Storing Data: Disk, File and Index

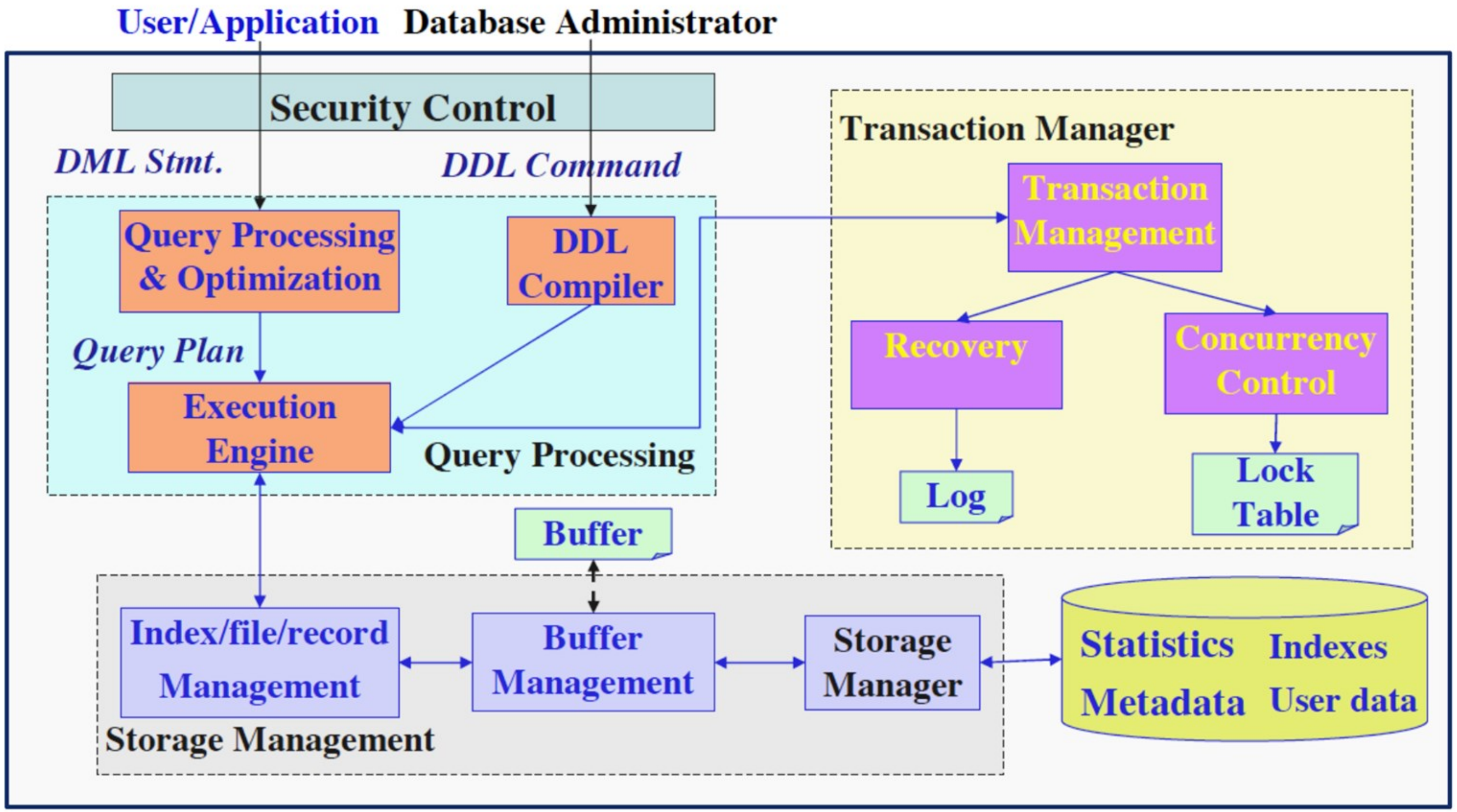
COMP9311 24T3; Week 7

By Zhengyi Yang, UNSW

Notice

- Marks and sample solutions for Assignment 1 have been released
- Contact your marking tutor by the end of this week if you have any problems with your marks
- The deadline for Project 1 has passed
- Assignment 2 will be released on Wednesday of this week.
- Assignment 2 deadline: 5pm Monday, Week 10 (11 November)

Functional Components of DBMS



Memory Hierarchy

- ***Primary Storage***: main memory.

  fast access, expensive.

- ***Secondary storage:*** hard disk.

  slower access, less expensive.

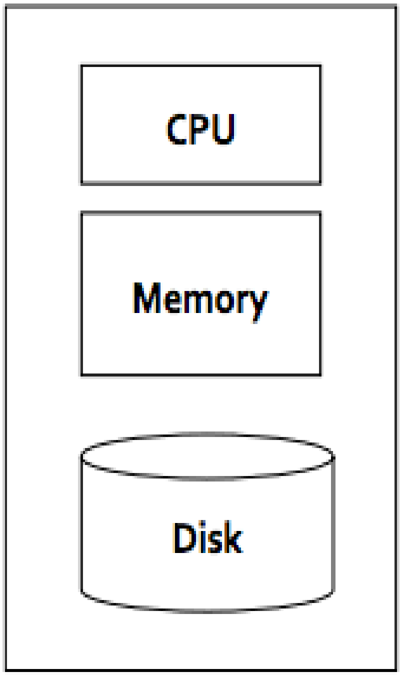
- ***Tertiary storage***: tapes, cd, etc.

  slowest access, cheapest.

Primary Storage

Main memory:

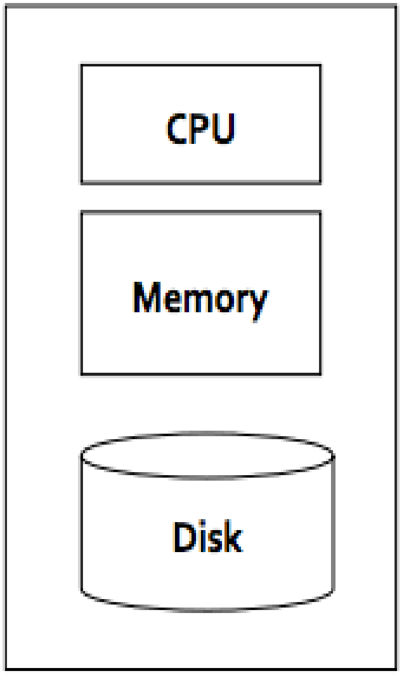
- Fast access (10s to 100s of nanoseconds; 1 nanosecond = 10^{-9} seconds)
- Generally too small (or too expensive) to store the entire database
- **Volatile** — contents of main memory are usually lost if a power failure or system crash occurs.



Secondary Storage

Magnetic-disk

- Data is stored on spinning disk, and read/written magnetically
- Primary medium for the long-term storage of data; typically stores entire database.
- **Data must be moved from disk to main memory for access, and written back for storage**
  - **Much slower access than main memory**
- **Direct-access** – possible to read data on disk in any order.
- Survives power failures and system crashes
  - Recall: disk failure can destroy data, but is rare



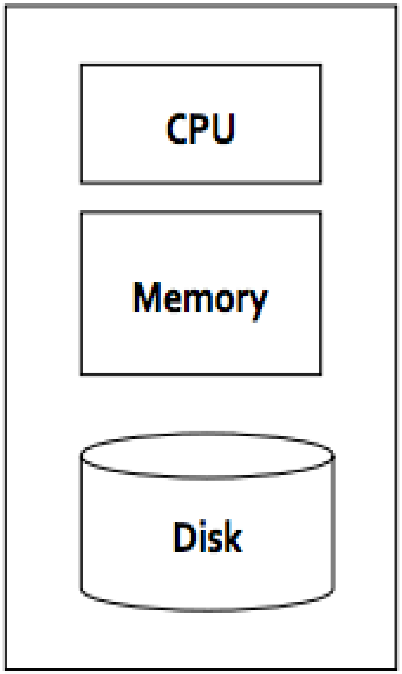
Latency Numbers Every Programmer Should Know

Event	Latency	Scaled
1 CPU cycle	0.3 ns	1 s
Level 1 cache access	0.9 ns	3 s
Level 2 cache access	2.8 ns	9 s
Level 3 cache access	12.9 ns	43 s
Main memory access (DRAM, from CPU)	120 ns	6 min
Solid-state disk I/O (flash memory)	50-150 μs	2-6 days
Rotational disk I/O	1-10 ms	1-12 months
Internet: San Francisco to New York	40 ms	4 years
Internet: San Francisco to United Kingdom	81 ms	8 years
Internet: San Francisco to Australia	183 ms	19 years
TCP packet retransmit	1-3 s	105-317 years

CPU cost vs I/O cost

The implementation issues

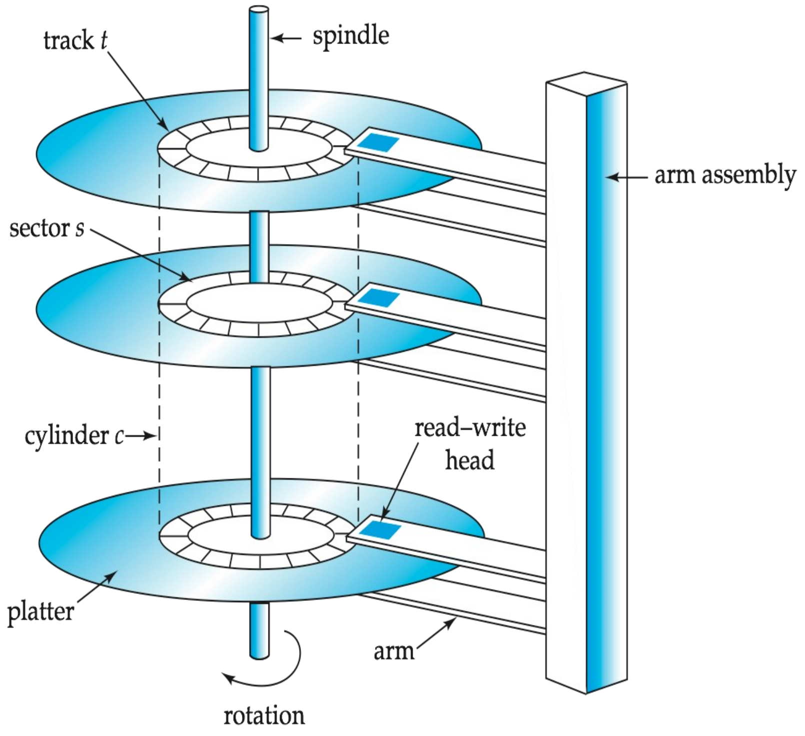
- There are two main costs, CPU cost and I/O (Input/Output) cost.
  - CPU cost is to process data in main memory.
  - I/O cost is to read/write data from/into disk.
- The dominating cost is I/O cost. For query processing in DBMS, CPU cost can be ignored.
- The key issue is to reduce I/O cost.
  - It is to reduce the number of I/O accesses.
- What is I/O cost?
  - A block (or page) to be read/written from/into disk is one I/O access (or one disk-block/page access).



OLD Magnetic Hard Disk

Characteristics of disks:

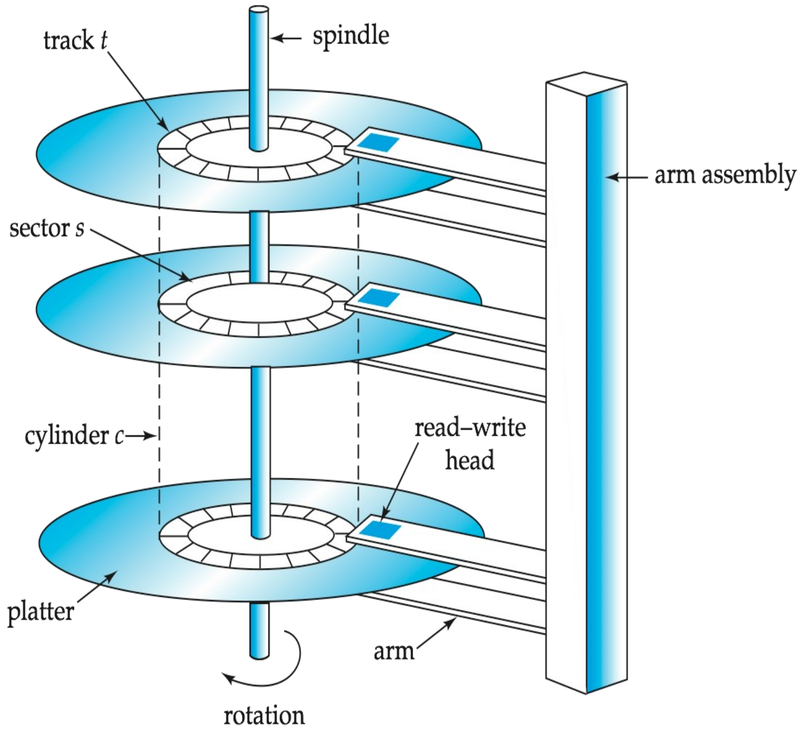
- collection of platters
- each platter = set of tracks
- each track = sequence of sectors (blocks)



NOTE: Diagram simplifies the structure of actual disk drives

OLD Magnetic Hard Disk

- Data must be in memory for the DBMS to operate on it.
- Smallest process unit is **Block**: If a single record in a block is needed, the entire block is transferred.



NOTE: Diagram simplifies the structure of actual disk drives

Disks

Access time includes:

- seek time (find the right track, e.g., 10msec)
- rotational delay (find the right sector, e.g., 5msec)
- transfer time (read/write block, e.g., 10μsec)

Random access is dominated by **seek time** and **rotational delay**

Disk Space Management

Improving Disk Access:

Use knowledge of data access patterns.

- E.g., two records often accessed together: put them in the same block (clustering)
- E.g., records scanned sequentially: place them in consecutive sectors on same track

Keep Track of Free Blocks

- Maintain a list of free blocks
- Use bitmap

Using OS File System to Manage Disk Space

- extend OS facilities, but not rely on the OS file system.
- (portability and scalability)

Storage Access

Data must be in memory for the DBMS to operate on it.

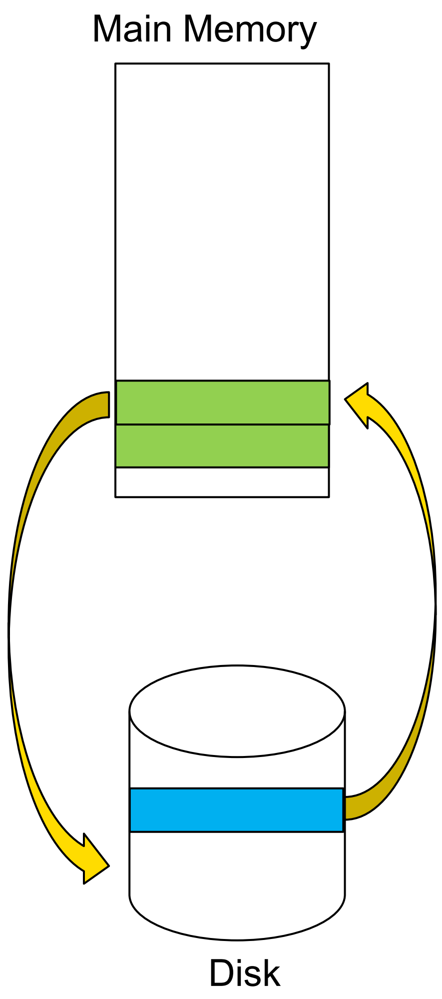
A database file is partitioned into fixed-length storage units called **blocks**. Blocks are units of both storage allocation and data transfer.

Database system seeks to minimize the number of block transfers between the disk and memory.

We can reduce the number of disk accesses by keeping as many blocks as possible in main memory.

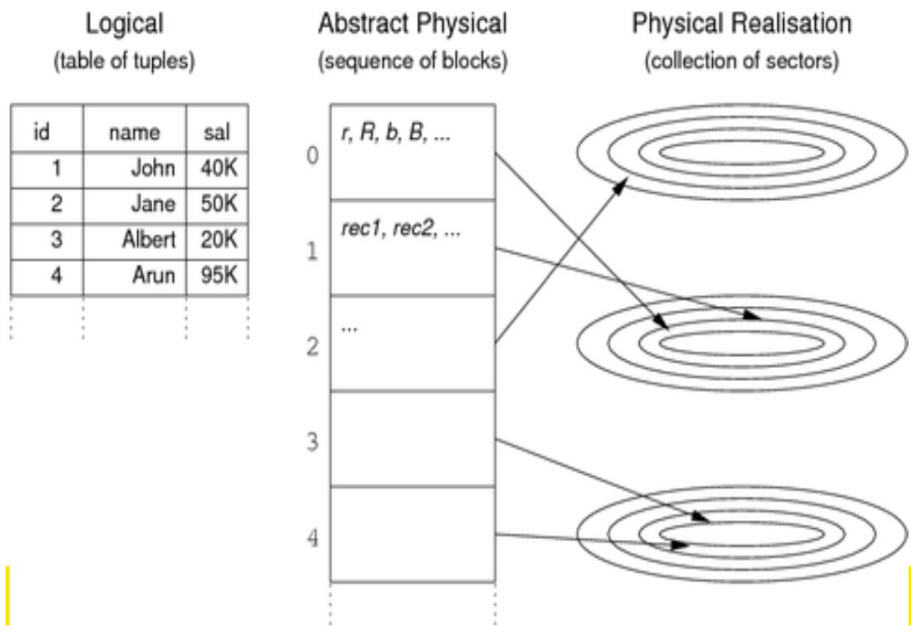
Buffer – portion of main memory available to store copies of disk blocks.

Buffer manager – subsystem responsible for allocating buffer space in main memory.

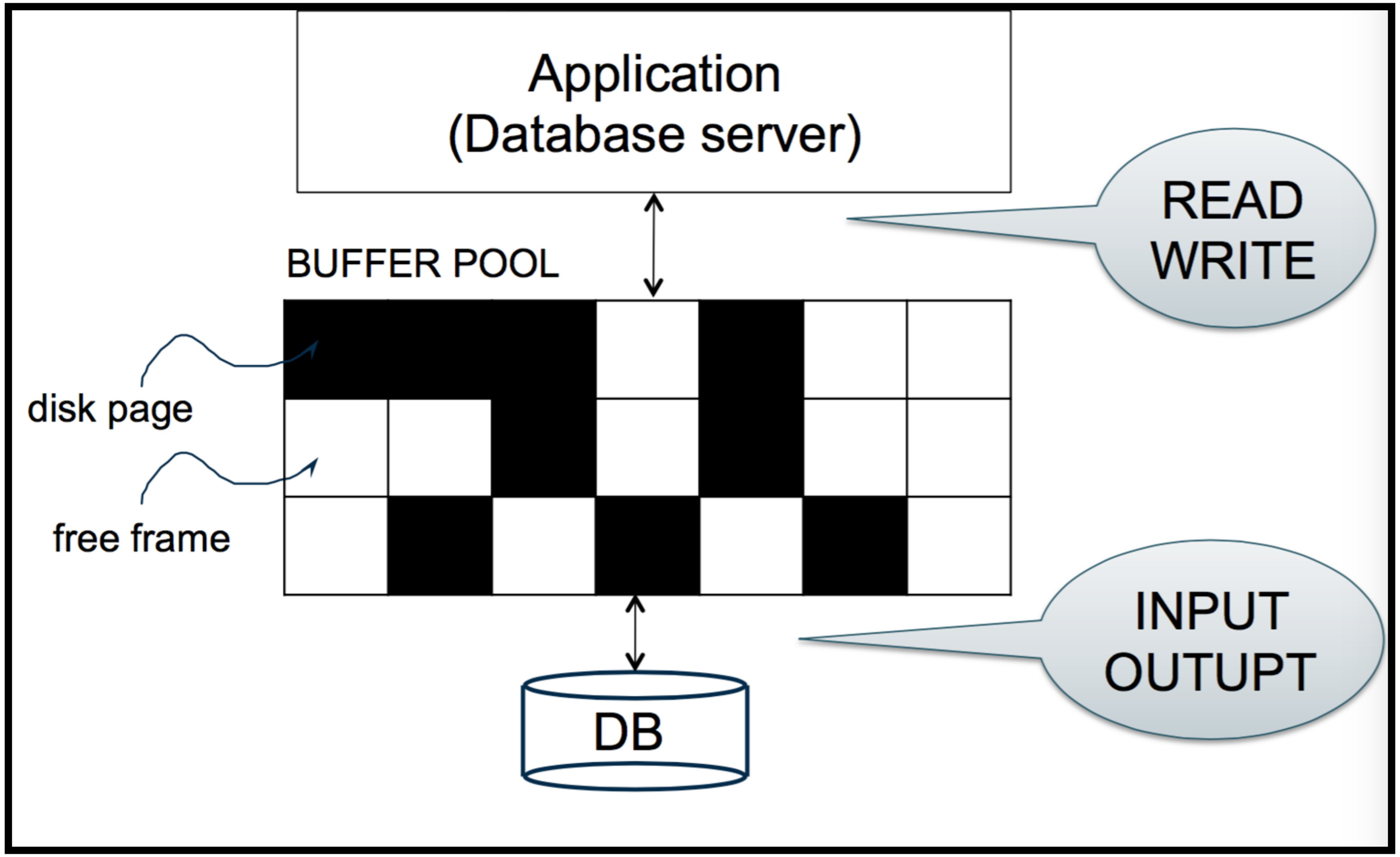


Disk-Block Access

- Smallest process unit is **a block**: If a single record in a block is needed, the entire block is transferred.
- Data are transferred between disk and main memory in units of blocks.
- A relation is stored as a **file** on **disk**.
- A file is a sequence of blocks, where a block is a fixed-length storage unit.
- A block is also called a page.



Buffer Management in a DBMS



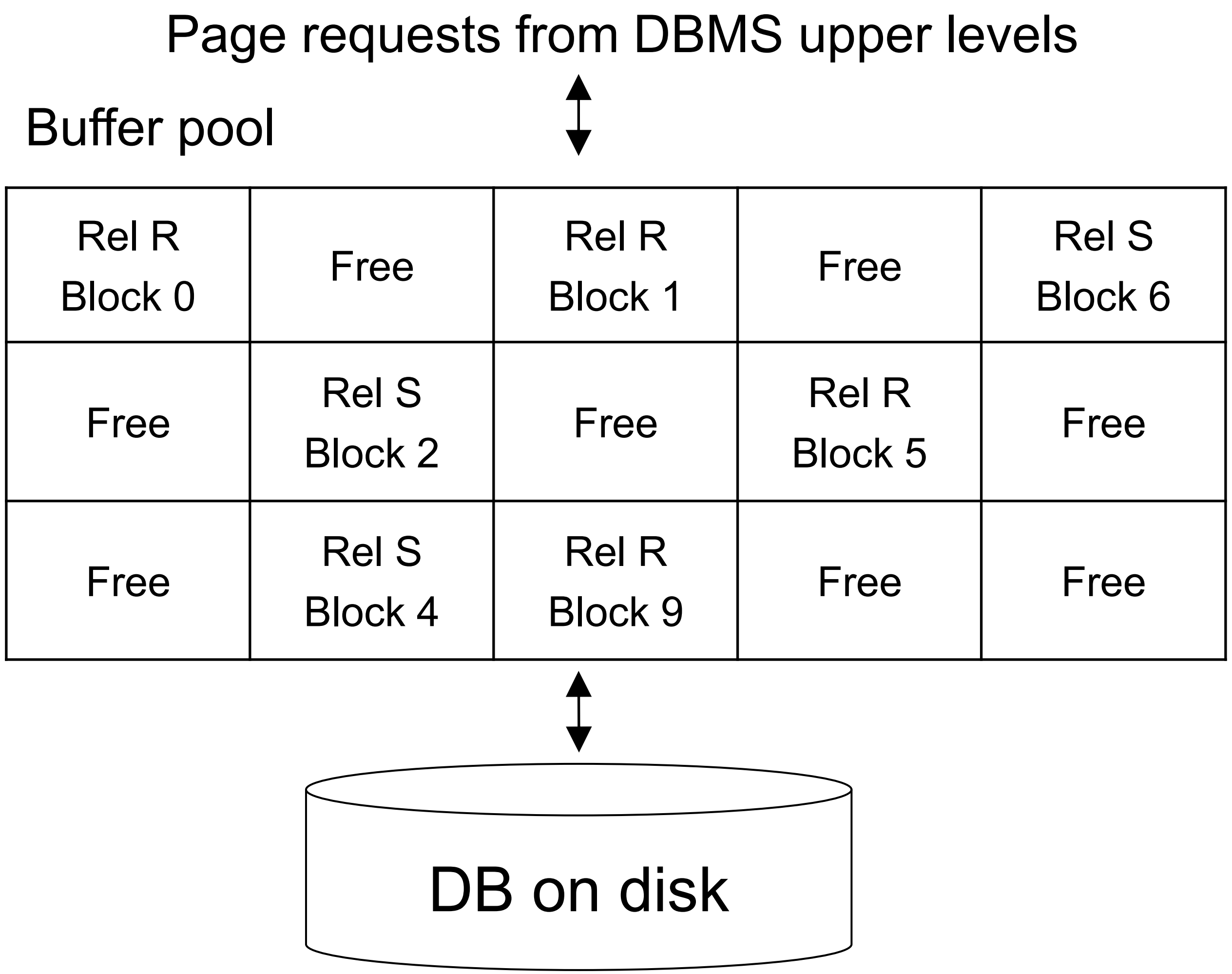
Buffer Management

Manages traffic between disk and memory by maintaining a **buffer pool** in main memory.

Buffer Pool

- collection of page slots (frames) which can be filled with copies of disk block data.
- E.g., One page = 4096 Bytes = One block

Buffer Pool


Page requests from DBMS upper levels
Buffer pool
Rel R Block 0
Free
Rel R Block 1
Free
Rel S Block 6
Free
Rel S Block 2
Free
Rel R Block 5
Free
Free
Rel S Block 4
Rel R Block 9
Free
Free
DB on disk

Buffer Pool

The **request_block** operation

If block **is** already in buffer pool:

- ➢ no need to read it again
- ➢ use the copy there (unless write-locked)

If block **is not** in buffer pool yet:

- ➢ need to read from hard disk into a free frame
- ➢ if no free frames, need to remove block using a **buffer replacement policy**.

The **release_block** function indicates that block is no longer in use

- ➢ good candidate for removal / replacing

Buffer Pool

For each frame, we need to know:

- whether it is currently in use
- whether it has been modified since loading (*dirty bit*)
- how many transactions are currently using it (*pin count*)
- (maybe) time-stamp for most recent access

Buffer Pool

The *release_block* operation

- Decrement pin count for specified page.
- No real effect until replacement required.

The *write_block* operation

- Updates contents of page in pool
- Set dirty bit on
- Note: Doesn’t actually write to disk, until been replaced, or forced to commit

The *force_block* operation

- "commits" by writing to disk.

Buffer Replacement Policies

Least Recently Used (LRU)

- release the frame that has not been used for the longest period.
- intuitively appealing idea but can perform badly

Most Recently Used (MRU):

- release the frame used most recently

First in First Out (FIFO)

- need to maintain a queue of frames
- enter tail of queue when read in

Random

No one is guaranteed to be better than the others.

Quite dependent on applications.

Quiz 1:

Example1:

Data pages: P1, P2, P3, P4

Queries:

Q1: read P1; Q2: read P2;

Q3: read P3; Q4: read P1;

Q5: read P2;

Buffer:

P1 Q1		

P1 Q1	**P2** Q2	

P1 Q1	P2 Q2	**P3** Q3

P1 Q4	P2 Q2	P3 Q3

P1 Q4	**P2** Q5	P3 Q3

Quiz 1:

Example1:

Data pages: P1, P2, P3, P4

Queries:

Q1: read P1; Q2: read P2;

Q3: read P3; Q4: read P1;

Q5: read P2;

Buffer:

P1 Q4	**P2** Q5	**P3** Q3

How about if Q6 read P4?
Using different buffer relacement policies

Quiz 1(LRU):

Example1:

Data pages: P1, P2, P3, P4

Queries:

Q1: read P1; Q2: read P2;

Q3: read P3; Q4: read P1;

Q5: read P2;

Buffer:

P1 Q4	P2 Q5	P3 Q3

How about if Q6 read P4?

Using different buffer relacement policies

<u>LRU: Least Recently Used</u>

P1 Q4	P2 Q5	**P4** Q6

Quiz 1(MRU):

Example1:

Data pages: P1, P2, P3, P4

Queries:

Q1: read P1; Q2: read P2;

Q3: read P3; Q4: read P1;

Q5: read P2;

Buffer:

P1 Q4	P2 Q5	P3 Q3

How about if Q6 read P4?

Using different buffer relacement policies

<u>MRU: Most Recently Used</u>

P1 Q4	**P4** Q6	P3 Q3

Quiz 1(FIFO):

Example1:

Data pages: P1, P2, P3, P4

Queries:

Q1: read P1; Q2: read P2;

Q3: read P3; Q4: read P1;

Q5: read P2;

Buffer:

P1 Q4	P2 Q5	P3 Q3

How about if Q6 read P4?

Using different buffer relacement policies

<u>FIFO: First In First Out</u>

P4 Q6	P2 Q5	P3 Q3

Quiz 1(Random):

Example1:

Data pages: P1, P2, P3, P4

Queries:

Q1: read P1; Q2: read P2;

Q3: read P3; Q4: read P1;

Q5: read P2;

Buffer:

P1 Q4	P2 Q5	P3 Q3

How about if Q6 read P4?
Using different buffer relacement policies
<u>Random</u>

Randomly choose one buffer to replace

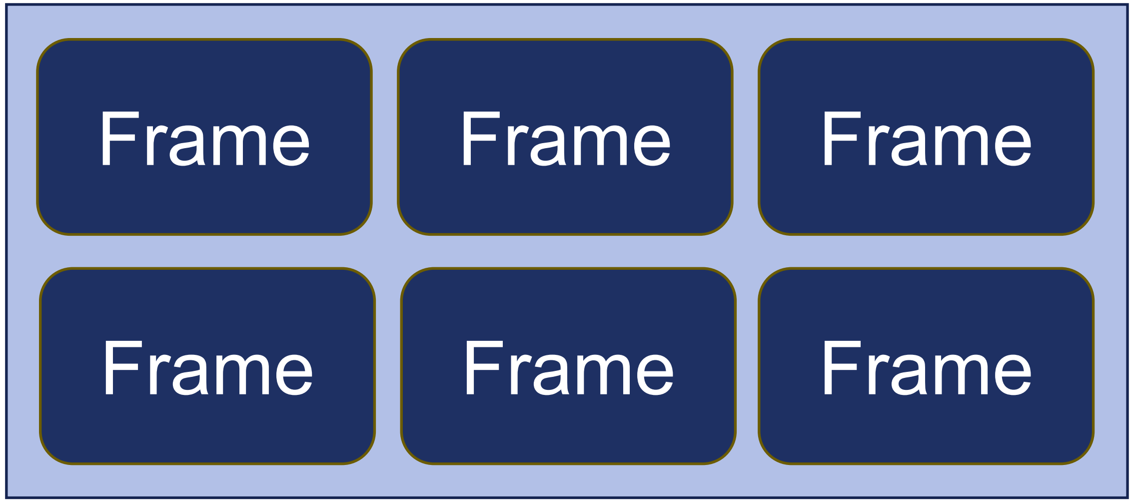
Cache Performance

- Cache hits
  - pages can be served by the cache
- Cache misses
  - pages have to be retrieved from the disk
- **Hit rate** = #cache hits / (#cache hits + #cache misses)

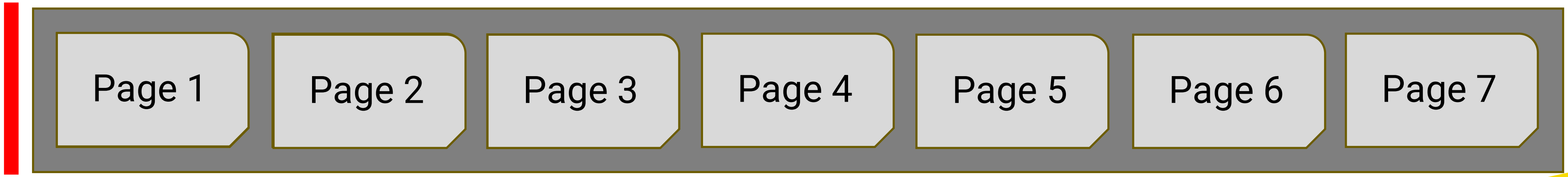
Repeated Scan (LRU)

Cache Hit: 0

Attempts: 0



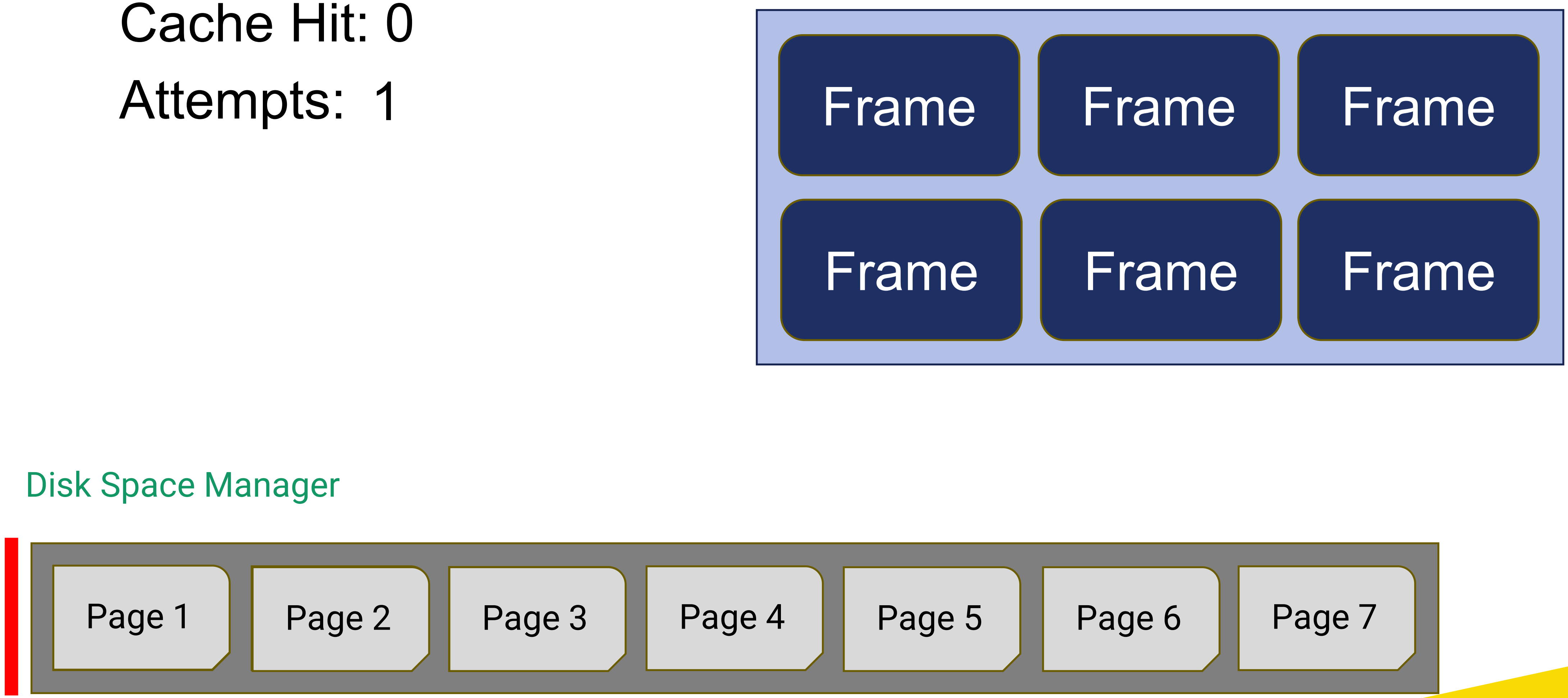
Disk Space Manager



Repeated Scan (LRU): Read Page 1

Cache Hit: 0

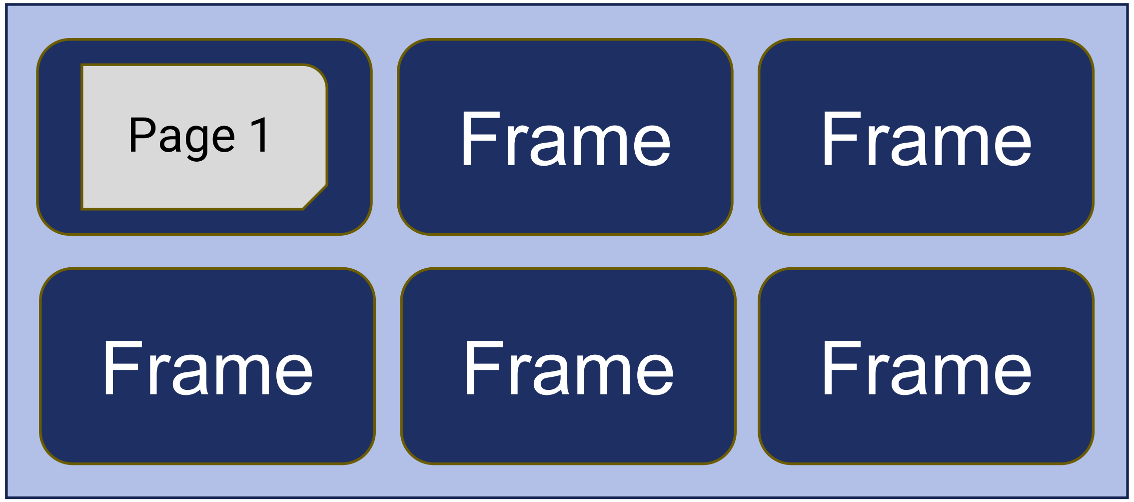
Attempts: 1



Repeated Scan (LRU): Read Page 2

Cache Hit: 0

Attempts: 2



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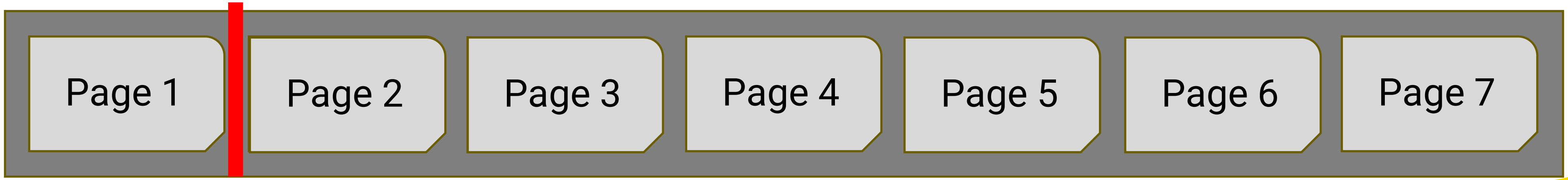
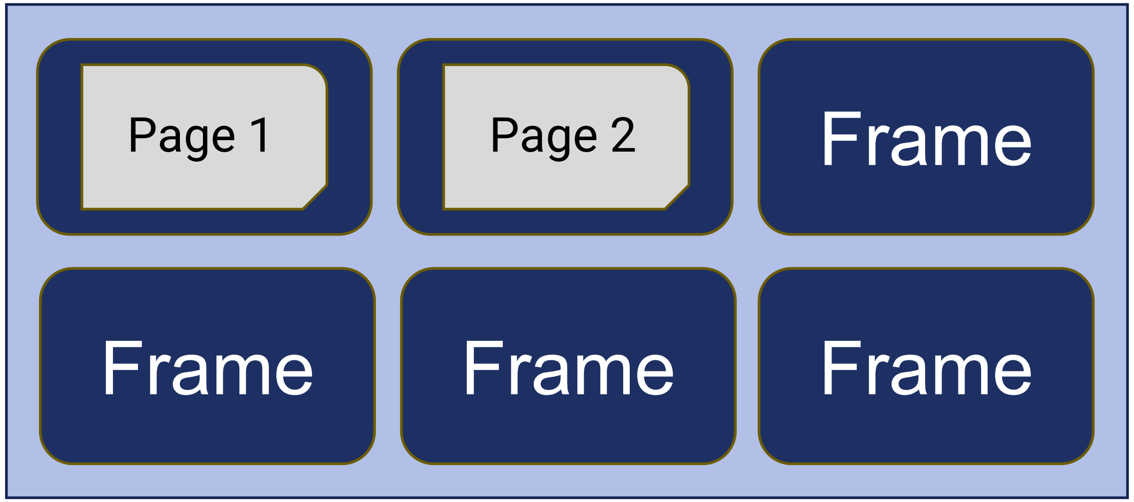
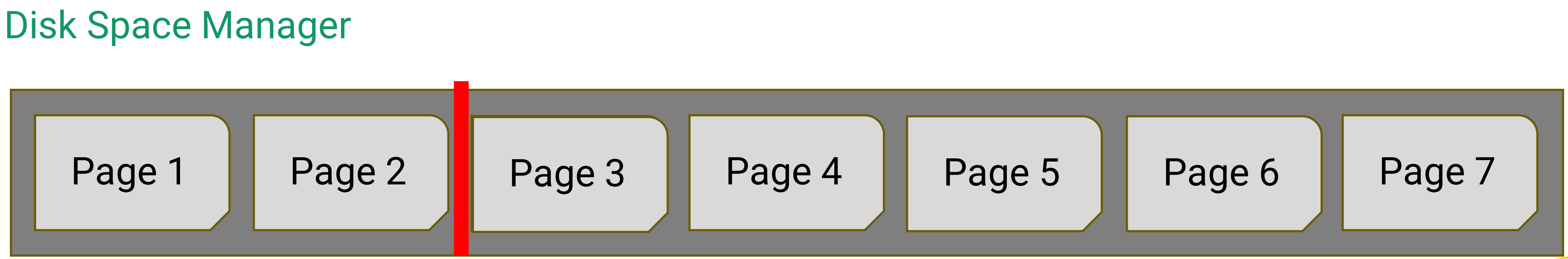


Repeated Scan (LRU): Read Page 3

Cache Hit: 0

Attempts: 3

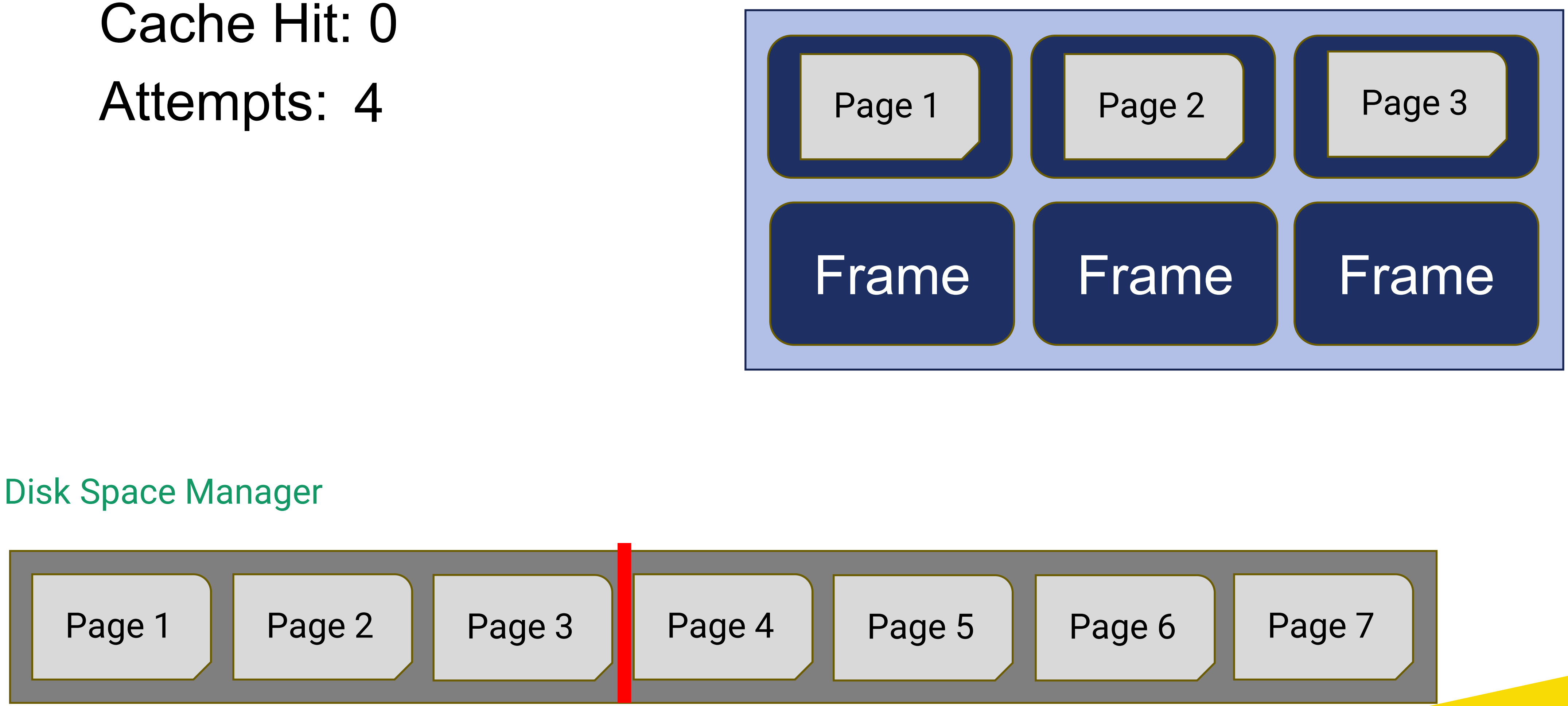




Repeated Scan (LRU): Read Page 4

Cache Hit: 0

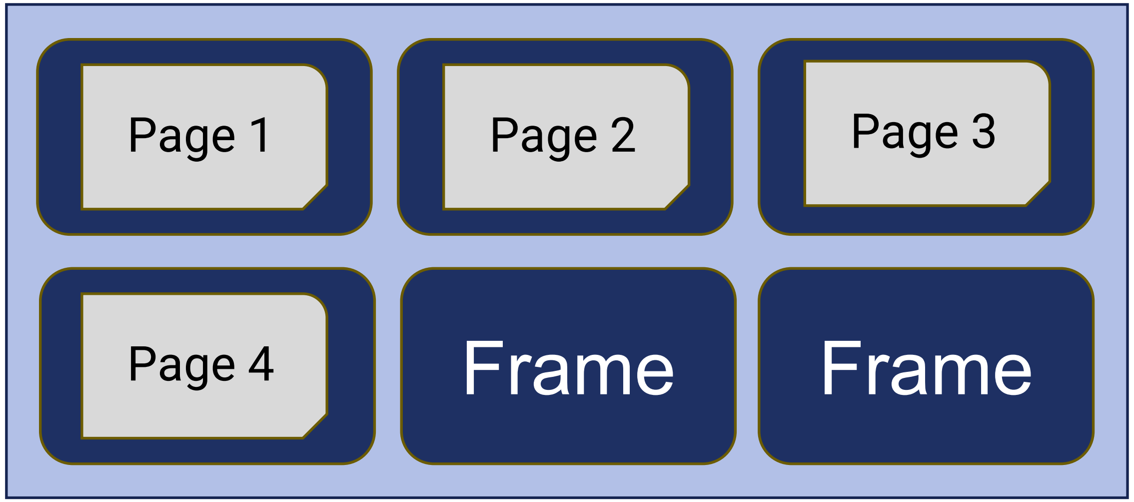
Attempts: 4



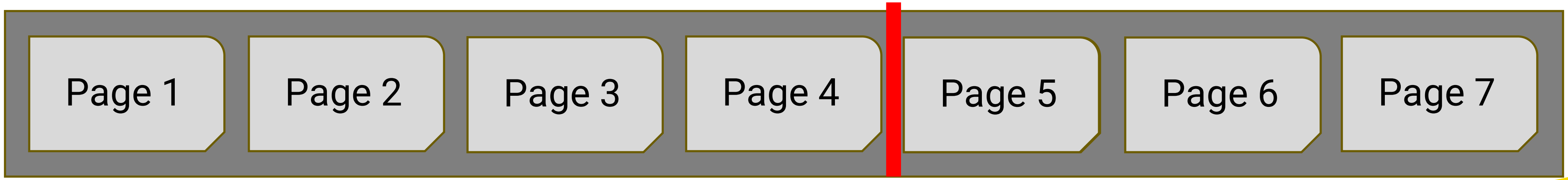
Repeated Scan (LRU): Read Page 5

Cache Hit: 0

Attempts: 5



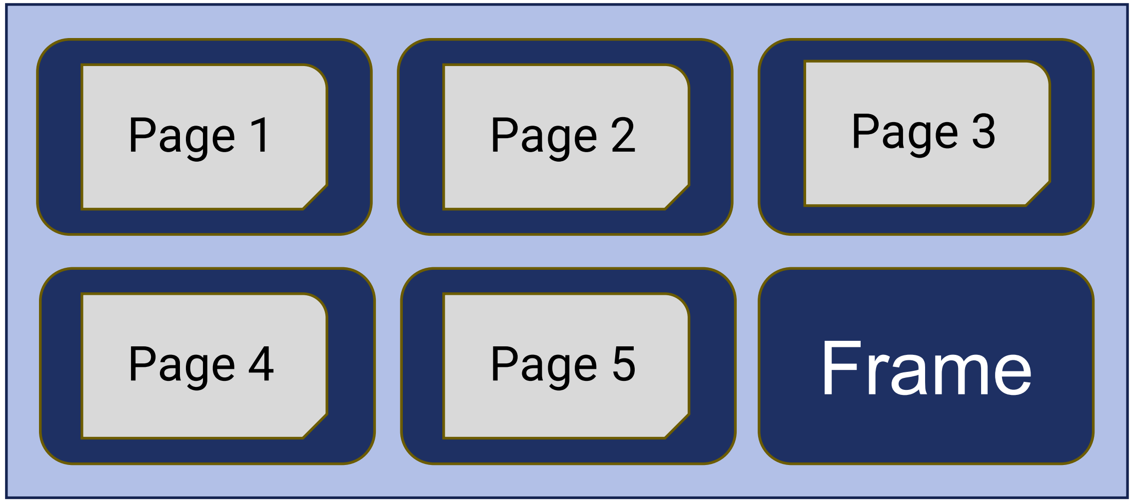
Disk Space Manager



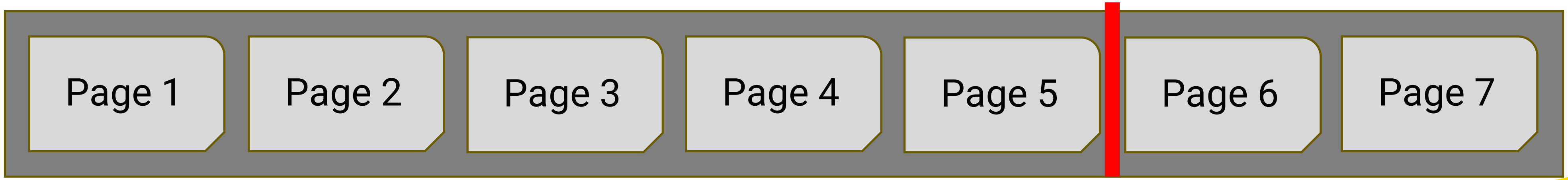
Repeated Scan (LRU): Read Page 6

Cache Hit: 0

Attempts: 6



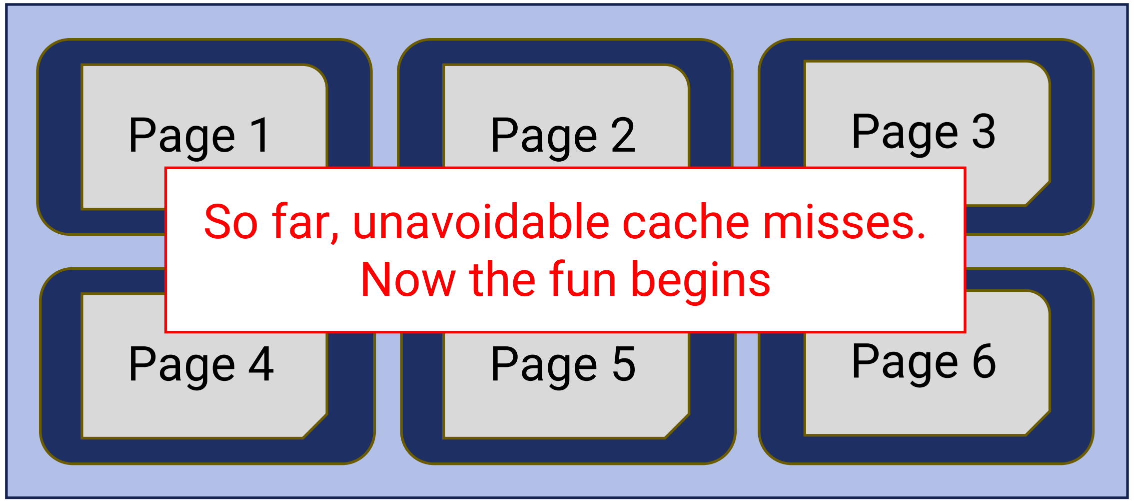
Disk Space Manager



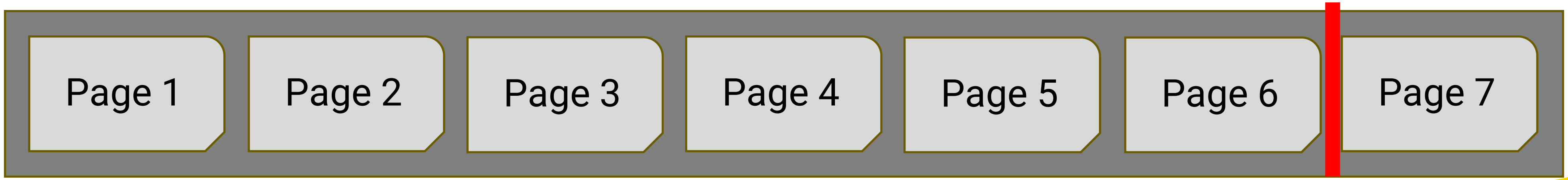
Repeated Scan (LRU): Read Page 6

Cache Hit: 0

Attempts: 6



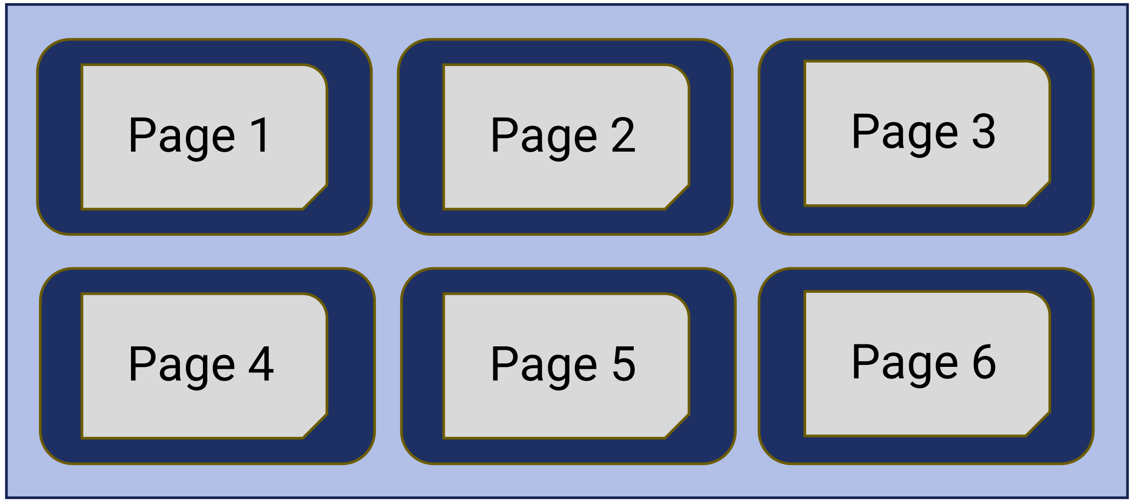
Disk Space Manager



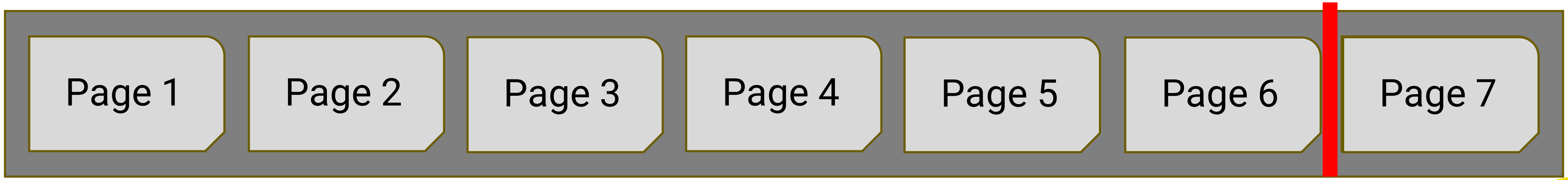
Repeated Scan (LRU): Read Page 7

Cache Hit: 0

Attempts: 7



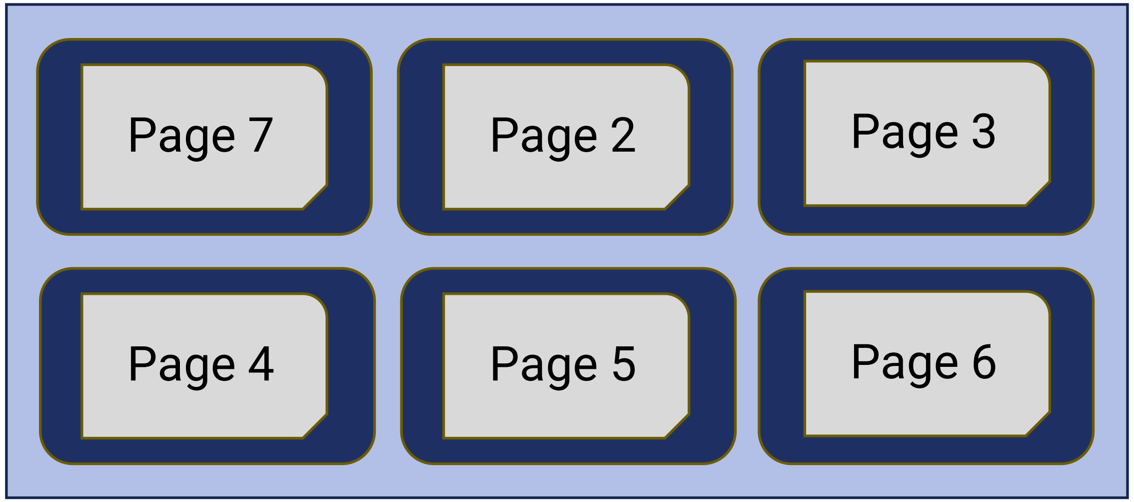
Disk Space Manager



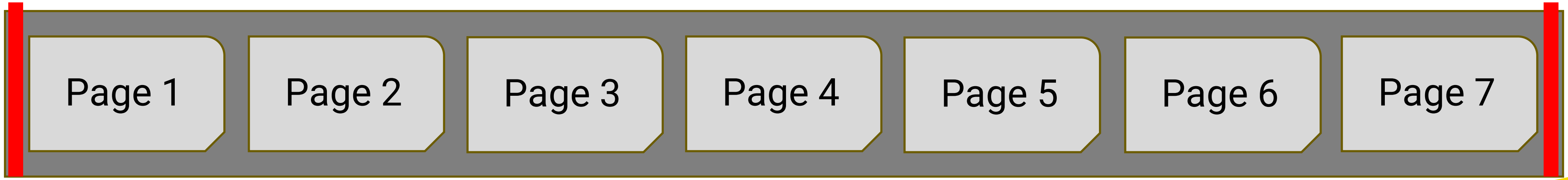
Repeated Scan (LRU): Reset to beginning

Cache Hit: 0

Attempts: 7



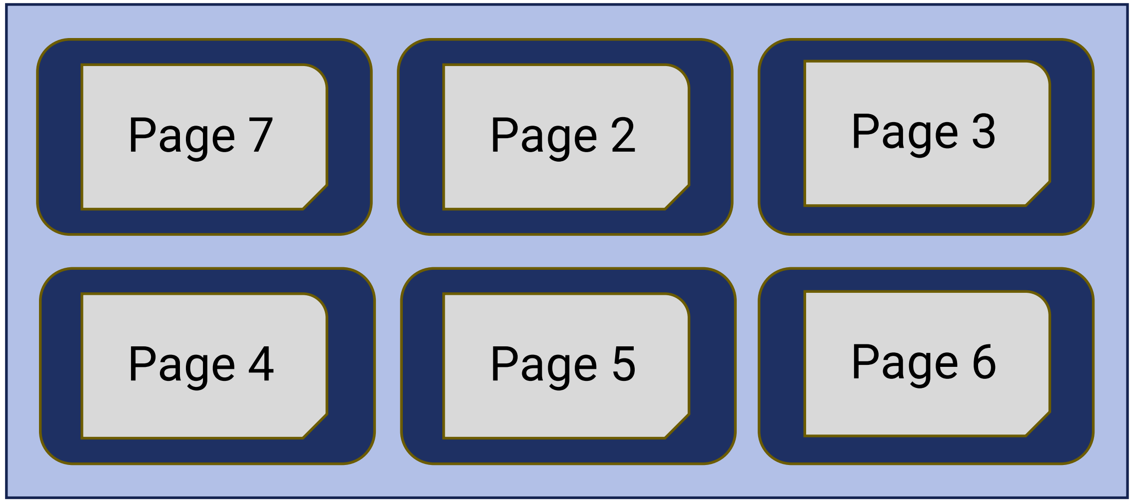
Disk Space Manager



Repeated Scan (LRU): Read Page 1(again)

Cache Hit: 0

Attempts: 8



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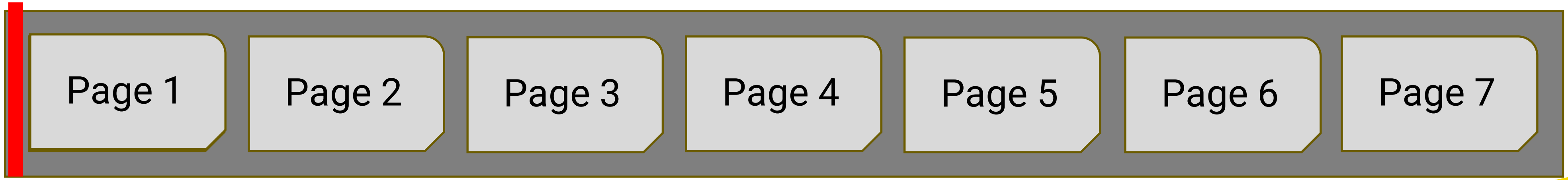
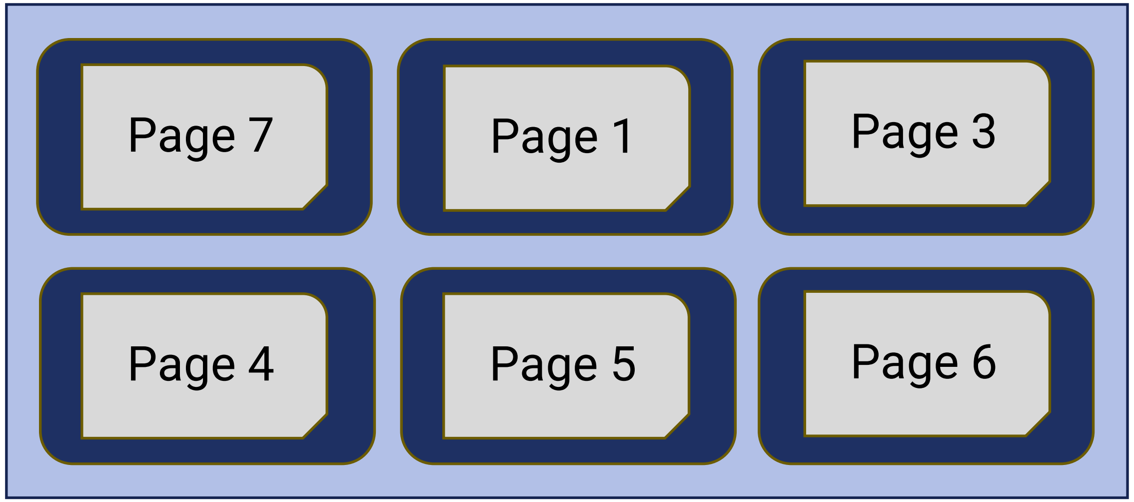


Repeated Scan (LRU): Read Page 2(again)

Cache Hit: 0

Attempts: 9



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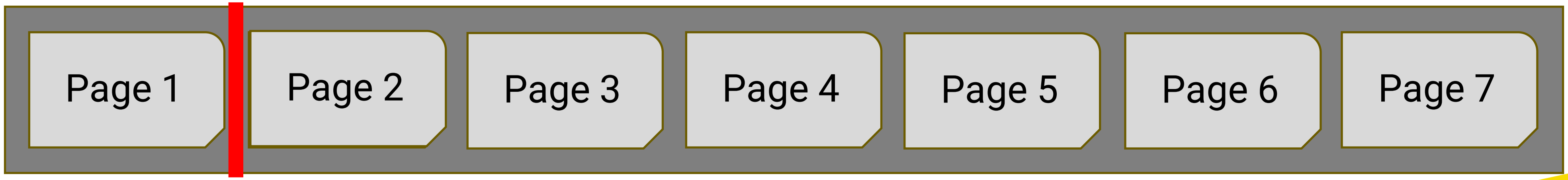
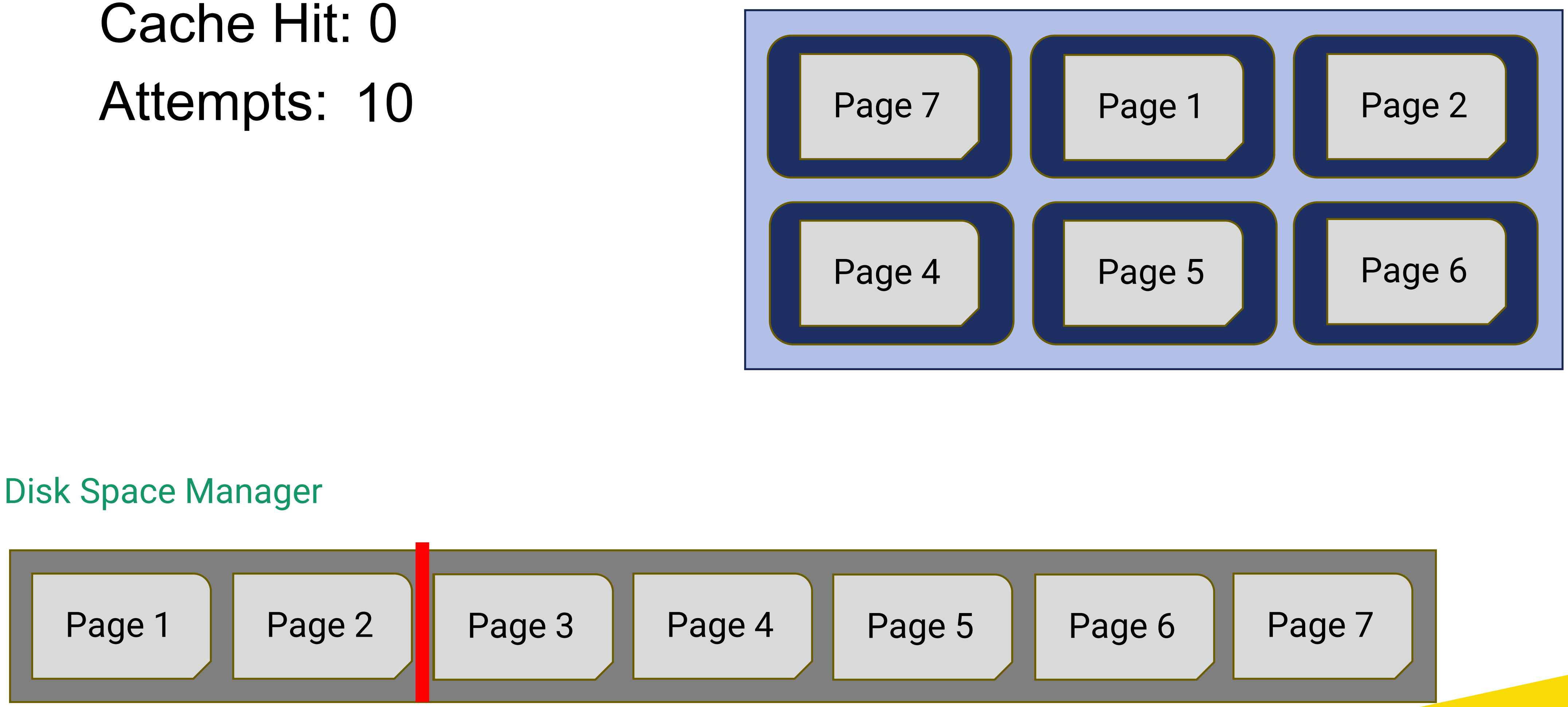


Repeated Scan (LRU): Read Page 3(again)

Cache Hit: 0

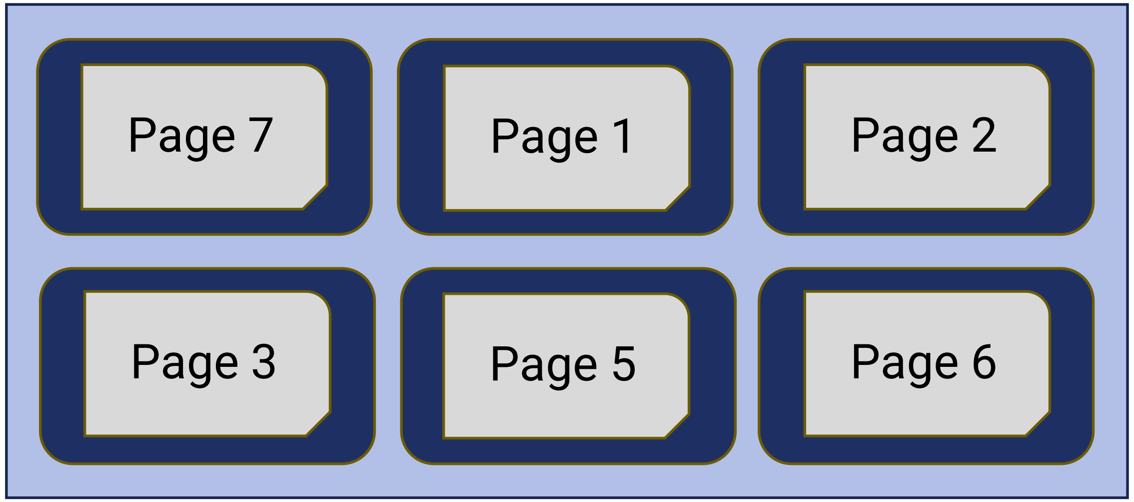
Attempts: 10



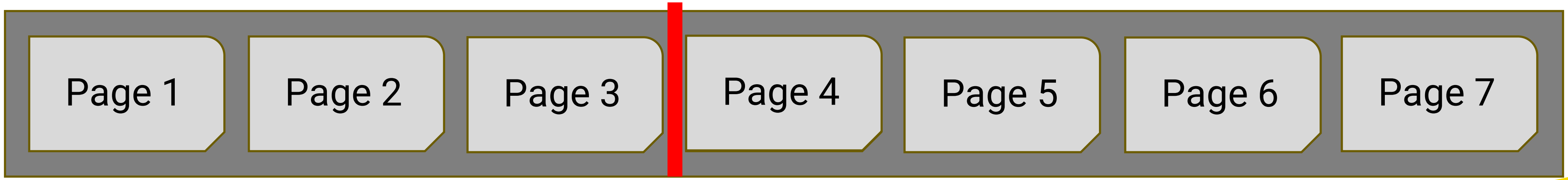
Repeated Scan (LRU): Read Page 4(again)

Cache Hit: 0

Attempts: 11



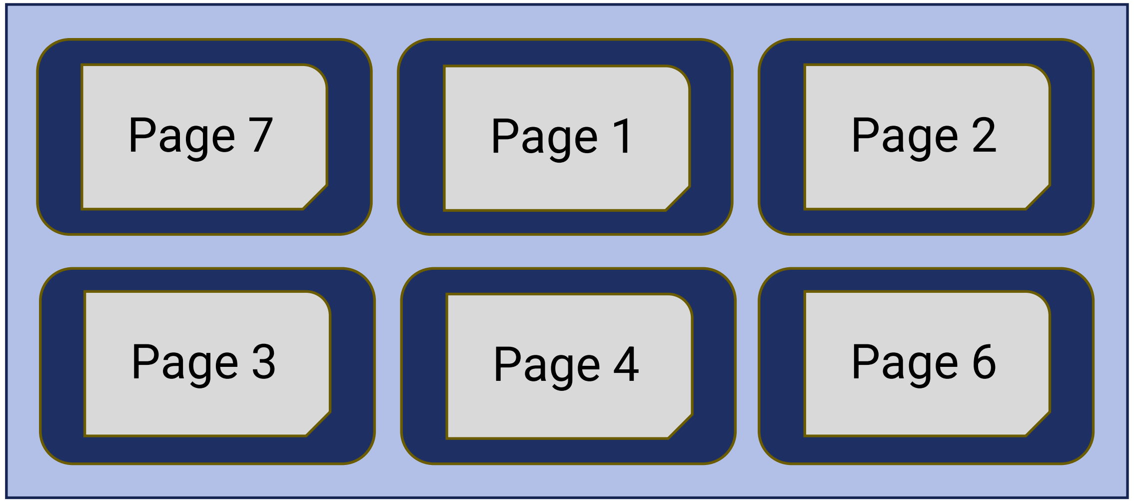
Disk Space Manager



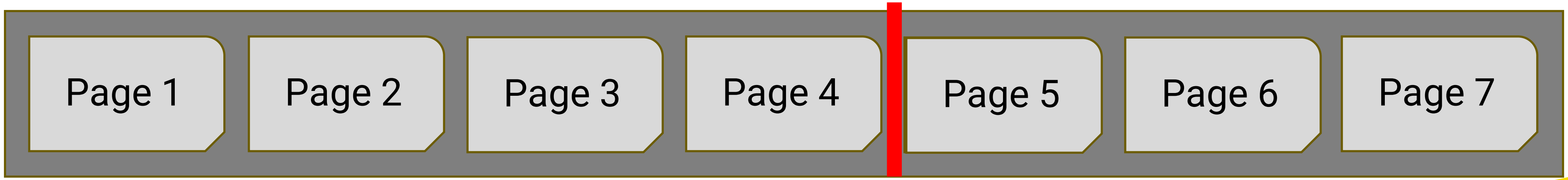
Repeated Scan (LRU): Read Page 5, cont

Cache Hit: 0

Attempts: 12



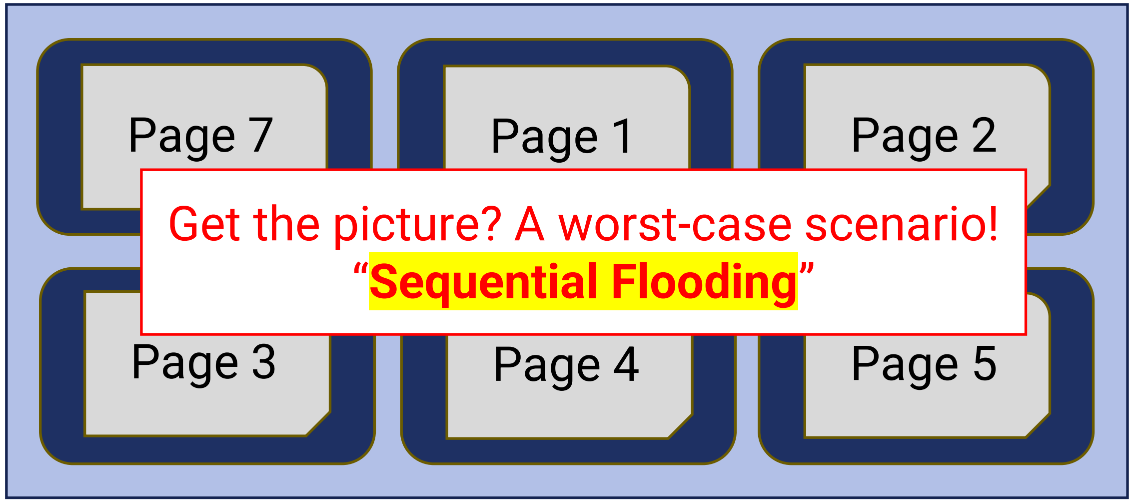
Disk Space Manager



Repeated Scan (LRU): Read Page 5, cont

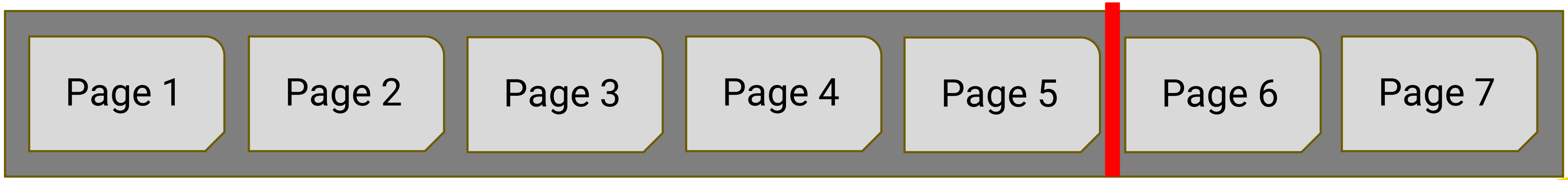
Cache Hit: 0

Attempts: 12



Get the picture? A worst-case scenario!
“**Sequential Flooding**”

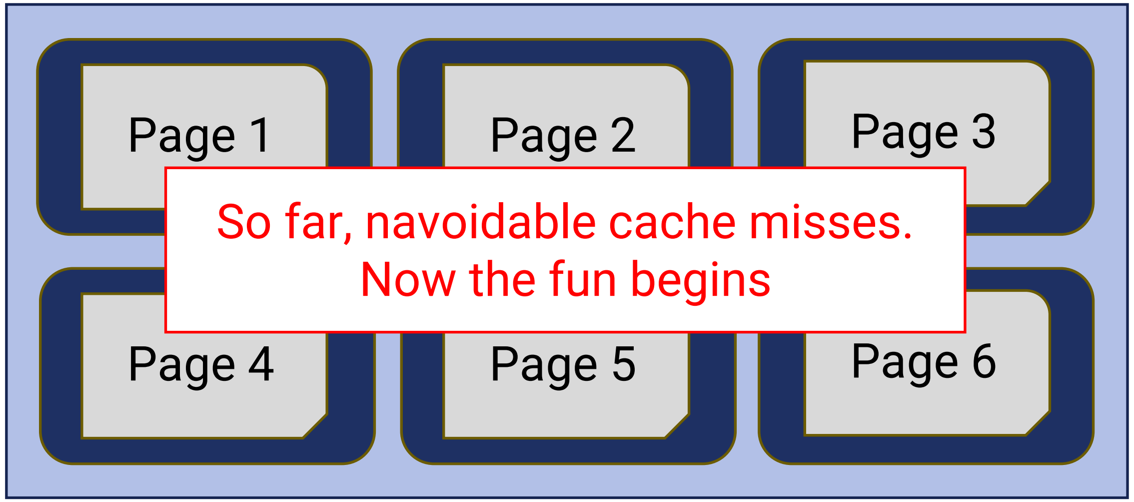
Disk Space Manager



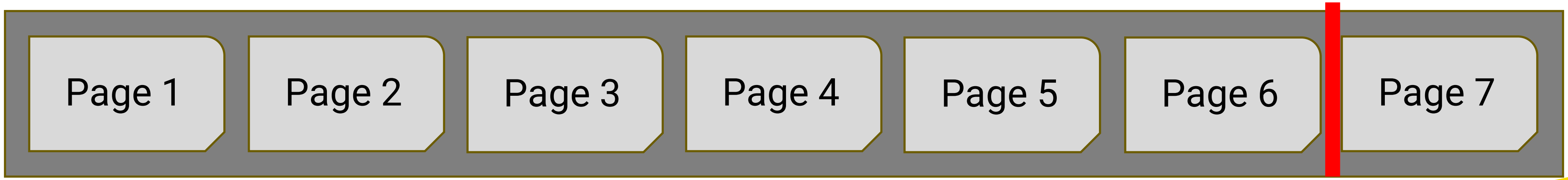
Repeated Scan (MRU)

Cache Hit: 0

Attempts: 6



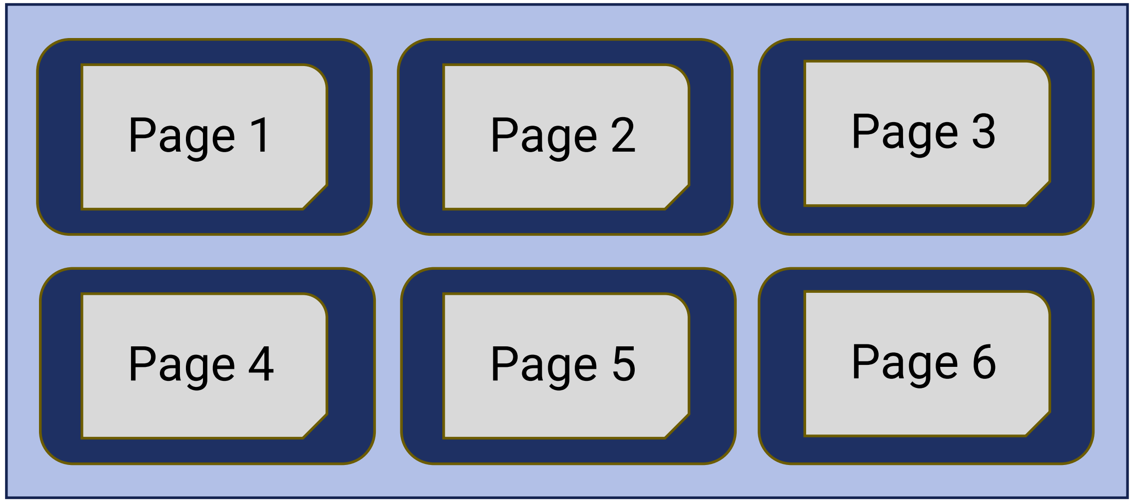
Disk Space Manager



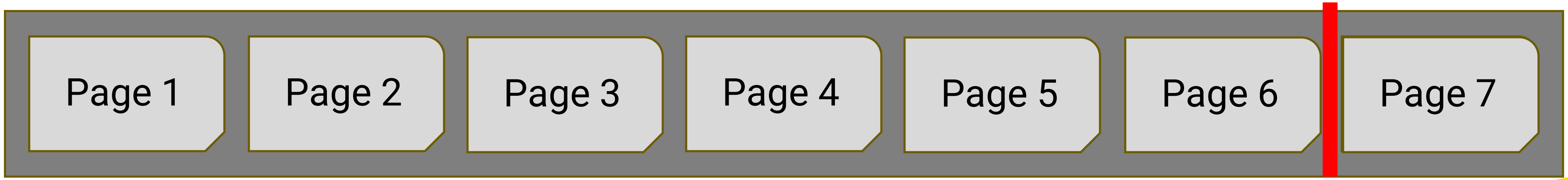
Repeated Scan (MRU): Read Page 7

Cache Hit: 0

Attempts: 7



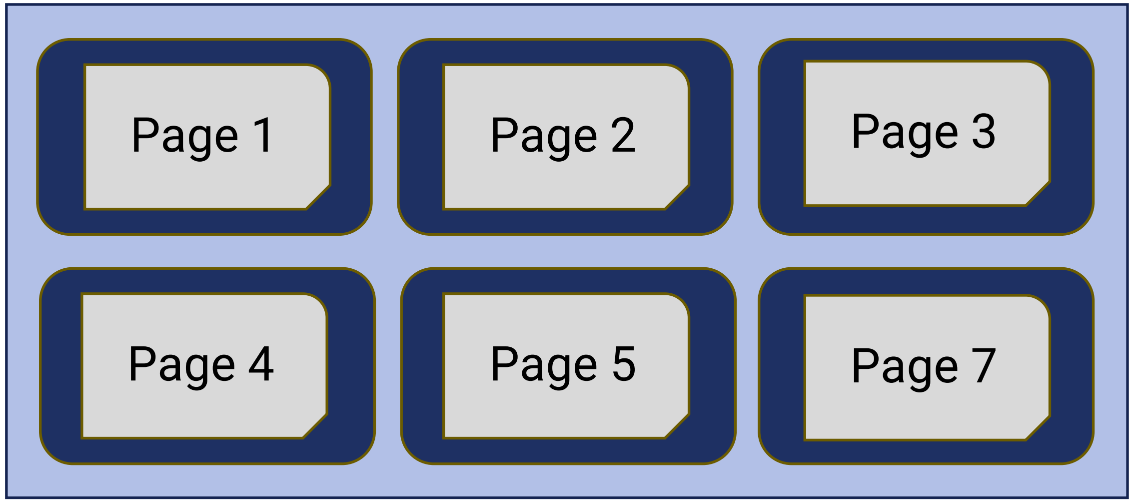
Disk Space Manager



Repeated Scan (MRU): Reset

Cache Hit: 0

Attempts: 7



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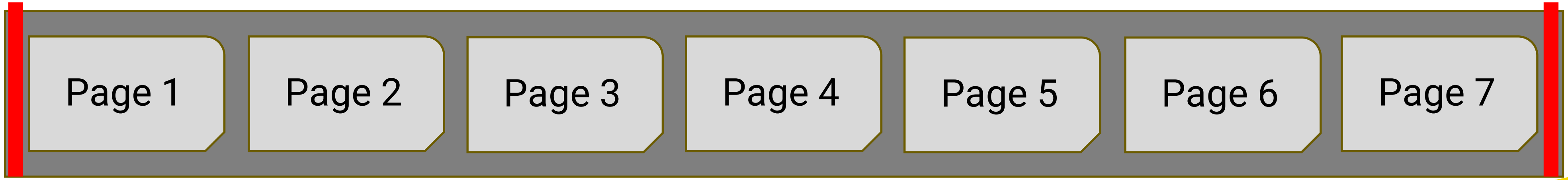
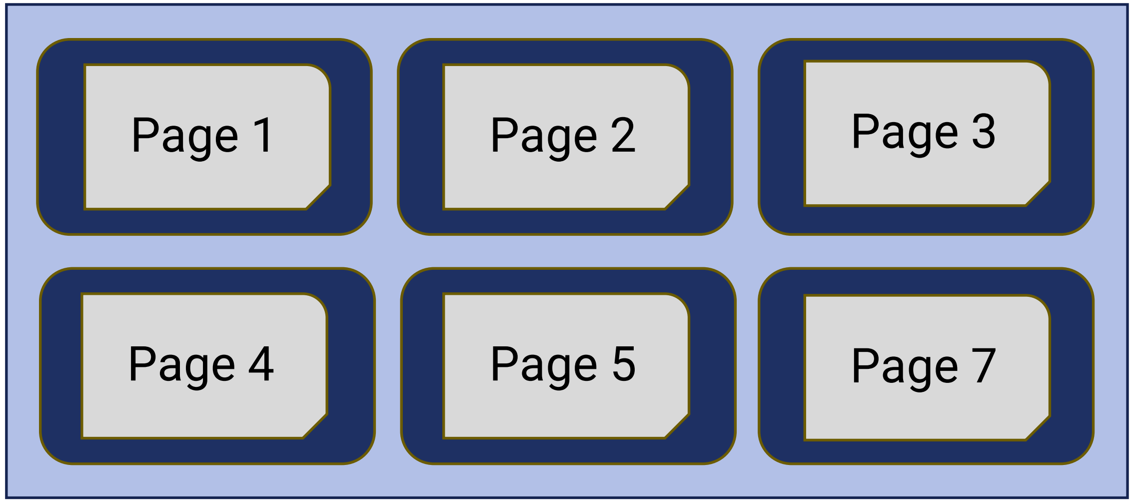


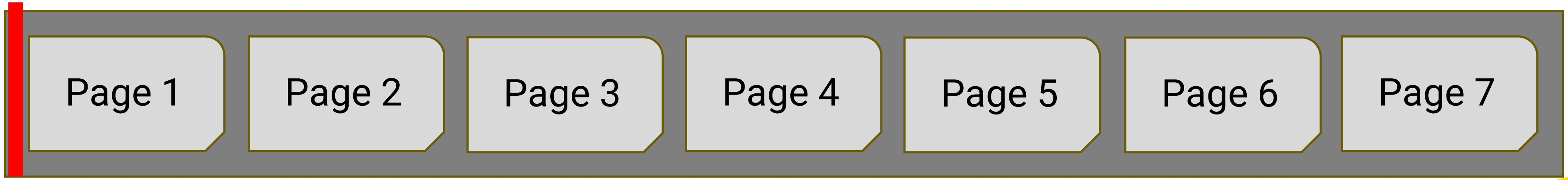
Repeated Scan (MRU): Read Page 1(again)

Cache Hit: 1

Attempts: 8



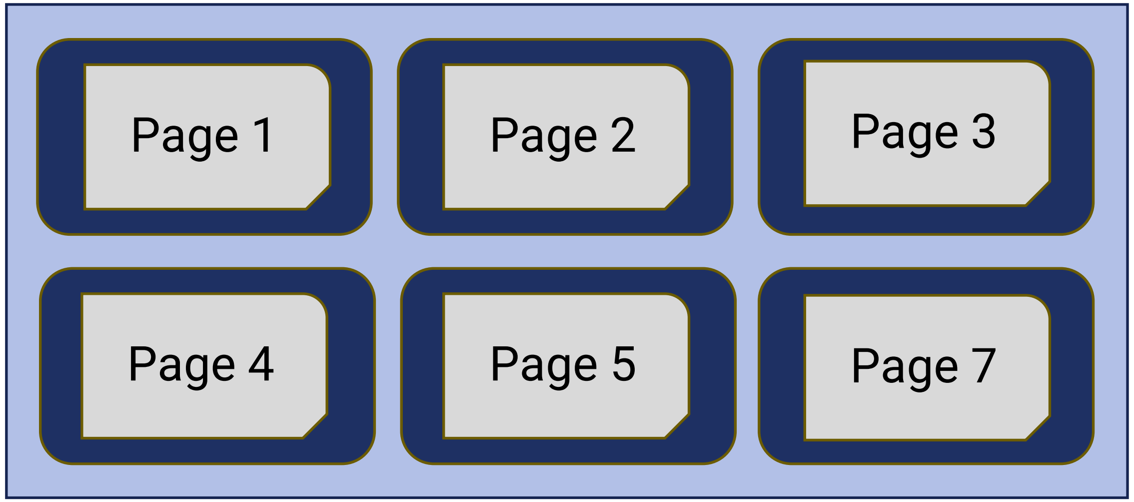
Disk Space Manager



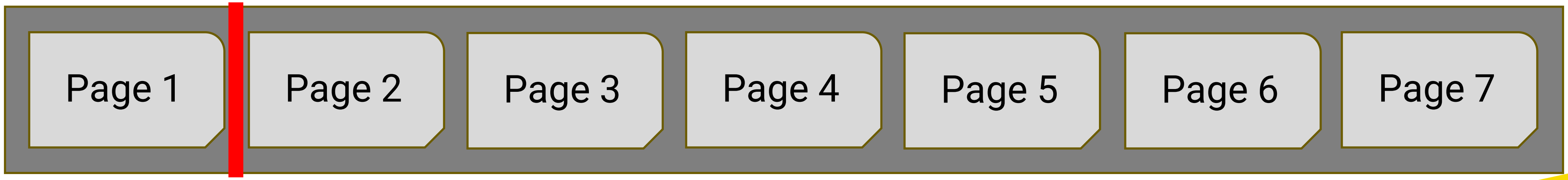
Repeated Scan (MRU): Read Page 2(again)

Cache Hit: 2

Attempts: 9



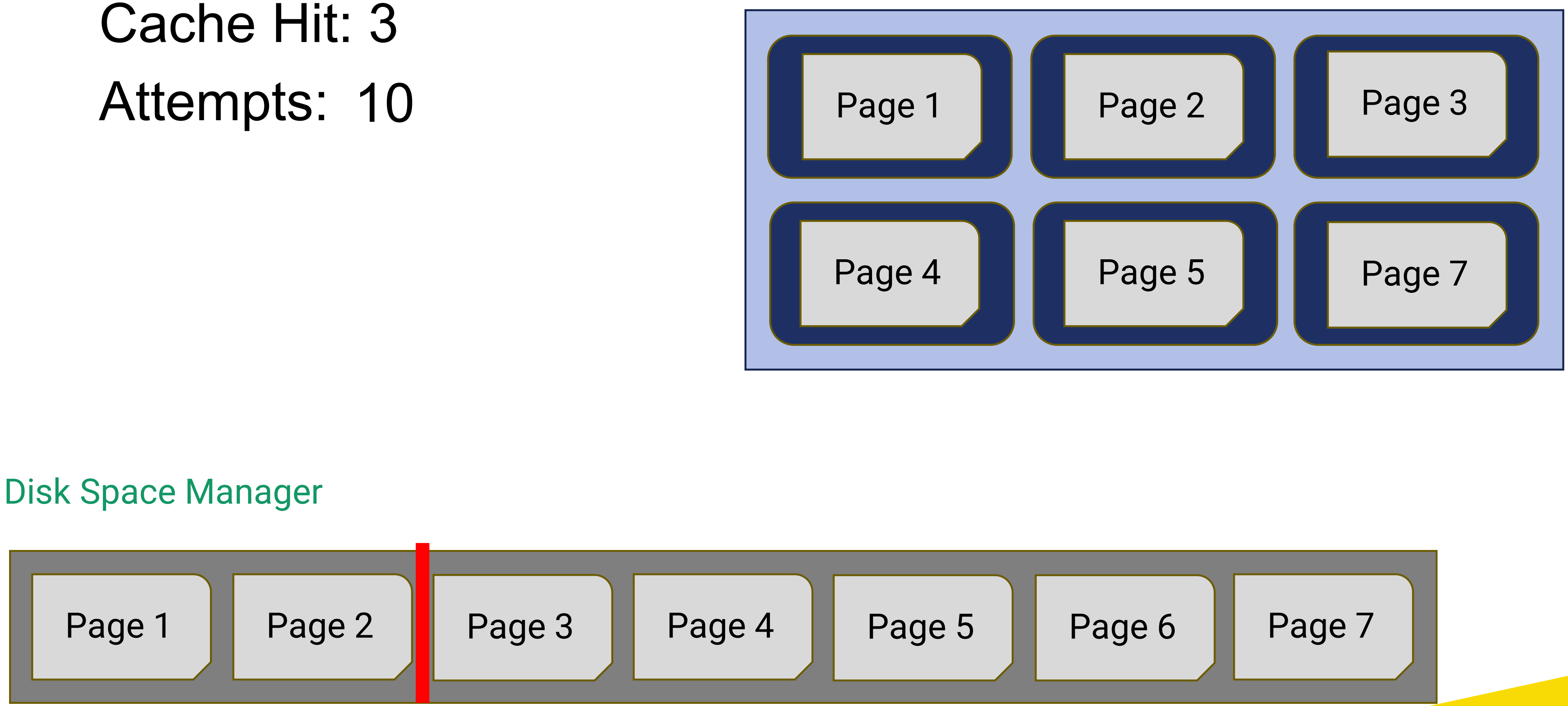
Disk Space Manager



Repeated Scan (MRU): Read Page 3(again)

Cache Hit: 3

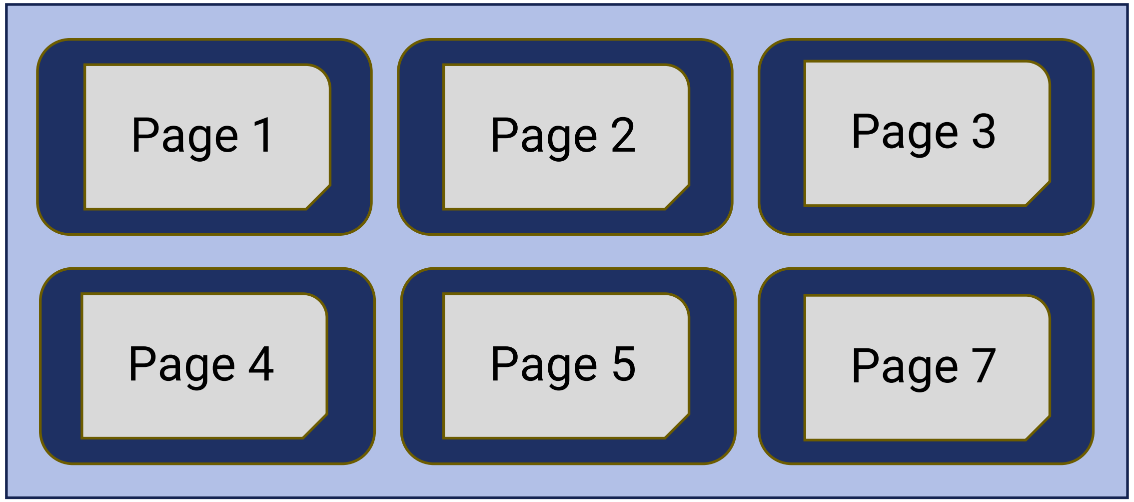
Attempts: 10



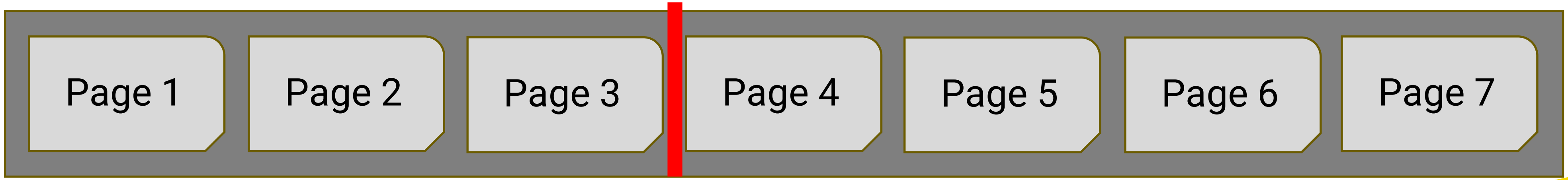
Repeated Scan (MRU): Read Page 4(again)

Cache Hit: 4

Attempts: 11



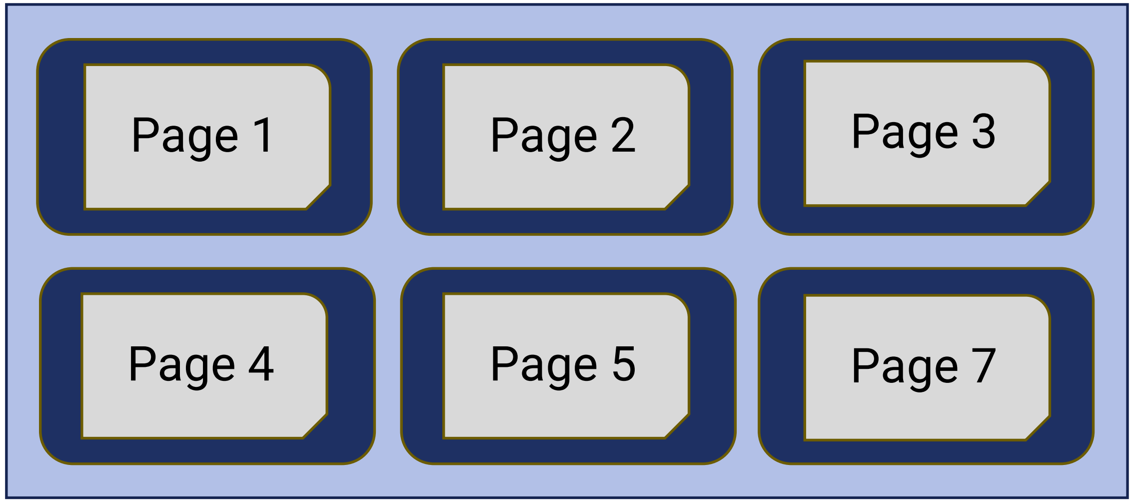
Disk Space Manager



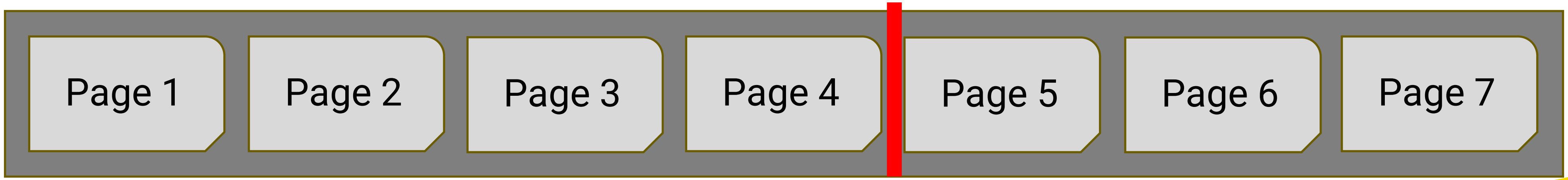
Repeated Scan (MRU): Read Page 5 (again)

Cache Hit: 5

Attempts: 12



Disk Space Manager



Compare LRU and MRU

When LRU and MRU both read Page 5 again

LRU:

Cache hit: 0

Attempts: 12

MRU:

Cache hit: 5

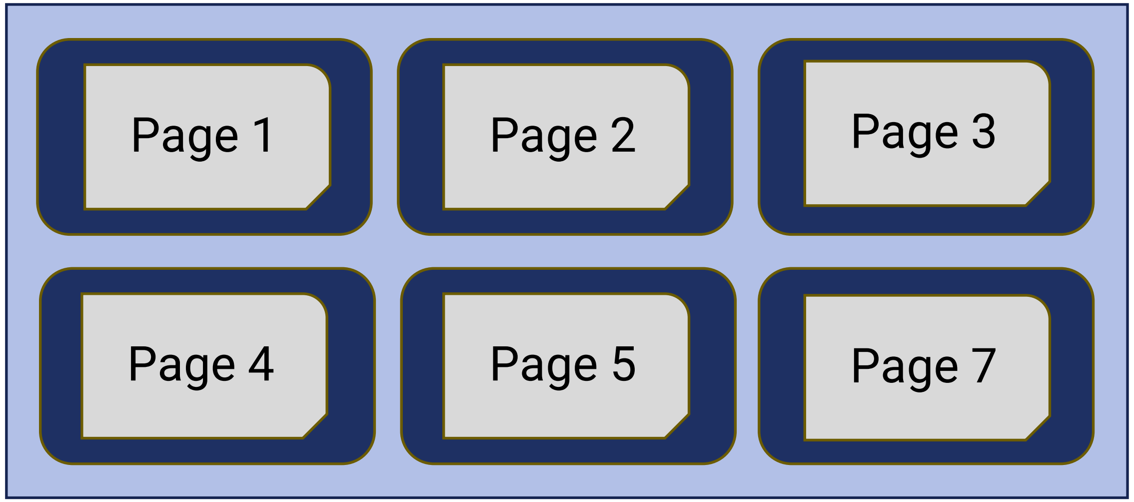
Attempts: 12

What if we keep reading the next page with MRU?

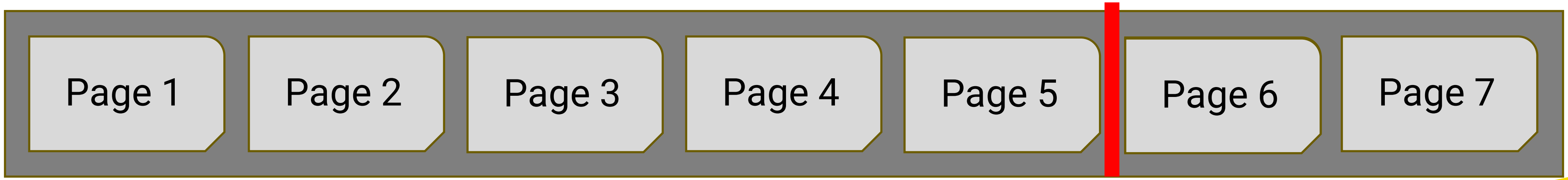
Repeated Scan (MRU): Read Page 6 (again)

Cache Hit: 5

Attempts: 13



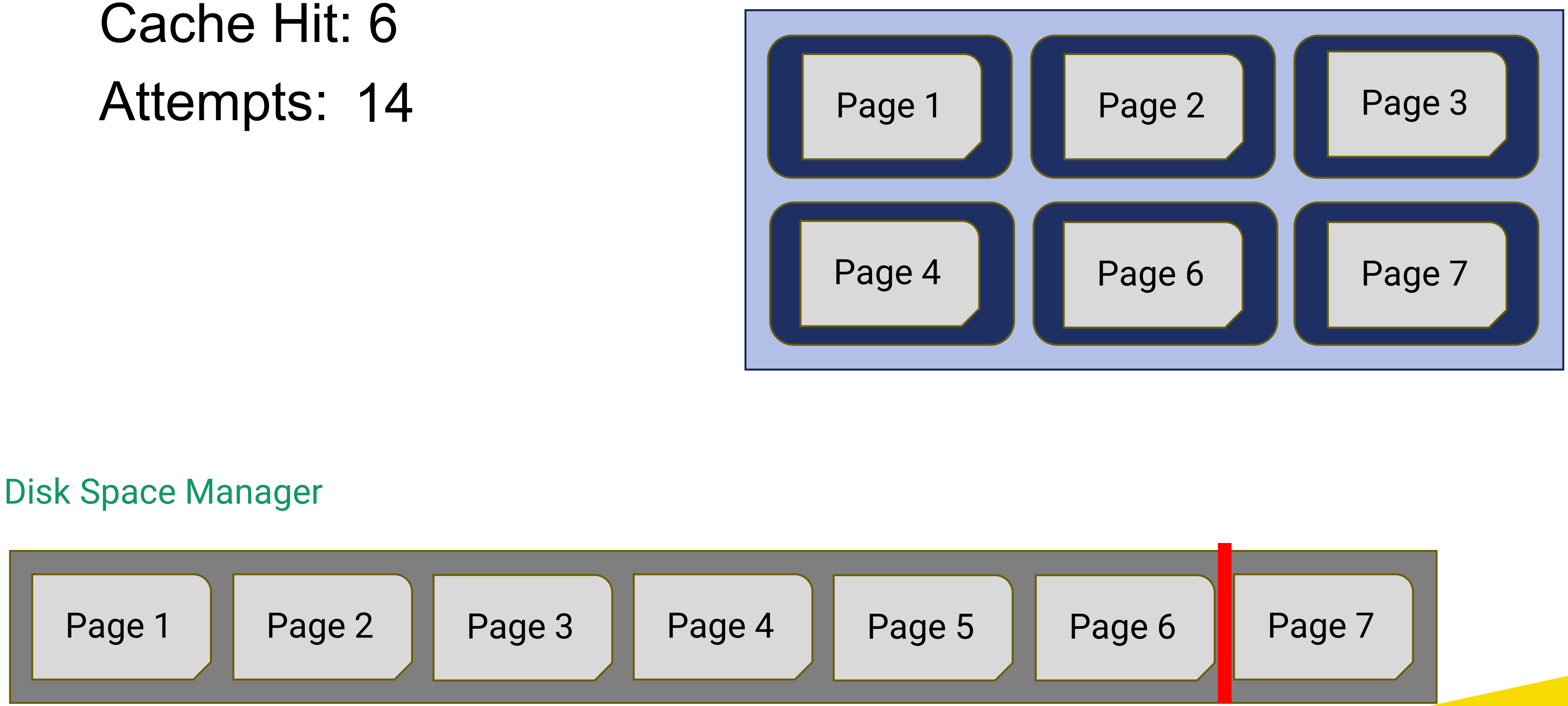
Disk Space Manager



Repeated Scan (MRU): Read Page 7 (again)

Cache Hit: 6

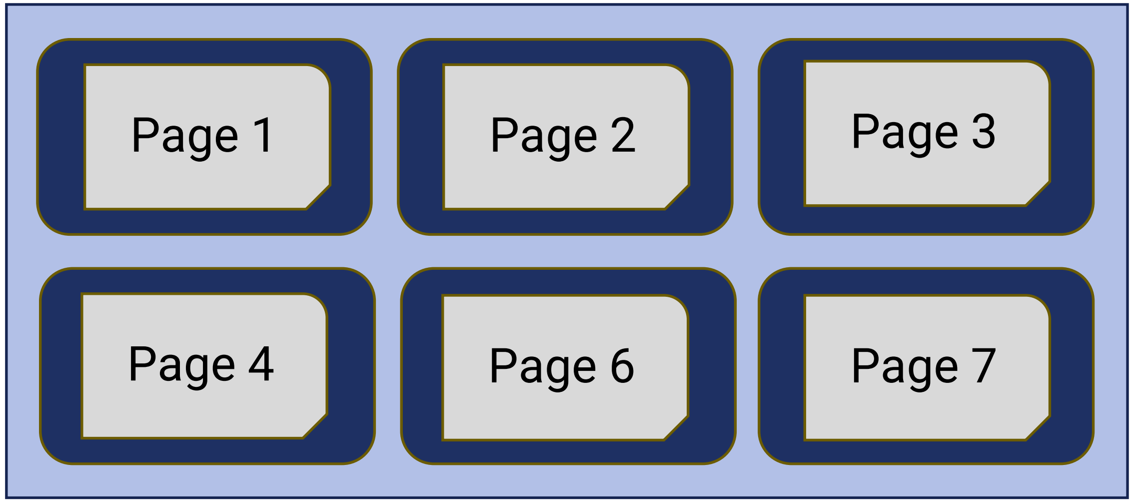
Attempts: 14



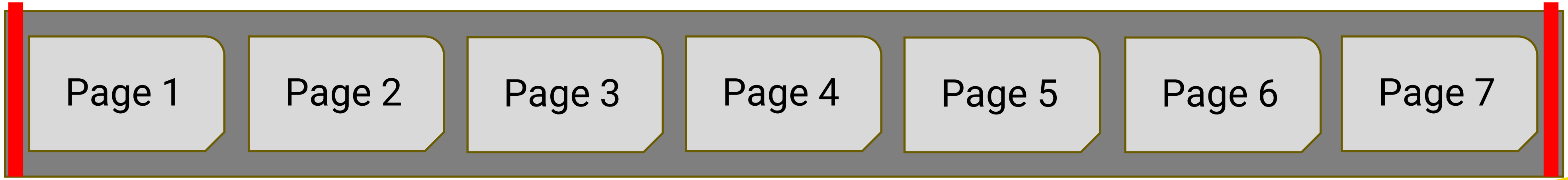
Repeated Scan (MRU): Reset (again)

Cache Hit: 6

Attempts: 14



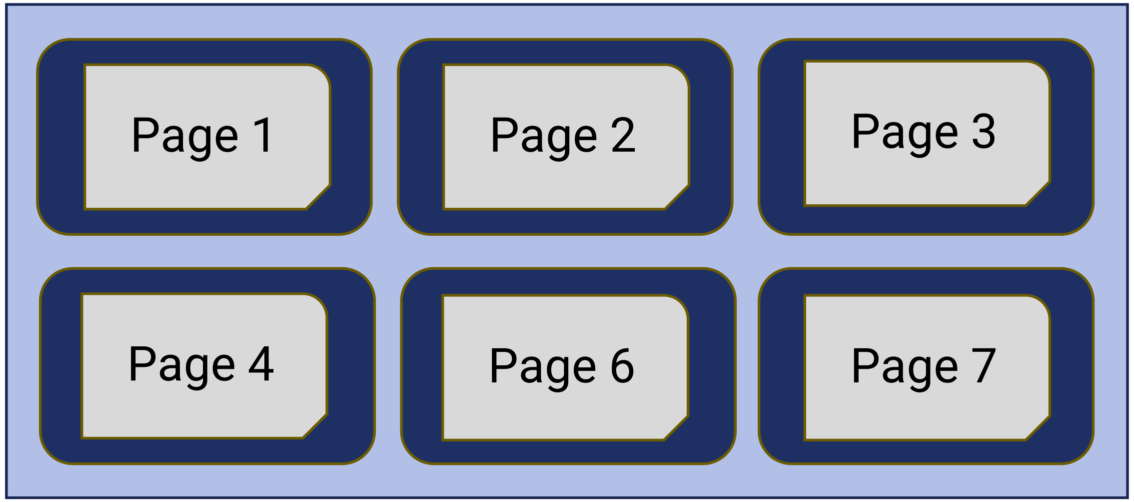
Disk Space Manager



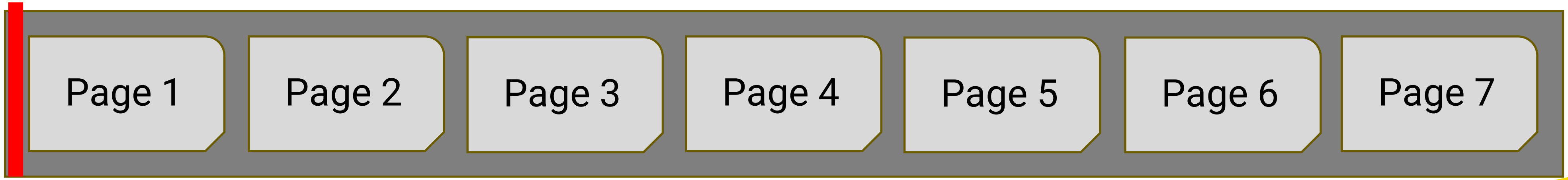
Repeated Scan (MRU): Read Page 1(againx2)

Cache Hit: 7

Attempts: 15



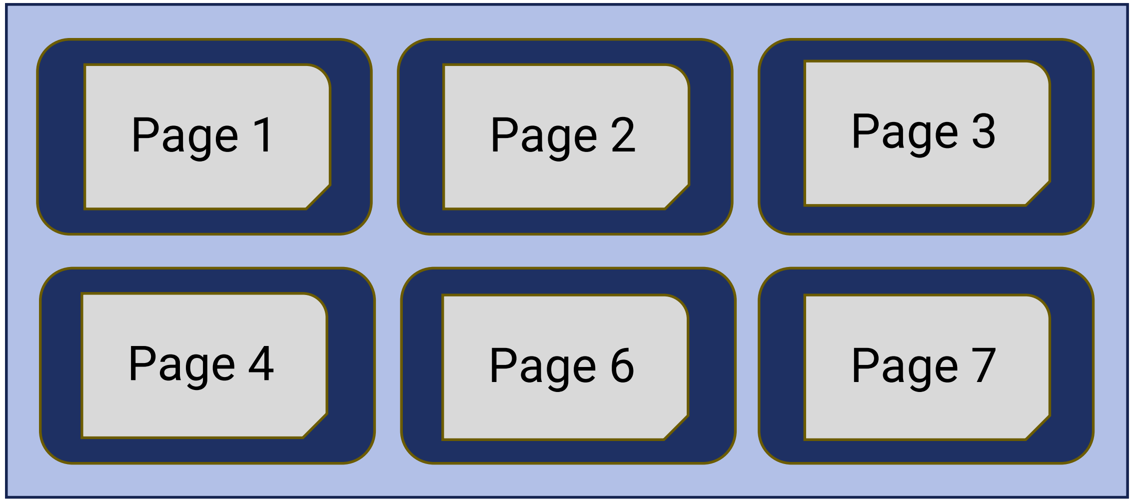
Disk Space Manager



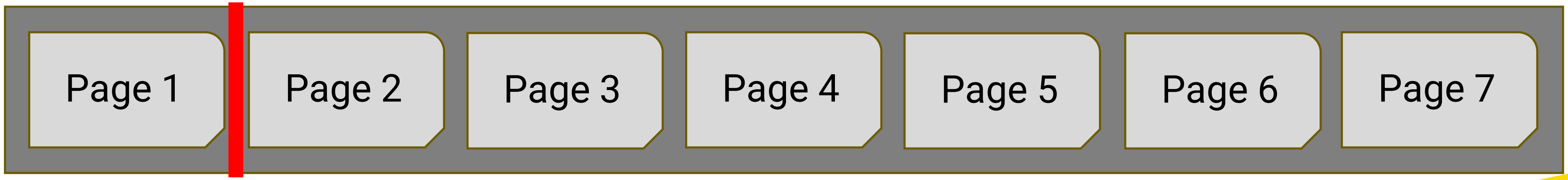
Repeated Scan (MRU): Read Page 2(againx2)

Cache Hit: 8

Attempts: 16



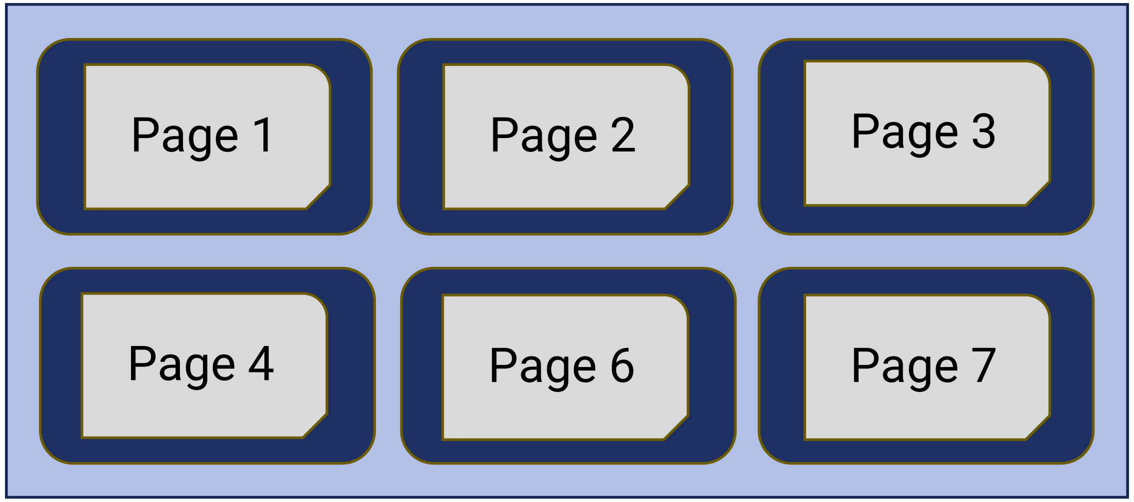
Disk Space Manager



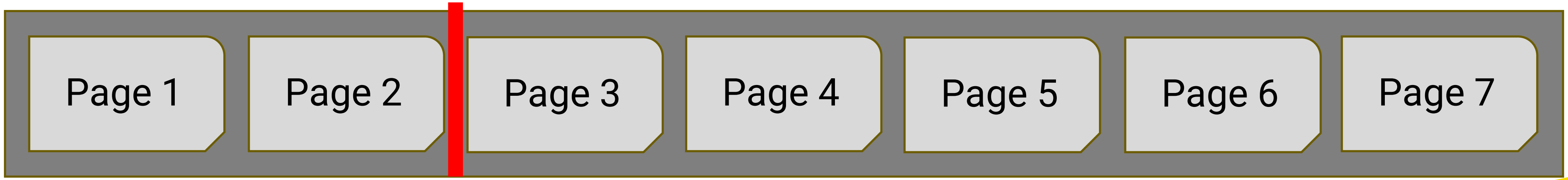
Repeated Scan (MRU): Read Page 3(againx2)

Cache Hit: 9

Attempts: 17



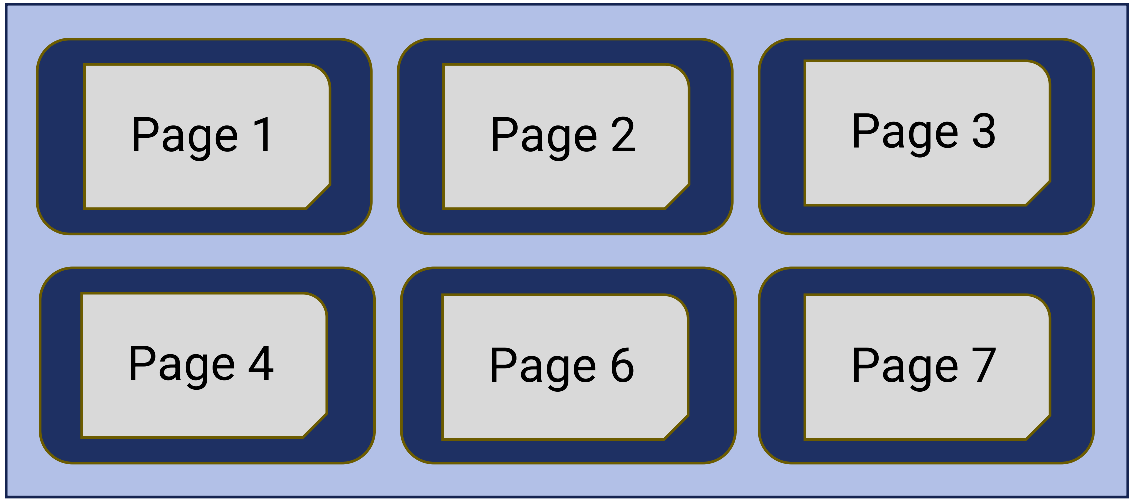
Disk Space Manager



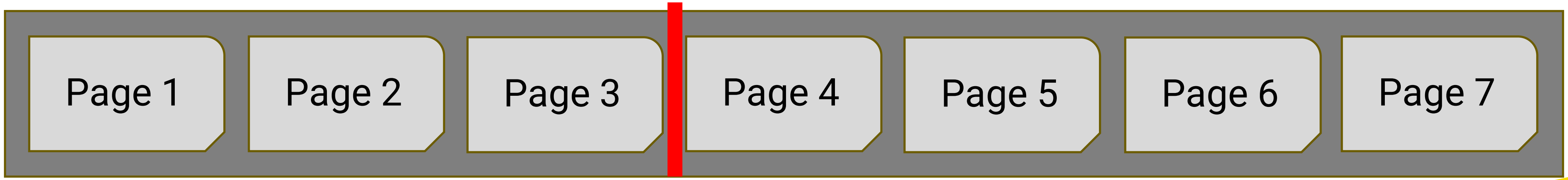
Repeated Scan (MRU): Read Page 4(againx2)

Cache Hit: 10

Attempts: 18



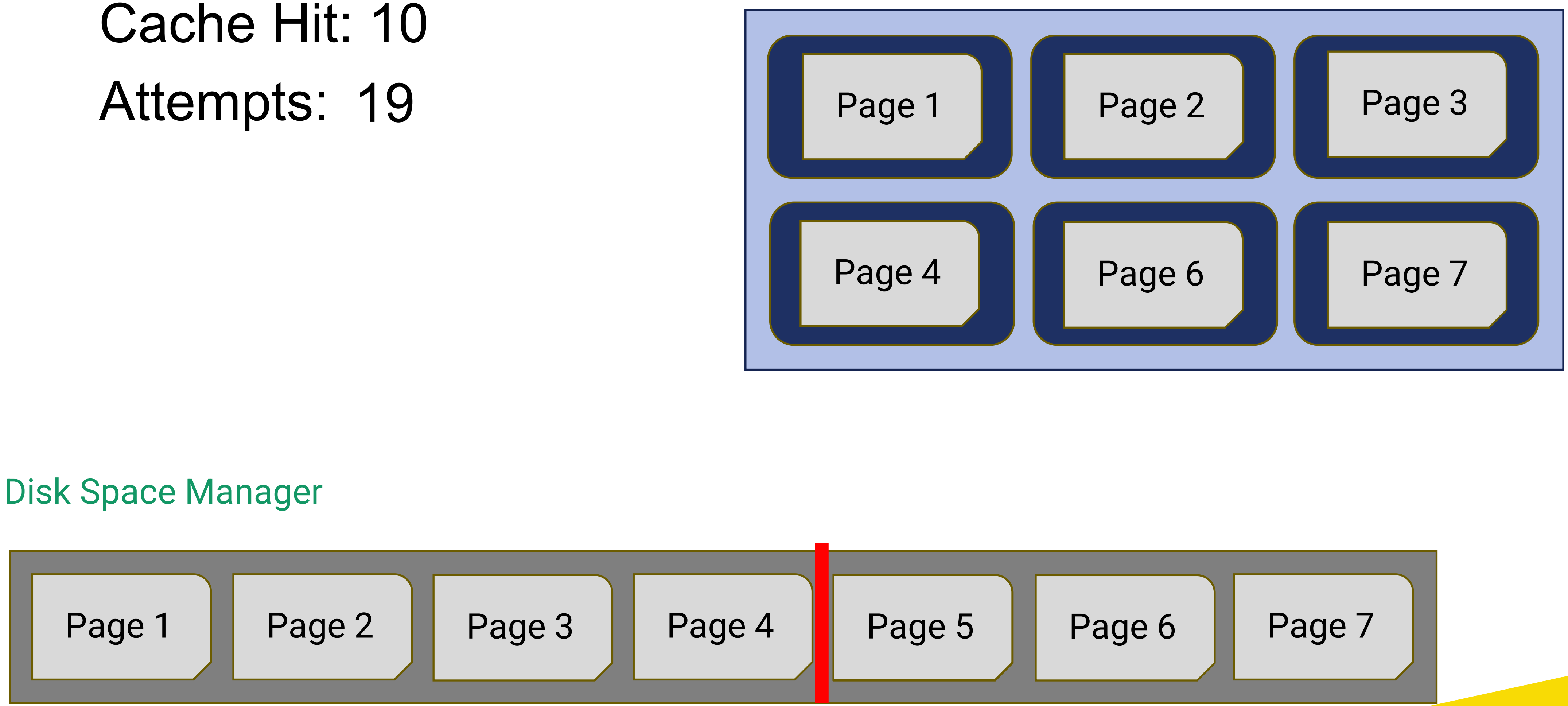
Disk Space Manager



Repeated Scan (MRU): Read Page 5(againx2)

Cache Hit: 10

Attempts: 19

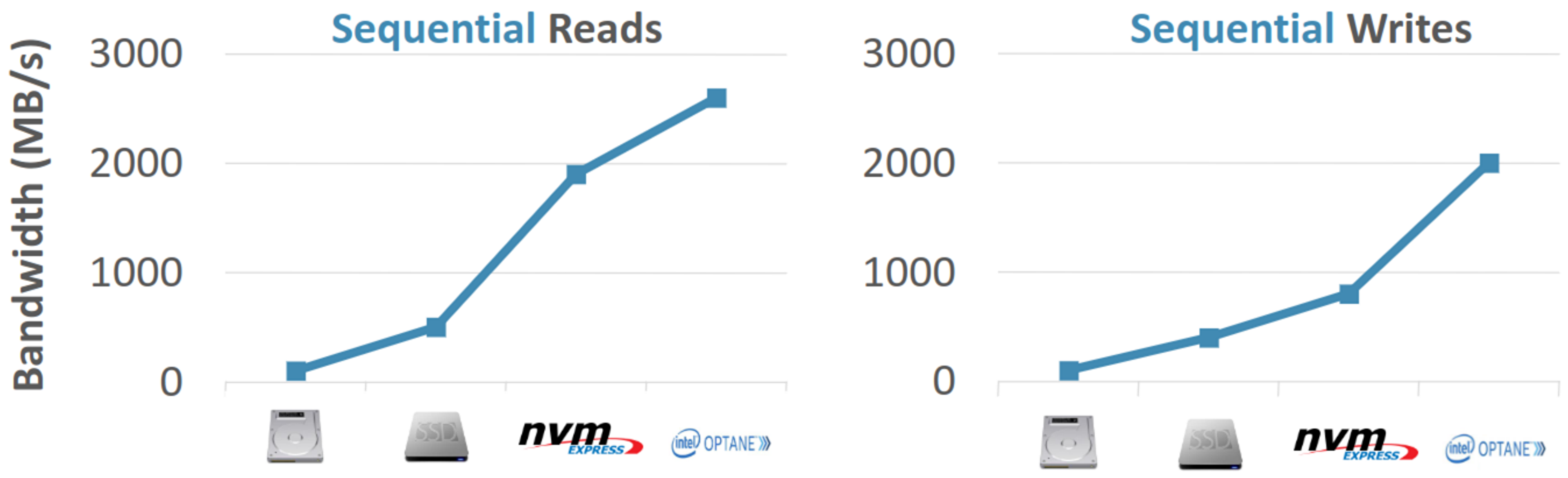


Sequential Flooding

- LRU: We need to get in/out every page
  - This is called Sequential Flooding
- MRU: performs the best in this case (**repeated scan**)

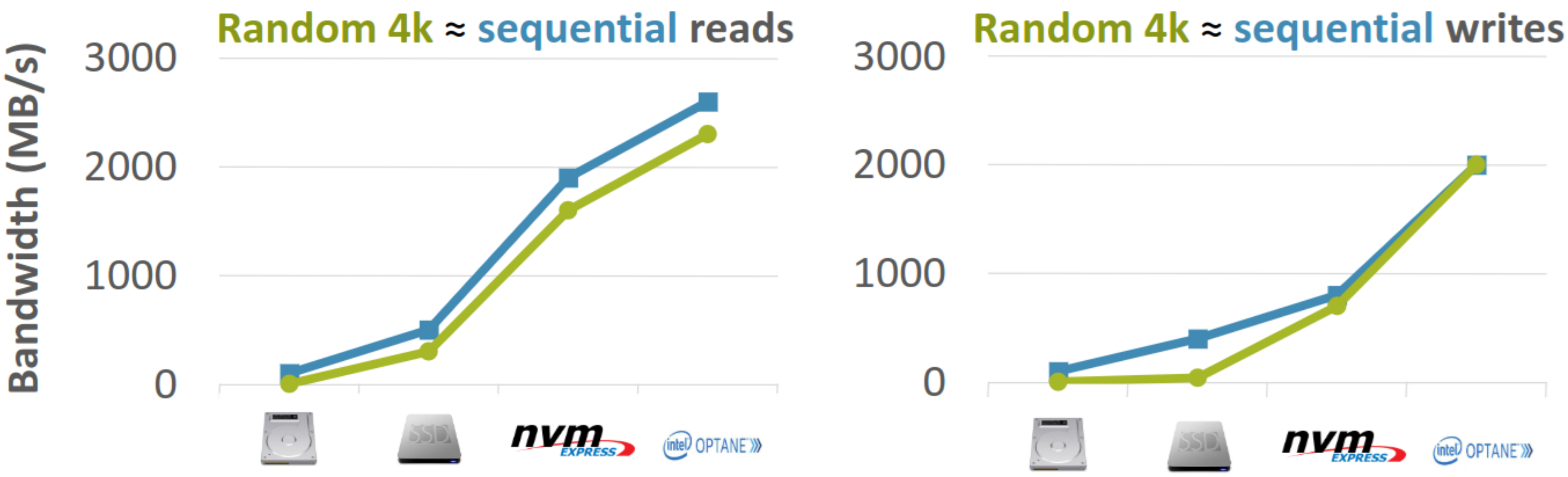
Again, *no replacement policy is guaranteed to be superior to the others*. The choice often depends on specific applications and their requirements.

New Trend: Disks are much faster

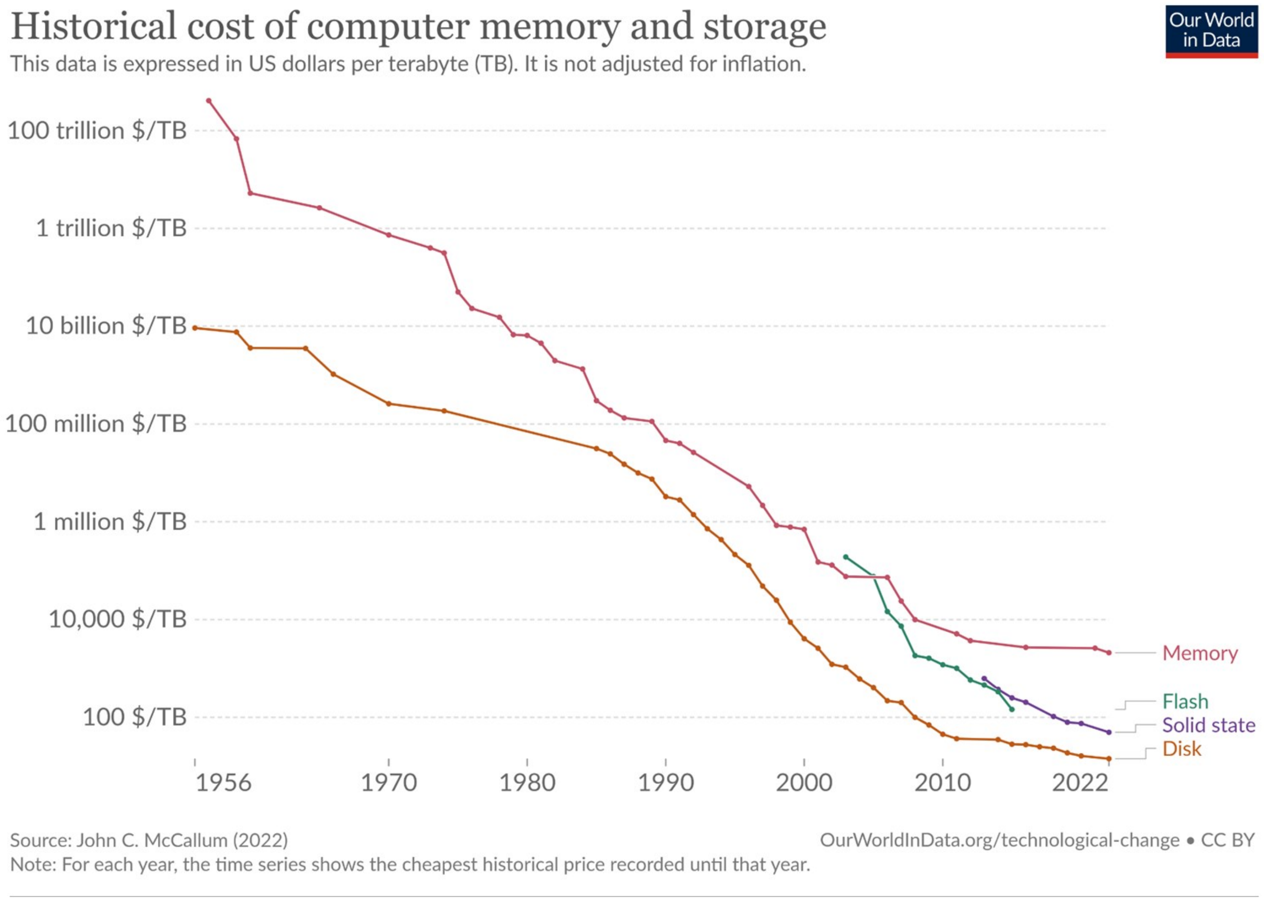


2010 2013 2016 2018

New Trend: Random vs Sequential Access



New Trend: Cheaper memory/disk



Overview: Block (Page) Formats

- **Block**: A block is a collection of *slots*.
- **Slot**: Each slot contains a record.
- **Record**: A record is identified by *record_id*: rid = <*page id, slot number*>.

Question: How are records physically stored on disk?

Record Formats

Records are stored within fixed-length blocks.

- ***Fixed-length***: each field has a fixed length as well as the number of fields.

33357462	Neil Young	Musician	0277
4 bytes	40 bytes	20 bytes	4 bytes

  - Easy for intra-block space management.
  - Possible waste of space.

- ***Variable-length***: some field is of variable length.

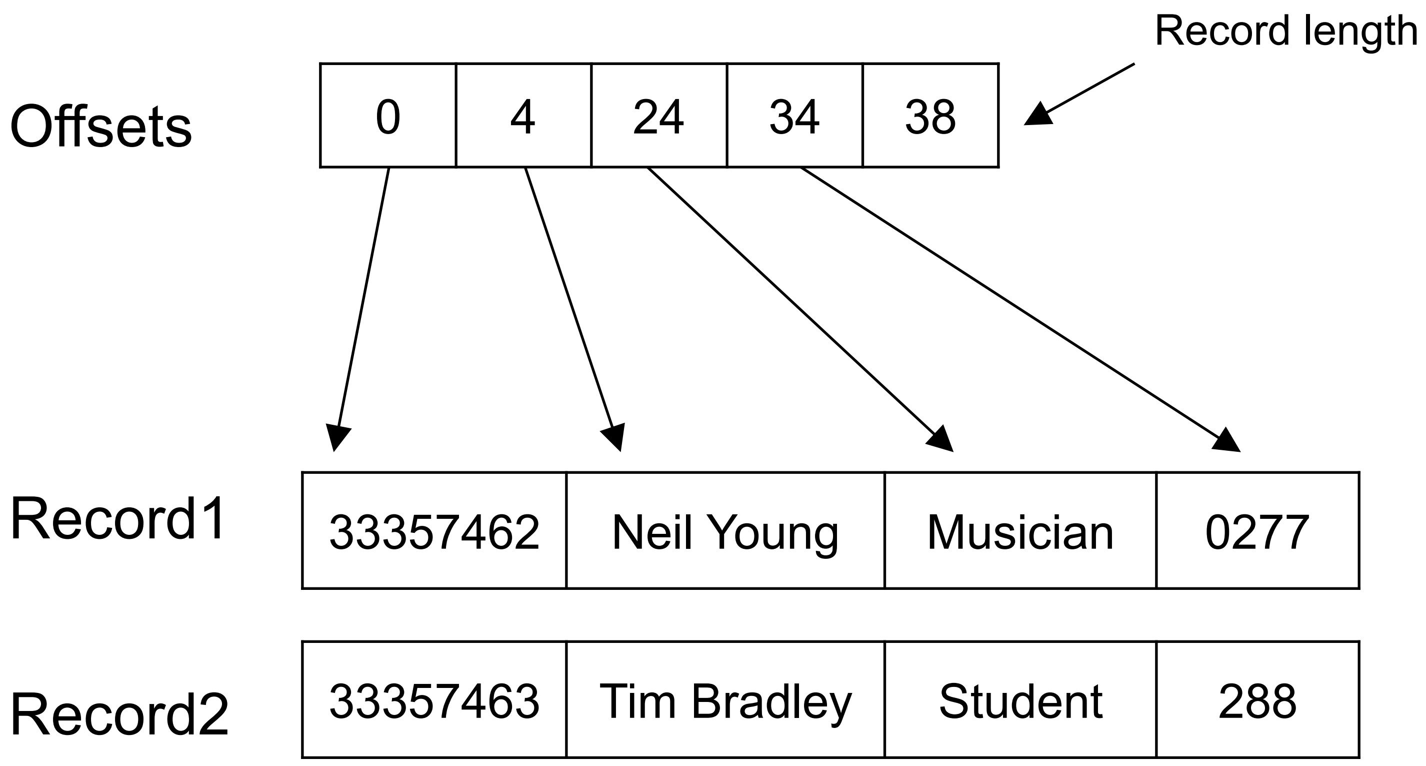
33357462	Neil Young	Musician	0277
4 bytes	10 bytes	8 bytes	4 bytes

  - complicates intra-block space management
  - does not waste (as much) space.

Fixed-Length

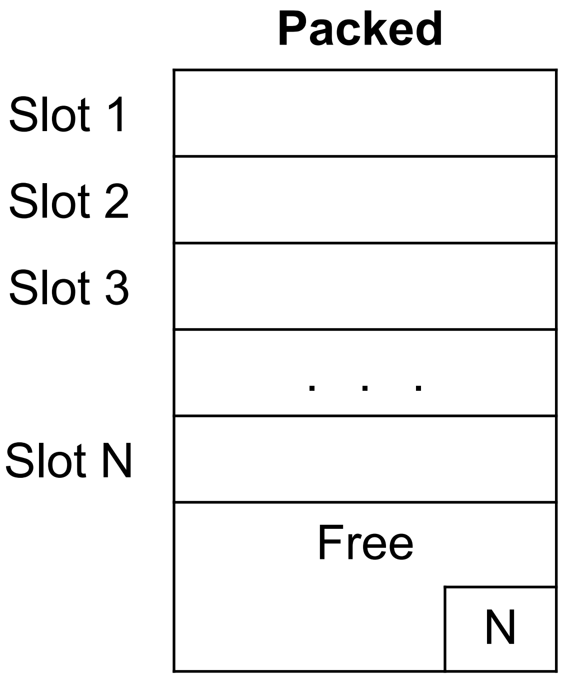
Encoding scheme for fixed-length records:

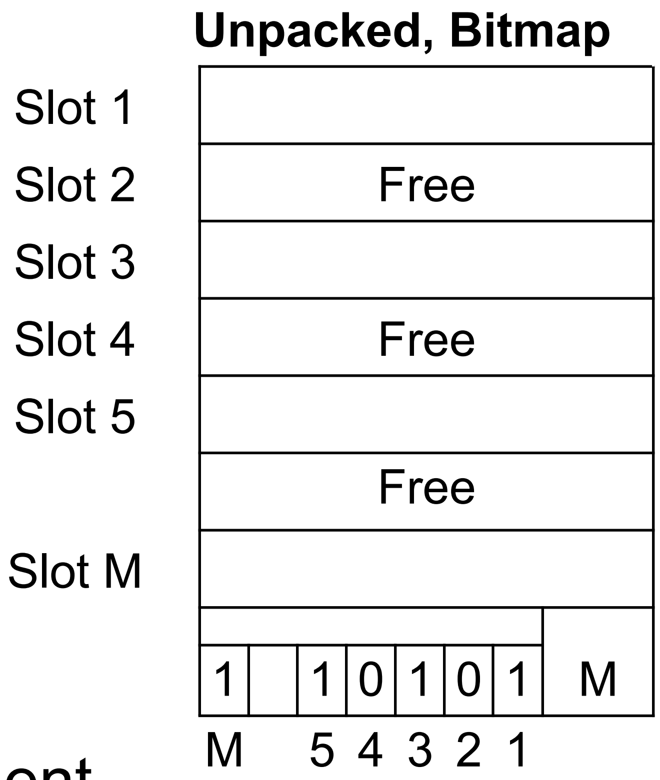
- length + offsets stored in header



Fixed-Length Records

For fixed-length records, use record slots:





Insertion: occupy first free slot; packed more efficient.

Deletion: (a) need to compact, (b) mark with 0; unpacked more efficient.

Deletion in Packed Fixed-Length Records

Simple approach:

- Store record i starting from byte $n \times (i - 1)$, where n is the size of each record.

record 0	10101	Srinivasan	Comp. Sci.	65000
record 1	12121	Wu	Finance	90000
record 2	15151	Mozart	Music	40000
record 3	22222	Einstein	Physics	95000
record 4	32343	El Said	History	60000
record 5	33456	Gold	Physics	87000
record 6	45565	Katz	Comp. Sci.	75000
record 7	58583	Califieri	History	62000
record 8	76543	Singh	Finance	80000
record 9	76766	Crick	Biology	72000
record 10	83821	Brandt	Comp. Sci.	92000
record 11	98345	Kim	Elec. Eng.	80000

Consider two ways in deleting record i:

- move records $i + 1, \ldots, n$ to $i, \ldots, n - 1$
- move record n to i

Variable-Length

Encoding schemes where attributes are stored **in order**.

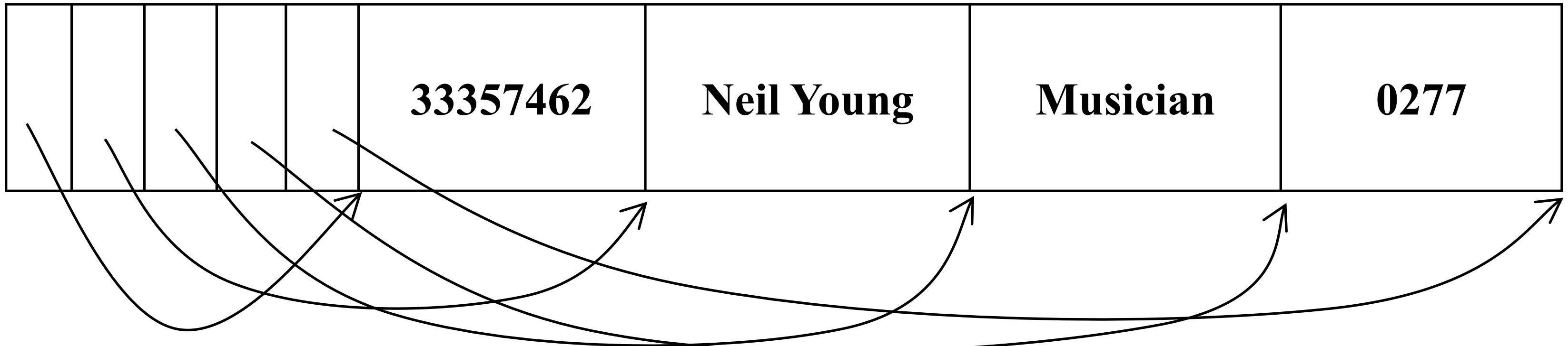
- Option1: Prefix each field by length

4 xxxx 10 Neil Young 8 Musician 4 xxxx

- Option 2: Terminate fields by delimiter

33357462/Neil Young/Musician/0277/

- Option 3: Array of offsets



Variable-Length Records (1)

Another encoding scheme: attributes are not stored in order.

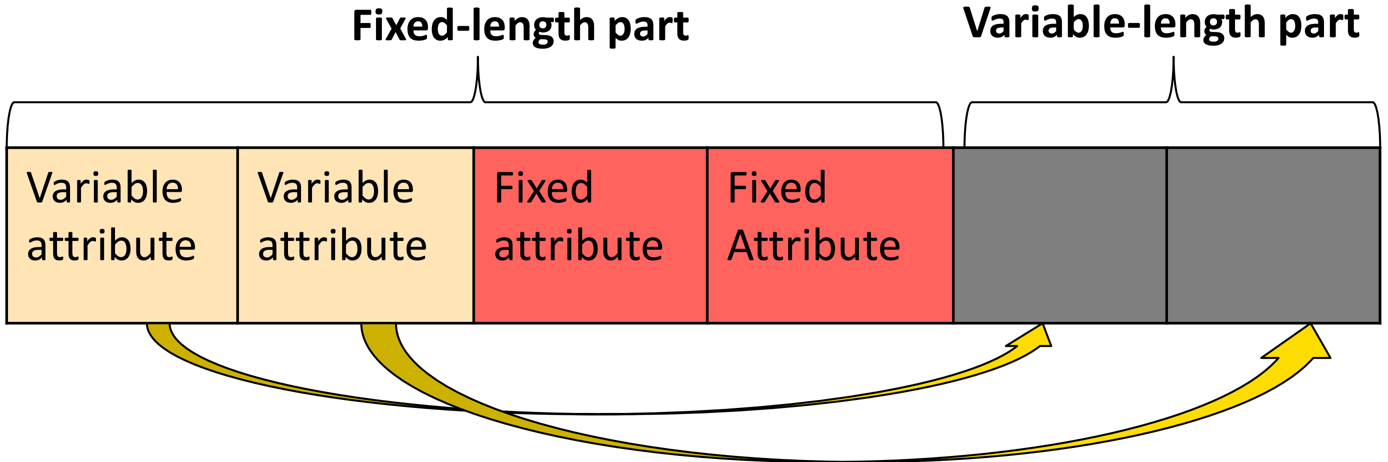
Fixed-length part followed by variable-length part.

- (b) The fixed-length part is to tell where we can find the data if it is a variable-length data field.
- (c) The variable-length part is to store the data.

Variable length attributes are represented by fixed size (offset, length) in the fixed-length part, and keep attribute values in the variable-length part.

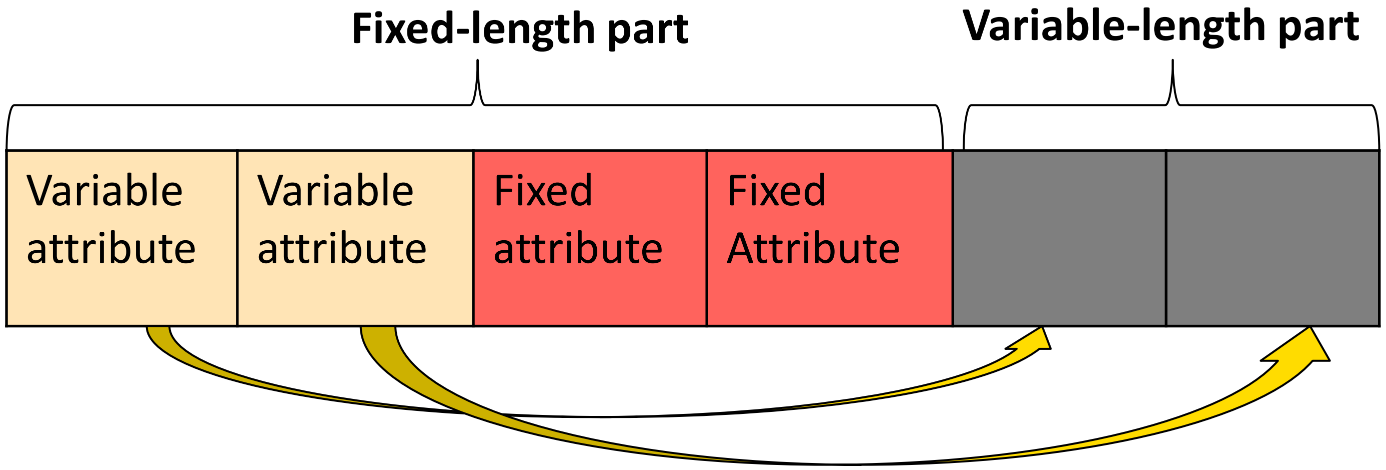
Fixed length attributes store attribute values in the fixed-length part.

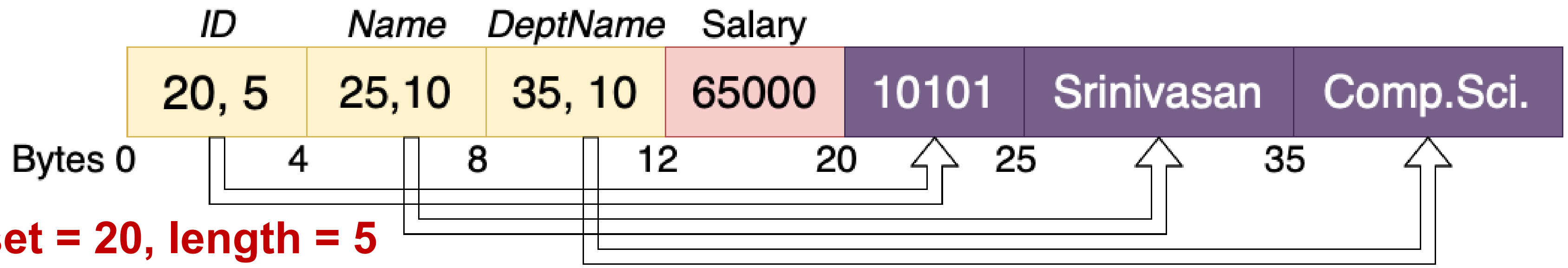
Suppose there is a relation with 4 attributes: 2 fixed-length and 2 variable-length.



Variable-Length Records (2)

Example: a tuple of (**ID, Name, DeptName**, Salary) where the **first three** are variable length.



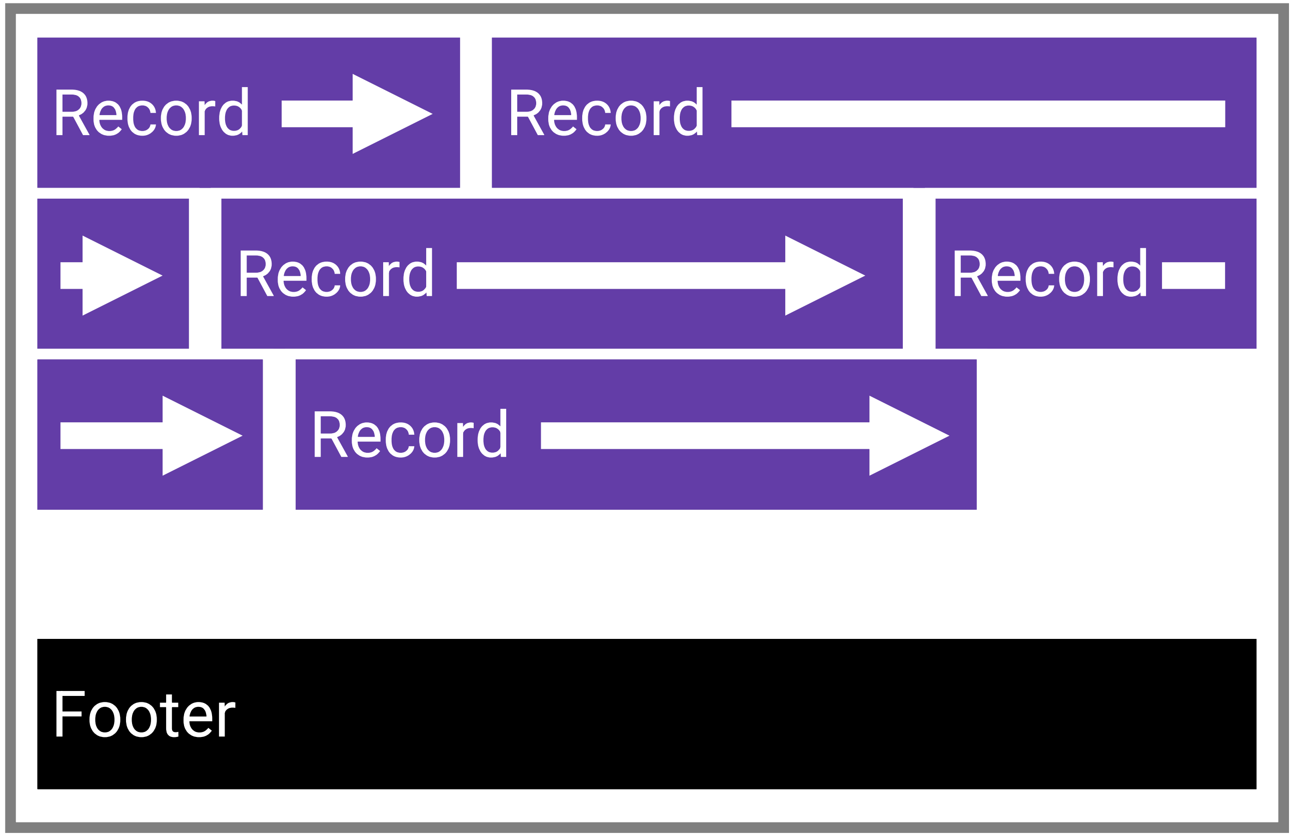


Offset = 20, length = 5

Variable-Length Records

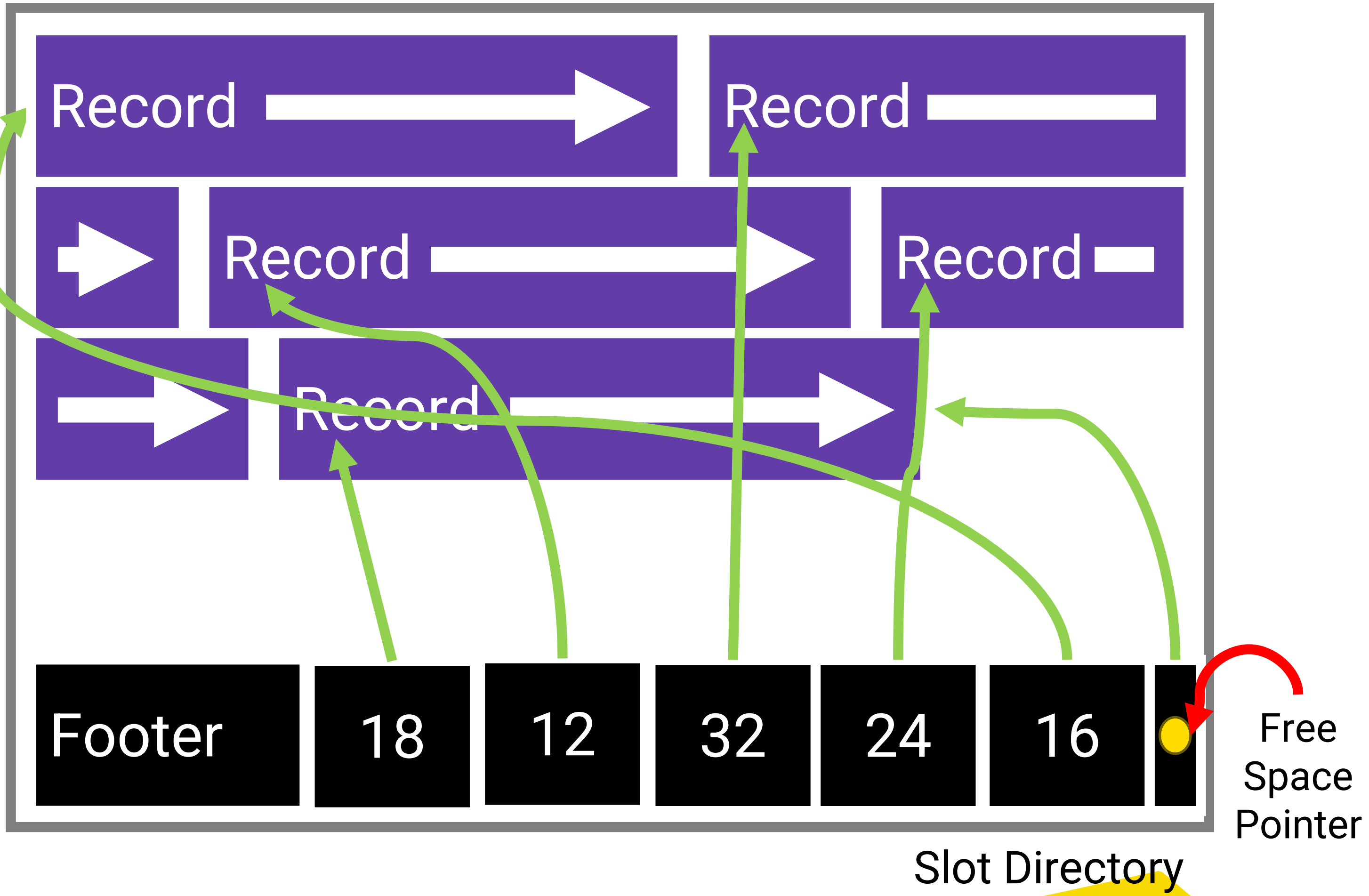
- How do we know where each record begins?
- What happens when we add and delete records?

Records metadata to **footer**



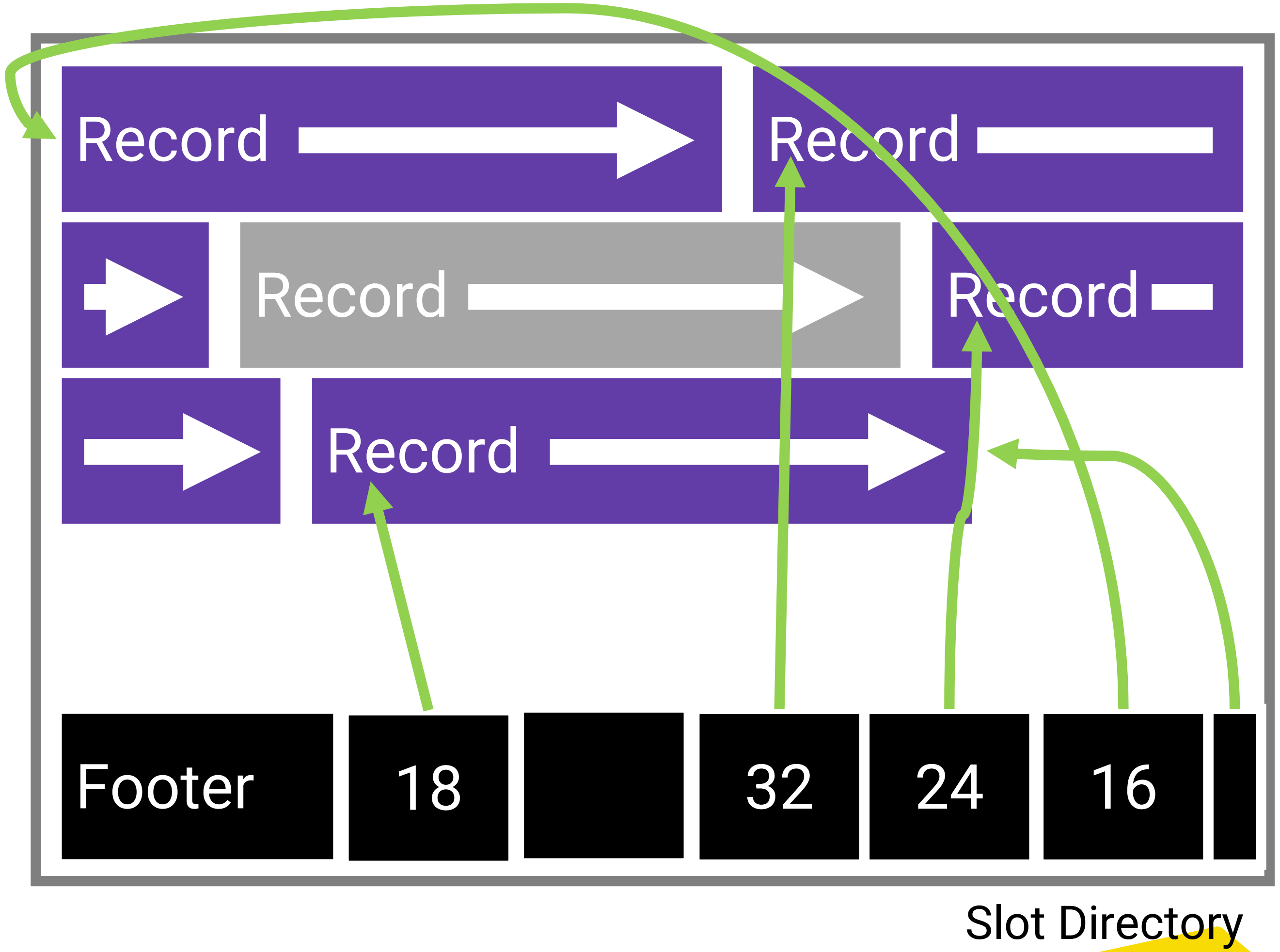
Slotted Page

- Introduce slot directory in footer
  - ➢ Pointer to free space
  - ➢ Length + Pointer to beginning of record
    - **Reverse** order
- Record ID = location in slot table
  - ➢ From right
- Delete?
  - ➢ E.g. 4th record on the page



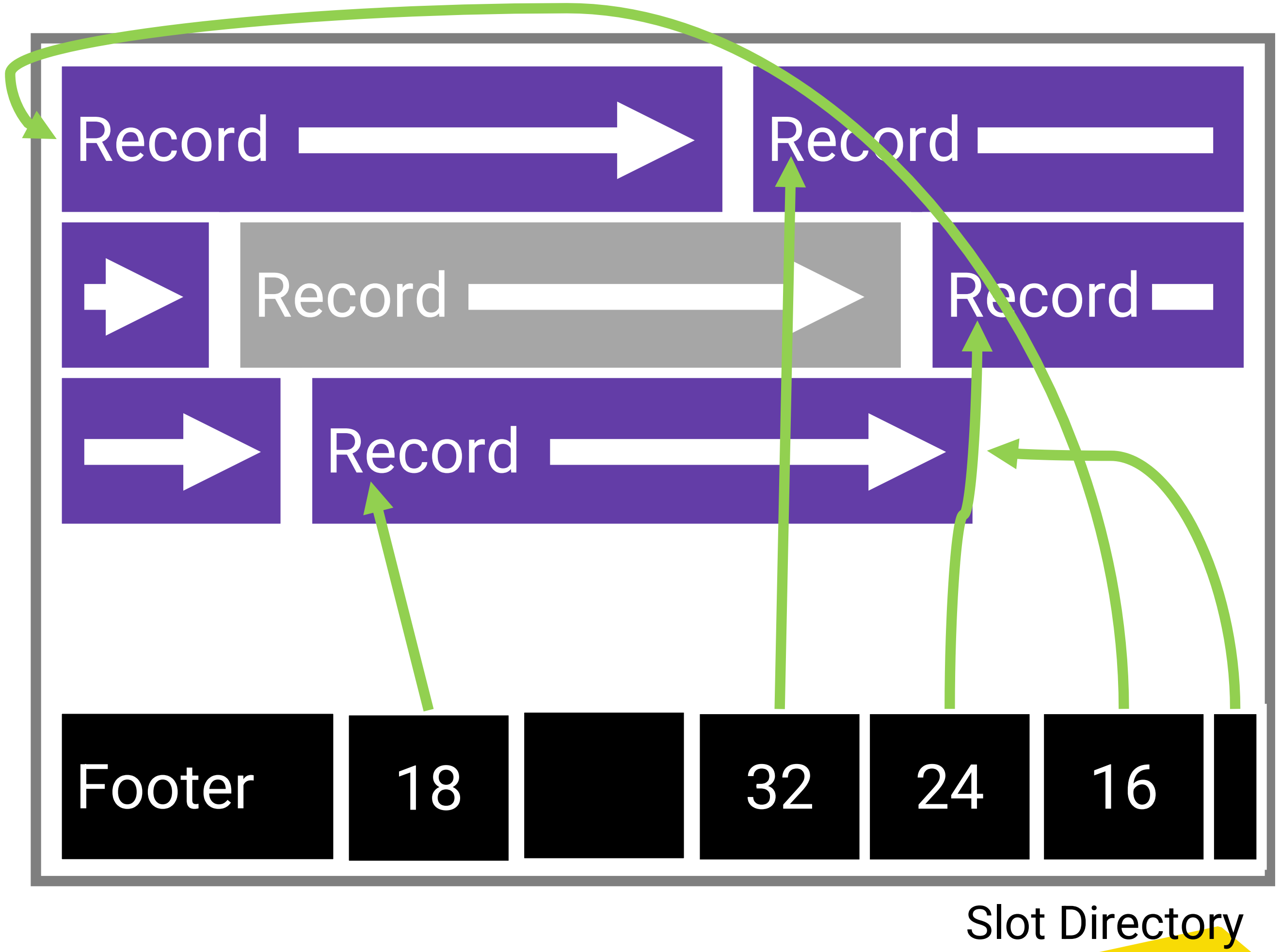
Slotted Page: Delete Record

- Delete record (Page 2, Record 4): Set 4th slot directory pointer to null
  - Doesn't affect pointers to other records



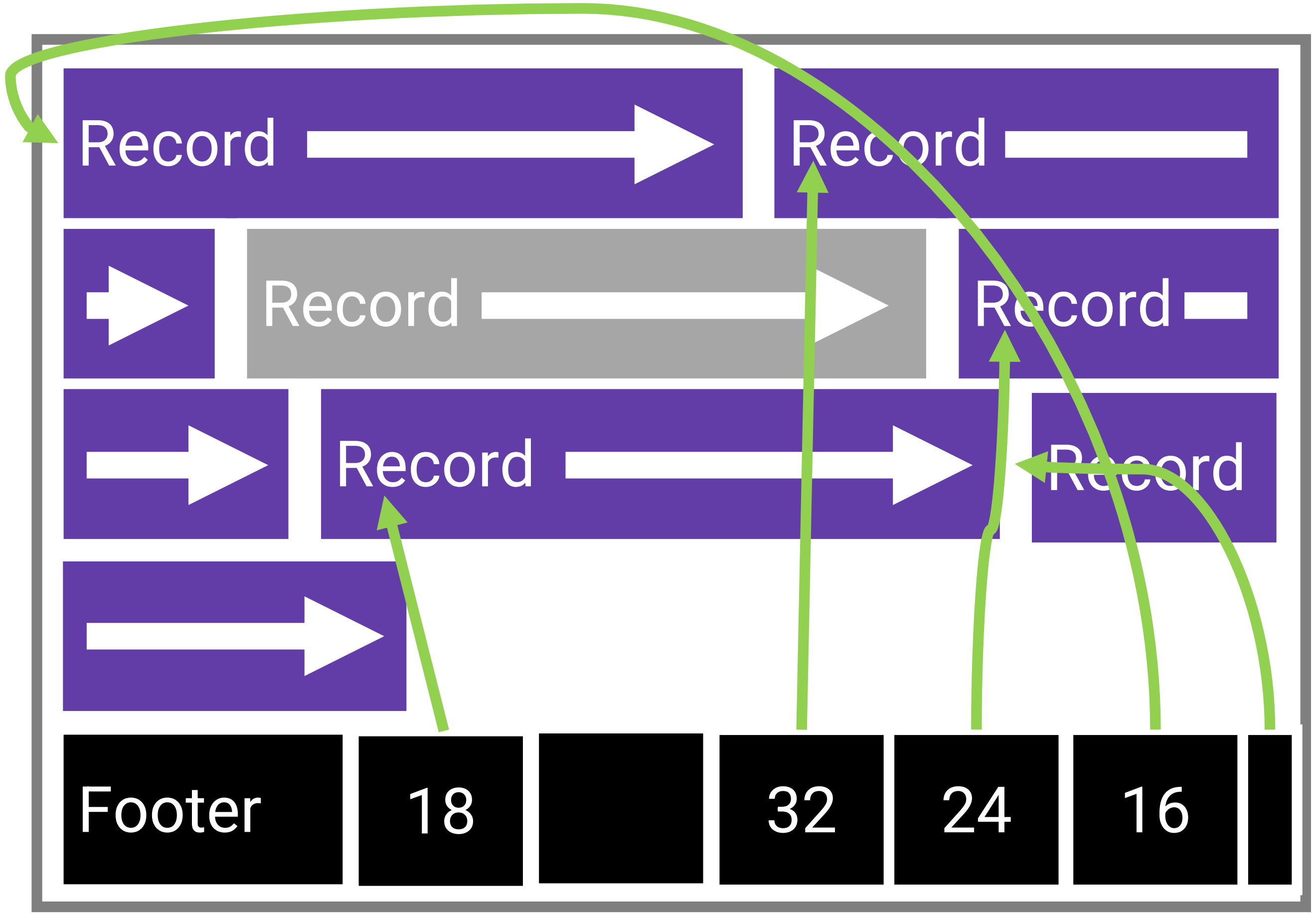
Slotted Page: Insert Record

- Insert:



Slotted Page: Insert Record, Pt 2.

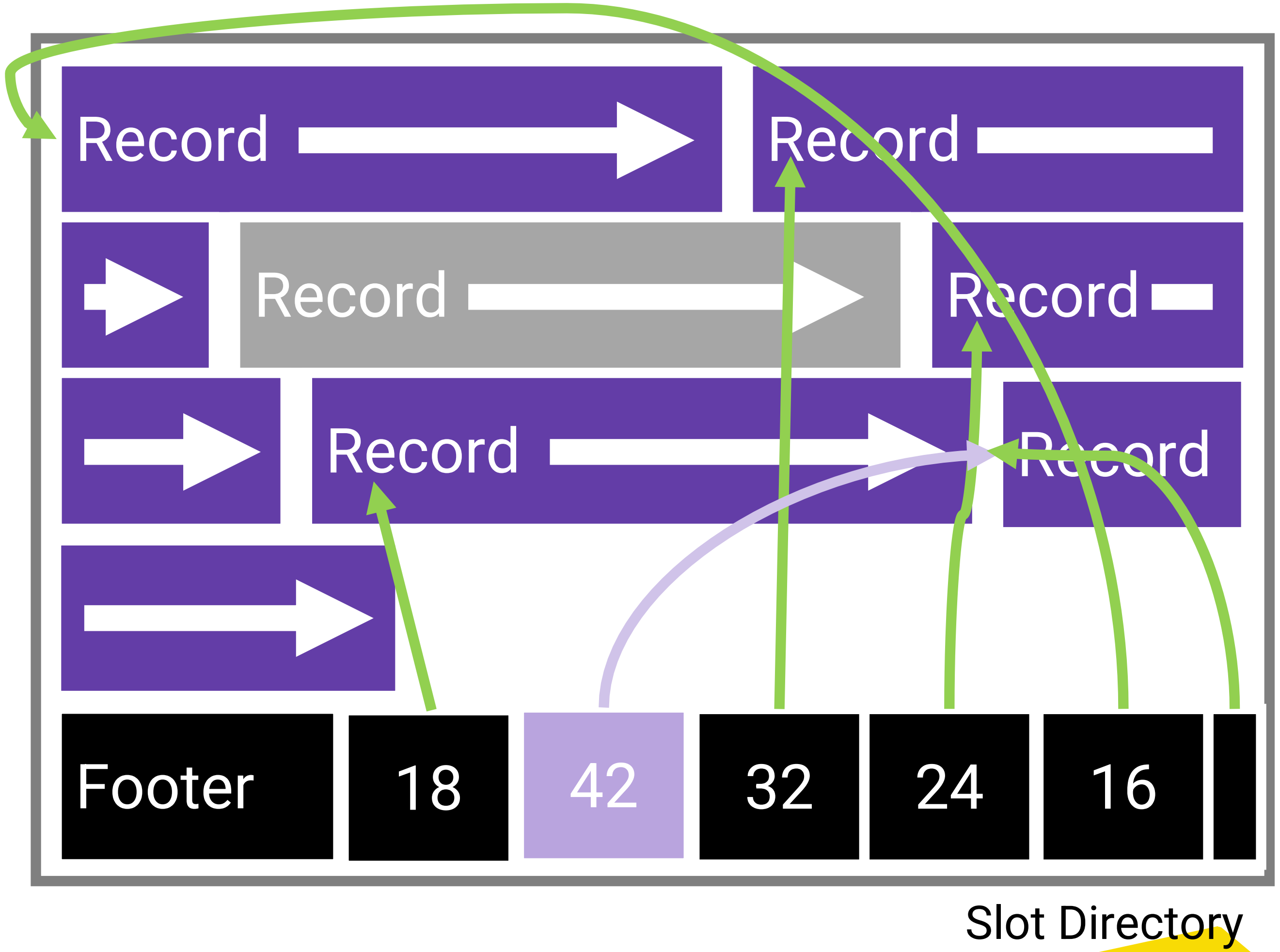
- Insert:
- Place record in free space on page



Slot Directory

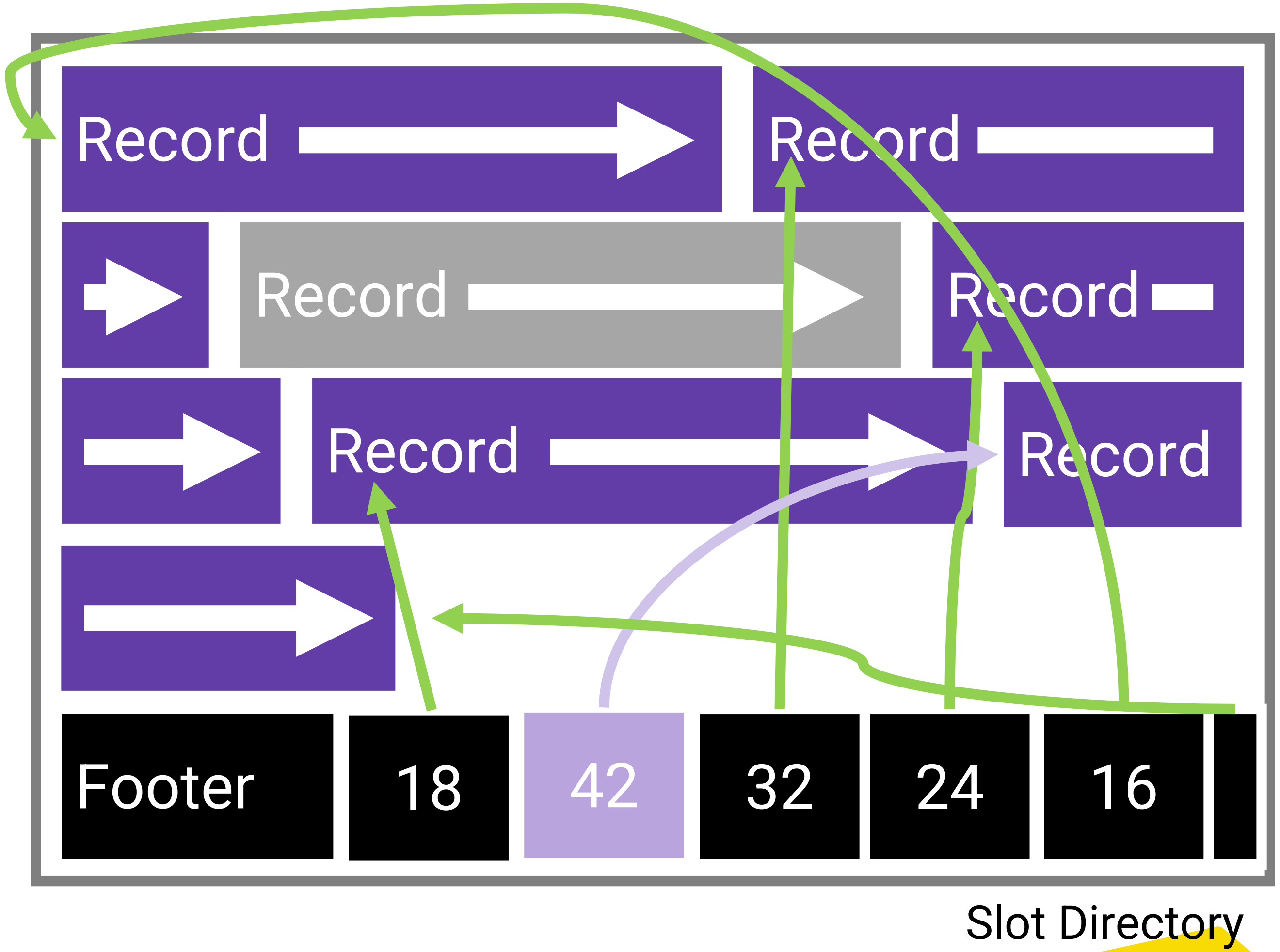
Slotted Page: Insert Record, Pt. 3

- Insert:
- Place record in free space on page
- Create pointer/length pair in next open slot in slot directory



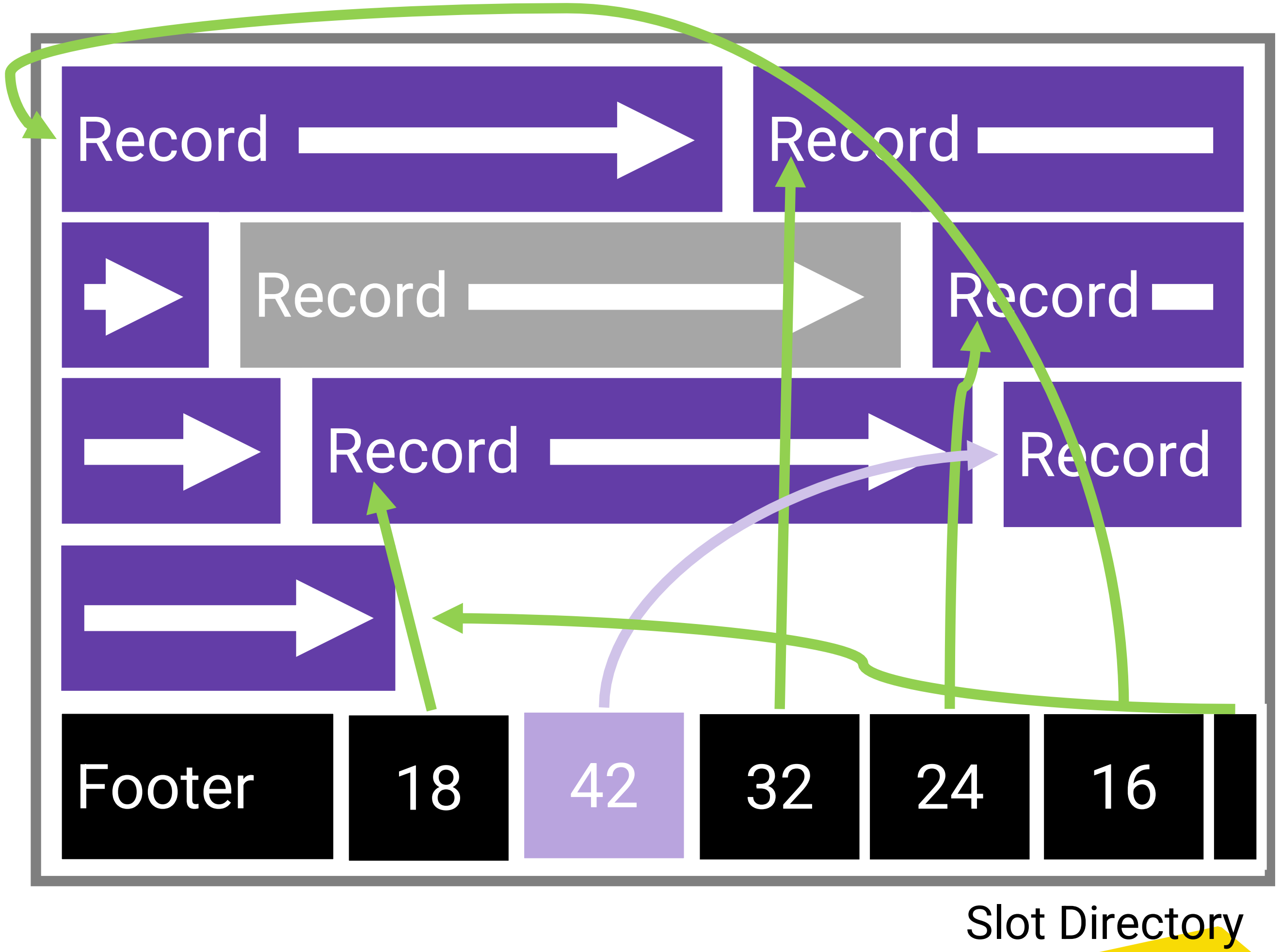
Slotted Page: Insert Record, Pt. 4

- Insert:
- Place record in free space on page
- Create pointer/length pair in next open slot in slot directory
- Update the free space pointer



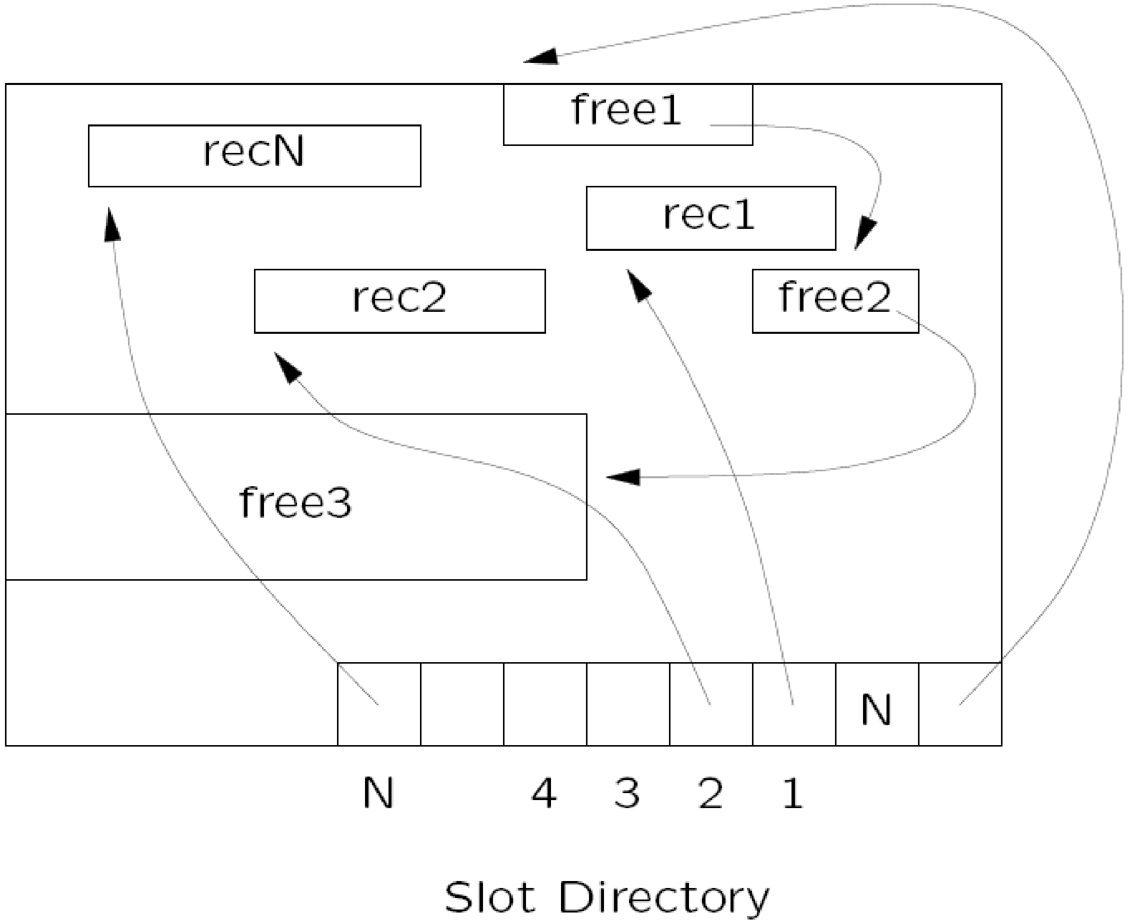
Slotted Page: Insert Record, Pt. 5

- Insert:
- Place record in free space on page
- Create pointer/length pair in next open slot in slot directory
- Update the free space pointer
- **Fragmentation**?



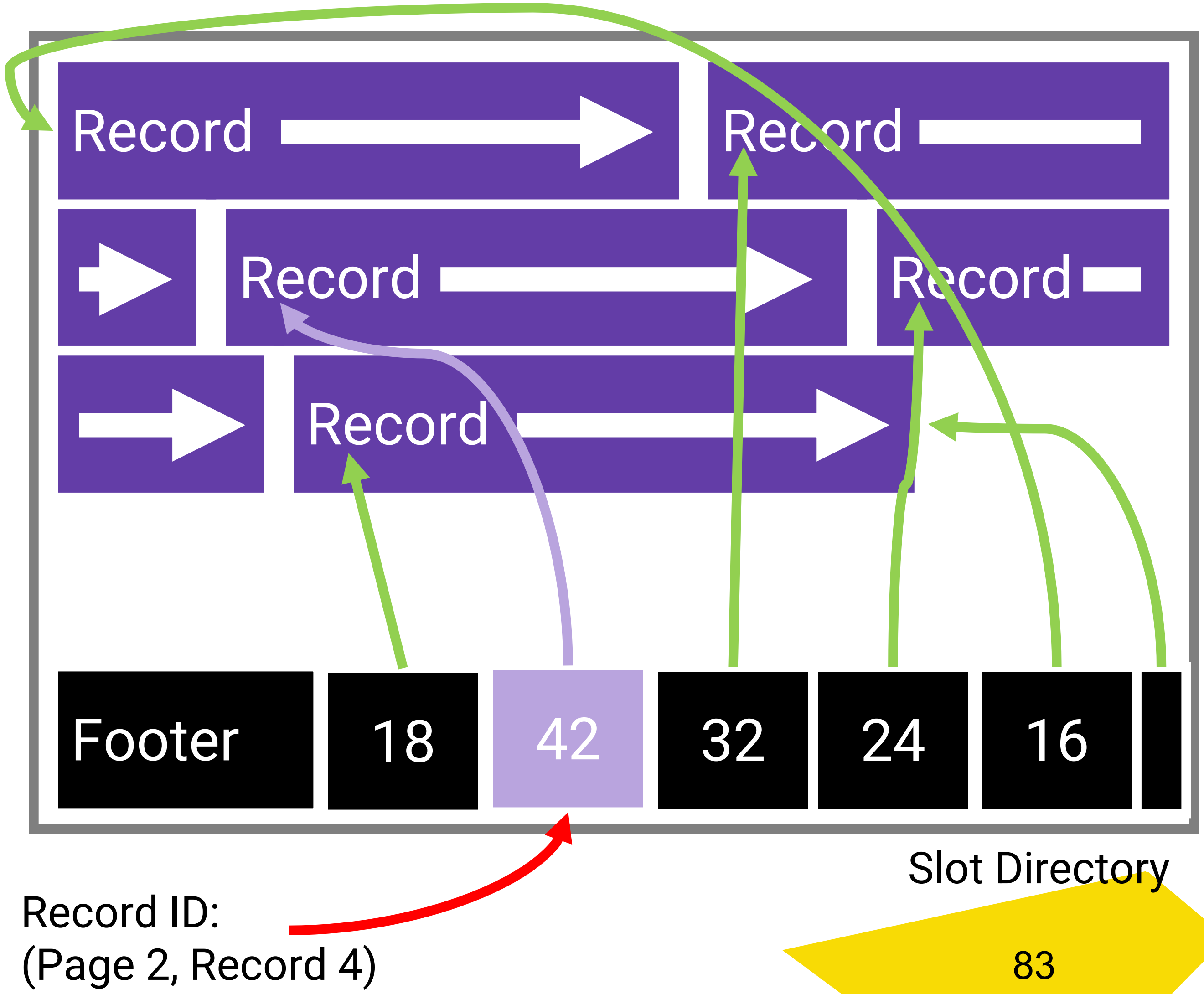
Variable-Length Records

Fragmented free space:



Fragmented Free Space

- Fragmentation?
  - <u>Reorganise data on page!</u>
- When should I reorganise?
  - We could reorganise on deletion
    - Too costly
  - Or wait until fragmentation blocks insertion
  - Modern RDBMS often do compaction when system is *idle*



Notes

Reminder:

- The basic store unit on disk (in memory) is block (page)
- We will use page/block interchangeably.
- One page consists of multiple data records.

Indexes (basic concept)

Find all subcode belonging to the Law faculty (i.e., subcode = LAWS)

Basic strategy = scan ..., test, select
Not efficient ...

An “idea” of an index on a file on the search key ‘subcode’ may look like ...

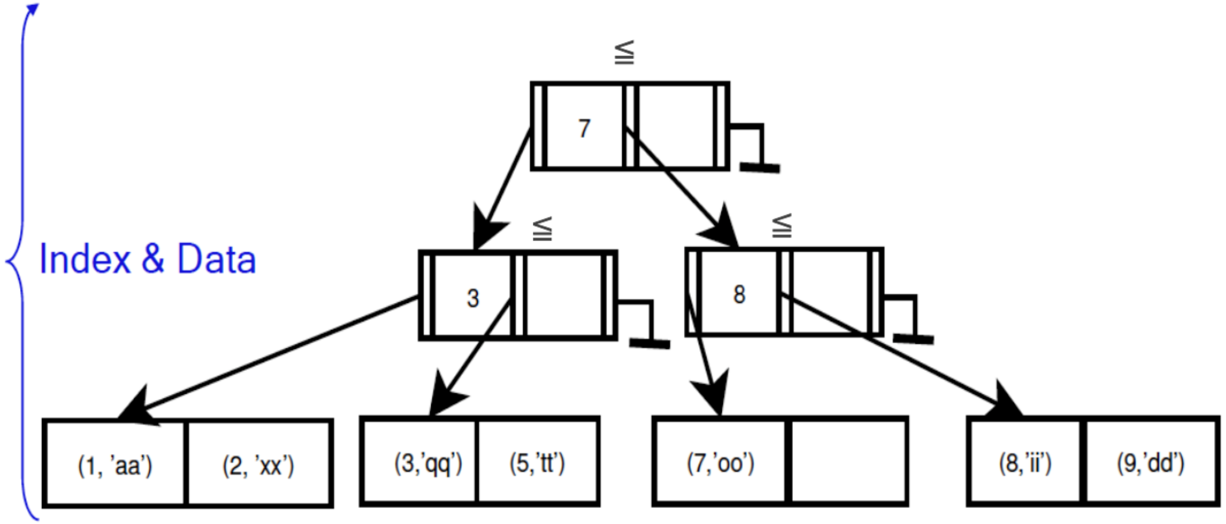
LAND, {1}
ANAT, {2,19}
BENV, {...}
LAWS, {4,7, ...}

An index gives a short cut to the tuples that match the search key

An added cost for building/maintaining it

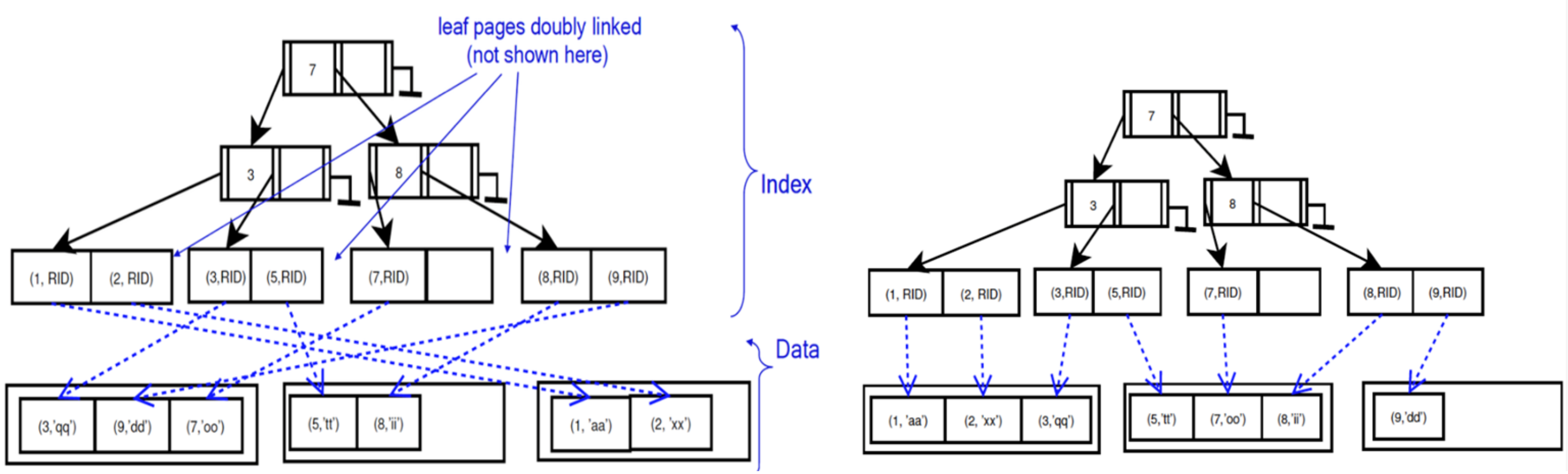
subcode	code	name	uoc	career
LAND	LAND1170	Design 1	4	UG
ANAT	ANAT2211	Histology 1	0	UG
CHEN	CHEN2062	Intro to Process Chemistry 2	3	UG
LAWS	LAWS2332	Law and Social Theory	8	UG
ECON	ECON4321	Economic History 4 Honours	48	UG
AHIS	AHIS1602	History 1	12	
LAWS	LAWS2425	Research Thesis	4	UG
ENVS	ENVS4503	Env Sci Hons (Geog) 18uoc	18	UG
SOLA	SOLA5058	Special Topic in PV	6	PG
BENV	BENV2704	Advanced Construction Systems	3	UG
ANAT	ANAT3141	Functional Anatomy 2	6	UG
BENV	BENV2205	Classical Architecture	3	UG
BENV	BENV2402	Design Modelling - Time Based	6	UG
BIOT	BIOT3081	Environmental Biotech	6	UG
BIOC	BIOC4103	Genetics 4 Honours Full-Time	24	UG
ECON	ECON4127	Thesis (Economics)	12	UG
ENVS	ENVS4404	Environmental Science 4 Chemis	24	UG
LAWS	LAWS2423	Research Thesis	8	UG
MUSC	MUSC2402	Professional Practices D	6	UG
REGS	REGS3756	Negotiation	8	UG
HPSC	HPSC5020	Supervised Reading Program	8	PG
CRIM	CRIM4000	Crim Honours (Research) F/T	24	UG
BIOC	BIOC4109	Genetics Honours (PT)	12	UG
CEIC	CEIC4105	Professional Electives	3	UG

e.g., Data record in B+ Tree



A	B
1	aa
2	xx
3	qq
5	tt
7	oo
8	ii
9	dd

e.g., B+ Tree



The leaves of the index contains a pointer to the data (single record)

You can build many such indexes on a file (different search keys) as the index is separated from the data

The underlying file that contains the records may or not be sorted by key ... when unsorted, the arrows (i.e., the pointers to the data) ‘cross’ each other, this is referred to as ‘unclustered’ index option (cf. clustered, on the right)

e.g., Hash index

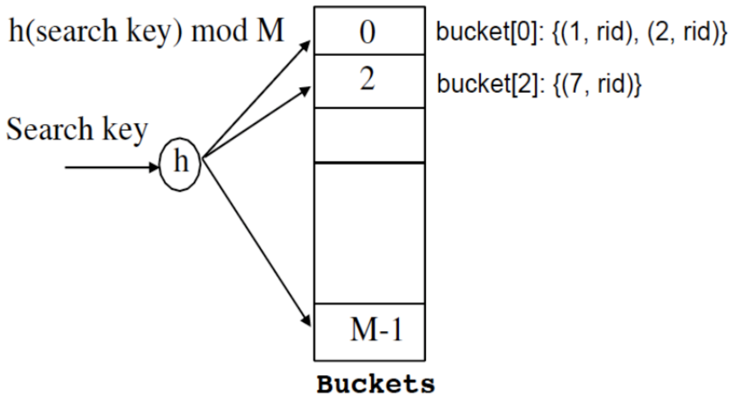
Index contains “buckets”, each bucket contains the index data entries ...

A hash function works on the search key and produces a number over the range of 0 ... M-1 (M is the number of buckets).

e.g., h(K) = (a * K + b), where a, b are constant ... K is the search key.

Fast to search (i.e., no traversing of tree nodes)

Best for equality searches, cannot support range searches.



(an approximate diagram of Hash Index)

Indexes

Indexes provide efficient content-based access to tuples (i.e., through search keys).

Can build indexes on any (combination of) attributes.

Defining indexes (syntax):

CREATE INDEX index_name ON table_name (attr1, attr2, ...)

e.g., CREATE INDEX idx_address_phone ON address(phone);

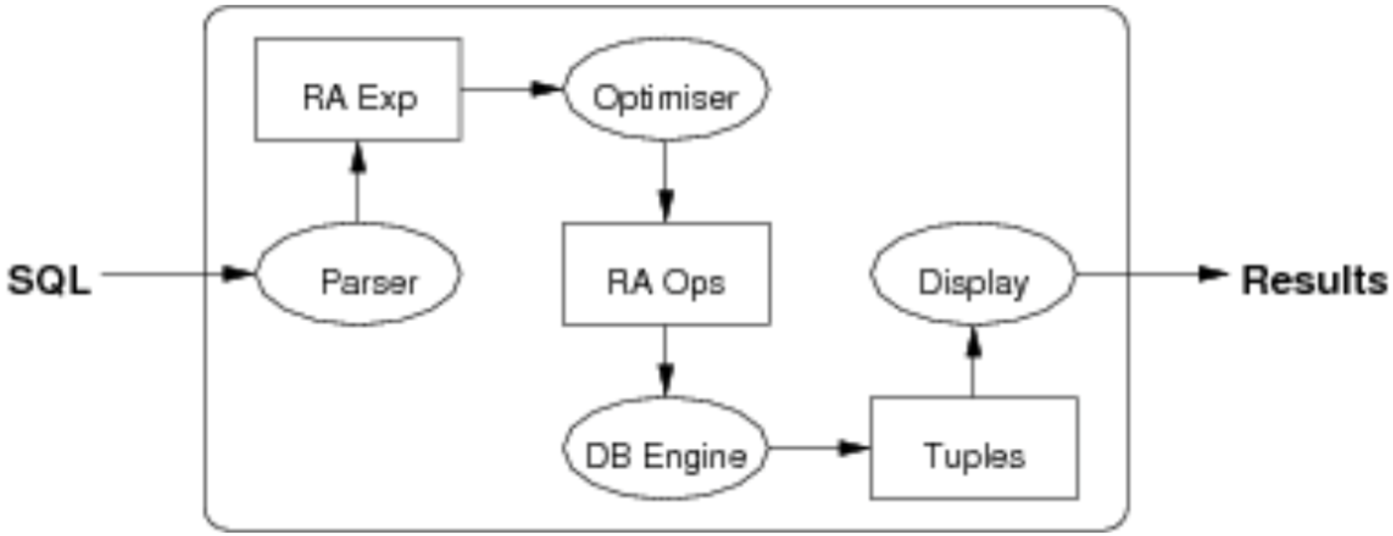
CREATE INDEX also allows us to specify

an access method (USING btree, hash, rtree, or gist)

e.g., CREATE INDEX idx_address_phone ON address USING hash (phone);

Query Processing

mapping SQL to relational algebra (RA)



RA Expressions → Optimiser → concrete RA operations
(e.g., JOIN on empid) (e.g., HASH JOIN on empid)

Query Optimisation Problem

An execution plan is a sequence of relational operations

Consider execution plans for: $\sigma_c\ (R \bowtie_d S \bowtie_e T)$

```
tmp1    :=  hash_join[d](R,S)
tmp2    :=  sort_merge_join[e](tmp1,T)
result  :=  binary_search[c](tmp2)
```

or

```
tmp1    :=  sort_merge_join[e](S,T)
tmp2    :=  hash_join[d](R,tmp1)
result  :=  linear_search[c](tmp2)
```

or

```
tmp1    :=  btree_search[c](R)
tmp2    :=  hash_join[d](tmp1,S)
result  :=  sort_merge_join[e](tmp2)
```

All produce same result but have different costs.

Query Optimisation Problem

The query optimizer start with an RA expression, then

- generates a set of equivalent expressions
- generates possible execution plans for each
- estimates cost of each plan, chooses cheapest

The cost of evaluating a query is determined by:

- size of relations (database relations and temporary relations)
- access mechanisms (indexing, hashing, sorting, join algorithms)
- size/number of main memory buffers (and replacement strategy)

Analysis of costs involves estimating:

- the size of intermediate results
- then, based on this, cost of disk storage accesses (i.e., I/O - page read/write)

PostgreSQL Query Tuning: EXPLAIN

Select on indexed attribute

```
ass2=# explain select * from student where id=100250;
                                 QUERY PLAN
-----------------------------------------------------------------------------
 Index Scan using student_pkey on student  (cost=0.00..5.94 rows=1 width=17)
   Index Cond: (id = 100250)

ass2=# explain analyze select * from student where id=100250;
                                 QUERY PLAN
-----------------------------------------------------------------------------
 Index Scan using student_pkey on student  (cost=0.00..5.94 rows=1 width=17)
                                 (actual time=31.209..31.212 rows=1 loops=1)
   Index Cond: (id = 100250)
 Total runtime: 31.252 ms
```

PostgreSQL Query Tuning: EXPLAIN

Select on non-indexed attribute

```
ass2=# explain select * from student where stype='local';
                          QUERY PLAN
----------------------------------------------------------
 Seq Scan on student  (cost=0.00..70.33 rows=18 width=17)
   Filter: ((stype)::text = 'local'::text)

ass2=# explain analyze select * from student where stype='local';
                                QUERY PLAN
--------------------------------------------------------------------
 Seq Scan on student  (cost=0.00..70.33 rows=18 width=17)
             (actual time=0.061..4.784 rows=2512 loops=1)
   Filter: ((stype)::text = 'local'::text)
 Total runtime: 7.554 ms
```

Key Learning Outcomes

- Buffer replacement policies: how does each policy work
- Record / Page management
- Index and query performance

Next Week: Transaction_Management