Reasoning about crashes and failures

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Example: file systems

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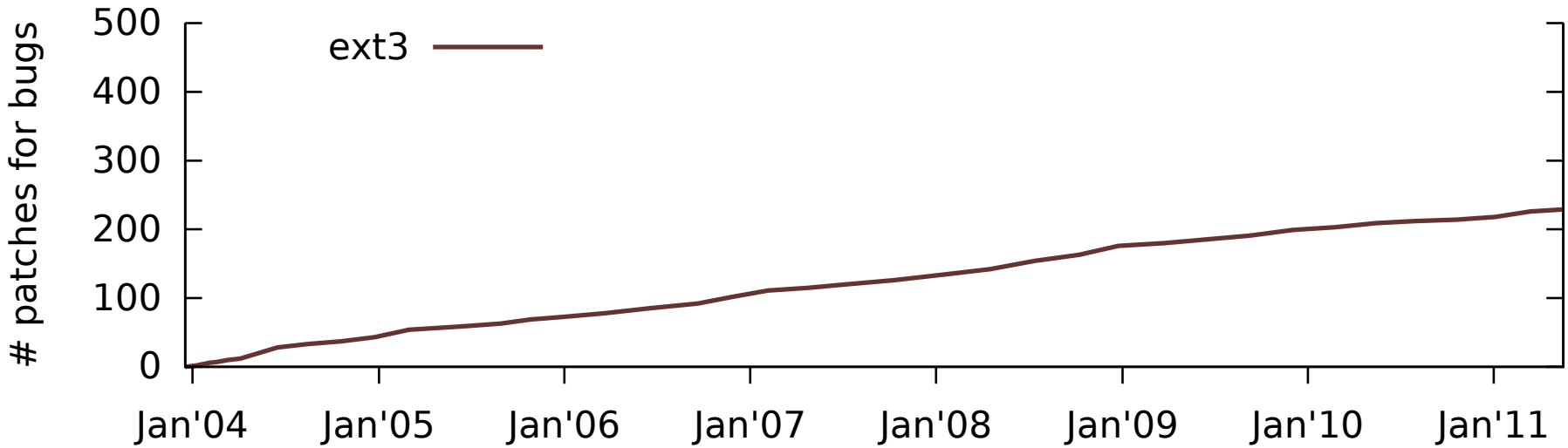

Cumulative number of patches for file-system bugs in Linux; data from [Lu et al., FAST'13]

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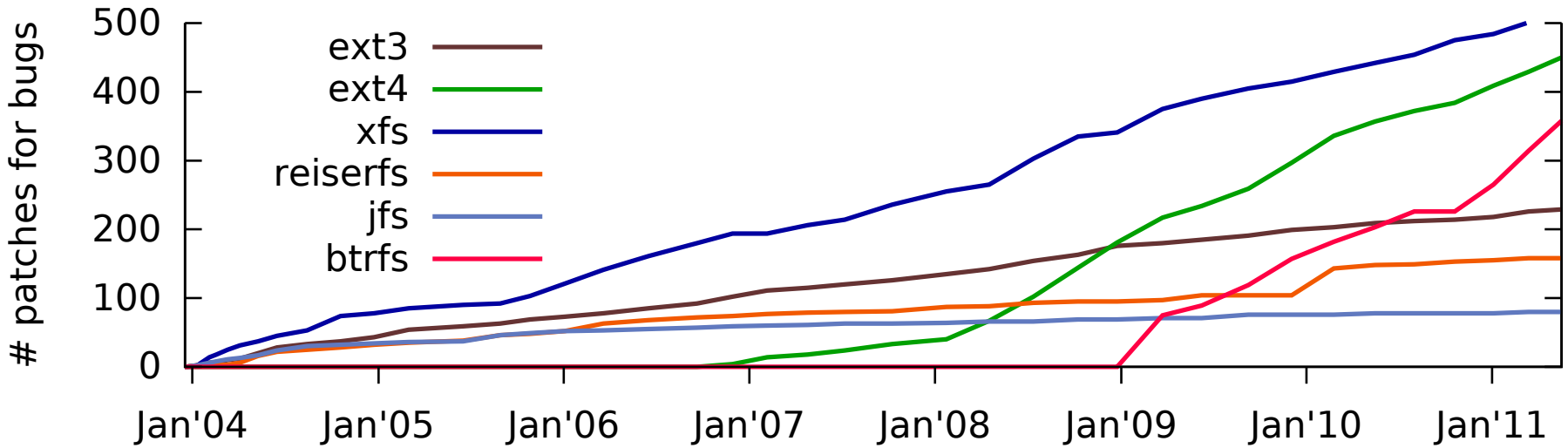

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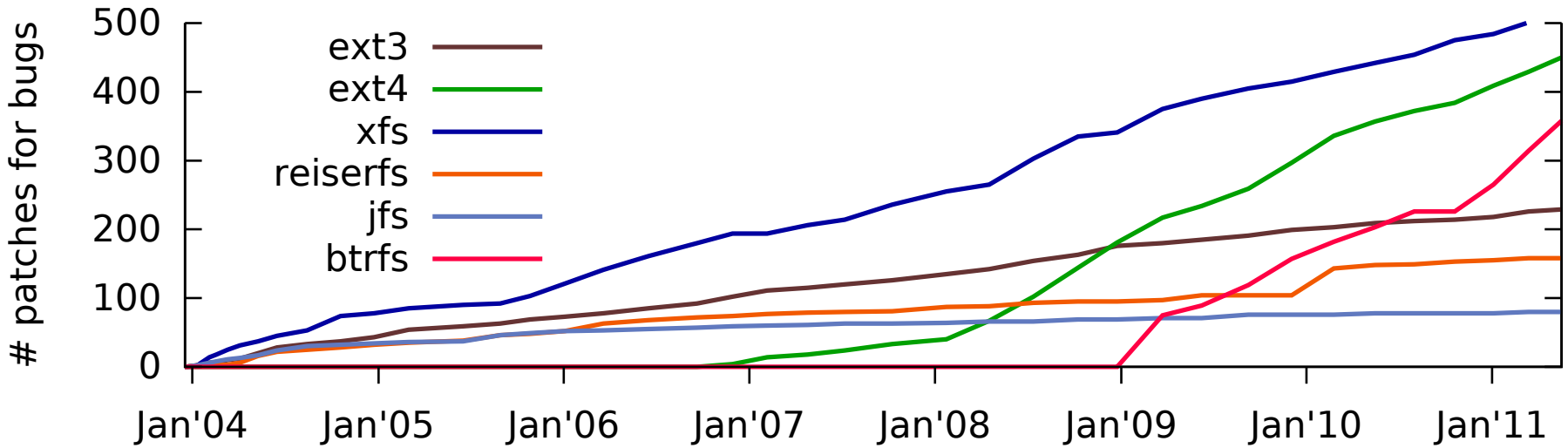

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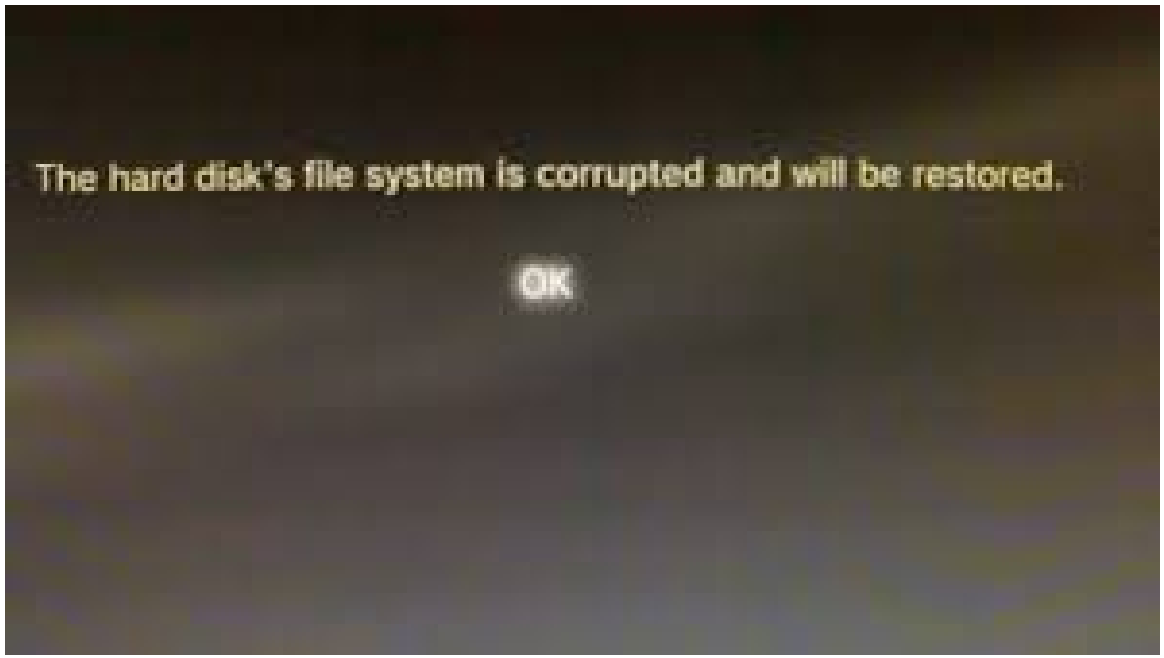
New file systems (and bugs) are introduced over time

Some bugs can lead to **data loss** or **security exploits**

Reasoning about crashes is important

File system must recover from crash with data intact

- Crash due to power failure, hardware failures, or software bugs



File system must preserve data after crash

Difficult because crashes expose many different partially-updated states

```
commit 353b67d8ced4dc53281c88150ad295e24bc4b4c5
--- a/fs/jbd/checkpoint.c
+++ b/fs/jbd/checkpoint.c
@@ -504,7 +503,25 @@ int cleanup_journal_tail(journal_t *journal)
                spin_unlock(&journal->j_state_lock);
                return 1;
        }
+       spin_unlock(&journal->j_state_lock);
+
+       /*
+        * We need to make sure that any blocks that were recently written out
+        * --- perhaps by log_do_checkpoint() --- are flushed out before we
+        * drop the transactions from the journal. It's unlikely this will be
+        * necessary, especially with an appropriately sized journal, but we
+        * need this to guarantee correctness.  Fortunately
+        * cleanup_journal_tail() doesn't get called all that often.
+        */
+       if (journal->j_flags & JFS_BARRIER)
+               blkdev_issue_flush(journal->j_fs_dev, GFP_KERNEL, NULL);

+       spin_lock(&journal->j_state_lock);
+       if (!tid_gt(first_tid, journal->j_tail_sequence)) {
+               spin_unlock(&journal->j_state_lock);
+               /* Someone else cleaned up journal so return 0 */
+               return 0;
+       }
        /* OK, update the superblock to recover the freed space.
         * Physical blocks come first: have we wrapped beyond the end of
         * the log?  */
```

File system must preserve security after crash

Mistakes in crash handling can also lead to data disclosure

- Two optimizations in Linux ext4: direct data write and log checksum
- Subtle interaction: new file can contain other users' data after crash
- Bug introduced in 2008, fixed in 2014 (six years later!)

```
Author: Jan Kara <jack@suse.cz>
Date:   Tue Nov 25 20:19:17 2014 -0500

    ext4: forbid journal_async_commit in data=ordered mode

    Option journal_async_commit breaks gurantees of data=ordered mode as it
    sends only a single cache flush after writing a transaction commit
    block. Thus even though the transaction including the commit block is
    fully stored on persistent storage, file data may still linger in drives
    caches and will be lost on power failure. Since all checksums match on
    journal recovery, we replay the transaction thus possibly exposing stale
    user data.

    [...]
```