Recon:
Verifying File System Consistency at Runtime

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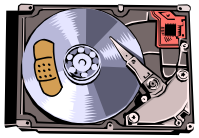
Problem in a Nutshell

- File systems store valuable data
  - Both business value and personal value
- Tension between performance and reliability
  - And availability, scalability, new features, backwards compatibility…
- Metadata describes content of file system
  - Complex relationships exist
  - Small errors can result in significant corruption

➢ Goal is to ensure metadata consistency

Causes of Metadata Inconsistency

1. Crash failures 
   - For performance, update metadata asynchronously
   - Badly timed crash can leave inconsistent updates
   - ✓ Enable recovery to consistent state after crash
     - ✓ Journaling, soft updates, copy-on-write systems
2. Hardware errors 
   - Latent sector errors (aka bitrot), lost or torn writes
   - ✓ Checksums + redundancy

➢ We assume these solutions are available

Remaining Cause of Inconsistency

3. Bugs in file systems

High Severity ext3 bug reports	Closed
ext3 corruption fix	2002-06
Linux: Data corrupting ext3 bug in 2.4.20	2002-12
panic/ext3 fs corruption with RHEL4-U6-re20070927.0	2007-11
Re: [2.6.27] filesystem (ext3) corruption (access beyond end)	2008-06
linux-2.6: ext3 filesystem corruption	2008-09
linux-image-2.6.29-2-amd64: occasional ext3 filesystem corruption	2009-06
ENOSPC during fsstress leads to filesystem corruption on ext2, ext3, and ext4	2010-03
ext3: Fix fs corruption when make_indexed_dir() fails	2011-06

- New bugs still being found in mature file systems

Current Approaches

- Offline consistency check and repair program (e2fsck)
  - ✘ Slow
  - ✘ Repairs may be incorrect
- Restore from last consistent backup
  - ✘ Loss of all data more recent than backup

➢ Can we protect file systems from themselves?

Our Approach

- Verify that file system always preserves metadata consistency
  - Observe file system behavior at runtime
  - Guard against updates that show symptoms of bugs
  - Prevent corruption from propagating to media
- Aim to handle arbitrary file system bugs, memory corruption
  - Assume system already handles crash failures, latent sector errors

➢ Recon makes *silent failures* detectable

Key Challenges

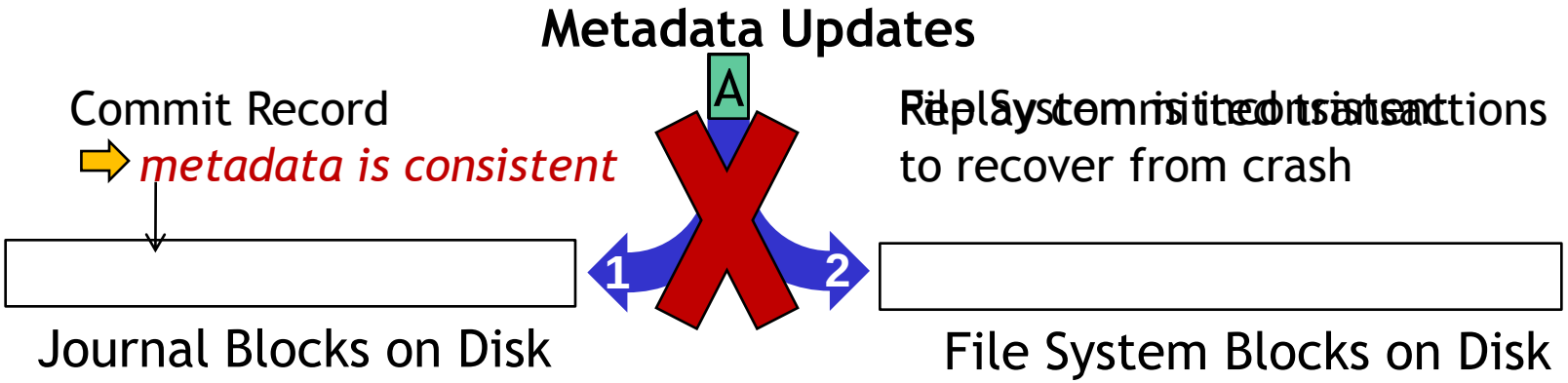
1. What consistency properties to check?
   - Same as offline checker
   - ✘ Global properties require full disk scan
   - ✓ Define *consistency invariants*, use local checks
2. When should consistency be checked?
   - When file system is supposed to be consistent
3. How should the properties be checked?
   - Must be independent of the file system

Consistency Invariants

- Each global consistency property can be converted to a local invariant
- Consistency property:
  - all in-use data blocks marked in block bitmap
- Corresponding consistency invariant
  - If transaction makes a data block live (add pointer to the block), it must also flip a corresponding bit (from 0 to 1) in block bitmap
  - Invariant can be checked locally, by examining updated pointer block and updated block bitmap

When to Check Consistency?

- In-memory metadata may be inconsistent
  - Can't check at arbitrary times
- Modern file systems use transactional updates
  - e.g., journaling, copy-on-write



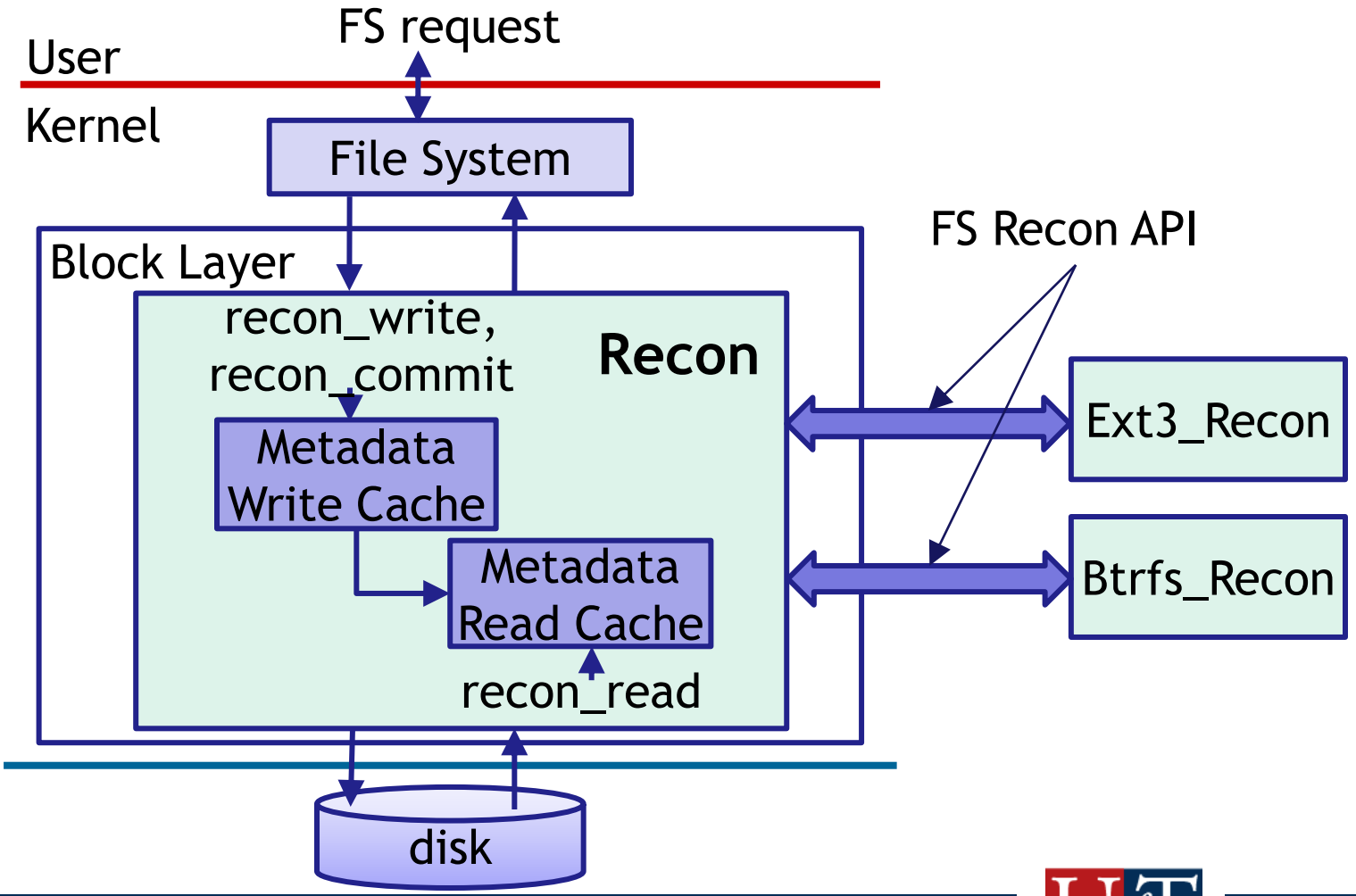
➢ Check consistency at commit points

How to Check Invariants?

- Conflicting requirements
  - Need to interpret file-system format, transaction semantics to make consistency assertions
  - Need to interpret semantics from outside because file system may be buggy
- Recon is a framework for file-system specific
  - metadata interpretation
  - invariant checking

➢ Relies on *pointer-before-block* assumption

Recon System Architecture



Ext3 Invariant Checking

Invariant:

block pointer set from 0 to N $\Longleftrightarrow$ *bit N set in bitmap*

Change Records

[Type, Identity, Field, Old, New]

[Inode, 12, block[1], 0, 22717]
[BBM, 22717, 0, 0, 1]
[BGD, 0, free_blocks, 1500, 1499]
[Inode, 12, i_size, 4052, 7249]
[Inode, 12, i_blocks, 8, 16]

Key	New Ptr	BBM bit set
…		
22717	1	1
…		

✓ Ok

- Each invariant is checked independently

Handling Violations

Several options exist:

- Log warning and continue
  - Obviously risky since we know something is inconsistent!
- Force unmount of file system, prevent writes
  - Reduces availability, loses most recent data
- Take snapshot of filesystem and continue
  - And log warning message
- Micro-reboot file system a la Membrane

That's All Folks

- Recon detects metadata corruption as well as the offline checker
  - But does so *before* the damage reaches disk
- The performance impact is reasonable

➢ Questions?