Are You Sure You Want to Use MMAP in Your Database Management System?

MMAP = ◡̈

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Outline

Outline

Authors

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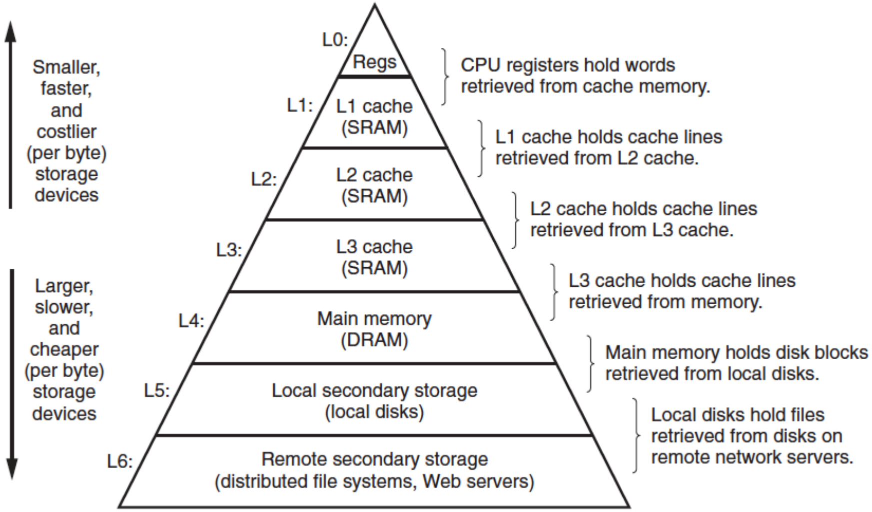
- Andrew Crotty
  - ✓ Andrew Crotty's Bio
  - ✓ Ph.D at Brown, in 2019. Post-doctoral at CMU.
- Viktor Leis
  - ✓ Viktor Leis Bio
  - ✓ Ph.D at TUM, full professor at Friedrich Schiller University Jena.
- Andy Pavlo
  - ✓ Andy Pavlo Bio
  - ✓ Ph.D at Brown, associate professor at CMU.
  - ✓ Never use mmap in a DBMS at his tombstone.

Storage hierarchy, Cont.



Architecture of RDBMS, Cont.

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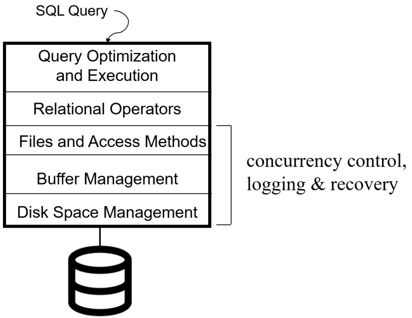
- Query optimization and execution
- Relational operators
- Files and access methods
- Buffer pool management
- Disk space management



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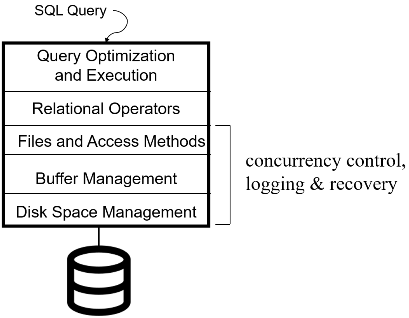

- Crash recovery is awfully difficult!
  - The recovery system depends on behavior of many other components of DBMS, such as concurrency control, buffer management, disk management, and query processing.

Buffer Pool Management, Cont.

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  - ✓ Useful for ensuring atomicity without UNDO logging.
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In practice, even to get Force/No-Steal to work requires some nasty details for handling unexpected failures...

Buffer Pool Replace Policy, Cont.

- No Force
  - What if system crashes before a modified page written by a committed transaction makes it to DB disk?
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- Steal
  - What if a transaction that performed updates aborts? → WAL Logging
  - What if system crashes before transaction is finished? → WAL Logging
    - ✓ Must remember the old value of P (to support UNDOing the write to page P).

Buffer Pool Management, Cont.

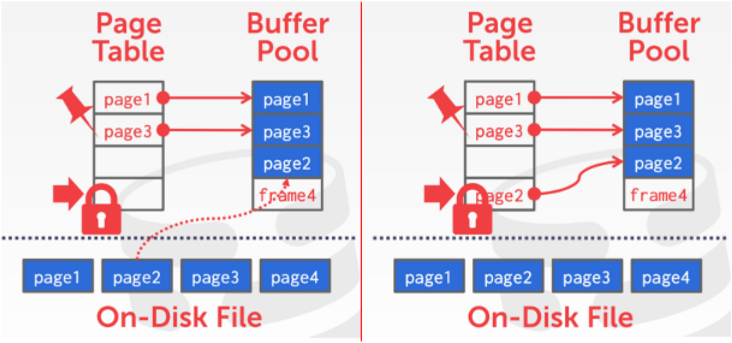
	No Steal	Steal
No Force		Fastest
Force	Slowest	

Performance Implications

	No Steal	Steal
No Force	No UNDO REDO	UNDO REDO
Force	No UNDO No REDO	UNDO No REDO

Log/Recovery Implications

Buffer Pool Management, Cont. [1]



[1] CMU 15-445/645 Fall 2021 Buffer Pool Slide

MMAP as Buffer Pool Replacement, Cont. [2]

- Memory-mapped (mmap) file I/O is an OS-provided feature.
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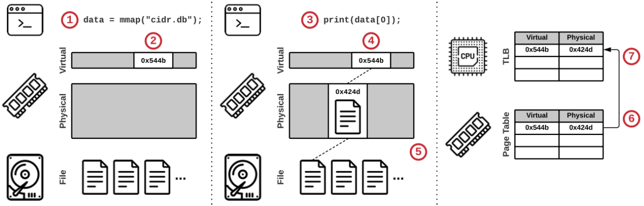

Step-by-step illustration of how a program accesses a file using mmap.

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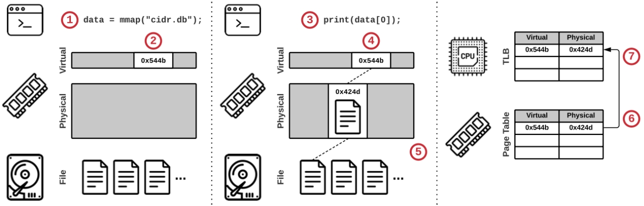

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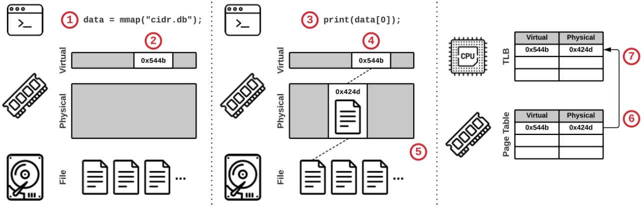
  - ✓ The OS automatically evicts pages if memory fills up.



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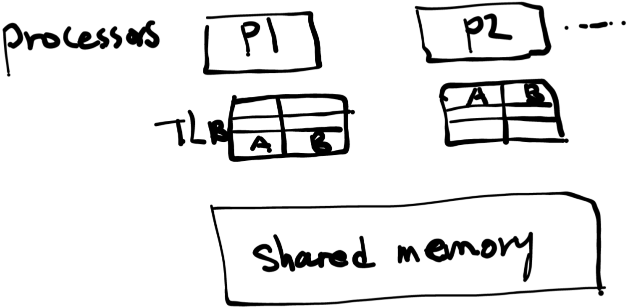
TLB shootdown

- Shared Memory Model[3]



[3] Ethanzjp Shared Memory Demo

Comparsion of Buffer Pool and MMAP

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- Buffer Pool
  - ✓ The DBMS maintaining complete control over how and when it transfers pages.
- MMAP
  - ✓ The OS handles all necessary paging behind the scenes rather than the DBMS's buffer pool.
- Stonebraker 1981 opinion [4]

> However, many DBMSs including INGRES [20] and System R [4] choose to put a DBMS managed buffer pool in user space to reduce overhead. Hence, each of these systems has gone to the trouble of constructing its own buffer pool manager to enhance performance.

[4] 1981 Stonebraker's Paper

POSIX API, Cont.

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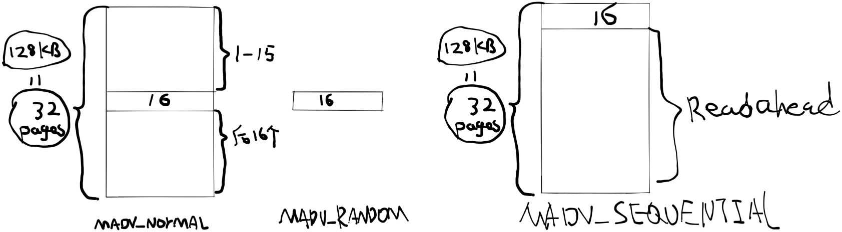
- mmap [5]
- madvise hints to the OS about expected data access patterns[6]



- mlock[7] allows DBMS pin memory. But OS is permitted to flush dirty pages to the backing file at any time, even if the page is pinned.
- msync[8] explicitly flushes the specified memory range to secondary storage.

[5] mmap man7 page
[6] madvise man7 page
[7] mlock man7 page
[8] msync man7 page

Modern MMAP-based DBMS

DBMS	MMAP Use	Details
MonetDB	2002–	[12, 21]
MongoDB	2009–2019	[14, 3]
LevelDB	2011–	[5]
LMDB	2011–	[20]
SQLite	2013–	[7]
SingleStore	2013–2015	[32]
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[9] LevelDB Snapshot Demo

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- MonetDB use WiredTiger and MMAPv1 (optional) as storage engine.
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- RocksDB replace mmap as a fork of LevelDB [9].

[9] LevelDB Snapshot Demo

What is the truth?

The DBMS seems no longer needs to manage its own buffer pool, as it cedes this responsibility to the OS.

Outline

Transactional Safety

- The challenges inherent with guaranteeing transactional safety of modified pages in mmap-based DBMSs are well-known.
  - Due to transparent paging, the OS can flush a dirty page to secondary storage at any time, irrespective of whether the writing transaction has committed.
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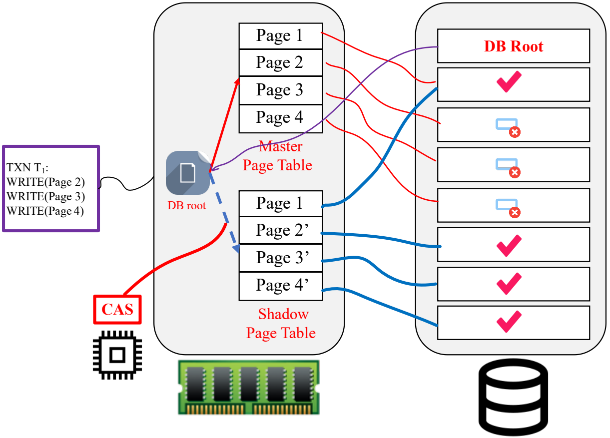
  - Shadow Paging

System R's Shadow paging



- Master: Contains only changes from committed txns.
- Shadow: Temporary db with changes made from uncommitted txns.

IO Stalls

- Accessing any page could result in an unexpected I/O stall because the DBMS cannot know whether the page is in memory.
  - ✓ Pinning memory.
  - ✓ mlock the memory.
  - ✓ madvise, but os is free ignore the advise.

Error Handling

- page-level checksums
- gracefully handling I/O errors

Performance Issues

- page table contention
- single-threaded page evictionand for larger-than- memory DBMS workloads on high-bandwidth secondary storage devices.
- TLB shootdowns.

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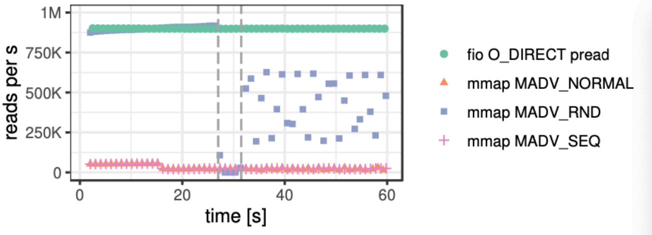
Random Reads on Bandwidth[10]

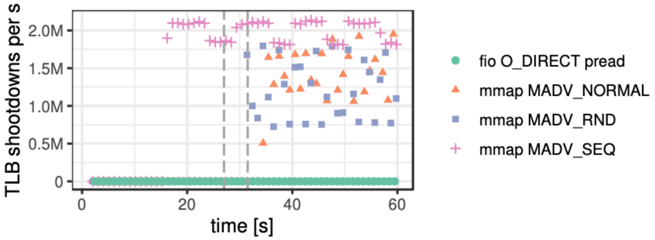


(a) Bandwidth

- Random access pattern over a 2 TB SSD range to simulate a larger-than-memory OLTP workload.
- The page cache had only 100 GB of memory, 95% of all accesses resulted in page faults
- fio baseline exhibited stable performance and achieved close to 900K reads per second

[10] mmapbenchmark

Random Reads on TLB Shootdown



(b) TLB Shootdowns

- we measured using /proc/interrupt

Sequential Scan on Bandwidth

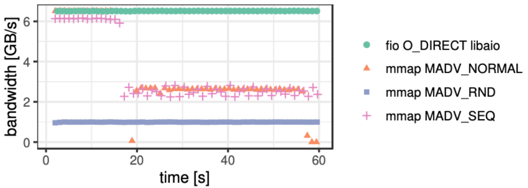


Figure 3: Sequential Scan – 1 SSD (mmap: 20 threads; `fio`: `libaio`, 1 thread, `iodepth` 256)

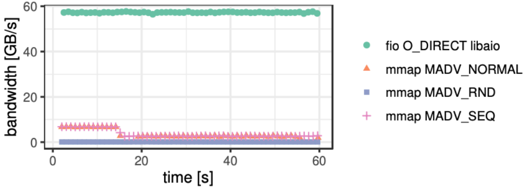


Figure 4: Sequential Scan – 10 SSDs (mmap: 20 threads; `fio`: `libaio`, 4 threads, `iodepth` 256)

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  - ✓ Otherwise, never.

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References

- RavenDB Response
- Community Comments

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Thank you!
Welcome for any questions!

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