Implications of Storage Class Memories (SCM) on Software Architectures

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Acknowledgments and References

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References:

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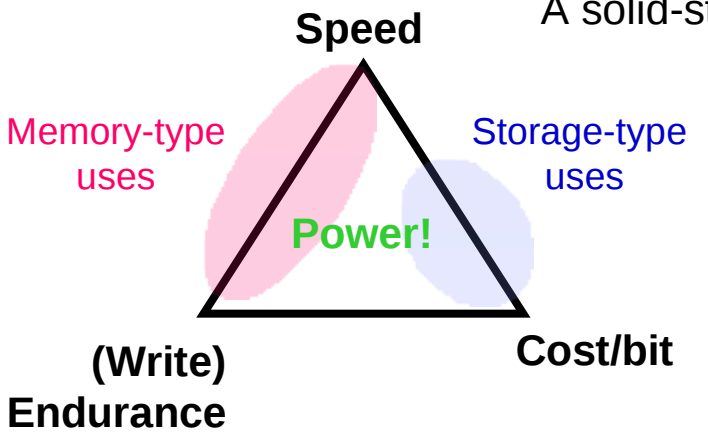
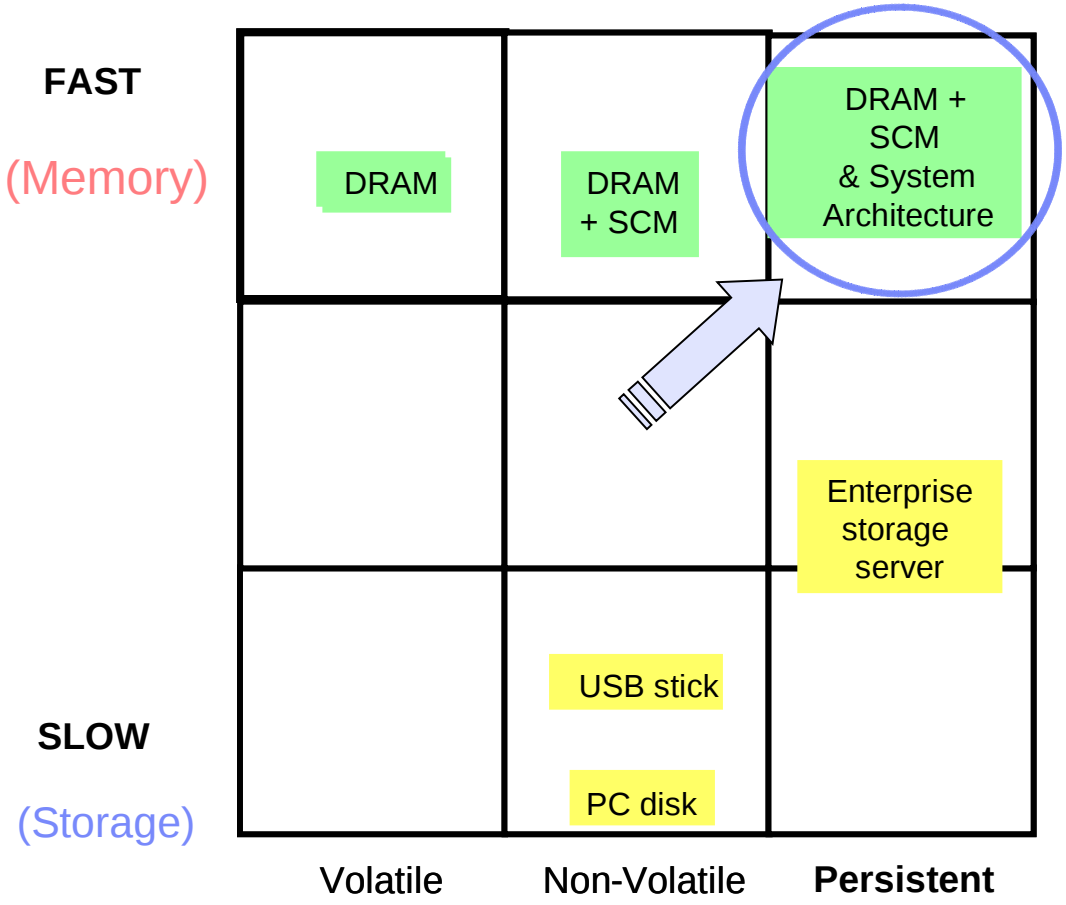
Storage Class Memory



A solid-state memory that **blurs the boundaries** between storage and memory by being **low-cost**, **fast**, and **non-volatile**.

- **SCM system requirements for Memory (Storage) apps**
  - No more than 3-5x the **Cost** of enterprise HDD (< $1 per GB in 2012)
  - **<200nsec (<1µsec) Read/Write/Erase time**
  - >100,000 **Read I/O operations** per second
  - **>1GB/sec (>100MB/sec)**
  - **Lifetime** of 10^9 – 10^{12} write/erase cycles
  - 10x lower **power** than enterprise HDD (100mW ON power, 1mW standby)

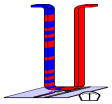
Speed/Volatility/Persistence Matrix



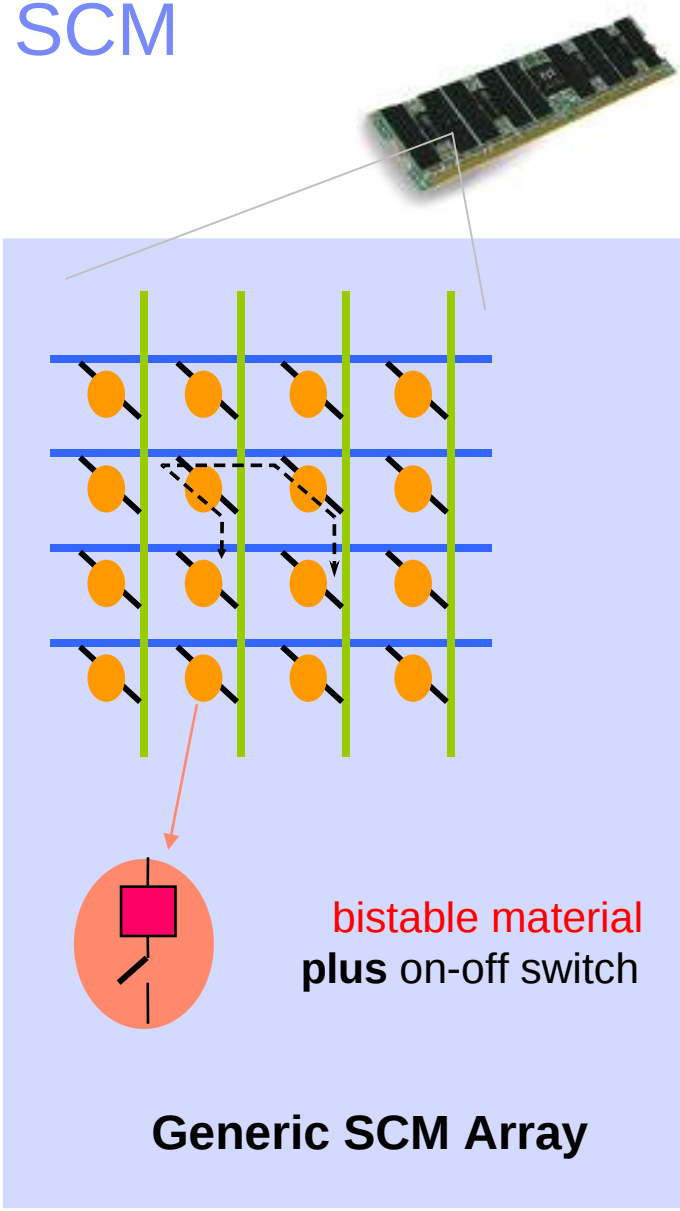
Persistent storage will not lose data

Many Competing Technologies for SCM

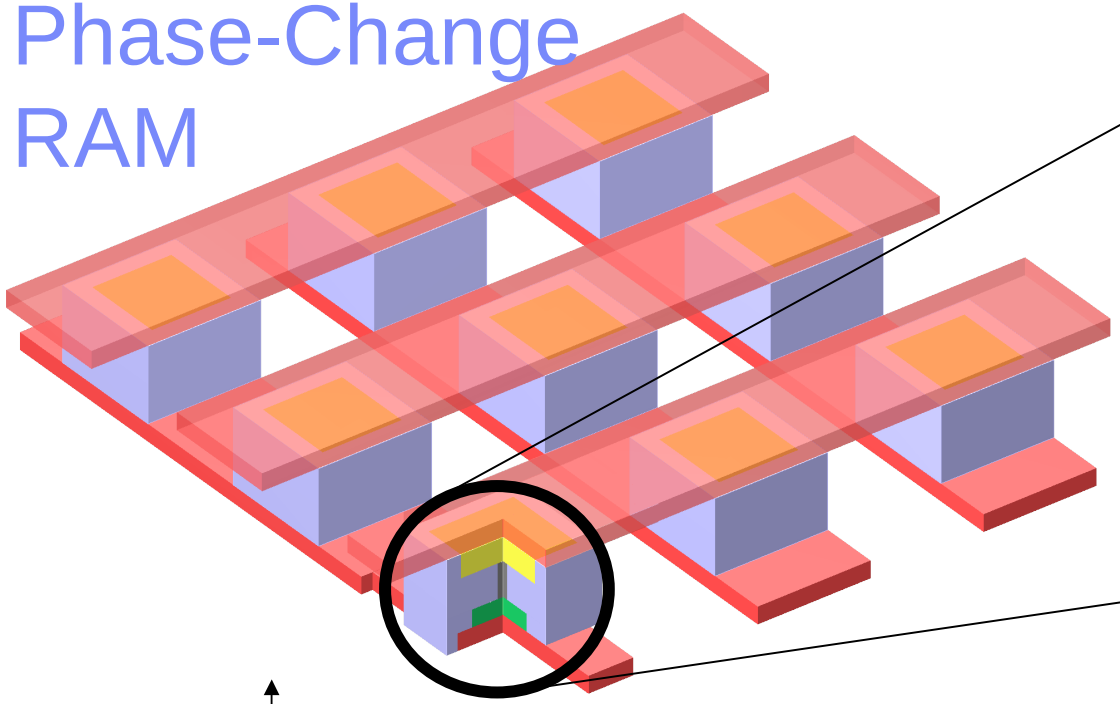
- Phase Change RAM
  - most promising now (scaling)
- Magnetic RAM
  - used today, but poor scaling and a space hog
- Magnetic Racetrack
  - basic research, but very promising long term
- Ferroelectric RAM
  - used today, but poor scalability

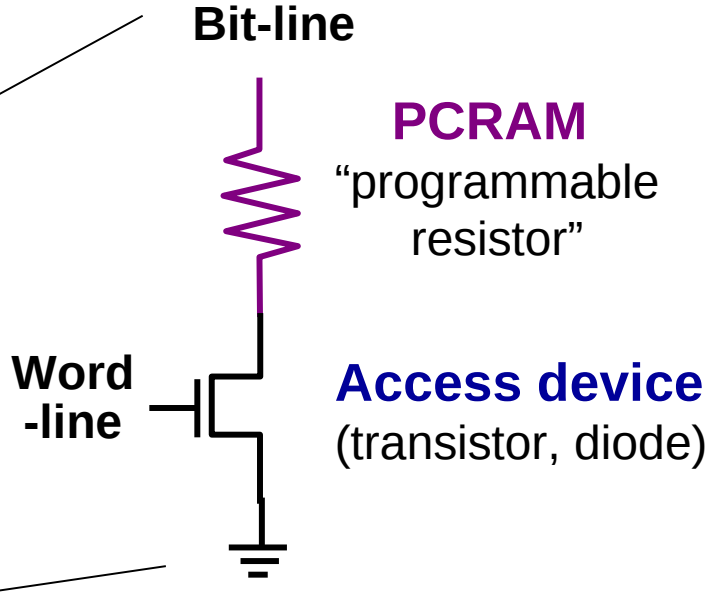


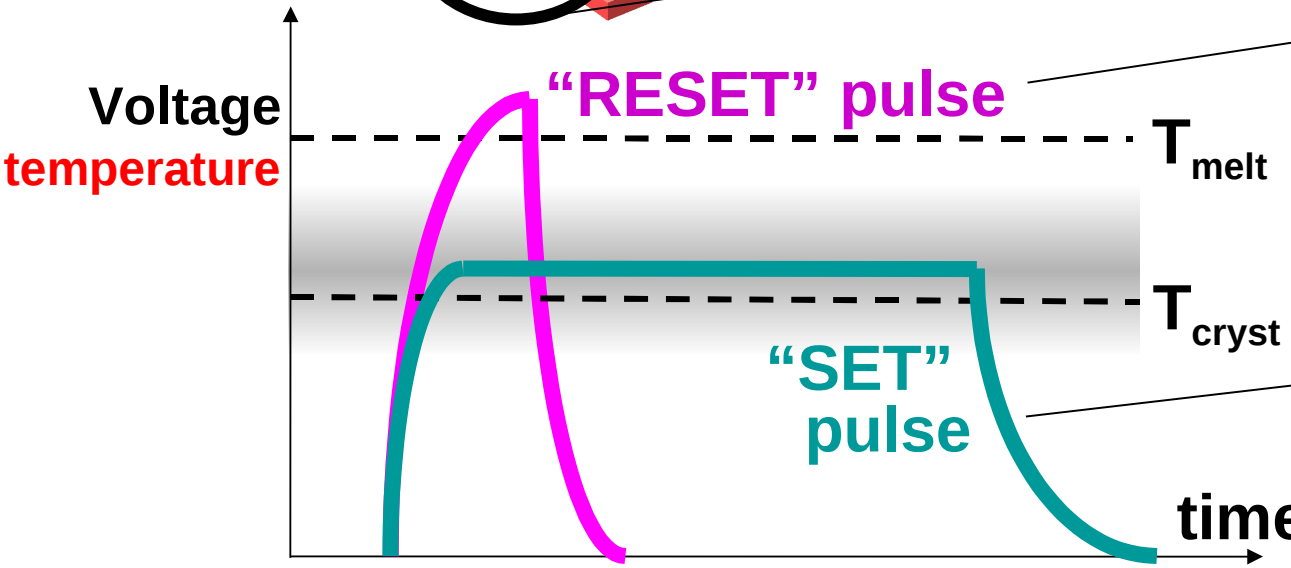
- Solid Electrolyte and resistive RAM (Memristor)
  - early development, maybe promising
- Organic, nano particle and polymeric RAM
  - many different devices in this class, unlikely
- Improved FLASH
  - still slow and poor write endurance



Phase-Change RAM



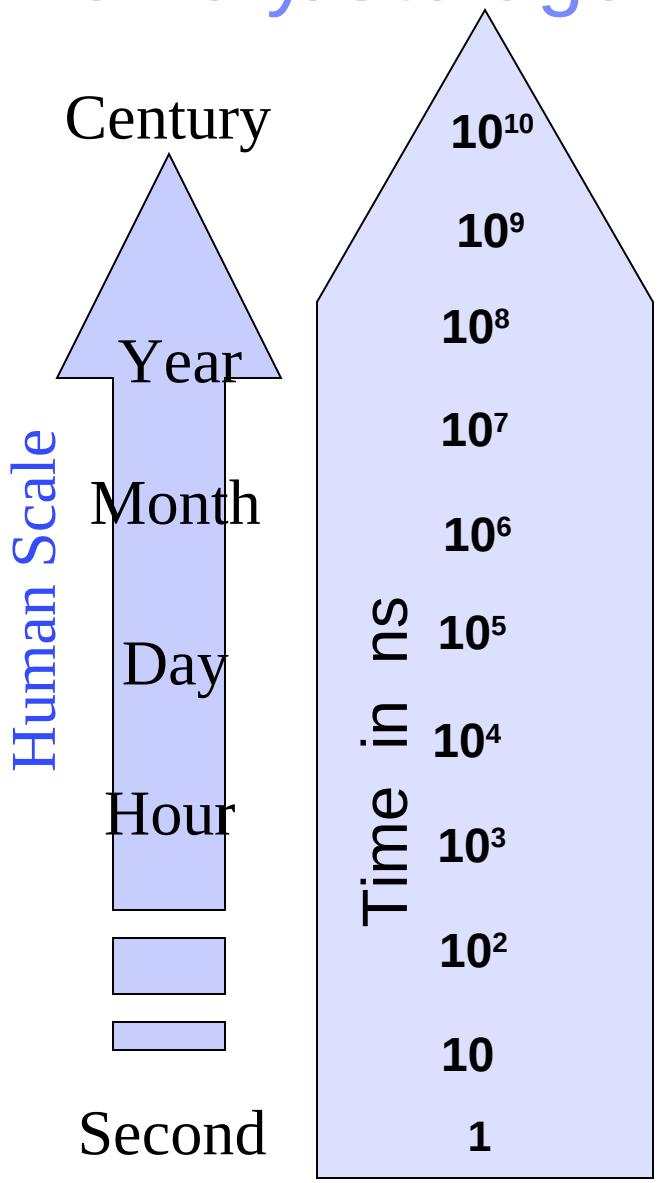




Potential headache:
High power/current
→ affects scaling!

Potential headache:
If crystallization is slow
→ affects performance!

Memory/Storage Stack Latency Problem



Get data from TAPE (40s)

Access DISK (5ms)

Storage

Access FLASH (20 us)

SCM

Access PCM (100 – 1000 ns)

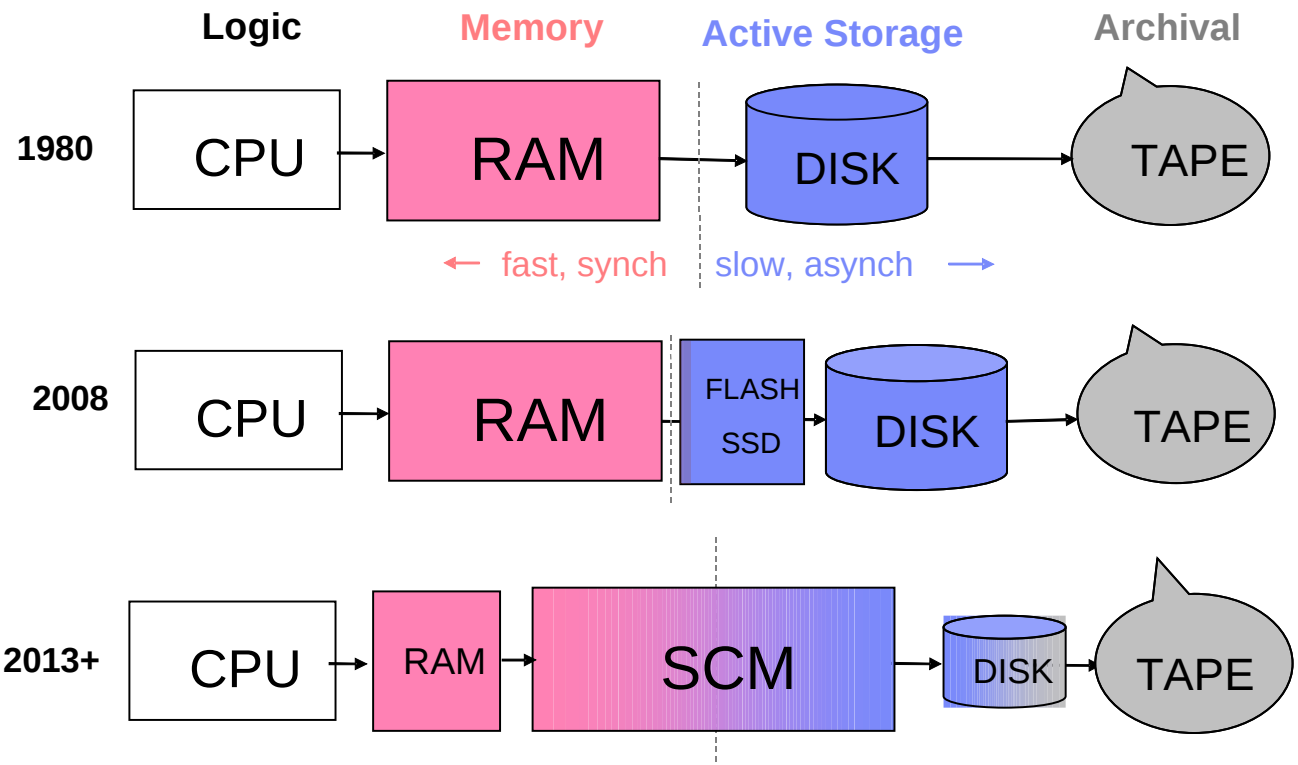
Get data from DRAM (60ns)

Get data from L2 cache (10ns)

Memory

CPU operations (1ns)

SCM as Part of Memory/Storage Solution Stack

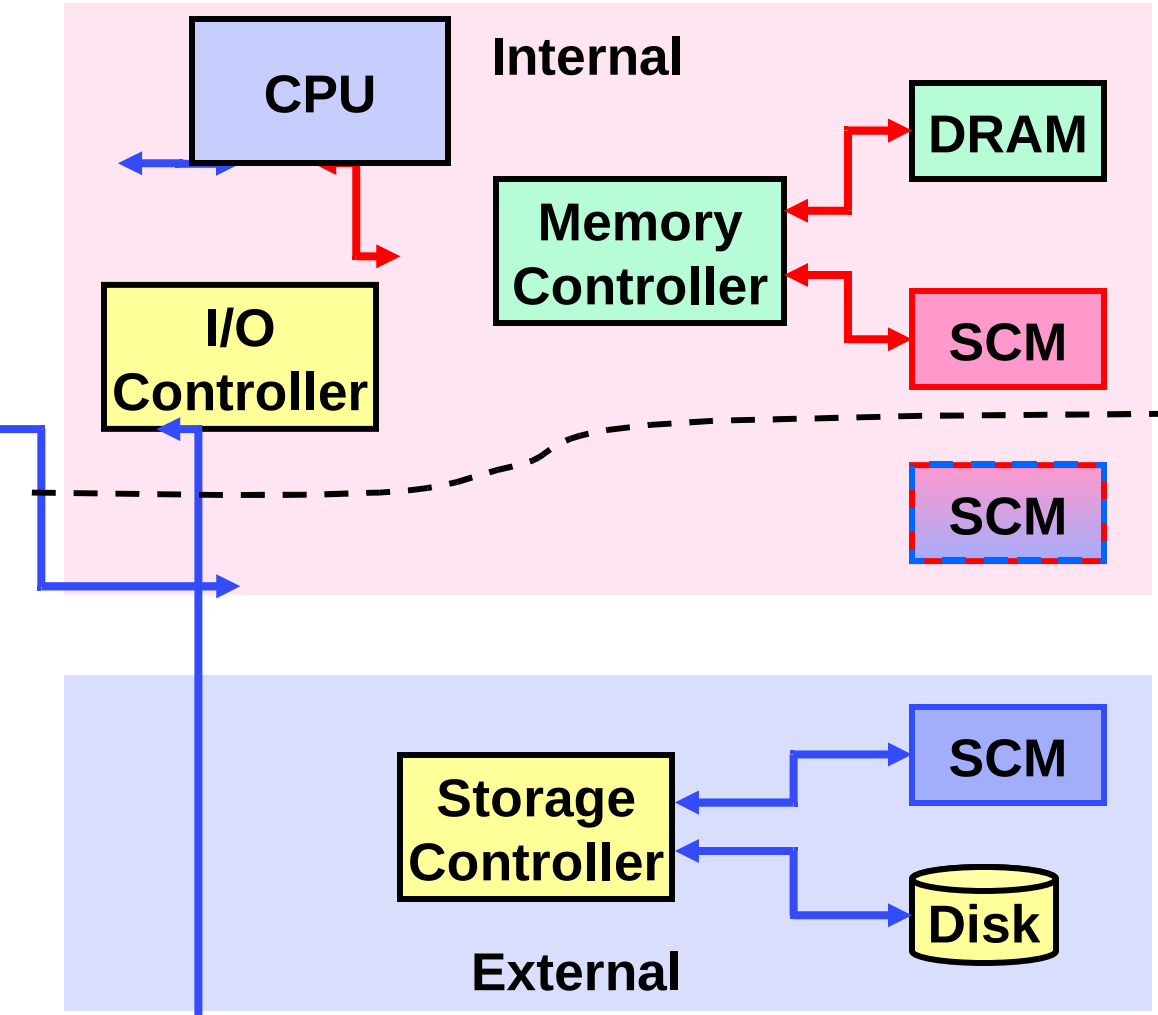


Memory like … storage like

2013 Possible Device Specs

Parameter	DRAM	PCM-S	PCM-M
Capacity		128 Gbits	16 Gbits
Feature Size F	32nm	32nm	32nm
Effective cell size	6 F^2	0.5 F^2	2 F^2
Read latency	60ns	800ns	300ns
Write latency	60ns	1400ns	1400ns
Retention time	ms	2-10 years	Strongly temp. dependent

Architecture



Synchronous

- Hardware managed
- Low overhead
- Processor waits
- Fast SCM, Not Flash
- Cached or pooled memory

Asynchronous

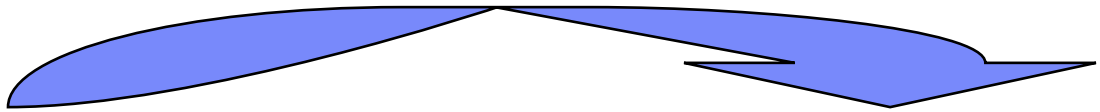
- Software managed
- High overhead
- Processor doesn't wait
- Switch processes
- Flash and slow SCM
- Paging or storage

Challenges with SCM

- Asymmetric performance
  - Flash: writes much slower than reads
  - Not as pronounced in other technologies
- Bad blocks
  - Devices are shipped with bad blocks
  - Blocks wear out, etc.

- The “fly in the ointment” is write endurance
  - In many SCM technologies writes are cumulatively destructive
  - For Flash it is the program/erase cycle
  - Current commercial flash varieties
    - Single level cell (SLC) → 10^5 writes/cell
    - Multi level cell (MLC) → 10^4 writes/cell
  - Coping strategy → Wear leveling, etc.

Shift in Systems and Applications



	DRAM – Disk – Tape	***DRAM – SCM – Disk – Tape***
Main Memory:	– Cost & power constrained – Paging not used – Only one type of memory: volatile	– Much larger memory space for same power and cost – Paging viable – Memory pools: different speeds, some persistent – Fast boot and hibernate
Storage:	– Active data on disk – Inactive data on tape – SANs in heavy use	– Active data on SCM – Inactive data on disk/tape – Direct Attached Storage?
Applications:	– Compute centric – Focus on hiding disk latency	– Data centric comes to fore – Focus on efficient memory use and exploiting persistence – Fast, persistent metadata

Potential early middle-ware exploiters of SCM

- Databases
  - Traditional RDBMS, specialized DBMS, in-memory DBMS
- Distributed object caching (in-memory grids)
  - Memcached, Websphere eXtreme Scale
- Alternate persistent stores
  - Document stores, key-value stores, DHTs
- Persistent message queues
- Data-intensive applications
  - Analytics, Genomics
- Long tail data access patterns (amenable to tiered store)

PCM Use Cases

- PCM as disk
- PCM as paging device
- PCM as memory
- PCM as extended memory

Let Us Explore DBMS as Middleware Exploiter of PCM

PCM as Logging Store – Permits > Log Forces/sec?

- Obvious one but options exist even for this one!
- Should log records be written directly to PCM or

  first to DRAM log buffers and then be forced to PCM (rather than disk)
- In the latter case, is it really that beneficial if ultimately you still want to have log on disk since PCM capacity won't be as much as disk – also since disk is more reliable and is a better long term storage medium
- In former case, all writes will be way slowed down!

PCM replaces DRAM? - Buffer pool in PCM?

- This PCM BP access will be slower than DRAM BP access!
- Writes will suffer even more than reads!!
- Should we instead have DRAM BPs backed by PCM BPs?

  This is similar to DB2 z in parallel sysplex environment with BPs in coupling facility (CF)

  But the DB2 situation has well defined rules on when pages move from DRAM BP to CF BP
- Variation was used in SafeRAM work at MCC in 1989

Assume whole DB fits in PCM?

- Apply old main memory DB design concepts directly?
- Shouldn't we leverage persistence specially?
- Every bit change persisting isn't always a good thing!
- Today's failure semantics lets fair amount of flexibility on tracking changes to DB pages – only some changes logged and inconsistent page states not made persistent!
- Memory overwrites will cause more damage!
- If every write assumed to be persistent as soon as write completes, then L1 & L2 caching can't be leveraged – need to do write through, further degrading perf

Assume whole DB fits in PCM? …

- Even if whole DB fits in PCM and even though PCM is persistent, still need to externalize DB regularly since PCM won't have good endurance!
- If DB spans both DRAM and PCM, then
  - need to have logic to decide what goes where – hot and cold data distinction?
  - persistence isn't uniform and so need to book-keep carefully

What about Logging?

- If PCM is persistent and whole DB in PCM, do we need logging?
- Of course it is needed to provide at least partial rollback even if data is being versioned (at least need to track what versions to invalidate or eliminate); also for auditing, disaster recovery, …

High Availability and PCM

- If PCM is used as memory and its persistence is taken advantage of, then such a memory should be dual ported (like for disks) so that its contents are accessible even if the host fails for backup to access
- Should locks also be maintained in PCM to speed up new transaction processing when host recovers

Start from Scratch?

- Maybe it is time for a fundamental rethink
- Design a DBMS from scratch keeping in mind the characteristics of PCM
- Reexamine data model, access methods, query optimizer, locking, logging, recovery, …
- What are the killer apps for PCM? For flash, they are consumer oriented - digital cameras, personal music devices, …