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XFS – The High Performance Enterprise File System

<jeff.liu@oracle.com> Jeff Liu

Agenda

1. About XFS
2. Design
3. Journal
4. Self-describing metadata
5. Performance
6. What's new && in progress

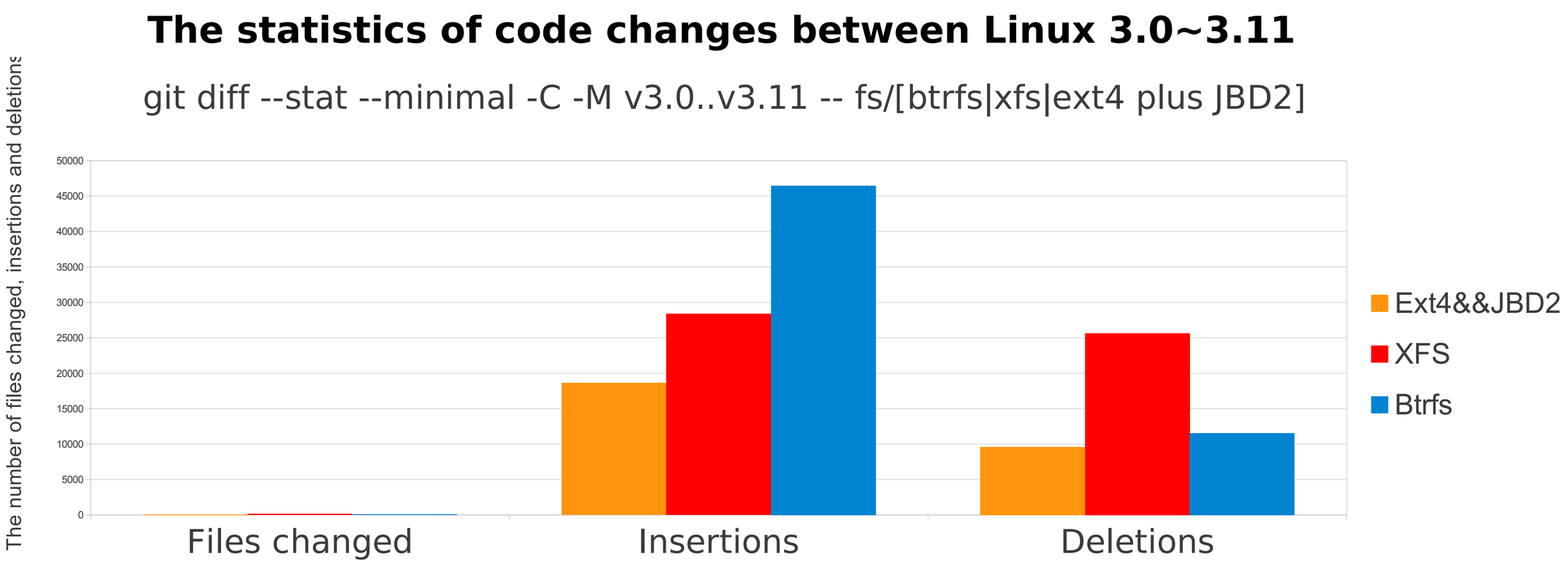
General information

- Created by SGI in 1993, ported to Linux since 2001
- Full 64-bit journaling file system, the best choice for >16TB storage
- Extent based and delayed allocation
- Maximum file system size/file size: 16 EiB/8EiB
- Variable blocks sizes: 512 bytes to 64 KB
- Freeze/Thaw to support volume level snapshot - xfs_freeze
- Online file system/file defragmentation - xfs_fsr
- Online file system resize – xfs_growfs
- User/Group/Project disk quota support
- Dumping and Restoring – xfsdump/xfsrestore

Linux distributions support

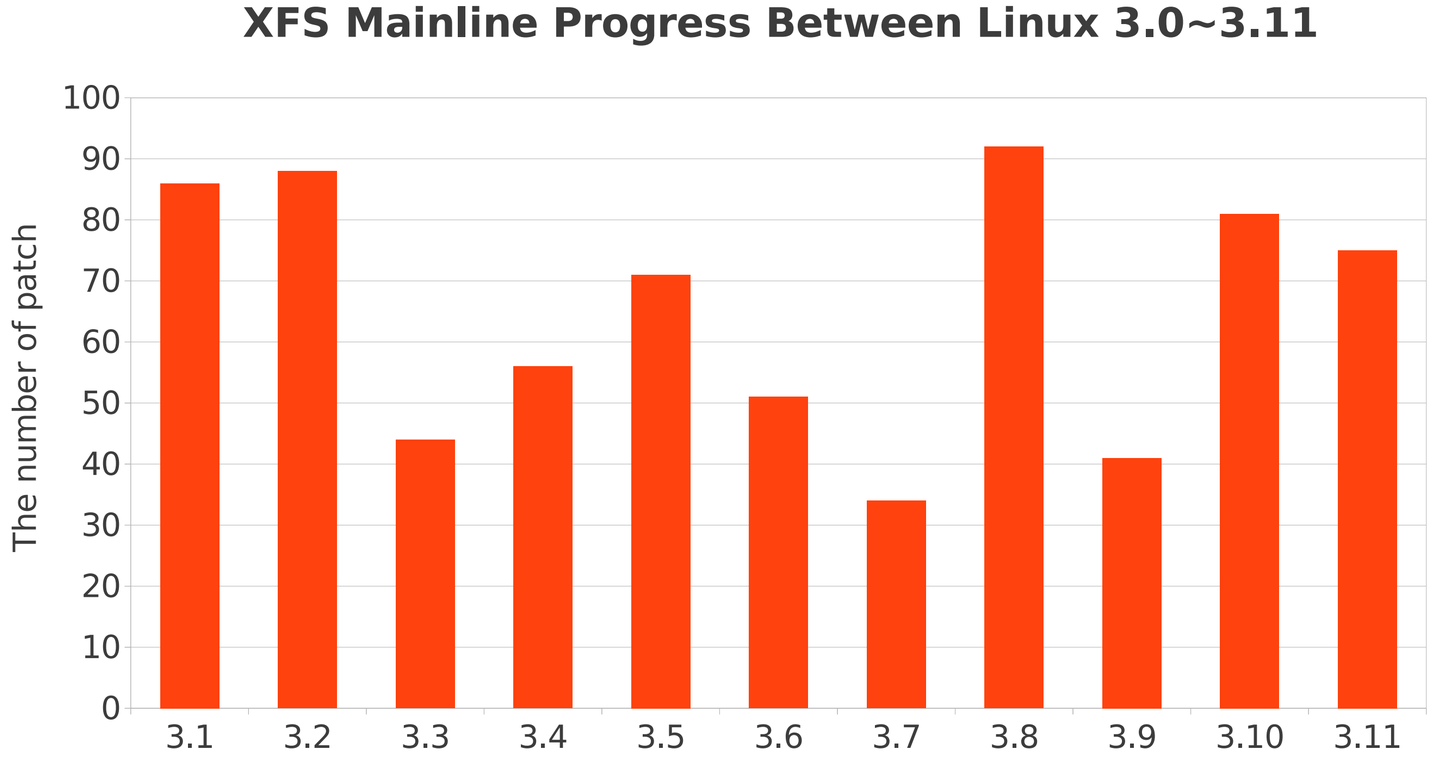
- Available on more than 15 Linux distributions
- SuSE has include XFS support since SLES8
- Will be the default file system on RHEL7
- Premier support on Oracle Linux 6
- Ceph OSD daemons recommend XFS as the underlying file system for production deployment

Community Efforts



Community Efforts

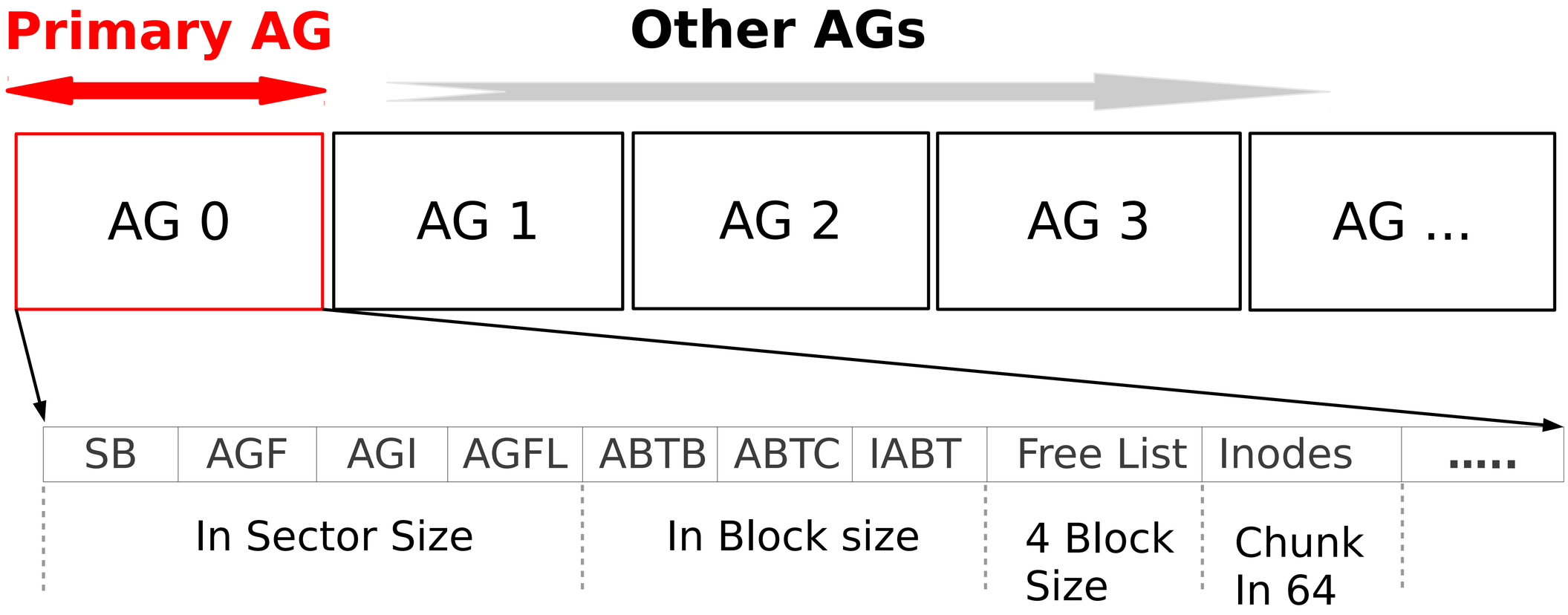
- Totally 719 patches
- Mainly on infrastructure, performance improvements as well as bug fixes



Design – Allocation group

- Allocation group
  - Can be thought as an individual file system
  - Primary AG and secondary AGs
- Each AG contains
  - Super block
  - Free space management
  - Inode allocation and tracking
- Benefits
  - Allows XFS to handle most operations in parallel without degrading performance

Design – AG layout



Design – Generic AG B+Tree Structures

- Generic btree header

```
struct xfs_btree_block {
        __be32          bb_magic;       /* magic number for block type */
        __be16          bb_level;       /* 0 is a leaf */
        __be16          bb_numrecs;     /* current # of data records */
        __be32/64       bb_leftsib;
        __be32/64       bb_rightsib;
        ...
}
```

- Data record/key structure

```
typedef struct xfs_alloc_rec {
        __be32          ar_startblock;   /* starting block number */
        __be32          ar_blockcount;  /* count of free blocks */
} xfs_alloc_rec_t, xfs_alloc_key_t;
```

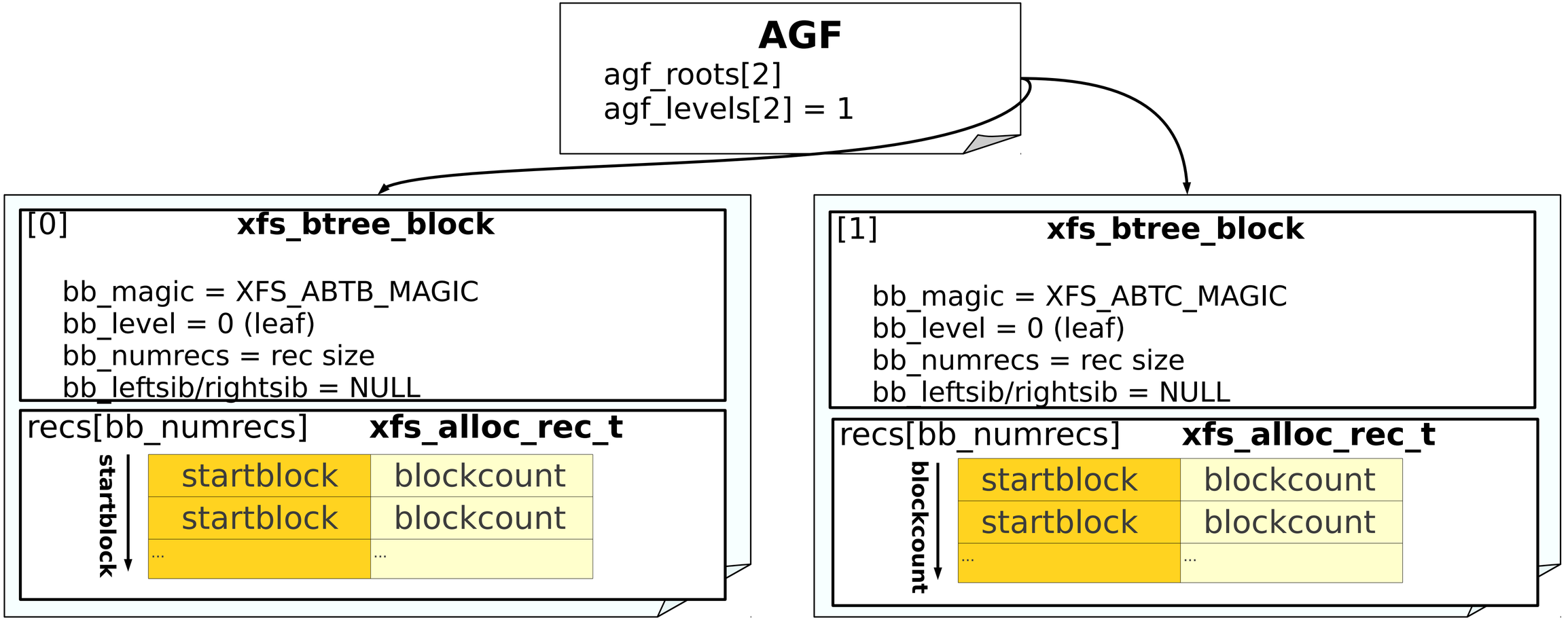
- Node pointers

```
typedef  __be32   xfs_alloc_ptr_t;
```

Design – AG Free Space Management

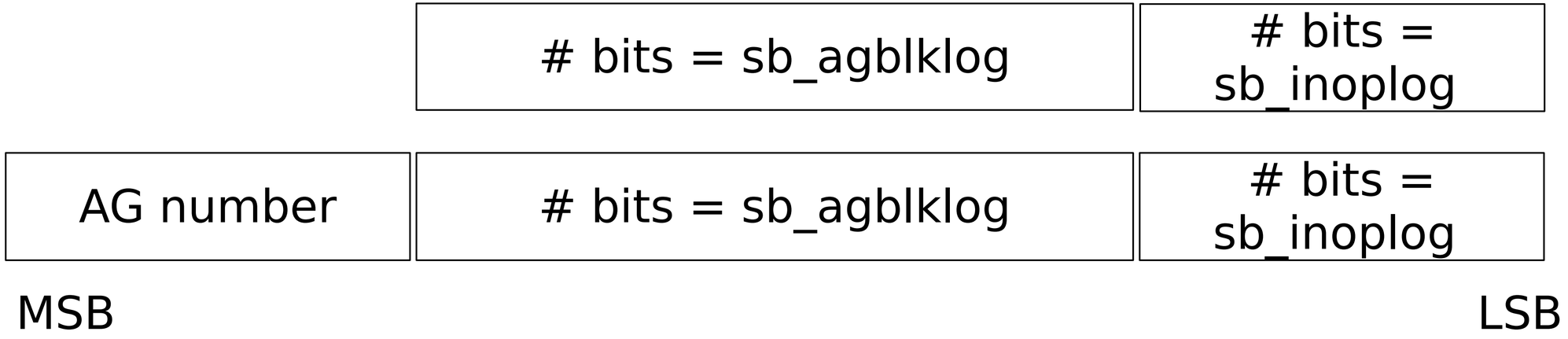
- Tracks free space in an AG using two B+tree
  - One B+tree tracks space by block number
  - Another by the count of the free space block
  - To quickly find free space near a given block or a give size
- All block numbers, indexes and counts are AG relative
- AG Free Space Block – 'AGF' locates in the 2rd sector of an AG

Design – AG Free Space B+trees (1 order)



Design – AG Inode Management

- Inode Number
  - Two forms: AG relative and absolute
  - Relative inode number format
  - Absolute inode number format



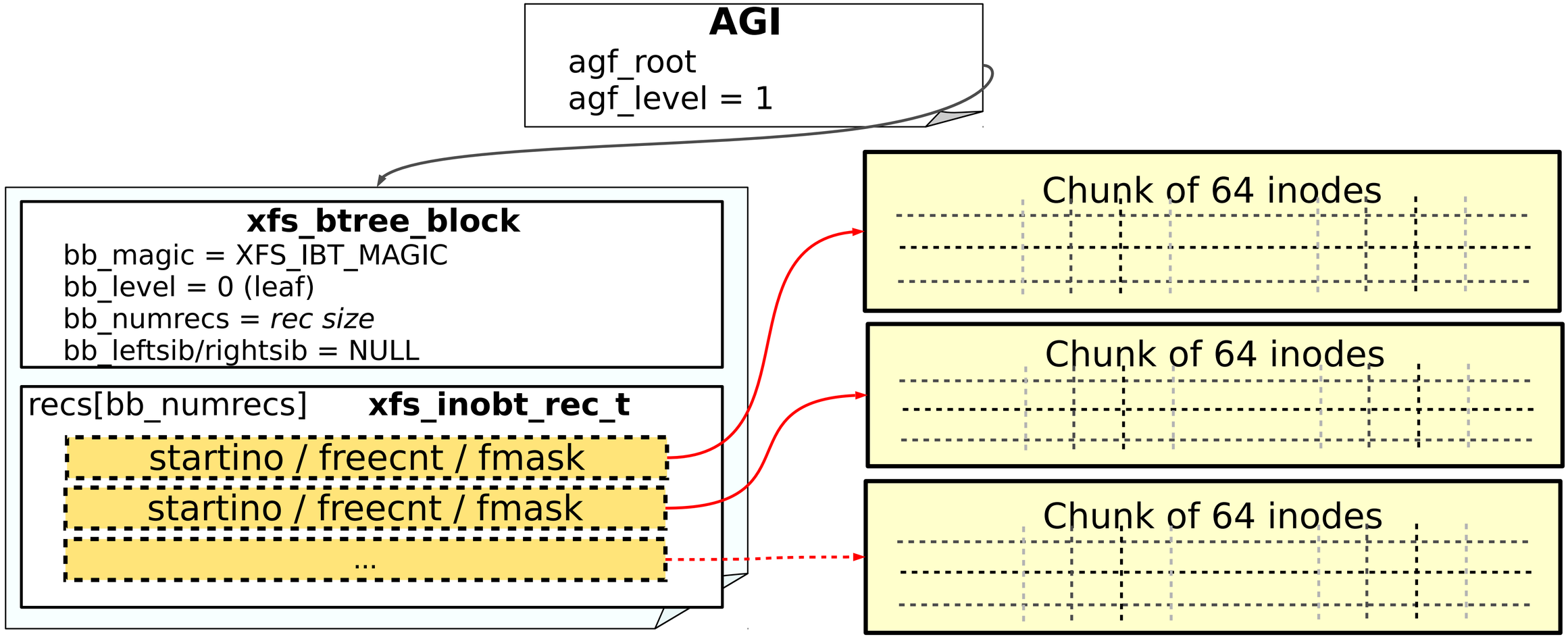
Design – AG Inode Information

- Locates at 3rd sector of AG, known as “AGI”
- Inodes are allocated in chunk of 64, and a B+tree is used to track these chunks of inodes as they are allocated and freed
- B+tree header – same as AGF header
- B+tree leaves
- Node's key/pointer pairs

```
typedef struct xfs_inobt_rec {
        __be32          ir_startino;      /* starting inode number */
        __be32          ir_freecount;     /* count of free inodes (set bits) */
        __be64          ir_free;          /* free inode mask */
} xfs_inobt_rec_t;
```

```
typedef struct xfs_inobt_key {
        __be32          ir_startino;    /* starting inode number */
} xfs_inobt_key_t;
typedef __be32 xfs_inobt_ptr_t;
```

Design – AGI B+tree (1 order)



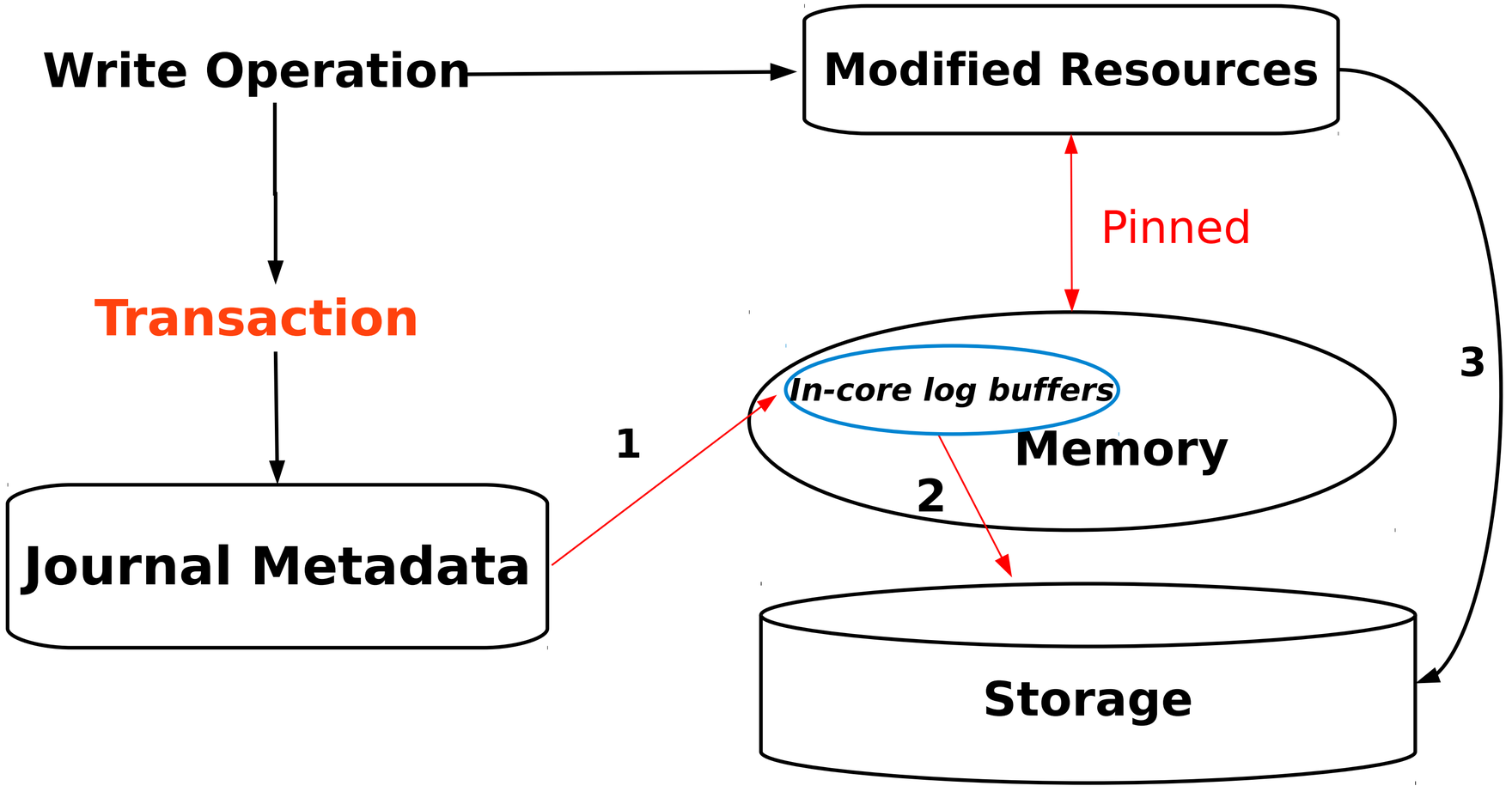
Journal

- Guarantee file system consistency in the event of power failure or system crash
- Need not conventional UNIX fsck
- Logical journaling (only log metadata changes)
- Automatically perform log recovery at mount time if needed
- Quick crash recovery
  - Independent to the size of the storage
  - Dependent to the activities of the file system at the mount of disasters

Journal

- Internal log blocks start near the middle of the disk
- External log volume support
- Maximum log size just under 2GB (2038 MB)
- File system update are written into journal before the actual disk blocks are updated
- Delayed logging is the only mode beginning from Linux 3.3
- Incore log and on-disk log
  - Journals metadata writing to in-core log buffers by first
  - The in-core log buffers are flushed to on-disk log asynchronously

Journal



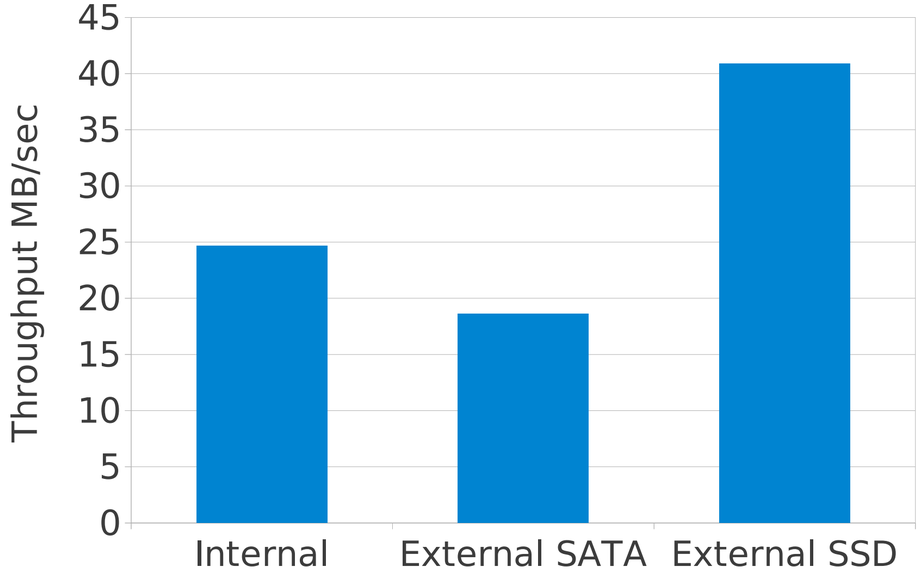
- Delayed logging Is the only mode Beginning from Linux 3.3

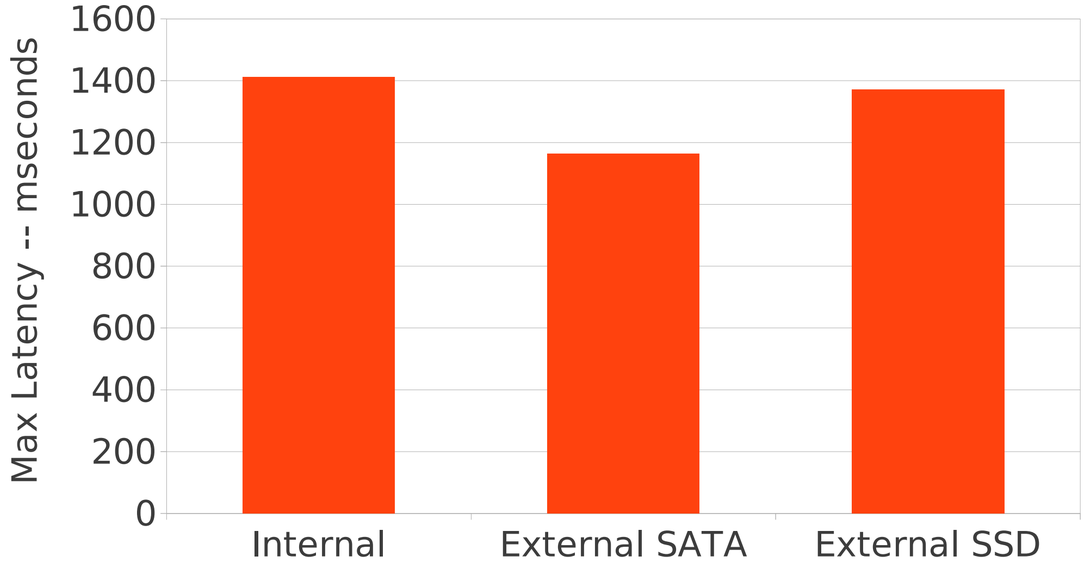
Journal

- Place journal on external faster device to get performance improvements

Dbench Benchmark – Run 600sec Threads 8

AMD FX(tm)-8120 Eight-Core Processor, 16G RAM





Journal

- External log volume support

```
# mkfs.xfs -f /dev/sda7 -l logdev=/dev/sda8,size=512m
  meta-data=/dev/sda7  isize=256    agcount=4, agsize=655360 blks
  .......
  log      =/dev/sda8  bsize=4096   blocks=131072, version=2
           =           sectsz=512   sunit=0 blks, lazy-count=1
  .....
# mount -o logdev=/dev/sda8 /dev/sda7 /xfs
# mount | grep xfs
/dev/sda7 on /xfs type xfs (rw,logdev=/dev/sda8)
```

Self-describing Metadata

- Solution with additional validation information
  - CRC32c
  - File system identifier
  - The owner of a metadata block
  - Logical sequence number of the most recent transaction

The typical on-disk structure

```
struct xfs_ondisk_hdr {
     __be32  magic;
     __be32  crc;
     uuid_t  uuid;
     __be64  owner;
     __be64  blkno;
     __be64  lsn;
}
```

Self-describing Metadata

The largest scalability problem facing XFS is not one of algorithmic scalability, but of verification of the file system structure...

– Kernel document

Self-describing Metadata

- Primary purpose
  - Minimize the time and efforts required for basic forensic analysis of PB scale file system
  - Detect common types of errors easily and automatically
- Existing XFS forensic analysis utilities
  - xfs_repair (xfs_check is effectively deprecated)
  - xfs_db
  - Need pretty much efforts to analysis large storage manually
- Problems with the current metadata format
  - Magic number is the only way
  - Even worse, lack of magic number identifying in AGFL, remote symlinks as well as remote attribute blocks

Self-describing Metadata – CRC enabled inode format

```
xfs_db> inode 67
xfs_db> p
core.magic = 0x494e
....
core.version = 3
....
next_unlinked = null
v3.crc = 0x90bc8bba
v3.change_count = 1
v3.lsn = 0x100000002
v3.flags2 = 0
v3.crtime.sec = Thu Oct 10 14:40:53 2013
v3.crtime.nsec = 543419982
v3.inumber = 67
v3.uuid = b7232b63-95fc-475e-a454-6f50e2725053
```

```
xfs_db> inode 67
xfs_db> p
core.magic = 0x494e
....
core.version = 2
....
core.filestream = 0
core.gen = 1
next_unlinked = null
```

- CRC increase the v3 inode size to 512 bytes, while v2 is 256 bytes by default

Self-describing Metadata – v3 inode format

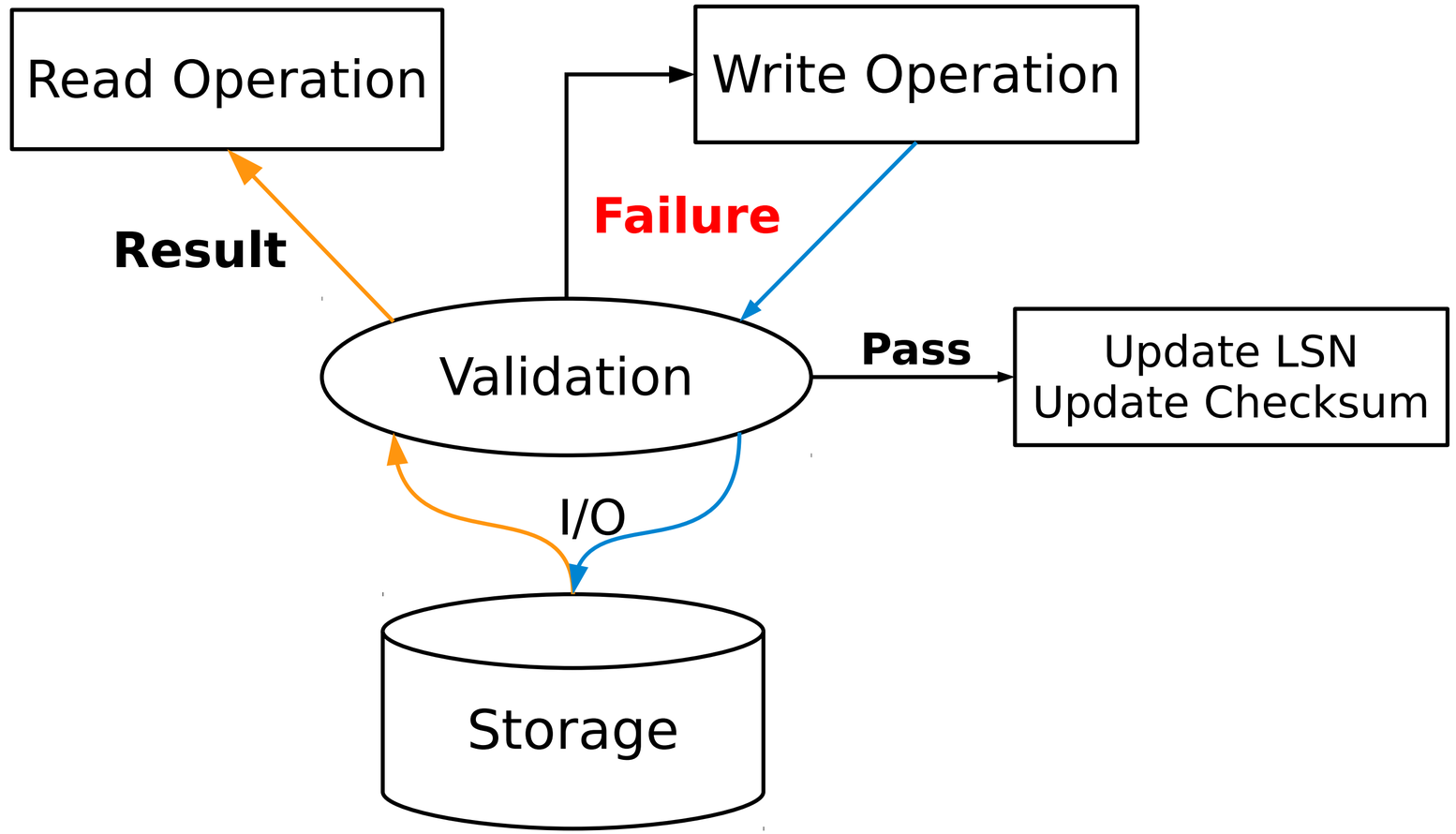
```
# blkid /dev/sda8
/dev/sda8: UUID="b7232b63-95fc-475e-a454-6f50e2725053" TYPE="xfs"

xfs_db> type text
xfs_db> p
000:  49 4e 81 a4 03 02 00 00 00 00 00 00 00 00 00 00  IN..............
010:  00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 01  ................
020:  52 56 4b f5 20 63 ee 4e 52 56 4b f5 20 63 ee 4e  RVK..c.NRVK..c.N
030:  52 56 4b f5 20 63 ee 4e 00 00 00 00 00 00 00 00  RVK..c.N........
040:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
050:  00 00 00 02 00 00 00 00 00 00 00 00 00 00 00 00  ................
060:  ff ff ff ff 90 bc 8b ba 00 00 00 00 00 00 00 01  ................
070:  00 00 00 01 00 00 00 02 00 00 00 00 00 00 00 00  ................
080:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
090:  52 56 4b f5 20 63 ee 4e 00 00 00 00 00 00 00 43  RVK..c.N.......C
0a0:  b7 23 2b 63 95 fc 47 5e a4 54 6f 50 e2 72 50 53  ...c..G..ToP.rPS
```

- CRC
- LSN
- INUMBER
- UUID

Self-describing Metadata

- Runtime Validation
  - Immediately after a successful read from disk
  - Immediately prior to write IO submission



Self-describing Metadata

- Enable CRC validation

```
# mkfs.xfs -f -m crc=1 /dev/sda8
meta-data=/dev/sda8              isize=512    agcount=4, agsize=1402050 blks
         =                       sectsz=512   attr=2, projid32bit=1
         =                       crc=1
data     =                       bsize=4096   blocks=5608198, imaxpct=25
         =                       sunit=0      swidth=0 blks
naming   =version 2              bsize=4096   ascii-ci=0
log      =internal log           bsize=4096   blocks=2738, version=2
         =                       sectsz=512   sunit=0 blks, lazy-count=1
realtime =none                   extsz=4096   blocks=0, rtextents=0
Version 5 superblock detected. xfsprogs has EXPERIMENTAL support enabled!
Use of these features is at your own risk!
```

Self-describing Metadata

- Does it cause noticeable overhead? Basically No

Compilebench	Runs	Non-CRC	CRC
Initial create	30	21.18 MB/s	19.70 MB/s
Create	14	13.91 MB/s	13.09 MB/s
Patch	15	4.85 MB/s	4.72 MB/s
Compile	14	38.14 MB/s	37.29 MB/s
Clean	10	235.85 MB/s	245.28 MB/s
Read tree	11	10.00 MB/s	8.98 MB/s
Read compiled tree	4	16.56 MB/s	16.12 MB/s
Delete tree	10	8.60 Sec	9.23 Sec
Delete compiled tree	4	11.05 Sec	11.82 Sec
Stat tree	11	4.83 Sec	4.52 Sec
Stat compiled tree	7	6.80 Sec	6.97 Sec

Self-describing Metadata

- Compatibility
  - Old file system does not support the new disk format
  - Old kernel and userspace can not read the new format
  - Kernel and userspace that the support the new format works just fine with the old non-CRC check enabled format
  - Support two different incompatible disk formats from this point onwards
  - Will not provide tools to convert the format of existing file system?

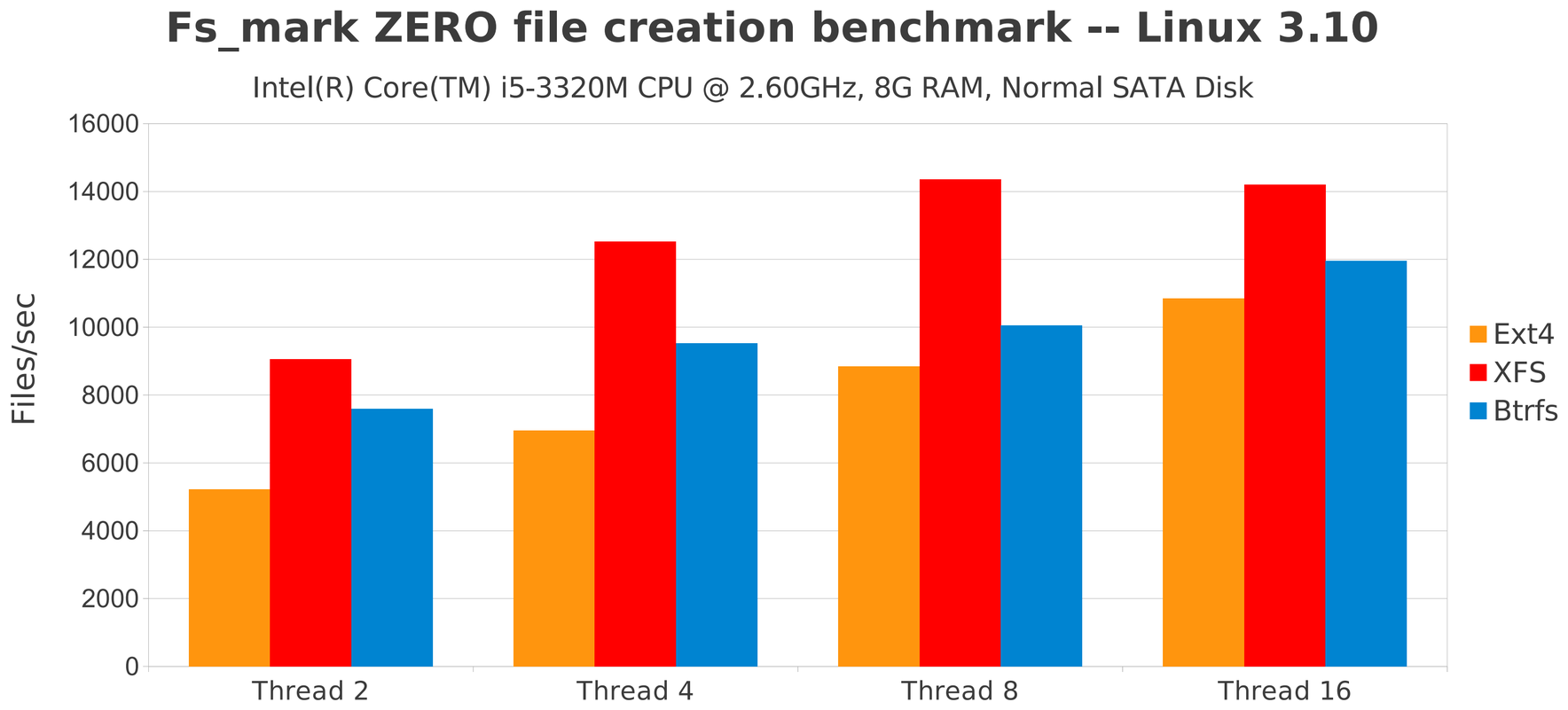
Performance && Scalability

XFS performs very well with large files but very poor to handle lots of small files – From the Internet

Maybe that's an old story!

Performance && Scalability

- Keep: Yes
- Sync Method: 0
- Directory: 10
- File: 1000
- Byte Count: 0
- Thread: 2/4/8/16



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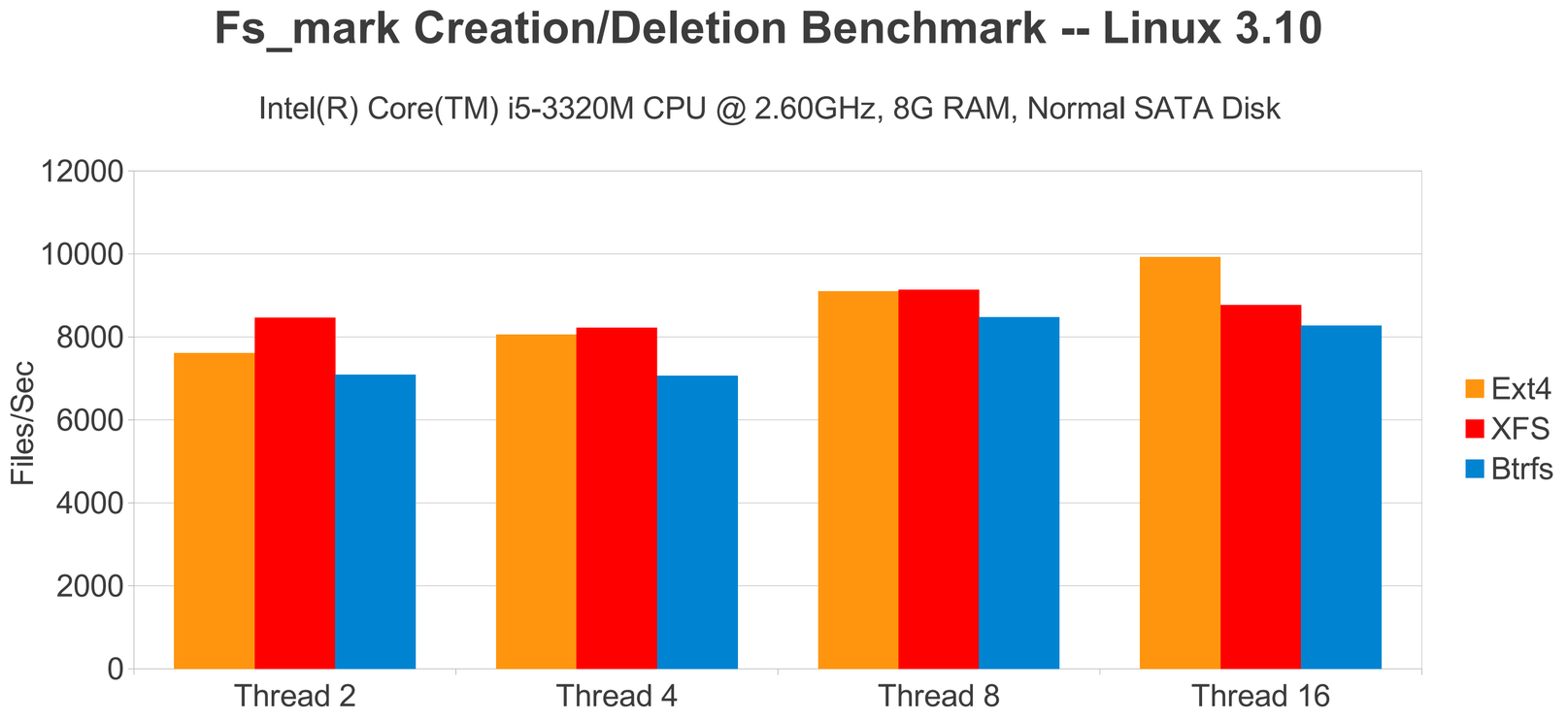
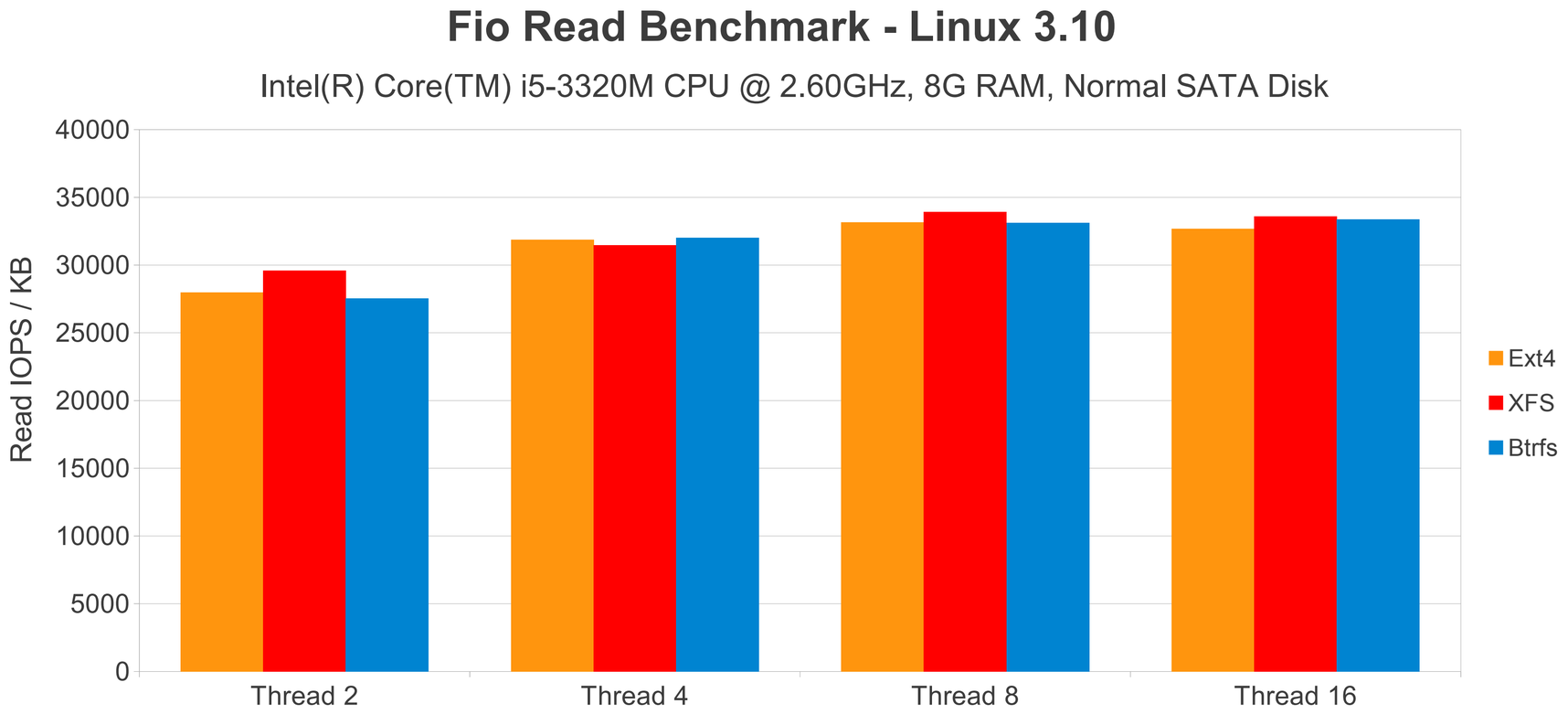


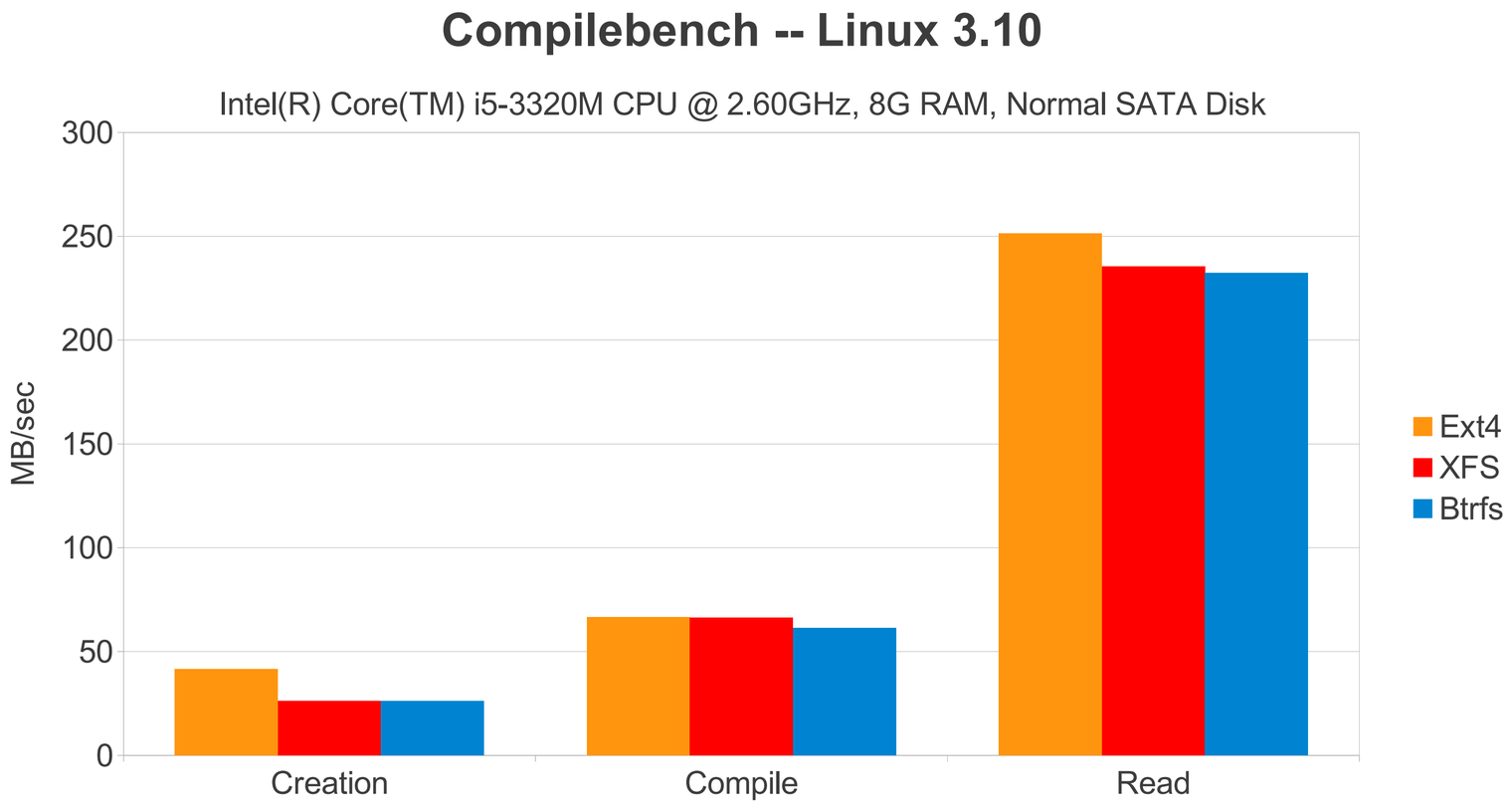
Performance && Scalability

- RW: Random
- Block Size: 4K
- File Size: 1GB
- Runtime: 120 Sec
- NumJobs: 2/4/8/16



Performance && Scalability

- Initial Dir: 10
- Makej: Yes



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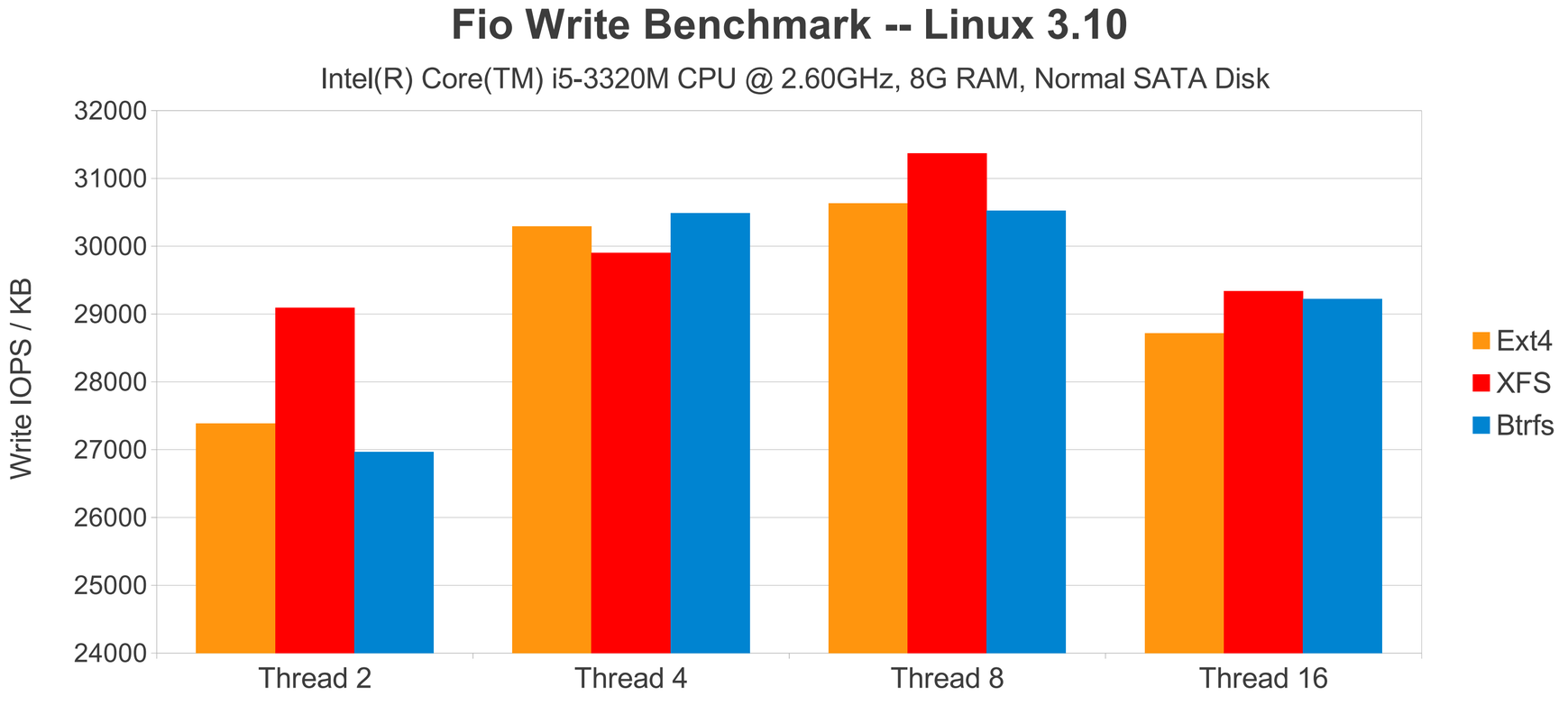
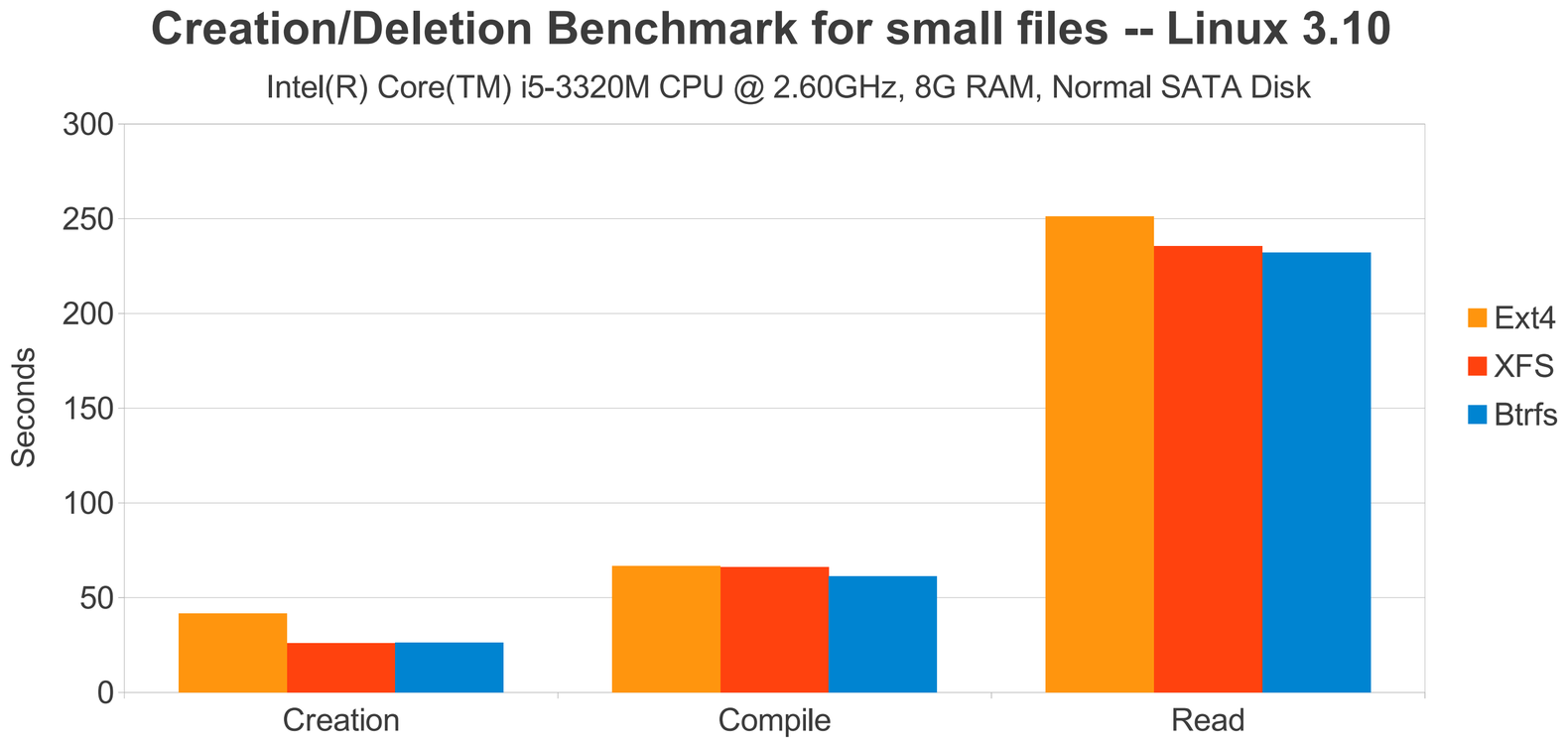


Performance && Scalability

More realistic case of creation/deletion

time/tar/rm
Uncompress Linux 3.10-bz2
package and remove



What's new && Wait in progress

- CONFIG_XFS_WARN
  - Less overhead than the old CONFIG_XFS_DEBUG option
  - Suitable to production environment
- Separate project disk quota inode
  - Can be enabled with group quota at the same time
- User namespace support for Linux container (LXC)
- Online file system shrink support (WIP)
- The free inode btree (WIP)

Thank You!