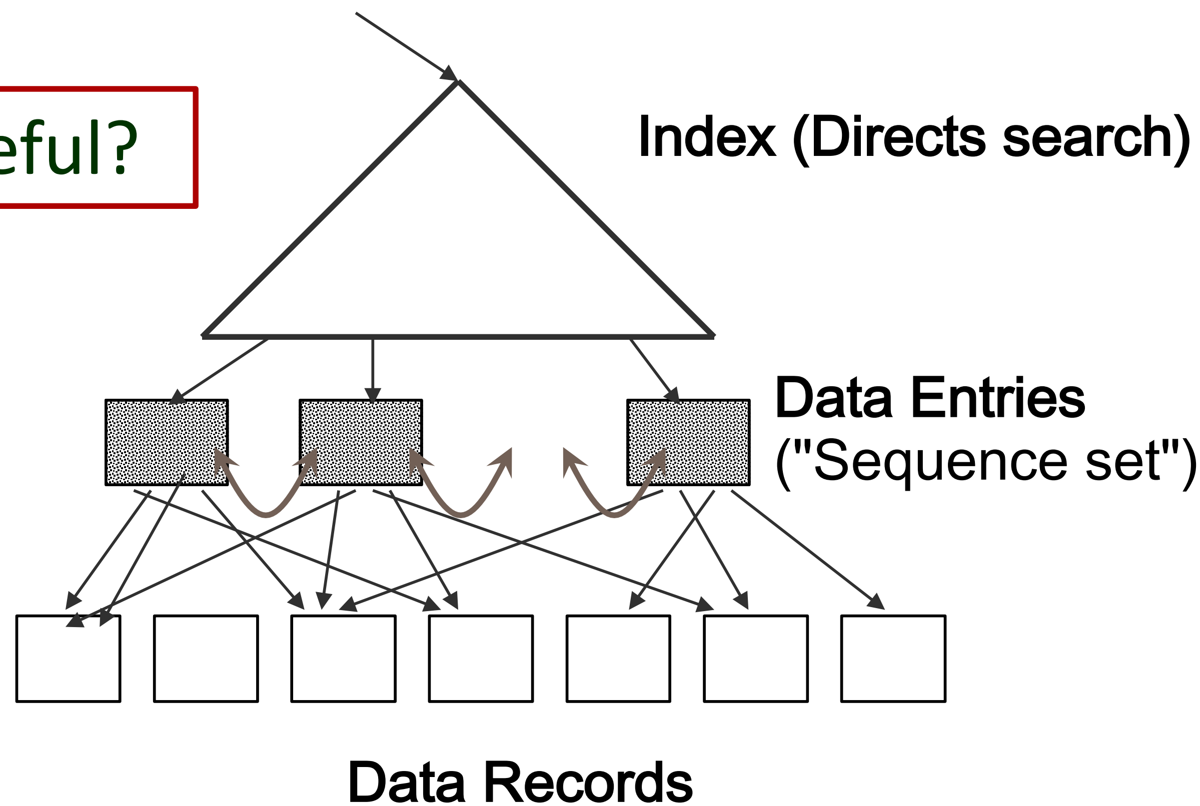
Faster than external sorting!

Why not scan the data file directly?

Unclustered B+ Tree Used for Sorting

- Unclustered B+-trees only have **rid**s in the data entries
- So, in general, one I/O per data record!

When can this be useful?



Sorting Records!

- Sorting is a competitive sport!
- See http://sortbenchmark.org/
  - Task is to sort 100 byte records.
  - Different flavors of metrics that people compete on.
  - Sort at trillion records as fast as you can,
    - using general purpose sorting code (Daytona) or
    - code specialized just for the benchmark (Indy)