A Brief History of the BSD Fast Filesystem

Brought to you by

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1979 − Early Filesystem Work

- Improved reliability
  - staged modifications to critical filesystem information
  - modifications could be either completed or repaired cleanly by **fsck** after a crash
- Increased the block size of the filesystem from 512 to 1K bytes
  - doubled performance because each disk transfer accessed twice as much data
  - eliminated the need for indirect blocks for many files
  - still utilized only about 4% of disk bandwidth

1982 − Birth of the Fast Filesystem

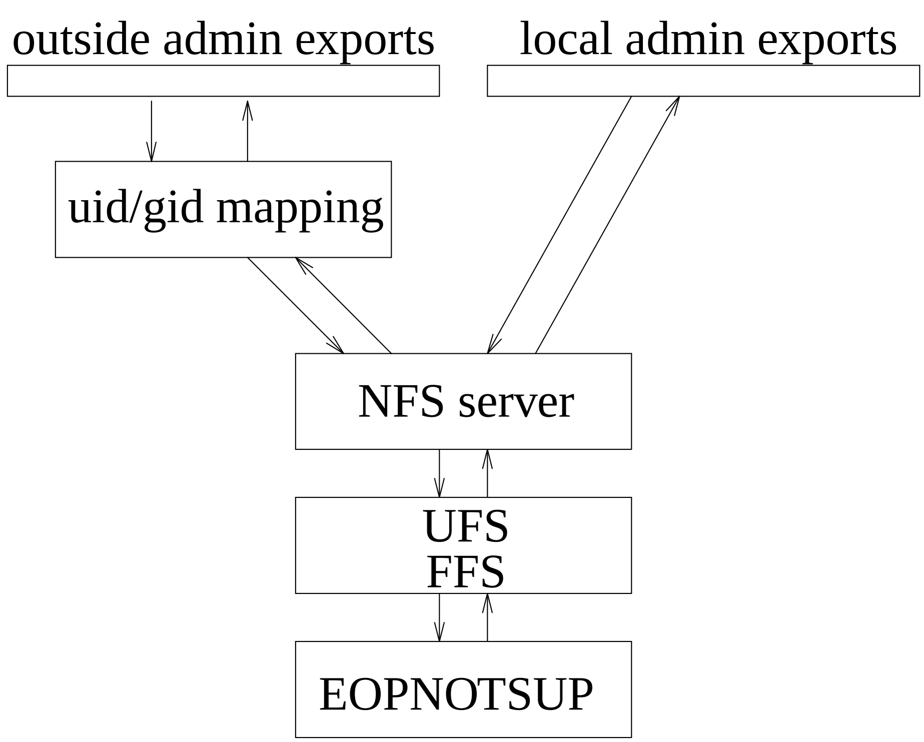
- Designed with a hybrid blocksize in which large blocks could be broken up into as many as eight fragments
- Large files used large blocks
- Small files could use as little as a single fragment
- First deployed with default blocksize 4K/512
- Still in use today on systems such as FreeBSD and Solaris

1986 − Dropping Disk-geometry Calculations

- Originally a cylinder group comprised one or more consecutive cylinders on a disk
- The filesystem could get an accurate view of the disk geometry and could compute the rotational location of every sector
- By 1986, disks were hiding this information and it was too complex to compute it
- All the rotational layout code was deprecated in favor of laying out files using numerically close block numbers (sequential being viewed as optimal)
- Cylinder group structure was retained only as a convenient way to manage logically-close groups of blocks

1987 − Filesystem Stacking

- Allows filesystem modules to be stacked
- When a request is not implemented by a layer it is passed down to the next lower layer.
- Requests that reach the bottom of the stack without being serviced return with EOPNOTSUPP
- Requests may be modified and then passed on to a lower layer



1988 − Raising the Blocksize

- Default blocksize raised to 8K/1K

- Small files use a minimum of two disk sectors

- Nearly doubled throughput at a cost of only 1.4% additional wasted disk space

1990 − Dynamic Block Reallocation

- With the advent of disk caches and tag queueing it became desirable to begin laying files out contiguously

- Size of file unknown when first opened
  - If always assume big and place in biggest available space, then soon have only small areas of contiguous space available
  - If always assume small and place in areas of fragmented space, then beginning of large files will be poorly laid out

Implementation of Dynamic Block Reallocation

- Dynamic block reallocation places file in small areas of free space, then moves them to larger areas of free space if file grows
  - small files use the small chunks of free space
  - large files get laid out contiguously in the large areas of free space
- Little increase in I/O load as the buffer cache generally holds the file until its final location is known
- Free space remains largely unfragmented even after years of use (15% versus 40% degredation after three years)

1996 − Soft Updates

- Speed up file and directory creation, deletion, and renaming
- Keep filesystem consistent enough that **fsck** need not be run after a system crash
- Ensure that unwritten data blocks never show up in files
- Minimize need to do synchronous disk writes

1999 − Snapshots

- Create a read-only frozen-in-time copy of a filesystem
- Minimize time that the filesystem is unavailable while taking the snapshot
- Minimize amount of disk space overhead to hold the snapshot
- Allow multiple snapshots to be concurrently maintained

2001 − Raising the Blocksize, Again

- Default blocksize raised to 16K/2K

  - Small files use a minimum of four disk sectors

  - Nearly doubled throughput at a cost of only 2.9% additional wasted disk space

2002 − Background Fsck

- Disk state is always valid but behind in-memory state
- Only inconsistencies:
  - Blocks marked in use that are free
  - Inodes marked in use that are free
- It is safe to run immediately after a crash though eventually lost space must be reclaimed

Background Block Recovery

- Block recovery on an active system:

  1) Snapshot the filesystem

  2) Run standard filesystem check program on the snapshot

  3) Add a system call to add lost blocks and inodes to the filesystem map

2003 − Multi-terabyte support

- Original fast filesystem used 32-bit pointers to reference a file's blocks
- The 32-bit block pointers of the original filesystem run out of space in the 1 to 4 terabyte range
- Considered other alternatives but chose to extend the original filesystem
  - Allowed reuse of most of existing code base which allowed quick development and deployment
  - Became stable and reliable rapidly
  - Same code base supported both 32-bit block and 64-bit block filesystem formats so bug fixes and feature or performance enhancements usually applied to both filesystem formats

2003 − Extended Attributes

- Extended attributes added at the same time as multi-terabyte support

- Extended attributes are a piece of auxiliary data storage associated with an inode that can be used to store auxiliary data that is separate from the contents of the file

- By integrating the extended attributes into the inode itself, **fsync**( ) can provide the same integrity guarantees as are made for the contents of the file itself

2004 − Access-control Lists

- Extended attributes were first used to support an access control list (ACL)
  - specific list of the users and groups that are permitted to access the file
  - a list of the permissions that each user or group is granted

Implementation of Access-control Lists

- Replaced an earlier implementation using a single auxiliary file per filesystem indexed by inode number which had two problems:
    - fixed size of the space per inode meant only short user lists
    - difficult to atomically commit changes to the ACL
- Both problems fixed by using extended attributes:
    - extended attribute can be 32K, so long list of users possible
    - atomic update is easy since it can be updated with one write of inode

2005 − Mandatory-access Controls

- Extended attributes next used for mandatory access control (MAC)

- MAC framework permits dynamically introduced system-security modules to modify system security functionality

    - MAC framework provides control over kernel entry points affecting access control and object creation

    - When hit, MAC framework then calls out to security modules to offer them the opportunity to modify security behavior

- Filesystem does not codify how the labels are used or enforced; it just stores the labels associated and produces them when a security modules needs to do a permission check

2006 − Symmetric Multi-processing

- In the late 1990’s, the FreeBSD Project began the long hard task of converting their kernel to support symmetric multi-processing

- Start with giant lock around kernel

- Piece-by-piece add multi-threaded locking and remove from giant lock

    2004 − Vnode interface

    2005 − Disk subsystem

    2006 − Fast filesystem

2009 − Journaled Soft Updates

Only need to journal operations that orphan resources

Journal needs only 16Mb independent of filesystem size

Filesystem operations that require journaling

- free operations in maps tracking blocks and inodes
- Link count changes
- Unlink while referenced

2011 − Raising the Blocksize, Yet Again

- Default blocksize raised to 32K/4K
  - Driven by the change of disk technology to 4K sectors
  - Small files once again use a minimum of one disk sector
  - Nearly doubled throughput with no additional wasted disk space

Questions

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May the Source Be With You!