Ideas and Observations
Foundations for a versatile filesystem

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Abstract

Cameleonica is a prototype of a highly versatile filesystem. This paper describes a wide range of concepts that could but have not been incorporated into popular filesystem designs. Both potential benefits and reasons why these features were not popularized earlier are presented. Expectations of their performance are then justified.

Introduction

When reading scientific papers that describe historical filesystem designs from the golden times of Unix development, one might come to a conclusion that evolution of filesystem designs was very incremental in nature and much effort was put into not making too many dramatical changes at any one time. Well known example would be a paper by McKusick et al, "A Fast File System for UNIX" where they mention increasing block size from 512 to 1024 bytes that lead to doubling of throughput from 2% to 4% of disk maximum performance. They conclude from this fact that increasing block size is a good method of increasing performance. Eventually they achieved 47% performance but it was a result of several modifications, including new allocation policies. One might be tempted to conjecture that achieving maximum performance might just as well require a complete overhaul of the entire design. Proposed filesystem is based exactly on this assumption: attempt radical changes to design.

New ideas

B-trees are not efficient. We can see a drift within filesystem design towards using both modified in-place and copy-on-write B-trees. This trend might be easily explained by common expectation that filesystems will be able to handle billions of files, that they will be able to scale. Today popular filesystems explicitly advertise their ability to scale among main points why to choose them over the competition. B-trees are a good approach if we expect huge amounts of keys to be stored. B-trees scale asymptotically with logarithmic complexity which means even billions of entries can be stored with only a few disk accesses needed to reach any given entry. This asymptotic behavior seems to have mislead many designers. It would be justified to use B-trees if we expected billions and billions of files to be stored, but that may be a false assumption. Everyday experience suggests that most computers hold something on the order of 100'000 files. Even a million entries can definitely be stored more efficiently by other means. Perhaps a sorted array or similar data structure would be adequate, being loaded as a whole and kept in memory for entire time, getting us from few to perhaps zero disk accesses per

entry access. This approach would be more efficient in most instances, and if better scalability was required as more files were added then an immediate transition to B-trees could be easily facilitated at any point in time.

Inodes are not efficient. Since the early days, filesystems were designed under a principle that data structures have to be broken down into fixed size blocks. This seems to have been due to the fact that hard disks require read and write operations to be carried out on 512 byte long, discrete blocks of data. Furthermore hard disks guarantee that any given block is written atomically. For a long time filesystems depended on this feature to ensure ongoing consistency. Today checksums are becoming the mainstream means of ensuring consistency but in the old days available computational power was not enough to support this approach. Tables in McKusick's paper show computational power was a bottleneck already. Let us get back to data structures. To fully describe a single file, we need an amount of data that takes space of several blocks. One main block (called inode) would hold most important data, several blocks would point to locations where actual content is being kept, some blocks would keep directory entries in a grouped linked list, and so on. For a large 1GB file for example, at least 128 blocks would be needed. Certain operations such as copying file or browsing directory would necessarily require all metadata blocks to be read. Consider now a range of possibilities, where all metadata blocks are either allocated in one continuous range (called an extent), are divided into subsets, or are spread into individual blocks. Last approach is prevalent in modern designs. This approach is efficient with respect to changing metadata, as changing any one detail at once should require only one block to be overwritten, but it is not efficient with respect to subsequent reading. It could be argued that first approach, where all metadata is always loaded and stored in one extent, is necessarily better in every possible usage scenario. To show that, we need to recognize that magnetic hard disks have quite disproportionate performance characteristics. Flash based disks are precluded due to reasons explained elsewhere. Representative hard disk is capable of ~120 MB/s of sustained throughput and ~10 ms seek time to random location. Quick calculation shows that reading or writing an extent smaller than 1.2 MB is faster than literally one seek, on average. This observation may seem counter intuitive. Filesystem designs seem to be based on the assumption that data needs to be processed in smallest chunks possible and only way to go is process as small amount of them. It seems that processing bigger chunks instead never gained traction. Intuitively, processing bigger chunks could make sense because in long term perspective, processing bigger chunks saves much time (related to latency) at the cost of less time (related to throughput), only that time is shaved off a future operation. Going back to processing metadata of any given file. If we need to read or change only one detail, then extent approach is better due to reasons described above as long as extent is smaller than 1.2 MB, which for all practical purposes can fit metadata of any file. If we need to read or change more details, then extent approach is even better in comparison. Splitting the extent could only save throughput time by causing additional seeks but we already established that processing the entire extent takes less than one seek.