Update on filesystems for flash storage

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https://bootlin.com/

About this document

Documents updates can be found or described on
https://bootlin.com/pub/conferences/2008/elce/

Contents

Introduction

Flash storage

We are talking about flash chips, accessed by the Linux kernel as Memory Technology devices.

Compact Flash, MMC/SD, Memory Stick cards, together with USB flash drives and Solid State Drives (SSD), are interfaced as block storage, like regular hard disks.

At the end, we will say a few words about dealing with the second category.

Existing solutions

For the last years, only 2 filesystem choices for flash storage

jffs2

Wear leveling, ECC

Power down resistant

Compression

Huge mount times

Rather big memory usage

Mainstream support

yaffs2

Wear leveling, ECC

Power down resistant

No compression

Very quick mount time

Programmed by Wookies (at least 1)

Available as a Linux patch.

2 solutions, but far from being perfect!

Election time!

At last, new choices have been developed.

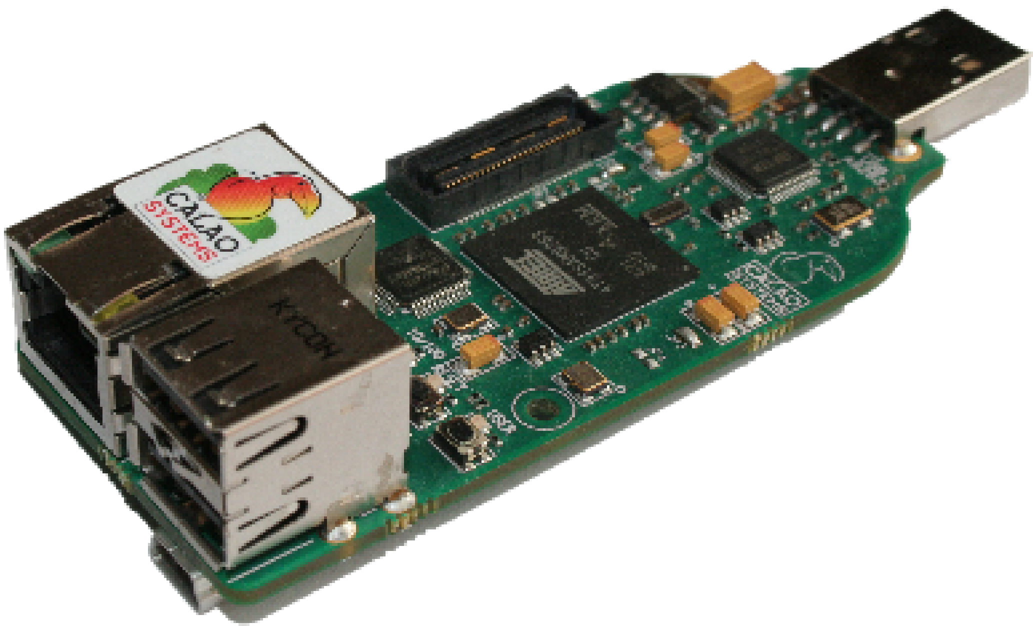
- LogFS
  - New filesystem for MTD storage
- UBI
  - New layer managing erase blocks and wear leveling
- UBIFS
  - New filesystem taking advantage of UBI's capabilities
- AXFS
  - Advanced XIP FileSystem

How do they compare to existing solutions?

- Mounting time
- Access speed
- Memory usage
- CPU usage
- Size?

Test hardware

Calao Systems USB-A9263



Supported by Linux 2.6.27!

AT91SAM9263 ARM CPU

64 MB RAM
256 MB flash

2 USB 2.0 host
1 USB device

100 Mbit Ethernet port

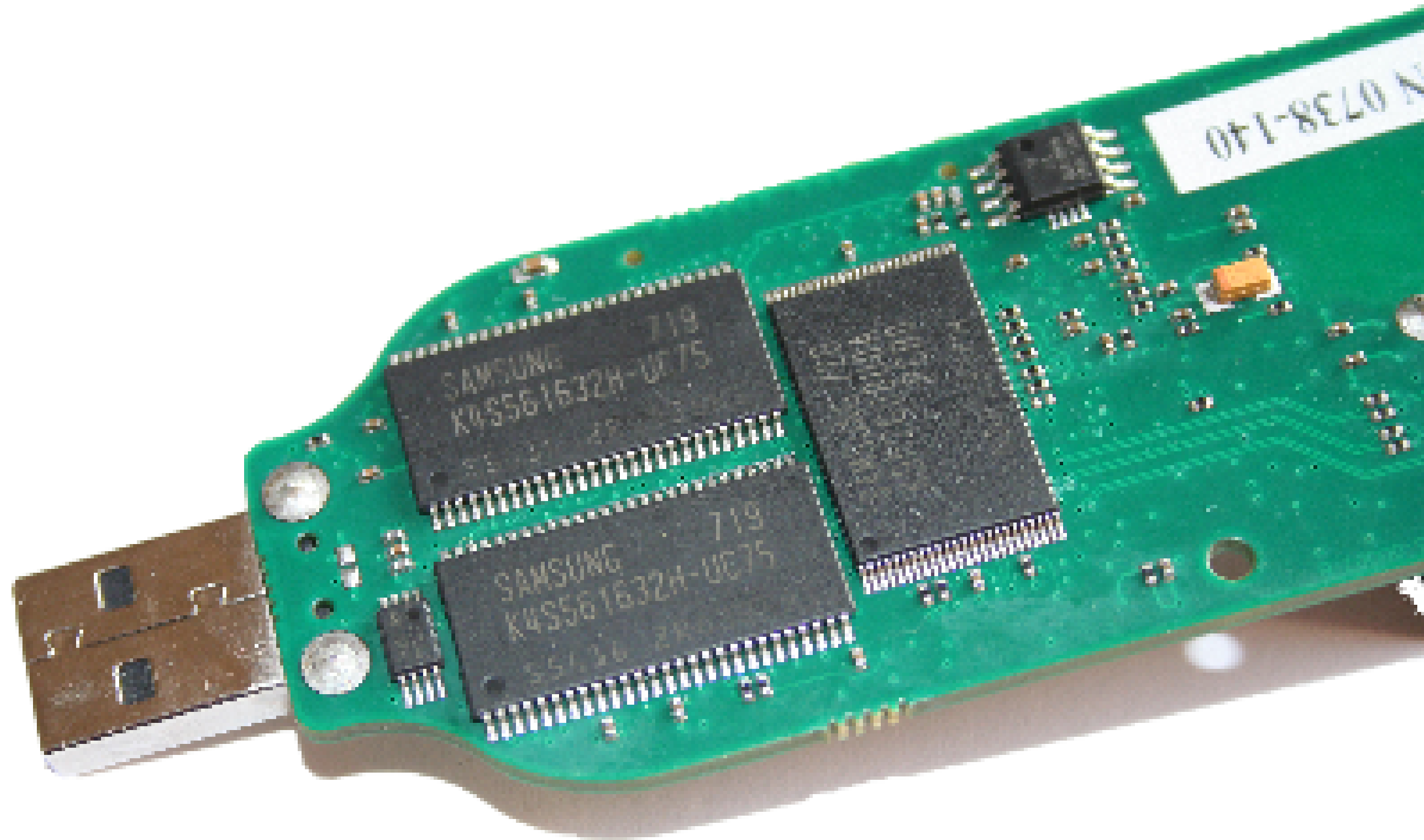
Powered by USB!
Serial and JTAG through this USB port.

Multiple extension boards.

162 EUR

Flash chips

NAND device: Manufacturer ID: 0xec, Chip ID: 0xda
(Samsung NAND 256MiB 3,3V 8-bit)

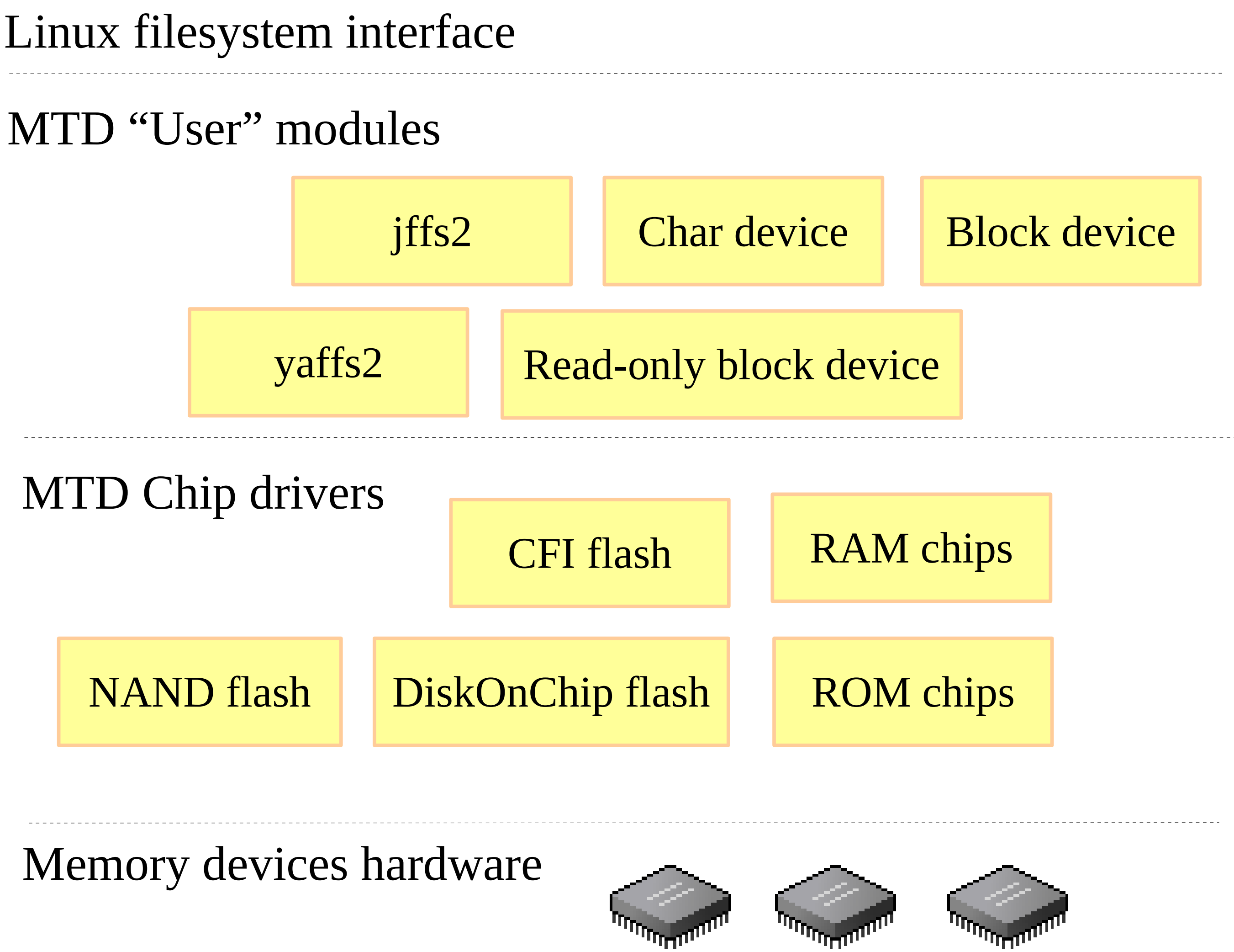


Samsung's reference: K4S561632H-UC75

Available flash filesystems

The MTD API

- A Linux kernel API to access Memory Technology Devices
- Abstracts the specifics of MTD devices: erase blocks, page size...



MTD - How to use

Creating the device nodes

Char device files

mknod /dev/mtd0 c 90 0 (bad idea!!!)

mknod /dev/mtd1 c 90 2 (Caution!)

mknod /dev/mtd2 c 90 4 (Caution)

Block device files

mknod /dev/mtdblock0 b 31 0 (bad idea!!!)

mknod /dev/mtdblock0 b 31 2

mknod /dev/mtdblock0 b 31 2

jffs2

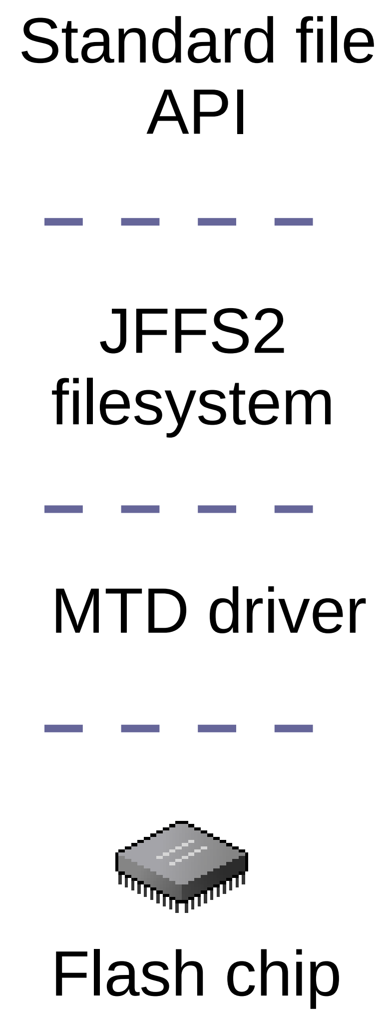
Today's standard filesystem for MTD flash

Nice features:

- On the fly compression. Saves storage space and reduces I/O.
- Power-down reliable.
- Implements wear-leveling

Drawbacks: doesn't scale well

- Mount time depending on filesystem size: the kernel has to scale the whole filesystem at mount time, to read which block belongs to each file.
- Keeping this information in RAM is memory hungry too.



New jffs2 features

`CONFIG_JFFS2_SUMMARY`
Reduces boot time by storing summary information.

New jffs2 compression options:

- Now supports lzo compression, and not only zlib (and also the rtime and rubin compressors)
- Can try all compressors and keep the one giving the best results
- Can also give preference to lzo, to the expense of size, because lzo has the fastest decompression times.

jffs2 - How to use

Compile mtd-tools if needed:

```
git-clone git://git.infradead.org/mtd-utils.git
```

Erase and format a partition with jffs2:

```
flash_eraseall -j /dev/mtd2
```

Mount the partition:

```
mount -t jffs2 /dev/mtdblock2 /mnt/flash
```

Fill the contents by writing

Or, use an image:

```
nandwrite -p /dev/mtd2 rootfs.jffs2
```

yaffs2

http://www.yaffs.net/

Supports both NAND and NOR flash

No compression

Wear leveling, ECC, power failure resistant

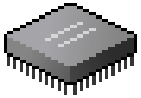
Fast boot time

Code available separately through CVS
(Dual GPL / Proprietary license
for non Linux operating systems)

Standard file API

YAFFS2 filesystem

MTD driver



Flash chip

yaffs2 - How to use

Erase a partition:

```
flash_eraseall /dev/mtd2
```

Format the partition:

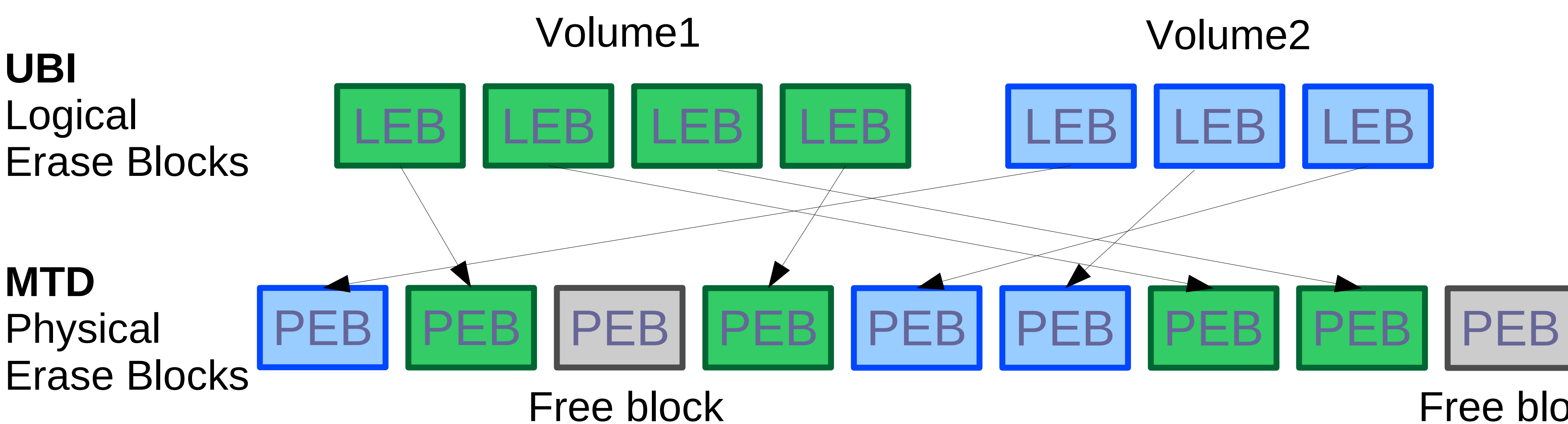
`sleep` (any command can do!)

Mount the partition:

```
mount -t yaffs2 /dev/mtdblock2 /mnt/flash
```

UBI

- Unsorted Block Images
- http://www.linux-mtd.infradead.org/doc/ubi.html
- Volume management system on top of MTD devices.
- Allows to create multiple logical volumes and spread writes across all physical blocks.
- Takes care of managing the erase blocks and wear leveling. Makes filesystem easier to implement.



UBI - How to use (1)

First, erase your partition (NEVER FORGET!)

```
flash_eraseall /dev/mtd1
```

First, format your partition:

```
ubiformat /dev/mtd1 -s 512
```

(possible to set an initial erase counter value)

See http://www.linux-mtd.infradead.org/faq/ubi.html if you face problems

Need to create a `/dev/ubi_crtl device` (if you don't have udev)

Major and minor number allocated in the kernel. Find these numbers in `/sys/class/misc/ubi_ctrl/dev/` (e.g.: `10:63`)

Or run `ubinfo`:

```
UBI version:                    1
Count of UBI devices:           1
UBI control device major/minor: 10:63
Present UBI devices:            ubi0
```

UBI - How to use (2)

Attach UBI to one (of several) of the MTD partitions:

```
ubiattach /dev/ubi_ctrl -m 1
```

Find the major and minor numbers used by UBI:

`cat /sys/class/ubi/ubi0/dev` (e.g. `253:0`)

Create the UBI device file:

```
mknod /dev/ubi0 c 253 0
```

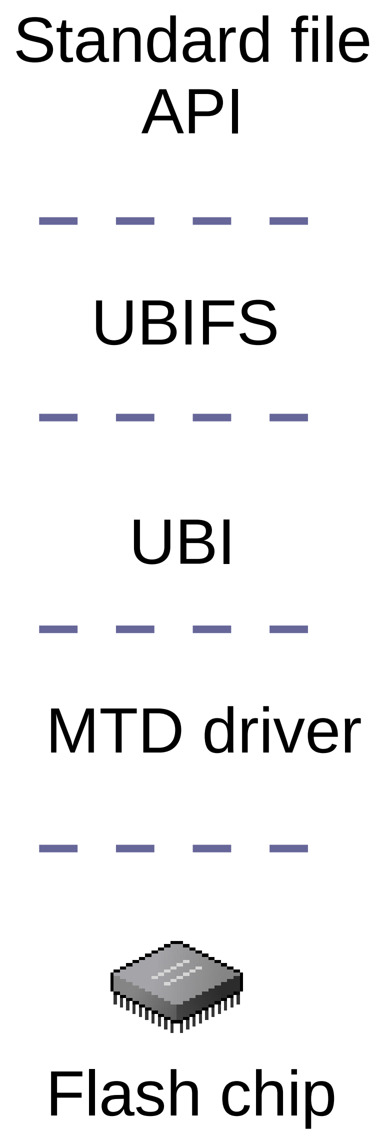
UBIFS

http://www.linux-mtd.infradead.org/doc/ubifs.html

The next generation of the jffs2 filesystem, from the same linux-mtd developers.

Available in Linux 2.6.27

Works on top of UBI volumes



UBIFS - How to use

Creating

```
ubimkvol /dev/ubi0 -N test -s 116MiB
```

```
mount -t ubifs ubi0:test /mnt/flash
```

Deleting

```
umount /mnt/flash
```

```
ubirmvol /dev/ubi0 -N test
```

Detach the MTD partition:

```
ubidetach /dev/ubi_ctrl -m 1
```

LogFS

http://logfs.org/logfs/

Also developed as a replacement for jffs2

We announced we would cover it, but its latest version only supports 2.6.25. Our board only supports 2.6.21, 2.6.27 and beyond, and the 2.6.25 LogFS patch doesn't compile in 2.6.27!

Anyway, LogFS is not ready yet for production. Will it ever be, now that jffs2 has a valuable replacement? Competition is useful though.

AXFS

Advanced XIP FileSystem for Linux
http://axfs.sourceforge.net/

Allows to execute code directly from flash, instead of copying it to memory.

As XIP is not possible with NAND flash, works best when there is a mix of NOR flash (for code) and NAND (for non XIP sections).

Currently posted for review / inclusion in the mainstream Linux kernel. To be accepted in 2.6.29 or later?

Not benchmarked here. We only have NAND flash anyway.

SquashFS

http://squashfs.sourceforge.net/

Filesystem for block storage!?

But read-only! No problem with managing erase blocks and wear-leveling. Fine to use with the mtdblock driver.

You can use it for the read-only sections in your filesystem.

Actively maintained. Releases for many kernel versions (recent and old).

Currently submitted by Philip Lougher for inclusion in mainline. Don't miss his talk tomorrow!

SquashFS - How to use

Very simple!

On your workstation, create your filesystem image (example: `120m/` directory in our benchmarks)

```
mfsquashfs 120m 120m.sqfs
```

Erase your flash partition:

```
flash_eraseall /dev/mtd2
```

Make your filesystem image available to your device (NFS, copy, etc.) and flash your partition:

```
dd if=120m.sqfs of=/dev/mtdblock2
```

Mount your filesystem:

```
mount -t squashfs /dev/mtdblock2 /mnt/flash
```

Benchmarks

Benchmark overview

Compared filesystems:

- jffs2, default options
- jffs2, lzo compression only
- yaffs2
- ubifs, default options
- ubifs, no compression
- squashfs

Different MTD partitions

- 8M
- 32M
- 120M

Corresponding to most embedded device scenarios.

Partitions filled at about 85%

All tested with Linux 2.6.27.

Read and mounting experiments

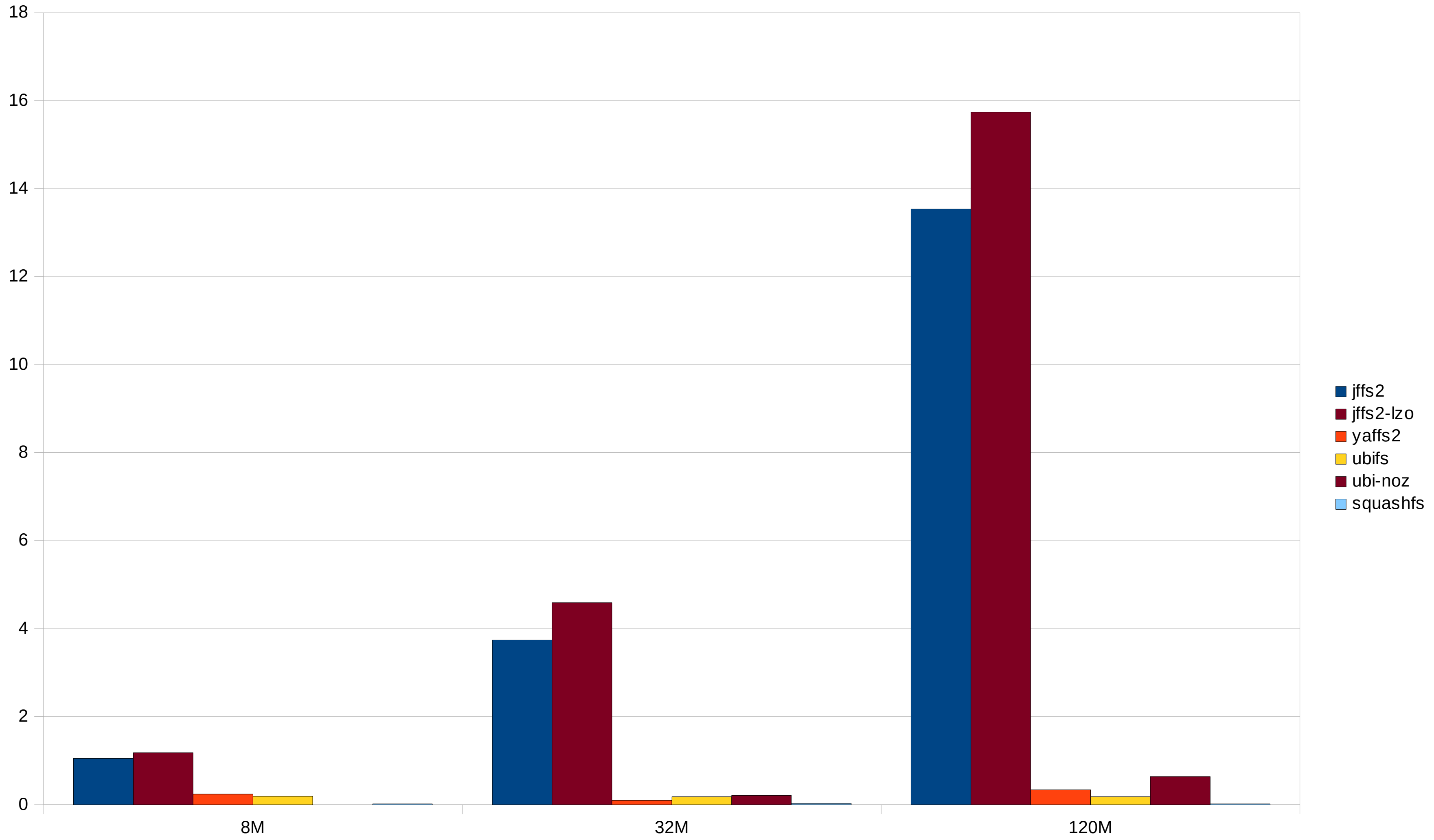
Mounting an arm Linux root filesystem, taken from the OpenMoko project.

Advantages: mainly contains compressible files (executables and shared libraries).

Represents a very important scenario: booting on a filesystem in flash. Mounting and file access time are major components of system boot time.

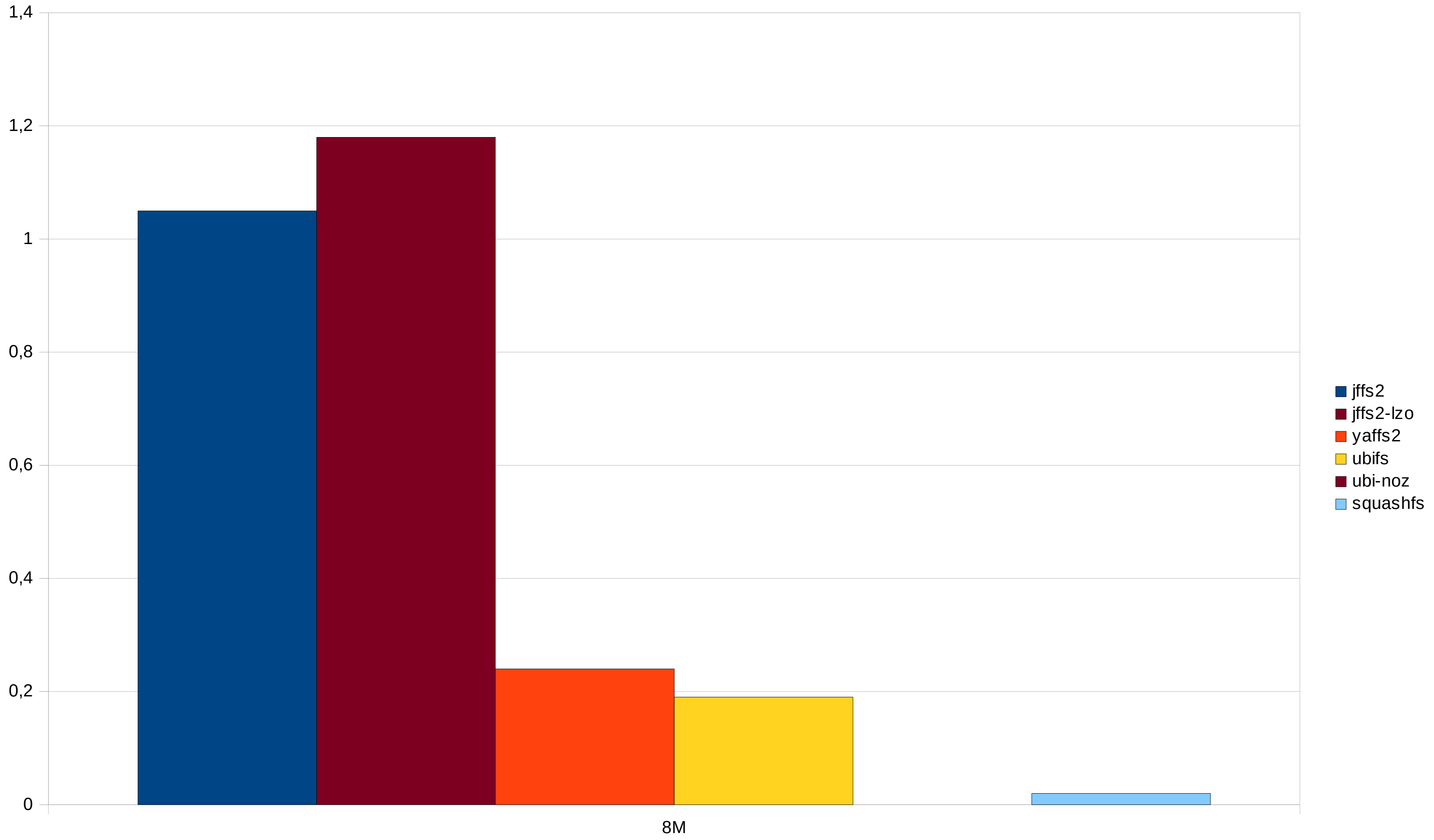
Mount time (seconds)

ubifs-noz / 8M: doesn't fit



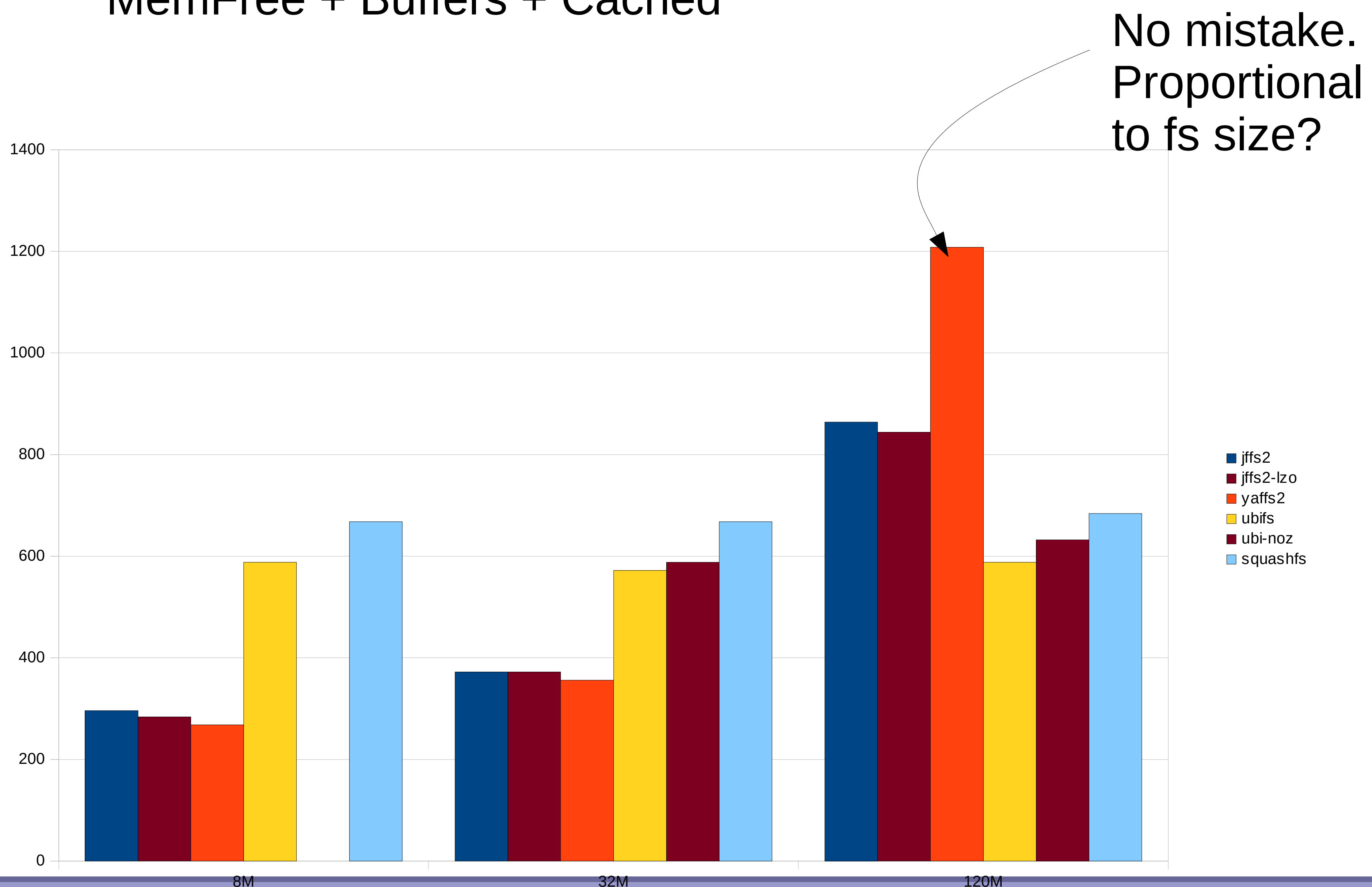
Zoom - Mount time (seconds) - 8M

ubifs-noz / 8M: doesn't fit



Memory consumption after mounting (KB)

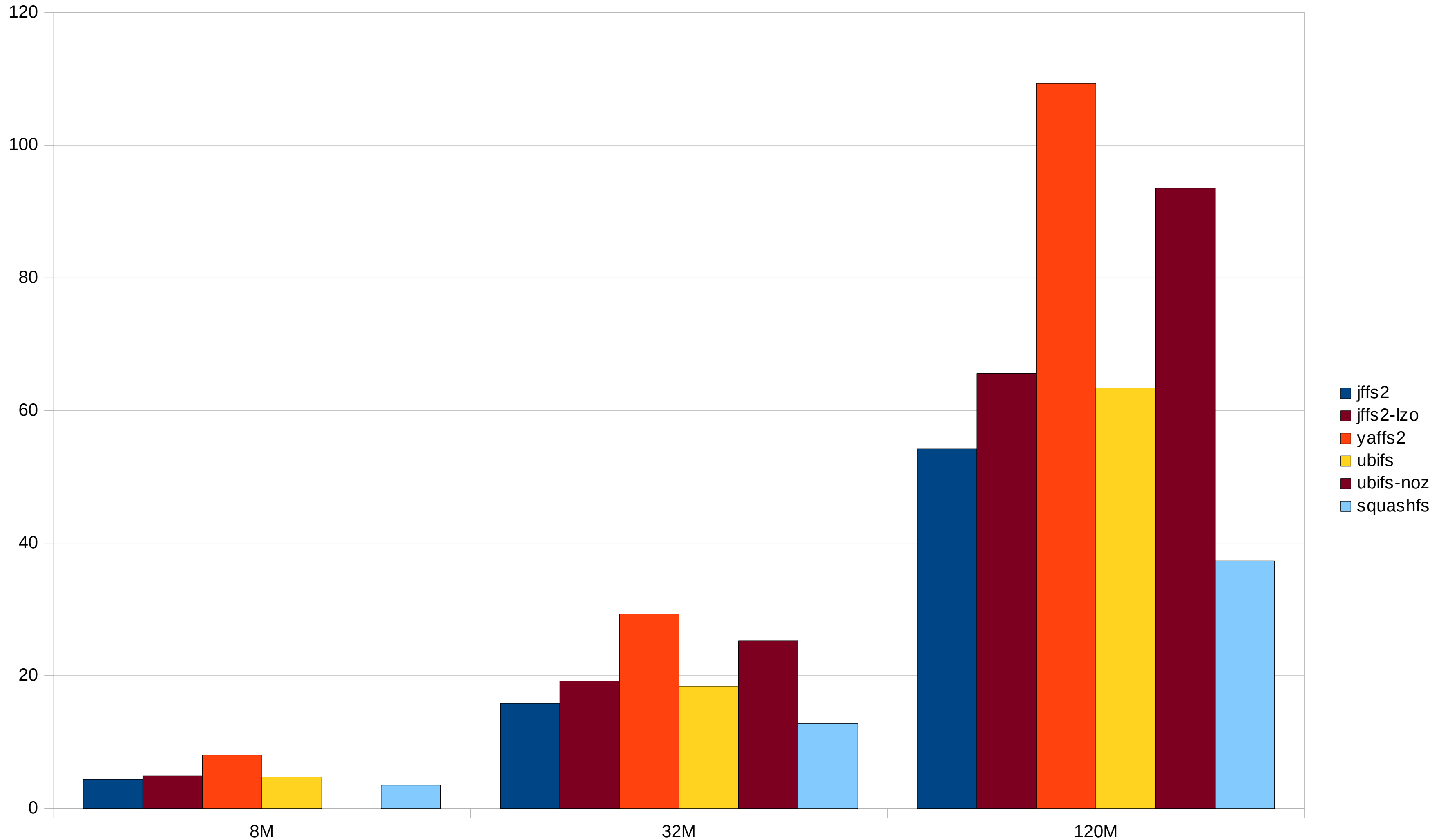
Free memory measured with /proc/meminfo:
MemFree + Buffers + Cached



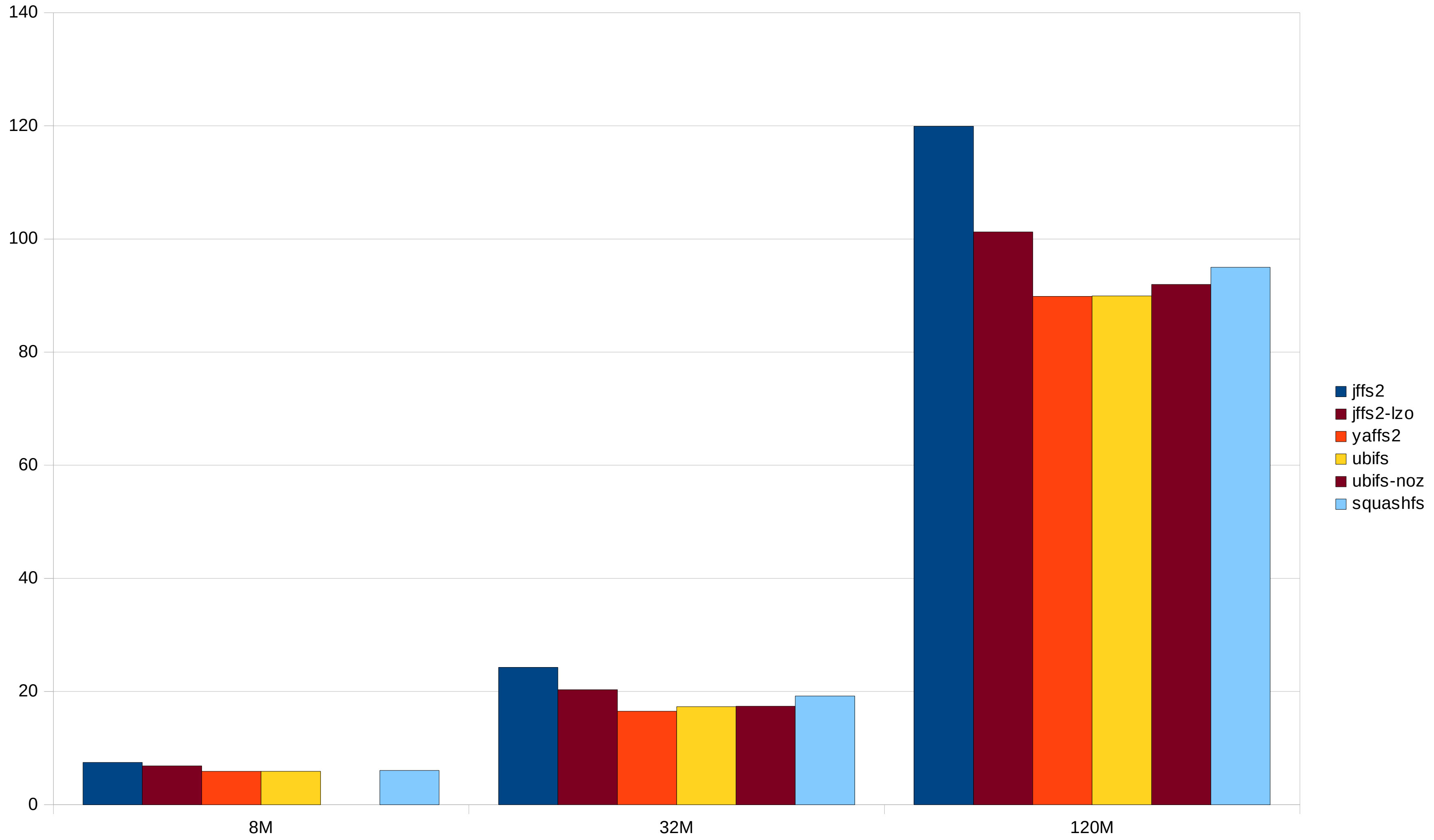
Used space (MB)

Measured with `df`

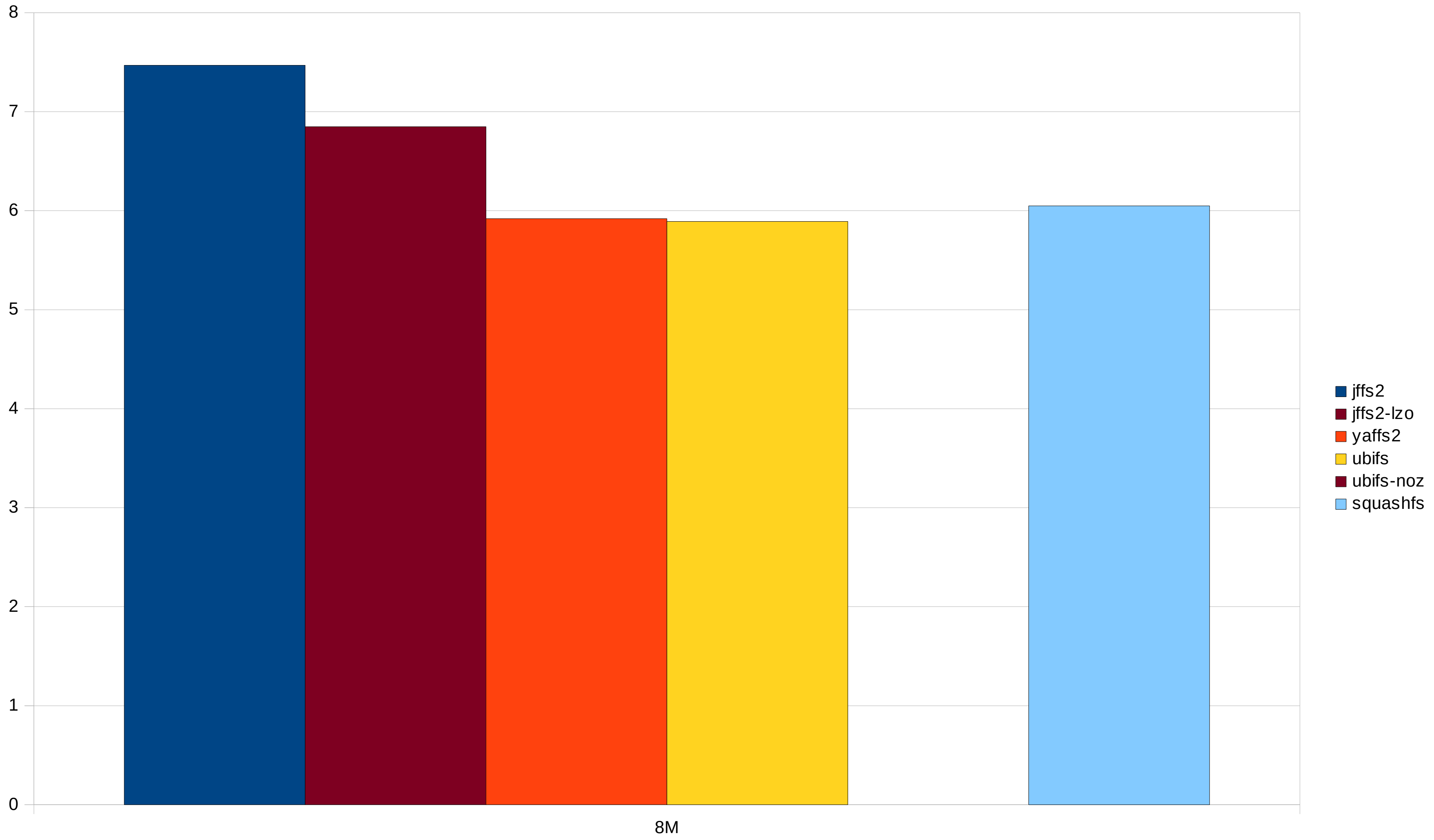
Add some space for UBIFS!
1 MB for 8 MB



Read time (seconds)

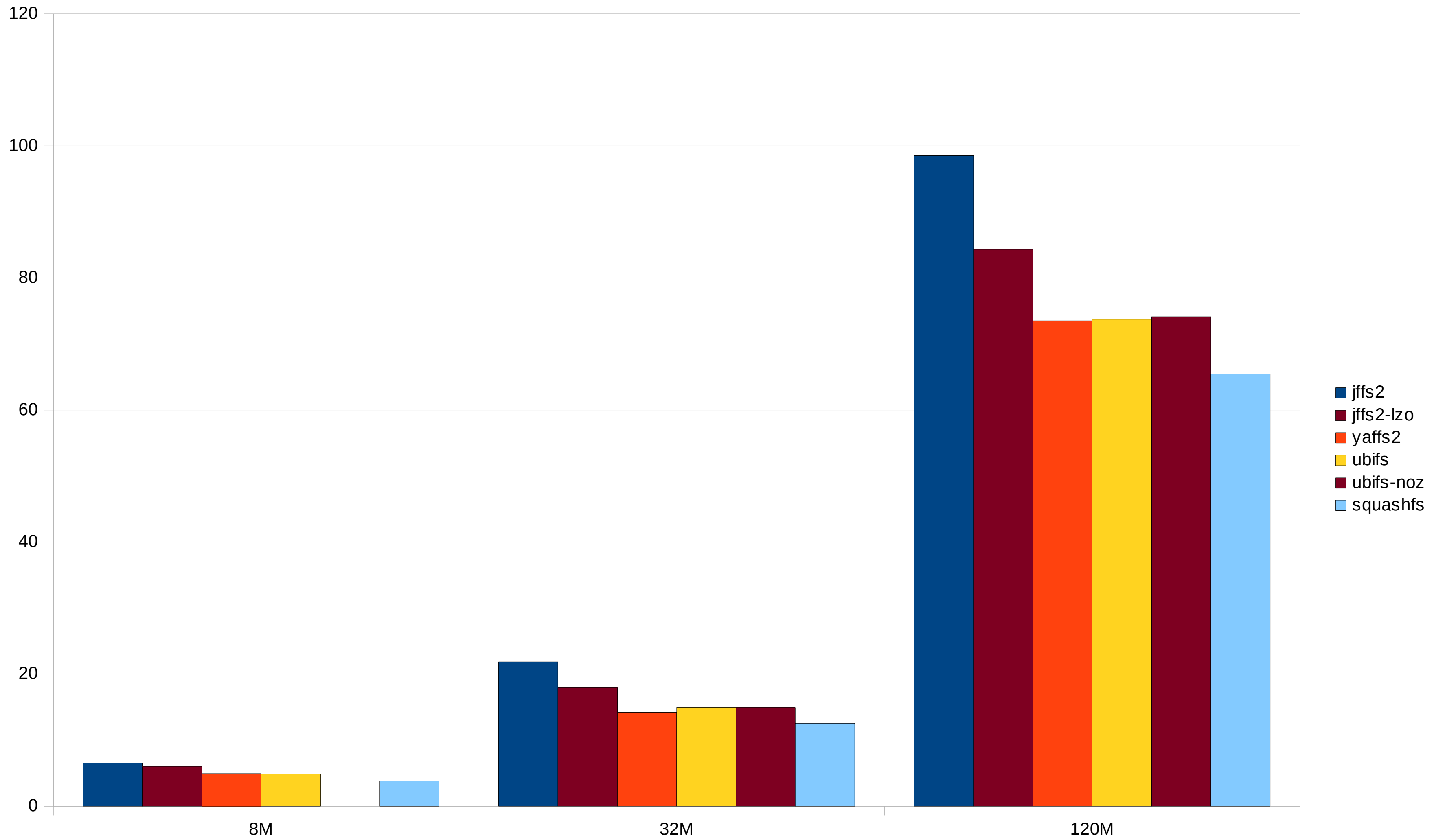


Zoom - Read time (seconds) - 8M



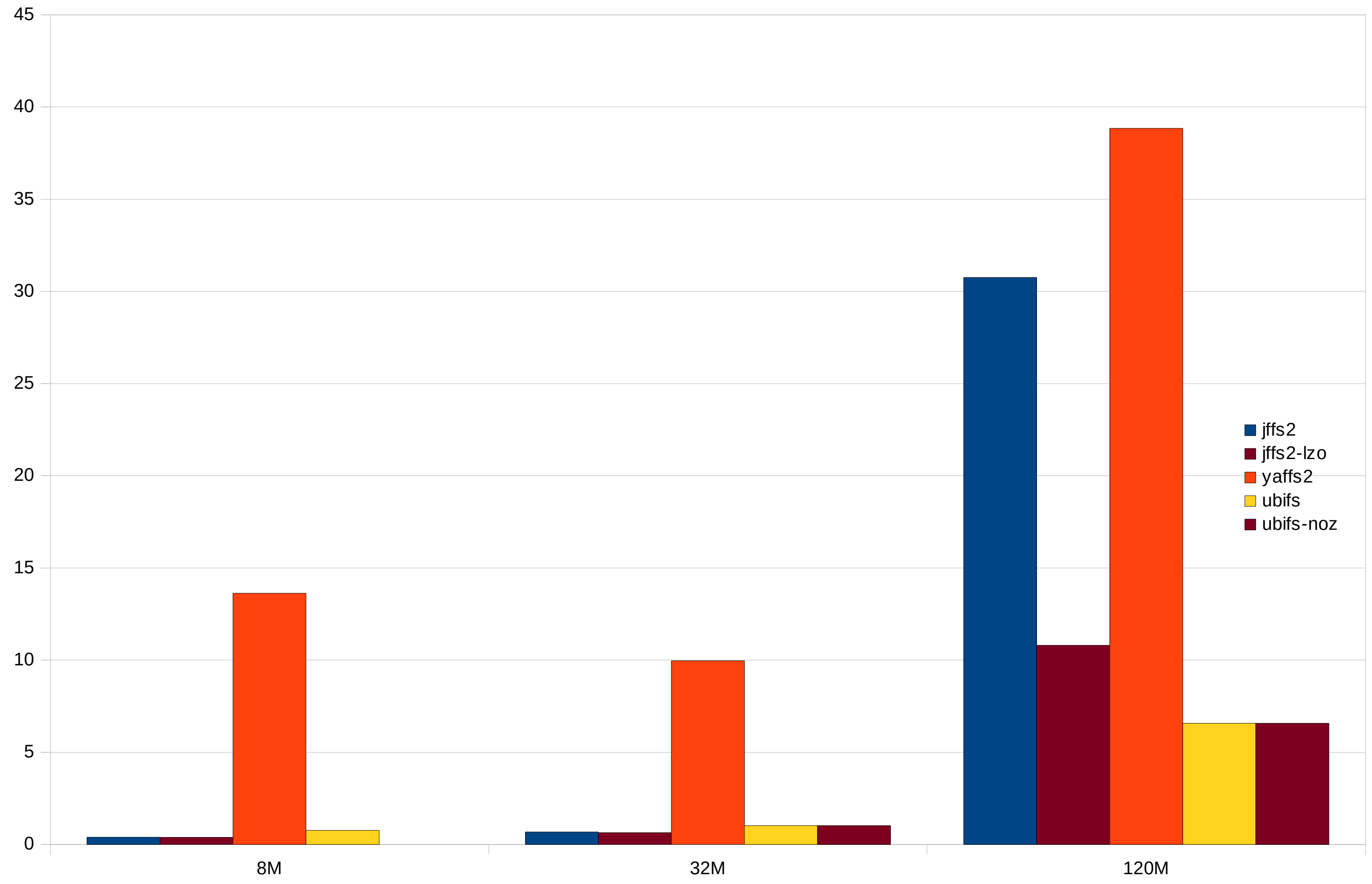
CPU usage during read (seconds)

During the experiments in the previous slide
(using the sys measure from the time command)



File removal time (seconds)

Removing all the files in the partition
(after the read experiment)



Write experiment

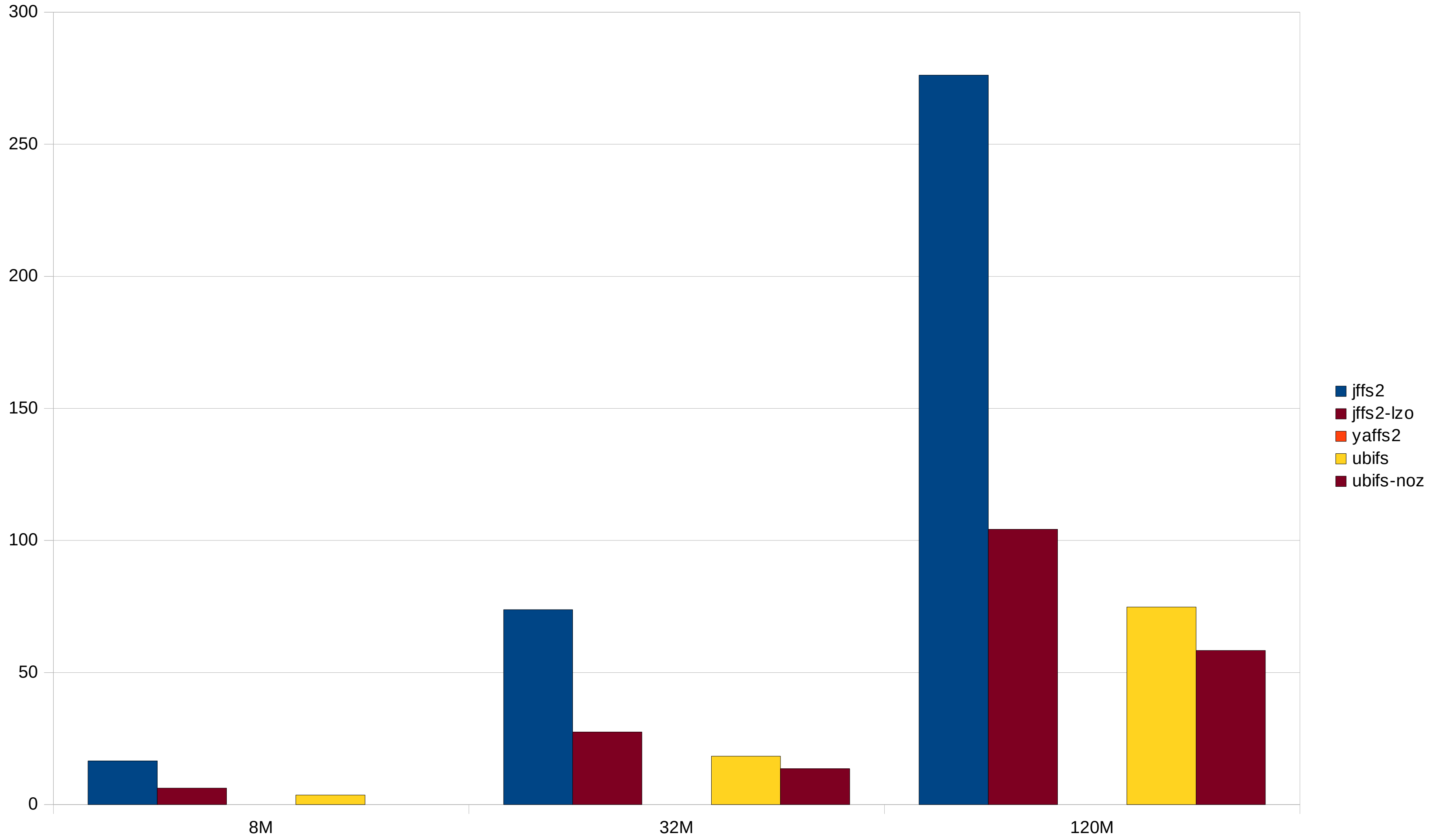
Writing 8M directory contents multiple times
  (less in the 8M case)
  Data copied from a tmpfs filesystem,
  for no overhead reading the files.

Contents: arm Linux root filesystem.
  Small to medium size files, mainly executables and shared libraries.

Not many files that can't be compressed.

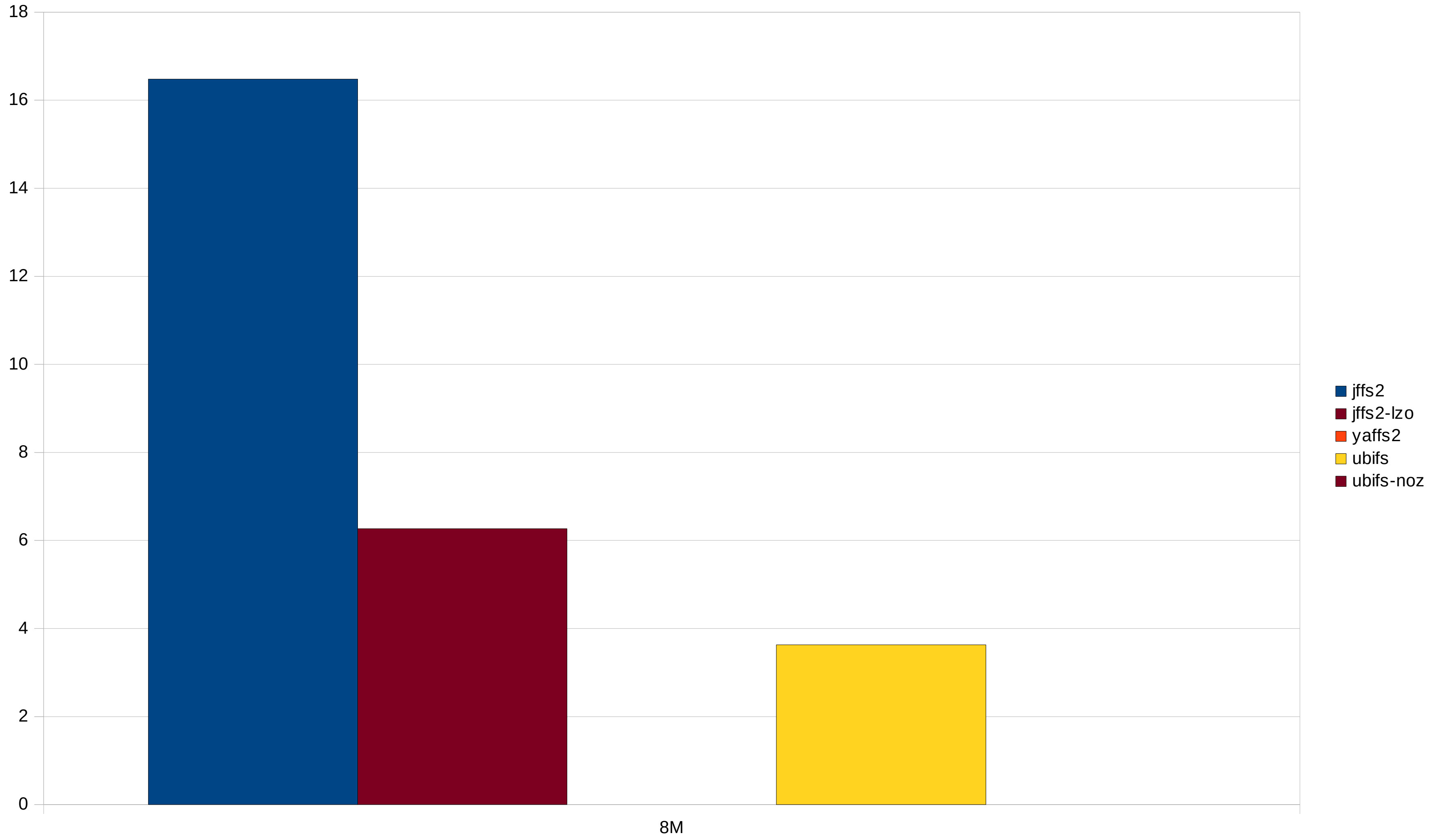
Write time (seconds)

yaffs2 / 8M-32M-120M: doesn't fit
ubifs-noz / 8M: doesn't fit



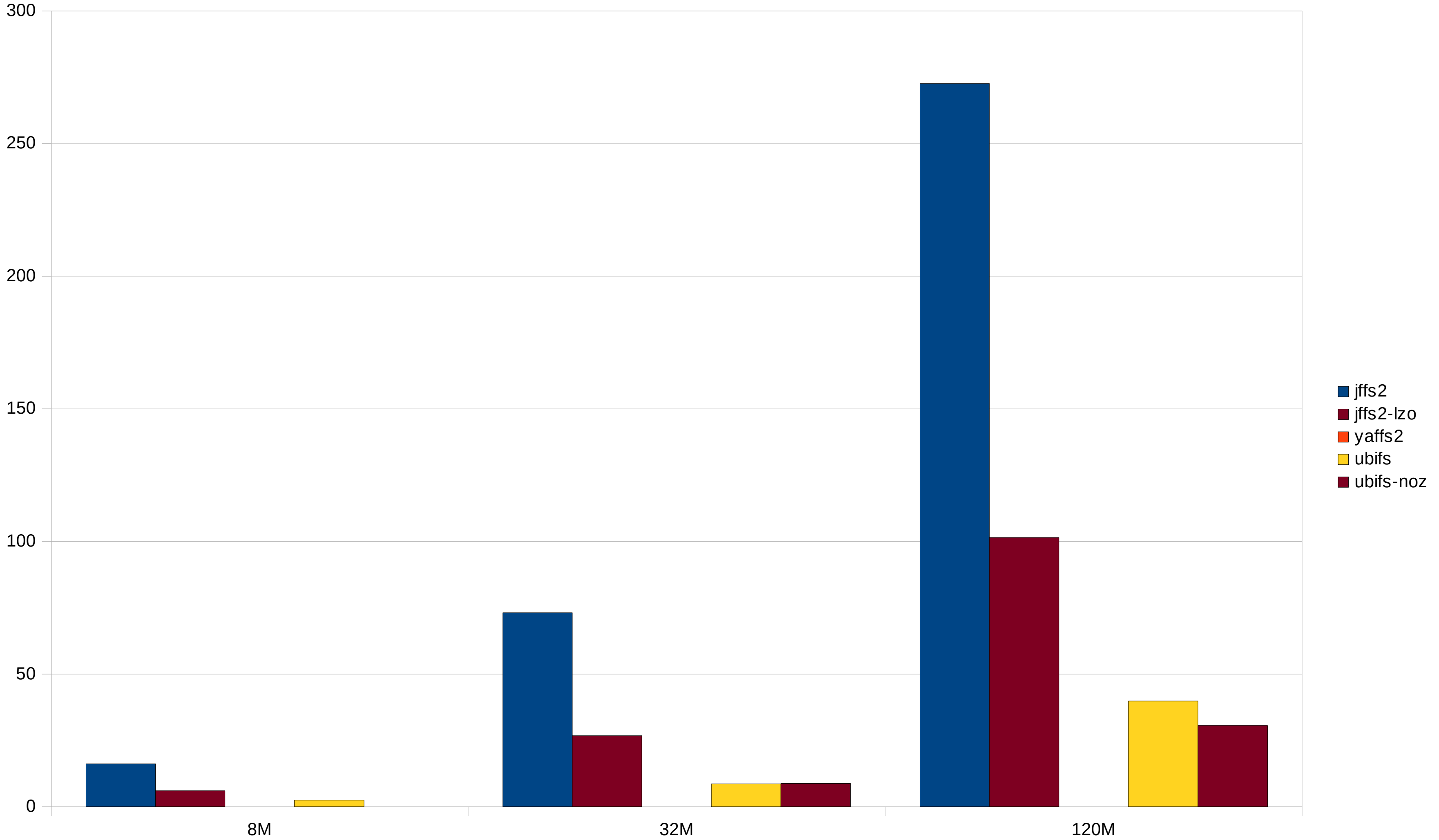
Zoom - Write time (seconds) - 8M

yaffs2 / 8M: doesn't fit
ubifs-noz / 8M: doesn't fit



CPU usage during write (seconds)

During the experiments in the previous slide
(using the sys measure from the time command)



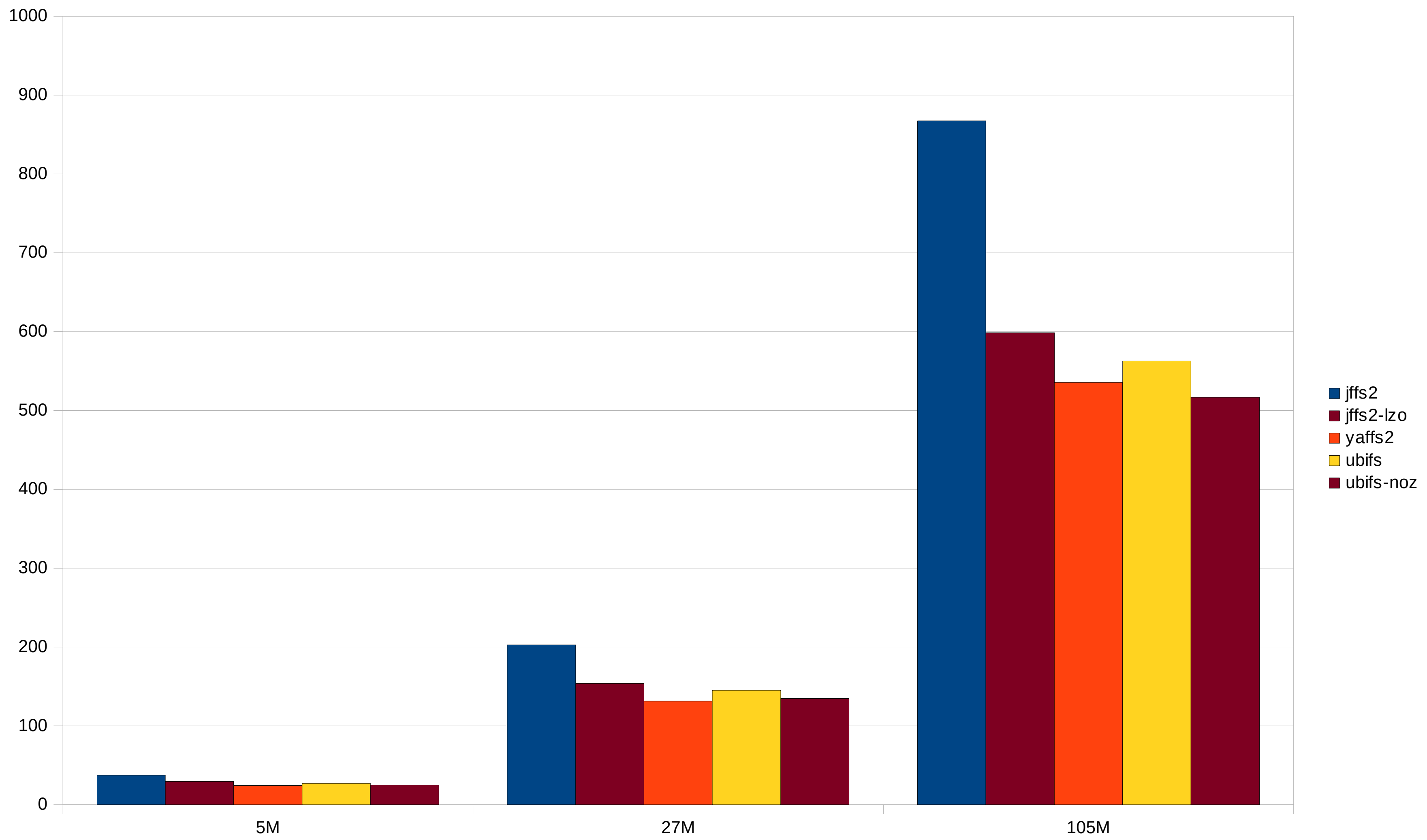
Random write experiment

Writing 1 MB chunks of random data (copied from `/dev/urandom`).

Trying to mimic the behavior of digital cameras and camcorders, recording already compressed data.

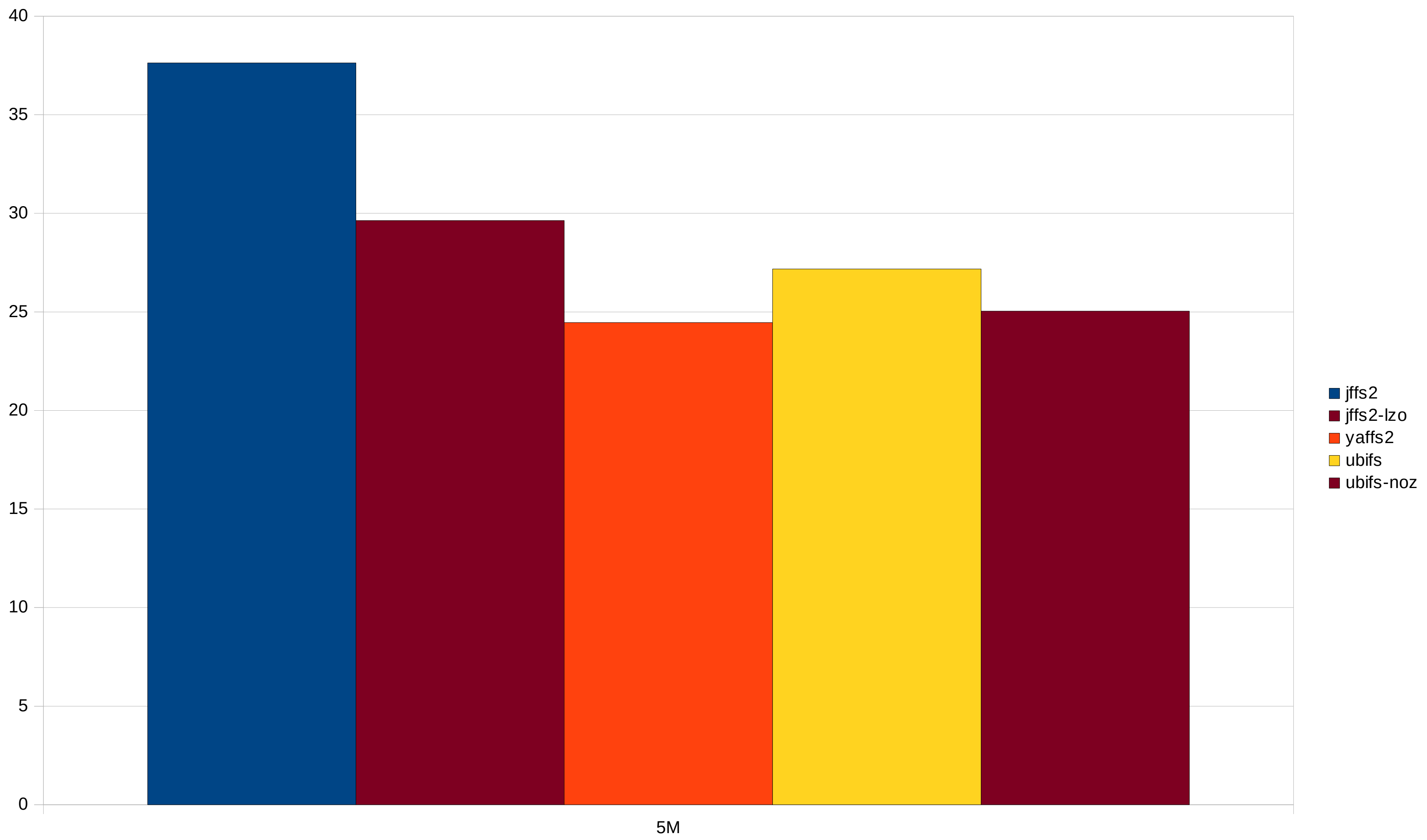
Random write time (seconds)

Caution: includes CPU time generating random numbers!



Zoom - Random write time (seconds) - 8M

Caution: includes CPU time generating random numbers!



Other experiments

UBIFS with only lzo support

UBIFS supports both lzo (faster to compress and uncompress) and zlib (slower, but compresses better), and tries to find the best speed / size compromise.

We tried UBIFS with only lzo support, hoping that having only one compressor would reduce runtime.

Results: tiny differences in all benchmarks, even in CPU usage. (roughly between 0.1 and 1%).

Conclusion: don't try to be too smart.
The filesystem is already fine tuned
to work great in most cases.

Suitability for very small partitions

8M MTD partition

jffs2 fits 13 MB of files
- But probably doesn't leave enough free blocks

UBI consumes 0.9 MB
- ubifs fits 6.6 MB of files

4M MTD partition

jffs2 fits 5.1 MB of files

UBI consumes 0.8 MB
- ubifs fits only 1.6 MB of files!

Bigger sizes: UBI overhead can be neglected:
32 MB: consumes 1.2 MB
128 MB: consumes 3.6 MB

What we observed

jffs2

Dramatically outperformed by ubifs in most aspects.

Huge mount / boot time.

yaffs2

Also outperformed by ubifs.

May not fit all your data

Ugly file removal time (poor directory update performance?)

Memory usage not scaling

ubifs leaves no reason to stick to yaffs2.

ubifs

Great performance in all corner cases.

SquashFS

Best or near best performance in all read-only scenarios.

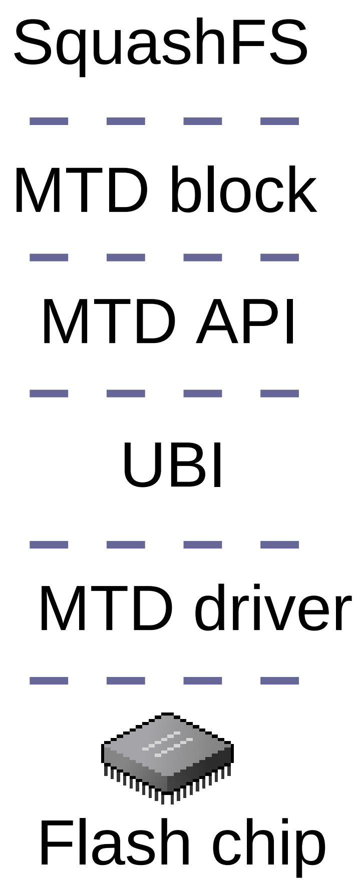
Conclusions

Convert your jffs2 partitions to ubifs!

It may only make sense to keep jffs2 for MTD partitions smaller than 10 MB, in case size is critical.

No reason left to use yaffs2 instead of jffs2?

You may also use SquashFS to squeeze more stuff on your flash storage. Advisable to use it on top of UBI, to let all flash sectors participate to wear leveling.



Experimental filesystems (1)

A look at possible future solutions?

wikifs

A CELF sponsored project.

A Wiki structured filesystem (today's flash filesystems are log structured).

Already used in Sony digital cameras and camcorders.

Pros: direct / easy export of device functionality description to elinux.org.

The author is in the room!

linuxtinyfs

Targets small embedded systems.

Negative memory consumption: achieved by compiling out the kernel file cache.

Pros: very fast mount time

Cons: a mount-only filesystem. Way to implement read and write not found yet.

Experimental filesystems (2)

fsckfs

An innovative filesystem rebuilding itself at each reboot.

Pros: no user space tools are needed.
No `fsck.fsckfs` utility needed.

Cons: mount time still needs improving.

Advice for flash-based block storage

Issues with flash-based block storage

Flash storage made available only through a block interface.

Hence, no way to access a low level flash interface and use the Linux filesystems doing wear leveling.

No details about the layer (Flash Translation Layer) they use. Details are kept as trade secrets, and may hide poor implementations.

Hence, it is highly recommended to limit the number of writes to these devices.

Reducing the number of writes

Mount your filesystems as read-only, or use read-only filesystems (SquashFS), whenever possible.

Keep volatile files in RAM (tmpfs)

Use the `noatime` mount option, to avoid updating the filesystem every time you access a file. Or at least, if you need to know whether files were read after their last change, use the `relatime` option.

Don't use the `sync` mount option (commits writes immediately). No optimizations possible.

You may decide to do without journaled filesystems. They cause more writes, but are also much more power down resistant.

Useful reading

Introduction to JFFS2 and LogFS:
http://lwn.net/Articles/234441/

Documentation on the linux-mtd website:
http://www.linux-mtd.infradead.org/

Other talks

During this ELCE 2008 conference

Thursday

11:50 - Managing NAND longevity in a product
Matthew Porter, Embedded Alley (too late!)

Friday

11:15 - Using the appropriate wear leveling to extend product lifespan. Bill Roman, Datalight

14:10 - Overview of SquashFS filesystem
Philip Lougher (independent)

15:25 - NAND chip driver optimization and tuning
Vitaly Wool, Embedded Alley

Thank you!

Questions?

New filesystem suggestions?