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Improved Redundancy and Consistency beyond RAID-1

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Agenda

1. Introduction
2. Safe Storage
3. Implementation
4. Evaluation
5. Conclusion

Part I

Introduction

Background of this work

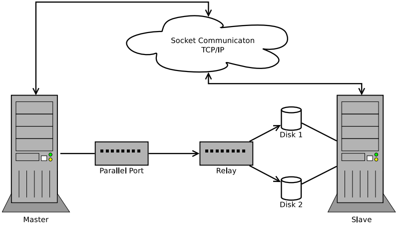
- Part of the thesis “Linux in safety-critical applications”
- Can we *trust* the way Linux (and FLOSS) is developed and tested
- LTP[1] was looking for RAID tests

[1] Linux Test Project (http://ltp.sf.net)

How does it work?

- RAID: Redundant Array of Inexpensive/Independent Disks
- Different RAID levels (e.g.):
  - RAID-0: striping
  - RAID-1: mirroring
- RAID-1 creates virtual hard disk
- Data written to virtual disk is mirrored to multiple physical disks
- If one disk fails, whole system is still operational

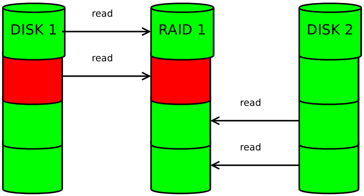
How to test it?



- Separate test environment from system under test
- Physically switch on/off hard disks
- Use cryptographic hashes to verify consistent state of files on the disk
- Linux software RAID has proven to be very stable

What are the problems?

- In general RAID-1 improves availability, *but* availability of storage can be part of the safety argumentation
- Consistency checks:



- Important properties are missing that qualify RAID-1 as safe storage.
- $\Rightarrow$ *RAID-1 like behaviour* is fine, but additional properties are necessary

Part II

Safe Storage

What is safe storage

Informal definition:

> *Storage is considered to be safe, if it provides a high degree of confidence that raw data that is read is exactly the same as the raw data that was written to it.*

Consistency

- Safe storage needs much stronger concept of consistency checking than standard RAID-1
- Whenever the safe storage detects an inconsistent state (e.g., a bit flip) it has to inform the reading application
- Of utmost importance for safety critical applications. If they are informed, a safe-state can be reached.

Diversity

- File system development is a difficult task. Modern file systems are getting more complex.

File System	Lines of Code	Open Bugs[2]
ext2	8965	4
ext3	16362	15
ext4	33979	45
xfs	74503	8
btrfs	57088	43

- Safe storage can benefit from the diversity in the file system sector
- Would be impossible to achieve in hardware (e.g., *one* file system on RAID-1 disk set)

[2] http://bugzilla.kernel.org

On-the-fly correction

- According to literature there is a large number of Undetected Disk Errors (UDEs).
- Use consistency and redundancy as a prerequisite
- Overwrite faulty copies on-the-fly with an agreed, consistent state (e.g., TMR + voting)

Simplicity

- As we have seen from the lines of code, file system development is a complex matter
- Implementation of safe storage should not introduce unnecessary complexity by itself
- $\Rightarrow$ a simple layer above existing file systems

Part III

Implementation

Tools of the trade - FLOSS software

- Linux:
  - Widely used
  - A lot of different file systems which are proven in use
  - Necessary design diversity (different programmes, different companies)
- FUSE:
  - Upstream and used by many projects (sshfs, ntfs-3g,. . .)
  - Really nice for rapid prototyping of crazy ideas

Tinysafefs

- Wrapper file system around existing file systems
- Has its own mount point (e.g., /mnt/tinysafefs)
- Reads/Writes data from/to existing mountpoints which should be the mointpoints of physical disks with distinct file systems

Two Disk Mode

- Simple “lowcost” version
- Similar to RAID-1, but *with* consistency checks (and file system diversity)
- On write: Data gets written to two mount points (i.e., two disks)
- On read: Data is read from *both* disks, gets compared and if (and only if) consistent gets forwarded to reading application
- If data not consistent: Return `ENOENT` (No such file or directory)

Two Disk Mode (2)

```
$ cd /tmp/tinysafefs
$ ls
  testfile.txt
$ ls /disk*/
  /disk1:
  testfile.txt

  /disk2:
  testfile.txt
$ mkdir testdir
$ ls
  testfile.txt
  testdir
$ ls /disk*/
  /disk1:
  testfile.txt
  testdir

  /disk2:
  testfile.txt
  testdir
```

Two Disk Mode (3)

```
$ cd /tmp/tinysafefs
$ echo "testdata" > ./testfile.txt
$ ls /disk*
  /disk1:
  testfile.txt

  /disk2:
  testfile.txt
$ cat ./testfile.txt
  testdata
$ echo "destroy it" > /disk1/testfile.txt
$ cat ./testfile.txt
  cat: ./testfile.txt: No such file or directory
```

Three Disk Mode

- Wrapped around three disks
- On write: data is written to three disks
- On read: data is read from all copies and consistency gets checked
  - If *at least two* copies have a consistent state, data gets forwarded to user space application
  - If one copy is inconsistent, tinysafefs tries to overwrite it
  - If all copies are inconsistent: `ENOENT`

Three Disk Mode (2)

```
$ cd /tmp/tinysafefs
$ echo "testdata" > ./testfile.txt
$ ls /disk*
  /disk1:
  testfile.txt

  /disk2:
  testfile.txt

  /disk3:
  testfile.txt
$ cat ./testfile.txt
  testdata
$ echo "destroy it" > /disk1/testfile.txt
$ cat ./testfile.txt
  testdata
$ cat /disk1/testfile.txt
  testdata
$ echo "destroy it 1" > /disk1/testfile.txt
$ echo "destroy it 2" > /disk2/testfile.txt
$ cat ./testfile.txt
  cat: ./testfile.txt: No such file or directory
```

Part IV

Evaluation

Evaluation Setup

- Hardware:
  - Standard PC with Ubuntu Server 10.04.1
  - One disk with the OS, 3 usb drives with ext2, ext4, xfs
  - Used for performance tests and selected scenarios
- Software:
  - Simulator written in Python
  - Simulates three disk mode with on-the-fly correction
  - Worst/Best case scenarios (and randomly selected cases) used for hardware evaluation

Performance of tinysafefs

- `dd` with `fsync`
- Caches were dropped after each run to minimize cache influence
- Block sizes from 128 bytes to 8192 bytes.

Read performance of tinysafefs - 3 disk mode

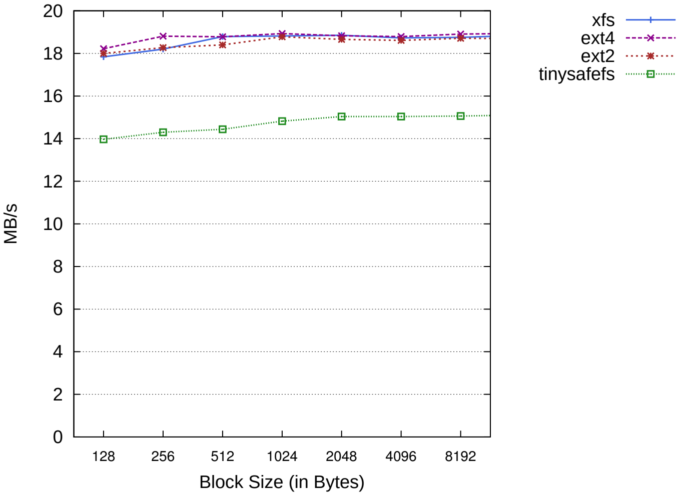


Figure: Read performance

Write performance of tinysafefs 3 disk mode

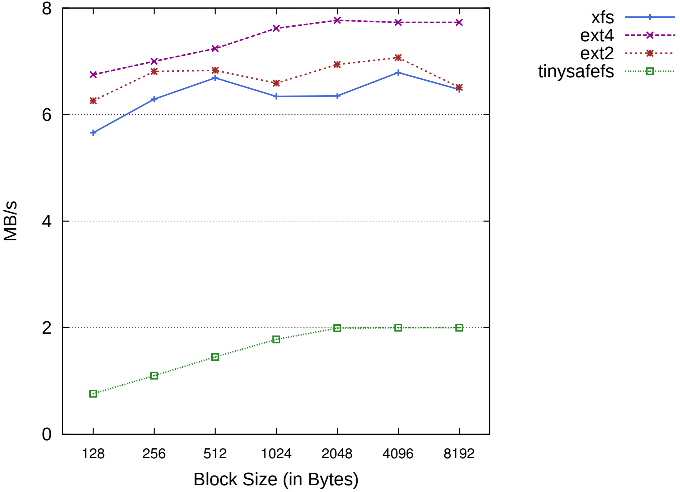


Figure: Write performance

Corrections of tinysafefs in 3 disk mode

- Hard to assume realistic numbers of failures per read. Assumption: 1 failure per 50 reads
- 1000 runs $\Rightarrow$ 1000 seeds for random generator
- 100 files per run
- After 50 reads, 1 random file on one random disk gets destroyed.
- Read until first uncorrectable fault

Until First Error	TDMC	Single Disk	Factor
Min. Repairs	0	None	-
Max. Repairs	849	None	-
Min. Reads	103	51	2.0
Max. Reads	42861	299	143.3
Overall Reads	5317517	117697	45.1
Overall Repairs	102033	None	-
Average Reads	5317	117	45.4
Average Repairs	102	None	-

Part V

Conclusion

Lessons learned

- Safe storage can be implemented by means of consistency, diversity, on-the-fly correction, and simplicity
- Safety critical systems can benefit from FLOSS
  - All the tools are already there
  - Trust is put on software that can be reviewed (no binary-blob firmware)

ETX and EOT

Thank you for your attention!