Indexing

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Storage hierarchy

Cache	Main memory	Disk	Tape
Very fast (nanosec)	Fast (10 nanosec)	Slower (millisec)	Slow (sec)
Very small (MB)	Small (GB)	Bigger (TB)	Very big (PB)
Built-in	Expensive	Cheap	Very cheap

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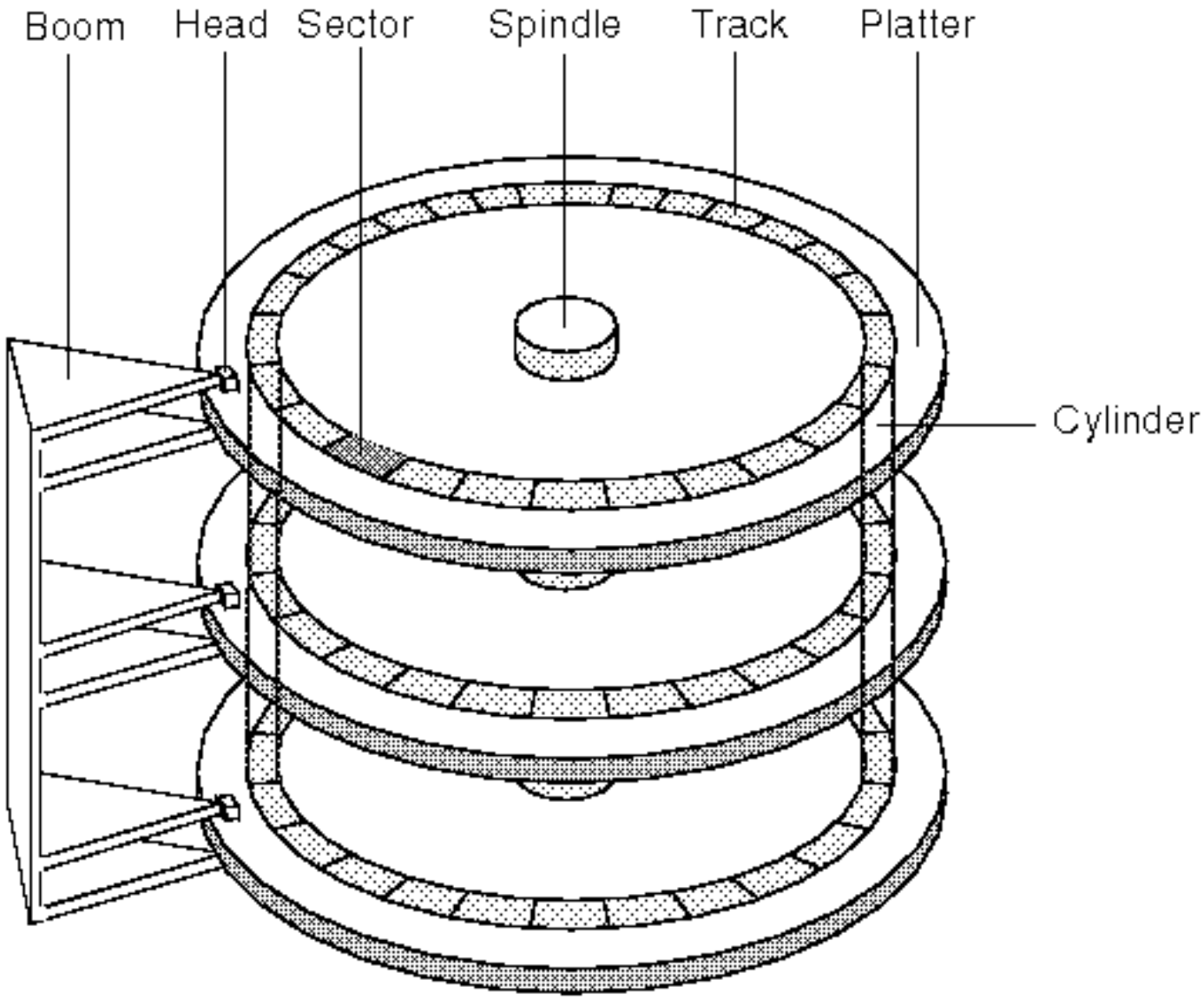
Disks:

- data is stored on concentric circular tracks
- each track is divided into fixed-length sectors
- a block (page) consists of one or more multiple contiguous hardware sectors
- between main memory and disk the data is moved in blocks
- block size: 4K-64K bytes

Hard disk drive



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What happens:

1. seek: position the read/write head ($1 - 10\ ms$)
2. rotational delay: wait for the beginning of the block ($0 - 10\ ms$)
3. data transfer: ($< 1\ ms$)

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Parallelism:

- data striping.

Physical data organization

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Block access is a cost unit for file operations.

Record layout

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Fixed-length records

Header info	$Field_1$	$\cdots$	$Field_k$

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Header information: record type, record length...

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Header:

- number of records in the block
- USED/UNUSED bits for every record slot
- DELETED bits for every record slot
- next block in the file
- timestamp

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Search key

- a set of fields A
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Operations

- SCAN: fetch all records in the file.
- LOOKUP: find all records satisfying an equality condition $A = a$.
- INSERT: add the record to the file (without considering duplicates)
- DELETE: find and remove the record from the file, given a key value.

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Parameters

n records in the file

R records per block (blocking factor).

B blocks in the file ($B = n/R$)

Operation	Number of block accesses
SCAN	B
LOOKUP	$B/2$ (average), B (worst case)
INSERT	2 (read and rewrite)
DELETE	number for LOOKUP +1 (rewrite)

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LOOKUP	$\log_2(B)$ (worst case)
INSERT	number for LOOKUP $+B$ (average)
DELETE	number for LOOKUP $+B$ (average)

Optimizations

- insertion: keeping a separate overflow file which is merged with the data file off-line.
- deletion: marking the record as **deleted**, without shifting other records.

Sorting

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Two-Phase Multiway Merge-Sort

```
repeat
     fill all the buffers with new tuples from the file;
     sort them in main memory;
     write the result to disk as a sorted sublist;
until the input is exhausted;
perform an (M-1)-way merge of the sorted sublists;
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Analysis

- required: $B \leq M(M-1)$
- otherwise: apply the algorithm recursively

Hashed file

- N buckets, each consisting of one primary and an unlimited number of overflow blocks
- hashing function $h : Keys \rightarrow \{0, 1, \ldots, N-1\}$
- keys are integers or converted to integers
- record located in bucket i iff its key hashes to i
- bucket directory with N entries

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	B/N (worst case)
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Index record: a pair `(Value,Address)` where `Value` is

- a unique value for primary indexes
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and `Address` is

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- a record id (rid) for dense indexes.

- datafile blocks: if file is sorted on the index key (clustered), then index can be sparse
- index blocks: always sorted

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- datafile block overflows are handled by allocating new overflow blocks
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Dynamic index

- the index changes dynamically
- no overflow blocks.

B-trees

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- guaranteed minimum fill ratio (at least 50%) in nonroot nodes
- max. number of index records per block $= 2d$ (min. number $= d$)

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Thus:

$$
\begin{aligned}
n/d^{i-1} &\geq 2 \\
\Rightarrow d^{i-1} &\leq n/2 \\
\Rightarrow i - 1 &\leq \log_d(n/2) \\
\Rightarrow i &\leq 1 + \log_d(n/2)
\end{aligned}
$$

B-trees: lookup

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Lookup algorithm

```
current block := root;
repeat
if current block is a leaf
then retrieve index record with key = Key;
     retrieve the data record with rid= Record Id;
else find the last index record in the current block
     with key ≤ Key and address = Addr;
     address of current block := Addr
until leaf reached;
```

B-trees: insertion

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Insertion algorithm

```
insert the record into a datafile block;
lookup the leaf index block to insert;
if enough room then store the record
else /*OVERFLOW*/
     allocate a new leaf index block;
     redistribute the records between the old and the new blocks;
     update the parent index block
     to reflect the new distribution of records;
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```

- Record redistribution should preserve ordering and B-tree minimum fill ratio.
- Updating the parent index block may lead to another index block OVERFLOW: handled using the same algorithm.
- Updates may ripple up to the root.

B-trees: deletion

Deletion algorithm

```
lookup the index record given the key;
delete the data record;
delete the index record;
if less than d records remain in the block
then /*UNDERFLOW*/
     consider left (or right) sibling block;
     if sibling contains d records
     then combine it with underfull block;
          release one block to the file system;
          update the parent index block;
     else/*sibling contains more than d records*/
          redistribute records between the two blocks;
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Special treatment of the root

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Some B-tree implementations

- underflows ignored
- index rebuilt from time to time

B-trees: analysis

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Parameters

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$2d$ index records per block (blocking factor): $2d > R$

an extra block access from the index to the datafile

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an extra block access from the index to the datafile

Operation	Number of block accesses
SCAN	B
LOOKUP	$\leq 2 + \log_d(n/2)$
INSERT (typically)	number for LOOKUP +2
INSERT (worst case)	$2 *$ number for LOOKUP+2
DELETE	like INSERT

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Indexes associated with individual columns.

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Bitmap indexes used where there are few domain values.

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CREATE INDEX Index-name
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Indexes are automatically created on attributes defined as `PRIMARY KEY` or `UNIQUE`.

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`CREATE INDEX` *Index-name*
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Bitmap indexes: `CREATE BITMAP INDEX`

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Different ways of accessing a table

`TABLE ACCESS FULL` (linear scan)

`TABLE ACCESS BY ROWID` (single row)

`INDEX UNIQUE SCAN` (single row through an index)

`INDEX RANGE SCAN` (a range of rows through an index)