Everything's a File Descriptor

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Linux Plumbers Conference 2015

“Everything’s a file”

- /home/josh/doc/presentations/lpc-2015/fd/fd.pdf

- /home/josh/doc/presentations/lpc-2015/fd/fd.pdf
- /etc/hostname

- /home/josh/doc/presentations/lpc-2015/fd/fd.pdf
- /etc/hostname
- /dev/null
- /dev/zero

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- /etc/hostname
- /dev/null
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- /sys/class/block/sda/queue/rotational
- /sys/firmware/acpi/tables/DSDT

Everything has a filename?

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- Pipes
- Sockets
- epoll
- memfd
- KVM virtual machines and CPUs
- ...

Everything's a file *descriptor*

- What is a file descriptor, really?
- What can you do with a file descriptor?
- What interesting file descriptors exist?
- How do you build a new type of file descriptors?
- What interesting file descriptors don't exist?

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What is a file descriptor, really?

- `struct fd`, `struct fdtable`
- `struct file`

struct fd versus struct file

testfile contains “0123456789”

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x = open("testfile", O_RDONLY);
xdup = dup(x);
y = open("testfile", O_RDONLY);
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testfile contains “0123456789”

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x = open("testfile", O_RDONLY);
xdup = dup(x);
y = open("testfile", O_RDONLY);
read(x, &c, 1);
putchar(c);
read(xdup, &c, 1);
putchar(c);
read(y, &c, 1);
putchar(c);
```

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x = open("testfile", O_RDONLY);
xdup = dup(x);
y = open("testfile", O_RDONLY);
read(x, &c, 1);
putchar(c); /* Prints '0' */
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putchar(c);
read(y, &c, 1);
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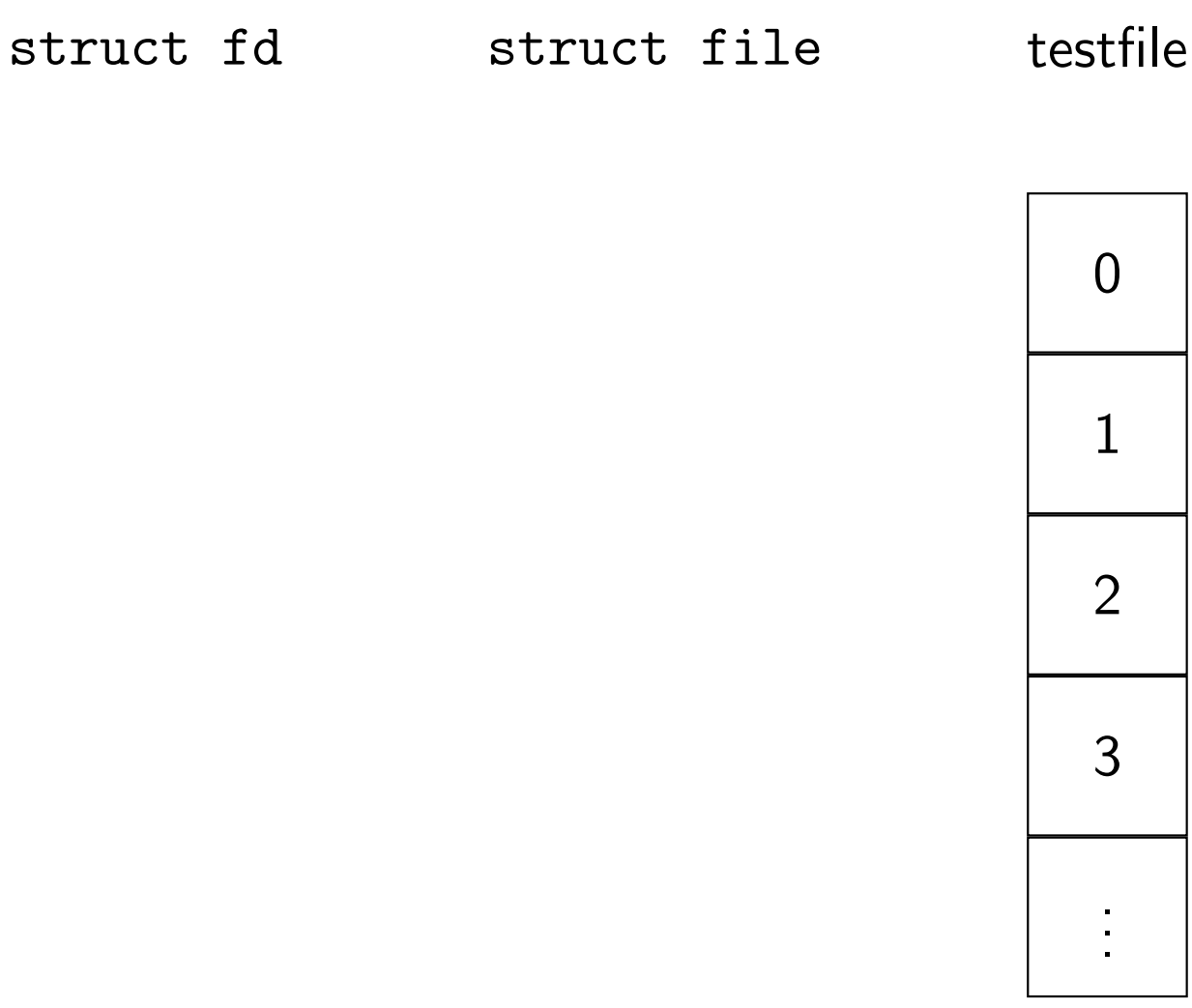
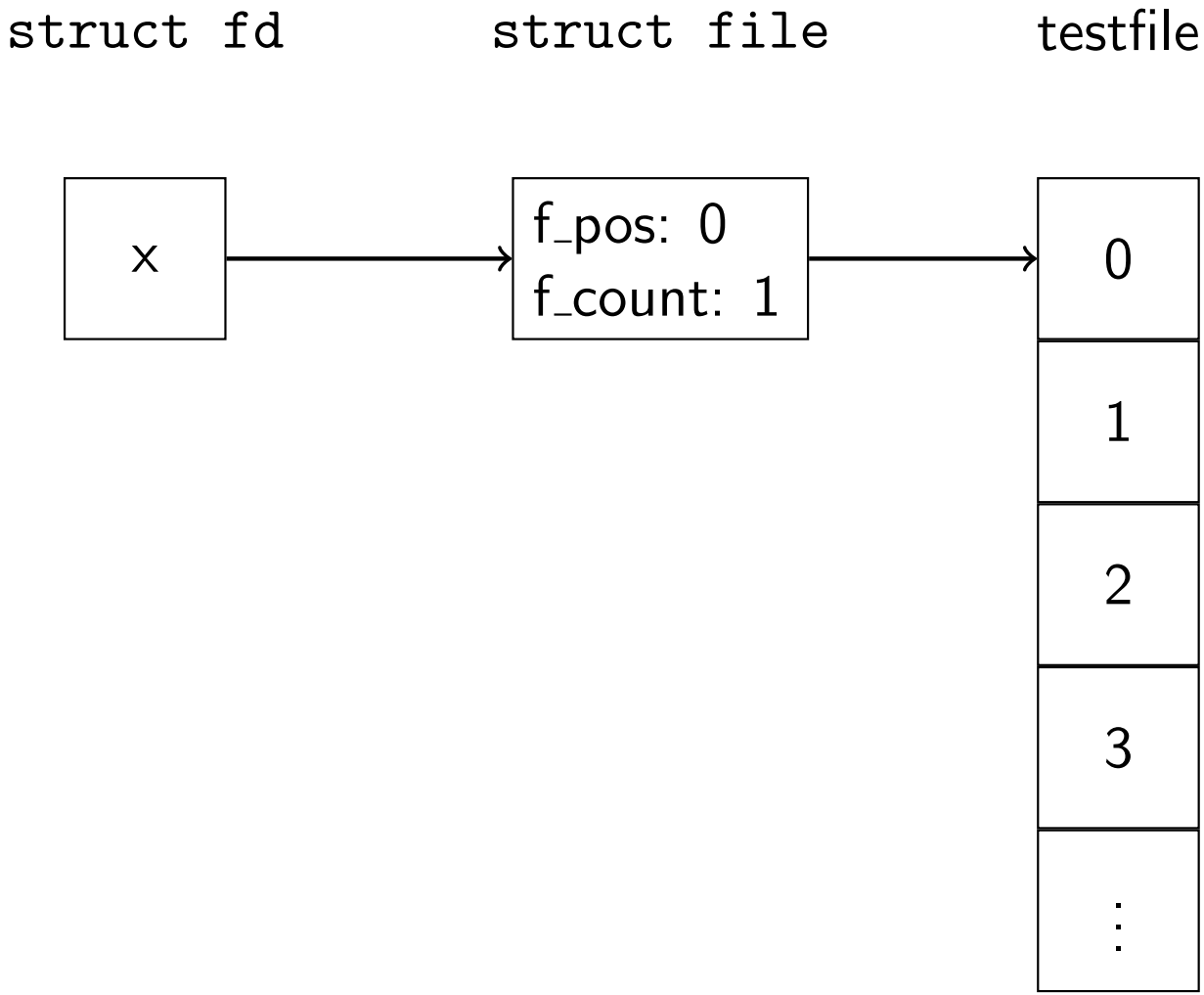

struct fd
struct file
testfile
0
1
2
3
⋮


struct fd
struct file
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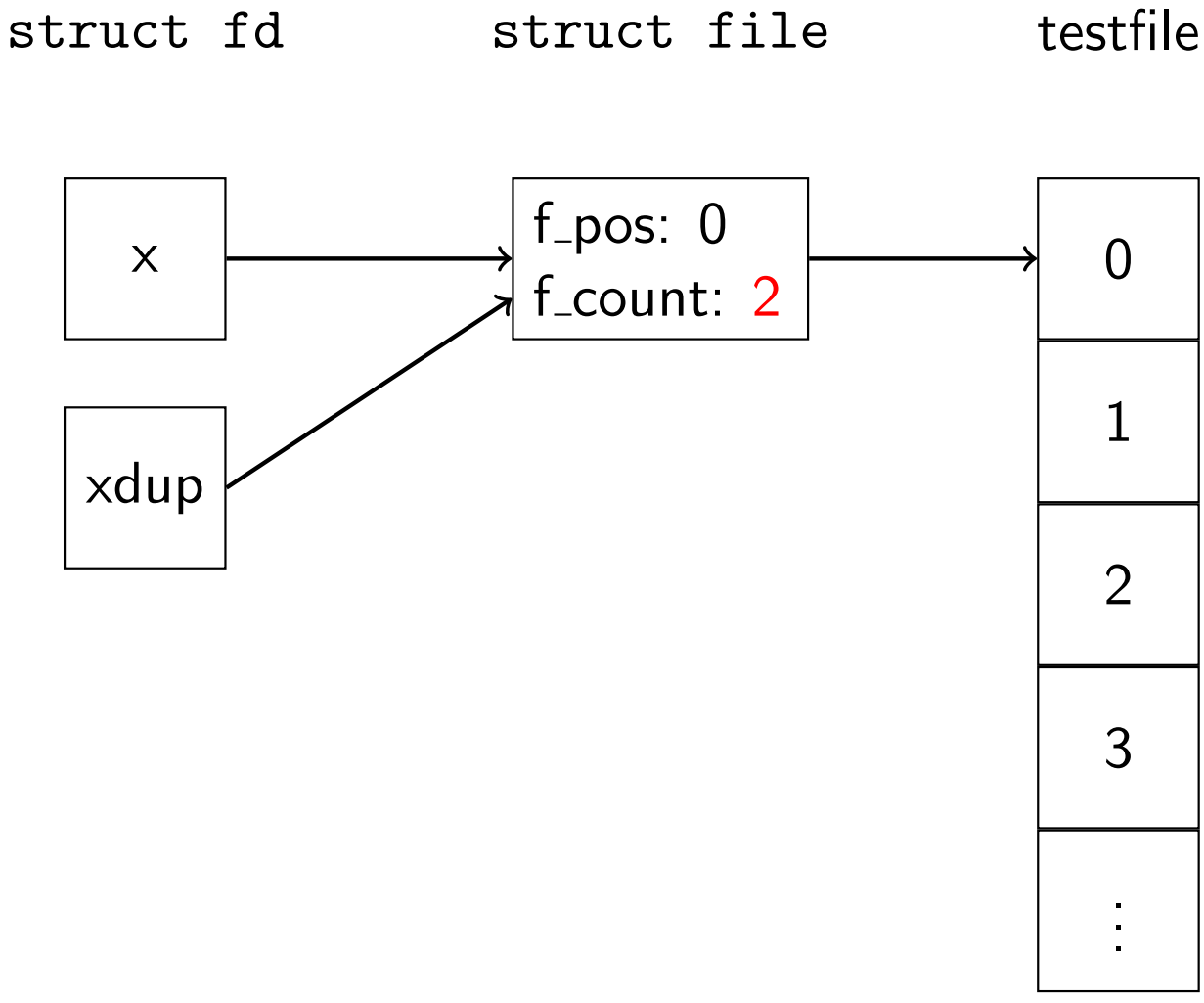
x
f_pos: 0
f_count: 1
0
1
2
3
⋮


struct fd
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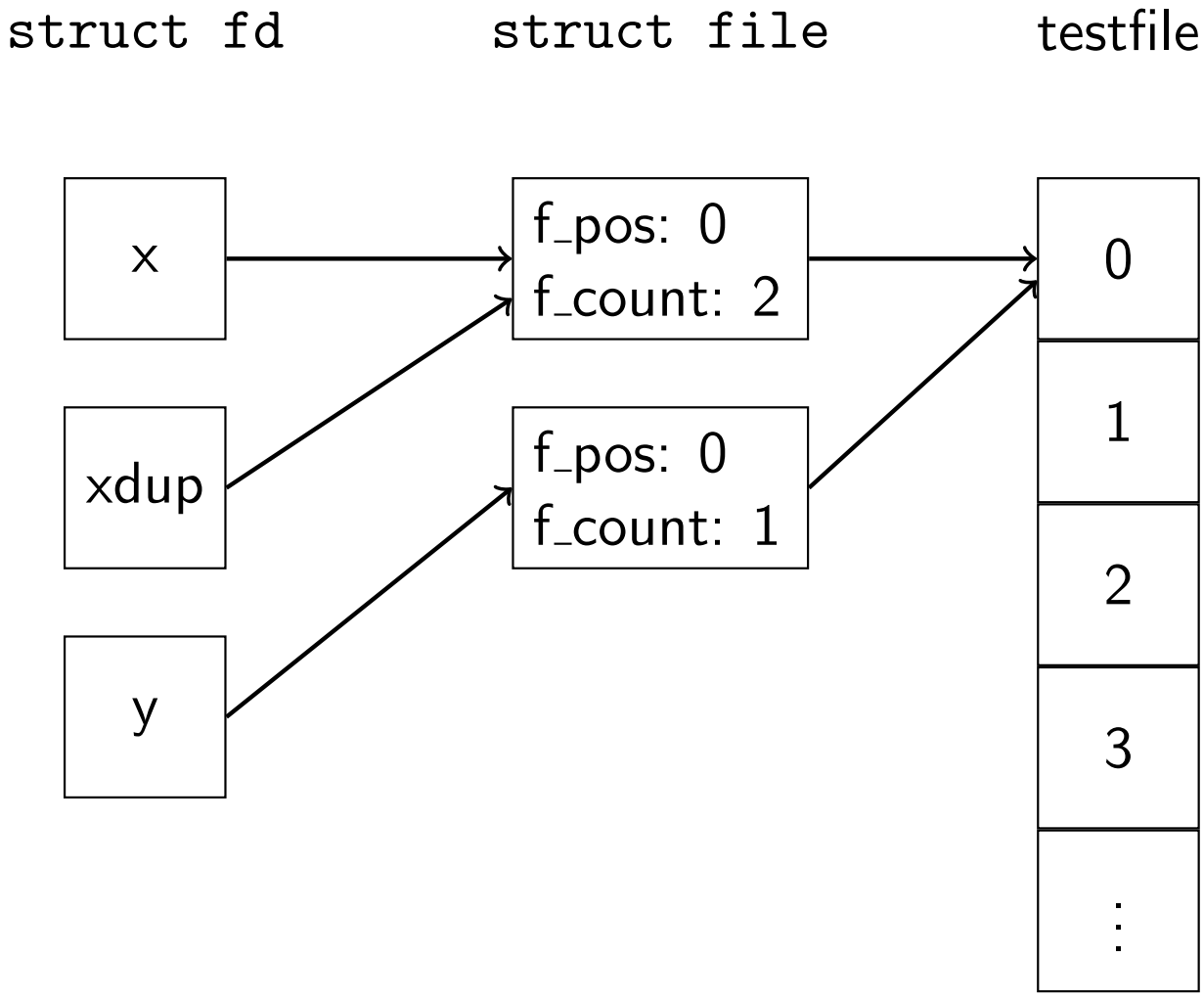
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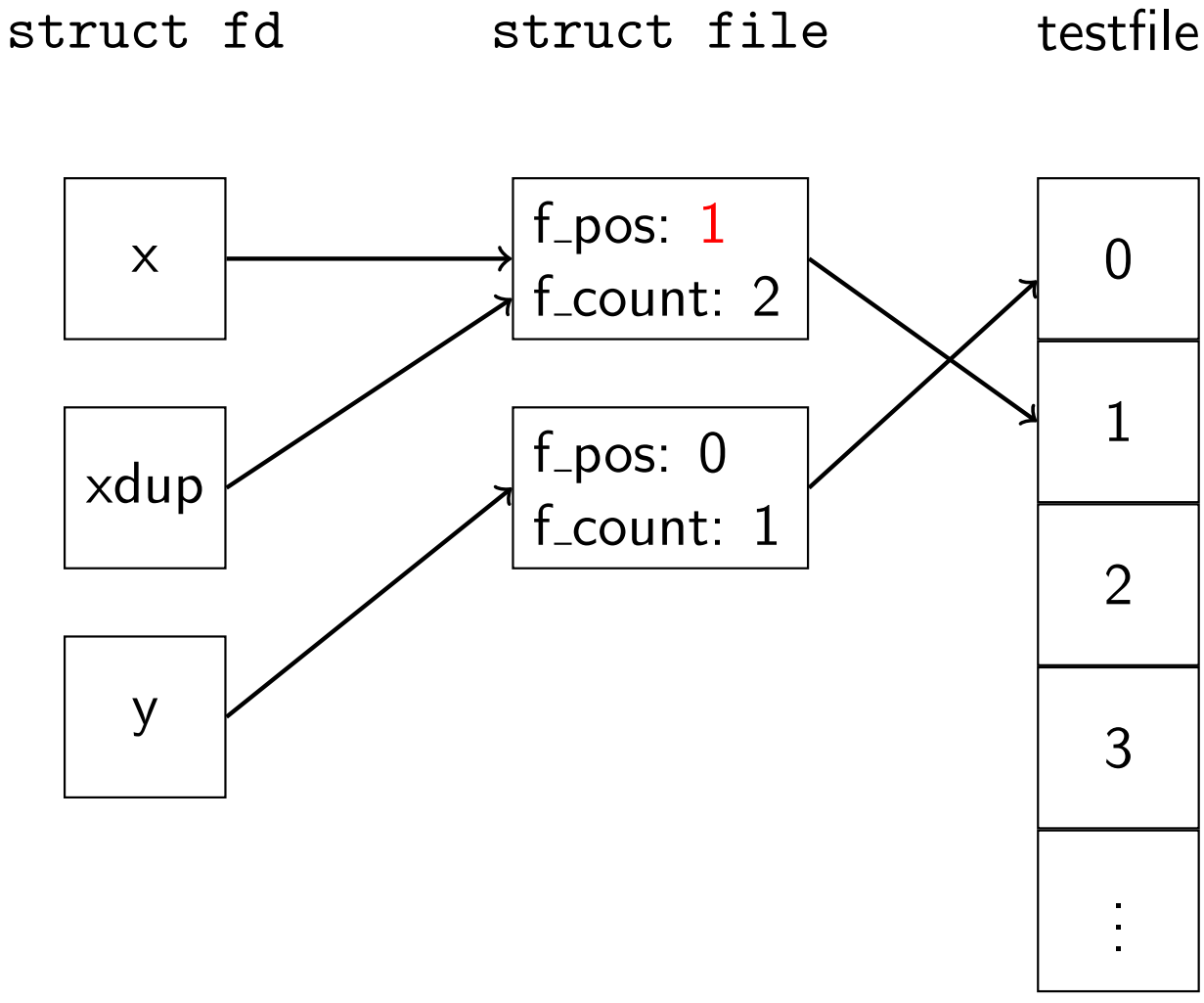
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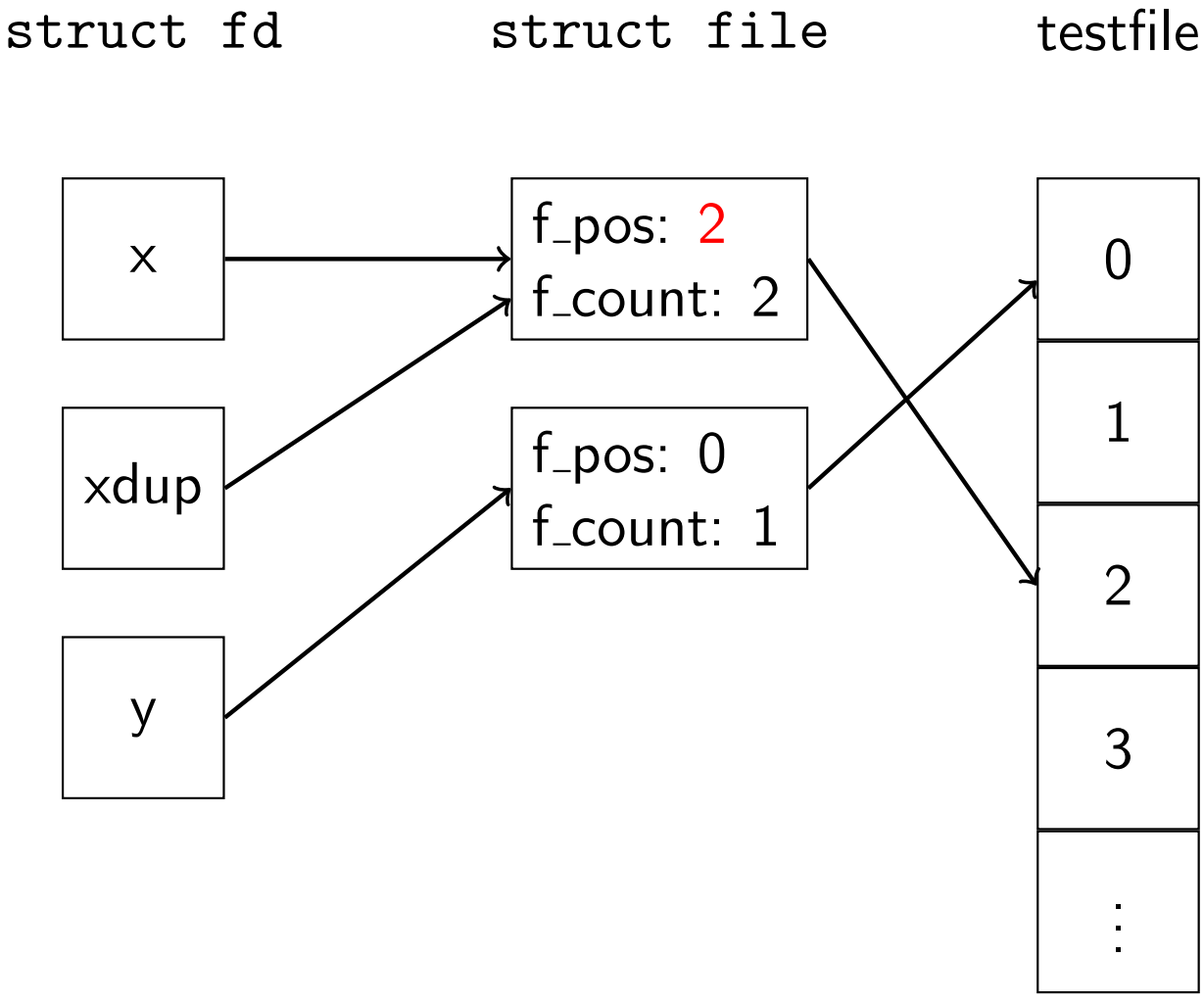
struct fd
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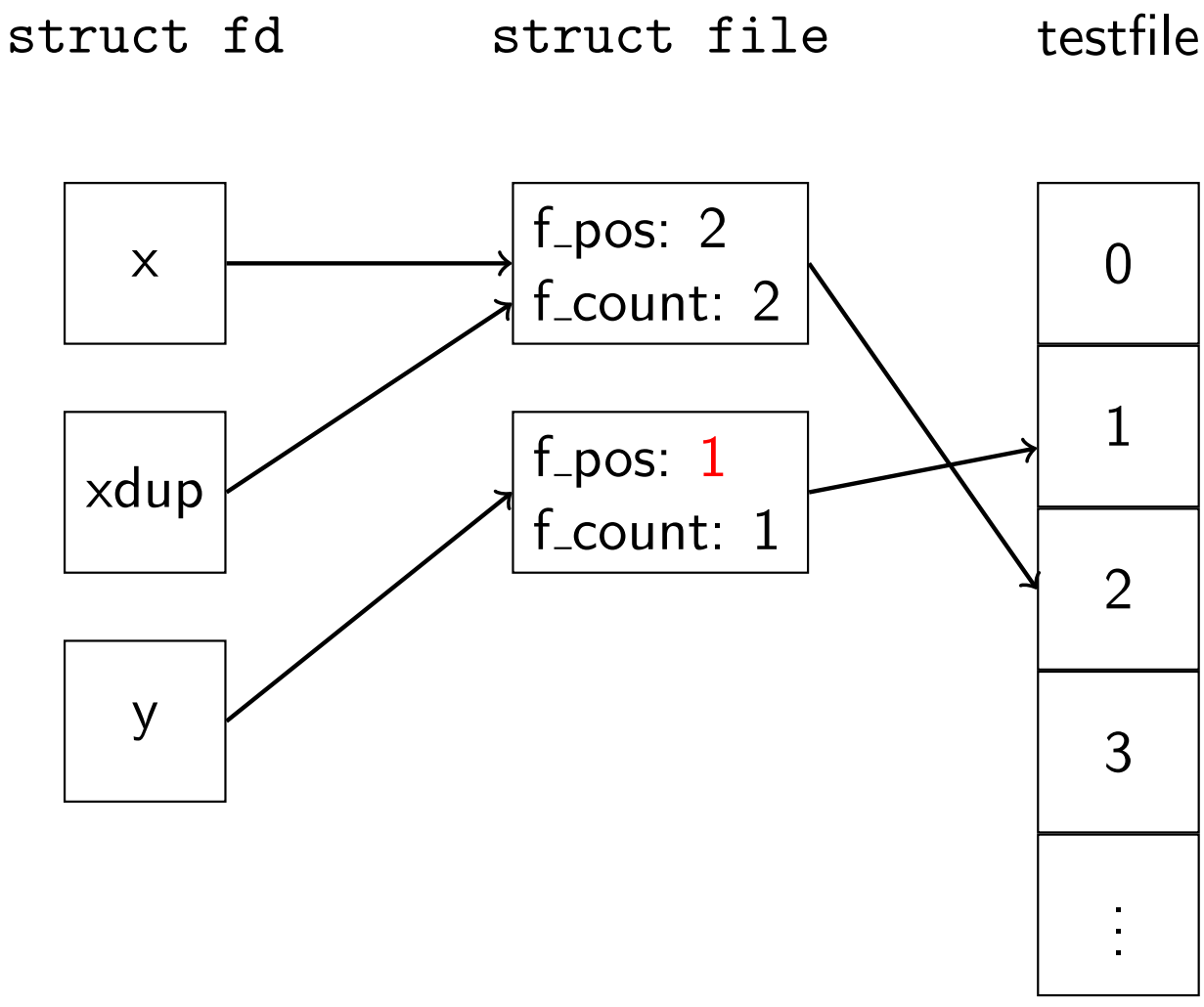
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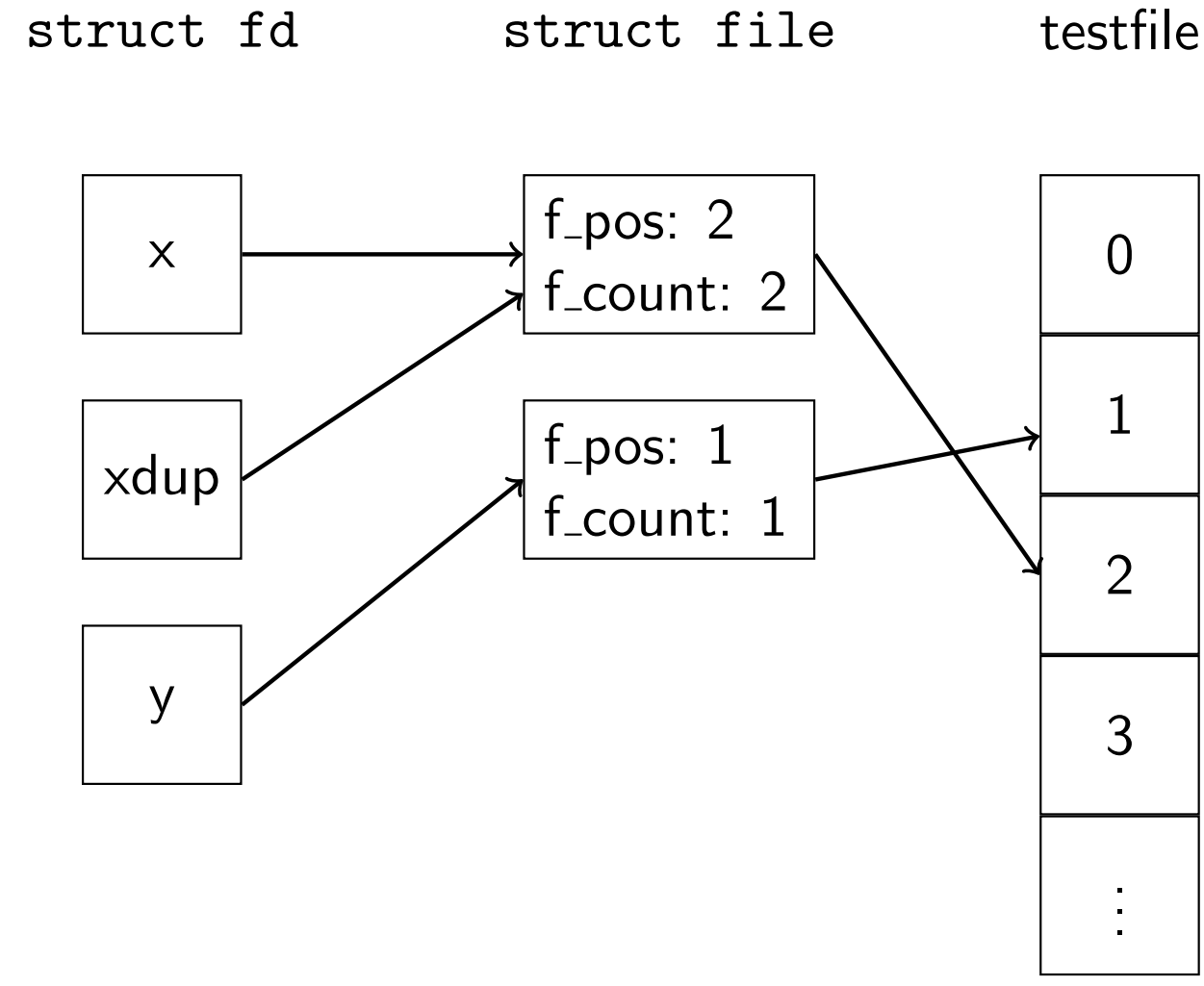
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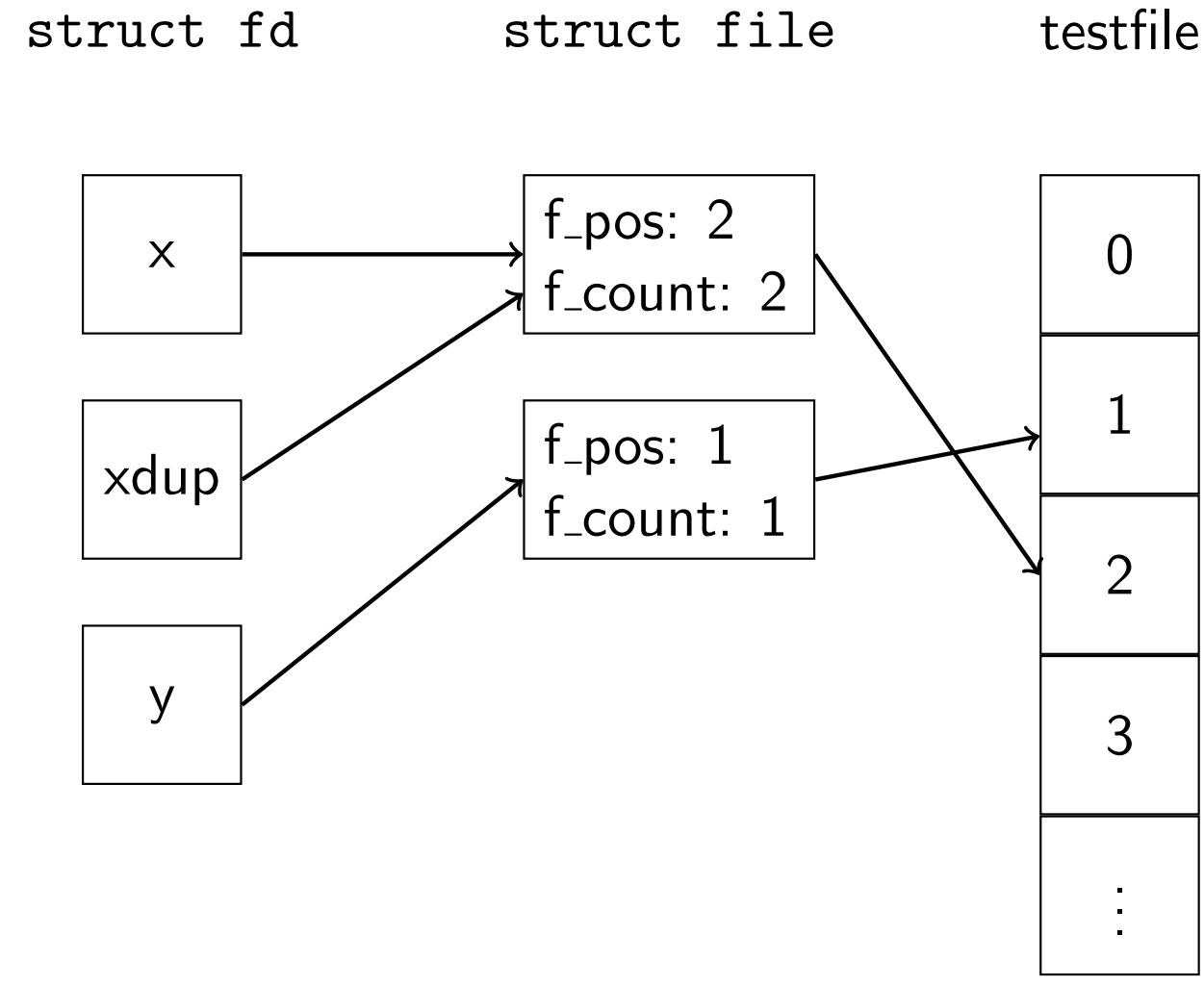
userspace int


struct fd
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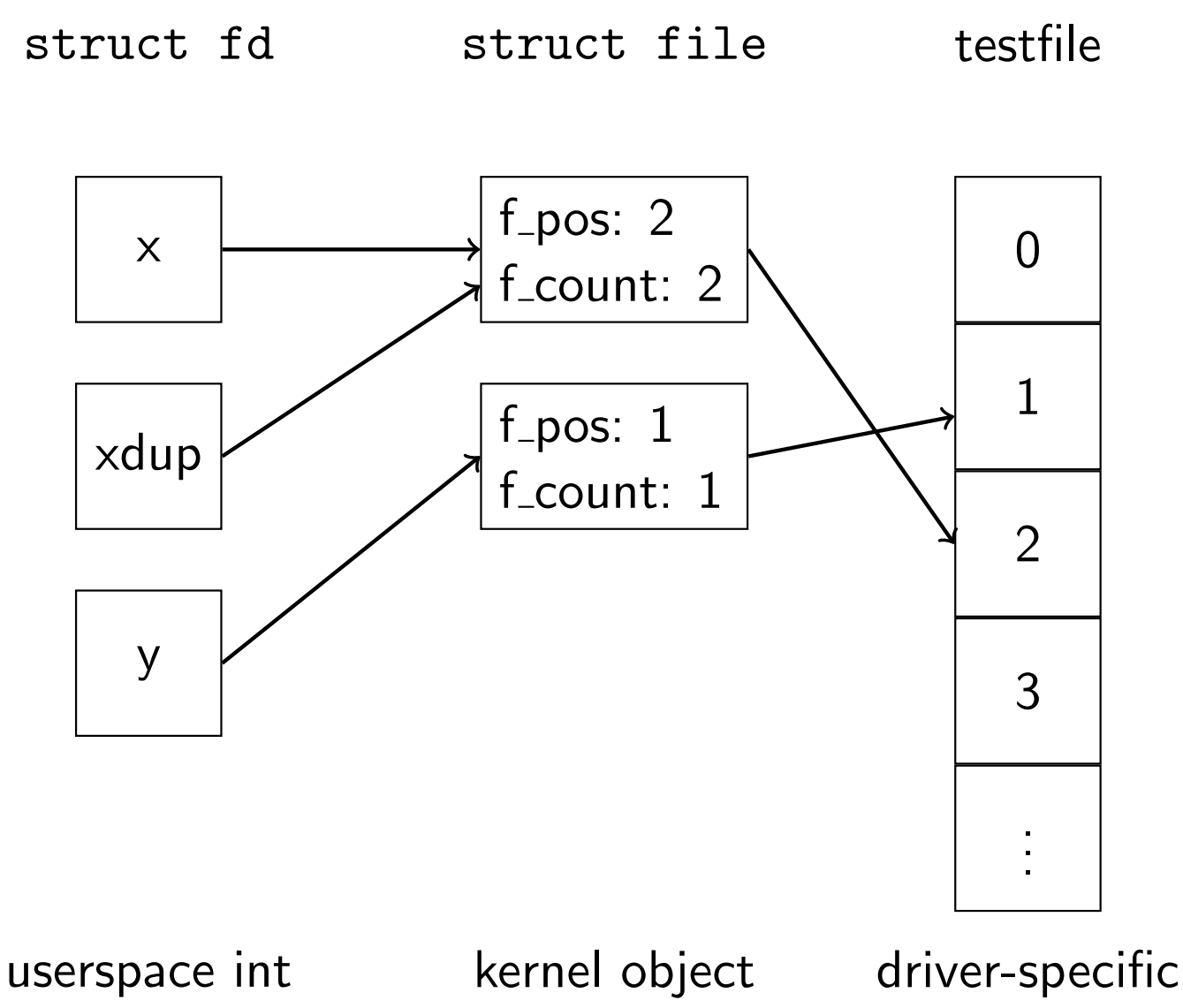
kernel object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userspace int
kernel object
driver-specific

File descriptor: Userspace reference to kernel object

What can you do with a file descriptor?

- `read`, `write`

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- `seek`

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- ...
- `ioctl`

Use file descriptors!

What interesting file descriptors exist?

eventfd

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- `poll`: Ready for reading if non-zero
- Several drivers use eventfd to signal events between kernel and userspace

timerfd

- Allows handling timers as file descriptors
- Throw them in the `poll` loop with everything else
- Create with specified timeout
- `read`: Block until timeout; return number of times expired
- `poll`: Reading for reading if timeout passed

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- Special syscalls that also set signal mask (`ppoll`, `pselect`, `KVM_SET_SIGNAL_MASK ioctl`)
- "async-signal-safe" library functions

Signed-off-by:  <(;,;)@r'lyeh>

signalfd

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- Block “normal” signal delivery; receive via signalfd instead

signalfd

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- Block “normal” signal delivery; receive via signalfd instead
- `read`: Block until signal, return `struct signalfd_siginfo`
- `poll`: Readable when signal received

How do you build a new type of file descriptor?

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- `seek` and file position
- `mmap`
- What happens with multiple processes, or `dup`?
- For everything else: `ioctl`

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- `no_llseek`, `fixed_size_llseek`
- Check `file->f_flags & O_NONBLOCK`
  - Blocking: `wait_queue_head`
  - Non-blocking: return `-EAGAIN`

What interesting file descriptors don't exist yet?

Child processes

- `fork/clone`

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Problems:

- Waiting not integrated with `poll` loops
- Signals
- Process-global; libraries can't manage only their own processes

Alternatives

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  - Still process-global; gets all child exit notifications
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- `signalfd` for `SIGCHLD`
  - Still process-global; gets all child exit notifications
  - Requires coordinating global signal handling between libraries
  - Must block `SIGCHLD`; breaks code expecting `SIGCHLD`

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- Maintains a reference to the child's `task_struct`
- Relatively simple, except...

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- `clone` is out of parameters (6) on some architectures
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- Low-level `copy_thread` function grabbed `tls` parameter directly from syscall register arguments; couldn't move it
  - Pass parameter normally via C, fix assembly syscall entry
  - Fixed with `copy_thread_tls` (merged in 4.2)

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- Need a new `clone` system call for the `fd` out parameter
- `clone` syscall parameters vary by architecture
  - Avoided in the new syscall
- `clone` is out of parameters (6) on some architectures
  - Pass parameters via a struct and size
- Low-level `copy_thread` function grabbed `tls` parameter directly from syscall register arguments; couldn't move it
  - Pass parameter normally via C, fix assembly syscall entry
  - Fixed with `copy_thread_tls` (merged in 4.2)
- `ptrace` and reparenting

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- `ptrace` and reparenting
  - Work in progress

History and status

- Thiago Macieira originally proposed `forkfd` to simplify Qt
- Josh and Thiago started on `clonefd` earlier this year
- Some infrastructure merged into 4.2
- Syscall aimed for future kernel after resolving `ptrace` issues

File descriptor: Userspace reference to kernel object

What else can we do with a reference to `task_struct`?

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- Used pervasively in process syscalls
- Enumerated as directories in `/proc`
- Unique within root container
- Container PID namespaces map a subset of these
- PIDs do not hold a reference; can be reused
- Race condition if used from non-parent process

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- Race-free
- Can pass via exec, UNIX sockets
- Allows non-parent processes to obtain exit information

Next steps

- Merge `clonefd`
- For each PID syscall, add an fd variant
- Add ioctls to obtain process information
- Add process enumeration (next, child, root)

Other future file descriptors

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Warning: wild speculation and conjecture ahead

User and group IDs

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- Set up arbitrary mappings when mounting a filesystem
- Allow a process to hold multiple credentials (like `setgroups`)

Filesystem mounts

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- Suppose `mount` returned a directory file descriptor
- `openat` relative to the filesystem
- Separate call to bind into the filesystem namespace
- Bind existing dirfd for bind mounts

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- File descriptor: Userspace reference to kernel object
- Reference-counted, race-free, unambiguous ID
- Well-defined semantics
- Extensive operations
- `poll` and blocking
- Use file descriptors in new APIs
- Don't invent new identifier namespaces