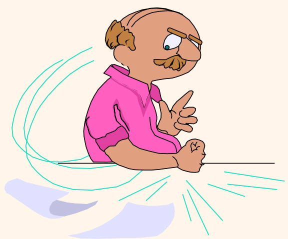
Introduction to Data Management

Lecture #22
(Physical DB Design)



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It's the penultimate episode of….

Friday Nights with Databases…!

Brought to you by…

Announcements

- No class Monday! *(Awwwww.....)*
- Two HW assignments remain:
  - HW #7: Due next Thursday, May 30th (5 PM)
    - Physical DB design (for MySQL and beyond)
  - HW #8: Due on Thursday, June 6th (5 PM)!
    - NoSQL (and **NoLateDay** due to Endterm timing)
- Today's plan :
  - Today: Physical DB design (esp. indexing)
  - Next up: **NoSQL & Big Data** (*a la* AsterixDB)
    - Not in the textbook, so... See the wiki for readings!

Overview

- After ER design, schema refinement, and the definition of views, we have the *conceptual* and *external* schemas for our database.
- Next step is to *choose indexes*, make *clustering decisions*, and *refine* the conceptual and external *schemas* (if needed) to meet *performance goals*.
- Start by understanding the ***workload***:
  - Most important queries and how often they arise.
  - Most important updates and how often they arise.
  - Desired performance goals for those queries/updates?

Decisions to Be Made Include...

- What indexes should we create?
  - Which relations should have indexes? What field(s) should be their search keys? Should we build several indexes?
- For each index, what kind of an index should it be?
  - B+ tree? Hashed? Clustered? Unclustered?
- Should we make changes to the conceptual schema?
  - Consider alternative normalized schemas? (There are multiple choices when decomposing into BCNF, etc.)
  - Should we ``undo'' some decomposition steps and settle for a lower normal form? (*"Denormalization."*)
  - Horizontal partitioning, materialized views, replication, ...

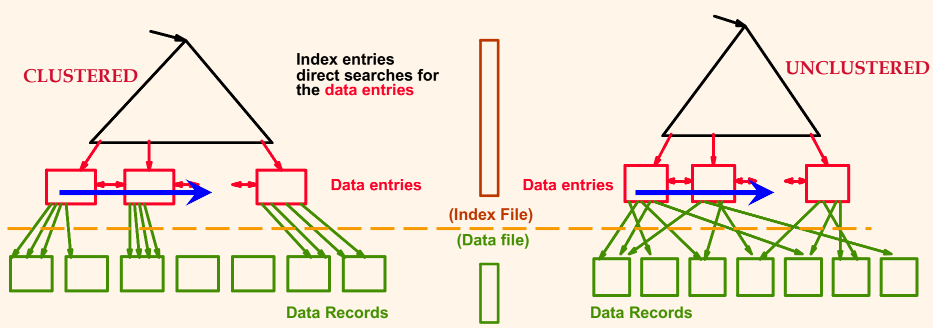
Understanding the Workload

- For each query in the workload:
  - Which relations does it access?
  - Which attributes are retrieved?
  - Which attributes appear in selection/join conditions? (And ***how selective*** are those conditions expected to be?)
- For each update in the workload:
  - Which attributes are involved in selection/join conditions? (And ***how selective*** are those conditions likely to be?)
  - The type of update (INSERT/DELETE/UPDATE), and the attributes that are affected.

*Index Classification (**Review**)*

- *Primary* vs. *secondary*: If index search key contains the primary key, this is called the primary index.
  - *Unique* index: Search key contains a *candidate* key.
- *Clustered* vs. *unclustered*: If the order of data records is the same as, or `close to', the order of stored data records, we have a clustered index.
  - A table can be clustered on *at most one* search key.
  - Cost of retrieving data records via an index varies *greatly* based on whether index is clustered or not!

*Clustered vs. Unclustered Indexes (**Reminder**)*



(Read each page once.) (Read more pages – and repeatedly!)

Choice of Indexes (Cont'd.)

- One approach: Consider the most important queries in turn. Consider the best query plan using the current indexes, and see if a better plan is possible with an additional index. If so, create it.
  - This means we must understand and see how a DBMS evaluates its queries. (*Query execution plans*.)
  - Let's start by discussing simple 1-table queries!
- Before creating an index, must also consider its impact on updates in the workload.
  - *Trade-off*: Indexes can make queries go faster, but updates will become slower. (Indexes require disk space, too.)

Index Selection Guidelines

- Attributes in **WHERE** clause are candidates for index keys.
  - Exact match condition → hashed index (or B+ tree if not).
  - Range query → B+ tree index.
    - Clustering especially useful for range queries, but can *also help with equality queries with* ***duplicate values*** (non-key field index).
- **Multi-attribute** search keys should be considered when a WHERE clause contains several conditions.
  - Order of attributes matters for range queries.
  - Such indexes can sometimes enable index-only strategies for important queries (e.g., aggregates / grouped aggregates).
    - *Note*: For index-only strategies, clustering isn't important!
- Choose indexes that benefit **as many queries** as possible.
  - Only **one** index can be clustered per relation, so choose it based on important queries that can benefit the most from clustering.

Examples of Clustered Indexes

SELECT E.dno
FROM Emp E
WHERE E.age > 40

- B+ tree index on E.age can be used to get qualifying tuples.
  - How selective is the condition?
  - Should the index be clustered?

SELECT E.dno,
COUNT (*)
FROM Emp E
WHERE E.age > 10
GROUP BY E.dno

- Consider the GROUP BY query.
  - If most tuples have *E.age* > 10, using *E.age* index and sorting the retrieved tuples may be costly.
  - Clustered *E.dno* index may win!

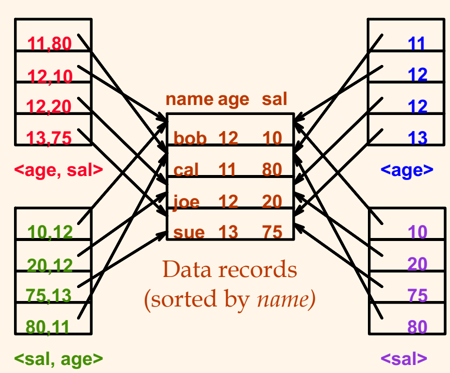
SELECT E.dno
FROM Emp E
WHERE E.hobby='Stamps'

- Equality queries & duplicates:
  - Clustering on *E.hobby* helps!

Indexes with Composite Search Keys

- *Composite Search Keys*: Search on a <u>combination</u> of fields.
  - Equality query: Every field value is equal to a constant value. E.g. wrt <sal,age> index:
    - (age=20 *AND* sal=75)
  - Range query: Some field value is a range, not a constant. E.g. again wrt <sal,age> index:
    - age=20; or (age=20 *AND* sal > 10)
- Data entries in index sorted by search key to support such range queries.
  - ***Lexicographic order***

Various composite key indexes using lexicographic (ASC) order.



Data entries in index sorted by <*sal,age*>

Data entries sorted by <*sal*>

Composite Search Keys

- To retrieve Emp records with *age*=30 **AND** *sal*=4000, an index on <*age,sal*> would be better than an index <u>only</u> on *age* or an index <u>only</u> on *sal*.
  - *Note*: Choice of index key is orthogonal to clustering.
- If condition is: 20<*age*<30 **AND** 3000<*sal*<5000:
  - Clustered B+ tree index on <*age,sal*> or <*sal,age*> is best.
- If condition is: *age*=30 **AND** 3000<*sal*<5000:
  - Clustered <*age,sal*> index much better than <*sal,age*> index! (***Think about why***! Picture the index…)
- Composite indexes are larger; updated more often.

Index-Only Query Plans

- Some queries can be answered without retrieving ***any*** tuples from one or more of the relations involved if a suitable index is available.

*(Sometimes called a "**covering index**" for the given query.)*

<E.dno>

```
SELECT  E.dno, COUNT(*)
FROM  Emp E
GROUP BY  E.dno
```

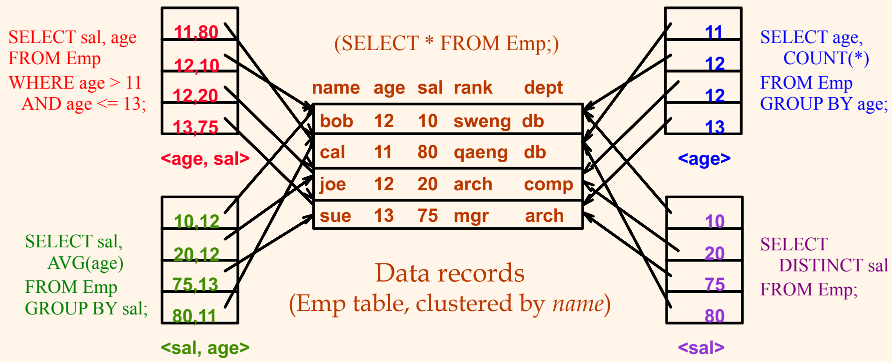
<E.dno,E.sal>
B+ tree index!

```
SELECT  E.dno, MIN(E.sal)
FROM  Emp E
GROUP BY  E.dno
```

<E. age,E.sal>
or
<E.sal, E.age>
B+ tree index!

```
SELECT AVG(E.sal)
FROM  Emp E
WHERE  E.age=25 AND
  E.sal BETWEEN 3000 AND 5000
```

Some Illustrated Index-Only Plans



Note: The index files are each much smaller than the main file!