Disk Drive: Parameters

D_{cyl}	total number of cylinders
D_{track}	total number of tracks
D_{sec}	total number of sectors
D_{tpc}	number of tracks per cylinder (= number of surfaces)

D_{cmd}	command interpretation time
D_{rot}	time for a full rotation
D_{rdsettle}	time for settle for read
D_{wrsettle}	time for settle for write
D_{hdswitch}	time for head switch

Disk Drive: Parameters (2)

D_{zone}	total number of zones
$D_{\text{zcyl}}(i)$	number of cylinders in zone i
$D_{\text{zspt}}(i)$	number of sectors per track in zone i
$D_{\text{zspc}}(i)$	number of sectors per cylinder in zone i $(= D_{\text{tpc}} D_{\text{zspt}}(i))$
$D_{\text{zscan}}(i)$	time to scan a sector in zone i $(= D_{\text{rot}}/Dzspti)$

Disk Drive: Parameters (3)

$D_{seekavg}$	average seek costs
D_{clim}	parameter for seek cost function
D_{ca}	parameter for seek cost function
D_{cb}	parameter for seek cost function
D_{cc}	parameter for seek cost function
D_{cd}	parameter for seek cost function

$D_{fseek}(d)$ cost of a seek of d cylinders

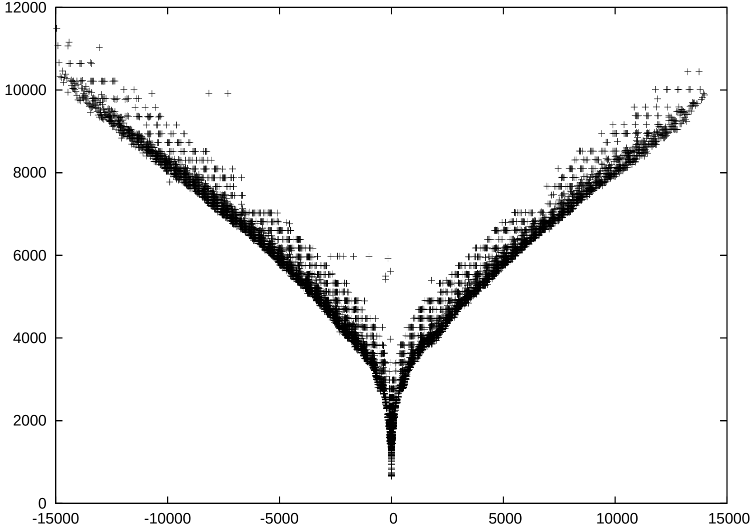
$$D_{fseek}(d) = \begin{cases} D_{ca} + D_{cb}\sqrt{d} & \text{if } d \leq D_{clim} \\ D_{cc} + D_{cd}\, d & \text{if } d > D_{clim} \end{cases}$$

$D_{frot}(s, i)$ rotation cost for s sectors of zone i $(= sD_{zscan}(i))$

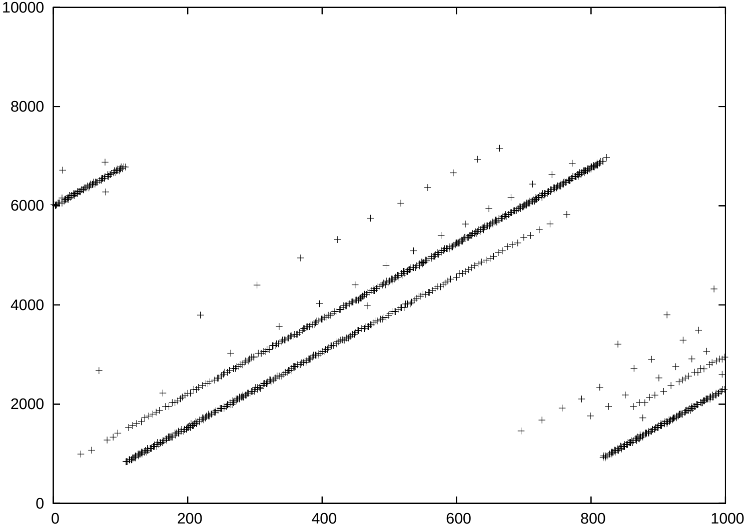
Extraction of Disk Drive Parameters

- documentation: often not sufficient
- mapping: interrogation via SCSI-Mapping command (disk drives lie)
- use benchmarking tools, e.g.:
  - Diskbench
  - Skippy (Microbenchmark)
  - Zoned

Seek Curve Measured with Diskbench



Skippy Benchmark Example



Interpretation of Skippy Results

- x-axis: distance (sectors)
- y-axis: time
- difference topmost/bottommost line: rotational latency
- difference two lowest 'lines': head switch time
- difference lowest 'line' topmost spots: cylinder switch time
- start lowest 'line': minimal time to media
- plus other parameters

Upper bound on Seek Time

Theorem (Qyang)

If the disk arm has to travel over a region of C cylinders, it is positioned on the first of the C cylinders, and has to stop at $s-1$ of them, then $sD_{fseek}(C/s)$ is an upper bound for the seek time.

Database Buffer

The database buffer

1. is a finite piece of memory,
2. typically supports a limited number of different page sizes (mostly one or two),
3. is often fragmented into several buffer pools,
4. each having a replacement strategy (typically enhanced by hints).

Given the page identifier, the buffer frame is found by a hashtable lookup.
Accesses to the hash table and the buffer frame need to be synchronized.
Before accessing a page in the buffer, it must be fixed.
These points account for the fact that the costs of accessing a page in the buffer are therefore greater than zero.

Buffer Accesses

Consider page acceses in a buffer with 2 pages:

page no	action
0	read page 0, place it in buffer
1	read page 1, place it in buffer
0	fix page 0 in buffer
2	swap out a page (e.g. 1), read 2, place it in buffer
0	fix page 0 in buffer
3	swap out a page, read 3, place it in buffer
...	

- replacement strategy is imporant
- unfixes omitted

Replacement Strategies

Some popular replacement strategies:

- random
- fifo
- lru
- Q2

lru is very popular

Replacement Strategies - random

- when a new page slot is needed, remove a random other page from the buffer
- easy to implements, needs no additional memory
- but does not take the access patterns into account
- primarily used as base line
- suitable for analytic results

Replacement Strategies - fifo

- first in - first out
- remove the page that was place in the buffer first
- easy to implement, needs no/few additional memory
- but does not adapt very well do access patterns
- increasing buffer size may hurt it

Fifo Anomaly:

- access pattern: 3 2 1 0 3 2 4 3 2 1 0 4
- buffer sizes: 3 vs. 4

Replacement Strategies - lru

- least recently used
- remove the page that has not been accessed for longest time
- requires a priority queue/linked list
- adapt to access patterns, popular pages stay in memory
- but slow to remove pages

very popular replacement strategy

Replacement Strategies - 2Q

- two queues
- a fifo queue and a lru queue
- place pages first in fifo, if they are accessed again place them in lru
- gets rid of pages that are accessed only once fast
- superior to lru, example of a "real" replacement strategy

Replacement Strategies - Effect on the Cost Model

- replacement affects the costs
- cost model needs predictions, though
- very hard to do in general

Typical approaches:

- ignore buffer effects
- assume random replacement
- make use of known access characteristics

Physical Database Organization

The database organizes the physical storage in multiple layers:

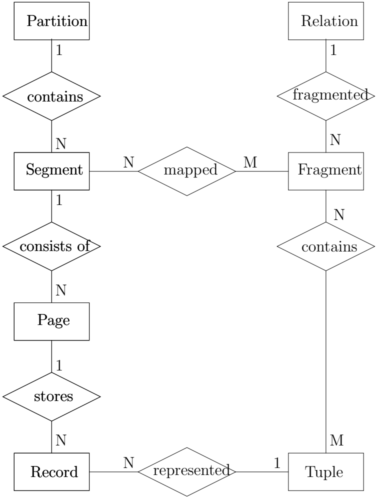
1. partition: sequence of pages (consecutive on disk)
2. extent: subsequence of a partition
3. segment (file): logical sequence of pages (implemented e.g. as set of extents)
4. record: sequence of bytes stored on a page

Note:

- partition/extent/page/record are physical structures
- a segment is a logical structure

Physical Storage of Relations

Mapping of a relation's tuples onto records stored on pages in segments:



Access to Database Items

- database item: something stored in DB
- database item can be set (bag, sequence) of items
- access to a database item then produces stream of smaller database items
- the operation that does so is called *scan*

Scan Example

Using a relation scan `rscan`, the query

select *
from Student

can be answered by `rscan(Student)`
(segments? extents?): Assumption:

- segment scans and each relation stored in one segment
- segment and relation name identical

Then `fscan(Student)` and `Student` denote scans of all tuples in a relation

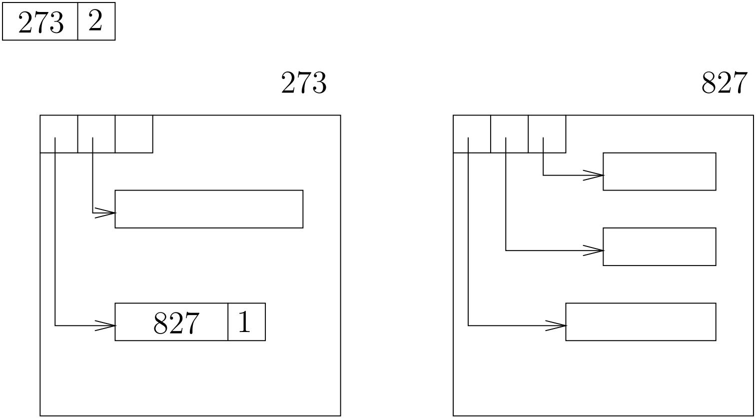
Model of a Segment

- for our cost model, we need a model of segments.
- we assume an extent-based segment implementation.
- every segment then is a sequence of extents.
- every extent can be described by a pair (F_j, L_j) containing its first and last cylinder.
  (For simplicity, we assume that extents span whole cylinders.)
- an extent may cross a zone boundary.
- hence: split extents to align them with zone boundaries.
- segment can be described by a sequence of triples (F_i, L_i, z_i) ordered on F_i where z_i is the zone number in which the extent lies.

Model of a Segment

S_{ext}	number of extents in the segment
$S_{\text{cfirst}}(i)$	first cylinder in extent i (F_i)
$S_{\text{clast}}(i)$	last cylinder in extent i (L_i)
$S_{\text{zone}}(i)$	zone of extent i (z_i)
$S_{\text{cpe}}(i)$	number of cylinders in extent i $(= S_{\text{clast}}(i) - S_{\text{cfirst}}(i) + 1)$
S_{sec}	total number of sectors in the segment $(= \sum_{i=1}^{S_{\text{ext}}} S_{\text{cpe}}(i) D_{\text{zspc}}(S_{\text{zone}}(i)))$

Slotted Page



- page is organized into areas (slots)
- slots point to data chunks
- slots may point to other pages

Tuple Identifier (TID)

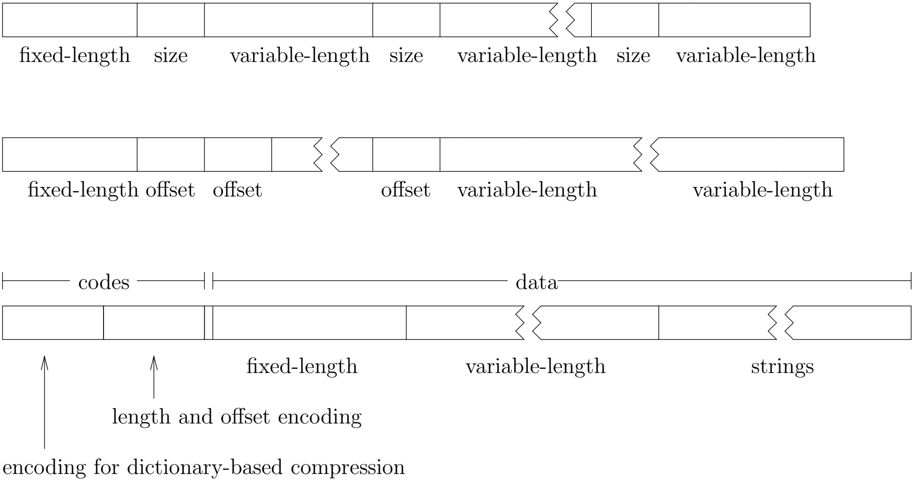
TID is conjunction of

- page identifier (e.g. partition/segment no, page no)
- slot number

TID sometimes called Row Identifier (RID)

Record Layout

Different layouts possible:



Record Layout (2)

Record layout is a compromise:

- space consumption vs. CPU
- data model specific properties: e.g. generalization
- versioning / easy schema migration
- record layout typically not trivial
- accessing an attribute value has non-zero cost

Physical Algebra

- building blocks for query execution
- implements the algorithms for query execution
- very generic, reusable components
- describes the general execution approach
- annotated with predicates etc. for query specific parts

Iterator Concept

The general interface of each operator is:

- open
- next
- close

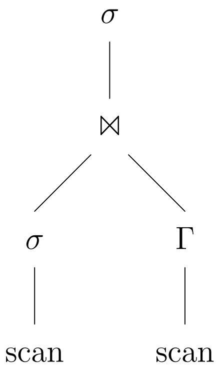
All physical algebraic operators are implemented as iterators.

- produce a stream of data items (tuples)

Implementations vary slightly for performance tuning (concept the same):

- `first`/`next` instead of `next`
- blocks of tuples instead of single tuples

Iterator Example



Note: all details (subscripts, implementations etc.) are omitted here

Pipelining

Pipelining is fundamental for the physical algebra:

- physical operators are iterators over the data
- they produce a stream of single tuples
- tuple stream if passed through other operators
- pipelining operators just pass the data through, they only filter or augment
- data is not copied or materialized
- very efficient processing

pipeline breakers disrupt this pipeline and materialize data:

- very expensive, can cause superfluous work
- sometimes cannot be avoided, though

Simple Scan

- a `rscan` operation is rarely supported.
- instead: scans on segments (files).
- since a (data) segment is sometimes called *file*, the correct plan for the above query is often denoted by `fscan(Student)`.

Several assumptions must hold:

- the `Student` relation is not fragmented, it is stored in a single segment,
- the name of this segment is the same as the relation name, and
- no tuples from other relations are stored in this segment.

Until otherwise stated, we assume that these assumptions hold.
Instead of `fscan(Student)`, we could then simply use `Student` to denote leaf nodes in a query execution plan.

Attributes/Variables and their Binding

select *
from Student

can be expressed as $Student[s]$ instead of $Student$.
Result type: set of tuples with a single attribute s.
s is assumed to bind a pointer

- to the physical record in the buffer holding the current tuple *or*
- a pointer to the slot pointing to the record holding the current tuple

Building Block

- scan
- a leaf of a query execution plan

Leaf can be complex.
But: Plan generator does not try to reorder within building blocks
Nonetheless:

- building block organized around a single database item

If more than a single database item is involved: *access path*