Index Files

Alvin Cheung

Aditya Parameswaran

R & G - Chapter 9-10

Connecting Back to the Storage Layer

- So far, we have been talking about a B+tree index pointing to unordered pages in a heap file
- This is not the only approach we can take.

- We'll talk about various alternatives for the:
  - Leaf nodes (the interface between index and the data)
  - Heap file (the actual data)

Three basic alternatives for leaf nodes

- Also applies for data entries for other types of indexes
- We’ll look in the context of B+-trees, but applies to any index

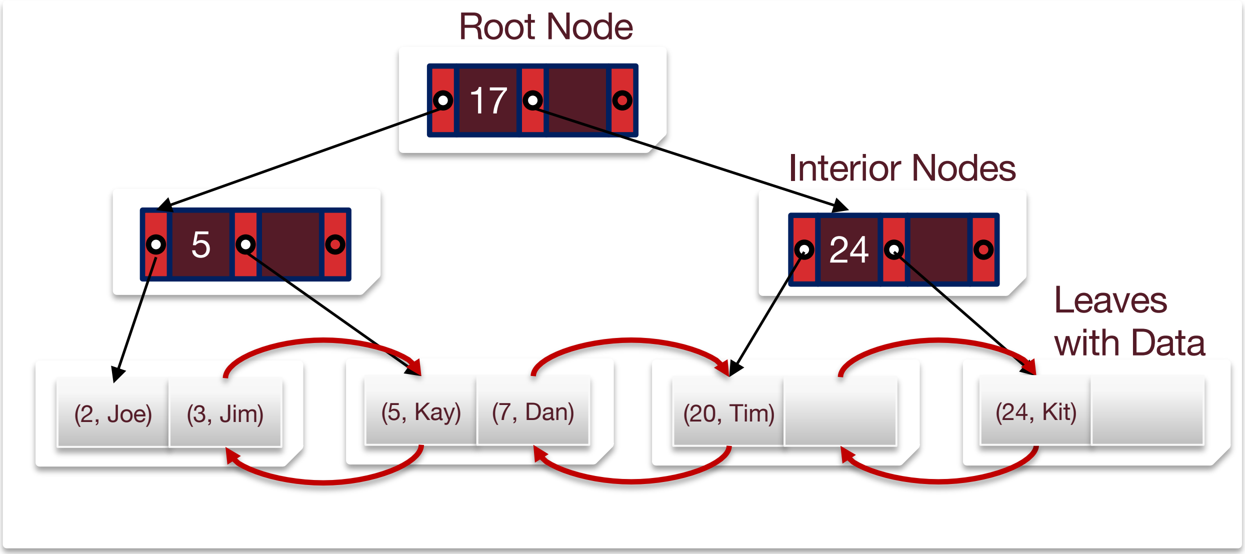
- Three basic alternatives (Textbook uses same numbering!)
  - Alternative 1: By Value — leaf stores the actual row data
  - Alternative 2: By Reference ← *this is what we’ve already seen*
  - Alternative 3: By List of references

useful when you have many dup keys, notice that record ID list can get quite long and can be bigger than a single block.

Alternative 1: By Value

- Leaf pages store records directly
    - No need to follow pointers

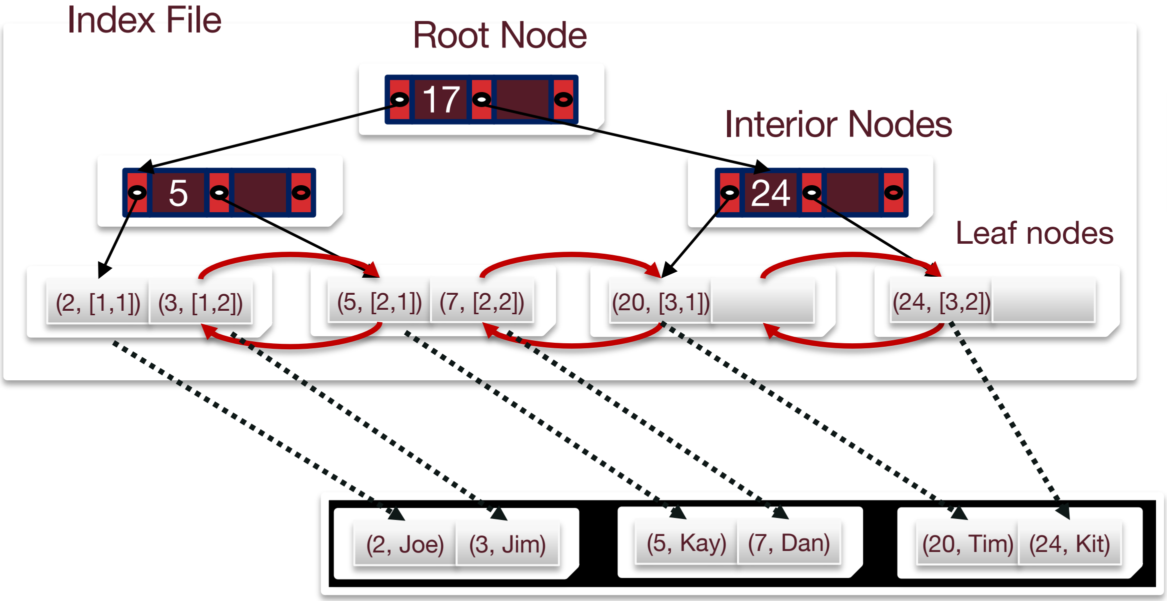
uid	name
2	Joe
3	Jim
5	Kay
7	Dan
20	Tim
24	Kit



Alternative 2: By Reference Pairs

- For each **k**, store recordId of matching data record as pairs
  - Each entry in leaf: <k, recordId>
    - Recordid = [page id, slot id]
  - We used this previously

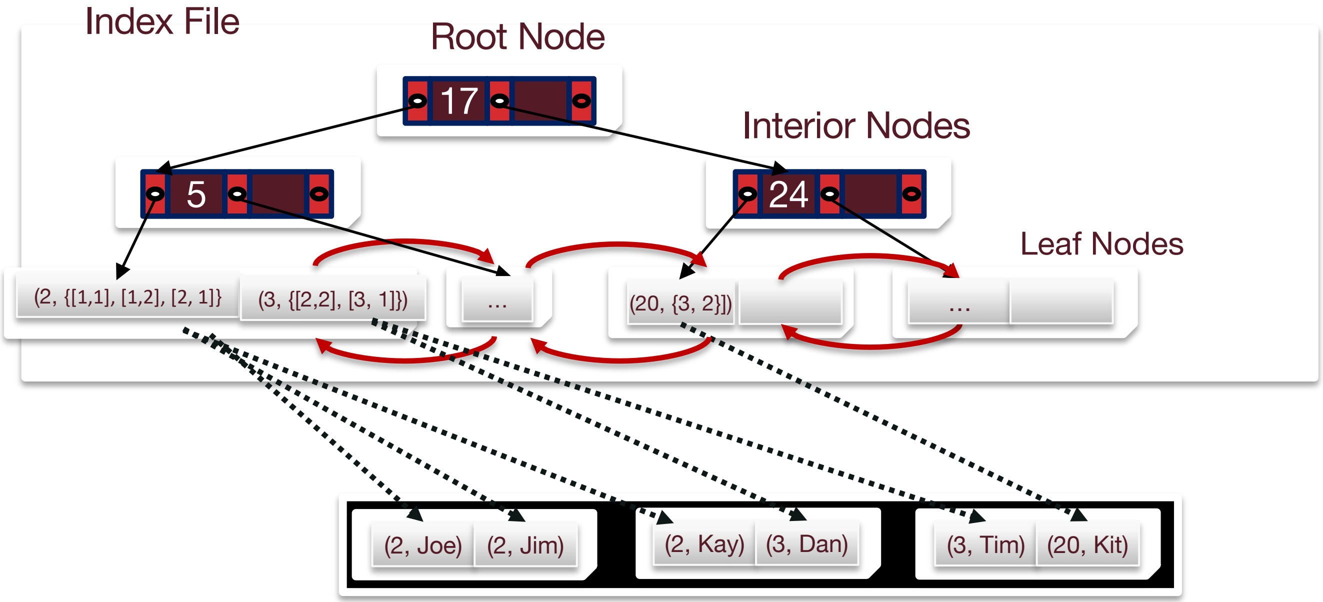
uid	name
2	Joe
3	Jim
5	Kay
7	Dan
20	Tim
24	Kit



Index Contains (Key, Record Id) Pairs

Alternative 3: By Reference List

- For each k, store recordIds of matching records as a list
  - Each leaf entry: <**k**, {list of rids of matching data records}>
  - Alternative 3 more compact than alternative 2
    - Very large rid lists can span multiple blocks, needs bookkeeping to manage that



Index Contains
(Key, {list of record Id}) Pairs

By Value vs. By Reference

- Both Alternative 2 and Alternative 3 index data *by reference*

- If we want to support multiple indexes per table, by reference is *required*
  - Otherwise we would be replicating entire tuples
  - Q: Why is replicating a problem?
  - Replicating data leads to complexity during updates, so we want to avoid
    - Need to make sure that all copies of the data are kept in sync.

Connecting Back to the Storage Layer

- So far, we have been talking about a B+tree index pointing to unordered pages in a heap file
- This is not the only approach we can take.
- We'll talk about various alternatives for the:
  - Leaf nodes (the interface between index and the data)
  - Heap file (the actual data, if outside the index) ⬅ *this is next*

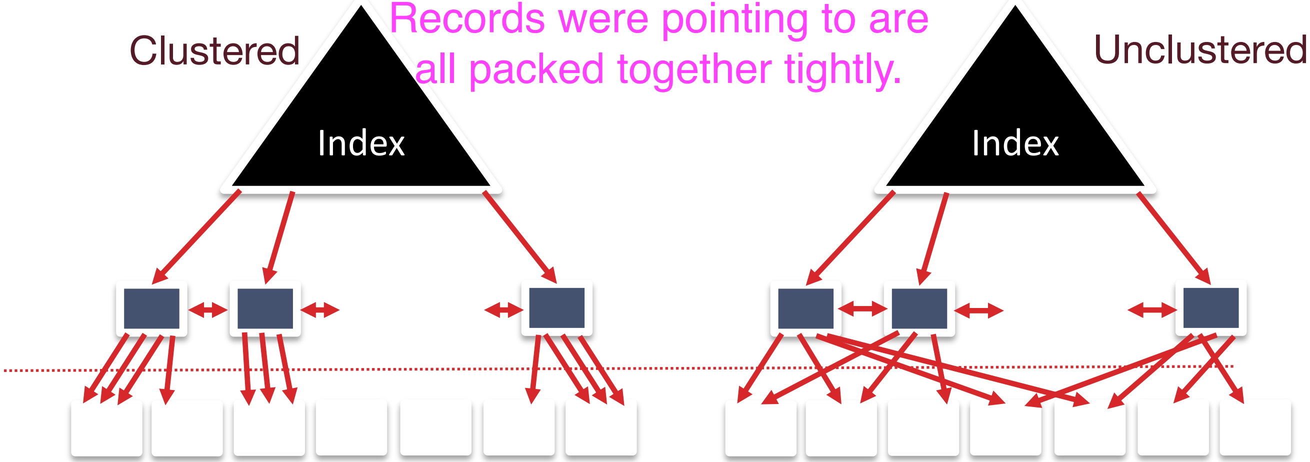
Clustered vs. Unclustered Index

- By-reference indexes (Alt 2 and 3) can be *clustered* or *unclustered*
    - In reality, this is a property of the heap file associated with the index!
- Clustered index:
    - Heap file records are kept *mostly* ordered according to **search keys** in index
        - Heap file order need not be perfect: this is just a performance hint
        - As we will see, cost of retrieving data records through index varies greatly based on whether index is clustered or not!
- Note: different definition of “clustering” in AI/data mining:
    - grouping nearby items in a high-dimensional space or network

Clustered vs. Unclustered Index Visualization 1

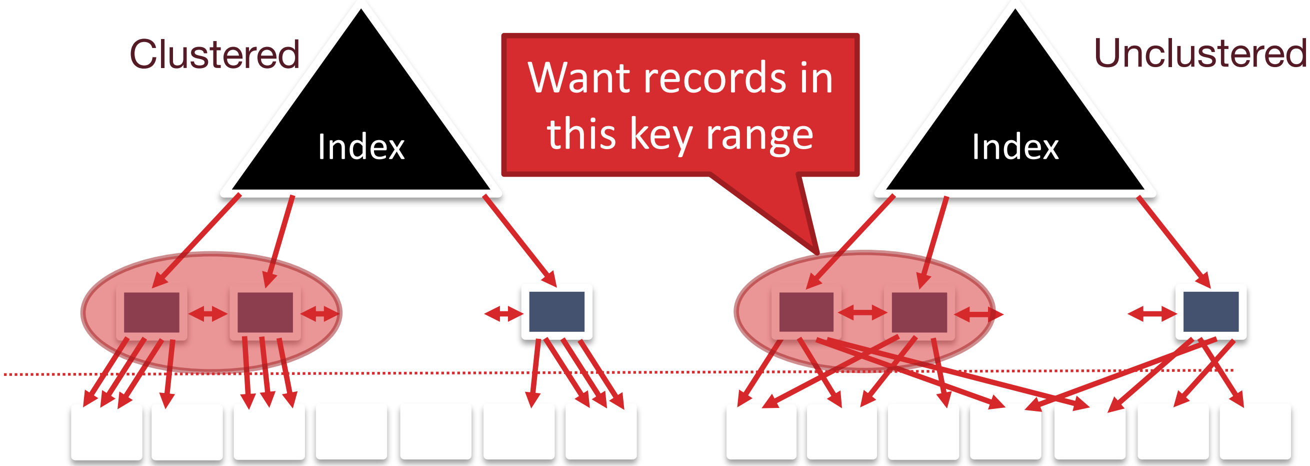
- To build a clustered index, first sort the heap file
  - Leave some free space on each block for future inserts
  - We then try to respect this order "as much as possible"
- In an unclustered index, there is no such restriction

Pointers mostly do not cross.
Records were pointing to are
all packed together tightly.



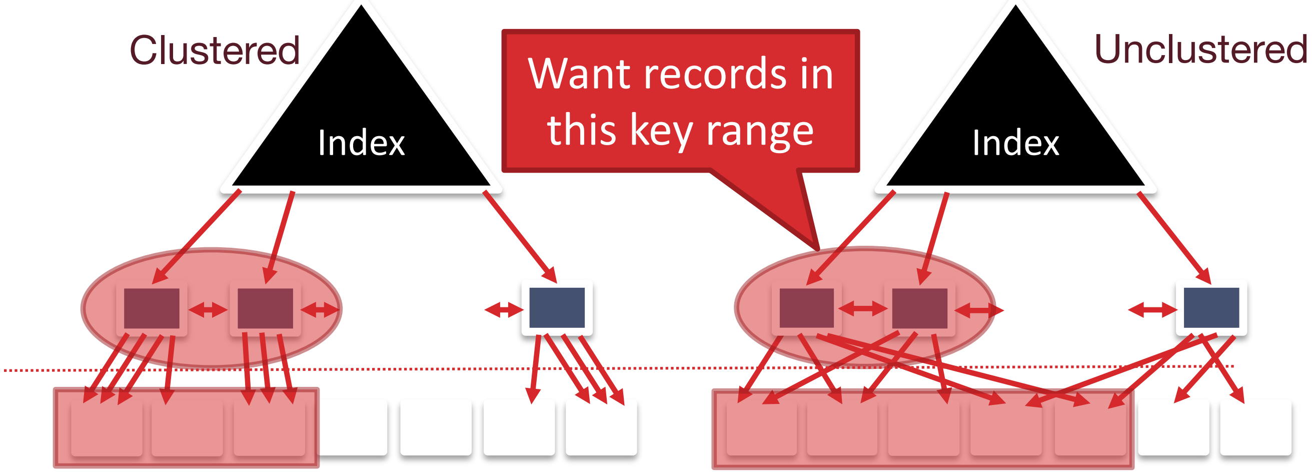
Clustered vs. Unclustered Index Visualization 2

- To build a clustered index, first sort the heap file
  - Leave some free space on each block for future inserts
  - We then try to respect this order "as much as possible"
- In an unclustered index, there is no such restriction



Clustered vs. Unclustered Index Visualization 3

- To build a clustered index, first sort the heap file
  - Leave some free space on each block for future inserts
  - We then try to respect this order “as much as possible”
- In an unclustered index, there is no such restriction



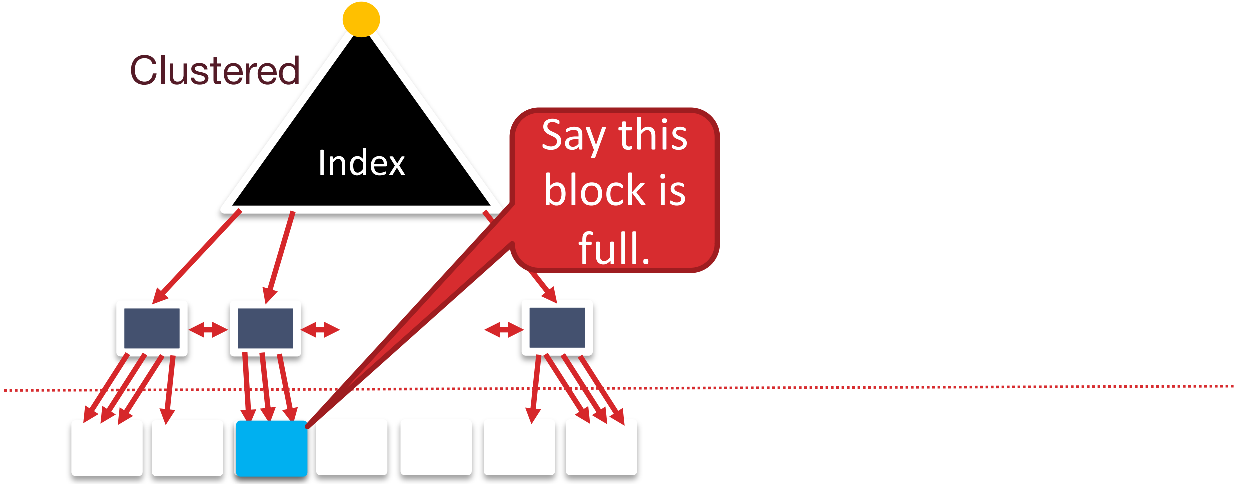
Want records in this key range

3 Heap file pages vs. 5 pages.

In general unclustered can be arbitrarily bad!

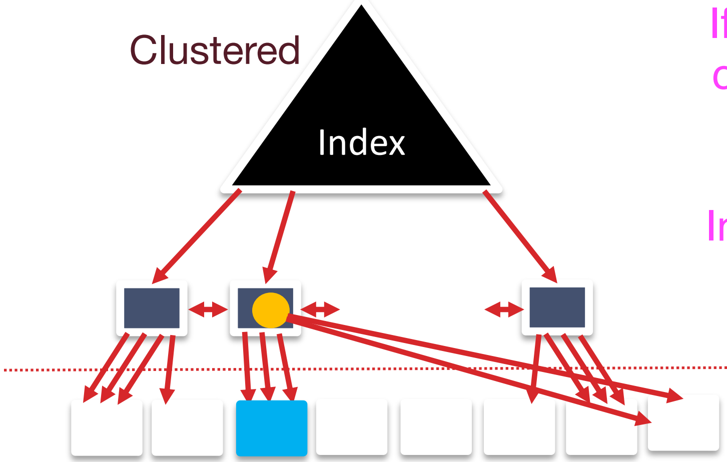
Clustered vs. Unclustered Index Visualization 5

- To build a clustered index, first sort the heap file
    - Leave some free space on each block for future inserts
    - We then try to respect this order "as much as possible"
- Blocks at end of file may be needed for inserts
    - Order of data records is "close to", but not identical to, the sort order



Clustered vs. Unclustered Index Visualization 6

- To build a clustered index, first sort the heap file
  - Leave some free space on each block for future inserts
  - We then try to respect this order "as much as possible"
- Blocks at end of file may be needed for inserts
  - Order of data records is "close to", but not identical to, the sort order



If you have lots of inserts, over time the clustering kinds of breaks down, and the heap file is no longer mostly in sorted order.

In that case if you want to re-cluster the index, what that means is resorting the heap file in the order of the index, and storing it back on disk in sorted order.

Clustered vs. Unclustered Indexes Pros

- Clustered Index Pros
  - Efficient for range searches due to potential locality benefits
    - Sequential disk access, prefetching, etc.
  - Support certain types of compression
    - More soon on this topic

Clustered vs. Unclustered Indexes Cons

- Clustered Cons
    - More expensive to maintain
        - If we don’t maintain, ends up becoming closer to unclustered after many inserts
        - To maintain, we need to periodically update heap file order
            - Can be done on the fly (more expensive per update, but lookup perf is good throughout)
            - Or lazily (less expensive per update but performance can degrade)
    - To reduce cost of maintenance, heap file usually only **packed to 2/3** (or some other fraction <1) to accommodate inserts