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Scaling the Btrfs Free Space Cache

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Outline

- Background
- Design Background
- Identifying the Problem
- Solution
  - The Free Space Tree
- Results
- Questions

Background

What is Btrfs?

- General-purpose filesystem
- Advanced features
  - First-class snapshots
  - Checksumming of all data and metadata
  - Transparent compression
  - Integrated multi-device support (RAID)
  - Incremental backups with send/receive
- Actively developed

Contributors

```
$ git log --since="January 1, 2015" --pretty=format:"%an" --no-merges -- fs/btrfs
```

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Btrfs at Facebook

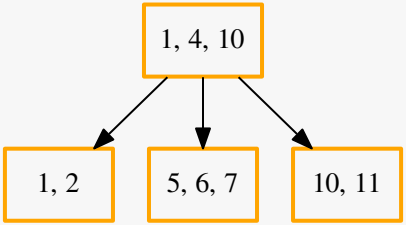
- GlusterFS
- Testing on other tiers
  - Web servers
  - Build machines
  - More...

Design Background

Copy-on-Write B-trees

- B+-trees with no leaf chaining
- Lock coupling
- Relaxed balancing contraints, proactive balancing
- Lazy reference-counting
- Update in memory, write out in periodic commits
- Due to O. Rodeh

Copy-on-Write B-tree Insertion



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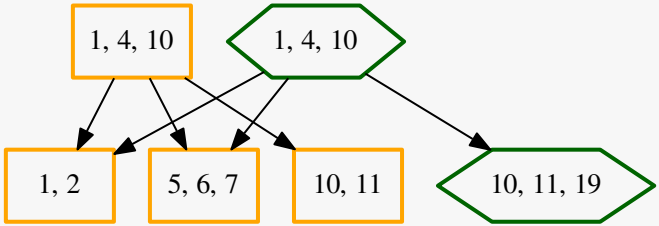
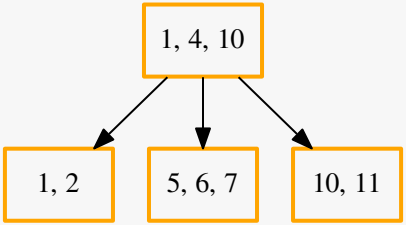


Copy-on-Write B-tree Deletion



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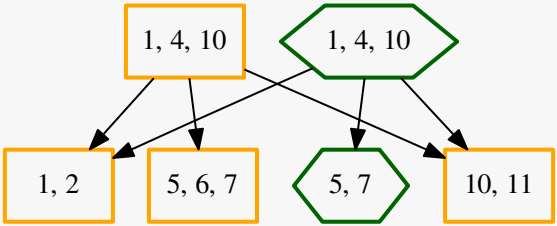
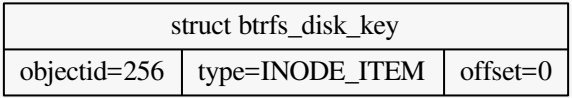


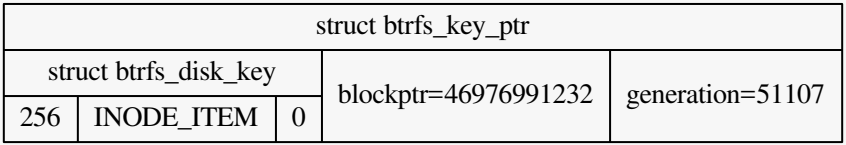
Btrfs B-trees

- Generic data structure
- Three main structures:
  - *Block header*: header of every block in the B-tree, contains checksum, flags, filesystem ID, generation, etc.
  - *Key*: comprises 64-bit object ID, 8-bit type, and 64-bit offset
  - *Item*: comprises key, 32-bit offset, and 32-bit size
- *Nodes* contain only keys and block pointers to children
- *Leaves* contain array of items and data

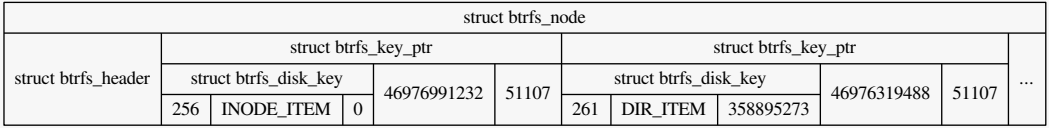
B-tree Nodes



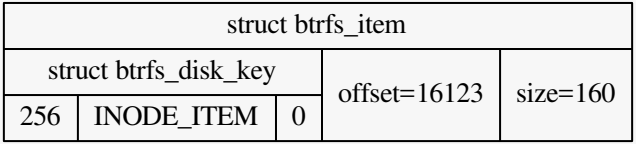
B-tree Nodes


struct btrfs_key_ptr
struct btrfs_disk_key
256
INODE_ITEM
0
blockptr=46976991232
generation=51107

B-tree Nodes


struct btrfs_node
struct btrfs_header
struct btrfs_key_ptr
struct btrfs_disk_key
256
INODE_ITEM
0
46976991232
51107
struct btrfs_key_ptr
struct btrfs_disk_key
261
DIR_ITEM
358895273
46976319488
51107
...

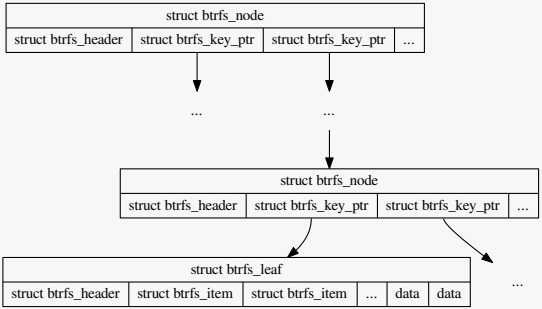
B-tree Leaves



B-tree Leaves

<table>
<tr><td colspan="12">struct btrfs_leaf</td></tr>
<tr><td rowspan="2">struct btrfs_header</td><td colspan="5">struct btrfs_item</td><td colspan="5">struct btrfs_item</td><td rowspan="2">...</td><td rowspan="2">struct btrfs_inode_ref</td><td rowspan="2">struct btrfs_inode_item</td></tr>
<tr><td colspan="3">struct btrfs_disk_key</td><td rowspan="2">16123</td><td rowspan="2">160</td><td colspan="3">struct btrfs_disk_key</td><td rowspan="2">16111</td><td rowspan="2">12</td></tr>
<tr><td>256</td><td>INODE_ITEM</td><td>0</td><td>256</td><td>INODE_REF</td><td>256</td></tr>
</table>

B-tree Structure



B-trees Used in Btrfs

- Root tree
- FS trees
- Extent tree
- Checksum tree
- Chunk tree, device tree
- Relocation tree, log tree, quota tree, UUID tree

B-trees Used in Btrfs

- Root tree
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- Extent tree
- Checksum tree
- Chunk tree, device tree
- Relocation tree, log tree, quota tree, UUID tree
- Free space tree: subject of this talk!

Identifying the Problem

Symptoms

- Large (tens of terabytes), busy filesystems on GlusterFS
- Stalls during commits, sometimes seconds long
- Narrowed down the problem to write-out of the free space cache

Terminology

- *Chunk*: physical unit of allocation, 1 GB for data, 256 MB for metadata
- *Block group*: logical unit of allocation, comprises one or more chunks
- *Extent*: range of filesystem used for a particular purpose

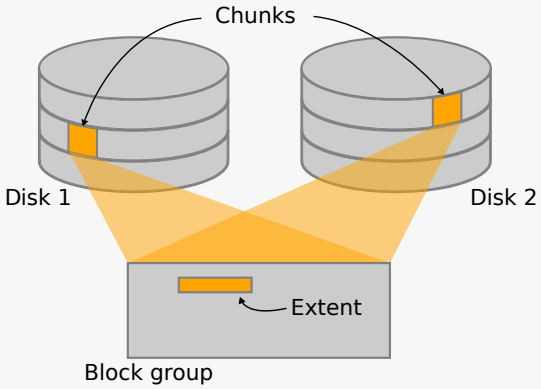

Figure: Basic terminology

Extent Tree

- Tracks allocated space with references
- Three types of items:
  - *Block group items*
  - *Extent items*
  - *Metadata items*

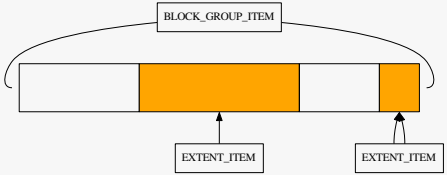

Figure: Data block group

Extent Tree

- Tracks allocated space with references
- Three types of items:
  - *Block group items*
  - *Extent items*
  - *Metadata items*

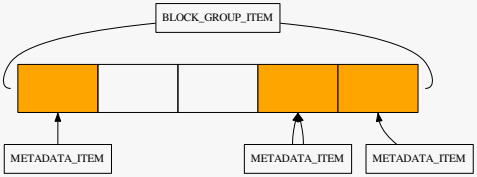

Figure: Metadata block group

Free Space Cache

- Track free space in memory after loading a block group
  - Red-black tree
  - Hybrid of extents + bitmaps
- Loading directly from the extent tree is slow
- Instead, dump the in-memory cache to disk
  - Special free space inodes, one per block group
  - Compact, very fast to load
  - Has to be to written out in entirety

Delayed Refs

- Don’t want to update extent tree on disk for every operation
- Instead, track updates in memory (red-black tree)
- Run at commit time as a batch

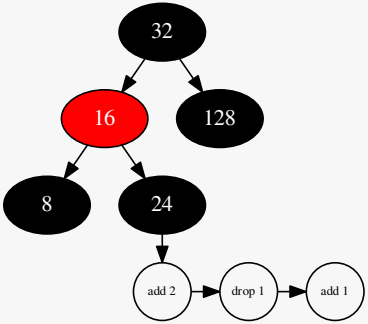

Figure: Delayed refs tree

Diagnosis

- Large, busy filesystem can dirty many block groups
- Have to write out the free space cache for each one
- Run during the critical section of the commit
  - Blocks other operations

Solution

False Start

- Start writing out free space cache outside of critical section
- Redo block groups that got dirtied again during that window
- Still possible for a lot to get dirtied again
    - Back to square one

The Free Space Tree

Key Ideas

- Use another B-tree instead
- Inverse of the extent tree

On-Disk Format

- Per-block group free space info
  - Extent count
  - Flags
- Free space extents
  - Start
  - Length
- Free space bitmaps
  - Start
  - Length
  - Bitmap

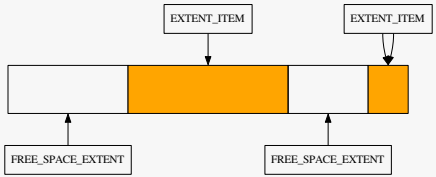

Figure: Free space tree extents

On-Disk Format

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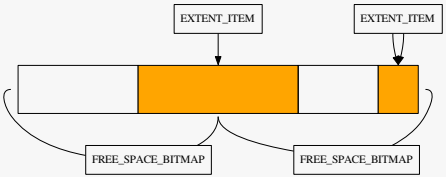


Figure: Free space tree bitmaps

Maintaining the Free Space Tree

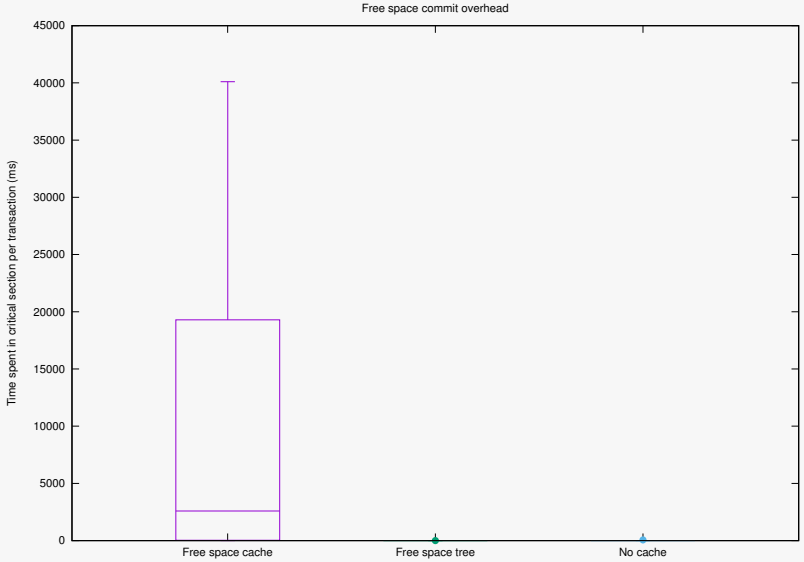
- Piggy-back updates on delayed-refs
  - Get batching for free
- Convert between extents or bitmaps
  - Thresholds for whichever is more space-efficient
  - Buffer to avoid thrashing between formats

Results

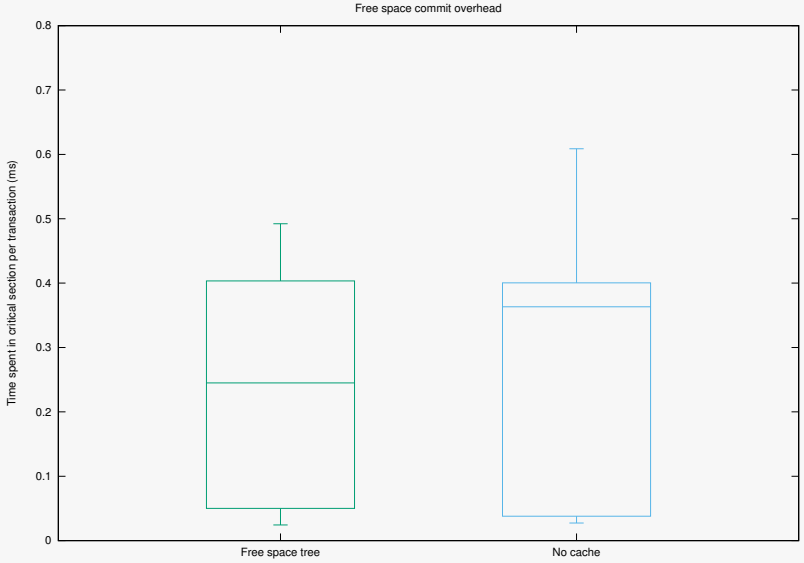
Measuring Commit Overhead

- Use `fallocate` and `unlink` to dirty a lot of block groups
- Sparse filesystem image on loop device to allow for exaggerated sizes (50TB of dirtied space)
- Measure time spent committing, esp. in critical section

Commit Overhead



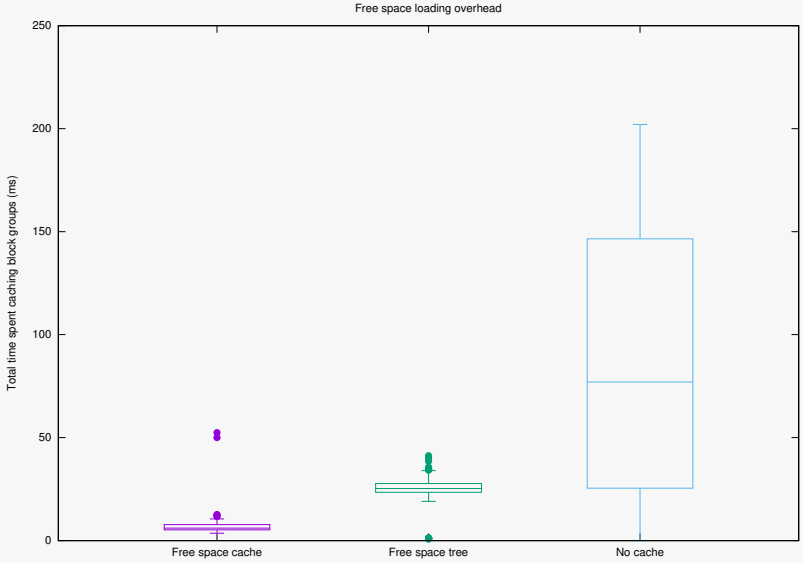
Commit Overhead



Measuring Load Overhead

- Create a fragmented filesystem with `fs_mark`
- Unmount, remount
- Run `fs_mark` again
- Measure time spent loading space cache

Load Overhead



Try It Out

```
mount -o space_cache=v2
```

(Since Linux v4.5)

Questions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