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CS 764: Topics in Database Management Systems
Lecture 4: Buffer Management

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9/20/2021

Today's Paper: Buffer Management

Algorithmica (1986) 1: 311–336

Algorithmica

An Evaluation of Buffer Management Strategies for Relational Database Systems[1]

Hong-Tai Chou[2,3] and David J. DeWitt[2]

Abstract. In this paper we present a new algorithm, DBMIN, for managing the buffer pool of a relational database management system. DBMIN is based on a new model of relational query behavior, the *query locality set model* (QLSM). Like the hot set model, the QLSM has an advantage over the stochastic models due to its ability to predict future reference behavior. However, the QLSM avoids the potential problems of the hot set model by separating the modeling of reference behavior from any particular buffer management algorithm. After introducing the QLSM and describing the DBMIN algorithm, we present a performance evaluation methodology for evaluating buffer management algorithms in a multiuser environment. This methodology employed a hybrid model that combines features of both trace-driven and distribution-driven simulation models. Using this model, the performance of the DBMIN algorithm in a multiuser environment is compared with that of the hot set algorithm and four more traditional buffer replacement algorithms.

Key Words. Buffer management, Database systems, Page replacement strategies, Hybrid simulation, Performance evaluation.

1. Introduction. In this paper we present a new algorithm, DBMIN, for managing the buffer pool of a relational database management system. DBMIN is based on a new model of relational query behavior, the *query locality set model* (QLSM.) Like the hot set model [Sacc 1], the QLSM has an advantage over stochastic models due to its ability to predict future reference behavior. However, the QLSM avoids the potential problems of the hot set model by separating the modeling of reference behavior from any particular buffer management algorithm. After introducing the QLSM and describing the DBMIN algorithm, the performance of the DBMIN algorithm in a multiuser environment is compared with that of the hot set algorithm and four more traditional buffer replacement algorithms.

A number of factors motivated this research. First, although Stonebraker [Ston 2] convincingly argued that conventional virtual memory page replacement algorithms (e.g., *least recently used* (LRU)) were generally not suitable for a

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[1] This research was partially supported by the Department of Energy under Contract No. DE-AC02-81ER10920 and the National Science Foundation under grant MCS82-01870.
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Algorithmica 1986

Agenda

Buffer management basics

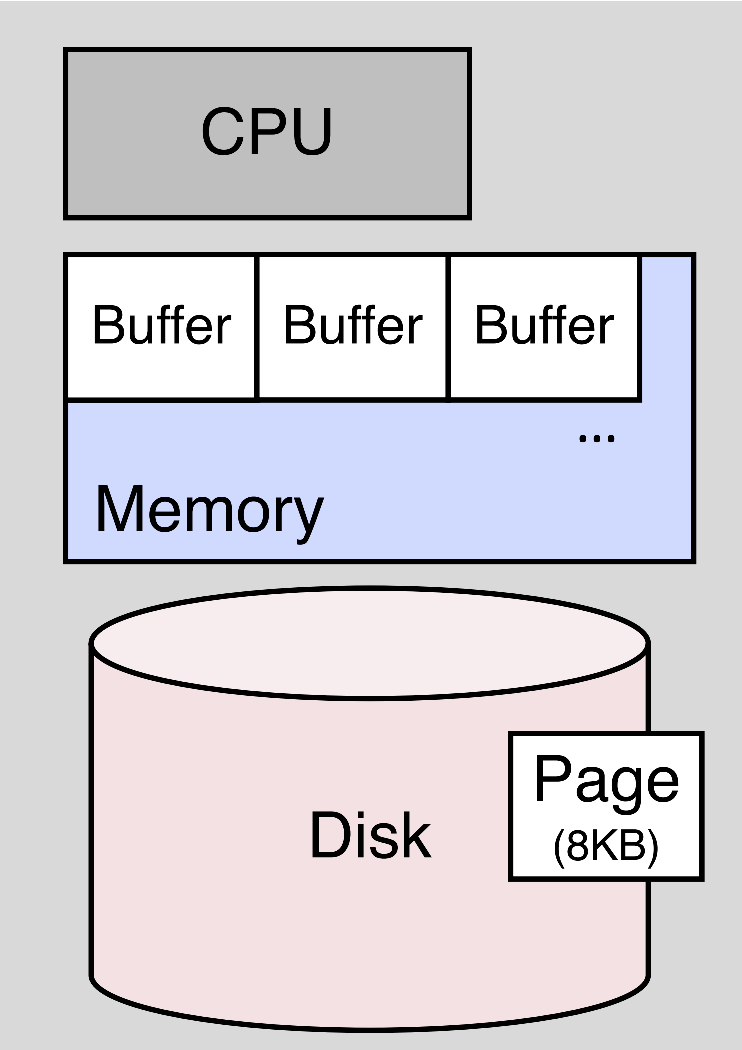
Query locality set model (QLSM)

DBMIN algorithm

Evaluation

Buffer Management Basics

Basic Concepts



A database management system (DBMS) manipulate data in memory

- Data on disk must be loaded to memory before processed

The unit of data movement is a **page**

Page replacement policy (what pages should stay in memory?)

- LRU (Lease recently used)
- Clock
- MRU (Most recently used)
- FIFO, Random, …

LRU Replacement

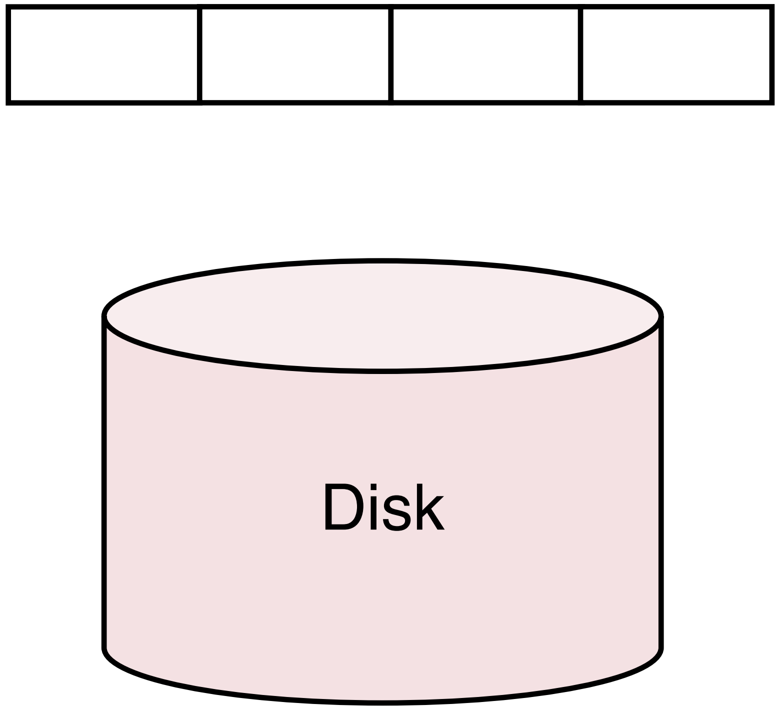
Replace the **least-recently used** (LRU) item in the buffer

Intuition: more recently used items will more likely to be used again in the future

LRU Replacement Example

Example: memory contains 4 buffers. LRU replacement policy

Memory



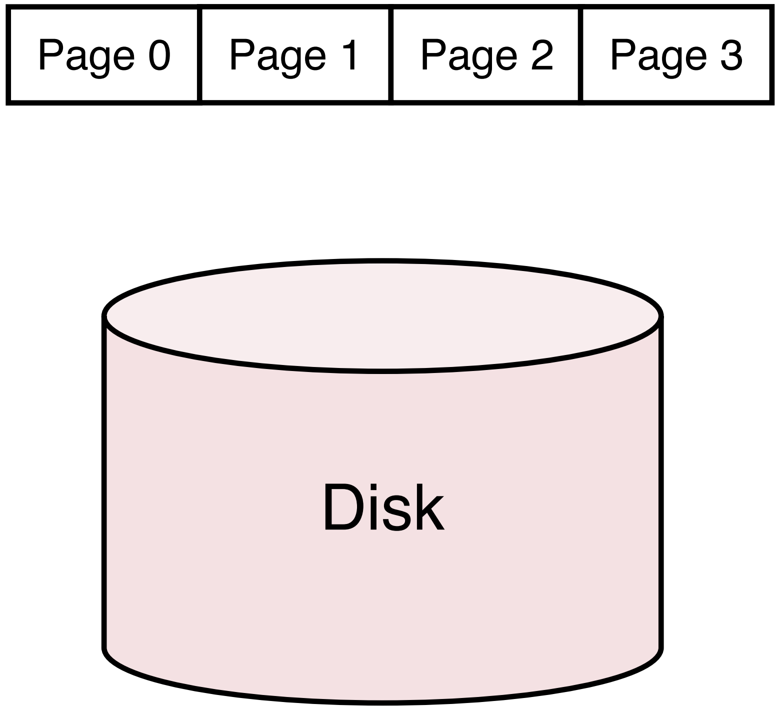
Incoming requests

0, 1, 2, 3, 0, 1, 2, 4, 0, 1, 2, 5, …

LRU Replacement Example

Example: memory contains 4 buffers. LRU replacement policy

Memory



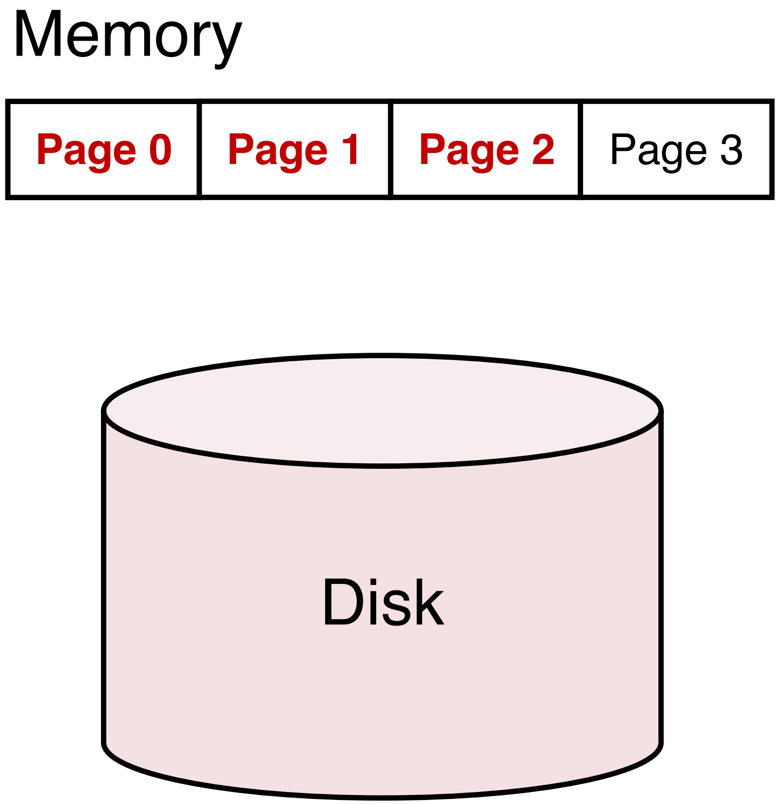
Incoming requests

0, 1, 2, 3, 0, 1, 2, 4, 0, 1, 2, 5, …

Cold start misses: load pages 0–3 to memory

LRU Replacement Example

Example: memory contains 4 buffers. LRU replacement policy



Incoming requests

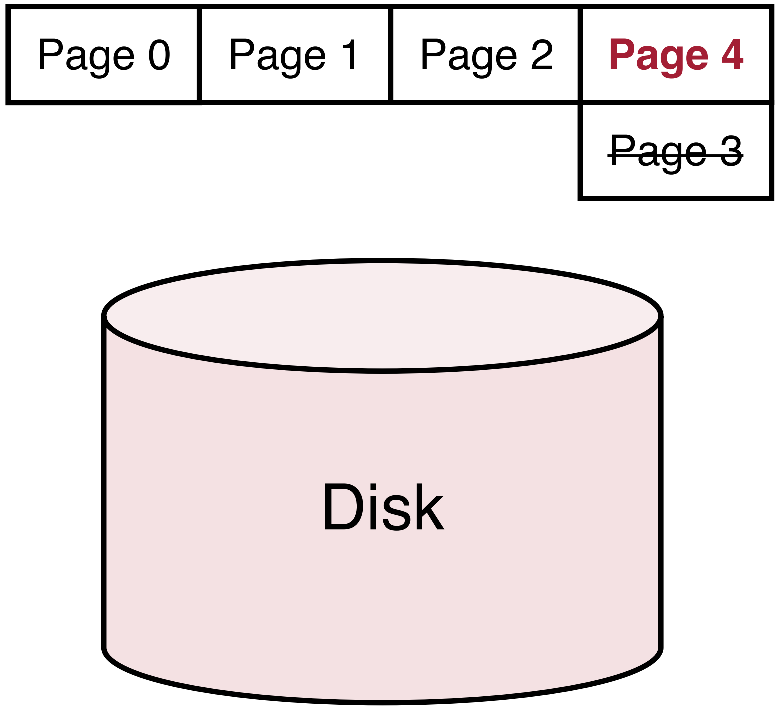
~~0, 1, 2, 3,~~ **0, 1, 2**, 4, 0, 1, 2, 5, …

Cache hits on pages 0–2

LRU Replacement Example

Example: memory contains 4 buffers. LRU replacement policy

Memory



Incoming requests

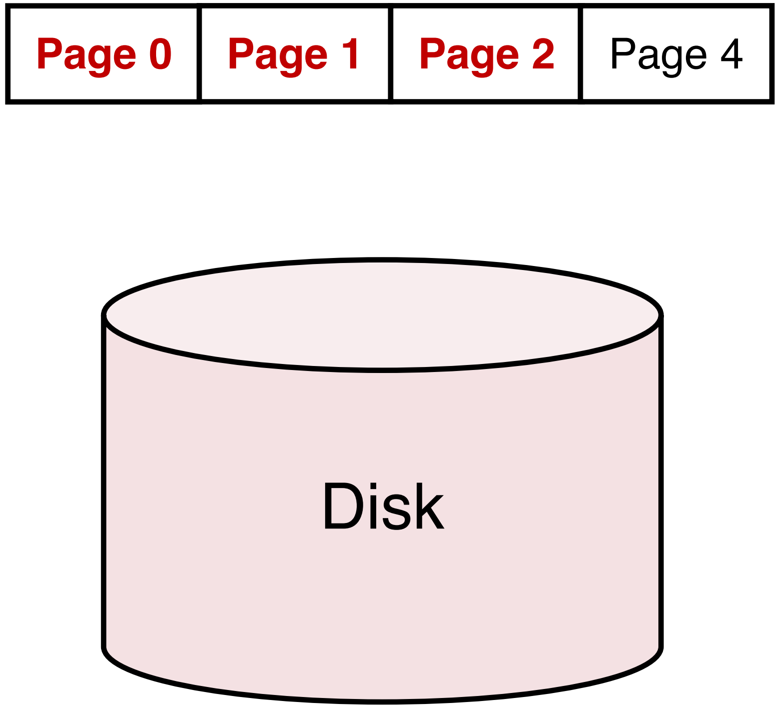
~~0, 1, 2, 3, 0, 1, 2~~, **4**, 0, 1, 2, 5, …

Page 4 replaces page 3 in the buffer since page 3 is the **least-recently used** page

LRU Replacement Example

Example: memory contains 4 buffers. LRU replacement policy

Memory



Incoming requests

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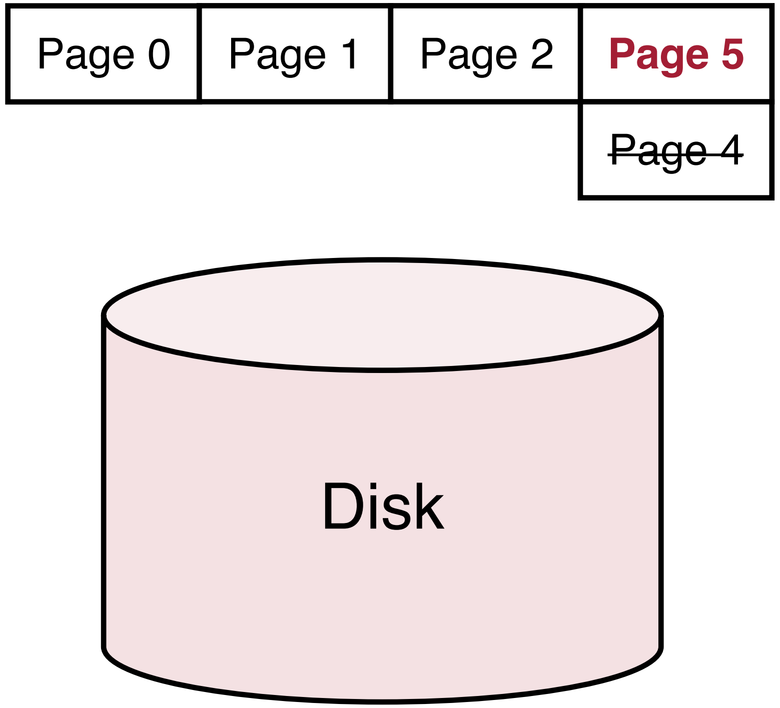
Cache hits on pages 0–2

LRU Replacement Example

Example: memory contains 4 buffers. LRU replacement policy

Memory



Incoming requests

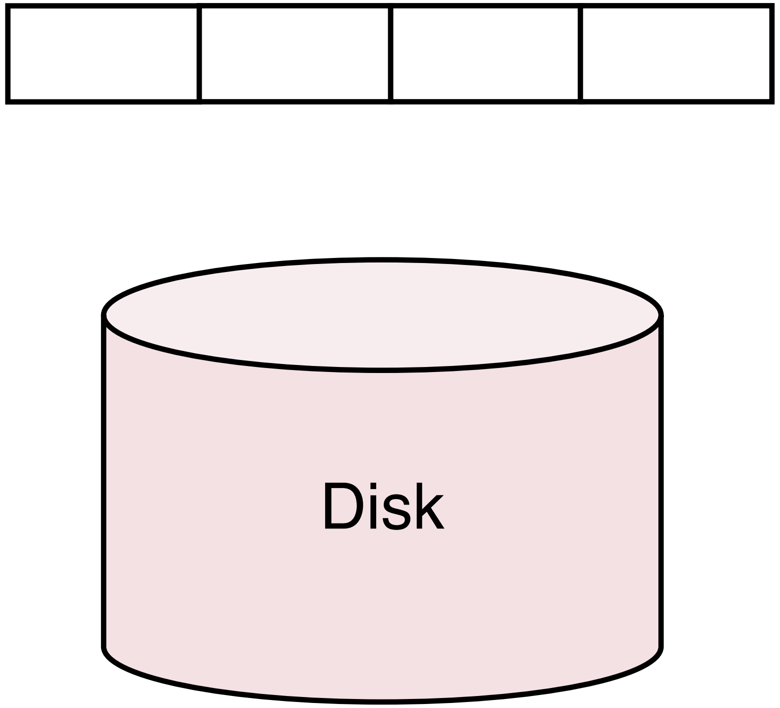
~~0, 1, 2, 3, 0, 1, 2, 4, 0, 1, 2~~, **5**, …

Page 5 replaces page 4 in the buffer since page 4 is the **least-recently used** page

A Different Access Pattern

Example: memory contains 4 buffers. LRU replacement policy

Memory



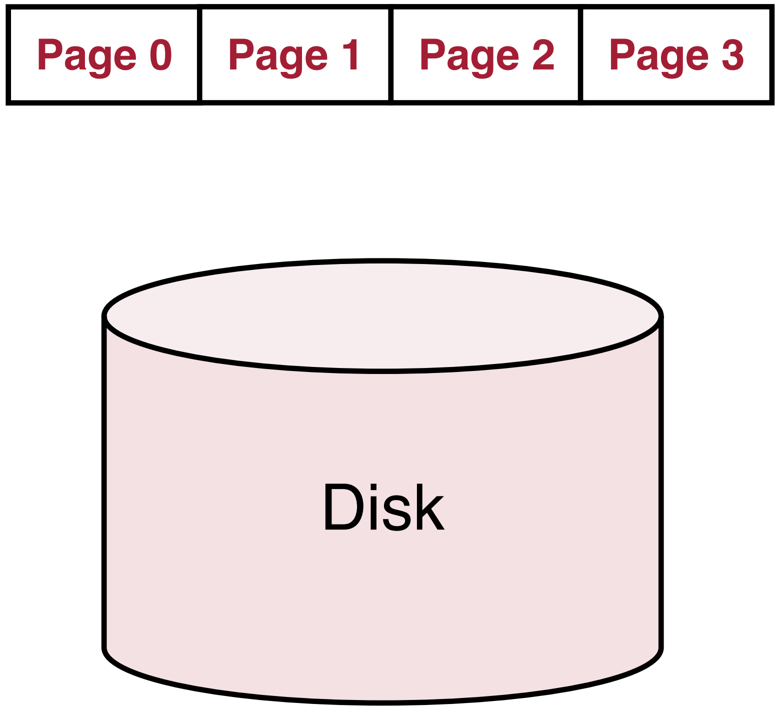
Incoming requests

0, 1, 2, 3, 4, 0, 1, 2, 3, 4, …

A Different Access Pattern

Example: memory contains 4 buffers. LRU replacement policy

Memory



Incoming requests

0, 1, 2, 3, 4, 0, 1, 2, 3, 4, …

Cold start misses: load pages 0—3 to memory

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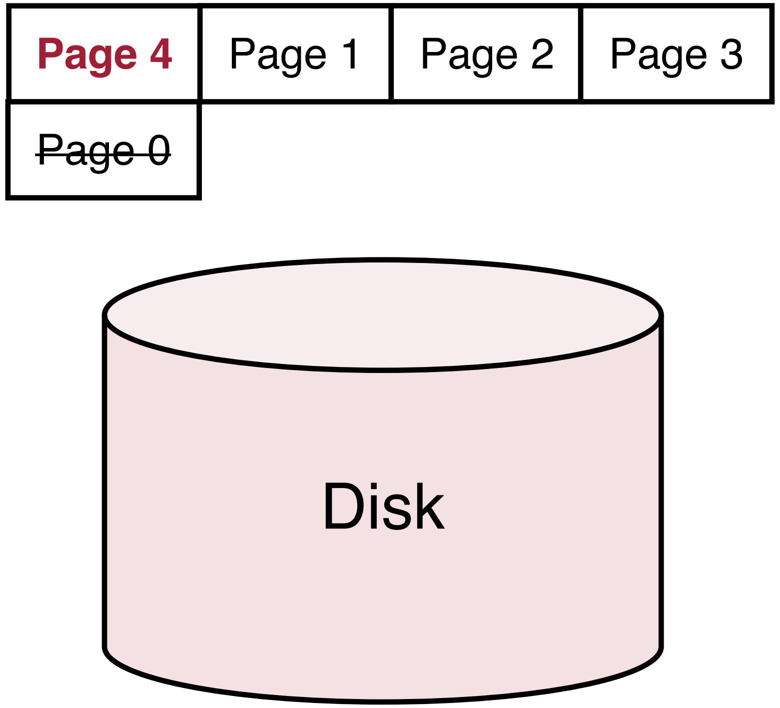
Example: memory contains 4 buffers. LRU replacement policy

Memory



Incoming requests

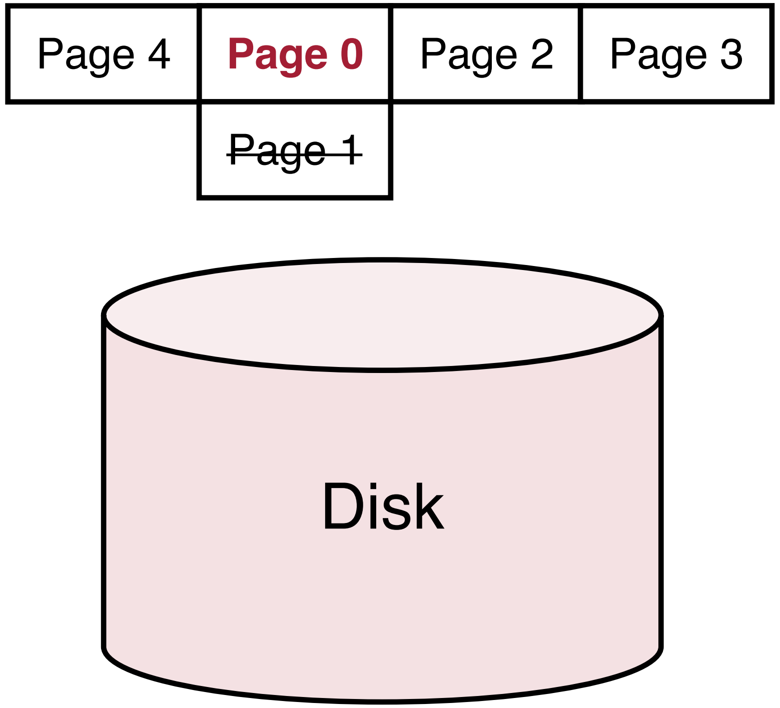
~~0, 1, 2, 3~~, **4**, 0, 1, 2, 3, 4, …

Page 4 replaces page 0 since page 0 is the **least-recently used** page

A Different Access Pattern

Example: memory contains 4 buffers. LRU replacement policy

Memory



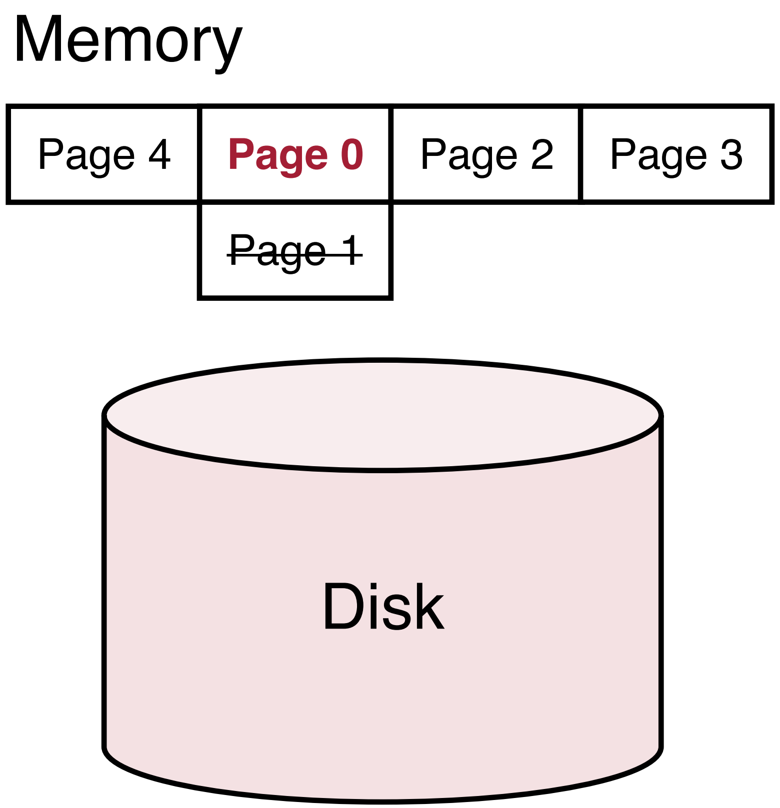
Incoming requests

~~0, 1, 2, 3, 4~~, **0**, 1, 2, 3, 4, …

Page 0 replaces page 1 since page 1 is the **least-recently used** page

A Different Access Pattern

Example: memory contains 4 buffers. LRU replacement policy



Incoming requests

~~0, 1, 2, 3, 4~~, 0, **1, 2, 3, 4, …**

Page 0 replaces page 1 since page 1 is the **least-recently used** page

Each future access will replace the page that will be immediately accessed, and all accesses are misses

MRU Replacement

Replace the **most-recently used** (LRU) item in the buffer

Intuition: avoid the cache thrashing problem in the previous example

MRU Replacement Example

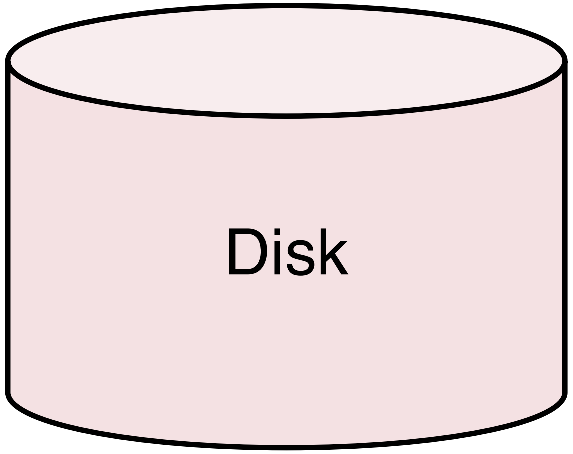
Example: memory contains 4 buffers. MRU replacement policy

Memory

Page 0	Page 1	Page 2	Page 3

Incoming requests

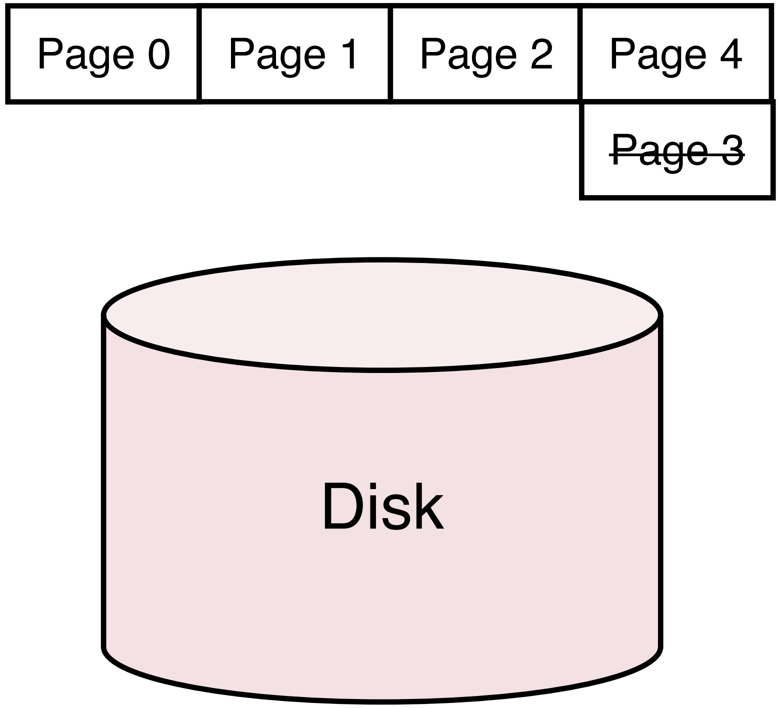
~~0, 1, 2, 3~~, 4, 0, 1, 2, 3, 4, …



MRU Replacement Example

Example: memory contains 4 buffers. MRU replacement policy

Memory



Incoming requests

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MRU Replacement Example

Example: memory contains 4 buffers. MRU replacement policy

Memory

Page 0	**Page 1**	**Page 2**	Page 4

Incoming requests

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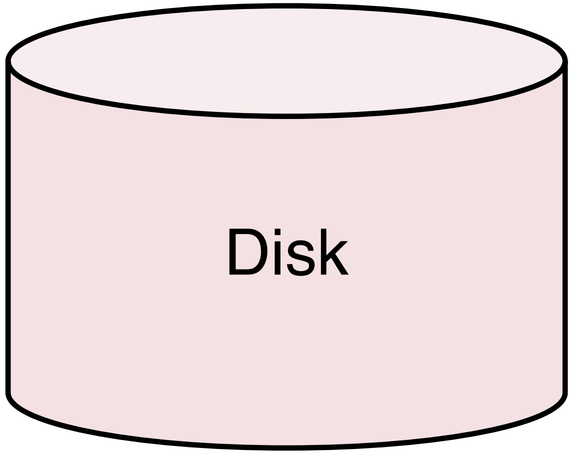
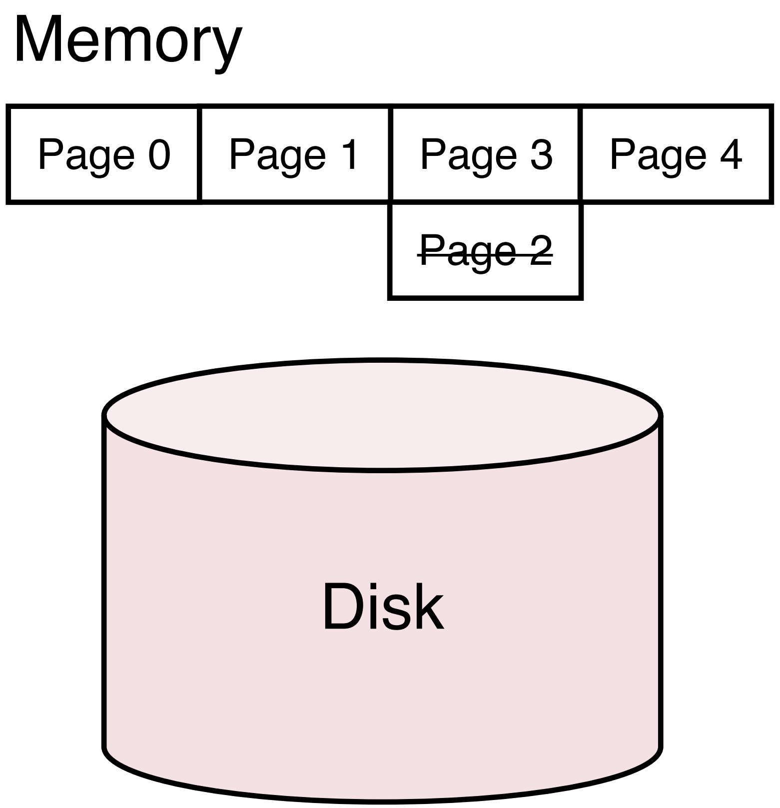
Cache hits on pages 0–2



MRU Replacement Example

Example: memory contains 4 buffers. MRU replacement policy



Incoming requests

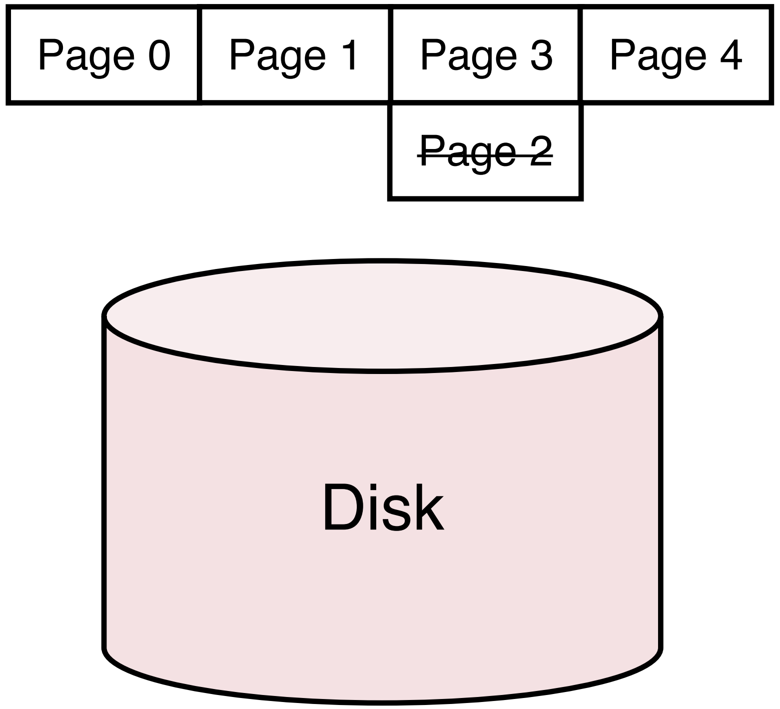
~~0, 1, 2, 3, 4, 0, 1, 2~~, **3**, 4, …

Page 3 replaces page 2 since page 2 is the **most-recently used** page

MRU Replacement Example

Example: memory contains 4 buffers. MRU replacement policy

Memory



Incoming requests

~~0, 1, 2, 3, 4, 0, 1, 2~~, **3**, 4, …

Page 3 replaces page 2 since page 2 is the **most-recently used** page

LRU: all accesses are misses
MRU: 25% of accesses are misses

Selection of replacement policy depends on the data access pattern

Insight

The optimal buffer **replacement and allocation policies** depend on the data access pattern

The data access pattern is relatively easy to predict in a DBMS compared to hardware or OS

Query Locality Set Model (QLSM)

Query Locality Set Model

Observations

- DBMS supports a limited set of operations
- Data reference patterns are regular and predictable
- Complex reference patterns can be decomposed into simple patterns

Query Locality Set Model

Observations

– DBMS supports a limited set of operations

– Data reference patterns are regular and predictable

– Complex reference patterns can be decomposed into simple patterns

Reference pattern classification

– Sequential

– Random

– Hierarchical

Locality set: the appropriate buffer pool size for each query

QLSM – Sequential References

Straight sequential (SS): each page in a file accessed only once

- E.g., select on an unordered relation
- Locality set: one page
- Replacement policy: any

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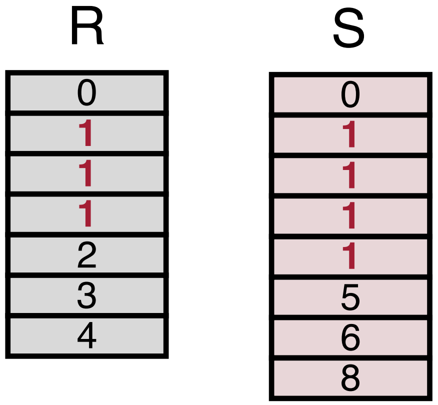
Clustered sequential (CS): repeatedly read a “chunk” sequentially

- E.g., sort-merge join with duplicate join keys
- Locality set: size of largest cluster
- Replacement policy: LRU or FIFO (buffer size ≥ cluster size), MRU (otherwise)



QLSM – Sequential References

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- E.g., sort-merge join with duplicate join keys
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- Replacement policy: LRU or FIFO (buffer size ≥ cluster size), MRU (otherwise)

Looping Sequential (LS): repeatedly read something sequentially

- E.g. nested-loop join
- Locality set: size of the file being repeated scanned.
- Replacement policy: MRU

QLSM – Random References

Independent random (IR): truly random accesses

- E.g., index scan through a non-clustered (e.g., secondary) index
- Locality set: one page or **b** pages (**b** unique pages are accessed in total)
- Replacement: any

QLSM – Random References

Independent random (IR): truly random accesses

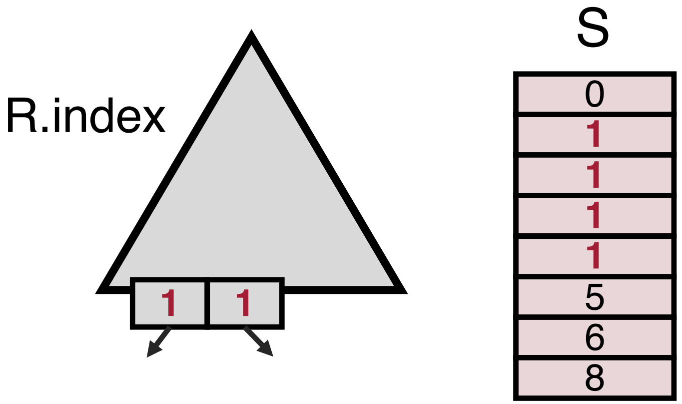
- E.g., index scan through a non-clustered (e.g., secondary) index
- Locality set: one page or **b** pages (**b** unique pages are accessed in total)
- Replacement: any

Clustered random (CR): random accesses with some locality

- E.g., join between non-clustered, non-unique index as inner relation and clustered, non-unique outer relation
- Locality set: size of the largest cluster
- Replacement policy :

  LRU or FIFO (buffer size ≥ cluster size)

  MRU (otherwise)



QLSM – Hierarchical References

Straight hierarchical (SH): single traversal of the index
- Similar to SS

Hierarchical with straight sequential (H/SS): traversal followed by straight sequential on leaves
- Similar to SS

Hierarchical with clustered sequential (H/CS): traversal followed by clustered sequential on leaves
- Similar to CS

Looping hierarchical (LH): repeatedly traverse an index
- Example: index nested-loop join
- Locality set: first few layers in the B-tree
- Replacement: LIFO

Summary of Reference Patters

Pattern	Example	Locality set	Replacement
Straight sequential (SS)	File scan	1 page	any
Clustered sequential (CS)	Sort-merge join with duplicate keys	Cluster size	LRU/FIFO
Looped sequential (LS)	Nested-loop join	Size of scanned file	LRU
		< Size of scanned file	MRU
Independent random (IR)	non-clustered index scan	1 or **b**	any
Clustered random (CR)	Non-clustered, non-unique index as inner relation in a join	Same as CS	
Straight hierarchical (SH)	Single index lookup	Same as SS	
Hierarchical with straight sequential (H/SS)	Index lookup + scan		
Hierarchical with clustered sequential (H/CS)	Index lookup + clustered scan	Same as CS	
Looping hierarchical (LH)	Index nested-loop join	First few layers in the B-tree	LIFO

DBMIN algorithm

DBMIN

For each open file operation

- Allocate a set of buffers (i.e., locality set)
- Choose a replacement policy
- Each open file instance has its own set of buffers
- If two file instances access the same page, they share the page

Predicatively estimate locality set size by examining the query plan and database statistics

Admission control: a query is allowed to run if its locality sets fit in free frames

Other Buffer Management Algorithms

Simple Algorithms

Replacement discipline is applied globally to all the buffers in the system

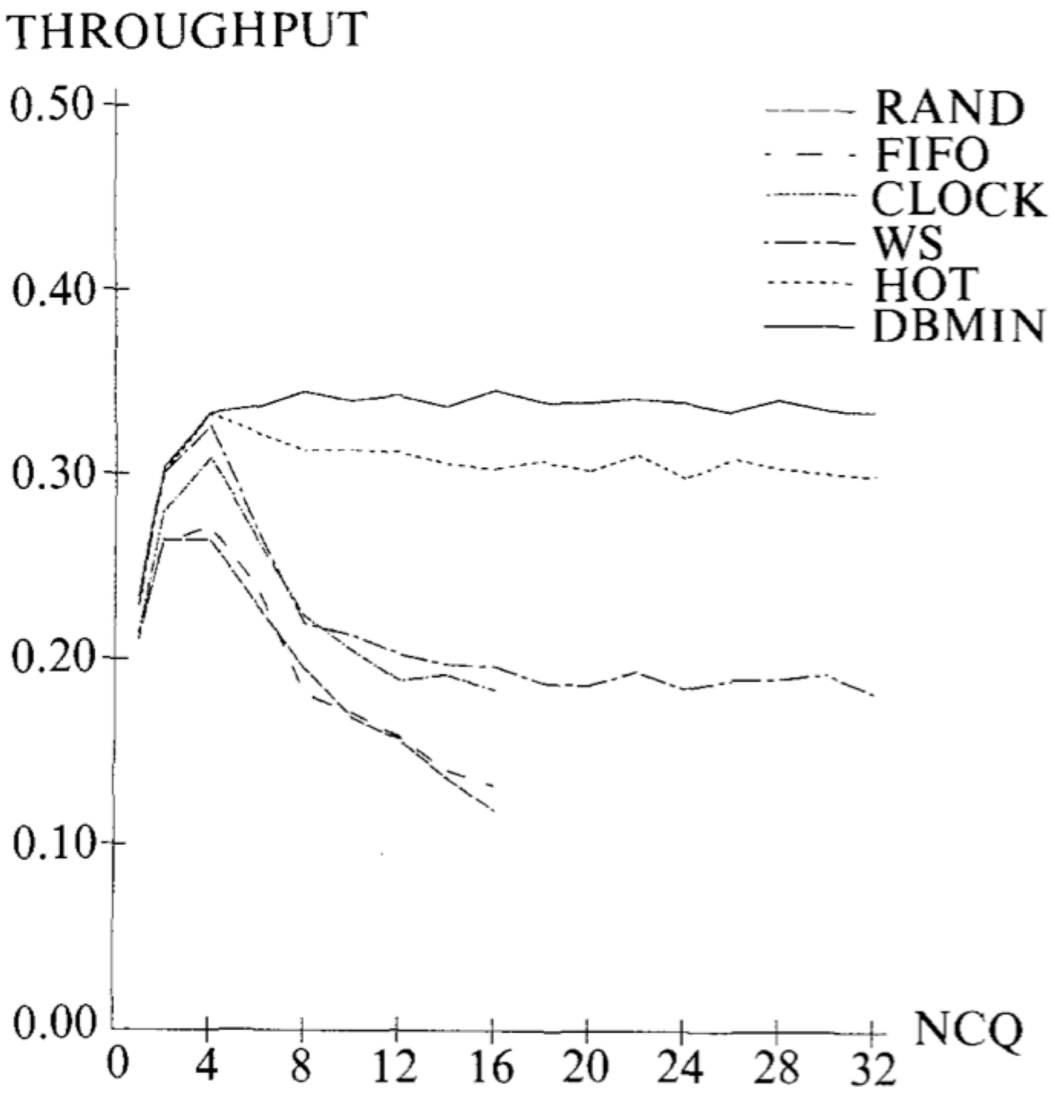
- RAND
- FIFO (first-in, first-out)
- CLOCK

Sophisticated Algorithms

Replacement discipline is applied locally to each query or file instance

- DBMIN
- HOT (the hot set algorithm): always using LRU
- WS (the working set algorithm)
- Domain separation: LRU within each domain (e.g., an index level)

Evaluation



Except DBMIN and HOT, performance of all the other algorithms thrashes at high concurrency

DBMIN outperforms HOT

Q/A – Buffer Management

File vs. Relation?

Wrong access pattern prediction?

DBMIN Use in practice?

What if a page belongs to multiple locality sets?

How to pick an optimal locality set size?

How is this related to the join techniques?

Data sharing requires concurrency control?

Group Discussion

In a conventional disk-based system, the bandwidth and latency gaps between DRAM and disks are large. Modern storage devices like non-volatile memory (NVM) have (1) bandwidth and latency close to DRAM and (2) byte-addressability. How do NVM devices change buffer management in a DBMS?

Before Next Lecture

Submit review for

Xinjing Zhou, et al. Spitfire: A Three-Tier Buffer Manager for Volatile and Non-Volatile Memory. SIGMOD, 2021