The five-minute rule thirty years later

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DATA-INTENSIVE APPLICATIONS AND SYSTEMS

EPFL

The five-minute rule in 1987

- Storage hardware: Two-tier hierarchy
  - 1MB RAM: $5,000 ~ $5,000/MB
  - 180MB HDD: $30,000 ~ $160/MB

- Optimization problem

  "When does it make sense to cache data in DRAM?"

- Gray & Putzolu's answer

"Pages referenced every 5 minutes should be memory resident"

Five-minute rule formulation

Break-even Reference Interval (seconds) =

$$\frac{PagesPerMBofRAM}{AccessPerSecondPerDisk}$$

Technology ratio

x

$$\frac{PricePerDiskDrive}{PricePerMBofDRAM}$$

Economic ratio

Five-minute rule formulation

Break-even Reference Interval (seconds) = *(400 secs)*

$$\frac{\textit{PagesPerMBofRAM}\ (1024)}{\textit{AccessPerSecondPerDisk}\ (15)}$$

Technology ratio

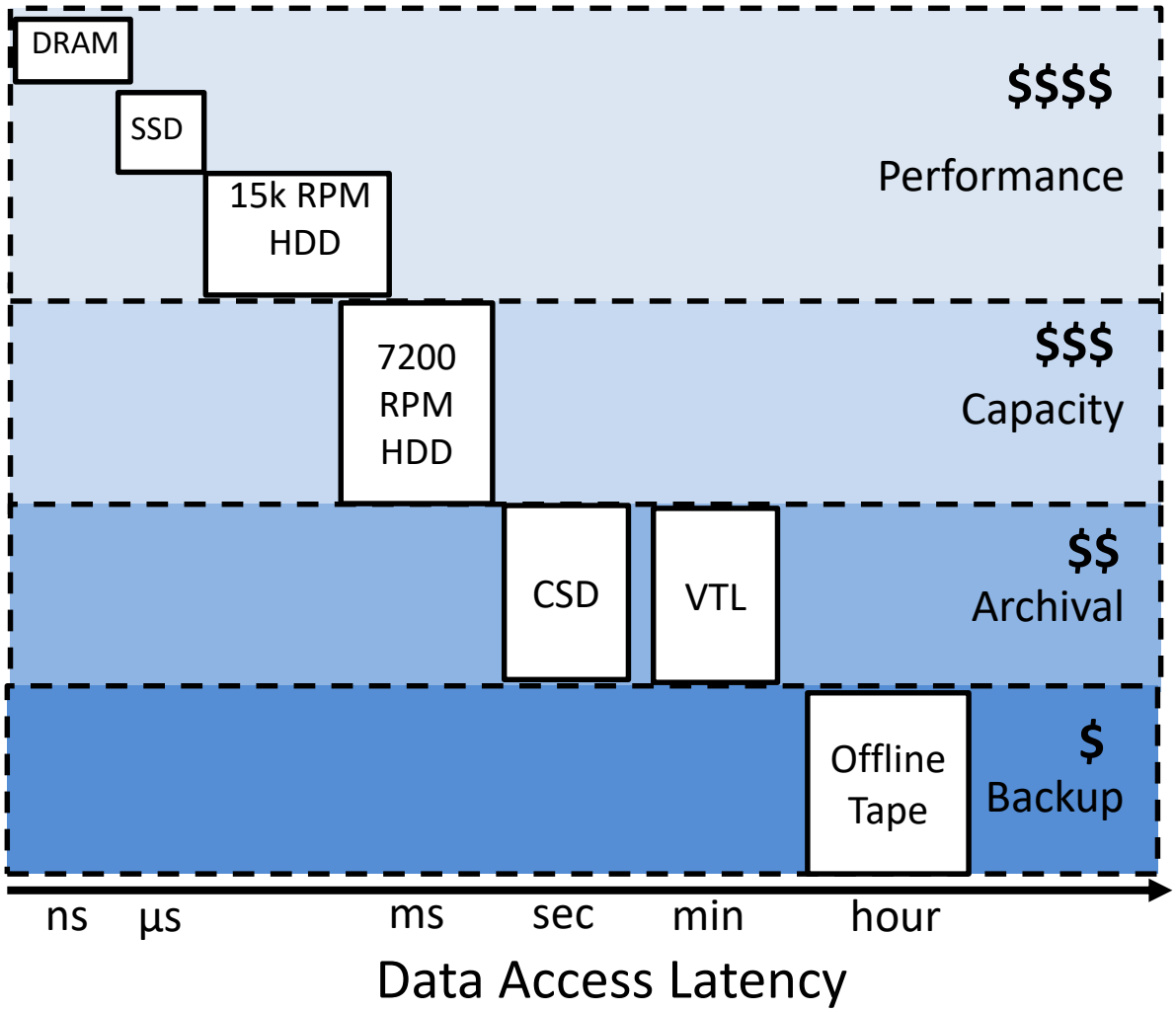
x

$$\frac{\textit{PricePerDiskDrive}\ (\$30k)}{\textit{PricePerMBofDRAM}\ (\$5k)}$$

Economic ratio

Popular rule of thumb for engineering data management systems

Modern storage hierarchy



Mutitier hierarchy with price and performance matching workload requirements

Agenda

- Revisiting the five-minute rule
  - DRAM-HDD break-even interval after 30 years
  - DRAM-SSD, HDD-SSD break-even intervals
- Five-minute rule and the performance tier
  - Break-even intervals with NVDIMM & NVMe SSD
- Five-minute rule and the capacity tier
  - Break-even intervals with Cold Storage, LTO-7 tape

Storage hardware 30 years later

Parameter	Disk (then)	Disk (now)	DRAM (then)	DRAM (now)
Unit cost ($)	$30,000	$49	$5,000	$80
Unit capacity	180MB	2TB	1MB	16GB
Random IO/s	15	200	-	-

- Capacity: ⬆10,000×, Cost: ⬇1,000×, HDD Performance: ⬆10×

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Page size (4KB)	Then	Now
RAM-HDD	5 mins	**5 hours**

- RAM-HDD break-even 60× higher due to fall in DRAM price

Store only extremely "cold" data in HDD

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Five-minute rule with SATA SSD

Parameter	Disk (now)	DRAM (now)	SATA SSD (now)
Unit cost ($)	$49	$80	560
Unit capacity	2TB	16GB	800GB
Cost/MB	0.00002	0.005	0.0007
Random IO/s	200	-	67k/20k

- Two properties of SSDs
  - Middleground between DRAM and HDD w.r.t cost/MB
  - 100-1000× higher random IOPS than HDD

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- Two properties of SSDs
  - Middleground between DRAM and HDD w.r.t cost/MB
  - 100-1000× higher random IOPS than HDD
- Two new rules with SSDs
  - DRAM-SSD rule: SSD as a primary store
  - SSD-HDD rule: SSD as a cache

Break-even interval for SATA SSD

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RAM-SSD	-	7 m (r)/24m (w)

5-minute rule now ~applicable to SATA SSD

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With 1 day interval, all active data will be in RAM/SSD

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Trends in performance tier

- SSDs inching closer to the CPU
  - SATA -> SAS/FiberChannel -> PCIe -> NVMe -> DIMM
  - NVMe PCIe SSDs are server accelerators of choice

Device	Capacity	Price ($)	IOPS (k) r/w	B/W (GBps)
SATA SSD	800GB	560	67/20	500/460
Intel 750	1TB	630	460/290	2.5/1.2

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  - NVMe PCIe SSDs are server accelerators of choice
- Storage Class Memory devices (ex: 3D Xpoint)
  - Faster than Flash, Denser than DRAM, and non-volatile
  - Standardized, byte-addressable, NVDIMM-P soon

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Break even interval for PCIe SSD/NVM

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DRAM-NVM break-even interval is shrinking

Interval disparity between reads and writes is shrinking

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Impending shift from DRAM to NVM-based data management engines

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  - 40% density growth due to volumetric + areal techniques
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- Cold storage devices (CSD) filling the gap
  - 1,000 high-density SMR disks in MAID setup
  - PB density, 10s latency, 2-10GB/s bandwidth

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Break-even interval for tape

Metric	DRAM	HDD	SpectraLogic T50e tape library
Unit capacity	16GB	2TB	10 * 15TB
Unit cost ($)	80	50	11,000
Latency	100ns	5ms	65s
Bandwidth	100GB/s	200MB/s	4 * 750 MB/s

- DRAM-tape break-even interval: 300 years!

  "Tape: The motel where data checks in and never checks out"

  - Jim Gray

- Kaps is not the right metric for tape
  - Maps, TB-scan better

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Alternate comparison metrics

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Unit cost ($)	80	50	11,000
Latency	100ns	5ms	65s
Bandwidth	100GB/s	200MB/s	4 * 750 MB/s
$/Kaps (amortized)	9e-14	5e-9	8e-3
$/TBScan (amortized)	8e-6	3e-3	3e-2

HDD 1,000,000× cheaper w.r.t Kaps, only 10× w.r.t TBScan

HDD—tape gap shrinking for sequential workloads

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- Is it economical to merge the two tiers?
  - "40% cost savings by using a cold storage tier" [Skipper, VLDB'16]
- Can batch analytics be done on tape/CSD?
  - Query Execution in Tertiary Memory Databases [VLDB'96]
  - Skipper: Cheap data analytics over cold storage devices [VLDB'16]
  - Nakshatra: Running batch analytics on an archive [MASCOTS'14]

Time to revisit traditional capacity—archival division of labor

Summary

- Growing DRAM-HDD & shrinking DRAM-NVM intervals

  Most performance critical data will sit in SSD/NVM

- Rapid improvements in SSD/NVM density

  All randomly accessed data can sit in SSD/NVM

- Shrinking HDD—tape/CSD difference w.r.t $/TBscan

  Can merge archival+capacity tier into cold storage tier

  Sequential batch analytics can be hosted on new tier

Five-minute rule suggests impending consolidation in the storage hierarchy