Fault-injection Testing for Distributed Storage System on Linux

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MAKE IT SIMPLE

About Me

- Kyle Zhang 张凯
- Computer Science, Tsinghua University
- Software Engineer, Infrastructure Team, Baidu
- Cofounder and CTO, SmartX
- Focused on distributed block storage system

After a storage developer release a new version...

The Terrible Thing...

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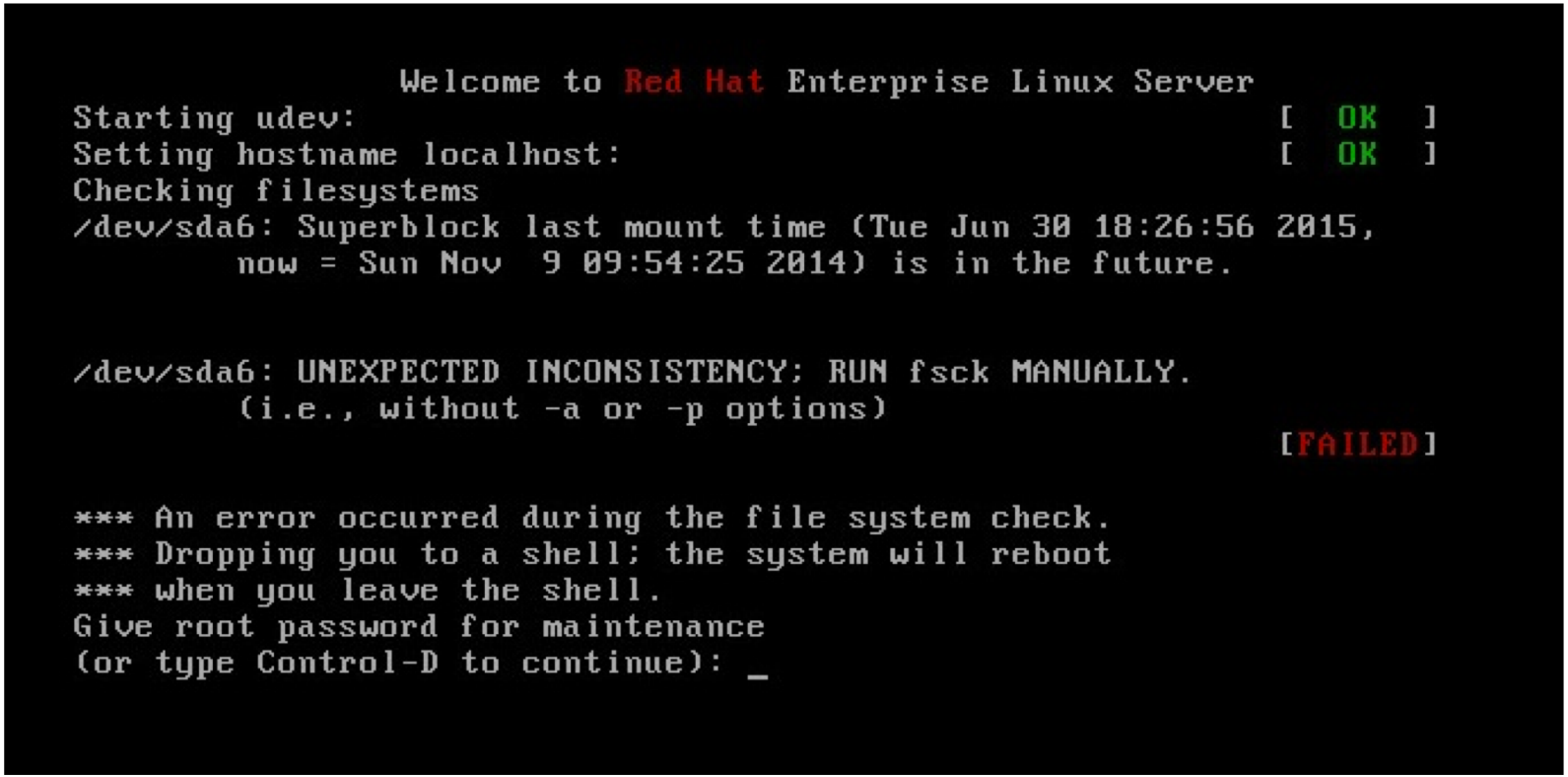
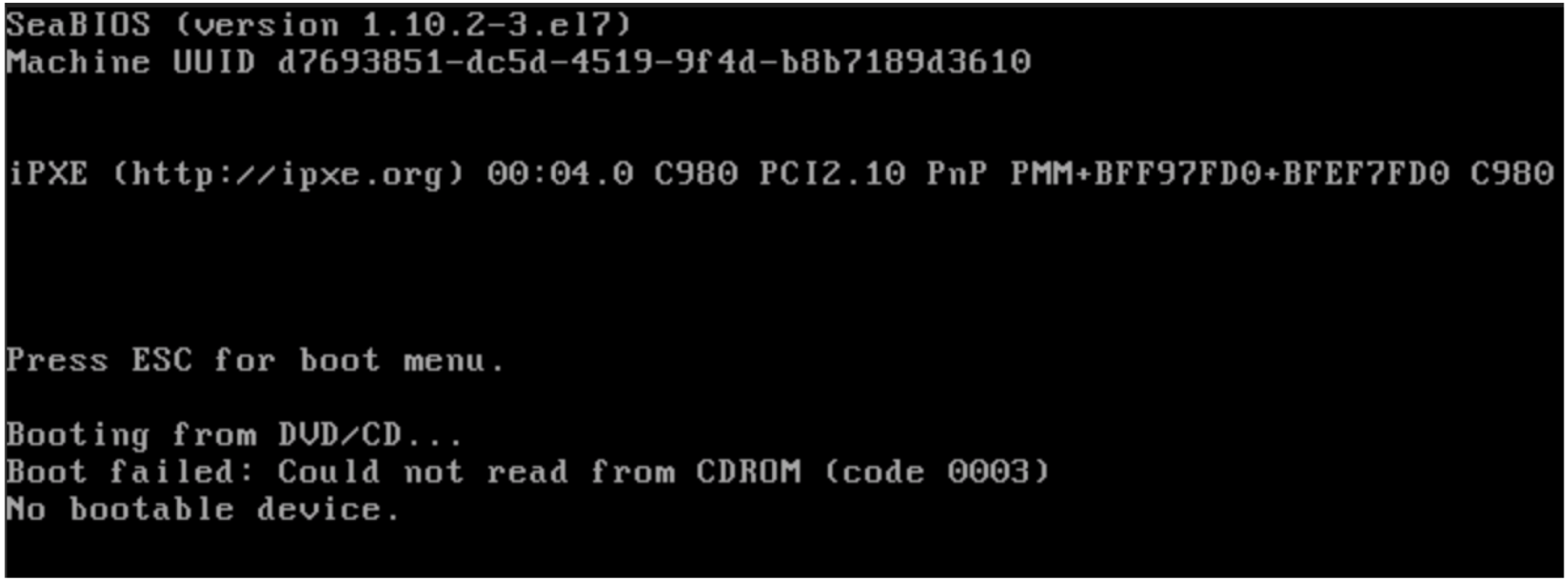


The More Terrible Thing...



The Most Terrible Thing…

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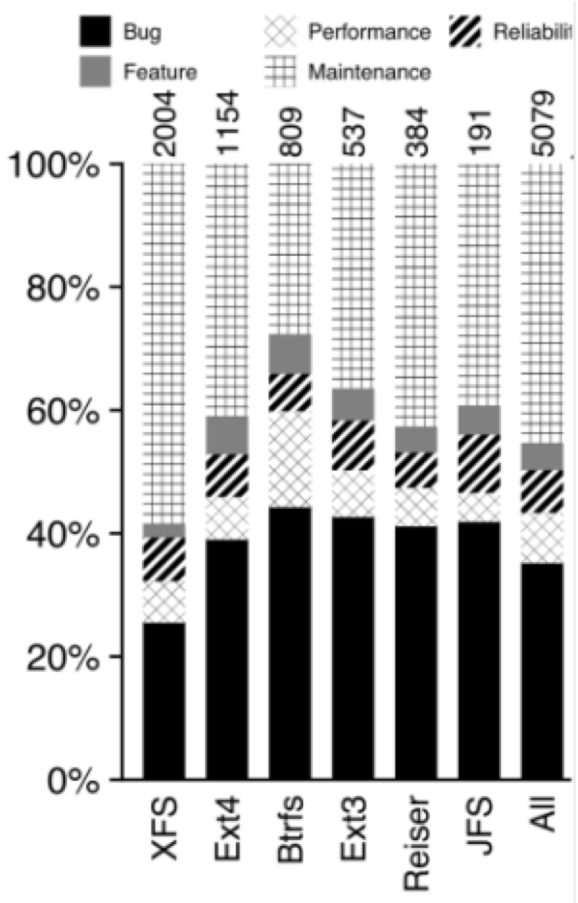
“Anything that can go wrong,
will go wrong”

Murphy’s law

A Study of Linux File System Evolution

- 40% patches are for bug fix
- 40% patches are for maintenance



A Study of Linux File System Evolution

Embracing Bugs

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It is normal that software has bugs.

Our mission is to find out bugs.

Fault-injection Testing

Fault-injection in Physical Way

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Fault-injection in Physical Way

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- *Subject*: [PATCH] Btrfs: fix log replay failure after unlink and link combination
- *From*: fdmanana@xxxxxxxxxx
- *Date*: Wed, 28 Feb 2018 15:56:10 +0000

```
From: Filipe Manana <fdmanana@xxxxxxxx>

If we have a file with 2 (or more) hard links in the same directory,
remove one of the hard links, create a new file (or link an existing file)
in the same directory with the name of the removed hard link, and then
finally fsync the new file, we end up with a log that fails to replay,
causing a mount failure.

Example:

  $ mkfs.btrfs -f /dev/sdb
  $ mount /dev/sdb /mnt

  $ mkdir /mnt/testdir
  $ touch /mnt/testdir/foo
  $ ln /mnt/testdir/foo /mnt/testdir/bar

  $ sync

  $ unlink /mnt/testdir/bar
  $ touch /mnt/testdir/bar
  $ xfs_io -c "fsync" /mnt/testdir/bar

  <power failure>

  $ mount /dev/sdb /mnt
  mount: mount(2) failed: /mnt: No such file or directory
```

Fault-injection in Physical Way

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- **Nice to have**
  - real world failures!
- **Limitations**
  - costly
  - not efficiency
  - hard to automate and reproduce

Fault-injection at Application-level

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- **Nice to have**
  - easy to automate and reproduce
  - find-grained control
- **Limitations**
  - redundant source codes for different languages/applications
  - hard to cover all cases

Fault-injection in Kernel

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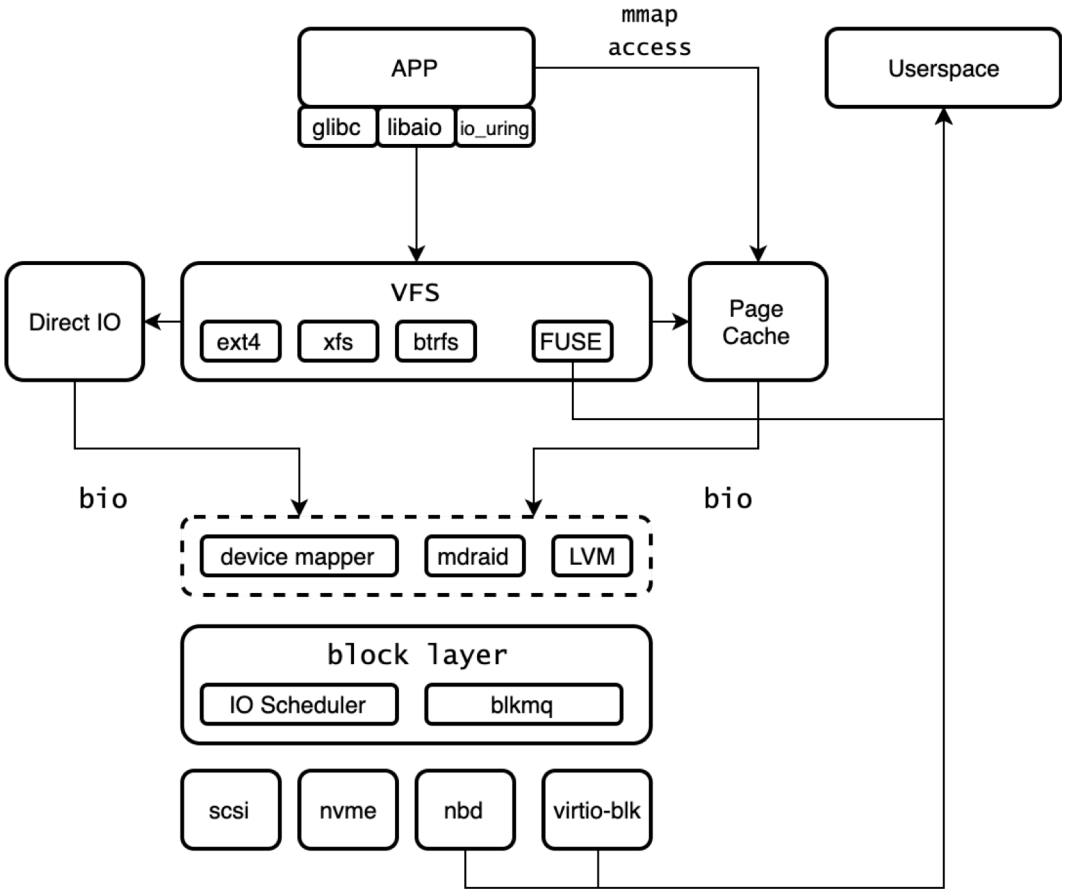
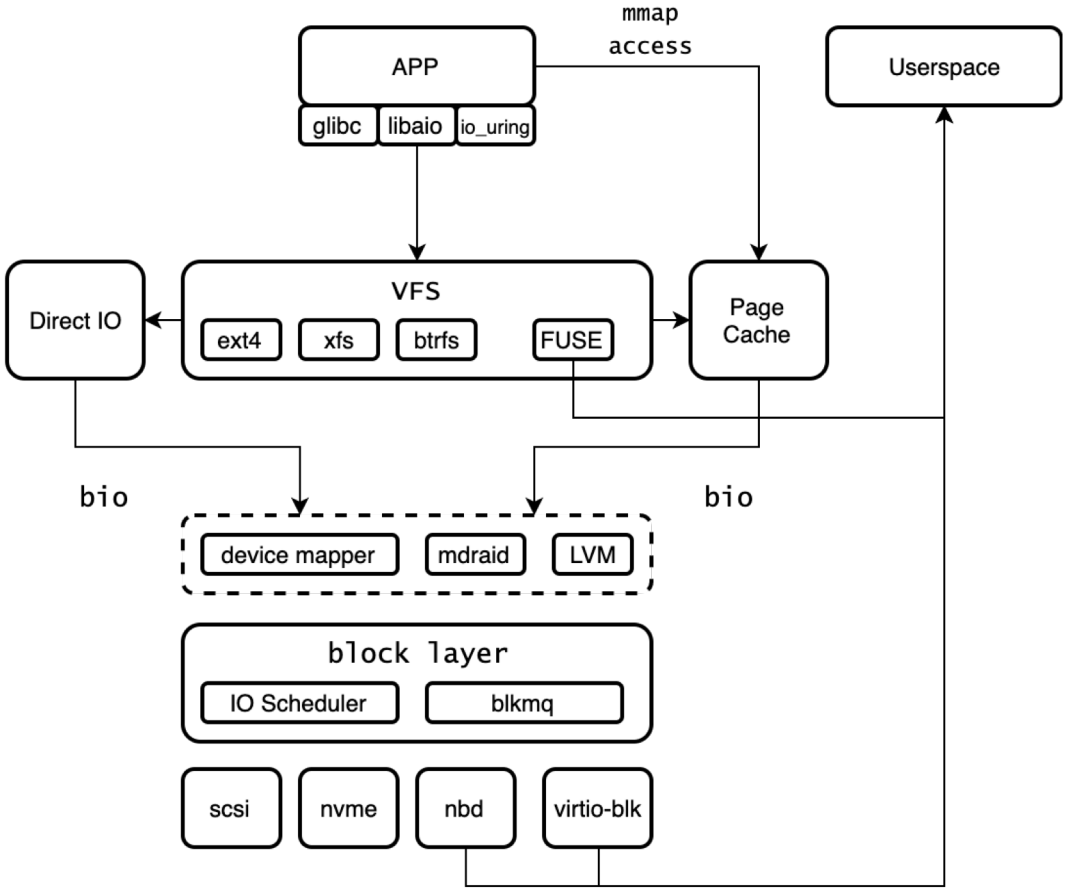
- **Nice to have**
  - easy to automate and reproduce
  - system-wide
  - find-grained control
- **Limitations**
  - depends on what you use

Linux Kernel IO Stack



Where to Inject Failures?

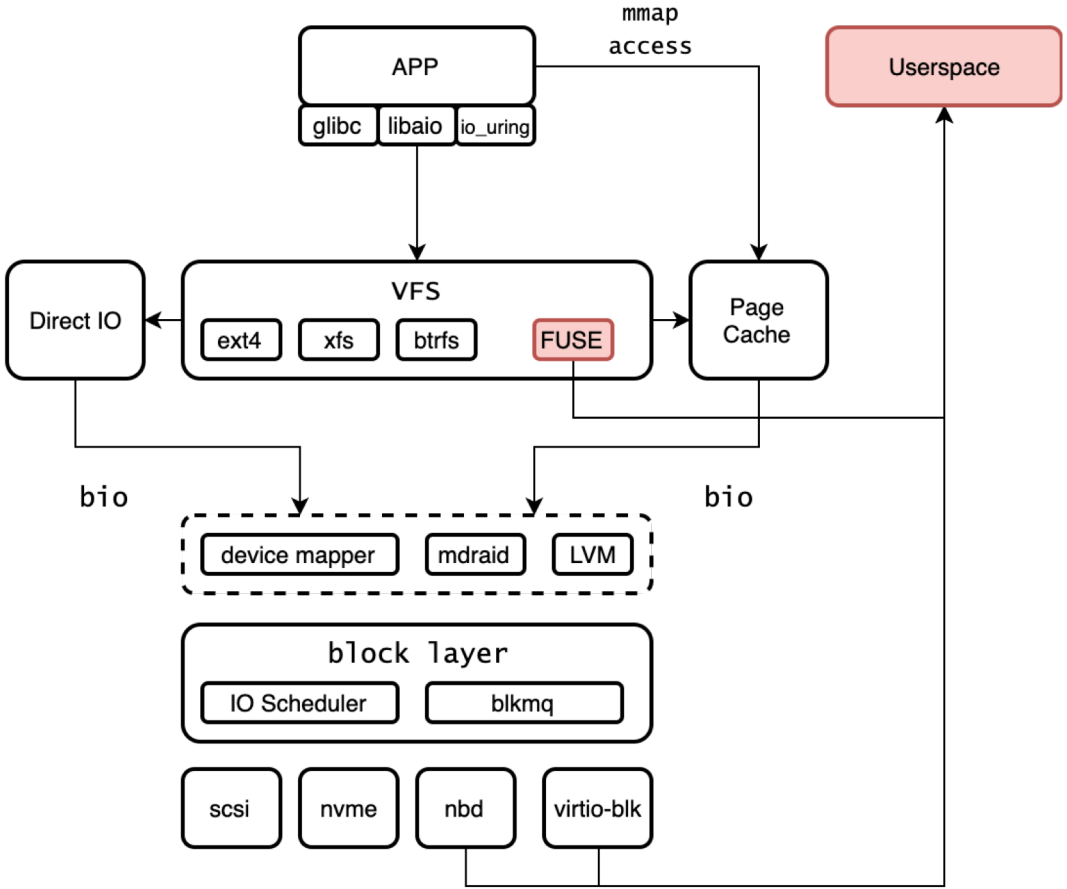
- Don’t modify application source code
- Portable with different kernel versions
- Easy to use
- Fine-grained control
  - fail/delay request
  - probability
  - dynamic configuration
  - mutate data



FUSE

- Hook IO at VFS layer
- Inject failures with userspace code
- Good at portability

- Namazu
  - static config
- CharybdeFS
  - dynamic config with thrift



CharybdeFS

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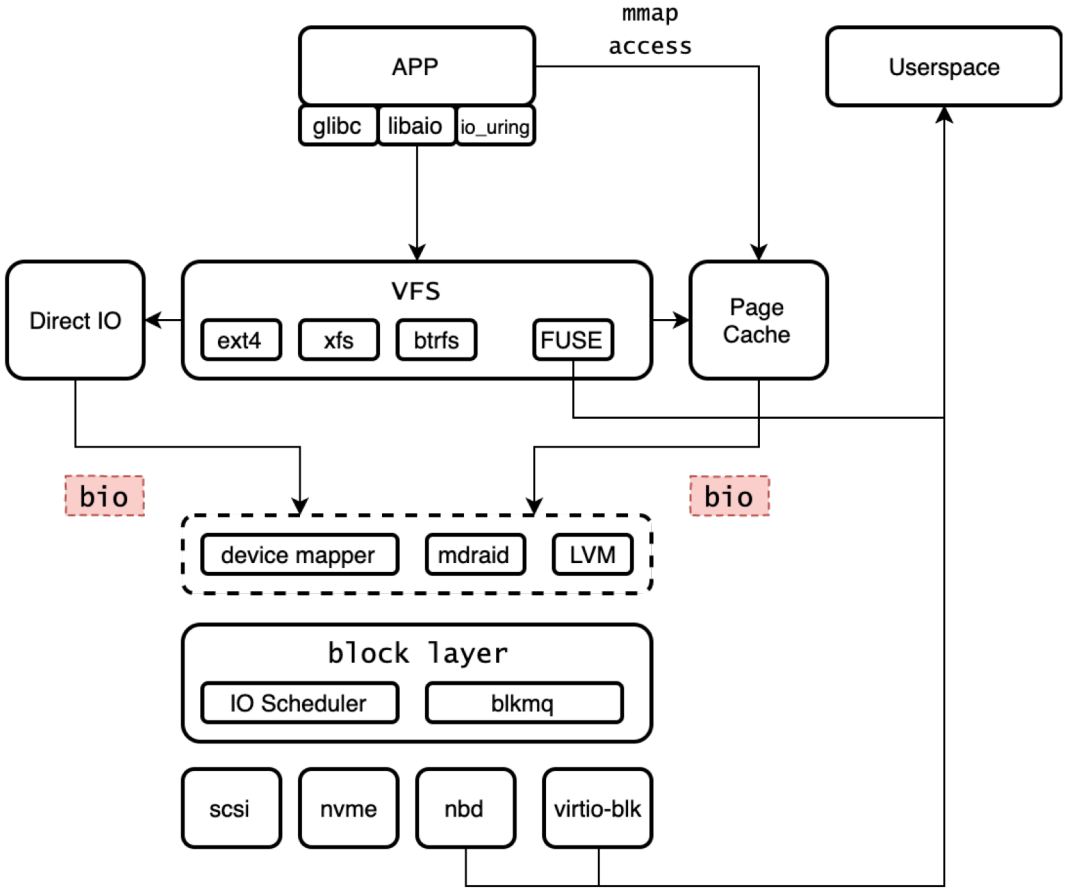
```
> sudo ./charybdefs /mnt/charybde -omodules=subdir,subdir=/xxx
> cd /mnt/charybde && ls

> python cookbook/recipes.py --io-error
Simulating IO error

> ls
ls: cannot open directory .: Input/output error
```

bio

- Fail bio request
  - return error at *generic_make_request()*
  - recompile kernel with *CONFIG_FAIL_MAKE_REQUEST*

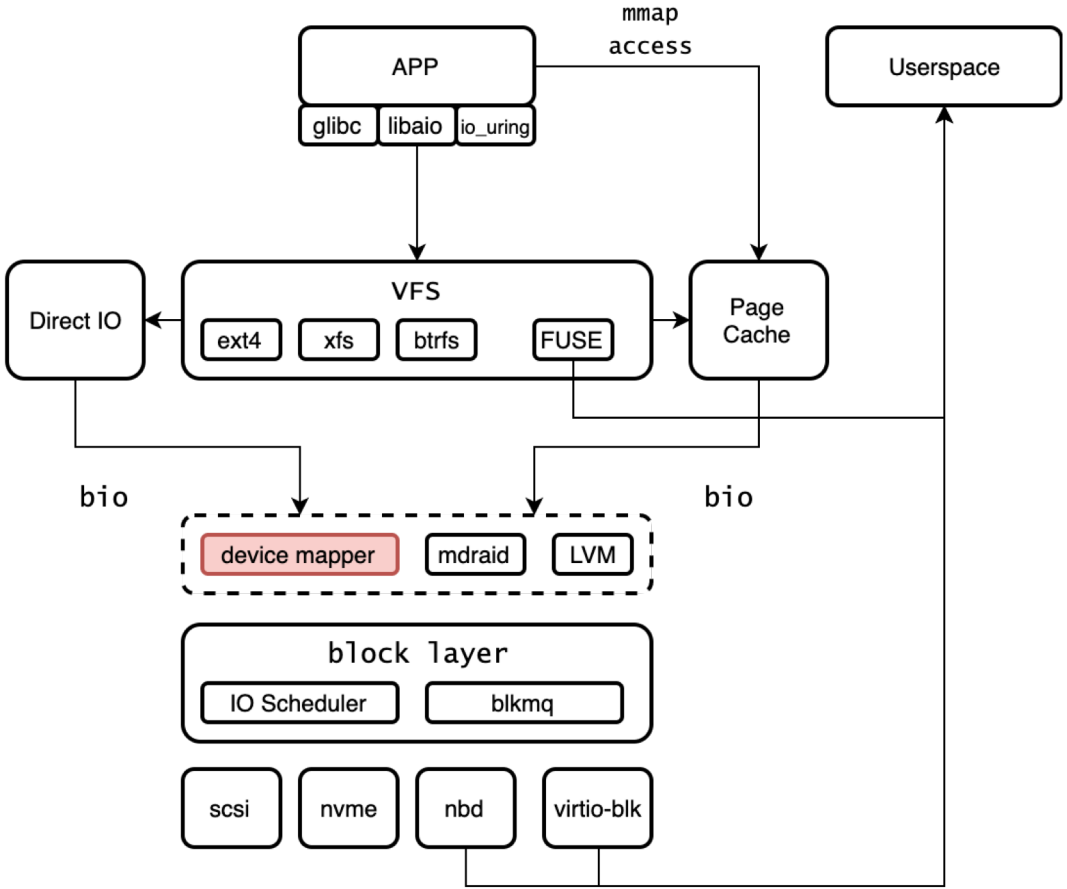
/sys/block/<device>/make-it-fail

- Not good at fine-grained control



Device Mapper

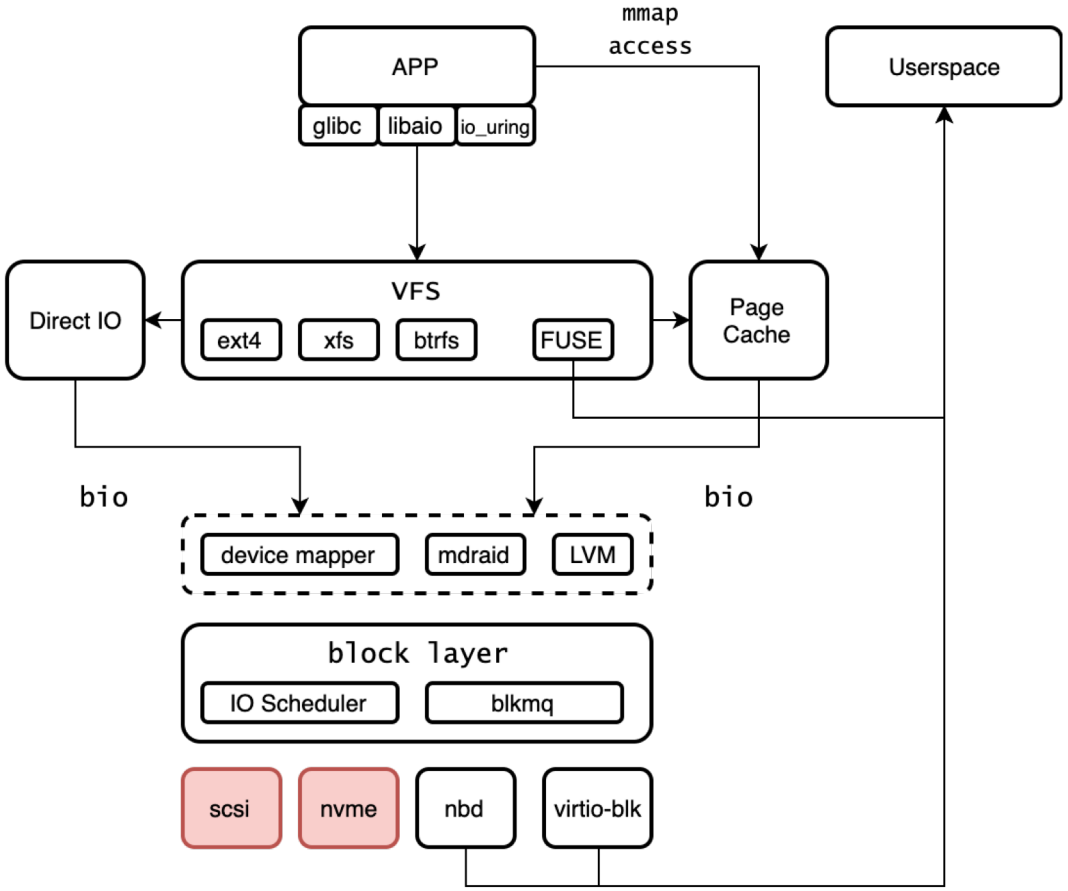
```
> dmsetup create bad_disk << EOF
0    1024 linear /dev/vdb 0
1024 8    error
1032 1016 linear /dev/vdb 1032
EOF

> badblocks -b 4096 /dev/dm-2
128
```



Driver Layer

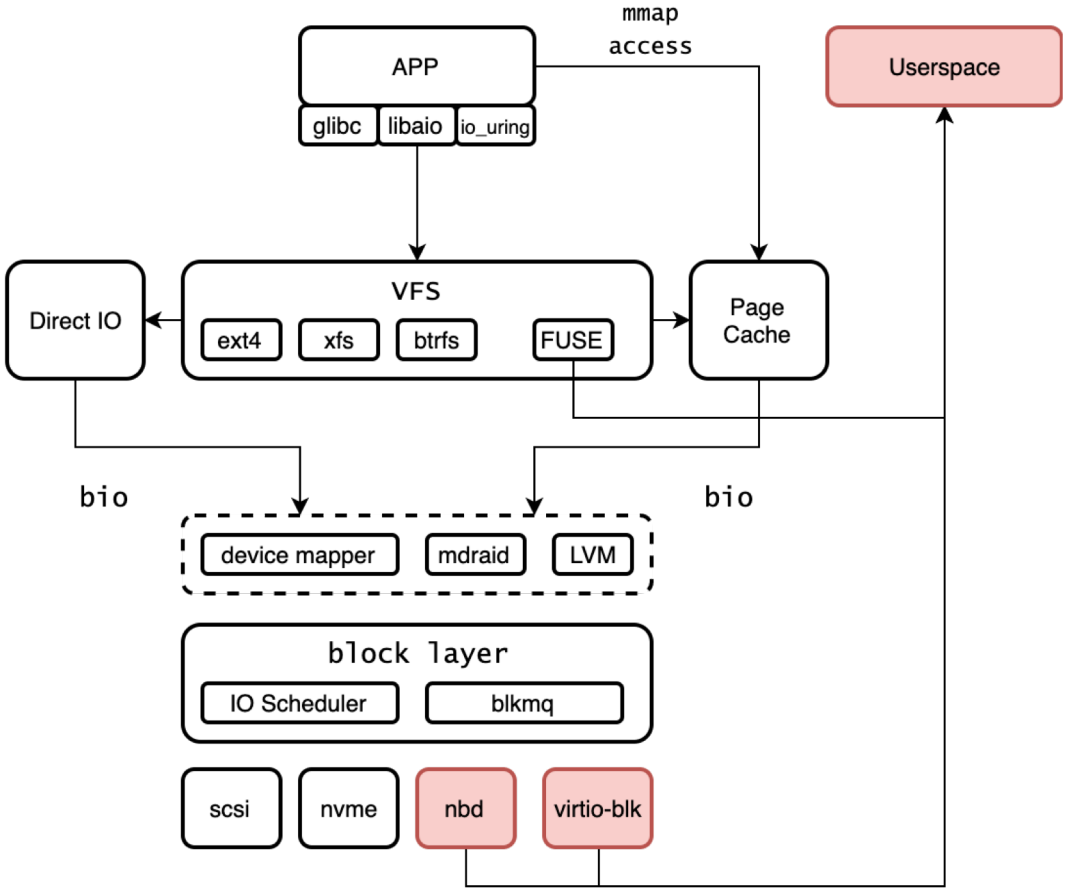
```
echo 1 >
/sys/block/<name>/device/delete
```

- No fine-grained control



NBD/virtio-blk

- Similar to FUSE



nbdkit Examples

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```
> fallocate -l 10m disk.img
> nbdkit -f --filter=error file disk.img error-pread-rate=10%
> nbd-client -b 512 localhost /dev/nbd0
> badblocks /dev/nbd0
5696
5697
5712
5716
5728
5740
```

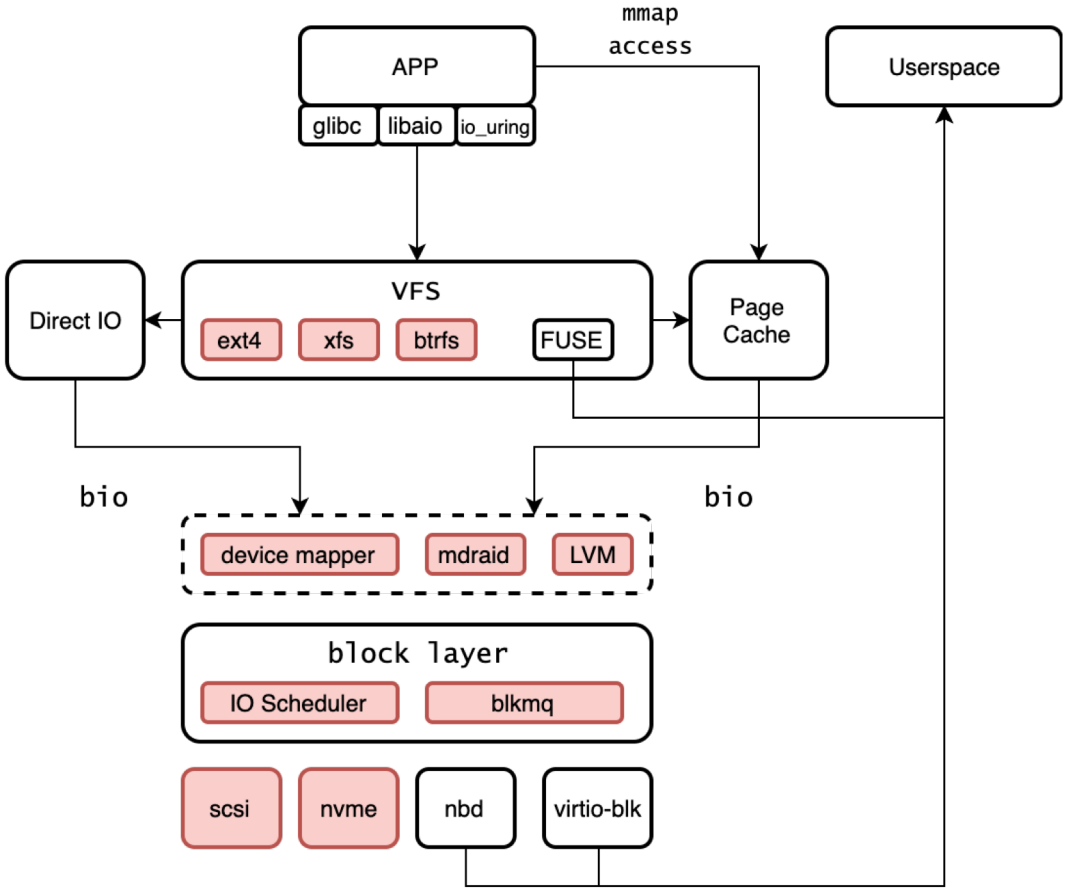
Demo?

```
$ cd /tmp
$ rm -f disk.img && fallocate -l 100m disk.img
$ nbdkit file disk.img

$ mkdir -p /mnt/nbd
$ mkfs.btrfs /dev/ndb0
$ mount /dev/nbd0 /mnt/nbd
$ cd /mnt/nbd
$ touch foo && ln foo bar
$ sync
$ unlink bar && touch bar
$ xfs_io -c "fsync" bar

# simulate power failure
$ killall nbdkit
$ cd .. && umount /mnt/nbd

$ nbdkit file disk.img
$ mount /dev/nbd0 /mnt/nbd
```

SystemTap

- Based on **kprobes**
- Fine-grained control
- Inject from remote

- Not portable with different versions of kernel



SystemTap Example

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```
#! /usr/bin/stap -g

global target_bdev_name
global target_bdev_part
global iocbs%[10000]

probe begin
{
  target_bdev_name = @1
  target_bdev_part = $2
  printf("\nbegin\n")
}

probe end
{
  printf("\nend\n")
}
```

```
probe kernel.function("do_blockdev_direct_IO@fs/direct-io.c")
{
  if ($bdev->bd_part)
    partno = $bdev->bd_part->partno
  else
    partno = $bdev->bd_disk->first_minor

  bdevname = kernel_string($bdev->bd_disk->disk_name)

  if (target_bdev_name == bdevname && target_bdev_part == partno) {
    iocbs[$iocb] = $iocb
  }
}

probe kernel.function("aio_complete@fs/aio.c")
{
  i = iocbs[$iocb]
  if (i) {
      delete iocbs[$iocb]
      // -5 is EIO
      $res = -5
  }
}
```

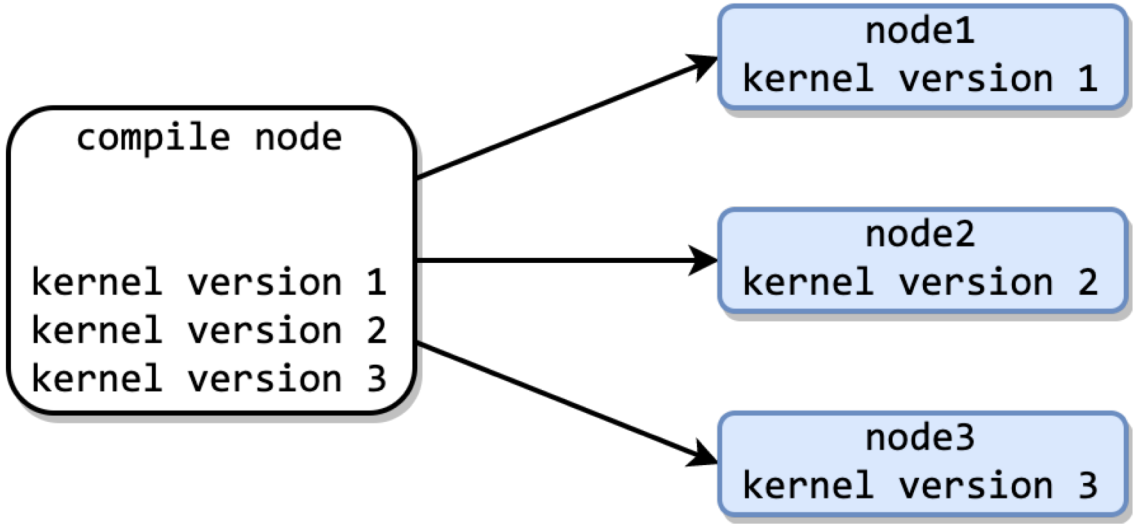
SystemTap Example

```
> stap -g --suppress-handler-errors -r 3.10.0-957.21.3.el7.x86_64 \
     --remote=root@<ip> tests/disk_error.stp sda 5

> fio --name=test --filename=/dev/sda5 --ioengine=libaio --direct=1
test: (g=0): rw=read, bs=4K-4K/4K-4K/4K-4K, ioengine=libaio, iodepth=1
fio-2.15
Starting 1 process
fio: io_u error on file /dev/sda5: Input/output error: read offset=0, buflen=4096
fio: pid=24508, err=5/file:io_u.c:1708, func=io_u error, error=Input/output error

> fio --name=test --filename=/dev/sda5 --direct=1
test: (g=0): rw=read, bs=4K-4K/4K-4K/4K-4K, ioengine=psync, iodepth=1
fio-2.15
Starting 1 process
Jobs: 1 (f=1): [R(1)] [0.3% done] [144.9MB/0KB/0KB /s] [37.8K/0/0 iops] [eta 29m:11s]
```

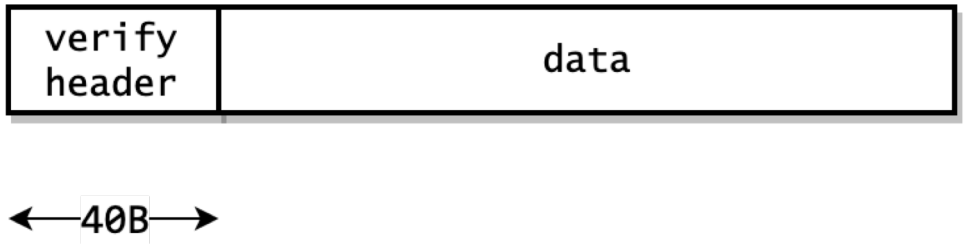
SystemTap Example



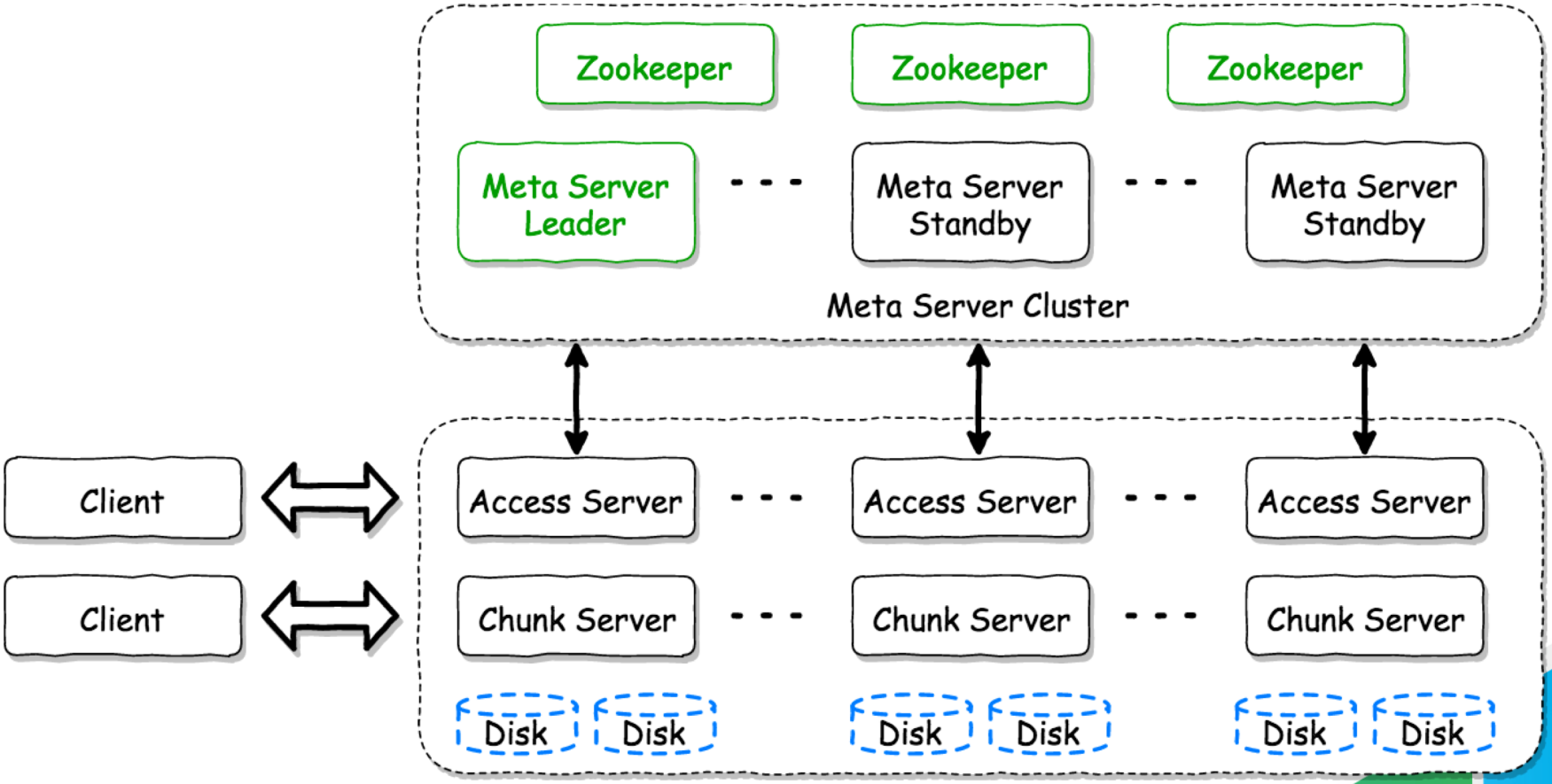
Use remote mode to handle multiple kernel versions

Data Verification

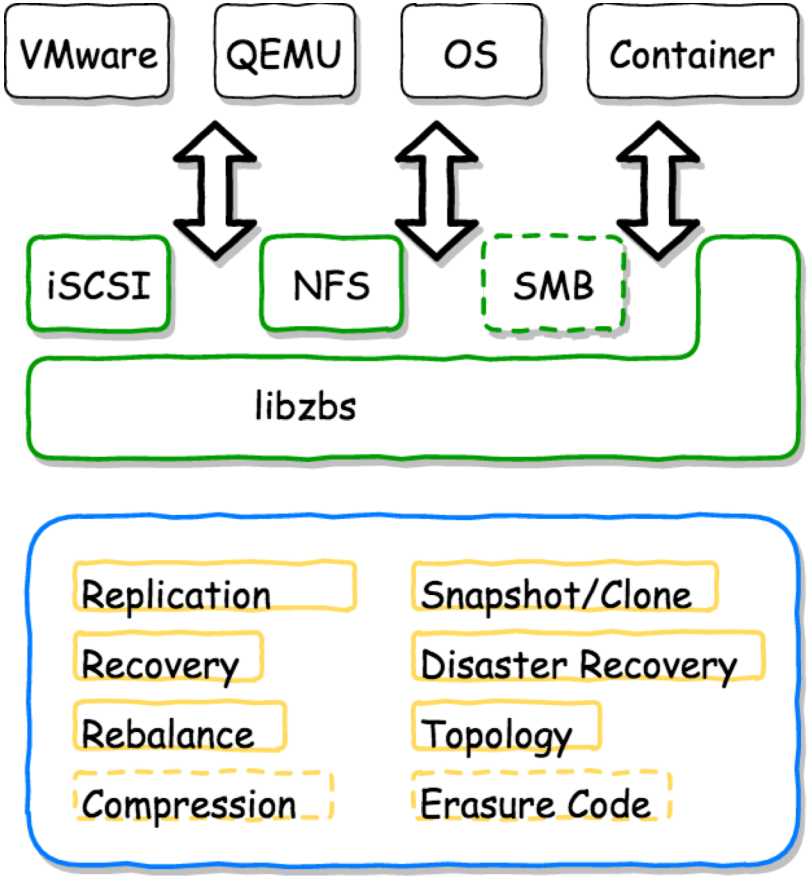
- **Filesystem**
  - xfstest
  - btrfs
- **FIO**
  - verify data
  - libiscsi engine



ZBS Architecture

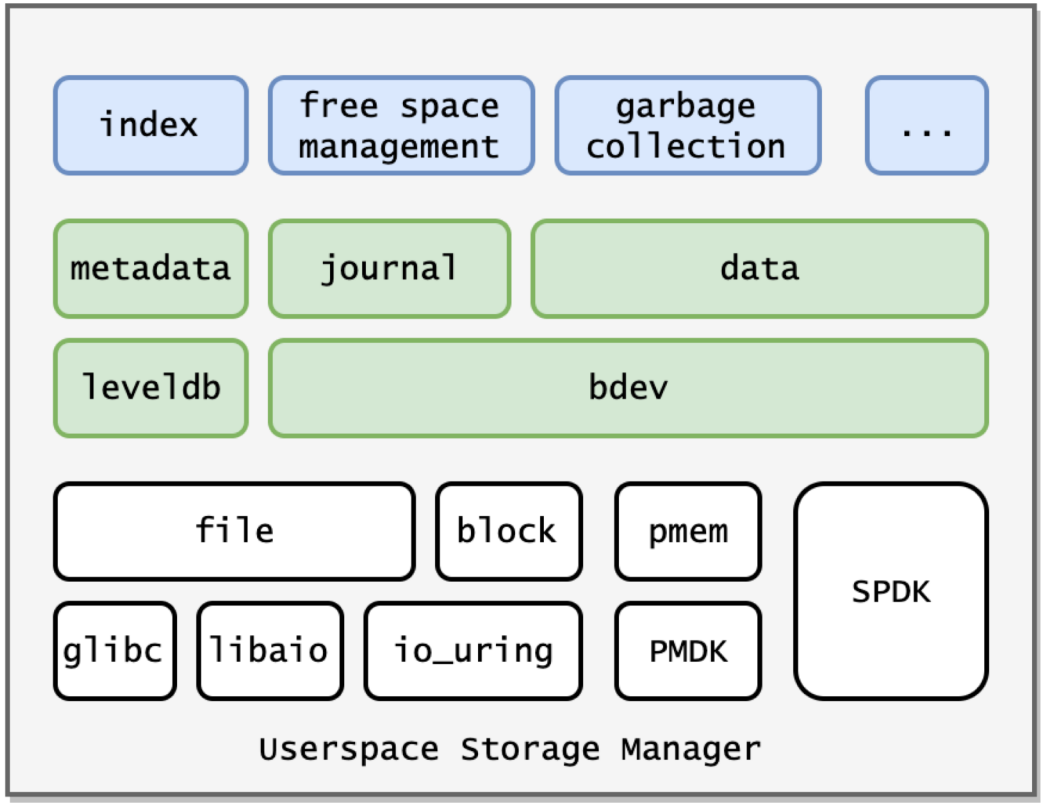


ZBS Interface

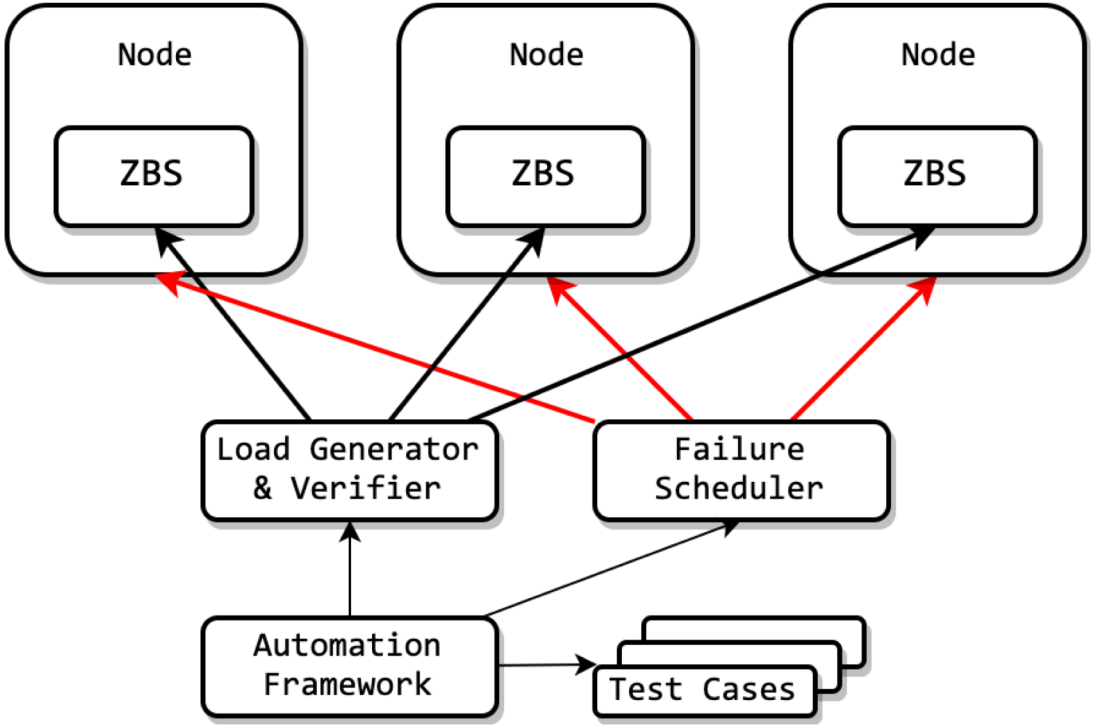


- **libzbs (c library)**
  - Optimized for performance
- **iSCSI/NFS**
  - Based on libzbs
  - Friendly for operating system, hypervisor...

ZBS Local Storage Manager



Fault Injection Framework



Testing ZBS

- Unit test
  - simulate failures with mocked classes
- Longevity test
  - simulate user operations
- Fault-injection test
  - inject failure at driver layer
  - SystemTap
- Dogfood

We are Walking on the Edge of the Cliff

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Thanks for listening!

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