Ext4: The Next Generation of Ext2/3 Filesystem

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Agenda

- Motivation for ext4
- Why fork ext4?
- What's new in ext4?
- Planned ext4 features

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Motivation for ext4

- 16TB filesystem size limitation (32-bit block numbers)
- Second resolution timestamps
- 32,768 limit on subdirectories
- Performance limitations

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Why fork ext4

- Many features require on-disk format changes
- Keep large ext3 user community unaffected
- Allows more experimentation than if the work is done outside of mainline
  - Make sure users understand that ext4 is risky: mount -t ext4dev
- Downsides
  - bug fixes must be applied to two code bases
  - smaller testing community

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What's new in ext4

- Ext4 was cloned and included in 2.6.19
- Replacing indirect blocks with extents
- Ability to address >16TB filesystems (48 bit block numbers)
- Use new forked 64-bit JBD2

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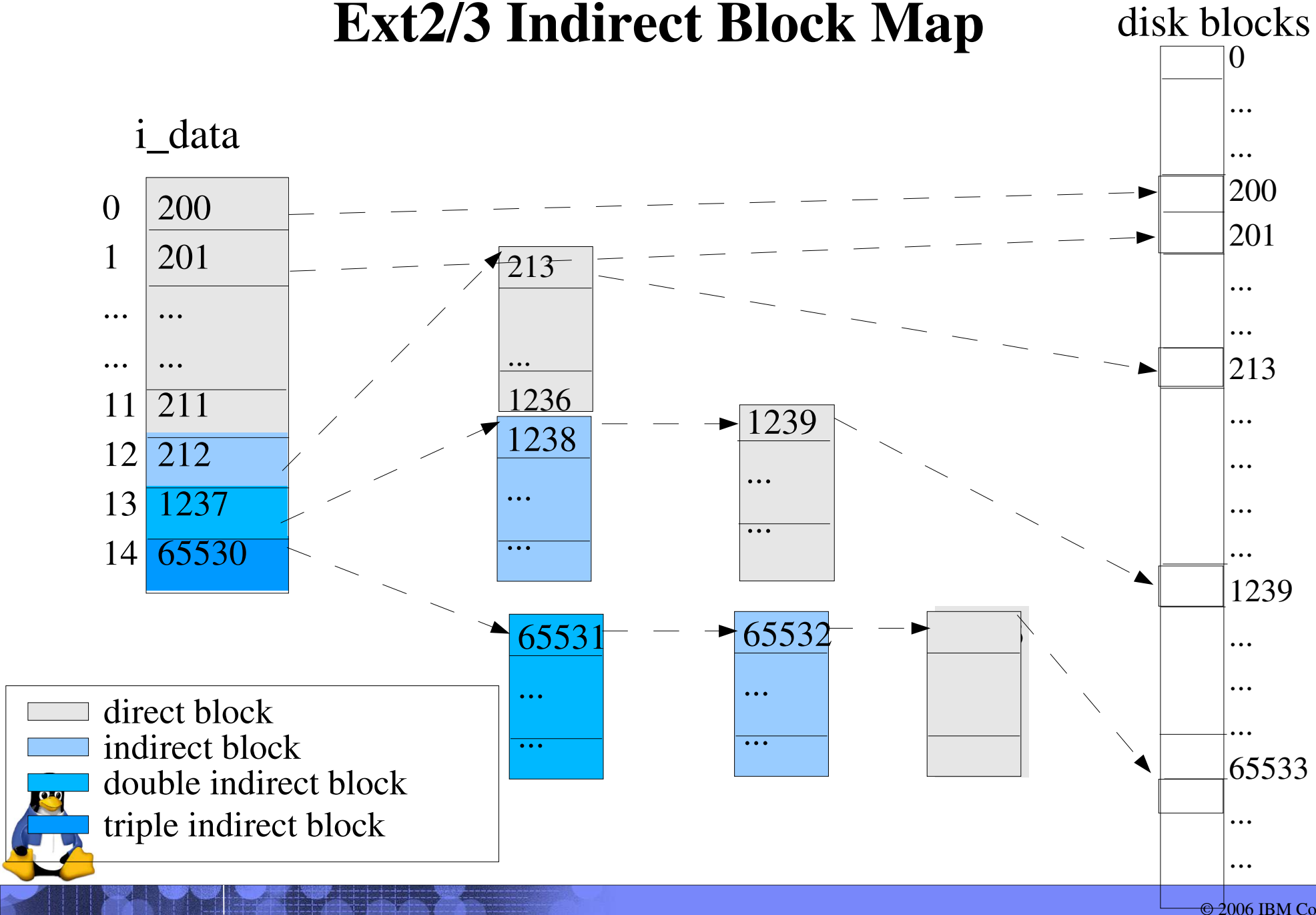
Ext2/3 Indirect Block Map



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Extents

- Indirect block maps are incredibly inefficient for large files
  - One extra block read (and seek) every 1024 blocks
  - Really obvious when deleting big CD/DVD image files
- An extent is a single descriptor for a range of contiguous blocks
  - a efficient way to represent large file
  - Better CPU utilization, fewer metadata IOs

logical	length	physical
0	1000	200

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On-disk extents format

- 12 bytes ext4_extent structure
  - address 1EB filesystem (48 bit physical block number)
  - max extent 128MB (15 bit extent length)
  - address 16TB file size (32 bit logical block number)

```
struct ext4_extent {
        __le32  ee_block;       /* first logical block extent covers */
        __le16  ee_len;         /* number of blocks covered by extent */
        __le16  ee_start_hi;    /* high 16 bits of physical block */
        __le32  ee_start;       /* low 32 bits of physical block */
};
```

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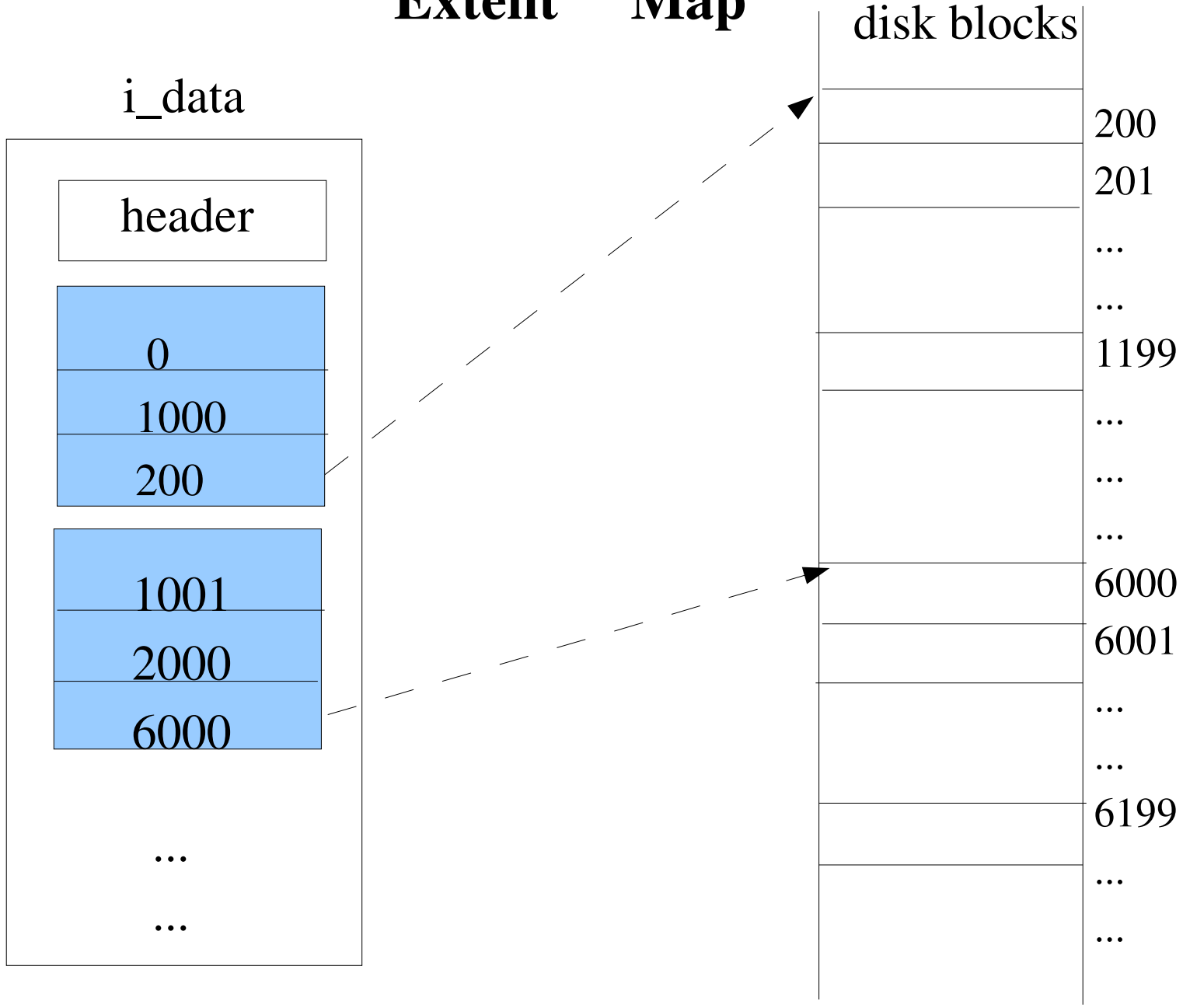
Extent Map



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Extents tree

- Up to 3 extents could stored in inode i_data body directly
- Use a inode flag to mark extents file vs ext3 indirect block file
- Convert to a B-Tree extents tree, for > 3 extents
- Last found extent is cached in-memory extents tree

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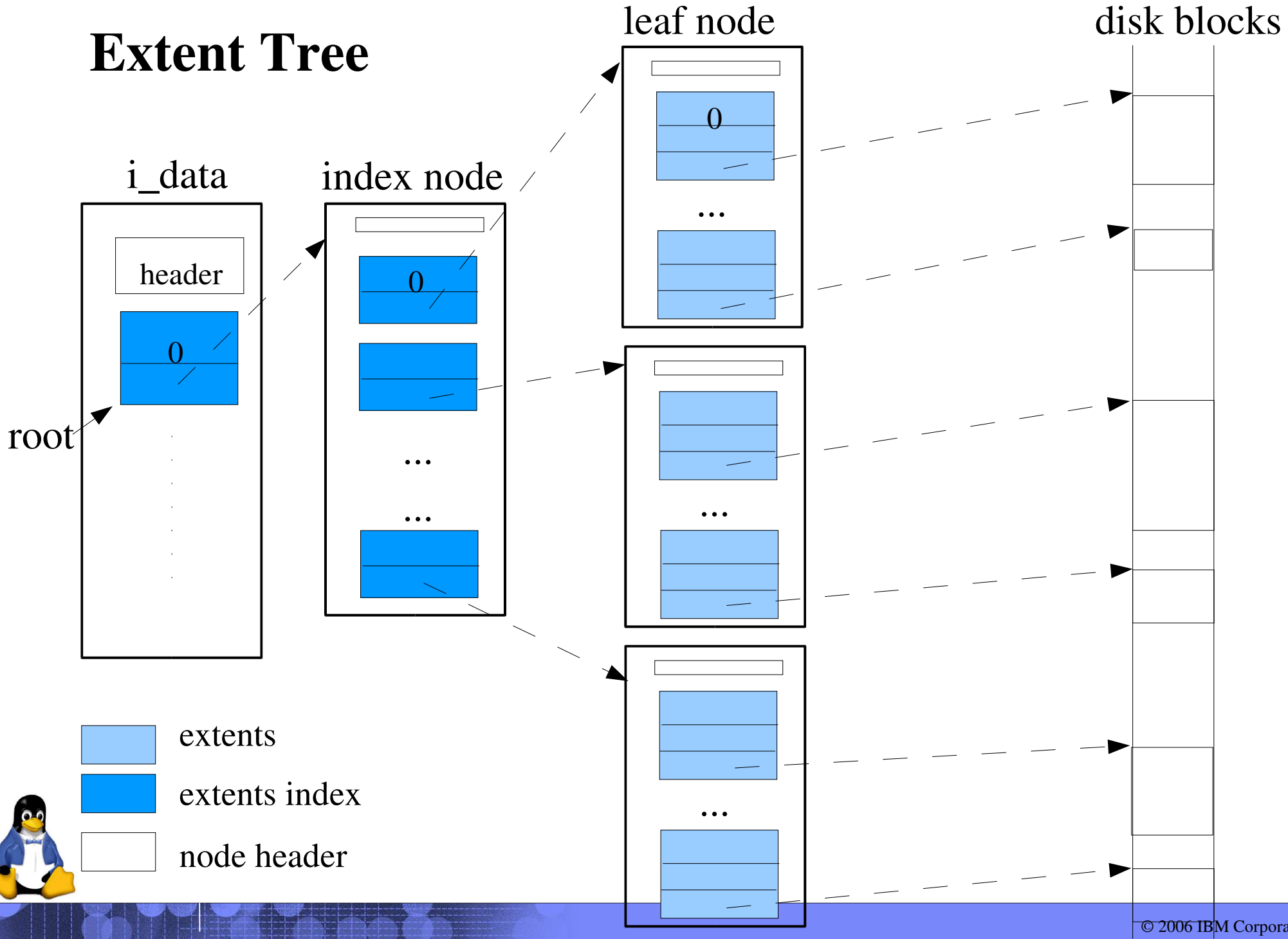
Extent Tree



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48-bit block numbers

- Part of the extents changes
  - 32bit ee_start and 16 bit ee_start_hi in ext4 extent struct
- Why not 64-bit
  - 48-bit is enough for a 2**60 (or 1EB) filesystem
  - Original lustre extent patches provide 48-bit block numbers
  - More packed meta data, less disk IO
  - Extent generation flag allow adapt to 64-bit block number easily

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64-bit meta data changes

- In kernel block variables to address >32 bit block number
- Super block fields: 32 bit -> 64 bit
- Larger block group descriptors (required doubling their size)
- extended attributes block number (32 bit -> 48 bit)

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64-bit JBD2

- Forked from JBD to handle 64-bit block numbers
- Could be used for 32bit journaling support as well
- Added JBD2_FEATURE_INCOMPAT_64BIT

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Testing ext4

- Mount it as ext4dev
  - mount -t ext4dev
- Enabling extents
  - mount -t ext4dev -o extents
  - compatible with the ext3 filesystem until you add a new file
- ext4 vs ext3 performance
  - improve large file read/rewrite/unlink

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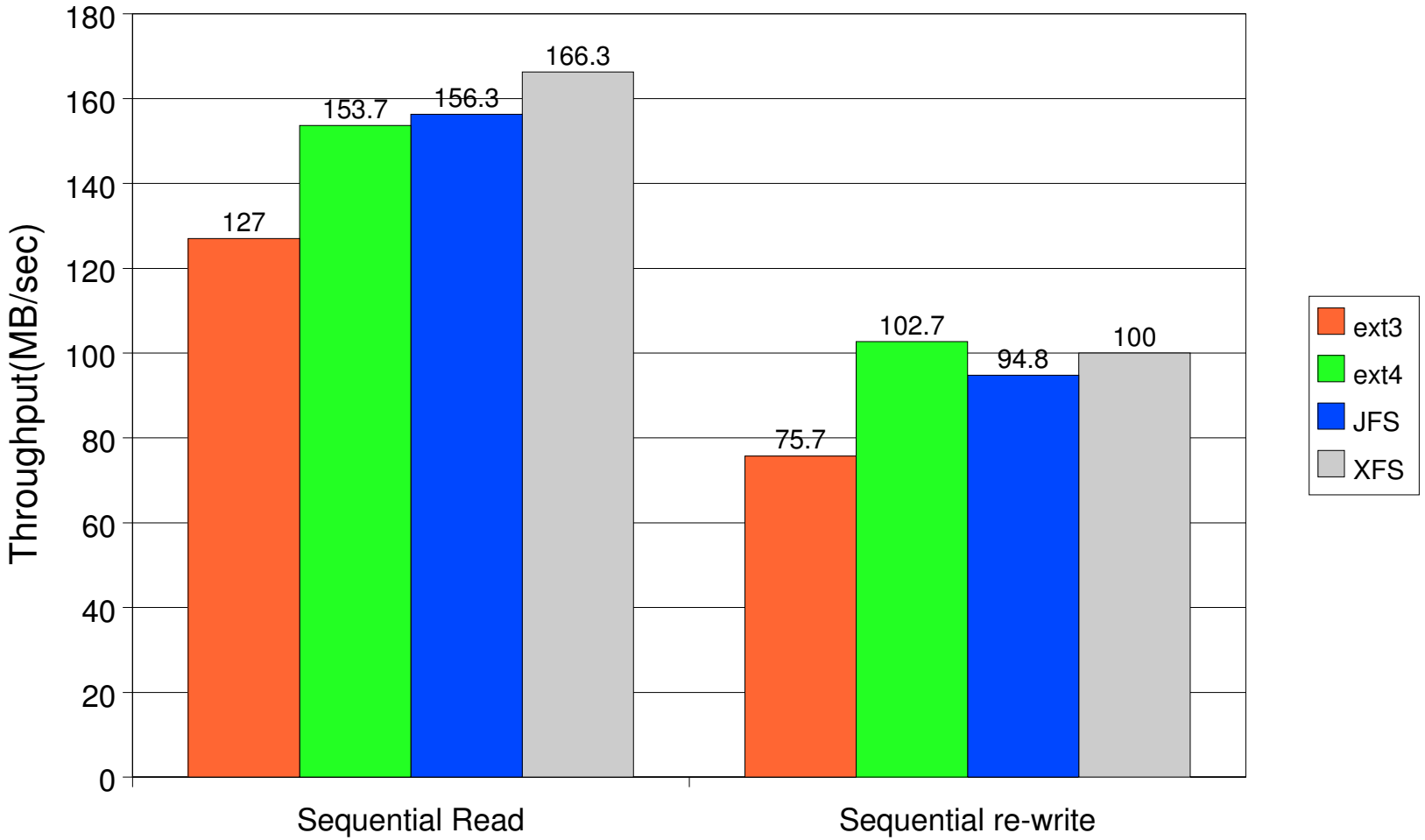
Large File Sequential Read &Rewrite Using FFSB



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New defaults for ext4

- Features available in ext3, enable by default in ext4
- directory indexing
- resize inode
- large inode (256bytes)

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Planned new features for ext4

- Work-in-progress: patches available
  - More efficient multiple block allocation
  - Delayed block allocation
  - Persistent file allocation
  - Online defragmentation
  - Nanosecond timestamps

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Others planned features

- Allow greater than 32k subdirectories
- Metadata checksumming
- Uninitialized groups to speed up mkfs/fsck
- Larger file (16TB)
- Extending Extended Attributes limit
- Caching directory contents in memory

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And maybe scales better?

- 64 bit inode number
  - challenge: user space might in trouble using 32bit stat()
- Dynamic inode table
- More scalable free inode/free block scheme
- fsck scalability issue
- Larger block size

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Multiple block allocation

- Multiple block allocation
  - Allocate contiguous blocks together
    - Reduce fragmentation, extent meta-data and cpu usage
    - Stripe aligned allocations
- Buddy free extent bitmap generated from on-disk bitmap
- Status
  - Patch available

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Delayed block allocation

- Defer block allocation to write back time
  - Improve chances allocating contiguous blocks, reducing fragmentation
- Blocks are reserved to avoid ENOSPC at writeback time:
  - At prepare_write() time, use page_private to flag page need block reservation later.
  - At commit_write() time, reserve block. Use PG_booked page flag to mark disk space is reserved for this page
- Trickier to implement in ordered mode

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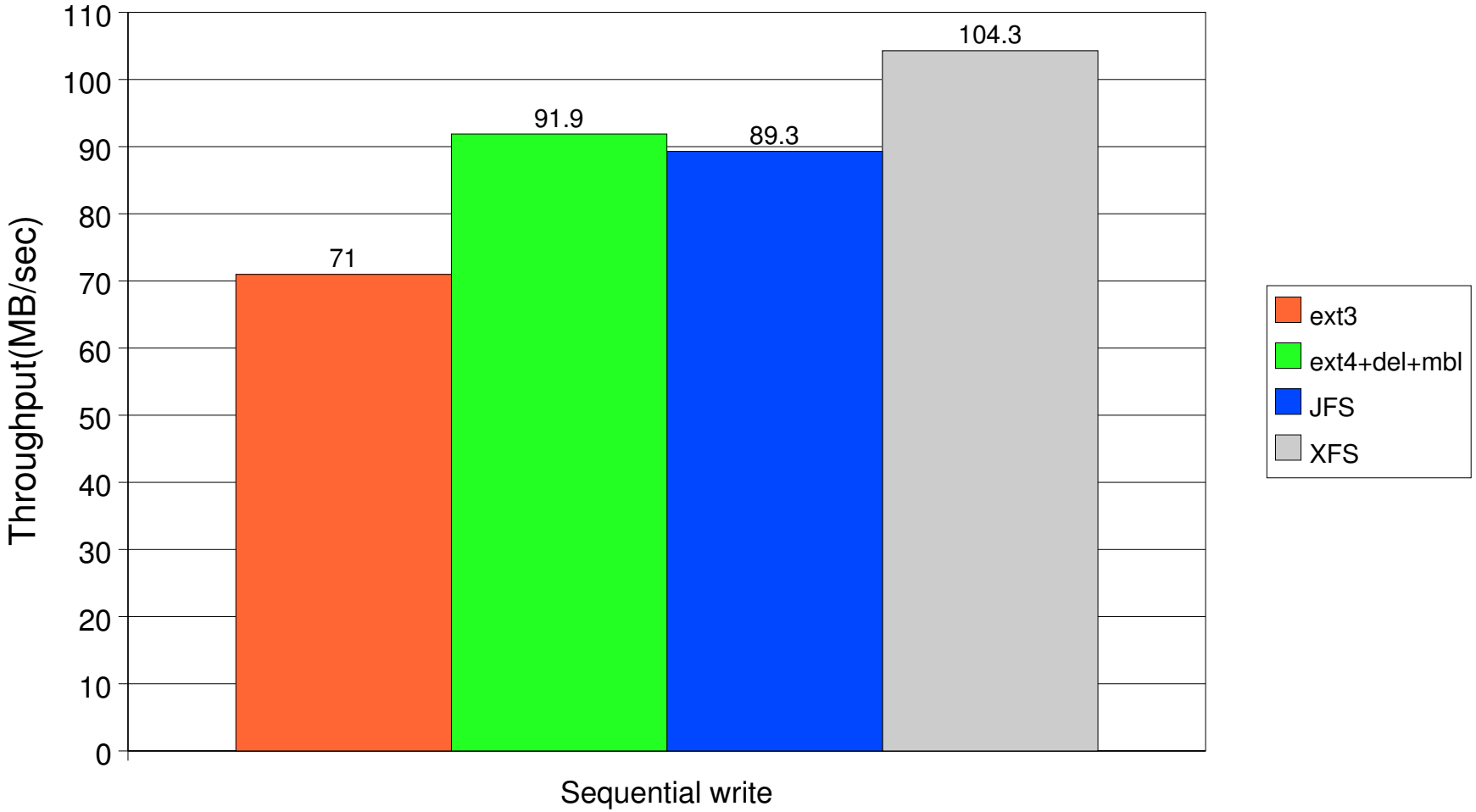
Large File Sequential Write Using FFSB



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Persistent file preallocation

- Allow preallocating blocks for a file without having to initialize them
  - Contiguous allocation to reduce fragmentation
  - Guaranteed space allocation
  - Useful for Streaming audio/video, databases
- Implemented as uninitialized extents
  - MSB of ee_len used to flag “invalid” extents
  - Reads return zero
  - Writes split the extent into valid and invalid extents
- API for preallocation
  - Current implementation uses ioctl
    - EXT4_IOC_FALLOCATE cmd, the offset and bytes to preallocate

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Online defragmentation

- Defragmentation is done in kernel, based on extent
- Allocate more contiguous blocks in a temporary inode
- Read a data block form the original inode, move the corresponding block number from the temporary inode to the original inode, and write out the page
- Join the ext4 online defragmentation talk for more detail

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Expanded inode

- Inode size is normally 128 bytes in ext3
- But can be 256, 512, 1024, etc. up to filesystem blocksize
- Extra space used for fast extended attributes
- 256 bytes needed for ext4 features
  - Nanosecond timestamps
  - Inode change version # for Lustre, NFSv4

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High resolution timestamps

- Address NFSv4 needs for more fine granularity time stamps
- Proposed solution used 30 bits out of the 32 bits field in larger inode (>128 bytes) for nanoseconds
- Performance concern: result in additional dirtying and writeout updates
  - might batched by journal

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Unlimited number of subdirectories

- Each subdirectory has a hard link to its parent
- Number of subdirectories under a single directory is limited by type of inode's link count(16 bit)
- Proposed solution to overcome this limit:
  - Not counting the subdirectory limit after counter overflow, storing link count of 1 instead.

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Metadata checksuming

- Proof of concept implementation described in the Iron Filesystem paper (from University of Wisconsin)
- Storage trends: reliability and seek times not keeping up with capacity increases
- Add checksums to extents, superblock, block group descriptors, inodes, journal

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Uninitialized block groups

- Add flags field to indicate whether or not the inode and bitmap allocation bitmaps are valid
- Add field to indicate how much of the inode table has been initialized
- Useful to create a large filesystem and fsck a not-very-full large filesystem

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Extend EA limit

- Allow EA data larger than a single filesystem block
- The last entry in EA block is reserved to point to a small number of extra EA data blocks, or to an indirect block

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ext3 vs ext4 summary

	ext3	ext4dev
filesystem limit	16TB	1EB
file limit	2TB	16TB
limit	2**32	2**32
default inode size	128 bytes	256 bytes
block mapping	indirect block map	extents
time stamp	second	nanosecond
sub dir limit	2**16	unlimited
EA limit	4K	>4K
preallocation	in-core reservation	for extent file
deframentation	No	yes
directory indexing	disabled	enabled
delayed allocation	No	yes
multiple block allocation	basic	advanced

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Getting involved

- Mailing list: linux-ext4@vger.kernel.org
- latest ext4 patch series
  ftp://ftp.kernel.org/pub/linux/kernel/people/tytso/ext4-patches
- Wiki: http://ext4.wiki.kernel.org
  - Still needs work; anyone want to jump in and help, talk to us
- Weekly conference call; minutes on the wiki
  - Contact us if you'd like dial in
- IRC channel: irc.oftc.net, /join #linuxfs

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The Ext4 Development Team

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Conclusion

- Ext4 work just beginning
- Extents merged, other patches on deck

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