An Introduction to Userspace Filesystem Development

Matt Turner
ACCU Oxford
25th April 2012

Why Filesystems?

- Filesystems are everywhere
- Data in a namespace
- Lots of tooling

```
matt@frogstar:~$ mount
/dev/sda1 on / type ext4 (rw,errors=remount-ro,commit=0)
proc on /proc type proc (rw,noexec,nosuid,nodev)
sysfs on /sys type sysfs (rw,noexec,nosuid,nodev)
fusectl on /sys/fs/fuse/connections type fusectl (rw)
none on /sys/kernel/debug type debugfs (rw)
none on /sys/kernel/security type securityfs (rw)
udev on /dev type devtmpfs (rw,mode=0755)
devpts on /dev/pts type devpts (rw,noexec,nosuid,gid=5,mode=0620)
tmpfs on /run type tmpfs (rw,noexec,nosuid,size=10%,mode=0755)
none on /run/lock type tmpfs (rw,noexec,nosuid,nodev,size=5242880)
none on /run/shm type tmpfs (rw,nosuid,nodev)
binfmt_misc on /proc/sys/fs/binfmt_misc type binfmt_misc
       (rw,noexec,nosuid,nodev)
gvfs-fuse-daemon on /home/matt/.gvfs type fuse.gvfs-fuse-daemon
       (rw,nosuid,nodev,user=matt)
```

Why Filesystems?

- In Unix, everything is a file
- Lifts data into the filesystem namespace
- Can be queried and manipulated with common tools

Sex in the Filesystem

```
unzip; strip; touch; finger; mount;
fsck; more; yes; umount; make
clean; sleep
```

Filesystems to the Extreme

- Under Plan9, **everything** is a file
- Processes have their own mount tables
- Individual processes can be “chroot()ed”
- 9P protocol allows for easy remote filesystem access
- Unionfs replaces $PATH
- Network represented as /net

Why Filesystems?

- UNIX inspired by Plan9 – more and more data in the filesystem
- smbclient, ftp replaced by filesystems
- New protocols should come with filesystems!

Example – A VM Filesystem

- VM hdd image is one big file
- Most blocks not accessed
- Some blocks accessed all the time
- Local modifications like log files not wanted globally
- Domain knowledge meant files could be handled cleverly, but couldn’t alter VMWare

Filesystems in Kernelspace

- Filesystems used to be in the Kernel
- Kernel development is hard!

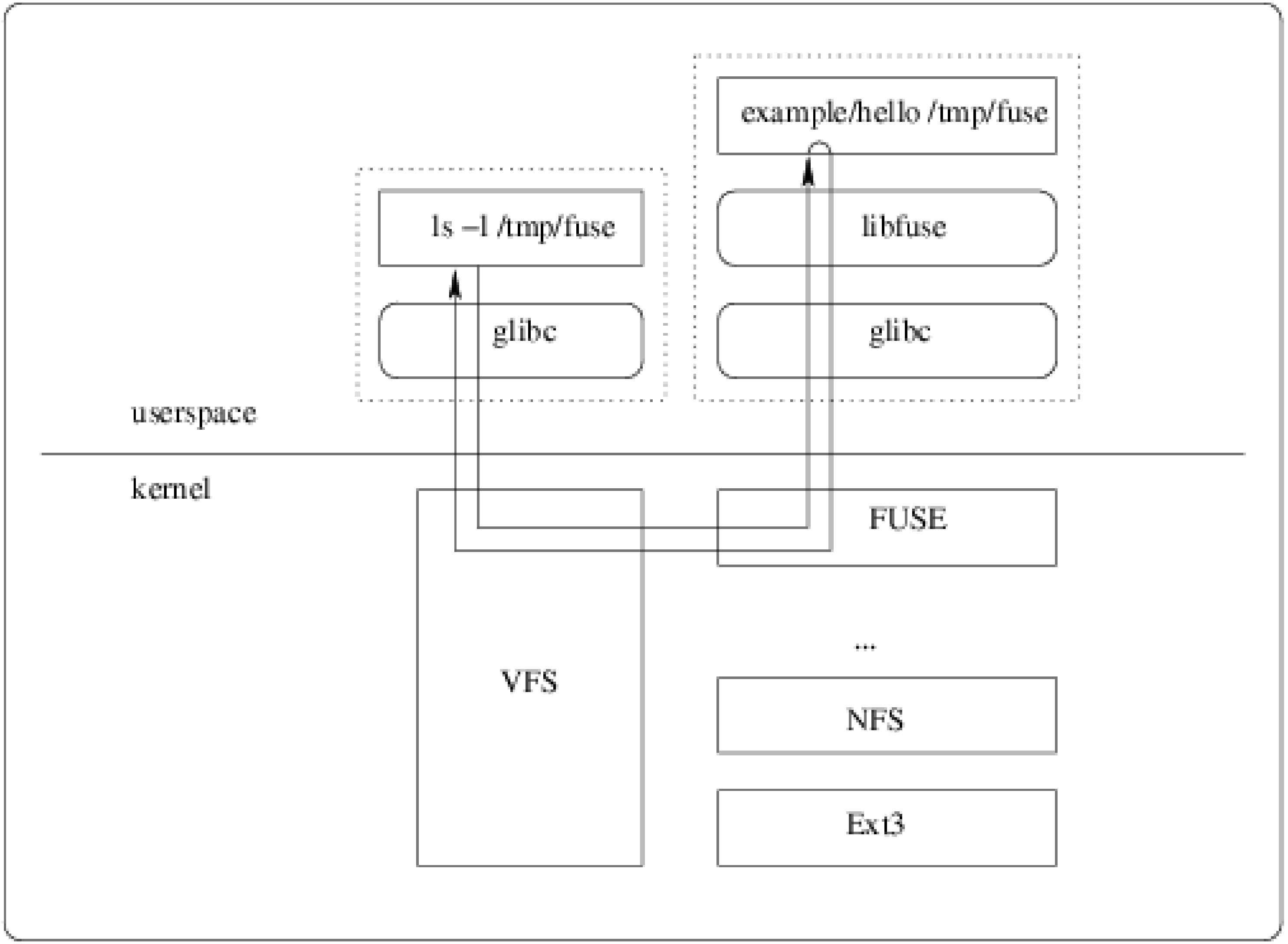
Filesystems in Userspace

- Much easier to develop, test, etc
- “filesystems” in libraries:
  - gfs (C++ API),
  - HDFS (Java API)
- Filesystem frameworks:
  - FUSE (& CUSE),
  - Dokan[.Net]

Filesystem in USErspace (FUSE)

- Not the spectrum emulator
- Fuse currently at version 2.9.0 (released Friday)
- Shipping with Linux kernel since 2.6.14
- Multiple OSes
- Native C, bindings to many other languages
- Lots of successful projects
- Tarballs at fuse.sourceforge.net
- git://fuse.git.sourceforge.net/gitroot/fuse/fuse

Architecture



[fuse.sourceforge.net]

```
Thread 1 (Thread 0x7ffff7fe5700 (LWP 15341)):
#0  sem_wait () from /lib64/libpthread.so.0
#1  fuse_session_loop_mt () at fuse_loop_mt.c:242
#2  fuse_loop_mt () at fuse_mt.c:117
#3  fuse_main_common () at helper.c:353
#4  __libc_start_main () from /lib64/libc.so.6
#5  _start ()
```

```
Thread 2 (Thread 0x7ffff71ee700 (LWP 15344)):
#0  read () from /lib64/libpthread.so.0
#1  read () at /usr/include/bits/unistd.h:45
#2  fuse_kern_chan_receive () at fuse_kern_chan.c:28
#3  fuse_ll_receive_buf () at fuse_lowlevel.c:2643
#4  fuse_do_work () at fuse_loop_mt.c:81
#5  start_thread () from /lib64/libpthread.so.0
#6  clone () from /lib64/libc.so.6
```

```
Breakpoint 4, xmp_access (path=0x623da0 "/", mask=4) at
fusexmp.c:48
48      {
(gdb) bt
Thread 3 (Thread 0x7ffff69ed700 (LWP 15345)):
#0  xmp_access (path=0x623da0 "/", mask=4) at fusexmp.c:48
#1  fuse_lib_access () at fuse.c:2765
#2  fuse_ll_process_buf () at fuse_lowlevel.c:2416
#3  fuse_do_work () at fuse_loop_mt.c:117
#4  start_thread () from /lib64/libpthread.so.0
#5  clone () from /lib64/libc.so.
```

Bash Filesystem

- Has bit-rot ☹

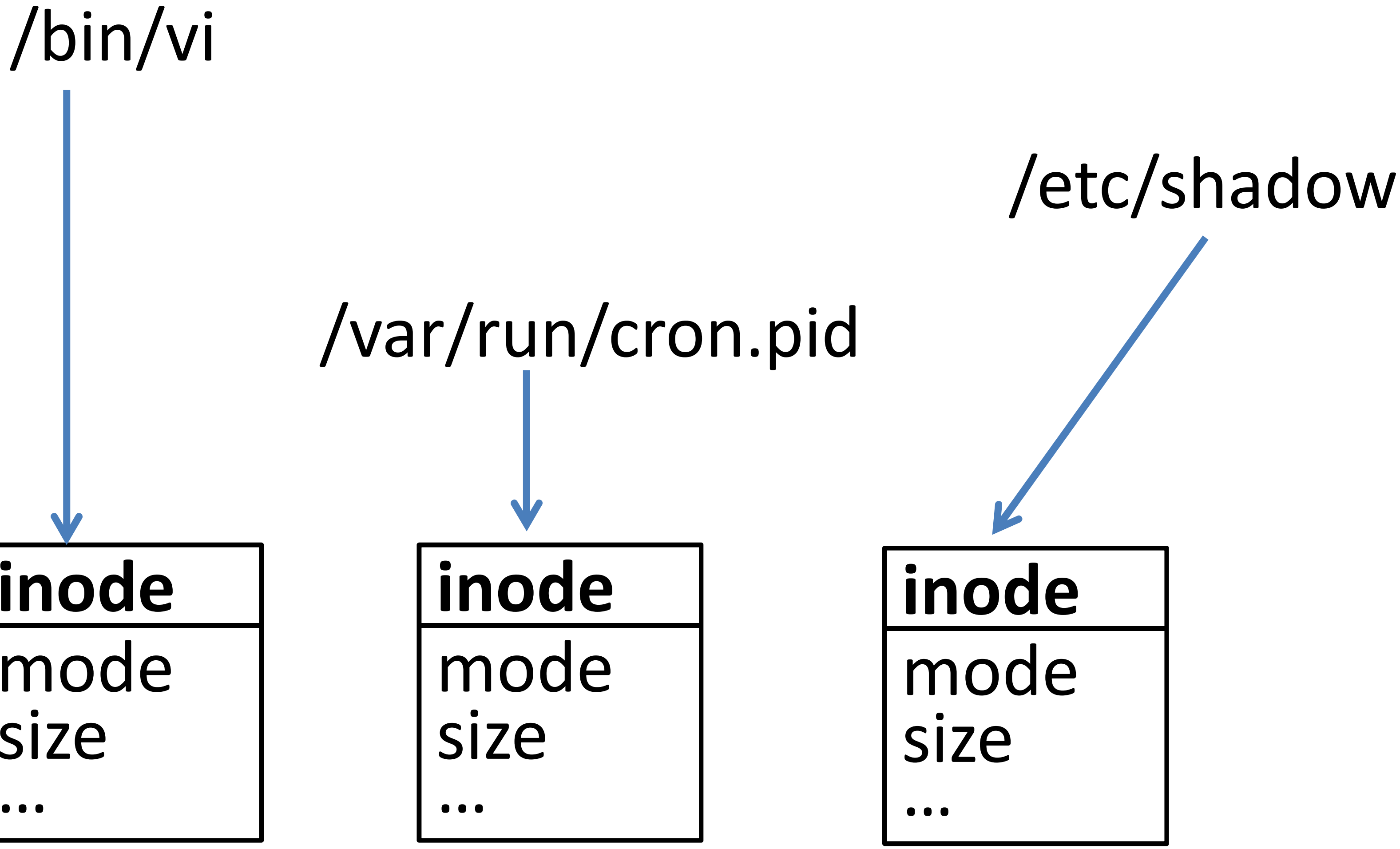
POSIX Filesystem API

/bin/vi

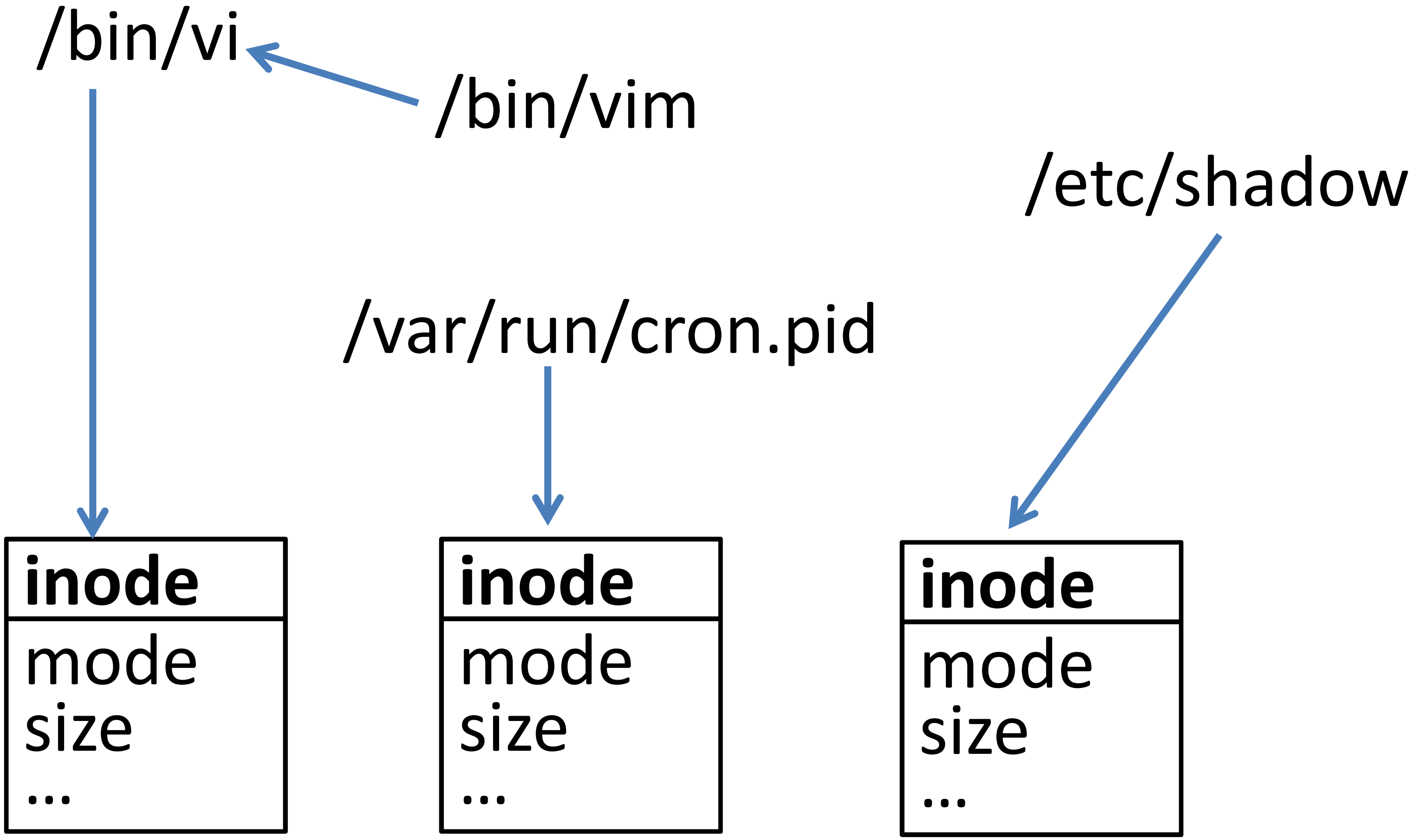
/etc/shadow

/var/run/cron.pid

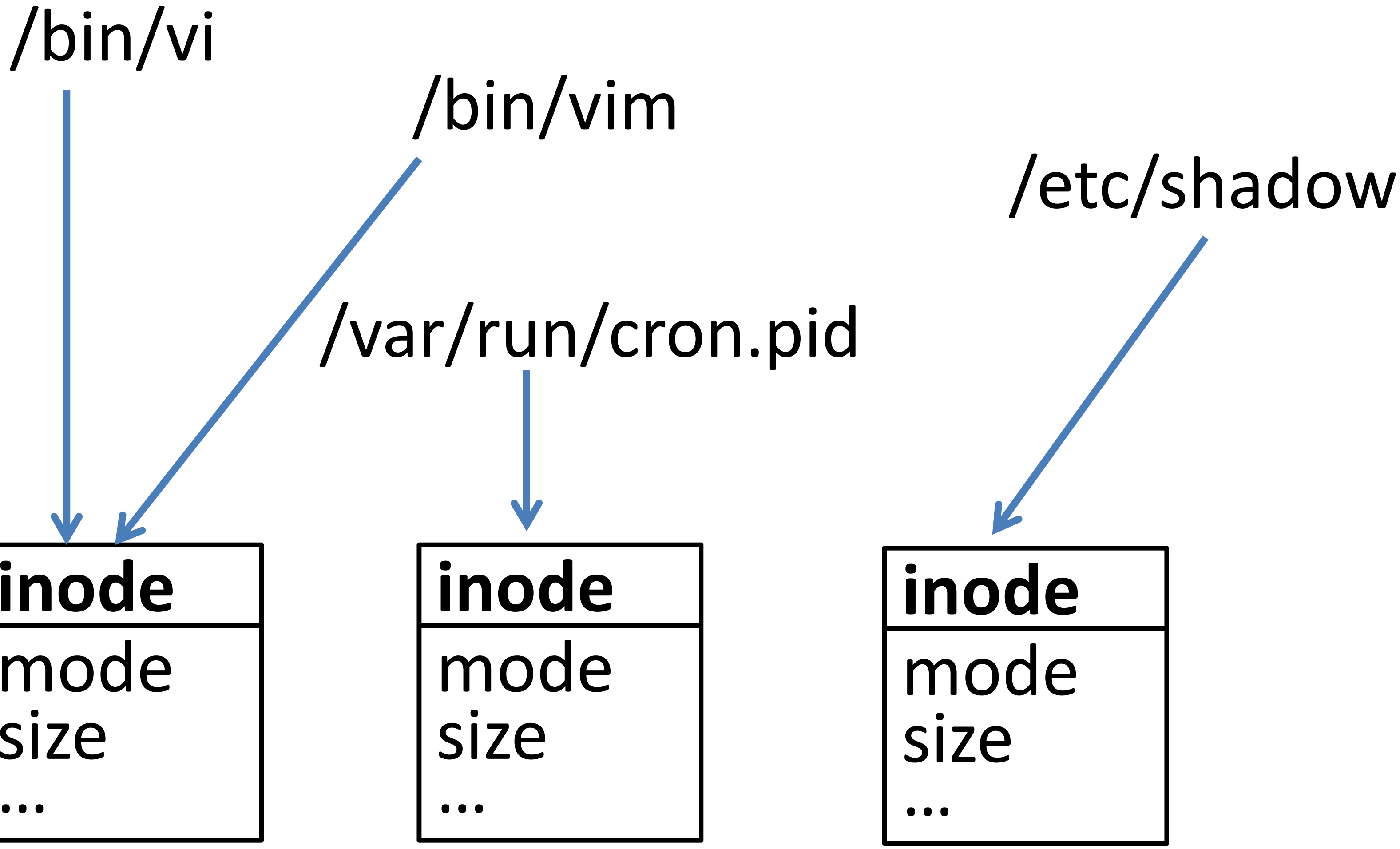
POSIX Filesystem API



POSIX Filesystem API



POSIX Filesystem API



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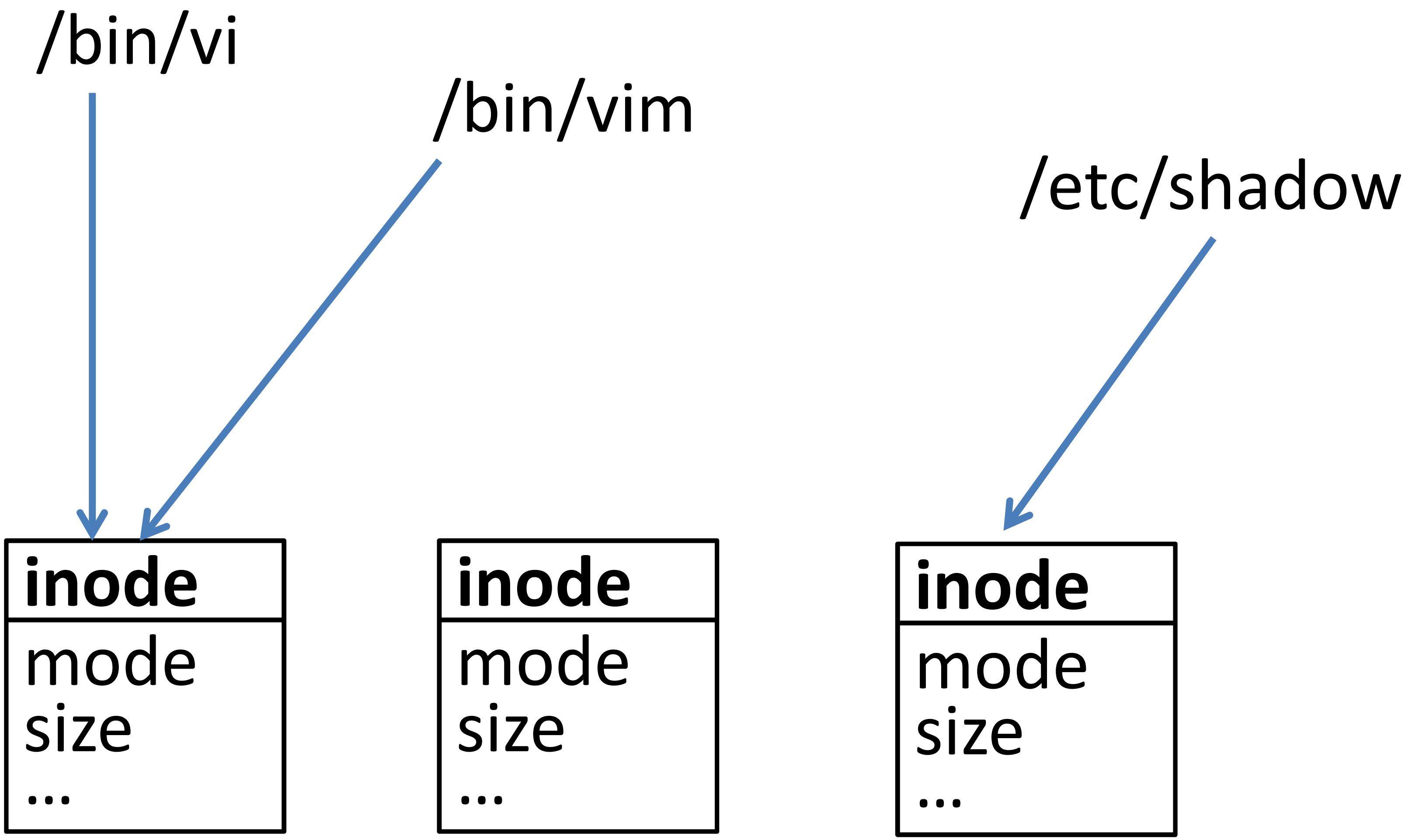

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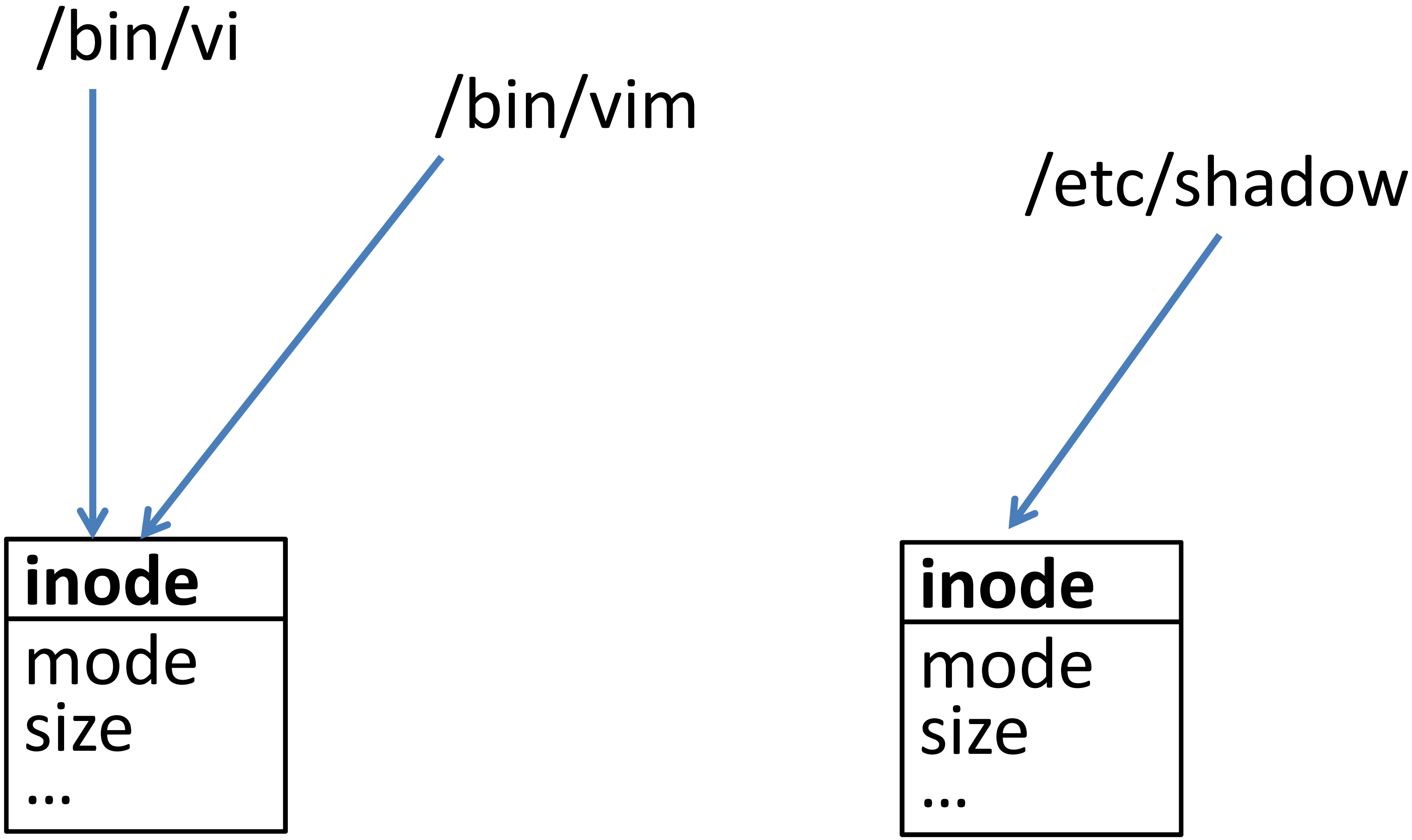

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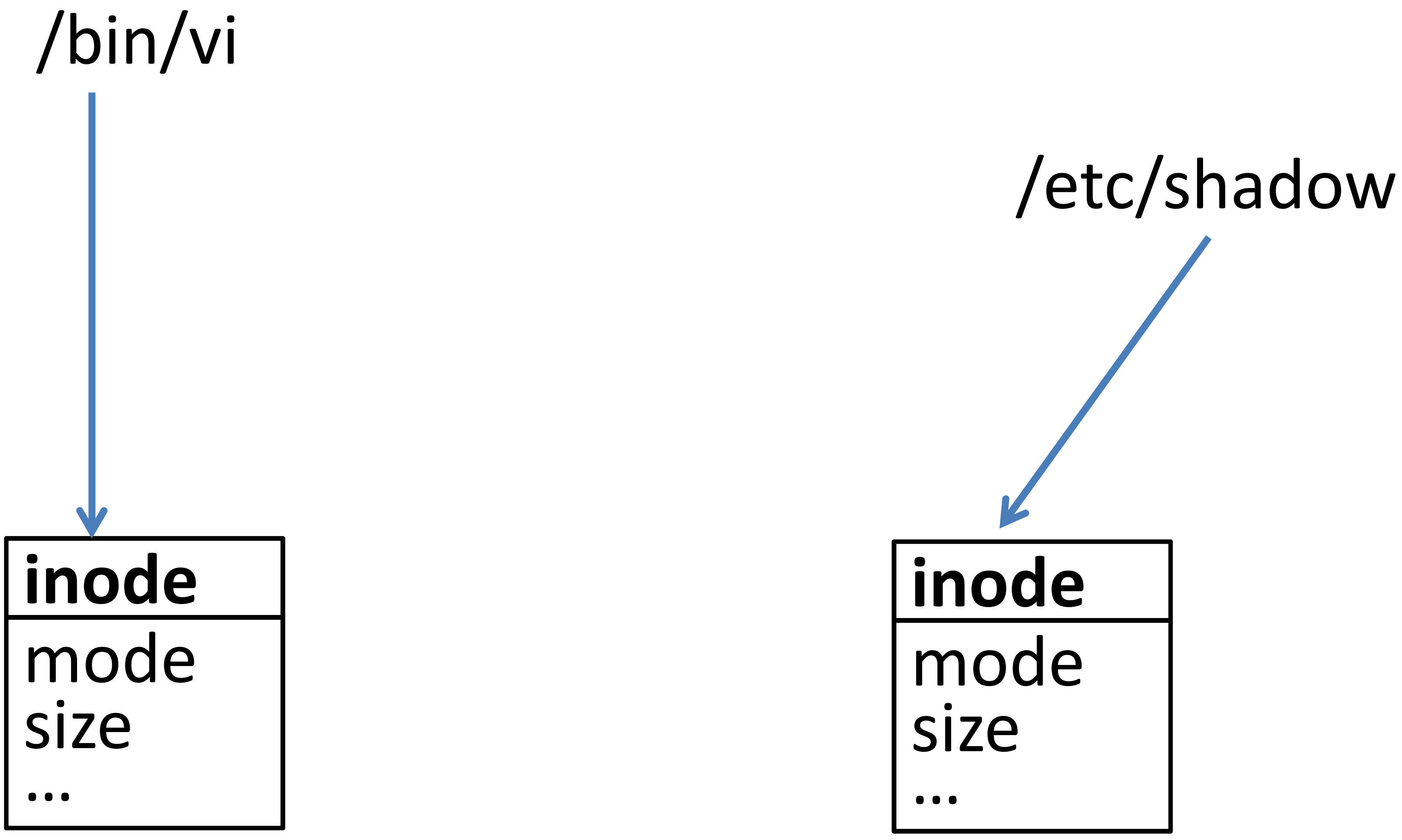
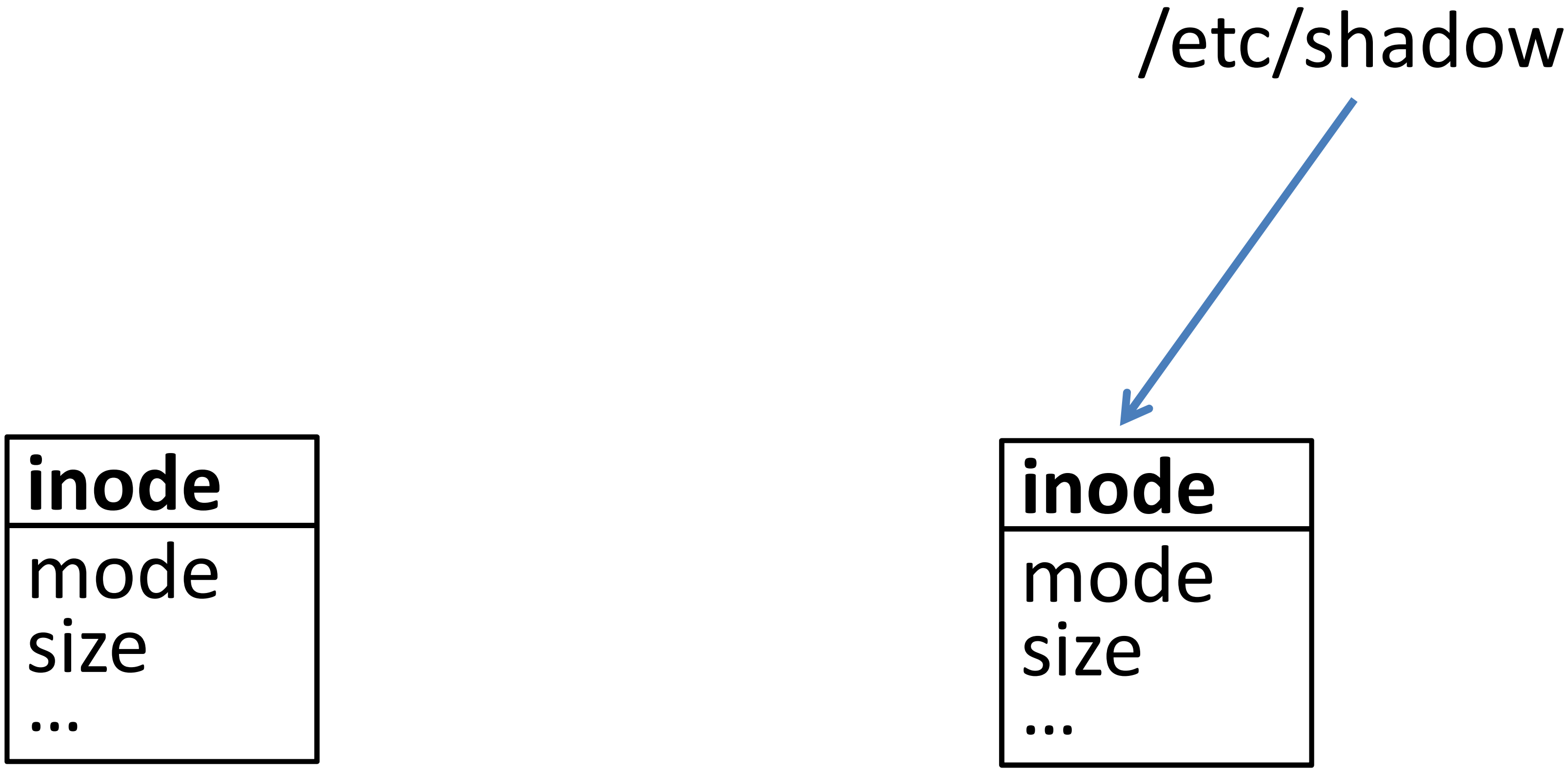


POSIX Filesystem API



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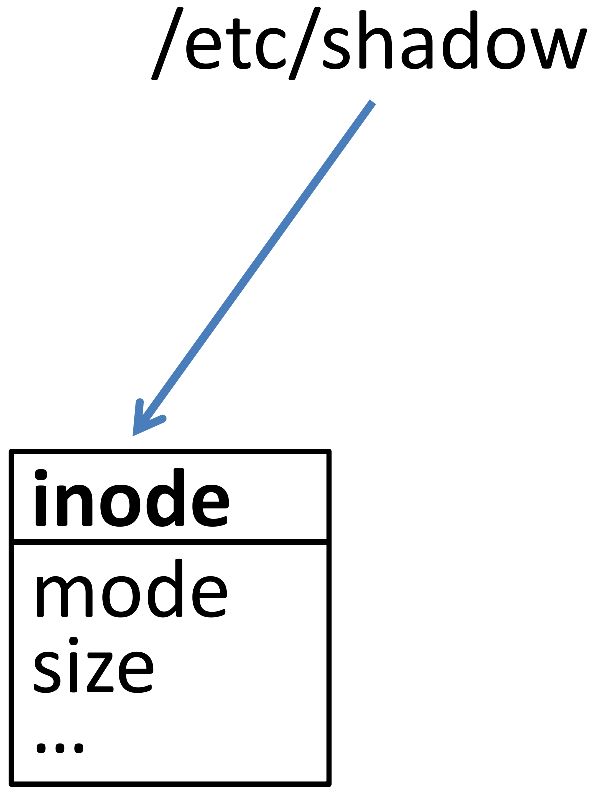

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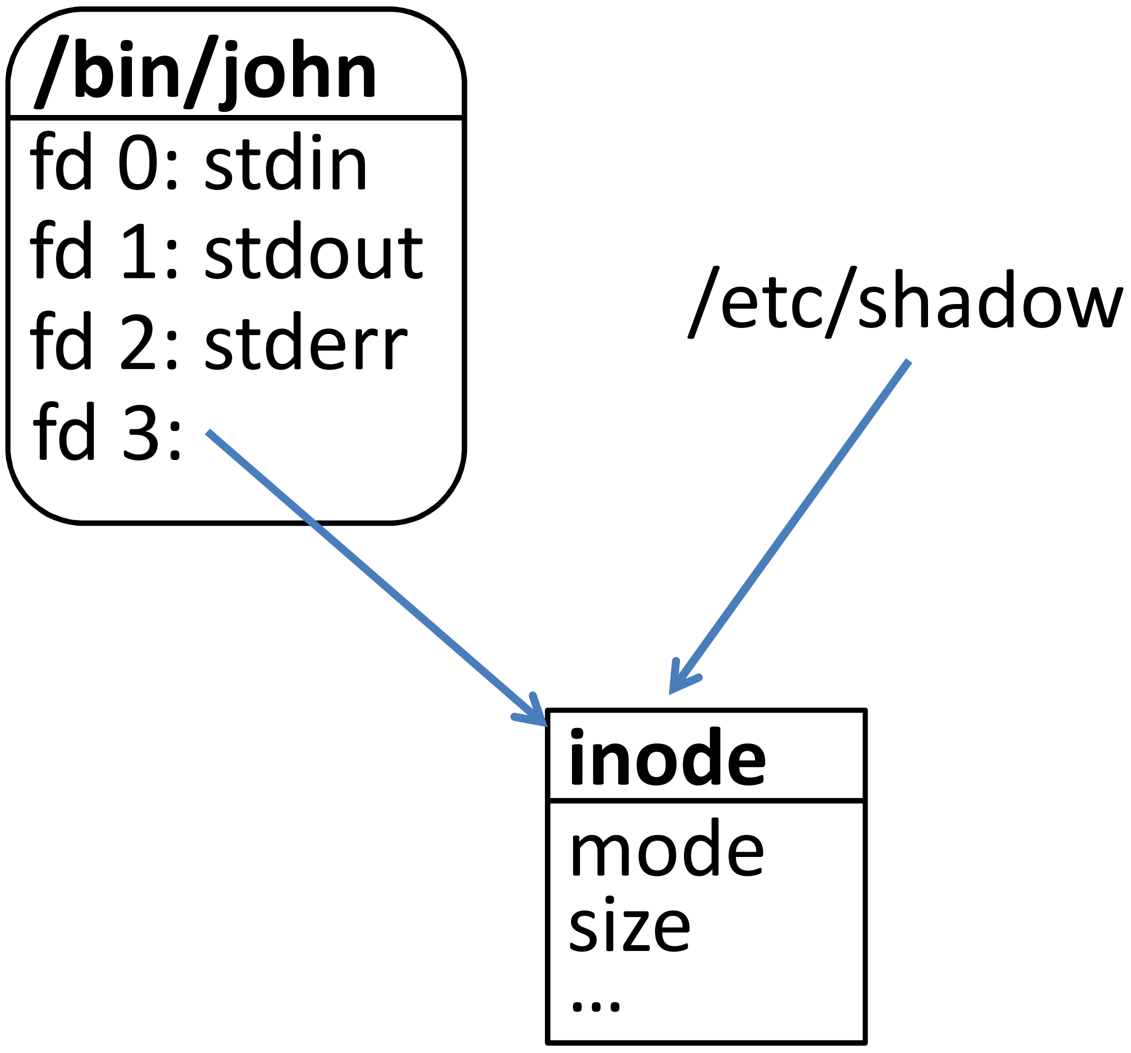

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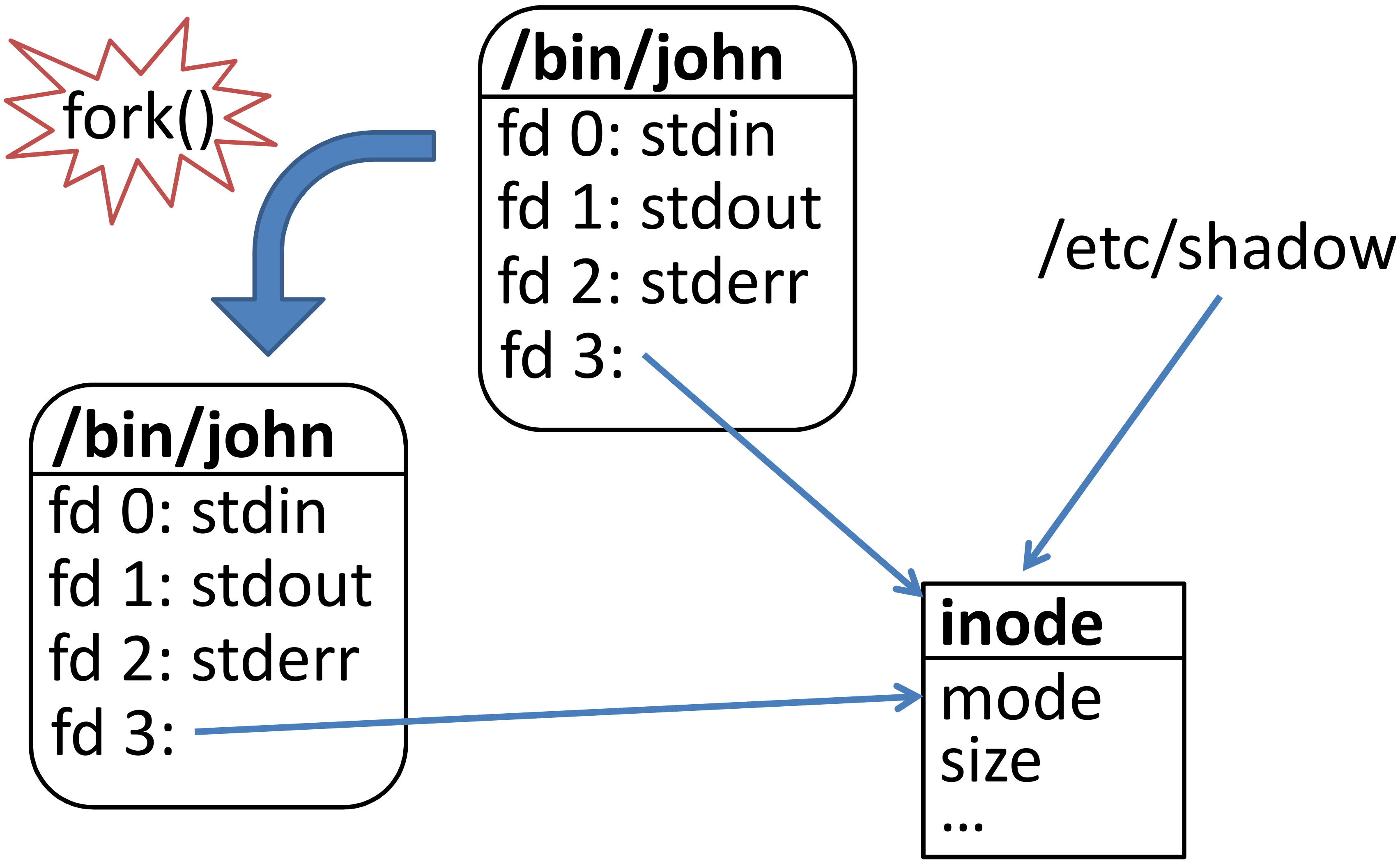

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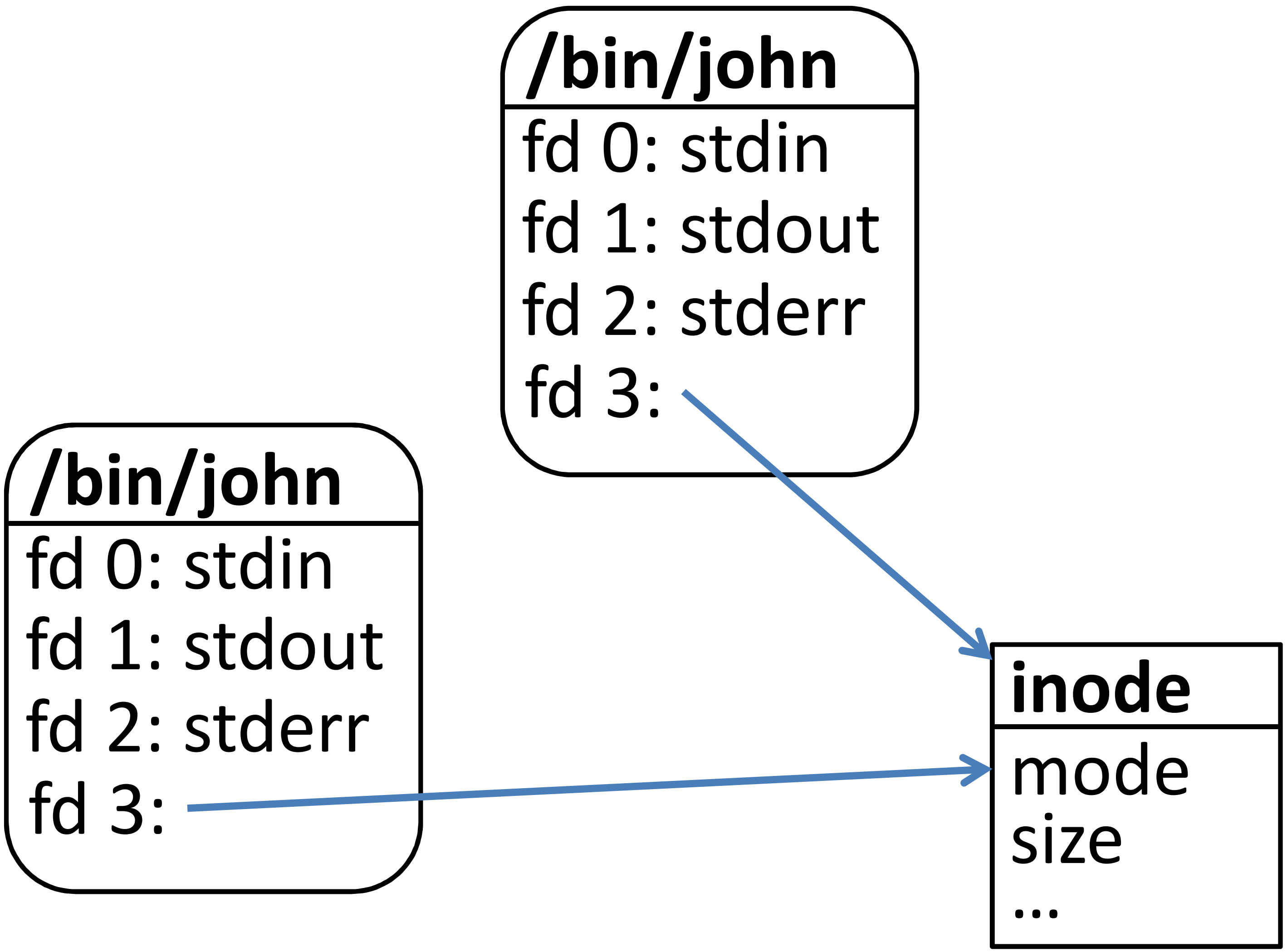

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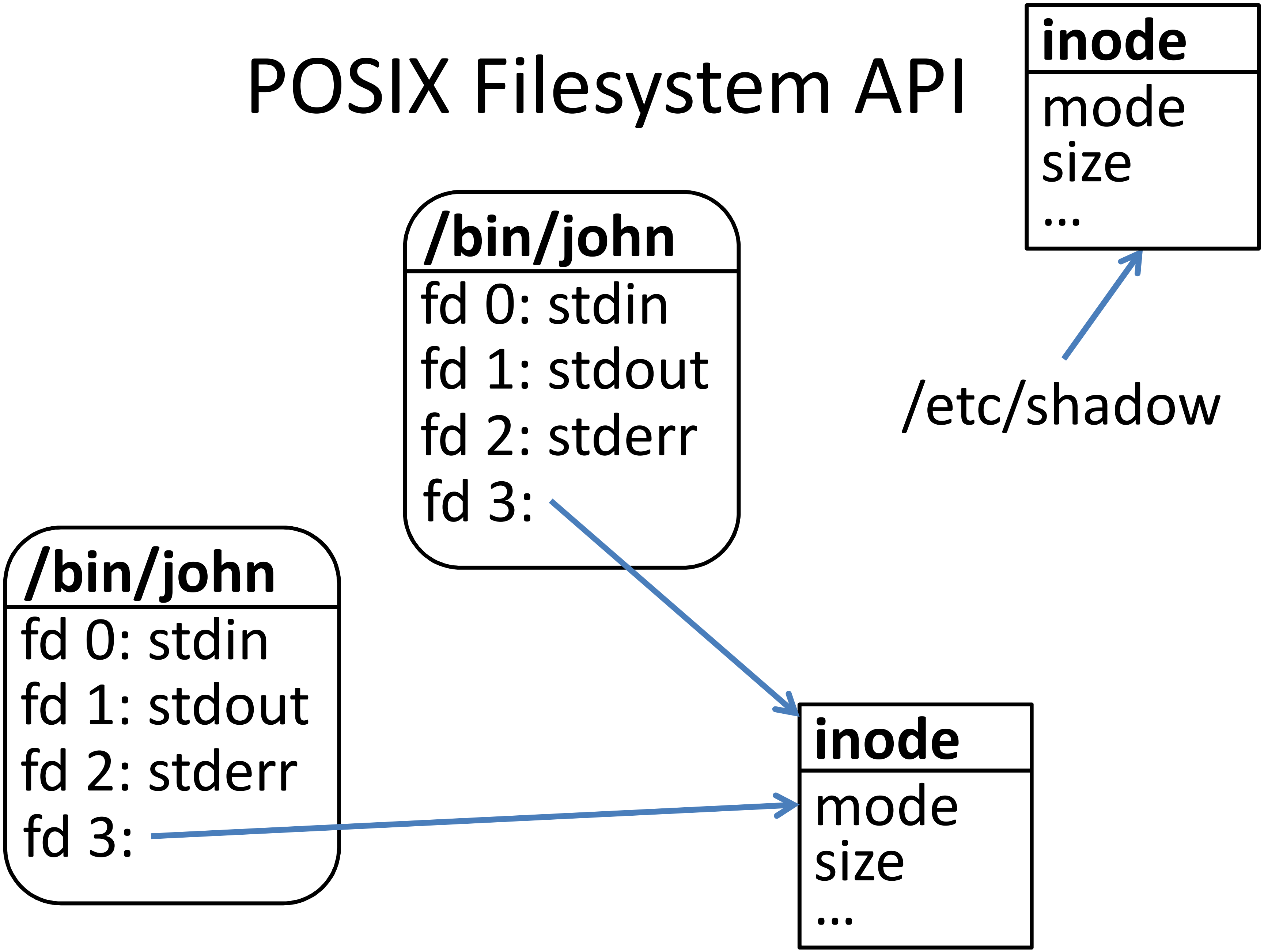

Highlevel API

- Very simple
- Pass control to fuse_main()
- Supply set of callbacks for fs operations
- Callbacks are called as userspace performs operations on the filesystem
- Callbacks are passed a path, return data or error code
- Single or multi-threaded

The Request

```
int (*open)(
    const char *path,
    struct fuse_file_info *fi
);
```

Highlevel Example

Highlevel Notes

- Return plausible link-count for /
- readdir() operates in pages
- Start additional threads from init callback

Lowlevel API

- Deals in inode numbers not paths
  - / is inode 1
  - Everything else is looked up name->inode
  - Directories are just lists of names
- Co-ordinates are Pair<inode,generation>
- Async – you can return from request and call reply later

Why the Lowlevel API?

- More performant in some cases
- More statefull
- More control over memory usage

The Request

```
int (*open)(
   fuse_req_t req,
   fuse_ino_t ino,
   struct fuse_file_info *fi
);
```

Lifecycles

- inodes are reference-counted
  - Incremented by LOOKUP, decremented by FORGET
  - You must field requests on any non-forgotten inode
- OPEN / FLUSH / RELEASE cycle also gives hints

Lowlevel Example

Debugging

- Same as any other user-space programme
- Can use gdb / ddd / $IDE / etc
- Can use valgrind (needs setup)
- Force unmount after crash with

```
fusermount –u /mnt/point
```

Testing

- fuse/test/test.c
- Linux Test Tools (ltp.sf.net/tooltable.php)
- POSIX compliance test suite at http://www.itl.nist.gov/div897/ctg/posix_form.htm
- Ntfs-3g has a couple

Performance

- FUSE filesystems can be very fast
- Be careful of memory usage – obey release and forget
- Inherently lots of copies – try to minimise these

Conclusions

- Write filesystems!
- It’s easy in userspace!
- Highlevel interface and scripting bindings make it trivial for simple tasks
- Lowlevel interface gives surprising performance and control

Thank You

Any Questions?