XFS Filesystem Structure

2nd Edition
Revision 2

[This document is incomplete and currently undergoing revision]

Table of Contents

Introduction

A Brief History of XFS

The original XFS design was circulated within SGI in October 1993 as "xFS: the extension of EFS".

The main ideas were:

- "x" for to-be-determined (but the name stuck)
- Large filesystems: one terabyte, 2^{40}, on 32-bit systems; unlimited on 64-bit systems
- Large files: one terabyte, 2^{40}, on 32-bit systems; 2^{63} on 64-bit systems
- Large number of inodes
- Large directories
- Large I/O
- Parallel access to inodes
- Balanced tree (B+tree) algorithms for searching large lists
- Asynchronous metadata transaction logging for quick recover
- Delayed allocation to improve data contiguity
- ACL's - Access Control Lists (see chacl(1), acl(4), acl_get_file(3c), acl_set_file(3c))

XFS was first released in IRIX 5.3.

The port to Linux began in 1999 against 2.3.40. It was accepted into the mainline in the 2.5 kernel in 2002, then into the 2.4 kernel in 2004.

Purpose of this Document

This document describes the on-disk layout of an XFS filesystem, not the code used to implement the filesystem driver. The exception is that the structures used in the XFS kernel code are used in this document to describe the on-disk structures.

This document also shows how to manually inspect a filesystem by showing examples using the `xfs_db` user-space tool supplied with the `xfs-progs` package.

All on-disk values are in big-endian format except the journaling log which is in native endian format.

Common XFS Types

This section documents the commonly used basic XFS types used in the various XFS structures. All types use the form xfs_TYPE_t. Some of the concepts for the descriptions of the basic types may not mean much but are covered in more detail in the associated uses. The online version of this document has links to help located the information. All structures are packed and not word padded.

All the following basic XFS types can be found in xfs_types.h. NULL values are always -1 on disk (ie. all bits for the value set to one).

xfs_ino_t

Unsigned 64 bit absolute inode number.

xfs_off_t

Signed 64 bit file offset.

xfs_daddr_t

Signed 64 bit device address.

xfs_agnumber_t

Unsigned 32 bit Allocation Group (AG) number.

xfs_agblock_t

Unsigned 32 bit AG relative block number.

xfs_extlen_t

Unsigned 32 bit extent length in blocks.

xfs_extnum_t

Signed 32 bit number of extents in a file.

xfs_dablk_t

Unsigned 32 bit block number for directories and extended attributes.

xfs_dahash_t

Unsigned 32 bit hash of a directory file name or extended attribute name.

xfs_dfsbno_t

Unsigned 64 bit filesystem block number combining AG number and block offset into the AG.

xfs_drfsbno_t

Unsigned 64 bit raw filesystem block number.

xfs_drtbno_t

Unsigned 64 bit extent number in the real-time sub-volume.

xfs_dfiloff_t

Unsigned 64 bit block offset into a file.

xfs_dfilblks_t

Unsigned 64 bit block count for a file.

Allocation Groups

XFS filesystems are divided into a number of equally sized chunks called Allocation Groups. Each AG can almost be thought of as an individual filesystem that maintains it's own space usage. Each AG can be up to one terabyte in size (512 bytes * 2^{31}), regardless of the underlying device's sector size.

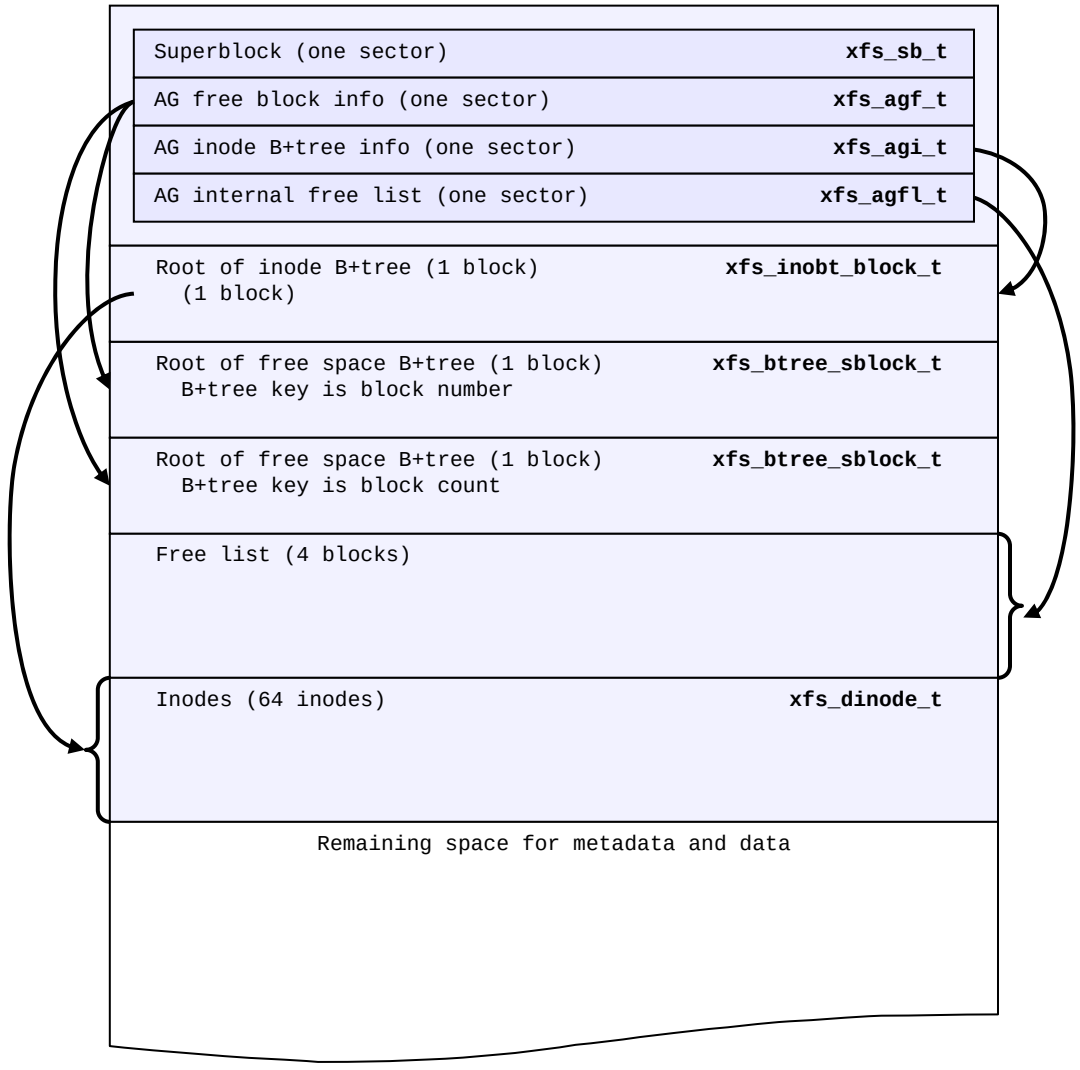
Each AG has the following characteristics:

- A super block describing overall filesystem info
- Free space management
- Inode allocation and tracking

Having multiple AGs allows XFS to handle most operations in parallel without degrading performance as the number of concurrent accessing increases.

The only global information maintained by the first AG (primary) is free space across the filesystem and total inode counts. If the `XFS_SB_VERSION2_LAZYSBCOUNTBIT` flag is set in the superblock, these are only updated on-disk when the filesystem is cleanly unmounted (umount or shutdown).

Immediately after a mkfs.xfs, the primary AG has the following disk layout and the subsequent AGs do not have any inodes allocated:



Each of these structures are expanded upon in the following sections.

Superblocks

Each AG starts with a superblock. The first one is the primary superblock that stores aggregate AG information. Secondary superblocks are only used by xfs_repair when the primary superblock has been corrupted.

The superblock is defined by the following structure. The unused fields and the remainder of the superblock sector is zeroed. The description of each field follows:

```
typedef struct xfs_sb
{
     __uint32_t           sb_magicnum;
     __uint32_t           sb_blocksize;
     xfs_drfsbno_t        sb_dblocks;
     xfs_drfsbno_t        sb_rblocks;
     xfs_drtbno_t         sb_rextents;
     uuid_t               sb_uuid;
     xfs_dfsbno_t         sb_logstart;
     xfs_ino_t            sb_rootino;
     xfs_ino_t            sb_rbmino;
     xfs_ino_t            sb_rsumino;
     xfs_agblock_t        sb_rextsize;
     xfs_agblock_t        sb_agblocks;
     xfs_agnumber_t       sb_agcount;
     xfs_extlen_t         sb_rbmblocks;
     xfs_extlen_t         sb_logblocks;
     __uint16_t           sb_versionnum;
     __uint16_t           sb_sectsize;
     __uint16_t           sb_inodesize;
     __uint16_t           sb_inopblock;
     char                 sb_fname[12];
     __uint8_t            sb_blocklog;
     __uint8_t            sb_sectlog;
     __uint8_t            sb_inodelog;
     __uint8_t            sb_inopblog;
     __uint8_t            sb_agblklog;
     __uint8_t            sb_rextslog;
     __uint8_t            sb_inprogress;
     __uint8_t            sb_imax_pct;
     __uint64_t           sb_icount;
     __uint64_t           sb_ifree;
     __uint64_t           sb_fdblocks;
     __uint64_t           sb_frextents;
     xfs_ino_t            sb_uquotino;
     xfs_ino_t            sb_gquotino;
     __uint16_t           sb_qflags;
     __uint8_t            sb_flags;
     __uint8_t            sb_shared_vn;
     xfs_extlen_t         sb_inoalignmt;
     __uint32_t           sb_unit;
     __uint32_t           sb_width;
     __uint8_t            sb_dirblklog;
     __uint8_t            sb_logsectlog;
     __uint16_t           sb_logsectsize;
     __uint32_t           sb_logsunit;
     __uint32_t           sb_features2;
} xfs_sb_t;
```

sb_magicnum *u32*

Identifies the filesystem. It's value is `XFS_SB_MAGIC = 0x58465342 "XFSB"`.

sb_blocksize *u32*

The size of a basic unit of space allocation in bytes. Typically, this is 4096 (4KB) but can range from one sector to 65536 bytes. A block is usually made up of several sectors (the size specified by `sb_sectsize`), and is most commonly eight (512 x 8 = 4096). The maximum size of `sb_blocksize` is the system's page size.

sb_dblocks *u64*

Total number of blocks available for data and metadata on the filesystem.

sb_rblocks *u64*

Number blocks in the real-time disk device. Refer to Real-time Devices for more information.

sb_rextents *u64*

Number of extents on the real-time device.

sb_uuid

UUID (Universally Unique ID) for the filesystem. Filesystems can be mounted by the UUID instead of device name.

sb_logstart *u64*

First block number for the journaling log if the log is internal (ie. not on a separate disk device). For an external log device, this will be zero (the log will also start on the first block on the log device).

sb_rootino *xfs_ino_t*

Root inode number for the filesystem. Typically, this is 128 when using a 4KB block size.

sb_rbmino *xfs_ino_t*

Bitmap inode for real-time extents.

sb_rsumino *xfs_ino_t*

Summary inode for real-time bitmap.

sb_rextsize *u32*

Realtime extent size in blocks.

sb_agblocks *u32*

Size of each AG in blocks. For the actual size of the last AG, refer to the AG Freespace Block's `agf_length` value.

sb_agcount *u32*

Number of AGs in the filesystem.

sb_rbmblocks *u32*

Number of real-time bitmap blocks.

sb_logblocks *u32*

Number of blocks for the journaling log. This applies to both internal and external logs.

sb_versionnum *u16*

Filesystem version number. This is a bitmask specifying the features enabled when creating the filesystem. Any disk checking tools or drivers that do not recognize any set bits must not

operate upon the filesystem. Most of the flags indicate features introduced over time. The value must be 4 plus the following flags as defined by mkfs options:

Flag	Description
XFS_SB_VERSION_ATTRBIT	Set if any inode have extended attributes.
XFS_SB_VERSION_NLINKBIT	Set if any inodes use 32-bit di_nlink values.
XFS_SB_VERSION_QUOTABIT	Set if quotas are enabled on the filesystem. This also brings in the various quota fields in the superblock.
XFS_SB_VERSION_ALIGNBIT	Set if sb_inoalignmt is used.
XFS_SB_VERSION_DALIGNBIT	Set if sb_unit and sb_width are used.
XFS_SB_VERSION_SHAREDBIT	Set if sb_shared_vn is used.
XFS_SB_VERSION_LOGV2BIT	Set if version 2 journaling logs are used.
XFS_SB_VERSION_SECTORBIT	Set if sb_sectsize is not 512.
XFS_SB_VERSION_EXTFLGBIT	Unwritten extents are used. This is always set today.
XFS_SB_VERSION_DIRV2BIT	Version 2 directories are used. This is always set today.
XFS_SB_VERSION_MOREBITSBIT	Set if the sb_features2 field in the superblock contains more flags.

sb_sectsize *u16*

Specifies the underlying disk sector size in bytes. Majority of the time, this is 512 bytes. This determines the minimum I/O alignment including Direct I/O.

sb_inodesize *u16*

Size of the inode in bytes. The default is 256 (2 inodes per standard sector) but can be made as large as 2048 bytes when creating the filesystem. An inode cannot be larger than a block.

sb_inopblock *u16*

Number of inodes per block. This is equivalent to sb_blocksize / sb_inodesize.

sb_fname[12] *char*

Name for the filesystem. This value can be used in the mount command. It ideally should use plain ASCII (32-127), but extended ASCII maybe used (ie. it's "just a bunch of bytes").

sb_blocklog *u8*

$\log_2$ value of sb_blocksize. In other terms, sb_blocksize = 2sb_blocklog.

sb_sectlog *u8*

$\log_2$ value of sb_sectsize.

sb_inodelog *u8*

$\log_2$ value of sb_inodesize.

sb_inopblog *u8*

$\log_2$ value of sb_inopblock.

sb_agblklog *u8*

$\log_2$ value of `sb_agblocks` (rounded up). This value is used to generate inode numbers and absolute block numbers defined in extent maps.

sb_rextslog *u8*

$\log_2$ value of `sb_rextents`.

sb_inprogress *u8*

Flag specifying that the filesystem is being created.

sb_imax_pct *u8*

Maximum percentage of filesystem space that can be used for inodes. The default value is 25%.

sb_icount *u64*

Global count for number inodes allocated on the filesystem. This is only maintained in the first superblock.

sb_ifree *u64*

Global count of free inodes on the filesystem. This is only maintained in the first superblock.

sb_fdblocks *u64*

Global count of free data blocks on the filesystem. This is only maintained in the first superblock.

sb_frextents *u64*

Global count of free real-time extents on the filesystem. This is only maintained in the first superblock.

sb_uquotino *xfs_ino_t*

Inode for user quotas. This and the following two quota fields only apply if `XFS_SB_VERSION_QUOTABIT` flag is set in `sb_versionnum`. Refer to Quota Inodes for more information.

sb_gquotino *xfs_ino_t*

Inode for group or project quotas. Group and Project quotas cannot be used at the same time.

sb_qflags *u16*

Quota flags. It can be a combination of the following flags:

Flag	Description
`XFS_UQUOTA_ACCT`	User quota accounting is enabled.
`XFS_UQUOTA_ENFD`	User quotas are enforced.
`XFS_UQUOTA_CHKD`	User quotas have been checked and updated on disk.
`XFS_PQUOTA_ACCT`	Project quota accounting is enabled.
`XFS_OQUOTA_ENFD`	Other (group/project) quotas are enforced.
`XFS_OQUOTA_CHKD`	Other (group/project) quotas have been checked.
`XFS_GQUOTA_ACCT`	Group quota accounting is enabled.

sb_flags *u8*

Miscellaneous flags.

sb_shared_vn *u8*

Reserved and must be zero ("vn" stands for version number).

sb_inoalignmt *u32*

Inode chunk alignment in fsblocks.

sb_unit *u32*

Underlying stripe or raid unit in blocks.

sb_width *u32*

Underlying stripe or raid width in blocks.

sb_dirblklog *u8*

$\log_2$ value multiplier that determines the granularity of directory block allocations in fsblocks.

sb_logsectlog *u8*

$\log_2$ value of the log device's sector size. This is only used if the journaling log is on a separate disk device (i.e. not internal).

sb_logsectsize *u16*

The log's sector size in bytes if the filesystem uses an external log device.

sb_logsunit *u32*

The log device's stripe or raid unit size. This only applies to version 2 logs (`XFS_SB_VERSION_LOGV2BIT` is set in `sb_versionnum`).

sb_features2 *u32*

Additional version flags if `XFS_SB_VERSION_MOREBITSBIT` is set in `sb_versionnum`. The currently defined additional features include:

- `XFS_SB_VERSION2_LAZYSBCOUNTBIT` (0x02): Lazy global counters. Making a filesystem with this bit set can improve performance. The global free space and inode counts are only updated in the primary superblock when the filesystem is cleanly unmounted.
- `XFS_SB_VERSION2_ATTR2BIT` (0x08): Extended attributes version 2. Making a filesystem with this optimises the inode layout of extended attributes.
- `XFS_SB_VERSION2_PARENTBIT` (0x10): Parent pointers. All inodes must have an extended attribute that points back to its parent inode. The primary purpose for this information is in backup systems.

xfs_db Example:

A filesystem is made on a single SATA disk with the following command:

```
# mkfs.xfs -i attr=2 -n size=16384 -f /dev/sda7
meta-data=/dev/sda7              isize=256    agcount=16, agsize=3923122 blks
         =                       sectsz=512   attr=2
data     =                       bsize=4096   blocks=62769952, imaxpct=25
         =                       sunit=0      swidth=0 blks, unwritten=1
naming   =version 2              bsize=16384
log      =internal log           bsize=4096   blocks=30649, version=1
         =                       sectsz=512   sunit=0 blks
realtime =none                   extsz=65536  blocks=0, rtextents=0
```

And in xfs_db, inspecting the superblock:

```
xfs_db> sb
xfs_db> p
magicnum = 0x58465342
blocksize = 4096
dblocks = 62769952
rblocks = 0
rextents = 0
uuid = 32b24036-6931-45b4-b68c-cd5e7d9a1ca5
logstart = 33554436
rootino = 128
rbmino = 129
rsumino = 130
rextsize = 16
agblocks = 3923122
agcount = 16
rbmblocks = 0
logblocks = 30649
versionnum = 0xb084
sectsize = 512
inodesize = 256
inopblock = 16
fname = "\000\000\000\000\000\000\000\000\000\000\000\000"
blocklog = 12
sectlog = 9
inodelog = 8
inopblog = 4
agblklog = 22
rextslog = 0
inprogress = 0
imax_pct = 25
icount = 64
ifree = 61
fdblocks = 62739235
frextents = 0
uquotino = 0
gquotino = 0
qflags = 0
flags = 0
shared_vn = 0
inoalignmt = 2
unit = 0
width = 0
dirblklog = 2
logsectlog = 0
logsectsize = 0
logsunit = 0
features2 = 8
```

AG Free Space Management

The XFS filesystem tracks free space in an allocation group using two B+trees. One B+tree tracks space by block number, the second by the size of the free space block. This scheme allows XFS to quickly find free space near a given block or of a given size.

All block numbers, indexes and counts are AG relative.

AG Free Space Block

The second sector in an AG contains the information about the two free space B+trees and associated free space information for the AG. The "AG Free Space Block", also knows as the AGF, uses the following structure:

```
typedef struct xfs_agf {
     __be32                  agf_magicnum;
     __be32                  agf_versionnum;
     __be32                  agf_seqno;
     __be32                  agf_length;
     __be32                  agf_roots[XFS_BTNUM_AGF];
     __be32                  agf_spare0;
     __be32                  agf_levels[XFS_BTNUM_AGF];
     __be32                  agf_spare1;
     __be32                  agf_flfirst;
     __be32                  agf_fllast;
     __be32                  agf_flcount;
     __be32                  agf_freeblks;
     __be32                  agf_longest;
     __be32                  agf_btreeblks;
} xfs_agf_t;
```

The rest of the bytes in the sector are zeroed. `XFS_BTNUM_AGF` is set to 2, index 0 for the count B+tree and index 1 for the size B+tree.

agf_magicnum

Specifies the magic number for the AGF sector: "XAGF" (0x58414746).

agf_versionnum

Set to `XFS_AGF_VERSION` which is currently 1.

agf_seqno

Specifies the AG number for the sector.

agf_length

Specifies the size of the AG in filesystem blocks. For all AGs except the last, this must be equal to the superblock's `sb_agblocks` value. For the last AG, this could be less than the `sb_agblocks` value. It is this value that should be used to determine the size of the AG.

agf_roots

Specifies the block number for the root of the two free space B+trees.

agf_levels

Specifies the level or depth of the two free space B+trees. For a fresh AG, this will be one, and the "roots" will point to a single leaf of level 0.

agf_flfirst

Specifies the index of the first "free list" block. Free lists are covered in more detail later on.

agf_fllast

Specifies the index of the last "free list" block.

agf_flcount

Specifies the number of blocks in the "free list".

agf_freeblks

Specifies the current number of free blocks in the AG.

agf_longest

Specifies the number of blocks of longest contiguous free space in the AG.

agf_btreeblks

Specifies the number of blocks used for the free space B+trees. This is only used if the `XFS_SB_VERSION2_LAZYSBCOUNTBIT` bit is set in `sb_features2`.

AG Free Space B+trees

The two Free Space B+trees store a sorted array of block offset and block counts in the leaves of the B+tree. The first B+tree is sorted by the offset, the second by the count or size.

The trees use the following header:

```
typedef struct xfs_btree_sblock {
     __be32                  bb_magic;
     __be16                  bb_level;
     __be16                  bb_numrecs;
     __be32                  bb_leftsib;
     __be32                  bb_rightsib;
} xfs_btree_sblock_t;
```

Leaves contain a sorted array of offset/count pairs which are also used for node keys:

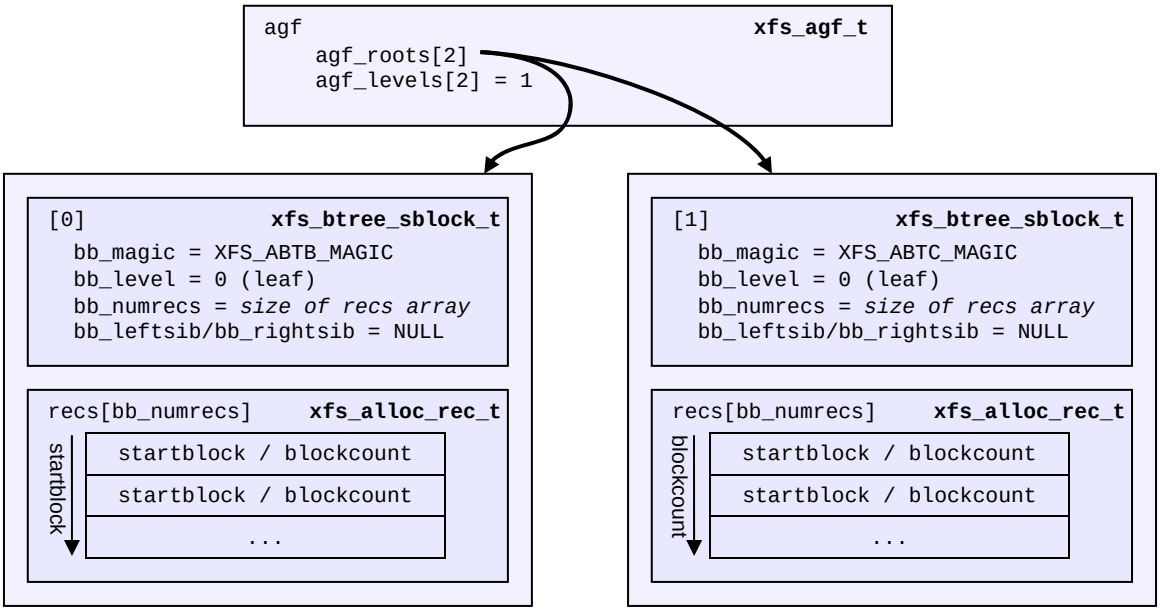
```
typedef struct xfs_alloc_rec {
     __be32                  ar_startblock;
     __be32                  ar_blockcount;
} xfs_alloc_rec_t, xfs_alloc_key_t;
```

Node pointers are an AG relative block pointer:

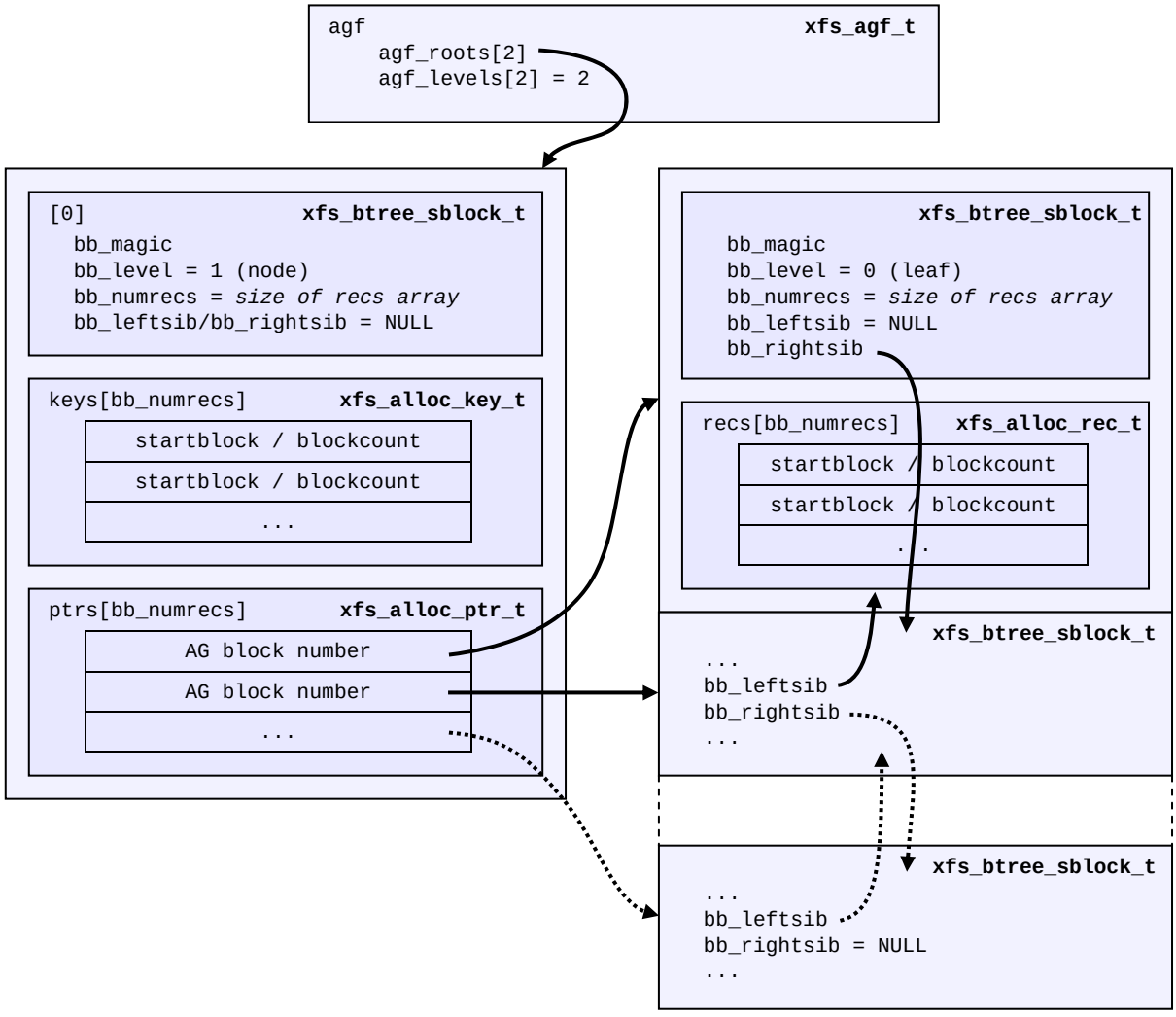
```
typedef __be32 xfs_alloc_ptr_t;
```

- As the free space tracking is AG relative, all the block numbers are only 32-bits.
- The `bb_magic` value depends on the B+tree: "ABTB" (0x41425442) for the block offset B+tree, "ABTC" (0x41425443) for the block count B+tree.
- The `xfs_btree_sblock_t` header is used for intermediate B+tree node as well as the leaves.
- For a typical 4KB filesystem block size, the offset for the `xfs_alloc_ptr_t` array would be `0xab0` (2736 decimal).
- There are a series of macros in `xfs_btree.h` for deriving the offsets, counts, maximums, etc for the B+trees used in XFS.

The following diagram shows a single level B+tree which consists of one leaf:



With the intermediate nodes, the associated leaf pointers are stored in a separate array about two thirds into the block. The following diagram illustrates a 2-level B+tree for a free space B+tree:



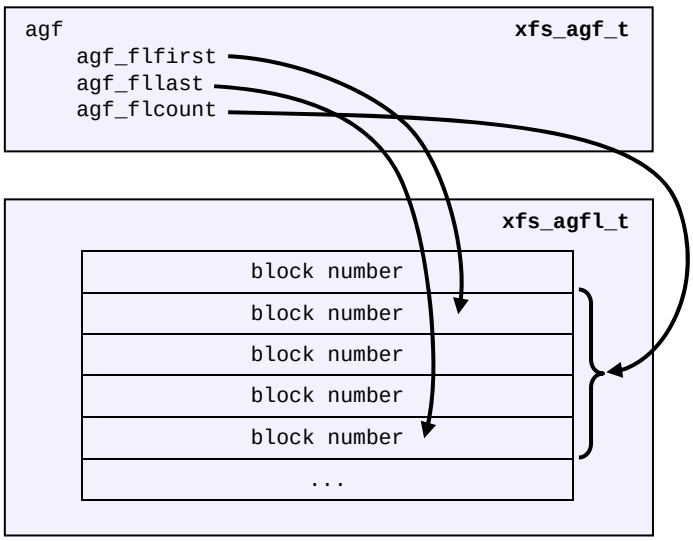
AG Free List

The AG Free List is located in the 4th sector of each AG and is known as the AGFL. It is an array of AG relative block pointers for reserved space for growing the free space B+trees. This space cannot be used for general user data including inodes, data, directories and extended attributes.

With a freshly made filesystem, 4 blocks are reserved immediately after the free space B+tree root blocks (blocks 4 to 7). As they are used up as the free space fragments, additional blocks will be reserved from the AG and added to the free list array.

As the free list array is located within a single sector, a typical device will have space for 128 elements in the array (512 bytes per sector, 4 bytes per AG relative block pointer). The actual size can be determined by using the `XFS_AGFL_SIZE` macro.

Active elements in the array are specified by the AGF's `agf_flfirst`, `agf_fllast` and `agf_flcount` values. The array is managed as a circular list.



The presence of these reserved block guarantees that the free space B+trees can be updated if any blocks are freed by extent changes in a full AG.

xfs_db Examples:

These examples are derived from an AG that has been deliberately fragmented.

The AGF:

```
xfs_db> agf <ag#>
xfs_db> p
magicnum = 0x58414746
versionnum = 1
seqno = 0
length = 3923122
bnoroot = 7
cntroot = 83343
bnolevel = 2
cntlevel = 2
flfirst = 22
fllast = 27
flcount = 6
freeblks = 3654234
longest = 3384327
btreeblks = 0
```

In the AGFL, the active elements are from 22 to 27 inclusive which are obtained from the `flfirst` and `fllast` values from the `agf` in the previous example:

```
xfs_db> agfl 0
xfs_db> p
bno[0-127] = 0:4 1:5 2:6 3:7 4:83342 5:83343 6:83344 7:83345 8:83346 9:83347
             10:4 11:5 12:80205 13:80780 14:81496 15:81766 16:83346 17:4 18:5
             19:80205 20:82449 21:81496 22:81766 23:82455 24:80780 25:5
             26:80205 27:83344
```

The free space B+tree sorted by block offset, the root block is from the AGF's `bnoroot` value:

```
xfs_db> fsblock 7
xfs_db> type bnobt
xfs_db> p
magic = 0x41425442
level = 1
numrecs = 4
leftsib = null
rightsib = null
keys[1-4] = [startblock,blockcount]
          1:[12,16] 2:[184586,3] 3:[225579,1] 4:[511629,1]
ptrs[1-4] = 1:2 2:83347 3:6 4:4
```

Blocks 2, 83347, 6 and 4 contain the leaves for the free space B+tree by starting block. Block 2 would contain offsets 16 up to but not including 184586 while block 4 would have all offsets from 511629 to the end of the AG.

The free space B+tree sorted by block count, the root block is from the AGF's `cntroot` value:

```
xfs_db> fsblock 83343
xfs_db> type cntbt
xfs_db> p
magic = 0x41425443
level = 1
numrecs = 4
leftsib = null
rightsib = null
keys[1-4] = [blockcount,startblock]
          1:[1,81496] 2:[1,511729] 3:[3,191875] 4:[6,184595]
ptrs[1-4] = 1:3 2:83345 3:83342 4:83346
```

The leaf in block 3, in this example, would only contain single block counts. The offsets are sorted in ascending order if the block count is the same.

Inspecting the leaf in block 83346, we can see the largest block at the end:

```
xfs_db> fsblock 83346
xfs_db> type cntbt
xfs_db> p
magic = 0x41425443
level = 0
numrecs = 344
leftsib = 83342
rightsib = null
recs[1-344] = [startblock,blockcount]
          1:[184595,6] 2:[187573,6] 3:[187776,6]
          ...
          342:[513712,755] 343:[230317,258229] 344:[538795,3384327]
```

The longest block count must be the same as the AGF's `longest` value.

AG Inode Management

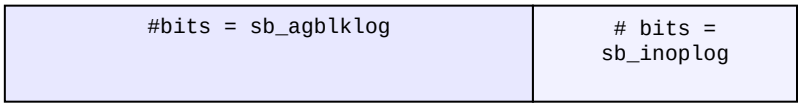
Inode Numbers

Inode numbers in XFS come in two forms: AG relative and absolute.

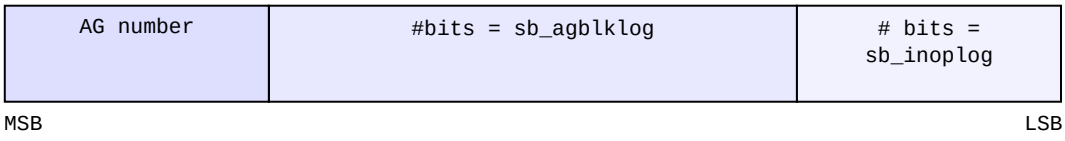
AG relative inode numbers always fit within 32 bits. The number of bits actually used is determined by the sum of the superblock's `sb_inoplog` and `sb_agblklog` values. Relative inode numbers are found within the AG's inode structures.

Absolute inode numbers include the AG number in the high bits, above the bits used for the AG relative inode number. Absolute inode numbers are found in directory entries.

Relative Inode number format



Absolute Inode number format



Inode Information

Each AG manages its own inodes. The third sector in the AG contains information about the AG's inodes and is known as the AGI.

The AGI uses the following structure:

```
typedef struct xfs_agi {
     __be32                  agi_magicnum;
     __be32                  agi_versionnum;
     __be32                  agi_seqno
     __be32                  agi_length;
     __be32                  agi_count;
     __be32                  agi_root;
     __be32                  agi_level;
     __be32                  agi_freecount;
     __be32                  agi_newino;
     __be32                  agi_dirino;
     __be32                  agi_unlinked[64];
} xfs_agi_t;
```

agi_magicnum

Specifies the magic number for the AGI sector: "XAGI" (0x58414749).

agi_versionnum

Set to `XFS_AGI_VERSION` which is currently 1.

agi_seqno

Specifies the AG number for the sector.

agi_length

Specifies the size of the AG in filesystem blocks.

agi_count

Specifies the number of inodes allocated for the AG.

agi_root

Specifies the block number in the AG containing the root of the inode B+tree.

agi_level

Specifies the number of levels in the inode B+tree.

agi_freecount

Specifies the number of free inodes in the AG.

agi_newino

Specifies AG relative inode number most recently allocated.

agi_dirino

Deprecated and not used, it's always set to NULL (-1).

agi_unlinked[64]

Hash table of unlinked (deleted) inodes that are still being referenced. Refer to Inode Unlinked Pointer for more information.

Inode B+trees

Inodes are allocated in chunks of 64, and a B+tree is used to track these chunks of inodes as they are allocated and freed. The block containing root of the B+tree is defined by the AGI's `agi_root` value.

The B+tree header for the nodes and leaves use the `xfs_btree_sblock` structure which is the same as the header used in the AGF B+trees:

```
typedef struct xfs_btree_sblock xfs_inobt_block_t;
```

Leaves contain an array of the following structure:

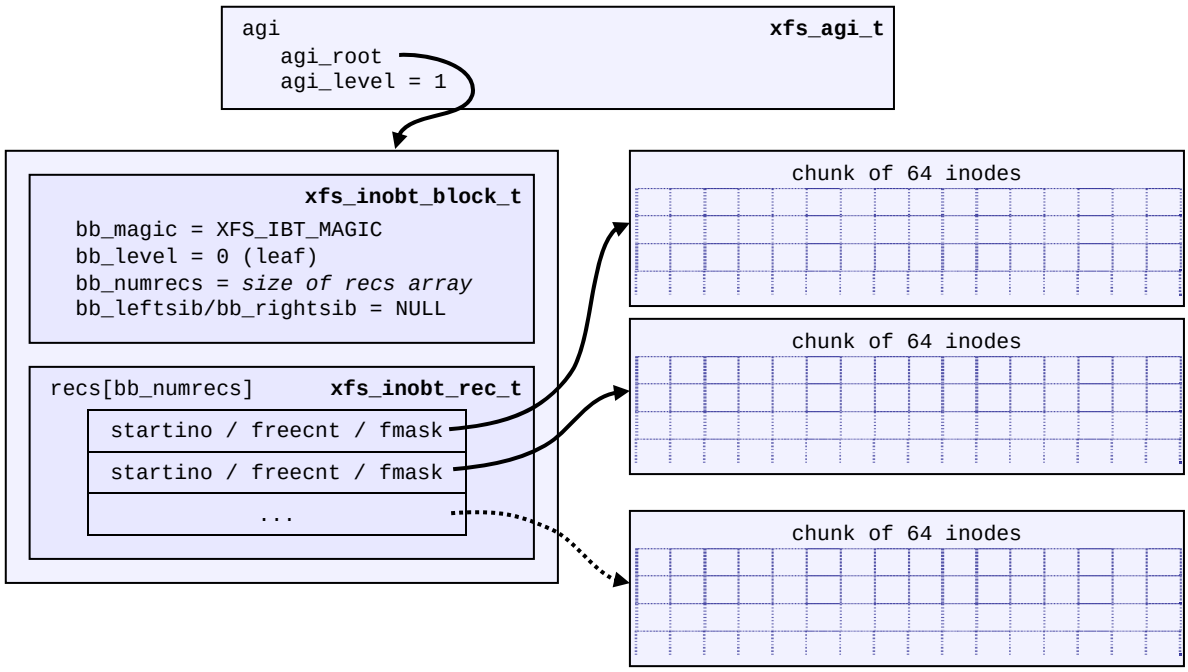
```
typedef struct xfs_inobt_rec {
     __be32                          ir_startino;
     __be32                          ir_freecount;
     __be64                          ir_free;
} xfs_inobt_rec_t;
```

Nodes contain key/pointer pairs using the following types:

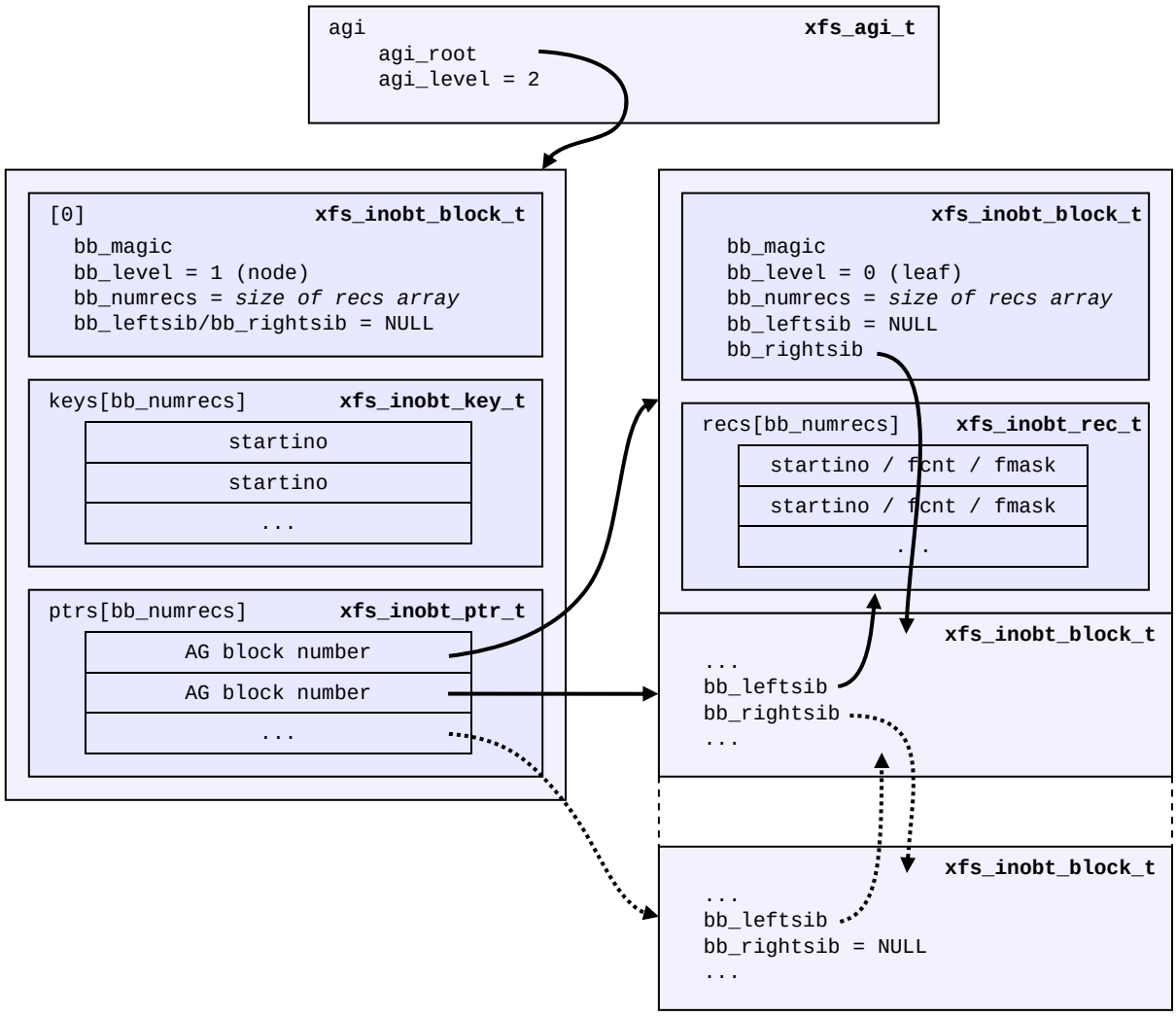
```
typedef struct xfs_inobt_key {
     __be32                          ir_startino;
} xfs_inobt_key_t;

typedef __be32 xfs_inobt_ptr_t;
```

For the leaf entries, `ir_startino` specifies the starting inode number for the chunk, `ir_freecount` specifies the number of free entries in the chuck, and the `ir_free` is a 64 element bit array specifying which entries are free in the chunk.

The following diagram illustrates a single level inode B+tree:



And a 2-level inode B+tree:



xfs_db Examples:

TODO:

Real-time Devices

XFS supports writing file data to a different volume to the normal XFS volume. This allows a more deterministic I/O performance characteristics compared to a normal XFS filesystem. This has been labelled "real-time".

Even though file data and metadata can go to different volumes, in a lot of cases, given the same hardware, real-time filesystems are not as fast as a single XFS filesystem. This is due to real-time filesystem I/O going through a single path with a single freespace allocation structure rather than the parallel AGs used for a normal XFS filesystem.

So, in practise, real-time filesystems are rarely used.

Free space for real-time filesystems are managed using a traditional bitmap which is stored in a special inode's data. To speed up free space searches, a bucket based array is used to track contiguous chunks of free space in the real-time free space bitmap. This is called the real-time summary and is stored in other special inode. Refer to Real-Time Inodes for more details on these inodes.

To create a filesystem with a real-time device, you need to use the following mkfs.xfs options:

```
# mkfs.xfs [opts] -r rtdev=</dev/rtpart>[,extsize=num] </dev/part>
```

The default for extsize is 64KB and has to be a power of 2 multiple of the filesystem's block size. This is the minimum allocation unit for the real-time device.

For example, to create a filesystem on `/dev/sda1` with a real-time device on `/dev/sdb1` and a 256KB real-time block (extent) size, use the following command:

```
# mkfs.xfs -r rtdev=/dev/sdb1,extsize=256m /dev/sda1
```

To mount the filesystem, the real-time device must be specifies as a mount option (using the previous example):

```
# mount /dev/sda1 -o rtdev=/dev/sdb1
```

By default, all files created will put the data on the normal XFS filesystem. For a file's data to be put on the real-time device, the inode's attributes must be changed to real-time before any data is written. This can be accomplished by two methods:

1. Changing the file's attribute itself
2. Marking the parent directory as inherited real-time so any files created after the parent's attributes are set automatically inherit the real-time attribute.

The `xfs_io` command must be used to change an inode's real-time attribute. To set a file's real-time bit, use the following command:

```
% xfs_io -c "chattr +r" <filename>
```

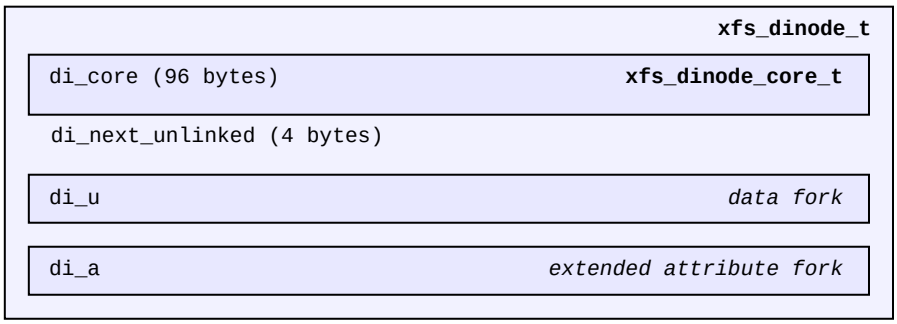
To set a directory's real-time inheritance bit, use the following command:

```
% xfs_io -c "chattr +t" <directory>
```

On-disk Inode

All files, directories and links are stored on disk with inodes and descend from the root inode with it's number defined in the superblock. The previous section on AG Inode Management describes the allocation and management of inodes on disk. This section describes the contents of inodes themselves.

An inode is divided into 3 parts:



- The core contains what the inode represents, stat data and information describing the data and attribute forks.
- The `di_u` "data fork" contains normal data related to the inode. It's contents depends on the file type specified by `di_core.di_mode` (eg. regular file, directory, link, etc) and how much information is contained in the file which determined by `di_core.di_format`. The following union to represent this data is declared as follows:

```
union {
      xfs_bmdr_block_t          di_bmbt;
      xfs_bmbt_rec_t            di_bmx[1];
      xfs_dir2_sf_t             di_dir2sf;
      char                      di_c[1];
      xfs_dev_t                 di_dev;
      uuid_t                    di_muuid;
      char                      di_symlink[1];
} di_u;
```

- The `di_a` "attribute fork" contains extended attributes. Its layout is determined by the `di_core.di_aformat` value. Its representation is declared as follows:

```
union {
      xfs_bmdr_block_t          di_abmbt;
      xfs_bmbt_rec_t            di_abmx[1];
      xfs_attr_shortform_t      di_attrsf;
} di_a;
```

Note: The above two unions are rarely used in the XFS code, but the structures within the union are directly cast depending on the `di_mode`/`di_format` and `di_aformat` values. They are referenced in this document to make it easier to explain the various structures in use within the inode.

The remaining space in the inode after `di_next_unlinked` where the two forks are located is called the inode's "literal area". This starts at offset 100 (0x64) in the inode.

The space for each of the two forks in the literal area is determined by the inode size, and `di_core.di_forkoff`. The data fork is located between the start of the literal area and `di_forkoff`. The attribute fork is located between `di_forkoff` and the end of the inode.

Inode Core

The inode's core is 96 bytes in size and contains information about the file itself including most stat data information about data and attribute forks after the core within the inode. It uses the following structure:

```
typedef struct xfs_dinode_core {
     __uint16_t               di_magic;
     __uint16_t               di_mode;
     __int8_t                 di_version;
     __int8_t                 di_format;
     __uint16_t               di_onlink;
     __uint32_t               di_uid;
     __uint32_t               di_gid;
     __uint32_t               di_nlink;
     __uint16_t               di_projid;
     __uint8_t                di_pad[8];
     __uint16_t               di_flushiter;
     xfs_timestamp_t          di_atime;
     xfs_timestamp_t          di_mtime;
     xfs_timestamp_t          di_ctime;
     xfs_fsize_t              di_size;
     xfs_drfsbno_t            di_nblocks;
     xfs_extlen_t             di_extsize;
     xfs_extnum_t             di_nextents;
     xfs_aextnum_t            di_anextents;
     __uint8_t                di_forkoff;
     __int8_t                 di_aformat;
     __uint32_t               di_dmevmask;
     __uint16_t               di_dmstate;
     __uint16_t               di_flags;
     __uint32_t               di_gen;
} xfs_dinode_core_t;
```

di_magic

The inode signature where these two bytes are 0x494e, or "IN" in ASCII.

di_mode

Specifies the mode access bits and type of file using the standard S_Ixxx values defined in stat.h.

di_version

Specifies the inode version which currently can only be 1 or 2. The inode version specifies the usage of the `di_onlink`, `di_nlink` and `di_projid` values in the inode core. Initially, inodes are created as v1 but can be converted on the fly to v2 when required.

di_format

Specifies the format of the data fork in conjunction with the `di_mode` type. This can be one of several values. For directories and links, it can be "local" where all metadata associated with the file is within the inode, "extents" where the inode contains an array of extents to other filesystem blocks which contain the associated metadata or data or "btree" where the inode contains a B+tree root node which points to filesystem blocks containing the metadata or data. Migration between the formats depends on the amount of metadata associated with the inode. "dev" is used for character and block devices while "uuid" is currently not used.

```
typedef enum xfs_dinode_fmt {
     XFS_DINODE_FMT_DEV,
     XFS_DINODE_FMT_LOCAL,
     XFS_DINODE_FMT_EXTENTS,
     XFS_DINODE_FMT_BTREE,
```

```
        XFS_DINODE_FMT_UUID
} xfs_dinode_fmt_t;
```

di_onlink

In v1 inodes, this specifies the number of links to the inode from directories. When the number exceeds 65535, the inode is converted to v2 and the link count is stored in `di_nlink`.

di_uid

Specifies the owner's UID of the inode.

di_gid

Specifies the owner's GID of the inode.

di_nlink

Specifies the number of links to the inode from directories. This is maintained for both inode versions for current versions of XFS. Old versions of XFS did not support v2 inodes, and therefore this value was never updated and was classed as reserved space (part of `di_pad`).

di_projid

Specifies the owner's project ID in v2 inodes. An inode is converted to v2 if the project ID is set. This value must be zero for v1 inodes.

di_pad[8]

Reserved, must be zero.

di_flushiter

Incremented on flush.

di_atime

Specifies the last access time of the files using UNIX time conventions the following structure. This value maybe undefined if the filesystem is mounted with the "noatime" option.

```
typedef struct xfs_timestamp {
        __int32_t                t_sec;
        __int32_t                t_nsec;
} xfs_timestamp_t;
```

di_mtime

Specifies the last time the file was modified.

di_ctime

Specifies when the inode's status was last changed.

di_size

Specifies the EOF of the inode in bytes. This can be larger or smaller than the extent space (therefore actual disk space) used for the inode. For regular files, this is the filesize in bytes, directories, the space taken by directory entries and for links, the length of the symlink.

di_nblocks

Specifies the number of filesystem blocks used to store the inode's data including relevant metadata like B+trees. This does not include blocks used for extended attributes.

di_extsize

Specifies the extent size for filesystems with real-time devices and an extent size hint for standard filesystems. For normal filesystems, and with directories, the `XFS_DIFLAG_EXTSZINHERIT` flag must be set in `di_flags` if this field is used. Inodes created in these directories will inherit the `di_extsize` value and have `XFS_DIFLAG_EXTSIZE` set in their `di_flags`. When a file is written to beyond allocated space, XFS will attempt to allocate additional disk space based on this value.

di_nextents

Specifies the number of data extents associated with this inode.

di_anextents

Specifies the number of extended attribute extents associated with this inode.

di_forkoff

Specifies the offset into the inode's literal area where the extended attribute fork starts. This is an 8-bit value that is multiplied by 8 to determine the actual offset in bytes (ie. attribute data is 64-bit aligned). This also limits the maximum size of the inode to 2048 bytes. This value is initially zero until an extended attribute is created. When in attribute is added, the nature of `di_forkoff` depends on the `XFS_SB_VERSION2_ATTR2BIT` flag in the superblock. Refer to the Extended Attribute Versions section for more details.

di_aformat

Specifies the format of the attribute fork. This uses the same values as `di_format`, but restricted to "local", "extents" and "btree" formats for extended attribute data.

di_dmevmask

DMAPI event mask.

di_dmstate

DMAPI state.

di_flags

Specifies flags associated with the inode. This can be a combination of the following values:

Flag	Description
`XFS_DIFLAG_REALTIME`	The inode's data is located on the real-time device.
`XFS_DIFLAG_PREALLOC`	The inode's extents have been preallocated.
`XFS_DIFLAG_NEWRTBM`	Specifies the `sb_rbmino` uses the new real-time bitmap format
`XFS_DIFLAG_IMMUTABLE`	Specifies the inode cannot be modified.
`XFS_DIFLAG_APPEND`	The inode is in append only mode.
`XFS_DIFLAG_SYNC`	The inode is written synchronously.
`XFS_DIFLAG_NOATIME`	The inode's `di_atime` is not updated.
`XFS_DIFLAG_NODUMP`	Specifies the inode is to be ignored by xfsdump.
`XFS_DIFLAG_RTINHERIT`	For directory inodes, new inodes inherit the `XFS_DIFLAG_REALTIME` bit.

XFS_DIFLAG_PROJINHERIT	For directory inodes, new inodes inherit the di_projid value.
XFS_DIFLAG_NOSYMLINKS	For directory inodes, symlinks cannot be created.
XFS_DIFLAG_EXTSIZE	Specifies the extent size for real-time files or a and extent size hint for regular files.
XFS_DIFLAG_EXTSZINHERIT	For directory inodes, new inodes inherit the di_extsize value.
XFS_DIFLAG_NODEFRAG	Specifies the inode is to be ignored when defragmenting the filesystem.

di_gen

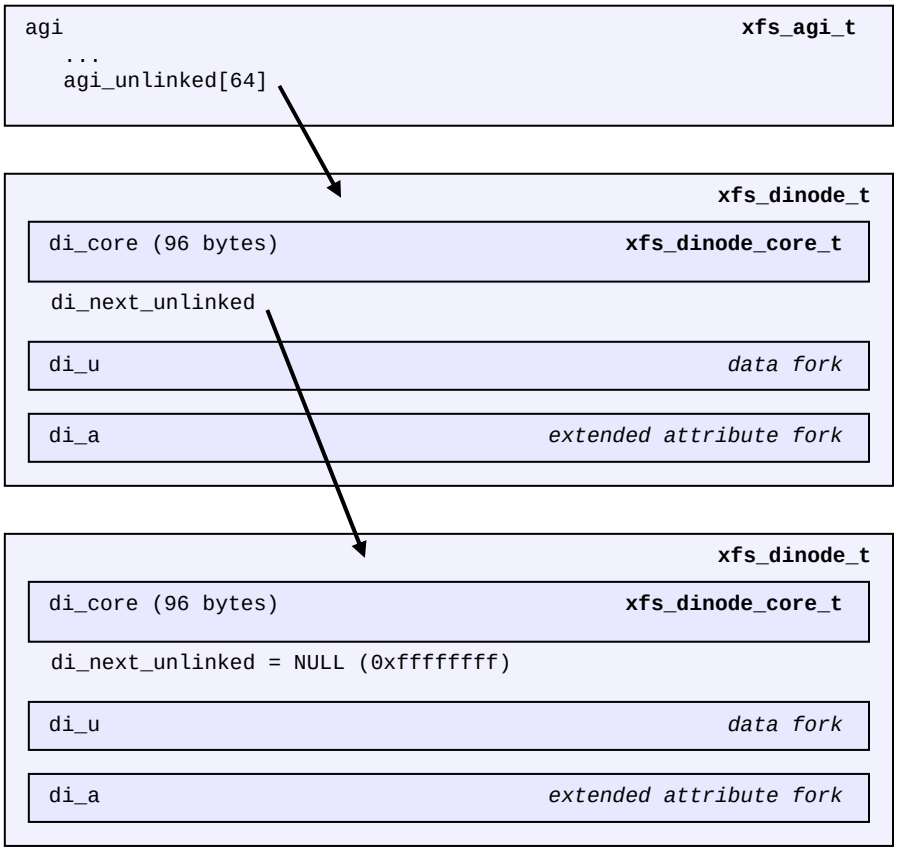
A generation number used for inode identification. This is used by tools that do inode scanning such as backup tools and xfsdump. An inode's generation number can change by unlinking and creating a new file that reuses the inode.

Unlinked Pointer

The `di_next_unlinked` value in the inode is used to track inodes that have been unlinked (deleted) but which are still referenced. When an inode is unlinked and there is still an outstanding reference, the inode is added to one of the AGI's `agi_unlinked` hash buckets. The AGI unlinked bucket points to an inode and the `di_next_unlinked` value points to the next inode in the chain. The last inode in the chain has `di_next_unlinked` set to NULL (-1).

Once the last reference is released, the inode is removed from the unlinked hash chain, and `di_next_unlinked` is set to NULL. In the case of a system crash, XFS recovery will complete the unlink process for any inodes found in these lists.

The only time the unlinked fields can be seen to be used on disk is either on an active filesystem or a crashed system. A cleanly unmounted or recovered filesystem will not have any inodes in these unlink hash chains.



Data Fork

The structure of the inode's data fork based is on the inode's type and `di_format`. It always starts at offset 100 (0x64) in the inode's space which is the start of the inode's "literal area". The size of the data fork is determined by the type and format. The maximum size is determined by the inode size and `di_forkoff`. In code, use the `XFS_DFORK_PTR` macro specifying `XFS_DATA_FORK` for the "`which`" parameter. Alternatively, the `XFS_DFORK_DPTR` macro can be used.

Each of the following sub-sections summarises the contents of the data fork based on the inode type.

Regular Files (S_IFREG)

The data fork specifies the file's data extents. The extents specify where the file's actual data is located within the filesystem. Extents can have 2 formats which is defined by the `di_format` value:

- `XFS_DINODE_FMT_EXTENTS`: The extent data is fully contained within the inode which contains an array of extents to the filesystem blocks for the file's data. To access the extents, cast the return value from `XFS_DFORK_DPTR` to `xfs_bmbt_rec_t*`.
- `XFS_DINODE_FMT_BTREE`: The extent data is contained in the leaves of a B+tree. The inode contains the root node of the tree and is accessed by casting the return value from `XFS_DFORK_DPTR` to `xfs_bmdr_block_t*`.

Details for each of these data extent formats are covered in the Data Extents section later on.

Directories (S_IFDIR)

The data fork contains the directory's entries and associated data. The format of the entries is also determined by the `di_format` value and can be one of 3 formats:

- `XFS_DINODE_FMT_LOCAL`: The directory entries are fully contained within the inode. This is accessed by casting the value from `XFS_DFORK_DPTR` to `xfs_dir2_sf_t*`.
- `XFS_DINODE_FMT_EXTENTS`: The actual directory entries are located in another filesystem block, the inode contains an array of extents to these filesystem blocks (`xfs_bmbt_rec_t*`).
- `XFS_DINODE_FMT_BTREE`: The directory entries are contained in the leaves of a B+tree. The inode contains the root node (`xfs_bmdr_block_t*`).

Details for each of these directory formats are covered in the Directories section later on.

Symbolic Links (S_IFLNK)

The data fork contains the contents of the symbolic link. The format of the link is determined by the `di_format` value and can be one of 2 formats:

- `XFS_DINODE_FMT_LOCAL`: The symbolic link is fully contained within the inode. This is accessed by casting the return value from `XFS_DFORK_DPTR` to `char*`.
- `XFS_DINODE_FMT_EXTENTS`: The actual symlink is located in another filesystem block, the inode contains the extents to these filesystem blocks (`xfs_bmbt_rec_t*`).

Details for symbolic links is covered in the Symbolic Links section later on.

Other File Types

For character and block devices (`S_IFCHR` and `S_IFBLK`), cast the value from `XFS_DFORK_DPTR` to `xfs_dev_t*`.

Attribute Fork

The attribute fork in the inode always contains the location of the extended attributes associated with the inode.

The location of the attribute fork in the inode's literal area (offset 100 to the end of the inode) is specified by the `di_forkoff` value in the inode's core. If this value is zero, the inode does not contain any extended attributes. Non-zero, the byte offset into the literal area = `di_forkoff * 8`, which also determines the 2048 byte maximum size for an inode. Attributes must be allocated on a 64-bit boundary on the disk. To access the extended attributes in code, use the `XFS_DFORK_PTR` macro specifying `XFS_ATTR_FORK` for the "`which`" parameter. Alternatively, the `XFS_DFORK_APTR` macro can be used.

Which structure in the attribute fork is used depends on the `di_aformat` value in the inode. It can be one of the following values:

- `XFS_DINODE_FMT_LOCAL`: The extended attributes are contained entirely within the inode. This is accessed by casting the value from `XFS_DFORK_APTR` to `xfs_attr_shortform_t*`.
- `XFS_DINODE_FMT_EXTENTS`: The attributes are located in another filesystem block, the inode contains an array of pointers to these filesystem blocks. They are accessed by casting the value from `XFS_DFORK_APTR` to `xfs_bmbt_rec_t*`.
- `XFS_DINODE_FMT_BTREE`: The extents for the attributes are contained in the leaves of a B+tree. The inode contains the root node of the tree and is accessed by casting the value from `XFS_DFORK_APTR` to `xfs_bmdr_block_t*`.

Detailed information on the layouts of extended attributes are covered in the Extended Attributes section later on in this document.

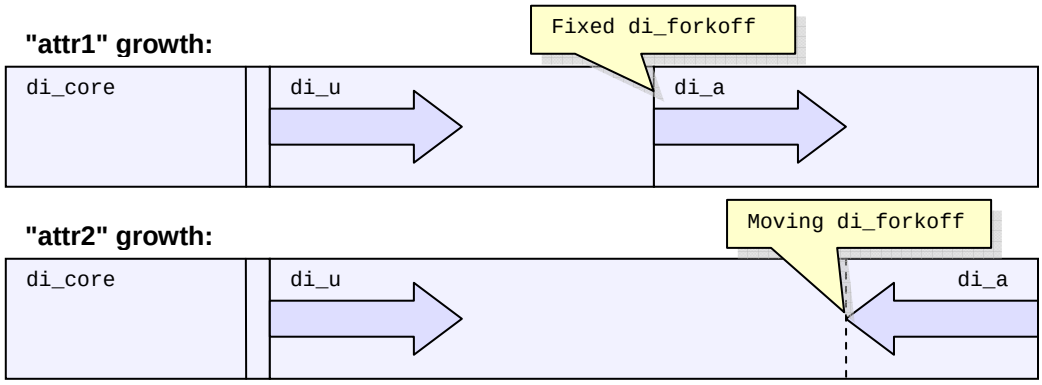
Extended Attribute Versions

Extended attributes come in two versions: "attr1" or "attr2". The attribute version is specified by the `XFS_SB_VERSION2_ATTR2BIT` flag in the `sb_features2` field in the superblock. It determines how the inode's extra space is split between `di_u` and `di_a` forks which also determines how the `di_forkoff` value is maintained in the inode's core.

With "attr1" attributes, the `di_forkoff` is set to somewhere in the middle of the space between the core and end of the inode and never changes (which has the effect of artificially limiting the space for data information). As the data fork grows, when it gets to `di_forkoff`, it will move the data to the level format level (ie. local > extent > btree). If very little space is used for either attributes or data, then a good portion of the available inode space is wasted with this version.

"Attr2" was introduced to maximum the utilisation of the inode's literal area. The `di_forkoff` starts at the end of the inode and works its way to the data fork as attributes are added. Attr2 is highly recommended if extended attributes are used.

The following diagram compares the two versions:

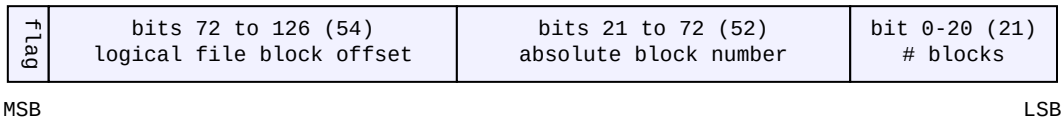


Data Extents

XFS allocates space for a file using extents: starting location and length. XFS extents also specify the file's logical starting offset for a file. This allows a files extent map to automatically support sparse files (i.e. "holes" in the file). A flag is also used to specify if the extent has been preallocated and not yet been written to (unwritten extent).

A file can have more than one extent if one chunk of contiguous disk space is not available for the file. As a file grows, the XFS space allocator will attempt to keep space contiguous and merge extents. If more than one file is being allocated space in the same AG at the same time, multiple extents for the files will occur as the extents get interleaved. The effect of this can vary depending on the extent allocator used in the XFS driver.

An extent is 128 bits in size and uses the following packed layout:



The extent is represented by the `xfs_bmbt_rec_t` structure which uses a big endian format on-disk. In-core management of extents use the `xfs_bmbt_irec_t` structure which is the unpacked version of `xfs_bmbt_rec_t`:

```
typedef struct xfs_bmbt_irec {
     xfs_fileoff_t              br_startoff;
     xfs_fsblock_t              br_startblock;
     xfs_filblks_t              br_blockcount;
     xfs_exntst_t               br_state;
} xfs_bmbt_irec_t;
```

The extent `br_state` field uses the following enum declaration:

```
typedef enum {
     XFS_EXT_NORM,
     XFS_EXT_UNWRITTEN,
     XFS_EXT_INVALID
} xfs_exntst_t;
```

Some other points about extents:

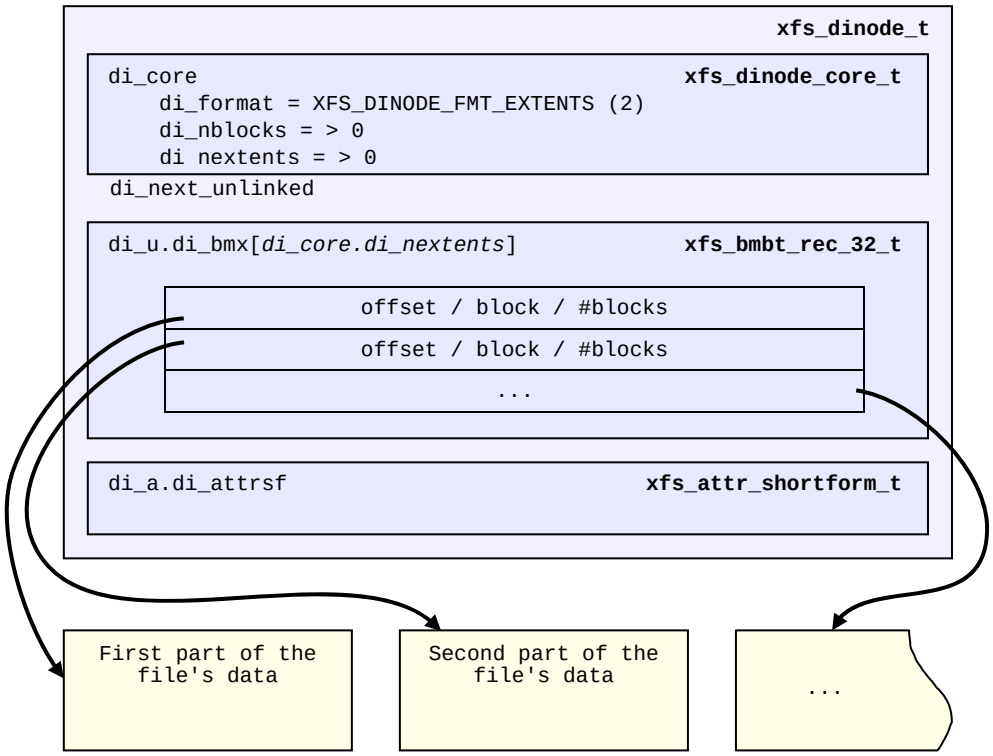
- The `xfs_bmbt_rec_32_t` and `xfs_bmbt_rec_64_t` structures are effectively the same as `xfs_bmbt_rec_t`, just different representations of the same 128 bits in on-disk big endian format.
- When a file is created and written to, XFS will endeavour to keep the extents within the same AG as the inode. It may use a different AG if the AG is busy or there is no space left in it.
- If a file is zero bytes long, it will have no extents, `di_nblocks` and `di_nexents` will be zero. Any file with data will have at least one extent, and each extent can use from 1 to over 2 million blocks (2^{21}) on the filesystem. For a default 4KB block size filesystem, a single extent can be up to 8GB in length.

The following two subsections cover the two methods of storing extent information for a file. The first is the fastest and simplest where the inode completely contains an extent array to the file's data. The second is slower and more complex B+tree which can handle thousands to millions of extents efficiently.

Extent List

Local extents are where the entire extent array is stored within the inode's data fork itself. This is the most optimal in terms of speed and resource consumption. The trade-off is the file can only have a few extents before the inode runs out of space.

The "data fork" of the inode contains an array of extents, the size of the array determined by the inode's `di_nextents` value.



The number of extents that can fit in the inode depends on the inode size and `di_forkoff`. For a default 256 byte inode with no extended attributes, a file can up to 19 extents with this format. Beyond this, extents have to use the B+tree format.

xfs_db Example:

An 8MB file with one extent:

```
xfs_db> inode <inode#>
xfs_db> p
core.magic = 0x494e
core.mode = 0100644
core.version = 1
core.format = 2 (extents)
...
core.size = 8294400
core.nblocks = 2025
core.extsize = 0
core.nextents = 1
core.naextents = 0
core.forkoff = 0
...
u.bmx[0] = [startoff,startblock,blockcount,extentflag]
         0:[0,25356,2025,0]
```

A 24MB file with three extents:

```
xfs_db> inode <inode#>
xfs_db> p
...
core.format = 2 (extents)
...
core.size = 24883200
core.nblocks = 6075
core.nextents = 3
...
u.bmx[0-2] = [startoff,startblock,blockcount,extentflag]
         0:[0,27381,2025,0]
         1:[2025,31431,2025,0]
         2:[4050,35481,2025,0]
```

Raw disk version of the inode with the third extent highlighted (`di_u` always starts at offset 0x64):

```
xfs_db> type text
xfs_db> p
00:  49 4e 81 a4 01 02 00 01 00 00 00 00 00 00 00 00  IN..............
10:  00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 01  ................
20:  44 b6 88 dd 2f 8a ed d0 44 b6 88 f7 10 8c 5b d0  D.......D.......
30:  44 b6 88 f7 10 8c 5b d0 00 00 00 00 01 7b b0 00  D.............. 
40:  00 00 00 00 00 00 17 bb 00 00 00 00 00 00 00 03  ................
50:  00 00 00 02 00 00 00 00 00 00 00 00 00 00 00 00  ................
60:  ff ff ff ff 00 00 00 00 00 00 00 00 00 00 00 0d  ................
70:  5e a0 07 e9 00 00 00 00 00 0f d2 00 00 00 0f     ................
80:  58 e0 07 e9 00 00 00 00 00 1f a4 00 00 00 00 11  X...............
90:  53 20 07 e9 00 00 00 00 00 00 00 00 00 00 00 00  S...............
a0:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
b0:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
c0:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
d0:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
e0:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
f0:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
```

We can expand the highlighted section into the following bit array from MSB to LSB with the file offset and the block count highlighted:

```
127-96:  0000 0000  0000 0000  0000 0000  0000 0000
 95-64:  0000 0000  0001 1111  1010 0100  0000 0000
 63-32:  0000 0000  0000 0000  0000 0000  0000 1111
 31-0 :  0101 1000  1110 0000  0000 0111  1110 1001

Grouping by highlights we get:
   file offset = 0x0fd2 (4050)
   start block = 0x7ac7 (31431)
   block count = 0x07e9 (2025)
```

A 4MB file with two extents and a hole in the middle, the first extent containing 64KB of data, the second about 4MB in containing 32KB (`write` 64KB, `lseek` ~4MB, `write` 32KB operations):

```
xfs_db> inode <inode#>
xfs_db> p
...
core.format = 2 (extents)
...
core.size = 4063232
core.nblocks = 24
core.nextents = 2
...
u.bmx[0-1] = [startoff,startblock,blockcount,extentflag]
         0:[0,37506,16,0]
         1:[984,37522,8,0]
```

B+tree Extent List

Beyond the simple extent array, to efficiently manage large extent maps, XFS uses B+trees. The root node of the B+tree is stored in the inode's data fork. All block pointers for extent B+trees are 64-bit absolute block numbers.

For a single level B+tree, the root node points to the B+tree's leaves. Each leaf occupies one filesystem block and contains a header and an array of extents sorted by the file's offset. Each leaf has left and right (or backward and forward) block pointers to adjacent leaves. For a standard 4KB filesystem block, a leaf can contain up to 254 extents before a B+tree rebalance is triggered.

For a multi-level B+tree, the root node points to other B+tree nodes which eventually point to the extent leaves. B+tree keys are based on the file's offset. The nodes at each level in the B+tree point to the adjacent nodes.

The base B+tree node is used for extents, directories and extended attributes. The structures used for inode's B+tree root are:

```
typedef struct xfs_bmdr_block {
     __be16                  bb_level;
     __be16                  bb_numrecs;
} xfs_bmdr_block_t;

typedef struct xfs_bmbt_key {
     xfs_dfiloff_t           br_startoff;
} xfs_bmbt_key_t, xfs_bmdr_key_t;

typedef xfs_dfsbno_t xfs_bmbt_ptr_t, xfs_bmdr_ptr_t;
```

- On disk, the B+tree node starts with the `xfs_bmbr_block_t` header followed by an array of `xfs_bmbt_key_t` values and then an array of `xfs_bmbt_ptr_t` values. The size of both arrays is specified by the header's `bb_numrecs` value.
- The root node in the inode can only contain up to 19 key/pointer pairs for a standard 256 byte inode before a new level of nodes is added between the root and the leaves. This will be less if `di_forkoff` is not zero (i.e. attributes are in use on the inode).

The subsequent nodes and leaves of the B+tree use the `xfs_bmbt_block_t` declaration:

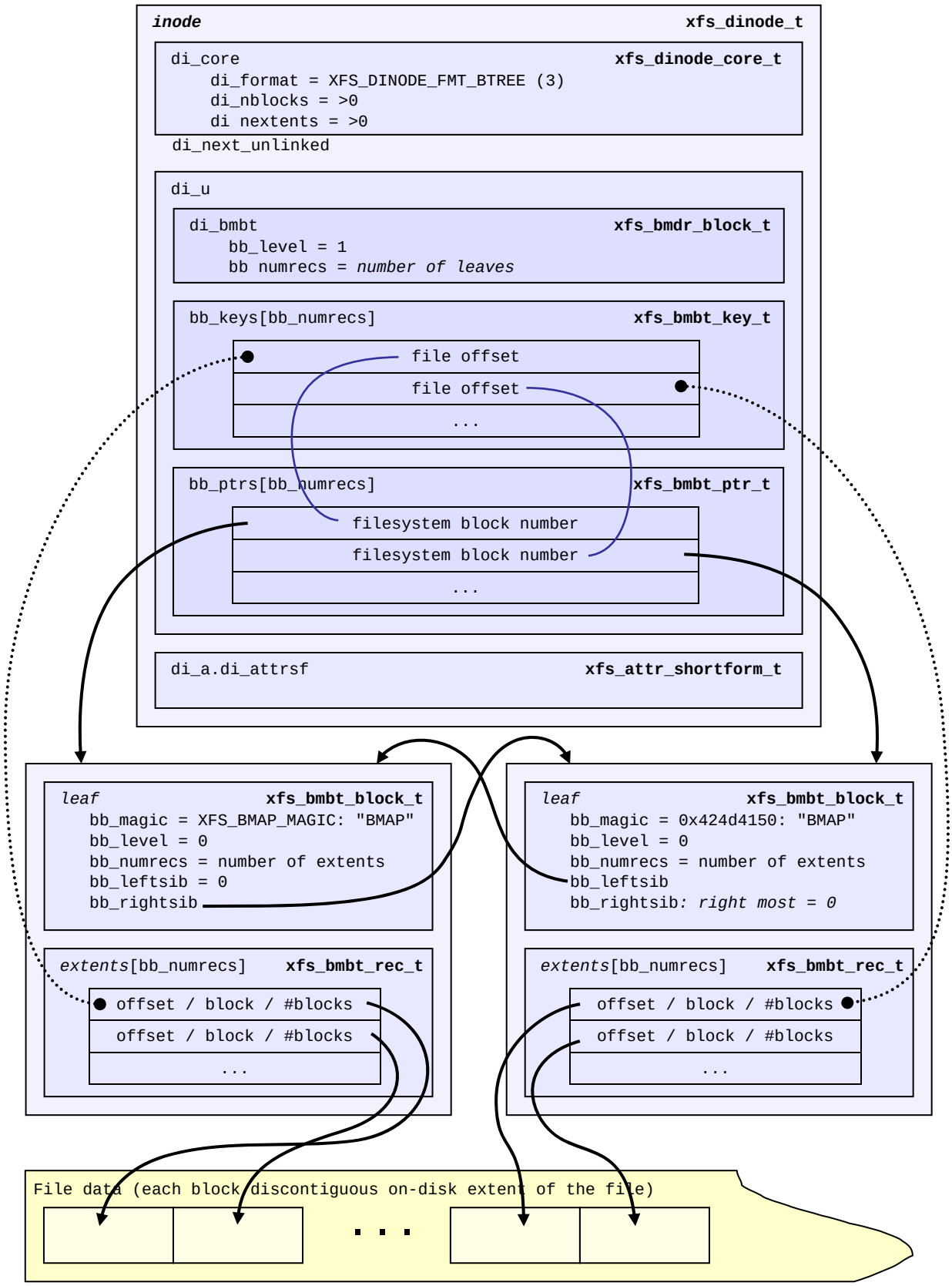
```
typedef struct xfs_btree_lblock xfs_bmbt_block_t;

typedef struct xfs_btree_lblock {
     __be32                  bb_magic;
     __be16                  bb_level;
     __be16                  bb_numrecs;
     __be64                  bb_leftsib;
     __be64                  bb_rightsib;
} xfs_btree_lblock_t;
```

- For intermediate nodes, the data following `xfs_bmbt_block_t` is the same as the root node: array of `xfs_bmbt_key_t` value followed by an array of `xfs_bmbt_ptr_t` values that starts halfway through the block (offset 0x808 for a 4096 byte filesystem block).
- For leaves, an array of `xfs_bmbt_rec_t` extents follow the `xfs_bmbt_block_t` header.
- Nodes and leaves use the same value for `bb_magic`:

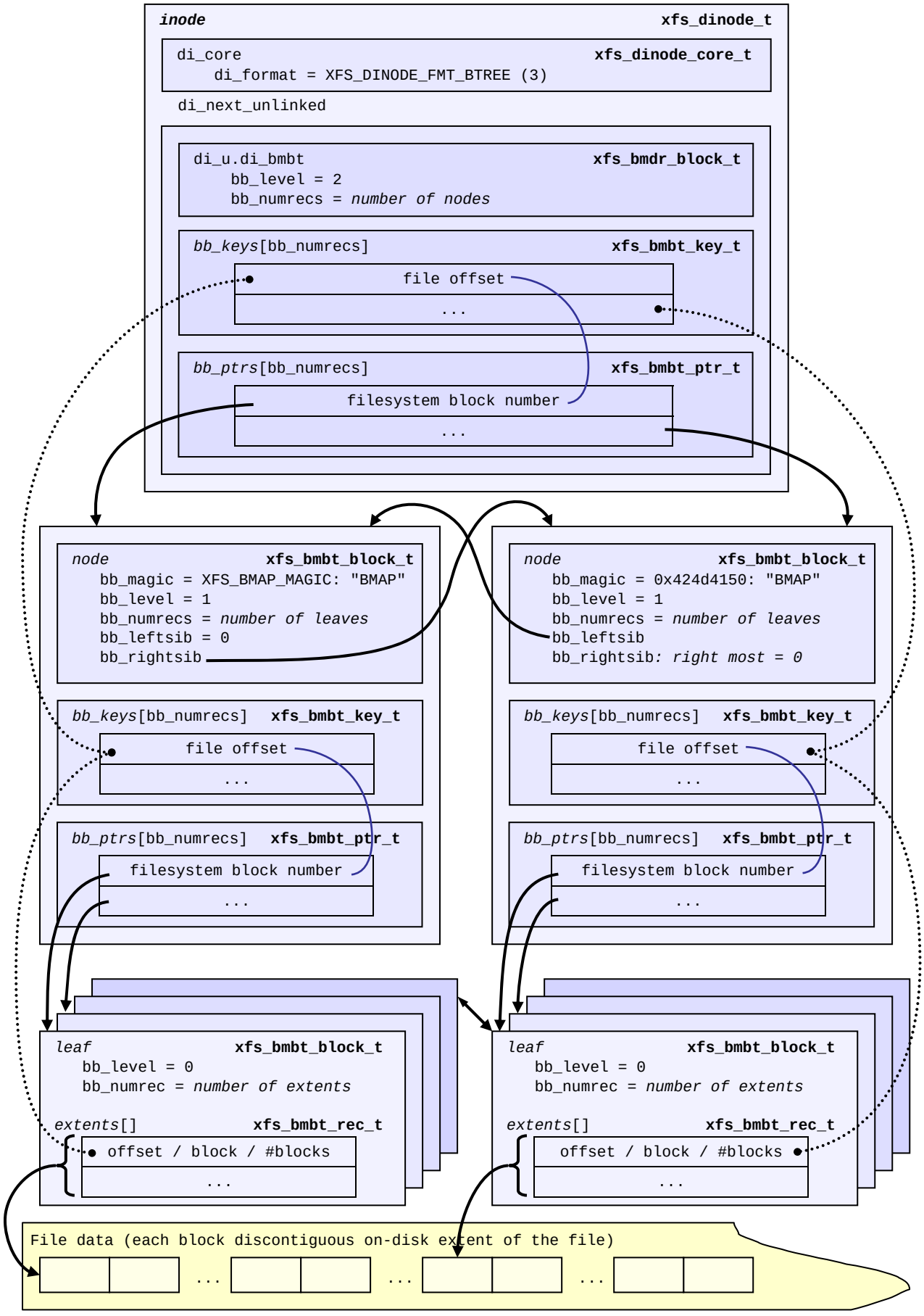
```
#define XFS_BMAP_MAGIC          0x424d4150   /* 'BMAP' */
```

- The `bb_level` value determines if the node is an intermediate node or a leaf. Leaves have a `bb_level` of zero, nodes are one or greater.
- Intermediate nodes, like leaves, can contain up to 254 pointers to leaf blocks for a standard 4KB filesystem block size as both the keys and pointers are 64 bits in size.

The following diagram illustrates a single level extent B+tree:



The following diagram illustrates a two level extent B+tree:



xfs_db Example:

TODO:

Directories

- Only v2 directories covered here. v1 directories are obsolete.
- The size of a "directory block" is defined by the superblock's `sb_dirblklog` value. The size in bytes = `sb_blocksize` * $2^{sb\_dirblklog}$. For example, if `sb_blocksize` = 4096, `sb_dirblklog` = 2, the directory block size is 16384 bytes. Directory blocks are always allocated in multiples based on `sb_dirblklog`. Directory blocks cannot be more that 65536 bytes in size.

  Note: the term "block" in this section will refer to directory blocks, not filesystem blocks unless otherwise specified.

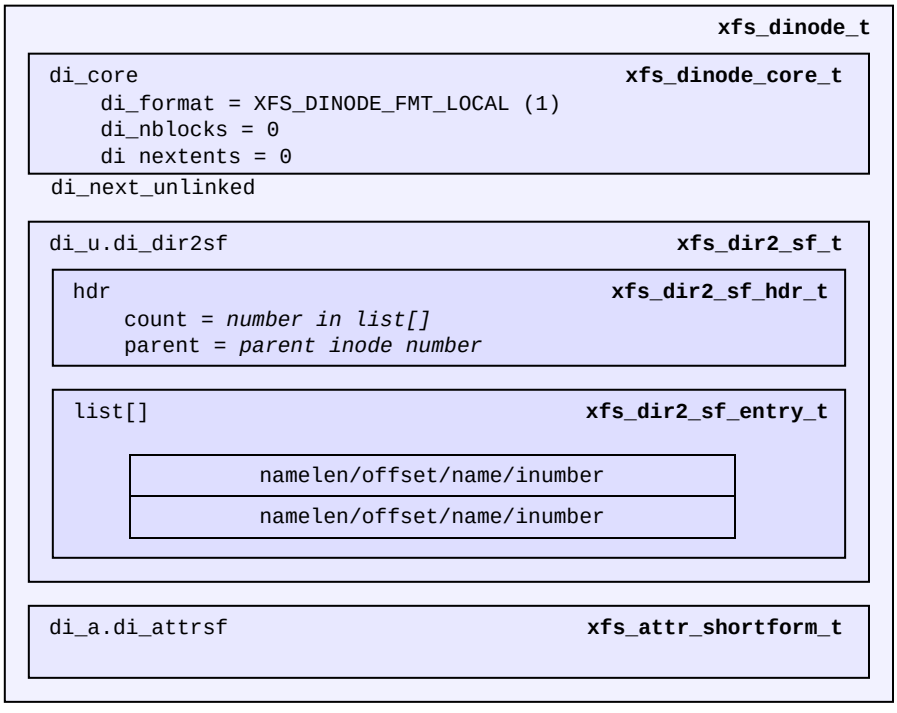
- All directory entries contain the following "data":
  - Entry's name (counted string consisting of a single byte `namelen` followed by `name` consisting of an array of 8-bit chars without a NULL terminator).
  - Entry's absolute inode number, which are always 64 bits (8 bytes) in size except a special case for shortform directories.
  - An `offset` or `tag` used for iterative readdir calls.
- All non-shortform directories also contain two additional structures: "leaves" and "freespace indexes".
  - Leaves contain the sorted hashed name value (`xfs_da_hashname()` in xfs_da_btree.c) and associated "address" which points to the effective offset into the directory's data structures. Leaves are used to optimise lookup operations.
  - Freespace indexes contain free space/empty entry tracking for quickly finding an appropriately sized location for new entries. They maintain the largest free space for each "data" block.
- A few common types are used for the directory structures:

```
typedef __uint16_t              xfs_dir2_data_off_t;
typedef __uint32_t              xfs_dir2_dataptr_t;
```

Shortform Directories

- Directory entries are stored within the inode.
- Only data stored is the name, inode # and offset, no "leaf" or "freespace index" information is required as an inode can only store a few entries.
- "." is not stored (as it's in the inode itself), and ".." is a dedicated `parent` field in the header.
- The number of directories that can be stored in an inode depends on the inode size, the number of entries, the length of the entry names and extended attribute data.
- Once the number of entries exceed the space available in the inode, the format is converted to a "Block Directory".
- Shortform directory data is packed as tightly as possible on the disk with the remaining space zeroed:

```
typedef struct xfs_dir2_sf {
     xfs_dir2_sf_hdr_t          hdr;
     xfs_dir2_sf_entry_t        list[1];
} xfs_dir2_sf_t;

typedef struct xfs_dir2_sf_hdr {
     __uint8_t                  count;
     __uint8_t                  i8count;
     xfs_dir2_inou_t            parent;
} xfs_dir2_sf_hdr_t;

typedef struct xfs_dir2_sf_entry {
     __uint8_t                  namelen;
     xfs_dir2_sf_off_t          offset;
     __uint8_t                  name[1];
     xfs_dir2_inou_t            inumber;
} xfs_dir2_sf_entry_t;
```



- Inode numbers are stored using 4 or 8 bytes depending on whether all the inode numbers for the directory fit in 4 bytes (32 bits) or not. If all inode numbers fit in 4 bytes, the header's `count` value specifies the number of entries in the directory and `i8count` will be zero. If any inode number exceeds 4 bytes, all inode numbers will be 8 bytes in size and the header's `i8count` value specifies the number of entries and `count` will be zero. The following union covers the shortform inode number structure:

```
typedef struct { __uint8_t i[8]; } xfs_dir2_ino8_t;
typedef struct { __uint8_t i[4]; } xfs_dir2_ino4_t;

typedef union {
     xfs_dir2_ino8_t           i8;
     xfs_dir2_ino4_t           i4;
} xfs_dir2_inou_t;
```

xfs_db Example:

A directory is created with 4 files, all inode numbers fitting within 4 bytes:

```
xfs_db> inode <inode#>
xfs_db> p
core.magic = 0x494e
core.mode = 040755
core.version = 1
core.format = 1 (local)
core.nlinkv1 = 2
...
core.size = 94
core.nblocks = 0
core.extsize = 0
core.nextents = 0
...
u.sfdir2.hdr.count = 4
u.sfdir2.hdr.i8count = 0
u.sfdir2.hdr.parent.i4 = 128                    /* parent = root inode */
u.sfdir2.list[0].namelen = 15
u.sfdir2.list[0].offset = 0x30
u.sfdir2.list[0].name = "frame000000.tst"
u.sfdir2.list[0].inumber.i4 = 25165953
u.sfdir2.list[1].namelen = 15
u.sfdir2.list[1].offset = 0x50
u.sfdir2.list[1].name = "frame000001.tst"
u.sfdir2.list[1].inumber.i4 = 25165954
u.sfdir2.list[2].namelen = 15
u.sfdir2.list[2].offset = 0x70
u.sfdir2.list[2].name = "frame000002.tst"
u.sfdir2.list[2].inumber.i4 = 25165955
u.sfdir2.list[3].namelen = 15
u.sfdir2.list[3].offset = 0x90
u.sfdir2.list[3].name = "frame000003.tst"
u.sfdir2.list[3].inumber.i4 = 25165956
```

The raw data on disk with the first entry highlighted. The six byte header precedes the first entry:

```
xfs_db> type text
xfs_db> p
00:  49 4e 41 ed 01 01 00 02 00 00 00 00 00 00 00 00  INA.............
10:  00 00 00 02 00 00 00 00 00 00 00 00 00 00 00 02  ................
20:  44 ad 3a 83 1d a9 4a d0 44 ad 3a ab 0b c7 a7 d0  D.....J.D.......
30:  44 ad 3a ab 0b c7 a7 d0 00 00 00 00 00 00 00 5e  D..............^
40:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
50:  00 00 00 02 00 00 00 00 00 00 00 00 00 00 00 00  ................
60:  ff ff ff ff 04 00 00 00 00 80 0f 00 30 66 72 61  ............0fra
70:  6d 65 30 30 30 30 30 30 2e 74 73 74 01 80 00 81  me000000.tst....
80:  0f 00 50 66 72 61 6d 65 30 30 30 30 30 31 2e 74  ..Pframe000001.t
```

```
90:  73 74 01 80 00 82 0f 00 70 66 72 61 6d 65 30 30  st......pframe00
a0:  30 30 30 32 2e 74 73 74 01 80 00 83 0f 00 90 66  0002.tst.......f
b0:  72 61 6d 65 30 30 30 30 30 33 2e 74 73 74 01 80  rame000003.tst..
c0:  00 84 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
...
```

Next, an entry is deleted (frame000001.tst), and any entries after the deleted entry are moved or compacted to "cover" the hole:

```
xfs_db> inode <inode#>
xfs_db> p
core.magic = 0x494e
core.mode = 040755
core.version = 1
core.format = 1 (local)
core.nlinkv1 = 2
...
core.size = 72
core.nblocks = 0
core.extsize = 0
core.nextents = 0
...
u.sfdir2.hdr.count = 3
u.sfdir2.hdr.i8count = 0
u.sfdir2.hdr.parent.i4 = 128
u.sfdir2.list[0].namelen = 15
u.sfdir2.list[0].offset = 0x30
u.sfdir2.list[0].name = "frame000000.tst"
u.sfdir2.list[0].inumber.i4 = 25165953
u.sfdir2.list[1].namelen = 15
u.sfdir2.list[1].offset = 0x70
u.sfdir2.list[1].name = "frame000002.tst"
u.sfdir2.list[1].inumber.i4 = 25165955
u.sfdir2.list[2].namelen = 15
u.sfdir2.list[2].offset = 0x90
u.sfdir2.list[2].name = "frame000003.tst"
u.sfdir2.list[2].inumber.i4 = 25165956
```

Raw disk data, the space beyond the shortform entries is invalid and could be non-zero:

```
xfs_db> type text
xfs_db> p
00:  49 4e 41 ed 01 01 00 02 00 00 00 00 00 00 00 00  INA.............
10:  00 00 00 02 00 00 00 00 00 00 00 00 00 00 00 03  ................
20:  44 b2 45 a2 09 fd e4 50 44 b2 45 a3 12 ee b5 d0  D.E....PD.E.....
30:  44 b2 45 a3 12 ee b5 d0 00 00 00 00 00 00 00 48  D.E............H
40:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
50:  00 00 00 02 00 00 00 00 00 00 00 00 00 00 00 00  ................
60:  ff ff ff ff 03 00 00 00 00 80 0f 00 30 66 72 61  ............0fra
70:  6d 65 30 30 30 30 30 30 2e 74 73 74 01 80 00 81  me000000.tst....
80:  0f 00 70 66 72 61 6d 65 30 30 30 30 30 32 2e 74  ..pframe000002.t
90:  73 74 01 80 00 83 0f 00 90 66 72 61 6d 65 30 30  st.......frame00
a0:  30 30 30 33 2e 74 73 74 01 80 00 84 0f 00 90 66  0003.tst.......f
b0:  72 61 6d 65 30 30 30 30 30 33 2e 74 73 74 01 80  rame000003.tst..
c0:  00 84 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
...
```

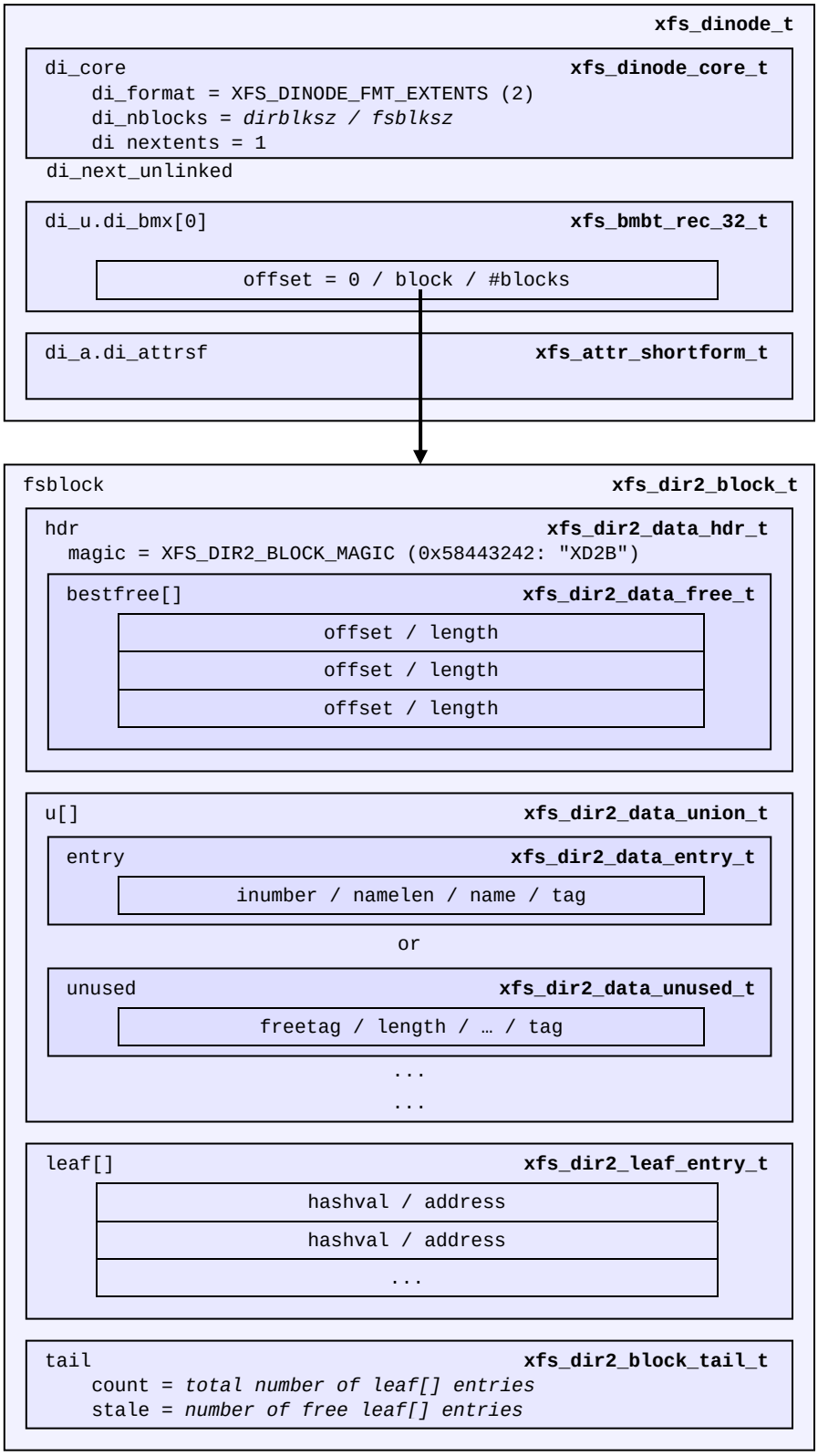
TODO: 8-byte inode number example

Block Directories

When the shortform directory space exceeds the space in an inode, the directory data is moved into a new single directory block outside the inode. The inode's format is changed from "local" to "extent". Following is a list of points about block directories.

- All directory data is stored within the one directory block, including "." and ".." entries which are mandatory.
- The block also contains "leaf" and "freespace index " information.
- The location of the block is defined by the inode's in-core extent list: the `di_u.u_bmx[0]` value. The file offset in the extent must always be zero and the `length` = (directory block size / filesystem block size). The block number points to the filesystem block containing the directory data.
- Block directory data is stored in the following structures:

```
#define XFS_DIR2_DATA_FD_COUNT  3

typedef struct xfs_dir2_block {
     xfs_dir2_data_hdr_t       hdr;
     xfs_dir2_data_union_t     u[1];
     xfs_dir2_leaf_entry_t     leaf[1];
     xfs_dir2_block_tail_t     tail;
} xfs_dir2_block_t;

typedef struct xfs_dir2_data_hdr {
     __uint32_t                magic;
     xfs_dir2_data_free_t      bestfree[XFS_DIR2_DATA_FD_COUNT];
} xfs_dir2_data_hdr_t;

typedef struct xfs_dir2_data_free {
     xfs_dir2_data_off_t       offset;
     xfs_dir2_data_off_t       length;
} xfs_dir2_data_free_t;

typedef union {
     xfs_dir2_data_entry_t     entry;
     xfs_dir2_data_unused_t    unused;
} xfs_dir2_data_union_t;

typedef struct xfs_dir2_data_entry {
     xfs_ino_t                 inumber;
     __uint8_t                 namelen;
     __uint8_t                 name[1];
     xfs_dir2_data_off_t       tag;
} xfs_dir2_data_entry_t;

typedef struct xfs_dir2_data_unused {
     __uint16_t                freetag;  /* 0xffff */
     xfs_dir2_data_off_t       length;
     xfs_dir2_data_off_t       tag;
} xfs_dir2_data_unused_t;

typedef struct xfs_dir2_leaf_entry {
     xfs_dahash_t              hashval;
     xfs_dir2_dataptr_t        address;
} xfs_dir2_leaf_entry_t;

typedef struct xfs_dir2_block_tail {
     __uint32_t                count;
     __uint32_t                stale;
} xfs_dir2_block_tail_t;
```



- The `tag` in the `xfs_dir2_data_entry_t` structure stores its offset from the start of the block.
- Start of a free space region is marked with the `xfs_dir2_data_unused_t` structure where the `freetag` is `0xffff`. The `freetag` and `length` overwrites the `inumber` for an entry. The `tag` is located at `length - sizeof(tag)` from the start of the `unused` entry on-disk.

- The `bestfree` array in the header points to as many as three of the largest spaces of free space within the block for storing new entries sorted by largest to third largest. If there are less than 3 empty regions, the remaining `bestfree` elements are zeroed. The `offset` specifies the offset from the start of the block in bytes, and the `length` specifies the size of the free space in bytes. The location each points to must contain the above `xfs_dir2_data_unused_t` structure. As a block cannot exceed 64KB in size, each is a 16-bit value. `bestfree` is used to optimise the time required to locate space to create an entry. It saves scanning through the block to find a location suitable for every entry created.
- The `tail` structure specifies the number of elements in the `leaf` array and the number of `stale` entries in the array. The `tail` is always located at the end of the block. The `leaf` data immediately precedes the `tail` structure.
- The `leaf` array, which grows from the end of the block just before the `tail` structure, contains an array of hash/address pairs for quickly looking up a name by a hash value. Hash values are covered by the introduction to directories. The `address` on-disk is the offset into the block divided by 8 (`XFS_DIR2_DATA_ALIGN`). Hash/address pairs are stored on disk to optimise lookup speed for large directories. If they were not stored, the hashes have to be calculated for all entries each time a lookup occurs in a directory.

xfs_db Example:

A directory is created with 8 entries, directory block size = filesystem block size:

```
xfs_db> sb 0
xfs_db> p
magicnum = 0x58465342
blocksize = 4096
...
dirblklog = 0
...
xfs_db> inode <inode#>
xfs_db> p
core.magic = 0x494e
core.mode = 040755
core.version = 1
core.format = 2 (extents)
core.nlinkv1 = 2
...
core.size = 4096
core.nblocks = 1
core.extsize = 0
core.nextents = 1
...
u.bmx[0] = [startoff,startblock,blockcount,extentflag] 0:[0,2097164,1,0]
```

Go to the "startblock" and show the raw disk data:

```
xfs_db> dblock 0
xfs_db> type text
xfs_db> p
000:  58 44 32 42 01 30 0e 78 00 00 00 00 00 00 00 00  XD2B.0.x........
010:  00 00 00 00 02 00 00 80 01 2e 00 00 00 00 00 10  ................
020:  00 00 00 00 00 00 00 80 02 2e 2e 00 00 00 00 20  ...............
030:  00 00 00 00 02 00 00 81 0f 66 72 61 6d 65 30 30  .........frame00
040:  30 30 30 30 2e 74 73 74 80 8e 59 00 00 00 00 30  0000.tst..Y....0
050:  00 00 00 00 02 00 00 82 0f 66 72 61 6d 65 30 30  .........frame00
060:  30 30 30 31 2e 74 73 74 d0 ca 5c 00 00 00 00 50  0001.tst.......P
070:  00 00 00 00 02 00 00 83 0f 66 72 61 6d 65 30 30  .........frame00
080:  30 30 30 32 2e 74 73 74 00 00 00 00 00 00 00 70  0002.tst.......p
090:  00 00 00 00 02 00 00 84 0f 66 72 61 6d 65 30 30  .........frame00
0a0:  30 30 30 33 2e 74 73 74 00 00 00 00 00 00 00 90  0003.tst........
0b0:  00 00 00 00 02 00 00 85 0f 66 72 61 6d 65 30 30  .........frame00
```

```
0c0:  30 30 30 34 2e 74 73 74 00 00 00 00 00 00 00 b0  0004.tst........
0d0:  00 00 00 00 02 00 00 86 0f 66 72 61 6d 65 30 30  .........frame00
0e0:  30 30 30 35 2e 74 73 74 00 00 00 00 00 00 00 d0  0005.tst........
0f0:  00 00 00 00 02 00 00 87 0f 66 72 61 6d 65 30 30  .........frame00
100:  30 30 30 36 2e 74 73 74 00 00 00 00 00 00 00 f0  0006.tst........
110:  00 00 00 00 02 00 00 88 0f 66 72 61 6d 65 30 30  .........frame00
120:  30 30 30 37 2e 74 73 74 00 00 00 00 00 00 01 10  0007.tst........
130:  ff ff 0e 78 00 00 00 00 00 00 00 00 00 00 00 00  ...x............
```

The "leaf" and "tail" structures are stored at the end of the block, so as the directory grows, the middle is filled in:

```
fa0:  00 00 00 00 00 00 01 30 00 00 00 2e 00 00 00 02  .......0........
fb0:  00 00 17 2e 00 00 00 04 83 a0 40 b4 00 00 00 0e  ..............
fc0:  93 a0 40 b4 00 00 00 12 a3 a0 40 b4 00 00 00 06  ..............
fd0:  b3 a0 40 b4 00 00 00 0a c3 a0 40 b4 00 00 00 1e  ..............
fe0:  d3 a0 40 b4 00 00 00 22 e3 a0 40 b4 00 00 00 16  ..............
ff0:  f3 a0 40 b4 00 00 00 1a 00 00 00 0a 00 00 00 00  ..............
```

In a readable format:

```
xfs_db> type dir2
xfs_db> p
bhdr.magic = 0x58443242
bhdr.bestfree[0].offset = 0x130
bhdr.bestfree[0].length = 0xe78
bhdr.bestfree[1].offset = 0
bhdr.bestfree[1].length = 0
bhdr.bestfree[2].offset = 0
bhdr.bestfree[2].length = 0
bu[0].inumber = 33554560
bu[0].namelen = 1
bu[0].name = "."
bu[0].tag = 0x10
bu[1].inumber = 128
bu[1].namelen = 2
bu[1].name = ".."
bu[1].tag = 0x20
bu[2].inumber = 33554561
bu[2].namelen = 15
bu[2].name = "frame000000.tst"
bu[2].tag = 0x30
bu[3].inumber = 33554562
bu[3].namelen = 15
bu[3].name = "frame000001.tst"
bu[3].tag = 0x50
...
bu[8].inumber = 33554567
bu[8].namelen = 15
bu[8].name = "frame000006.tst"
bu[8].tag = 0xf0
bu[9].inumber = 33554568
bu[9].namelen = 15
bu[9].name = "frame000007.tst"
bu[9].tag = 0x110
bu[10].freetag = 0xffff
bu[10].length = 0xe78
bu[10].tag = 0x130
bleaf[0].hashval = 0x2e
bleaf[0].address = 0x2
bleaf[1].hashval = 0x172e
bleaf[1].address = 0x4
bleaf[2].hashval = 0x83a040b4
bleaf[2].address = 0xe
...
```

```
bleaf[8].hashval = 0xe3a040b4
bleaf[8].address = 0x16
bleaf[9].hashval = 0xf3a040b4
bleaf[9].address = 0x1a
btail.count = 10
btail.stale = 0
```

Note that with block directories, all xfs_db fields are preceded with "b".

For a simple lookup example, the hash of frame000000.tst is 0xb3a040b4. Looking up that value, we get an address of 0x6. Multiply that by 8, it becomes offset 0x30 and the inode at that point is 33554561.

When we remove an entry from the middle (frame000004.tst), we can see how the freespace details are adjusted:

```
bhdr.magic = 0x58443242
bhdr.bestfree[0].offset = 0x130
bhdr.bestfree[0].length = 0xe78
bhdr.bestfree[1].offset = 0xb0
bhdr.bestfree[1].length = 0x20
bhdr.bestfree[2].offset = 0
bhdr.bestfree[2].length = 0
...
bu[5].inumber = 33554564
bu[5].namelen = 15
bu[5].name = "frame000003.tst"
bu[5].tag = 0x90
bu[6].freetag = 0xffff
bu[6].length = 0x20
bu[6].tag = 0xb0
bu[7].inumber = 33554566
bu[7].namelen = 15
bu[7].name = "frame000005.tst"
bu[7].tag = 0xd0
...
bleaf[7].hashval = 0xd3a040b4
bleaf[7].address = 0x22
bleaf[8].hashval = 0xe3a040b4
bleaf[8].address = 0
bleaf[9].hashval = 0xf3a040b4
bleaf[9].address = 0x1a
btail.count = 10
btail.stale = 1
```

A new "bestfree" value is added for the entry, the start of the entry is marked as unused with 0xffff (which overwrites the inode number for an actual entry), and the length of the space. The tag remains intact at the `offset+length - sizeof(tag)`. The address for the hash is also cleared. The affected areas are highlighted below:

```
090:  00 00 00 00 02 00 00 84 0f 66 72 61 6d 65 30 30  .........frame00
0a0:  30 30 30 33 2e 74 73 74 00 00 00 00 00 00 00 90  0003.tst........
0b0:  ff ff 00 20 02 00 00 85 0f 66 72 61 6d 65 30 30  .........frame00
0c0:  30 30 30 34 2e 74 73 74 00 00 00 00 00 00 00 b0  0004.tst........
0d0:  00 00 00 00 02 00 00 86 0f 66 72 61 6d 65 30 30  .........frame00
0e0:  30 30 30 35 2e 74 73 74 00 00 00 00 00 00 00 d0  0005.tst........
...
fb0:  00 00 17 2e 00 00 00 04 83 a0 40 b4 00 00 00 0e  ..............
fc0:  93 a0 40 b4 00 00 00 12 a3 a0 40 b4 00 00 00 06  ..............
fd0:  b3 a0 40 b4 00 00 00 0a c3 a0 40 b4 00 00 00 1e  ..............
fe0:  d3 a0 40 b4 00 00 00 22 e3 a0 40 b4 00 00 00 00  ..............
ff0:  f3 a0 40 b4 00 00 00 1a 00 00 00 0a 00 00 00 01  ..............
```

Leaf Directories

Once a Block Directory has filled the block, the directory data is changed into a new format. It still uses extents and the same basic structures, but the "data" and "leaf" are split up into their own extents. The "leaf" information only occupies one extent. As "leaf" information is more compact than "data" information, more than one "data" extent is common.

- Block to Leaf conversions retain the existing block for the data entries and allocate a new block for the leaf and freespace index information.
- As with all directories, data blocks must start at logical offset zero.
- The "leaf" block has a special offset defined by `XFS_DIR2_LEAF_OFFSET`. Currently, this is 32GB and in the extent view, a block offset of 32GB/sb_blocksize. On a 4KB block filesystem, this is 0x800000 (8388608 decimal).
- The "data" extents have a new header (no "leaf" data):

```
typedef struct xfs_dir2_data {
     xfs_dir2_data_hdr_t        hdr;
     xfs_dir2_data_union_t      u[1];
} xfs_dir2_data_t;
```

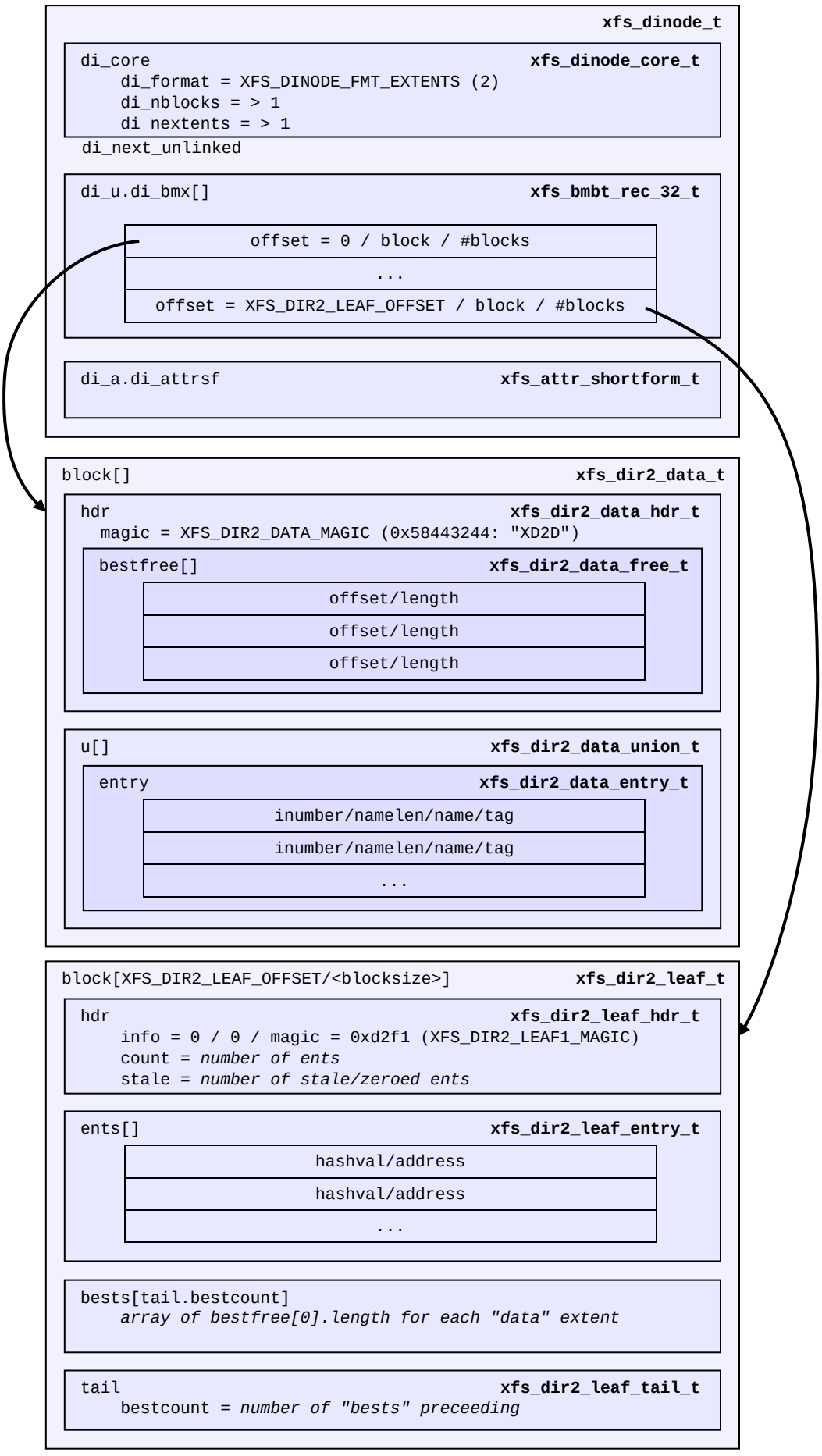
- The "leaf" extent uses the following structures:

```
typedef struct xfs_dir2_leaf {
     xfs_dir2_leaf_hdr_t        hdr;
     xfs_dir2_leaf_entry_t      ents[1];

     xfs_dir2_data_off_t        bests[1];
     xfs_dir2_leaf_tail_t       tail;
} xfs_dir2_leaf_t;

typedef struct xfs_dir2_leaf_hdr {
     xfs_da_blkinfo_t           info;
     __uint16_t                 count;
     __uint16_t                 stale;
} xfs_dir2_leaf_hdr_t;

typedef struct xfs_dir2_leaf_tail {
     __uint32_t                 bestcount;
} xfs_dir2_leaf_tail_t;
```

- The leaves use the `xfs_da_blkinfo_t` filesystem block header. This header is used for directory and extended attribute leaves and B+tree nodes:

```
typedef struct xfs_da_blkinfo {
     __be32                             forw;
     __be32                             back;
     __be16                             magic;
     __be16                             pad;
} xfs_da_blkinfo_t;
```

- The size of the `ents` array is specified by `hdr.count`.
- The size of the `bests` array is specified by the `tail.bestcount` which is also the number of "data" blocks for the directory. The `bests` array maintains each data block's `bestfree[0].length` value.


xfs_dinode_t
di_core
xfs_dinode_core_t
di_format = XFS_DINODE_FMT_EXTENTS (2)
di_nblocks = > 1
di nextents = > 1
di_next_unlinked
di_u.di_bmx[]
xfs_bmbt_rec_32_t
offset = 0 / block / #blocks
...
offset = XFS_DIR2_LEAF_OFFSET / block / #blocks
di_a.di_attrsf
xfs_attr_shortform_t
block[]
xfs_dir2_data_t
hdr
xfs_dir2_data_hdr_t
magic = XFS_DIR2_DATA_MAGIC (0x58443244: "XD2D")
bestfree[]
xfs_dir2_data_free_t
offset/length
offset/length
offset/length
u[]
xfs_dir2_data_union_t
entry
xfs_dir2_data_entry_t
inumber/namelen/name/tag
inumber/namelen/name/tag
...
block[XFS_DIR2_LEAF_OFFSET/<blocksize>]
xfs_dir2_leaf_t
hdr
xfs_dir2_leaf_hdr_t
info = 0 / 0 / magic = 0xd2f1 (XFS_DIR2_LEAF1_MAGIC)
count = number of ents
stale = number of stale/zeroed ents
ents[]
xfs_dir2_leaf_entry_t
hashval/address
hashval/address
...
bests[tail.bestcount]
array of bestfree[0].length for each "data" extent
tail
xfs_dir2_leaf_tail_t
bestcount = number of "bests" preceeding

xfs_db Example:

For this example, a directory was created with 256 entries (frame000000.tst to frame000255.tst) and then deleted some files (frame00005*, frame00018* and frame000240.tst) to show free list characteristics.

```
xfs_db> inode <inode#>
xfs_db> p
core.magic = 0x494e
core.mode = 040755
core.version = 1
core.format = 2 (extents)
core.nlinkv1 = 2
...
core.size = 12288
core.nblocks = 4
core.extsize = 0
core.nextents = 3
...
u.bmx[0-2] = [startoff,startblock,blockcount,extentflag]
         0:[0,4718604,1,0]
         1:[1,4718610,2,0]
         2:[8388608,4718605,1,0]
```

As can be seen in this example, three blocks are used for "data" in two extents, and the "leaf" extent has a logical offset of 8388608 blocks (32GB).

Examining the first block:

```
xfs_db> dblock 0
xfs_db> type dir2
xfs_db> p
dhdr.magic = 0x58443244
dhdr.bestfree[0].offset = 0x670
dhdr.bestfree[0].length = 0x140
dhdr.bestfree[1].offset = 0xff0
dhdr.bestfree[1].length = 0x10
dhdr.bestfree[2].offset = 0
dhdr.bestfree[2].length = 0
du[0].inumber = 75497600
du[0].namelen = 1
du[0].name = "."
du[0].tag = 0x10
du[1].inumber = 128
du[1].namelen = 2
du[1].name = ".."
du[1].tag = 0x20
du[2].inumber = 75497601
du[2].namelen = 15
du[2].name = "frame000000.tst"
du[2].tag = 0x30
du[3].inumber = 75497602
du[3].namelen = 15
du[3].name = "frame000001.tst"
du[3].tag = 0x50
...
du[51].inumber = 75497650
du[51].namelen = 15
du[51].name = "frame000049.tst"
du[51].tag = 0x650
du[52].freetag = 0xffff
du[52].length = 0x140
du[52].tag = 0x670
du[53].inumber = 75497661
du[53].namelen = 15
du[53].name = "frame000060.tst"
```

```
du[53].tag = 0x7b0
...
du[118].inumber = 75497758
du[118].namelen = 15
du[118].name = "frame000125.tst"
du[118].tag = 0xfd0
du[119].freetag = 0xffff
du[119].length = 0x10
du[119].tag = 0xff0
```

Note that the xfs_db field output is preceded by a "d" for "data".

The next "data" block:

```
xfs_db> dblock 1
xfs_db> type dir2
xfs_db> p
dhdr.magic = 0x58443244
dhdr.bestfree[0].offset = 0x6d0
dhdr.bestfree[0].length = 0x140
dhdr.bestfree[1].offset = 0xe50
dhdr.bestfree[1].length = 0x20
dhdr.bestfree[2].offset = 0xff0
dhdr.bestfree[2].length = 0x10
du[0].inumber = 75497759
du[0].namelen = 15
du[0].name = "frame000126.tst"
du[0].tag = 0x10
...
du[53].inumber = 75497844
du[53].namelen = 15
du[53].name = "frame000179.tst"
du[53].tag = 0x6b0
du[54].freetag = 0xffff
du[54].length = 0x140
du[54].tag = 0x6d0
du[55].inumber = 75497855
du[55].namelen = 15
du[55].name = "frame000190.tst"
du[55].tag = 0x810
...
du[104].inumber = 75497904
du[104].namelen = 15
du[104].name = "frame000239.tst"
du[104].tag = 0xe30
du[105].freetag = 0xffff
du[105].length = 0x20
du[105].tag = 0xe50
du[106].inumber = 75497906
du[106].namelen = 15
du[106].name = "frame000241.tst"
du[106].tag = 0xe70
...
du[117].inumber = 75497917
du[117].namelen = 15
du[117].name = "frame000252.tst"
du[117].tag = 0xfd0
du[118].freetag = 0xffff
du[118].length = 0x10
du[118].tag = 0xff0
```

And the last data block:

```
xfs_db> dblock 2
xfs_db> type dir2
xfs_db> p
dhdr.magic = 0x58443244
dhdr.bestfree[0].offset = 0x70
dhdr.bestfree[0].length = 0xf90
```

```
dhdr.bestfree[1].offset = 0
dhdr.bestfree[1].length = 0
dhdr.bestfree[2].offset = 0
dhdr.bestfree[2].length = 0
du[0].inumber = 75497918
du[0].namelen = 15
du[0].name = "frame000253.tst"
du[0].tag = 0x10
du[1].inumber = 75497919
du[1].namelen = 15
du[1].name = "frame000254.tst"
du[1].tag = 0x30
du[2].inumber = 75497920
du[2].namelen = 15
du[2].name = "frame000255.tst"
du[2].tag = 0x50
du[3].freetag = 0xffff
du[3].length = 0xf90
du[3].tag = 0x70
```

Examining the "leaf" block (with the fields preceded by an "l" for "leaf"):

The directory before deleting some entries:

```
xfs_db> dblock 8388608
xfs_db> type dir2
xfs_db> p
lhdr.info.forw = 0
lhdr.info.back = 0
lhdr.info.magic = 0xd2f1
lhdr.count = 258
lhdr.stale = 0
lbests[0-2] = 0:0x10 1:0x10 2:0xf90
lents[0].hashval = 0x2e
lents[0].address = 0x2
lents[1].hashval = 0x172e
lents[1].address = 0x4
lents[2].hashval = 0x23a04084
lents[2].address = 0x116
...
lents[257].hashval = 0xf3a048bc
lents[257].address = 0x366
ltail.bestcount = 3
```

Note how the `lbests` array correspond with the `bestfree[0].length` values in the "data" blocks:

```
xfs_db> dblock 0
xfs_db> type dir2
xfs_db> p
dhdr.magic = 0x58443244
dhdr.bestfree[0].offset = 0xff0
dhdr.bestfree[0].length = 0x10
...
xfs_db> dblock 1
xfs_db> type dir2
xfs_db> p
dhdr.magic = 0x58443244
dhdr.bestfree[0].offset = 0xff0
dhdr.bestfree[0].length = 0x10
...
xfs_db> dblock 2
xfs_db> type dir2
xfs_db> p
dhdr.magic = 0x58443244
dhdr.bestfree[0].offset = 0x70
dhdr.bestfree[0].length = 0xf90
```

Now after the entries have been deleted:

```
xfs_db> dblock 8388608
xfs_db> type dir2
xfs_db> p
lhdr.info.forw = 0
lhdr.info.back = 0
lhdr.info.magic = 0xd2f1
lhdr.count = 258
lhdr.stale = 21
lbests[0-2] = 0:0x140 1:0x140 2:0xf90
lents[0].hashval = 0x2e
lents[0].address = 0x2
lents[1].hashval = 0x172e
lents[1].address = 0x4
lents[2].hashval = 0x23a04084
lents[2].address = 0x116
...
```

As can be seen, the `lbests` values have been update to contain each `hdr.bestfree[0].length` values. The leaf's `hdr.stale` value has also been updated to specify the number of stale entries in the array. The stale entries have an address of zero.

TODO: Need an example for where new entries get inserted with several large free spaces.

Node Directories

When the "leaf" information fills a block, the extents undergo another separation. All "freeindex" information moves into its own extent. Like Leaf Directories, the "leaf" block maintained the best free space information for each "data" block. This is not possible with more than one leaf.

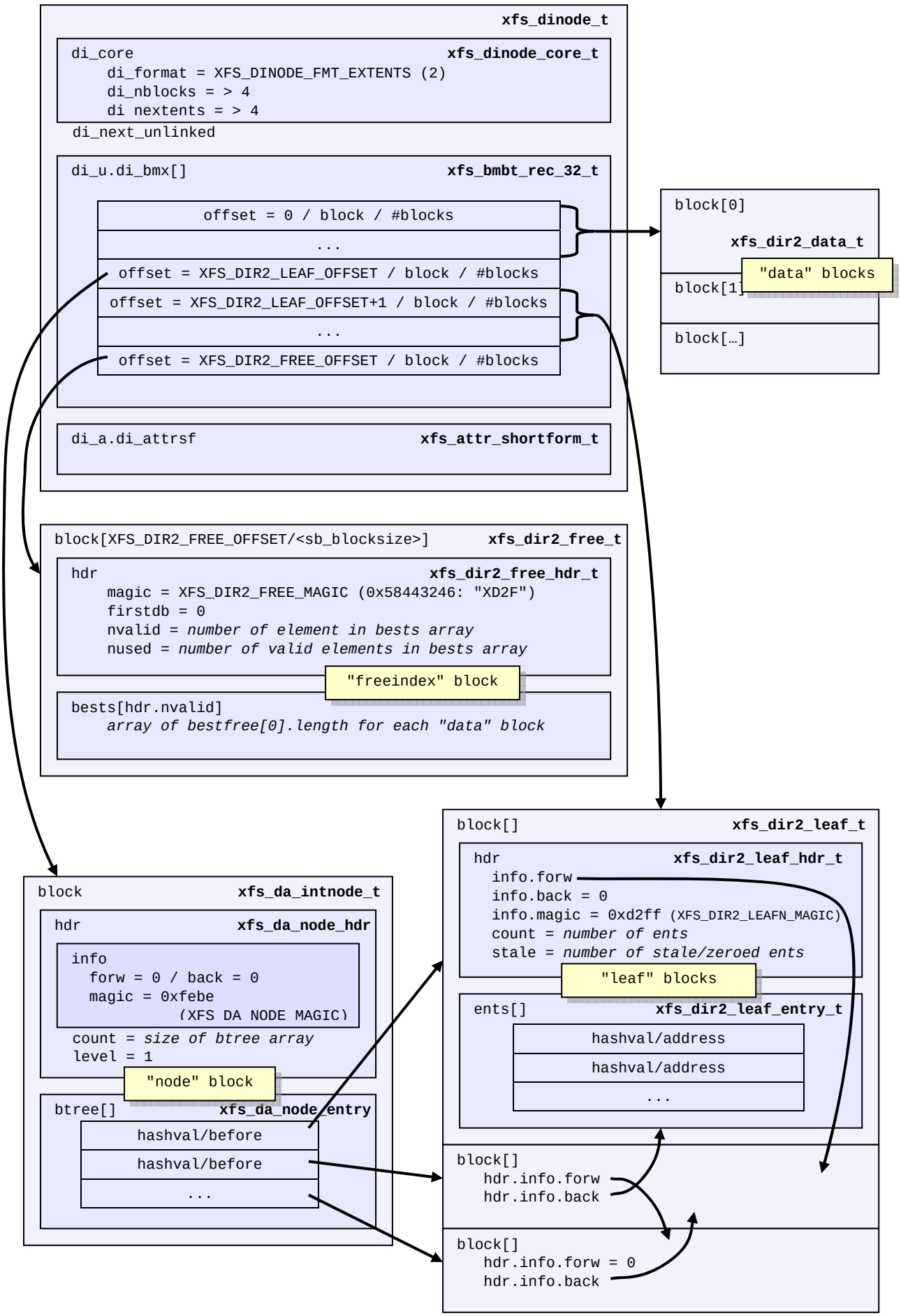
- The "data" blocks stay the same as leaf directories.
- The "leaf" blocks eventually change into a B+tree with the generic B+tree header pointing to directory "leaves" as described in Leaf Directories. The top-level blocks are called "nodes". It can exist in a state where there is still a single leaf block before it's split. Interpretation of the node vs. leaf blocks has to be performed by inspecting the magic value in the header. The combined leaf/freeindex blocks has a magic value of `XFS_DIR2_LEAF1_MAGIC (0xd2f1)`, a node directory's leaf/leaves have a magic value of `XFS_DIR2_LEAFN_MAGIC (0xd2ff)` and intermediate nodes have a magic value of `XFS_DA_NODE_MAGIC (0xfebe)`.
- The new "freeindex" block(s) only contains the bests for each data block.
- The freeindex block uses the following structures:

```
typedef struct xfs_dir2_free_hdr {
     __uint32_t                magic;
     __int32_t                 firstdb;
     __int32_t                 nvalid;
     __int32_t                 nused;
} xfs_dir2_free_hdr_t;

typedef struct xfs_dir2_free {
     xfs_dir2_free_hdr_t       hdr;
     xfs_dir2_data_off_t       bests[1];
} xfs_dir2_free_t;
```

- The location of the leaf blocks can be in any order, the only way to determine the appropriate is by the node block hash/before values. Given a hash to lookup, you read the node's `btree` array and first `hashval` in the array that exceeds the given hash and it can then be found in the block pointed to by the `before` value.

```
typedef struct xfs_da_intnode {
     struct xfs_da_node_hdr {
          xfs_da_blkinfo_t     info;
          __uint16_t           count;
          __uint16_t           level;
     } hdr;
     struct xfs_da_node_entry {
          xfs_dahash_t         hashval;
          xfs_dablk_t          before;
     } btree[1];
} xfs_da_intnode_t;
```

- The freeindex's `bests` array starts from the end of the block and grows to the start of the block.
- When an data block becomes unused (ie. all entries in it have been deleted), the block is freed, the data extents contain a hole, and the freeindex's `hdr.nused` value is decremented and the associated `bests[]` entry is set to 0xffff.
- As the first data block always contains "." and "..", it's invalid for the directory to have a hole at the start.
- The freeindex's `hdr.nvalid` should always be the same as the number of allocated data directory blocks containing name/inode data and will always be less than or equal to `hdr.nused`. `hdr.nused` should be the same as the index of the last data directory block plus one (i.e. when the last data block is freed, `nused` and `nvalid` are decremented).


xfs_dinode_t
di_core
xfs_dinode_core_t
di_format = XFS_DINODE_FMT_EXTENTS (2)
di_nblocks = > 4
di nextents = > 4
di_next_unlinked
di_u.di_bmx[]
xfs_bmbt_rec_32_t
offset = 0 / block / #blocks
...
offset = XFS_DIR2_LEAF_OFFSET / block / #blocks
offset = XFS_DIR2_LEAF_OFFSET+1 / block / #blocks
...
offset = XFS_DIR2_FREE_OFFSET / block / #blocks
di_a.di_attrsf
xfs_attr_shortform_t
block[0]
xfs_dir2_data_t
"data" blocks
block[1]
block[…]
block[XFS_DIR2_FREE_OFFSET/<sb_blocksize>]
xfs_dir2_free_t
hdr
xfs_dir2_free_hdr_t
magic = XFS_DIR2_FREE_MAGIC (0x58443246: "XD2F")
firstdb = 0
nvalid = number of element in bests array
nused = number of valid elements in bests array
"freeindex" block
bests[hdr.nvalid]
array of bestfree[0].length for each "data" block
block
xfs_da_intnode_t
hdr
xfs_da_node_hdr
info
forw = 0 / back = 0
magic = 0xfebe
(XFS DA NODE MAGIC)
count = size of btree array
level = 1
"node" block
btree[]
xfs_da_node_entry
hashval/before
hashval/before
...
block[]
xfs_dir2_leaf_t
hdr
xfs_dir2_leaf_hdr_t
info.forw
info.back = 0
info.magic = 0xd2ff (XFS_DIR2_LEAFN_MAGIC)
count = number of ents
stale = number of stale/zeroed ents
"leaf" blocks
ents[]
xfs_dir2_leaf_entry_t
hashval/address
hashval/address
...
block[]
hdr.info.forw
hdr.info.back
block[]
hdr.info.forw = 0
hdr.info.back

xfs_db Example:

With the node directory examples, we are using a filesystems with 4KB block size, and a 16KB directory size. The directory has over 2000 entries:

```
xfs_db> sb 0
xfs_db> p
magicnum = 0x58465342
blocksize = 4096
...
dirblklog = 2
...

xfs_db> inode <inode#>
xfs_db> p
core.magic = 0x494e
core.mode = 040755
core.version = 1
core.format = 2 (extents)
...
core.size = 81920
core.nblocks = 36
core.extsize = 0
core.nextents = 8
...
u.bmx[0-7] = [startoff,startblock,blockcount,extentflag] 0:[0,7368,4,0]
1:[4,7408,4,0] 2:[8,7444,4,0] 3:[12,7480,4,0] 4:[16,7520,4,0]
5:[8388608,7396,4,0] 6:[8388612,7524,8,0] 7:[16777216,7516,4,0]
```

As can already be observed, all extents are allocated is multiples of 4 blocks.

Blocks 0 to 19 (16+4-1) are used for the data. Looking at blocks 16-19, it can seen that it's the same as the single-leaf format, except the `length` values are a lot larger to accommodate the increased directory block size:

```
xfs_db> dblock 16
xfs_db> type dir2
xfs_db> p
dhdr.magic = 0x58443244
dhdr.bestfree[0].offset = 0xb0
dhdr.bestfree[0].length = 0x3f50
dhdr.bestfree[1].offset = 0
dhdr.bestfree[1].length = 0
dhdr.bestfree[2].offset = 0
dhdr.bestfree[2].length = 0
du[0].inumber = 120224
du[0].namelen = 15
du[0].name = "frame002043.tst"
du[0].tag = 0x10
du[1].inumber = 120225
du[1].namelen = 15
du[1].name = "frame002044.tst"
du[1].tag = 0x30
du[2].inumber = 120226
du[2].namelen = 15
du[2].name = "frame002045.tst"
du[2].tag = 0x50
du[3].inumber = 120227
du[3].namelen = 15
du[3].name = "frame002046.tst"
du[3].tag = 0x70
du[4].inumber = 120228
du[4].namelen = 15
du[4].name = "frame002047.tst"
du[4].tag = 0x90
du[5].freetag = 0xffff
du[5].length = 0x3f50
```

```
du[5].tag = 0
```

Next, the "node" block, the fields are preceded with 'n' for node blocks:

```
xfs_db> dblock 8388608
xfs_db> type dir2
xfs_db> p
nhdr.info.forw = 0
nhdr.info.back = 0
nhdr.info.magic = 0xfebe
nhdr.count = 2
nhdr.level = 1
nbtree[0-1] = [hashval,before] 0:[0xa3a440ac,8388616] 1:[0xf3a440bc,8388612]
```

The following leaf blocks have been allocated once as XFS knows it needs at two blocks when allocating a B+tree, so the length is 8 fsblocks. For all hashes < 0xa3a440ac, they are located in the directory offset 8388616 and hashes below 0xf3a440bc are in offset 8388612. Hashes above f3a440bc don't exist in this directory.

```
xfs_db> dblock 8388616
xfs_db> type dir2
xfs_db> p
lhdr.info.forw = 8388612
lhdr.info.back = 0
lhdr.info.magic = 0xd2ff
lhdr.count = 1023
lhdr.stale = 0
lents[0].hashval = 0x2e
lents[0].address = 0x2
lents[1].hashval = 0x172e
lents[1].address = 0x4
lents[2].hashval = 0x23a04084
lents[2].address = 0x116
...
lents[1021].hashval = 0xa3a440a4
lents[1021].address = 0x1fa2
lents[1022].hashval = 0xa3a440ac
lents[1022].address = 0x1fca

xfs_db> dblock 8388612
xfs_db> type dir2
xfs_db> p
lhdr.info.forw = 0
lhdr.info.back = 8388616
lhdr.info.magic = 0xd2ff
lhdr.count = 1027
lhdr.stale = 0
lents[0].hashval = 0xa3a440b4
lents[0].address = 0x1f52
lents[1].hashval = 0xa3a440bc
lents[1].address = 0x1f7a
...
lents[1025].hashval = 0xf3a440b4
lents[1025].address = 0x1f66
lents[1026].hashval = 0xf3a440bc
lents[1026].address = 0x1f8e
```

An example lookup using xfs_db:

```
xfs_db> hash frame001845.tst
0xf3a26094

Doing a binary search through the array, we get address 0x1ce6, which is
offset 0xe730. Each fsblock is 4KB in size (0x1000), so it will be offset
0x730 into directory offset 14. From the extent map, this will be fsblock
7482:

xfs_db> fsblock 7482
```

```
xfs_db> type text
xfs_db> p
...
730:  00 00 00 00 00 01 d4 da 0f 66 72 61 6d 65 30 30  .........frame00
740:  31 38 34 35 2e 74 73 74 00 00 00 00 00 00 27 30  1845.tst.......0
```

Looking at the freeindex information (fields with an 'f' tag):

```
xfs_db> fsblock 7516
xfs_db> type dir2
xfs_db> p
fhdr.magic = 0x58443246
fhdr.firstdb = 0
fhdr.nvalid = 5
fhdr.nused = 5
fbests[0-4] = 0:0x10 1:0x10 2:0x10 3:0x10 4:0x3f50
```

Like the Leaf Directory, each of the `fbests` values correspond to each data block's `bestfree[0].length` value.

The raw disk layout, old data is not cleared after the array. The fbests array is highlighted:

```
xfs_db> type text
xfs_db> p
000:  58 44 32 46 00 00 00 00 00 00 00 05 00 00 00 05  XD2F............
010:  00 10 00 10 00 10 00 10 3f 50 00 00 1f 01 ff ff  ........?P......
```

TODO: Example with a hole in the middle

B+tree Directories

When the extent map in an inode grows beyond the inode's space, the inode format is changed to a "btree". The inode contains a filesystem block point to the B+tree extent map for the directory's blocks. The B+tree extents contain the extent map for the "data", "node", "leaf" and "freeindex" information as described in Node Directories.

Refer to the previous section on B+tree Data Extents for more information on XFS B+tree extents.

The following situations and changes can apply over Node Directories, and apply here as inode extents generally cannot contain the number of directory blocks that B+trees can handle:

- The node/leaf trees can be more than one level deep.
- More than one freeindex block may exist, but this will be quite rare. It would required hundreds of thousand files with quite long file names (or millions with shorter names) to get a second freeindex block.

xfs_db Example:

A directory has been created with 200,000 entries with each entry being 100 characters long. The filesystem block size and directory block size are 4KB:

```
xfs_db> inode 772
xfs_db> p
core.magic = 0x494e
core.mode = 040755
core.version = 1
core.format = 3 (btree)
...
core.size = 22757376
core.nblocks = 6145
core.extsize = 0
core.nextents = 234
core.naextents = 0
core.forkoff = 0
...
u.bmbt.level = 1
u.bmbt.numrecs = 1
u.bmbt.keys[1] = [startoff] 1:[0]
u.bmbt.ptrs[1] = 1:89

xfs_db> fsblock 89
xfs_db> type bmapbtd
xfs_db> p
magic = 0x424d4150
level = 0
numrecs = 234
leftsib = null
rightsib = null
recs[1-234] = [startoff,startblock,blockcount,extentflag]
   1:[0,53,1,0] 2:[1,55,13,0] 3:[14,69,1,0] 4:[15,72,13,0]
   5:[28,86,2,0] 6:[30,90,21,0] 7:[51,112,1,0] 8:[52,114,11,0]
   ...
   125:[5177,902,15,0] 126:[5192,918,6,0] 127:[5198,524786,358,0]
   128:[8388608,54,1,0] 129:[8388609,70,2,0] 130:[8388611,85,1,0]
   ...
   229:[8389164,917,1,0] 230:[8389165,924,19,0] 231:[8389184,944,9,0]
   232:[16777216,68,1,0] 233:[16777217,7340114,1,0] 234:[16777218,5767362,1,0]
```

We have 128 extents and a total of 5555 blocks being used to store name/inode pairs. With only about 2000 values that can be stored in the freeindex block, 3 blocks have been allocated for this information. The `firstdb` field specifies the starting directory block number for each array:

```
xfs_db> dblock 16777216
xfs_db> type dir2
xfs_db> p
fhdr.magic = 0x58443246
fhdr.firstdb = 0
fhdr.nvalid = 2040
fhdr.nused = 2040
fbests[0-2039] = ...

xfs_db> dblock 16777217
xfs_db> type dir2
xfs_db> p
fhdr.magic = 0x58443246
fhdr.firstdb = 2040
fhdr.nvalid = 2040
fhdr.nused = 2040
fbests[0-2039] = ...

xfs_db> dblock 16777218
xfs_db> type dir2
xfs_db> p
fhdr.magic = 0x58443246
fhdr.firstdb = 4080
fhdr.nvalid = 1476
fhdr.nused = 1476
fbests[0-1475] = ...
```

Looking at the root node in the node block, it's a pretty deep tree:

```
xfs_db> dblock 8388608
xfs_db> type dir2
xfs_db> p
nhdr.info.forw = 0
nhdr.info.back = 0
nhdr.info.magic = 0xfebe
nhdr.count = 2
nhdr.level = 2
nbtree[0-1] = [hashval,before] 0:[0x6bbf6f39,8389121] 1:[0xfbbf7f79,8389120]

xfs_db> dblock 8389121
xfs_db> type dir2
xfs_db> p
nhdr.info.forw = 8389120
nhdr.info.back = 0
nhdr.info.magic = 0xfebe
nhdr.count = 263
nhdr.level = 1
nbtree[0-262] = ... 262:[0x6bbf6f39,8388928]

xfs_db> dblock 8389120
xfs_db> type dir2
xfs_db> p
nhdr.info.forw = 0
nhdr.info.back = 8389121
nhdr.info.magic = 0xfebe
nhdr.count = 319
nhdr.level = 1
nbtree[0-318] = [hashval,before] 0:[0x70b14711,8388919] ...
```

The leaves at each the end of a node always point to the end leaves in adjacent nodes. Directory block 8388928 forward pointer is to block 8388919, and vice versa as highlighted in the following example:

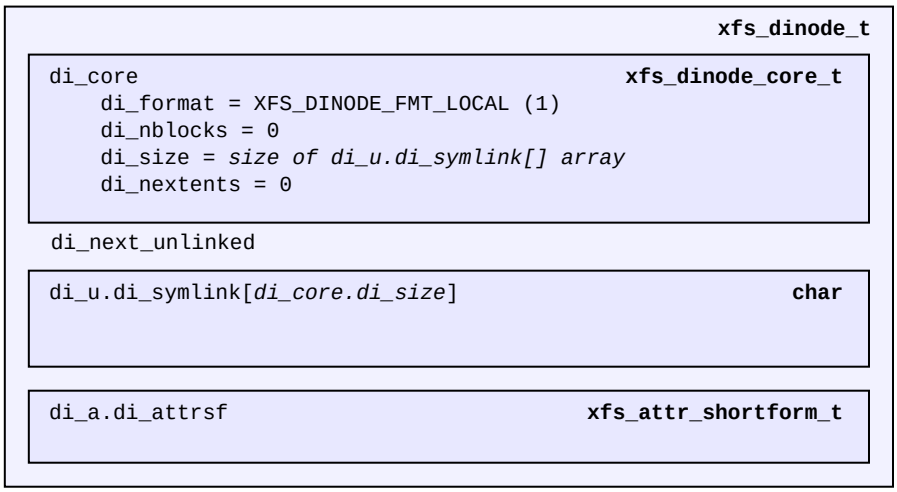
```
xfs_db> dblock 8388928
xfs_db> type dir2
xfs_db> p
lhdr.info.forw = 8388919
lhdr.info.back = 8388937
lhdr.info.magic = 0xd2ff
...

xfs_db> dblock 8388919
xfs_db> type dir2
xfs_db> p
lhdr.info.forw = 8388706
lhdr.info.back = 8388928
lhdr.info.magic = 0xd2ff
...
```

Symbolic Links

Symbolic links to a file can be stored in one of two formats: "local" and "extents". The length of the symlink contents is always specified by the inode's `di_size` value.

Shortform Symbolic Links

Symbolic links are stored with the "local" `di_format` if the symbolic link can fit within the inode's data fork. The link data is an array of characters (`di_symlink` array in the data fork union).



xfs_db Example:

A short symbolic link to a file is created:

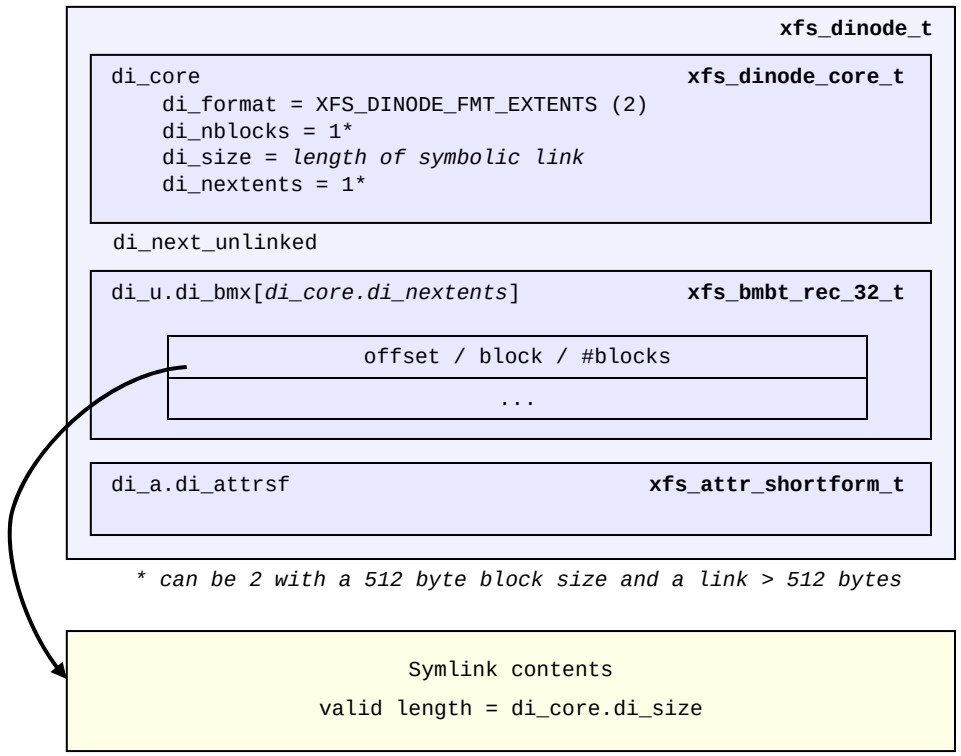
```
xfs_db> inode <inode#>
xfs_db> p
core.magic = 0x494e
core.mode = 0120777
core.version = 1
core.format = 1 (local)
...
core.size = 12
core.nblocks = 0
core.extsize = 0
core.nextents = 0
...
u.symlink = "small_target"
```

Raw on-disk data with the link contents highlighted:

```
xfs_db> type text
xfs_db> p
00:  49 4e a1 ff 01 01 00 01 00 00 00 00 00 00 00 00  IN..............
10:  00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 01  ................
20:  44 bc e1 c7 03 c4 d4 18 44 bc e1 c7 03 c4 d4 18  D.......D.......
30:  44 bc e1 c7 03 c4 d4 18 00 00 00 00 00 00 00 0c  D...............
40:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
50:  00 00 00 02 00 00 00 00 00 00 00 00 00 00 00 00  ................
60:  ff ff ff ff 73 6d 61 6c 6c 5f 74 61 72 67 65 74  ....small.target
70:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
...
```

Extent Symbolic Links

If the length of the symbolic link exceeds the space available in the inode's data fork, the link is moved to a new filesystem block and the inode's `di_format` is changed to "extents". The location of the block(s) is specified by the data fork's `di_bmx[]` array. In the significant majority of cases, this will be in one filesystem block as a symlink cannot be longer than 1024 characters.



xfs_db Example:

A longer link is created (greater than 156 bytes):

```
xfs_db> inode <inode#>
xfs_db> p
core.magic = 0x494e
core.mode = 0120777
core.version = 1
core.format = 2 (extents)
...
core.size = 182
core.nblocks = 1
core.extsize = 0
core.nextents = 1
...
u.bmx[0] = [startoff,startblock,blockcount,extentflag] 0:[0,37530,1,0]

xfs_db> dblock 0
xfs_db> type symlink
xfs_db> p
"symlink contents..."
```

Extended Attributes

Extended attributes implement the ability for a user to attach name:value pairs to inodes within the XFS filesystem. They could be used to store meta-information about the file.

The attribute names can be up to 256 bytes in length, terminated by the first 0 byte. The intent is that they be printable ASCII (or other character set) names for the attribute. The values can be up to 64KB of arbitrary binary data. Some XFS internal attributes (eg. parent pointers) use non-printable names for the attribute.

Access Control Lists (ACLs) and Data Migration Facility (DMF) use extended attributes to store their associated metadata with an inode.

XFS uses two disjoint attribute name spaces associated with every inode. They are the root and user address spaces. The root address space is accessible only to the superuser, and then only by specifying a flag argument to the function call. Other users will not see or be able to modify attributes in the root address space. The user address space is protected by the normal file permissions mechanism, so the owner of the file can decide who is able to see and/or modify the value of attributes on any particular file.

To view extended attributes from the command line, use the `getfattr` command. To set or delete extended attributes, use the `setfattr` command. ACLs control should use the `getfacl` and `setfacl` commands.

XFS attributes supports three namespaces: "user", "trusted" (or "root" using IRIX terminology) and "secure".

The location of the attribute fork in the inode's literal area is specified by the `di_forkoff` value in the inode's core. If this value is zero, the inode does not contain any extended attributes. Non-zero, the byte offset into the literal area = `di_forkoff * 8`, which also determines the 2048 byte maximum size for an inode. Attributes must be allocated on a 64-bit boundary on the disk except shortform attributes (they are tightly packed). To determine the offset into the inode itself, add 100 (0x64) to `di_forkoff * 8`.

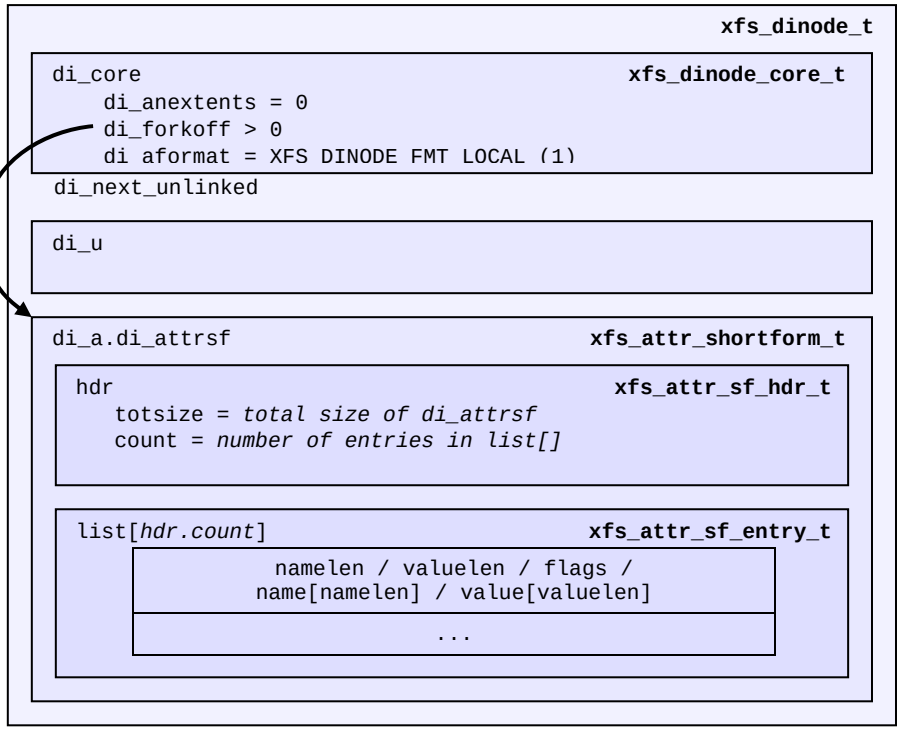
The following four sections describe each of the on-disk formats.

Shortform Attributes

When the all extended attributes can fit within the inode's attribute fork, the inode's `di_aformat` is set to "local" and the attributes are stored in the inode's literal area starting at offset `di_forkoff * 8`.

Shortform attributes use the following structures:

```
typedef struct xfs_attr_shortform {
     struct xfs_attr_sf_hdr {
          __be16               totsize;
          __u8                 count;
     } hdr;
     struct xfs_attr_sf_entry {
          __uint8_t            namelen;
          __uint8_t            valuelen;
          __uint8_t            flags;
          __uint8_t            nameval[1];
     } list[1];
} xfs_attr_shortform_t;

typedef struct xfs_attr_sf_hdr xfs_attr_sf_hdr_t;
typedef struct xfs_attr_sf_entry xfs_attr_sf_entry_t;
```



- `namelen` and `valuelen` specify the size of the two byte arrays containing the name and value pairs. `valuelen` is zero for extended attributes with no value.
- `nameval[]` is a single array where it's size is the sum of `namelen` and `valuelen`. The names and values are not null terminated on-disk. The value immediately follows the name in the array.
- `flags` specifies the namespace for the attribute (0 = "user"):

Flag	Description
XFS_ATTR_ROOT	The attribute's namespace is "trusted".
XFS_ATTR_SECURE	The attribute's namespace is "secure".

xfs_db Example:

A file is created and two attributes are set:

```
# setfattr -n user.empty few_attr
# setfattr -n trusted.trust -v val1 few_attr
```

Using xfs_db, we dump the inode:

```
xfs_db> inode <inode#>
xfs_db> p
core.magic = 0x494e
core.mode = 0100644
...
core.naextents = 0
core.forkoff = 15
core.aformat = 1 (local)
...
a.sfattr.hdr.totsize = 24
a.sfattr.hdr.count = 2
a.sfattr.list[0].namelen = 5
a.sfattr.list[0].valuelen = 0
a.sfattr.list[0].root = 0
a.sfattr.list[0].secure = 0
a.sfattr.list[0].name = "empty"
a.sfattr.list[1].namelen = 5
a.sfattr.list[1].valuelen = 4
a.sfattr.list[1].root = 1
a.sfattr.list[1].secure = 0
a.sfattr.list[1].name = "trust"
a.sfattr.list[1].value = "val1"
```

We can determine the actual inode offset to be 220 (15 x 8 + 100) or `0xdc`.

Examining the raw dump, the second attribute is highlighted:

```
xfs_db> type text
xfs_db> p
00:  49 4e 81 a4 01 02 00 01 00 00 00 00 00 00 00 00  IN..............
10:  00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 02  ................
20:  44 be 1a be 38 d1 26 98 44 be 1a be 38 d1 26 98  D...8...D...8...
30:  44 be 1a e1 3a 9a ea 18 00 00 00 00 00 00 00 04  D...............
40:  00 00 00 00 00 00 00 01 00 00 00 00 00 00 00 01  ................
50:  00 00 0f 01 00 00 00 00 00 00 00 00 00 00 00 00  ................
60:  ff ff ff ff 00 00 00 00 00 00 00 00 00 00 00 12  ................
70:  53 a0 00 01 00 00 00 00 00 00 00 00 00 00 00 00  S...............
80:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
90:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
a0:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
b0:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
c0:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
d0:  00 00 00 00 00 00 00 00 00 00 00 00 00 18 02 00  ................
e0:  05 00 00 65 6d 70 74 79 05 04 02 74 72 75 73 74  ...empty...trust
f0:  76 61 6c 31 00 00 00 00 00 00 00 00 00 00 00 00  val1............
```

hdr.totsize

Adding another attribute with attr1, the format is converted to extents and `di_forkoff` remains unchanged (and all those zeros in the dump above remain unused):

```
xfs_db> inode <inode#>
xfs_db> p
...
core.naextents = 1
core.forkoff = 15
core.aformat = 2 (extents)
...
a.bmx[0] = [startoff,startblock,blockcount,extentflag] 0:[0,37534,1,0]
```

Performing the same steps with attr2, adding one attribute at a time, you can see `di_forkoff` change as attributes are added:

```
xfs_db> inode <inode#>
xfs_db> p
...
core.naextents = 0
core.forkoff = 15
core.aformat = 1 (local)
...
a.sfattr.hdr.totsize = 17
a.sfattr.hdr.count = 1
a.sfattr.list[0].namelen = 10
a.sfattr.list[0].valuelen = 0
a.sfattr.list[0].root = 0
a.sfattr.list[0].secure = 0
a.sfattr.list[0].name = "empty_attr"
```

Attribute added:

```
xfs_db> p
...
core.naextents = 0
core.forkoff = 15
core.aformat = 1 (local)
...
a.sfattr.hdr.totsize = 31
a.sfattr.hdr.count = 2
a.sfattr.list[0].namelen = 10
a.sfattr.list[0].valuelen = 0
a.sfattr.list[0].root = 0
a.sfattr.list[0].secure = 0
a.sfattr.list[0].name = "empty_attr"
a.sfattr.list[1].namelen = 7
a.sfattr.list[1].valuelen = 4
a.sfattr.list[1].root = 1
a.sfattr.list[1].secure = 0
a.sfattr.list[1].name = "trust_a"
a.sfattr.list[1].value = "val1"
```

Another attribute is added:

```
xfs_db> p
...
core.naextents = 0
core.forkoff = 13
core.aformat = 1 (local)
...
a.sfattr.hdr.totsize = 52
a.sfattr.hdr.count = 3
a.sfattr.list[0].namelen = 10
a.sfattr.list[0].valuelen = 0
a.sfattr.list[0].root = 0
a.sfattr.list[0].secure = 0
a.sfattr.list[0].name = "empty_attr"
a.sfattr.list[1].namelen = 7
a.sfattr.list[1].valuelen = 4
a.sfattr.list[1].root = 1
a.sfattr.list[1].secure = 0
a.sfattr.list[1].name = "trust_a"
a.sfattr.list[1].value = "val1"
a.sfattr.list[2].namelen = 6
a.sfattr.list[2].valuelen = 12
a.sfattr.list[2].root = 0
a.sfattr.list[2].secure = 0
a.sfattr.list[2].name = "second"
a.sfattr.list[2].value = "second_value"
```

One more is added:

```
xfs_db> p
core.naextents = 0
core.forkoff = 10
core.aformat = 1 (local)
...
a.sfattr.hdr.totsize = 69
a.sfattr.hdr.count = 4
a.sfattr.list[0].namelen = 10
a.sfattr.list[0].valuelen = 0
a.sfattr.list[0].root = 0
a.sfattr.list[0].secure = 0
a.sfattr.list[0].name = "empty_attr"
a.sfattr.list[1].namelen = 7
a.sfattr.list[1].valuelen = 4
a.sfattr.list[1].root = 1
a.sfattr.list[1].secure = 0
a.sfattr.list[1].name = "trust_a"
a.sfattr.list[1].value = "val1"
a.sfattr.list[2].namelen = 6
a.sfattr.list[2].valuelen = 12
a.sfattr.list[2].root = 0
a.sfattr.list[2].secure = 0
a.sfattr.list[2].name = "second"
a.sfattr.list[2].value = "second_value"
a.sfattr.list[3].namelen = 6
a.sfattr.list[3].valuelen = 8
a.sfattr.list[3].root = 0
a.sfattr.list[3].secure = 1
a.sfattr.list[3].name = "policy"
a.sfattr.list[3].value = "contents"
```

A raw dump is shown to compare with the attr1 dump on a prior page, the header is highlighted:

```
xfs_db> type text
xfs_db> p
00:  49 4e 81 a4 01 02 00 01 00 00 00 00 00 00 00 00  IN..............
10:  00 00 00 01 00 00 00 00 00 00 00 00 00 00 00 05  ................
20:  44 be 24 cd 0f b0 96 18 44 be 24 cd 0f b0 96 18  D.......D.......
30:  44 be 2d f5 01 62 7a 18 00 00 00 00 00 00 00 04  D....bz.........
40:  00 00 00 00 00 00 00 01 00 00 00 00 00 00 00 01  ................
50:  00 00 0a 01 00 00 00 00 00 00 00 00 00 00 00 00  ................
60:  ff ff ff ff 00 00 00 00 00 00 00 00 00 00 00 01  ................
70:  41 c0 00 01 00 00 00 00 00 00 00 00 00 00 00 00  A...............
80:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
90:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
a0:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
b0:  00 00 00 00 00 45 04 00 0a 00 00 65 6d 70 74 79  .....E.....empty
c0:  5f 61 74 74 72 07 04 02 74 72 75 73 74 5f 61 76  .attr...trust.av
d0:  61 6c 31 06 0c 00 73 65 63 6f 6e 64 73 65 63 6f  al1...secondseco
e0:  6e 64 5f 76 61 6c 75 65 06 08 04 70 6f 6c 69 63  nd.value...polic
f0:  79 63 6f 6e 74 65 6e 74 73 64 5f 76 61 6c 75 65  ycontentsd.value
```

It can be clearly seen that attr2 allows many more attributes to be stored in an inode before they are moved to another filesystem block.

Leaf Attributes

When an inode's attribute fork space is used up with shortform attributes and more are added, the attribute format is migrated to "extents".

Extent based attributes use hash/index pairs to speed up an attribute lookup. The first part of the "leaf" contains an array of fixed size hash/index pairs with the flags stored as well. The remaining part of the leaf block contains the array name/value pairs, where each element varies in length.

Each leaf is based on the `xfs_da_blkinfo_t` block header declared in Leaf Directories. The structure encapsulating all other structures in the `xfs_attr_leafblock_t`.

The structures involved are:

```
typedef struct xfs_attr_leaf_map {
     __be16                    base;
     __be16                    size;
} xfs_attr_leaf_map_t;

typedef struct xfs_attr_leaf_hdr {
     xfs_da_blkinfo_t          info;
     __be16                    count;
     __be16                    usedbytes;
     __be16                    firstused;
     __u8                      holes;
     __u8                      pad1;
     xfs_attr_leaf_map_t       freemap[3];
} xfs_attr_leaf_hdr_t;

typedef struct xfs_attr_leaf_entry {
     __be32                    hashval;
     __be16                    nameidx;
     __u8                      flags;
     __u8                      pad2;
} xfs_attr_leaf_entry_t;

typedef struct xfs_attr_leaf_name_local {
     __be16                    valuelen;
     __u8                      namelen;
     __u8                      nameval[1];
} xfs_attr_leaf_name_local_t;

typedef struct xfs_attr_leaf_name_remote {
     __be32                    valueblk;
     __be32                    valuelen;
     __u8                      namelen;
     __u8                      name[1];
} xfs_attr_leaf_name_remote_t;

typedef struct xfs_attr_leafblock {
     xfs_attr_leaf_hdr_t          hdr;
     xfs_attr_leaf_entry_t        entries[1];
     xfs_attr_leaf_name_local_t   namelist;
     xfs_attr_leaf_name_remote_t  valuelist;
} xfs_attr_leafblock_t;
```

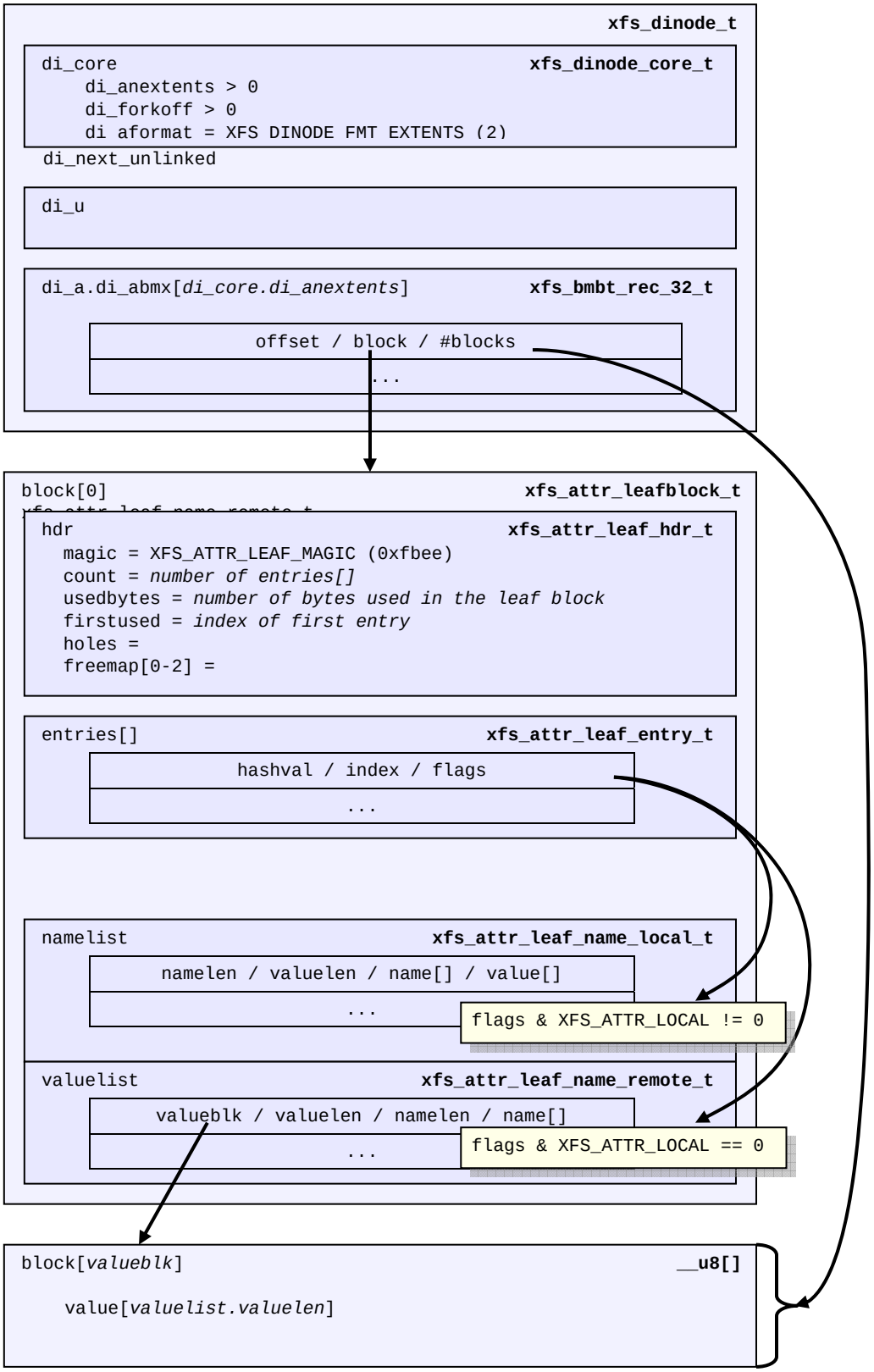
Each leaf header uses the following magic number:

```
#define XFS_ATTR_LEAF_MAGIC     0xfbee
```

The hash/index elements in the `entries[]` array are packed from the top of the block. Name/values grow from the bottom but are not packed. The `freemap` contains run-length-encoded entries for the free bytes after the `entries[]` array, but only the three largest runs are stored (smaller runs are dropped). When the `freemap` doesn't show enough space for an allocation, name/value area is

compacted and allocation is tried again. If there still isn't enough space, then the block is split. The name/value structures (both local and remote versions) must be 32-bit aligned.

For attributes with small values (ie. the value can be stored within the leaf), the XFS_ATTR_LOCAL flag is set for the attribute. The entry details are stored using the `xfs_attr_leaf_name_local_t` structure. For large attribute values that cannot be stored within the leaf, separate filesystem blocks are allocated to store the value. They use the `xfs_attr_leaf_name_remote_t` structure.



Both local and remote entries can be interleaved as they are only addressed by the hash/index entries. The flag is stored with the hash/index pairs so the appropriate structure can be used.

Since duplicate hash keys are possible, for each hash that matches during a lookup, the actual name string must be compared.

An “incomplete” bit is also used for attribute flags. It shows that an attribute is in the middle of being created and should not be shown to the user if we crash during the time that the bit is set. The bit is cleared when attribute has finished being setup. This is done because some large attributes cannot be created inside a single transaction.

xfs_db Example:

A single 30KB extended attribute is added to an inode:

```
xfs_db> inode <inode#>
xfs_db> p
...
core.nblocks = 9
core.nextents = 0
core.naextents = 1
core.forkoff = 15
core.aformat = 2 (extents)
...
a.bmx[0] = [startoff,startblock,blockcount,extentflag]
         0:[0,37535,9,0]

xfs_db> ablock 0
xfs_db> p
hdr.info.forw = 0
hdr.info.back = 0
hdr.info.magic = 0xfbee
hdr.count = 1
hdr.usedbytes = 20
hdr.firstused = 4076
hdr.holes = 0
hdr.freemap[0-2] = [base,size] 0:[40,4036] 1:[0,0] 2:[0,0]
entries[0] = [hashval,nameidx,incomplete,root,secure,local]
         0:[0xfcf89d4f,4076,0,0,0,0]
nvlist[0].valueblk = 0x1
nvlist[0].valuelen = 30692
nvlist[0].namelen = 8
nvlist[0].name = "big_attr"
```

Attribute blocks 1 to 8 (filesystem blocks 37536 to 37543) contain the raw binary value data for the attribute.

Index 4076 (0xfec) is the offset into the block where the name/value information is. As can be seen by the value, it's at the end of the block:

```
xfs_db> type text
xfs_db> p
000:  00 00 00 00 00 00 00 00 fb ee 00 00 00 01 00 14  ................
010:  0f ec 00 00 00 28 0f c4 00 00 00 00 00 00 00 00  ................
020:  fc f8 9d 4f 0f ec 00 00 00 00 00 00 00 00 00 00  ...O............
030:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
...
fe0:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 01  ................
ff0:  00 00 77 e4 08 62 69 67 5f 61 74 74 72 00 00 00  ..w..big.attr...
```

A 30KB attribute and a couple of small attributes are added to a file:

```
xfs_db> inode <inode#>
xfs_db> p
...
core.nblocks = 10
core.extsize = 0
core.nextents = 1
core.naextents = 2
core.forkoff = 15
core.aformat = 2 (extents)
...
u.bmx[0] = [startoff,startblock,blockcount,extentflag]
         0:[0,81857,1,0]
a.bmx[0-1] = [startoff,startblock,blockcount,extentflag]
         0:[0,81858,1,0]
         1:[1,182398,8,0]

xfs_db> ablock 0
xfs_db> p
hdr.info.forw = 0
hdr.info.back = 0
hdr.info.magic = 0xfbee
hdr.count = 3
hdr.usedbytes = 52
hdr.firstused = 4044
hdr.holes = 0
hdr.freemap[0-2] = [base,size] 0:[56,3988] 1:[0,0] 2:[0,0]
entries[0-2] = [hashval,nameidx,incomplete,root,secure,local]
         0:[0x1e9d3934,4044,0,0,0,1]
         1:[0x1e9d3937,4060,0,0,0,1]
         2:[0xfcf89d4f,4076,0,0,0,0]
nvlist[0].valuelen = 6
nvlist[0].namelen = 5
nvlist[0].name = "attr2"
nvlist[0].value = "value2"
nvlist[1].valuelen = 6
nvlist[1].namelen = 5
nvlist[1].name = "attr1"
nvlist[1].value = "value1"
nvlist[2].valueblk = 0x1
nvlist[2].valuelen = 30692
nvlist[2].namelen = 8
nvlist[2].name = "big_attr"
```

As can be seen in the entries array, the two small attributes have the local flag set and the values are printed.

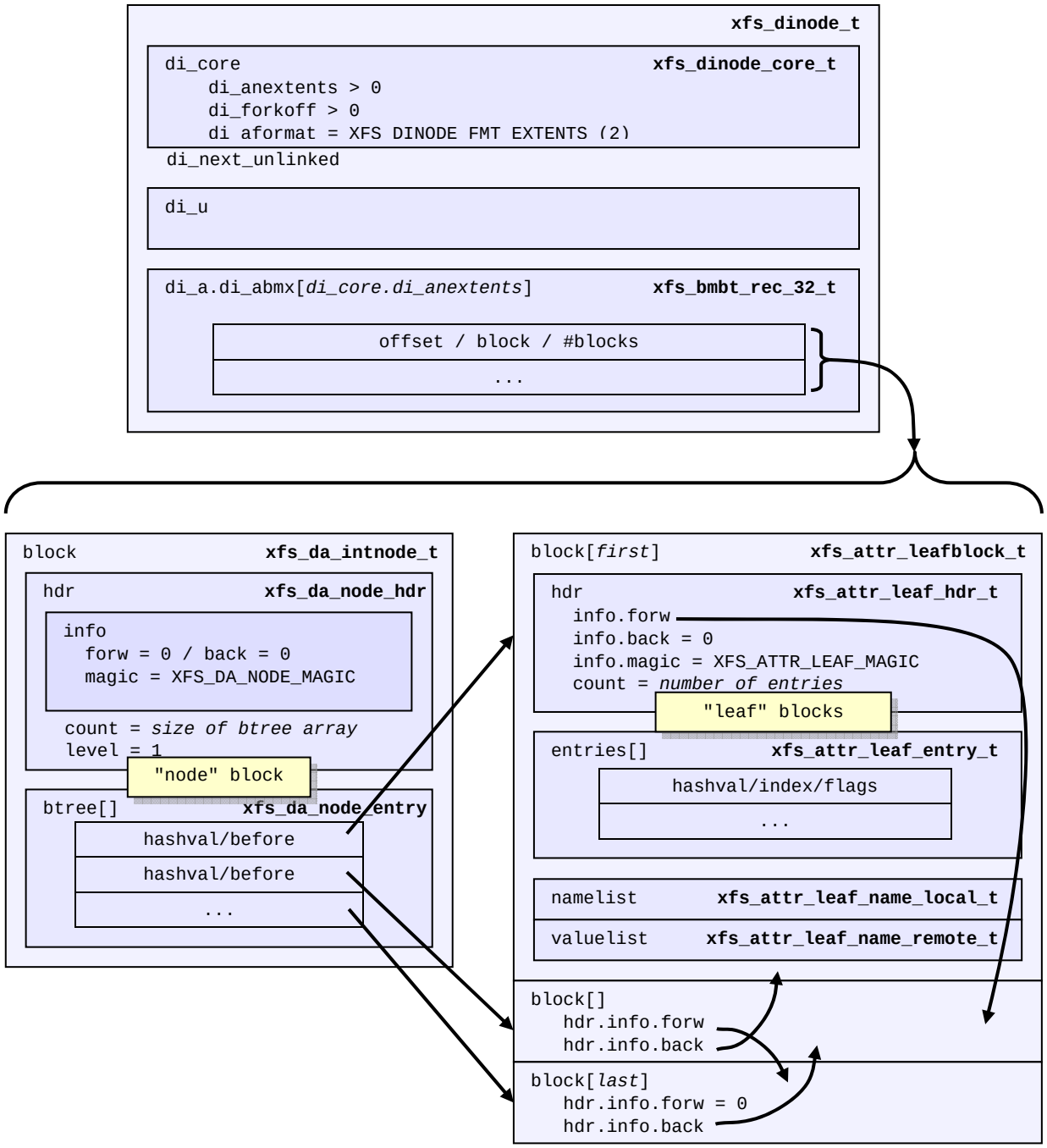
A raw disk dump shows the attributes. The last attribute added is highlighted (offset 4044 or 0xfcc):

```
000:  00 00 00 00 00 00 00 00 fb ee 00 00 00 03 00 34  ...............4
010:  0f cc 00 00 00 38 0f 94 00 00 00 00 00 00 00 00  .....8..........
020:  1e 9d 39 34 0f cc 01 00 1e 9d 39 37 0f dc 01 00  ..94......97....
030:  fc f8 9d 4f 0f ec 00 00 00 00 00 00 00 00 00 00  ...O............
040:  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
...
fc0:  00 00 00 00 00 00 00 00 00 00 00 00 00 06 05 61  ...............a
fd0:  74 74 72 32 76 61 6c 75 65 32 00 00 00 06 05 61  ttr2value2.....a
fe0:  74 74 72 31 76 61 6c 75 65 31 00 00 00 00 00 01  ttr1value1......
ff0:  00 00 77 e4 08 62 69 67 5f 61 74 74 72 00 00 00  ..w..big.attr...
```

Node Attributes

When the number of attributes exceeds the space that can fit in one filesystem block (ie. hash, flag, name and local values), the first attribute block becomes the root of a B+tree where the leaves contain the hash/name/value information that was stored in a single leaf block. The inode's attribute format itself remains extent based. The nodes use the `xfs_da_intnode_t` structure introduced in Node Directories.

The location of the attribute leaf blocks can be in any order, the only way to determine the appropriate is by the node block hash/before values. Given a hash to lookup, you read the node's `btree` array and first `hashval` in the array that exceeds the given hash and it can then be found in the block pointed to by the `before` value.



xfs_db Example:

An inode with 1000 small attributes with the naming "attribute_n" where 'n' is a number:

```
xfs_db> inode <inode#>
xfs_db> p
...
core.nblocks = 15
core.nextents = 0
core.naextents = 1
core.forkoff = 15
core.aformat = 2 (extents)
...
a.bmx[0] = [startoff,startblock,blockcount,extentflag] 0:[0,525144,15,0]

xfs_db> ablock 0
xfs_db> p
hdr.info.forw = 0
hdr.info.back = 0
hdr.info.magic = 0xfebe
hdr.count = 14
hdr.level = 1
btree[0-13] = [hashval,before]
          0:[0x3435122d,1]
          1:[0x343550a9,14]
          2:[0x343553a6,13]
          3:[0x3436122d,12]
          4:[0x343650a9,8]
          5:[0x343653a6,7]
          6:[0x343691af,6]
          7:[0x3436d0ab,11]
          8:[0x3436d3a7,10]
          9:[0x3437122d,9]
          10:[0x3437922e,3]
          11:[0x3437d22a,5]
          12:[0x3e686c25,4]
          13:[0x3e686fad,2]
```

The hashes are in ascending order in the btree array, and if the hash for the attribute we are looking up is before the entry, we go to the addressed attribute block.

For example, to lookup attribute "attribute_267":

```
xfs_db> hash attribute_267
0x3437d1a8
```

In the root btree node, this falls between `0x3437922e` and `0x3437d22a`, therefore leaf 11 or attribute block 5 will contain the entry.

```
xfs_db> ablock 5
xfs_db> p
hdr.info.forw = 4
hdr.info.back = 3
hdr.info.magic = 0xfbee
hdr.count = 96
hdr.usedbytes = 2688
hdr.firstused = 1408
hdr.holes = 0
hdr.freemap[0-2] = [base,size] 0:[800,608] 1:[0,0] 2:[0,0]
entries[0-95] = [hashval,nameidx,incomplete,root,secure,local]
          0:[0x3437922f,4068,0,0,0,1]
          1:[0x343792a6,4040,0,0,0,1]
          2:[0x343792a7,4012,0,0,0,1]
          3:[0x343792a8,3984,0,0,0,1]
          ...
          82:[0x3437d1a7,2892,0,0,0,1]
          83:[0x3437d1a8,2864,0,0,0,1]
```

```
            84:[0x3437d1a9,2836,0,0,0,1]
            ...
            95:[0x3437d22a,2528,0,0,0,1]
nvlist[0].valuelen = 10
nvlist[0].namelen = 13
nvlist[0].name = "attribute_310"
nvlist[0].value = "value_310\d"
nvlist[1].valuelen = 10
nvlist[1].namelen = 13
nvlist[1].name = "attribute_309"
nvlist[1].value = "value_309\d"
nvlist[2].valuelen = 10
nvlist[2].namelen = 13
nvlist[2].name = "attribute_308"
nvlist[2].value = "value_308\d"
nvlist[3].valuelen = 10
nvlist[3].namelen = 13
nvlist[3].name = "attribute_307"
nvlist[3].value = "value_307\d"
...
nvlist[82].valuelen = 10
nvlist[82].namelen = 13
nvlist[82].name = "attribute_268"
nvlist[82].value = "value_268\d"
nvlist[83].valuelen = 10
nvlist[83].namelen = 13
nvlist[83].name = "attribute_267"
nvlist[83].value = "value_267\d"
nvlist[84].valuelen = 10
nvlist[84].namelen = 13
nvlist[84].name = "attribute_266"
nvlist[84].value = "value_266\d"
...
```

Each of the hash entries has XFS_ATTR_LOCAL flag set (1), which means the attribute's value follows immediately after the name. Raw disk of the name/value pair at offset 2864 (0xb30), highlighted with "value_267\d" following immediately after the name:

```
b00:  62 75 74 65 5f 32 36 35 76 61 6c 75 65 5f 32 36  bute.265value.26
b10:  35 0a 00 00 00 0a 0d 61 74 74 72 69 62 75 74 65  5......attribute
b20:  5f 32 36 36 76 61 6c 75 65 5f 32 36 36 0a 00 00  .266value.266...
b30:  00 0a 0d 61 74 74 72 69 62 75 74 65 5f 32 36 37  ...attribute.267
b40:  76 61 6c 75 65 5f 32 36 37 0a 00 00 00 0a 0d 61  value.267......a
b50:  74 74 72 69 62 75 74 65 5f 32 36 38 76 61 6c 75  ttribute.268valu
b60:  65 5f 32 36 38 0a 00 00 00 0a 0d 61 74 74 72 69  e.268......attri
b70:  62 75 74 65 5f 32 36 39 76 61 6c 75 65 5f 32 36  bute.269value.26
```

Each entry starts on a 32-bit (4 byte) boundary, therefore the highlighted entry has 2 unused bytes after it.

B+tree Attributes

When the attribute's extent map in an inode grows beyond the available space, the inode's attribute format is changed to a "btree". The inode contains root node of the extent B+tree which then address the leaves that contains the extent arrays for the attribute data. The attribute data itself in the allocated filesystem blocks use the same layout and structures as described in Node Attributes.

Refer to the previous section on B+tree Data Extents for more information on XFS B+tree extents.

xfs_db Example:

Added 2000 attributes with 729 byte values to a file:

```
xfs_db> inode <inode#>
xfs_db> p
...
core.nblocks = 640
core.extsize = 0
core.nextents = 1
core.naextents = 274
core.forkoff = 15
core.aformat = 3 (btree)
...
a.bmbt.level = 1
a.bmbt.numrecs = 2
a.bmbt.keys[1-2] = [startoff] 1:[0] 2:[219]
a.bmbt.ptrs[1-2] = 1:83162 2:109968

xfs_db> fsblock 83162
xfs_db> type bmapbtd
xfs_db> p
magic = 0x424d4150
level = 0
numrecs = 127
leftsib = null
rightsib = 109968
recs[1-127] = [startoff,startblock,blockcount,extentflag]
         1:[0,81870,1,0]
         ...

xfs_db> fsblock 109968
xfs_db> type bmapbtd
xfs_db> p
magic = 0x424d4150
level = 0
numrecs = 147
leftsib = 83162
rightsib = null
recs[1-147] = [startoff,startblock,blockcount,extentflag]
         ...

xfs_db> ablock 0            (which is fsblock 81870)
xfs_db> p
hdr.info.forw = 0
hdr.info.back = 0
hdr.info.magic = 0xfebe
hdr.count = 2
hdr.level = 2
btree[0-1] = [hashval,before] 0:[0x343612a6,513] 1:[0x3e686fad,512]
```

The extent B+tree has two leaves that specify the 274 extents used for the attributes. Looking at the first block, it can be seen that the attribute B+tree is two levels deep. The two blocks at offset 513 and 512 (ie. access using the `ablock` command) are intermediate `xfs_da_intnode_t` nodes that index all the attribute leaves.

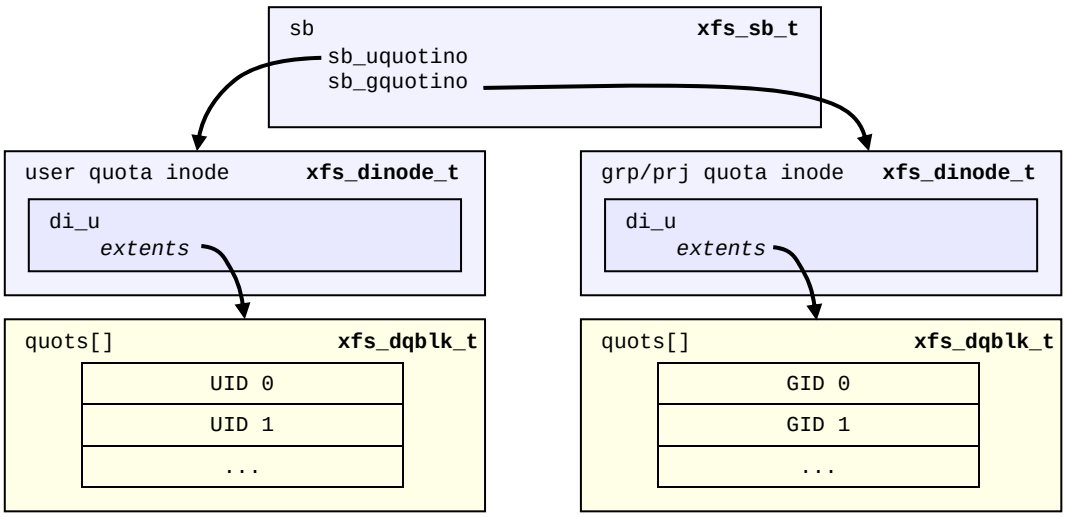
Internal Inodes

XFS allocates several inodes when a filesystem is created. These are internal and not accessible from the standard directory structure. These inodes are only accessible from the superblock.

Quota Inodes

If quotas are used, two inodes are allocated for user and group quota management. If project quotas are used, these replace the group quota management and therefore uses the group quota inode.

- Project quota's primary purpose is to track and monitor disk usage for directories. For this to occur, the directory inode must have the `XFS_DIFLAG_PROJINHERIT` flag set so all inodes created underneath the directory inherit the project ID.
- Inodes and blocks owned by ID zero do not have enforced quotas, but only quota accounting.
- Extended attributes do not contribute towards the ID's quota .
- To access each ID's quota information in the file, seek to the ID offset multiplied by the size of `xfs_dqblk_t` (136 bytes).



Quota information stored in the two inodes (in data extents) are an array of the `xfs_dqblk_t` structure where there is one instance for each ID in the system:

```
typedef struct xfs_disk_dquot {
     __be16                  d_magic;
     __u8                    d_version;
     __u8                    d_flags;
     __be32                  d_id;
     __be64                  d_blk_hardlimit;
     __be64                  d_blk_softlimit;
     __be64                  d_ino_hardlimit;
     __be64                  d_ino_softlimit;
     __be64                  d_bcount;
     __be64                  d_icount;
     __be32                  d_itimer;
     __be32                  d_btimer;
     __be16                  d_iwarns;
     __be16                  d_bwarns;
     __be32                  d_pad0;
     __be64                  d_rtb_hardlimit;
     __be64                  d_rtb_softlimit;
     __be64                  d_rtbcount;
```

```
        __be32                  d_rtbtimer;
        __be16                  d_rtbwarns;
        __be16                  d_pad;
} xfs_disk_dquot_t;

typedef struct xfs_dqblk {
        xfs_disk_dquot_t        dd_diskdq;
        char                    dd_fill[32];
} xfs_dqblk_t;
```

d_magic

Specifies the signature where these two bytes are 0x4451 (`XFS_DQUOT_MAGIC`), or "DQ" in ASCII.

d_version

Specifies the structure version, currently this is one (`XFS_DQUOT_VERSION`).

d_flags

Specifies which type of ID the structure applies to:

```
#define XFS_DQ_USER             0x0001
#define XFS_DQ_PROJ             0x0002
#define XFS_DQ_GROUP            0x0004
```

d_id

The ID for the quota structure. This will be a uid, gid or projid based on the value of `d_flags`.

d_blk_hardlimit

Specifies the hard limit for the number of filesystem blocks the ID can own. The ID will not be able to use more space than this limit. If it is attempted, `ENOSPC` will be returned.

d_blk_softlimit

Specifies the soft limit for the number of filesystem blocks the ID can own. The ID can temporarily use more space than by `d_blk_softlimit` up to `d_blk_hardlimit`. If the space is not freed by the time limit specified by ID zero's `d_btimer` value, the ID will be denied more space until the total blocks owned goes below `d_blk_softlimit`.

d_ino_hardlimit

Specifies the hard limit for the number of inodes the ID can own. The ID will not be able to create or own any more inodes if `d_icount` reaches this value.

d_ino_softlimit

Specifies the soft limit for the number of inodes the ID can own. The ID can temporarily create or own more inodes than specified by `d_ino_softlimit` up to `d_ino_hardlimit`. If the inode count is not reduced by the time limit specified by ID zero's `d_itimer` value, the ID will be denied from creating or owning more inodes until the count goes below `d_ino_softlimit`.

d_bcount

Specifies how many filesystem blocks are actually owned by the ID.

d_icount

Specifies how many inodes are actually owned by the ID.

d_itimer

Specifies the time when the ID's `d_icount` exceeded `d_ino_softlimit`. The soft limit will turn into a hard limit after the elapsed time exceeds ID zero's `d_itimer` value. When `d_icount` goes back below `d_ino_softlimit`, `d_itimer` is reset back to zero.

d_btimer

Specifies the time when the ID's `d_bcount` exceeded `d_blk_softlimit`. The soft limit will turn into a hard limit after the elapsed time exceeds ID zero's `d_btimer` value. When `d_bcount` goes back below `d_blk_softlimit`, `d_btimer` is reset back to zero.

d_iwarns
d_bwarns
d_rtbwarns

Specifies how many times a warning has been issued. Currently not used.

d_rtb_hardlimit

Specifies the hard limit for the number of real-time blocks the ID can own. The ID cannot own more space on the real-time device beyond this limit.

d_rtb_softlimit

Specifies the soft limit for the number of real-time blocks the ID can own. The ID can temporarily own more space than specified by `d_rtb_softlimit` up to `d_rtb_hardlimit`. If `d_rtbcount` is not reduced by the time limit specified by ID zero's `d_rtbtimer` value, the ID will be denied from owning more space until the count goes below `d_rtb_softlimit`

d_rtbcount

Specifies how many real-time blocks are currently owned by the ID.

d_rtbtimer

Specifies the time when the ID's `d_rtbcount` exceeded `d_rtb_softlimit`. The soft limit will turn into a hard limit after the elapsed time exceeds ID zero's `d_rtbtimer` value. When `d_rtbcount` goes back below `d_rtb_softlimit`, `d_rtbtimer` is reset back to zero.

Real-time Inodes

There are two inodes allocated to managing the real-time device's space, the Bitmap Inode and the Summary Inode.

Real-Time Bitmap Inode

The Bitmap Inode tracks the used/free space in the real-time device using an old-style bitmap. One bit is allocated per real-time extent. The inode's number is stored in the superblock's `sb_rbmino` field. The size of an extent is specified by the superblock's `sb_rextsize` value.

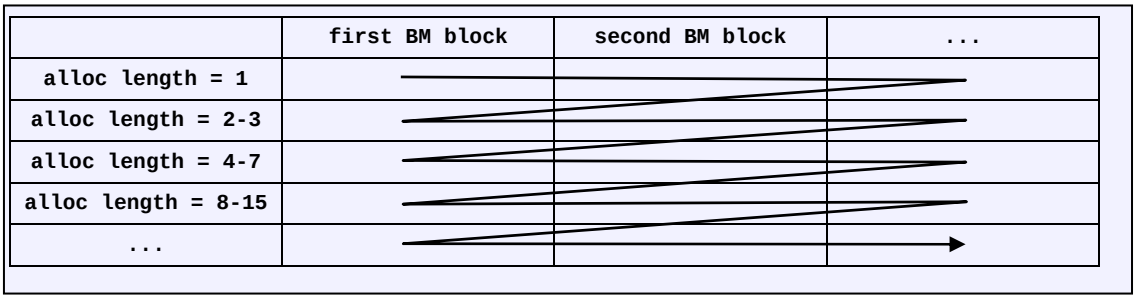
The number of blocks used by the bitmap inode is equal to the number of real-time extents (`sb_rextents`) divided by the block size (`sb_blocksize`) and bits per byte. This value is stored in `sb_rbmblocks`. The `nblocks` and extent array for the inode should match this.

As the bitmap inode is created at mkfs time, the extent should be one contiguous array of blocks on disk.

Real-Time Summary Inode

The Summary Inode stores information on chunks of free contiguous space and which bitmap block the free space starts in. The inode's number is stored in the superblock's `sb_rsumino` field.

The summary is divided into buckets for each power of two for free contiguous lengths. Each bucket counts the number of extents that fall into the power of two. For example, a contiguous range of 127 extents is free in the second bitmap block, the count for the second block in the 8th bucket is incremented. If a free range covers more than one block, the count is stored in the appropriate bucket for the starting block of the range. The buckets are represented by an array of `xfs_suminfo_t` types which is a 32-bit integer. On disk, it looks similar to the following diagram:



The size of summary array = `sizeof(xfs_suminfo_t) * sb_rbmblocks * sb_rextslog`. All bitmap block counts are grouped together in the one bucket on disk. So, for the above diagram, the contents offset moves left to right, then top to bottom.

xfs_db Example:

```
xfs_db> sb 0
xfs_db> p
magicnum = 0x58465342
blocksize = 4096
dblocks = 3933904
rblocks = 65388558
rextents = 255424
...
rbmino = 129
rsumino = 130
rextsize = 256
```

```
agblocks = 245869
agcount = 16
rbmblocks = 8
...
rextslog = 17
...
```

Journaling Log

TODO: