The Five-minute Rule Thirty Years Later and its Impact on the Storage Hierarchy

Summary:
In 1987, the break-even interval between DRAM-HDD was 5 mins which led to the name five minutes rule proposed by Jim Gray and Gianfranco Putzolu. The five minutes rule compares the trade-off between the cost of DRAM and the cost of disk I/O using the formula: PagesPerMBofDRAM/AccessesPerSecondPerDisk x PricePerDiskDrive/PricePerMBofDRAM.This formula has two components: first component as technological ratio which is based on the advancement in hardware technology and the second component as economic ratio which is dependent on gb/cost. A database engine typically used to have a two-tier storage hierarchy which had online tier where the hdd resided and a backup tier with offline tape cartridge or optical drives in case of failure. However, the backup tier were slow and the recovery time should be as minimal as possible. This led to the invention of new archival tier based system like virtual tape libraries(VTL). Today's enterprise databases uses the four tier approach: performance using DRAM,SDD, 15k RPM HDD, Capacity using 7200 RPM HDD, archival tier using VTL and backup with offline tape. Database engine based on the use case such as frequency of data access determine the ideal storage tier. The HSM then moves the data between the Online, near and offline layer. The reason why online tier is divided into performance and capacity is because of two issues: NAND wear out and huge cost. Eventually the technology improved, the traditional hdd tier got divided into two sub tiers. Since ssd focused on performance, hdd shifted their focus on capacity leading to new enterprise grade, high density HDDs like Shingled magnetic recording(SMR) and high performance PCIe. The solid-state storage has also seen a lot of changes like NAND flash with NVMe SSD, the non-Volatile Dual Inline Memory module (NVDIMM) and Intel 3DXpoint(fun fact: intel optane died before it could survive). There are three implication of the five minute rule: cost of Nand flash will drop faster than DRAM, SSDs support concurrent requests and third DRAM require significantly less power. Similarly, the trend in high density storage have certain implications. 7200 RPM hdd are typically used in primary storage. HDDs were improving based on the Kryders rate(40%) each year but due to issues with conventional pmr techniques, the rate has been reduced to 16%. The issue with the traditional approach have lead to new devices to reduce cost/GB such as tape based high density storage and HDD based high density storage. In this approach, they use helium instead of air giving more area per density, new techniques like HMR, SMR and using the CSD to use SMR SSD as ensemble. Hence the design of the new tier architecture and the trend that is followed in the industry is shown with respect to the five minute rule.
Comments:
This was an informative, survey paper comparing different storage hierarchy and the decisions/tradeoffs between them. I got exposed to a lot of different technologies and terminologies through this paper. I guess AWS glacier also uses

the archival and backup tier. I guess something the paper could explore is also the caching layers like the l1,l2 and l3 caches (the memory wall) and its relation with the DRAM? This paper explored the hardware side, however something about the burden of optimizing software side could also have been explored and at what pace is it able to exploit the hardware effectively. Also how the improvement of storage systems has lead to different architecture decisions such as connecting pga to storage , desegregated computing can also be explored.