Indexes

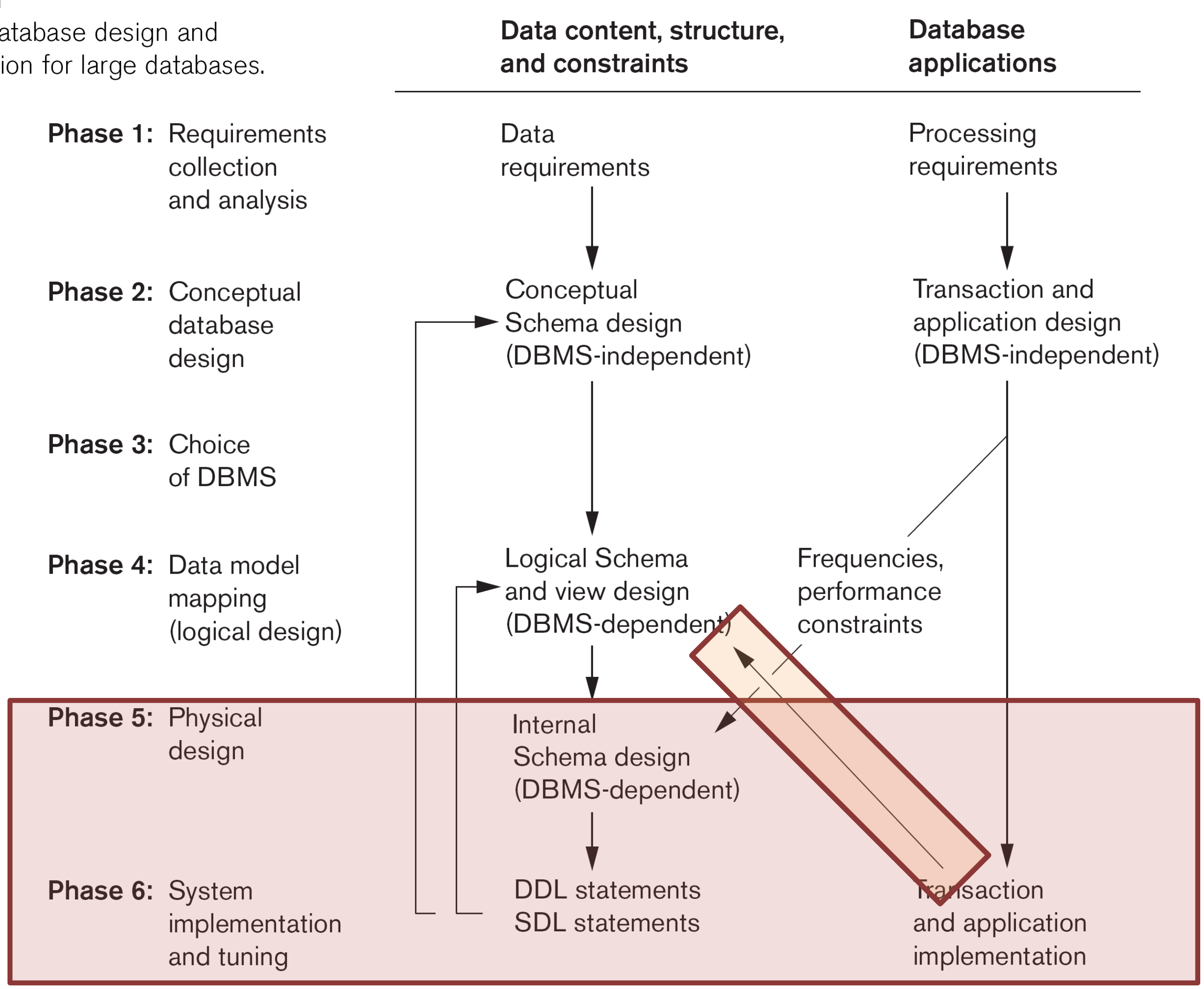
Lecture 11

Outline

- Context
- Functionality
- Utility
- Tradeoffs and considerations
  - Selectivity
- Index types

Database Design and Implementation Process

Figure 10.1
Phases of database design and implementation for large databases.



What is an Index?

- Persistent data structure, stored in the database
- Primary mechanism to get improved query performance
- Many interesting issues (see Ch. 16-17); we will focus on usage, tradeoffs

Creating an Index

```
CREATE [UNIQUE] INDEX index_name
ON table_name (c_name1, …)
[OPTIONS];
```

Notes

- Ordering of columns is VERY important
- Options often refer to the type of index being used and other important flags

Functionality

An index answers certain kinds of questions very efficiently (depends upon type)

- **Equality**: fieldname=value
- **Range/ordering**: fieldname>value
  - Only index that maintains ordering (e.g. tree-based)

Can be used for `WHERE` clause, as well as `JOIN` and `ORDER BY`

Comparison (1)

```
SELECT * FROM T
WHERE …
```

- No indexes (indices)
  Anything = full **table scan**
- Index on (A)
  `A = 'panda'` (fast)
  `A > 'dog'` (fast, if ordered index)
  `ORDER BY A` (fast, if ordered)
- Index on (B)
  `B = 1` (fast)
  `B <= 5` (fast, if ordered)
  `ORDER BY B` (fast, if ordered)
- Index on (A, B)
  `A = 'cat'` (fast)
  `A = 'cat' AND B >= 3` (fast, if ordered)
  `A <= 'panda' ORDER BY B` (fast, if ordered)
  Anything not starting with A = full table scan
- Index on (C,A), (C,B), … (i.e. start with C)
  Anything not starting with C = full table scan

T	A	B	C
1	cat	1	…
2	dog	3	…
3	panda	7	…
4	cat	4	…
5	cat	5	…
6	panda	9	…
7	moose	10	…
8	dog	8	…
9	dog	10	…

Comparison (2)

T1	A	B	C
1	cat	1	…
2	dog	3	…
3	panda	7	…
4	cat	4	…

T2	X	Y	Z
i	felidae	1	…
ii	canidae	3	…
iii	bear	7	…
iv	felidae	4	…

```
T1 JOIN T2 ON T1.B=T2.Y
```

- No indexes: scan T1, scan T2 (n^2)
- Index on T1(B): scan T2, fast search in T1
- Index on T2(Y): scan T1, fast search in T2
- Index on T1(B), T2(Y): merge sort (if ordered)

Utility

Pro

- Can make the difference between full table scan and log/constant lookup

Con

- Extra space
  - Linear with # rows
- Extra time
  - Creation (moderate)
  - Maintenance (can offset savings)

Choosing the Index(es) to Create

- Table size
  - Many rows = larger cost to table scan
- Data distribution (selectivity)
  - Fewer distinct values = higher likelihood needing to touch many rows, independent of index usage
    - Index can lead to lots of IO/cache misses vs. sequential scan via clustered index
- Query vs. update load
  - Many updates = higher relative index maintenance cost
  - Analysis of frequent queries leads to choosing key attributes that get you the most bang for your buck

Selectivity

- **Cardinality**: # distinct values in a column

```
SELECT COUNT(DISTINCT col_name)
FROM table_name;
```

- **Selectivity**: 100% * cardinality / # rows
  - Compare for 10K rows…
    - Gender (M/F)
    - Country (195 + Taiwan)
    - Birthday (Jan. 1 -> Dec. 31)

General Advice

- Use narrow indexes (i.e. few columns); these are more efficient than compound indices
- Avoid a large number of indices on a table
- Avoid "overlapping" indices that contain shared columns (often a single index can service multiple queries)
- For indices that contain more than one column: given no other constraints, place the most selective column first
- Unless you have very good reason, always define a PK (in most RDBMSs, results in a *clustered* index, more shortly)

Index Types

- Clustered vs. Non-clustered
- Covering (w.r.t. a query)
- Balanced Trees (B+-Trees)
- Hash Tables
- Other

Clustered vs. Non-clustered

- Clustered: affects physical order on disk
  - At most one per table (for some RDBMS, PK)
  - Fast when data accessed in order/reverse
- Non-clustered: induces logical ordering
  - Arbitrary number per table
  - Depending on the query/data, can lead to significant slowdown due to cache misses and frequent disk access

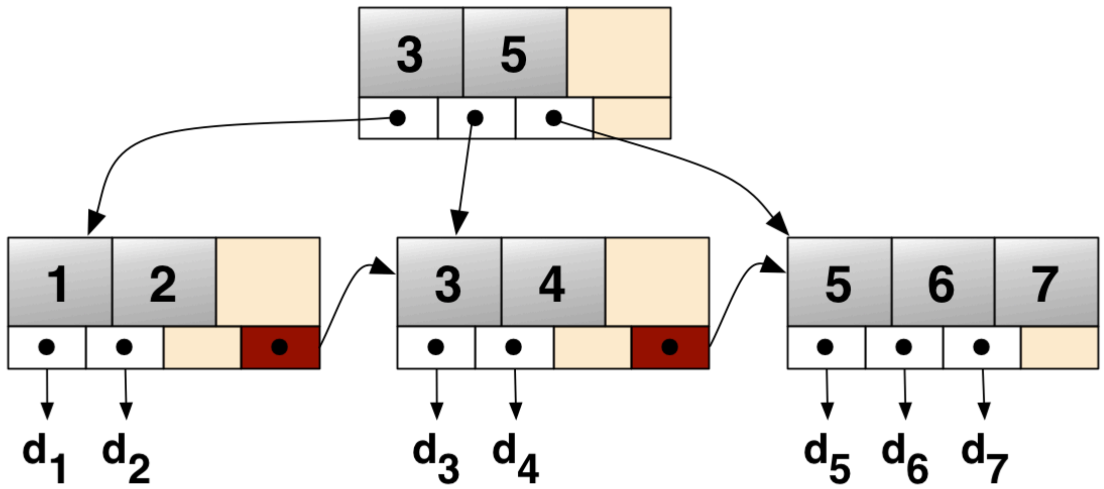
Covering

- Typically indexes help the DBMS *find* the row of interest
  - ID -> Name
  - Name->ID

ID	Name
1	Alice
2	Bob
3	Carol
4	Dan

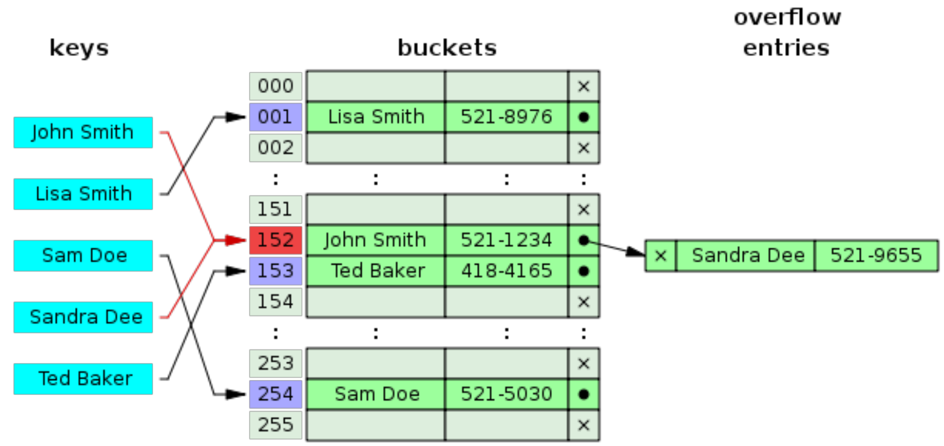
- A covering index contains all the necessary data within the index itself (w.r.t. to query or queries)
  - More storage vs. IO savings
  - (ID, Name) or (Name, ID)

B+-Trees



- Balanced, constant out-degree (within range)
- Values (i.e. row pointer) only at leaves
  - Distinguishes from a B-tree
  - Linked list at leaves, in order
- Logarithmic traversal, constant at leaf
  - Top k levels usually kept in memory (e.g. 2-3)
- Typical default index for DBMS; also used in file systems, etc.

Hash Table



- "Constant" access time (under certain assumptions, amortized)
- No range queries

Other

- Bitmap
  - Useful for low-update systems (e.g. read-only) with low cardinality attributes (e.g. gender)
- Trie
  - Useful for sequence queries (e.g. bioinformatics)
- Spatial (e.g. R-tree)
  - Useful for queries about space (e.g. what stores are close to me? what planes are within 1 mile of each other?)
- Inverted
  - Useful for full-text search (e.g. search engines)

Summary

- Indexes are persistent data structures, such as has tables and b+-trees), stored in the database in order to improve the speed of certain query operations
  - An important aspect of the physical design of a database
- When creating an index, attribute order is very important!
- Indexes are an example of a space-time tradeoff
  - To make an informed decision, you should consider query load, table size, data distribution, and details about the index type (e.g. ordered)