

xv6©-rev10
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I/O subsystem

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I/O: The user mode side.

I/O system calls

- System calls using file descriptors:

```
read(int fd, char *buf, int len);  
write(int fd, char *buf, int len);  
stat(int fd, struct stat *);  
dup(int fd);  
close(int fd);
```

- Name services:

```
link(char *oldpath, char *newpath);  
fd = open(char *path, int flags);  
unlink(char *path);  
mkdir(char *path);  
rmdir(char *path);
```

- Strange one:

```
pipe(int pipefd[2]);
```

- A vast number of different devices is served by few system calls!

I/O: The kernel side

Layered system

1. System calls.
2. File layer.
 - pipe subsystem.
 - inode subsystem:
 - Name layer.
 - inode layer.
 - Buffer layer.
 - Driver layer.

The layers model is not perfect, e.g.,

- System calls call the file layer, name layer, and inode layer.

How?

- Different structures.
- Different methods.
- Different hardware.
- How to present uniform interface to user mode?

xv6 'abstract' file type

```
4150 struct file {  
    enum {FD_NONE, FD_PIPE, FD_INODE} type;  
    int ref; // reference count  
    char readable;  
    char writable;  
    struct pipe *pipe;  
    struct inode *ip;  
    uint off;  
};
```

File descriptor vs. struct file *

- The struct file is what open SHOULD have returned to the user.
- The user SHOULD have supplied this pointer to the other system calls.
- However! The user is NOT trustable.
- Hence the kernel HIDES the struct file pointer and supplies the index fd.

ofile and file structures relation

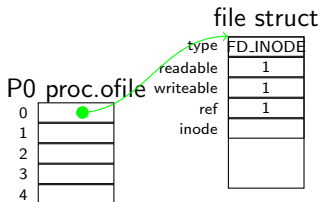
No file open

P0 proc.ofile

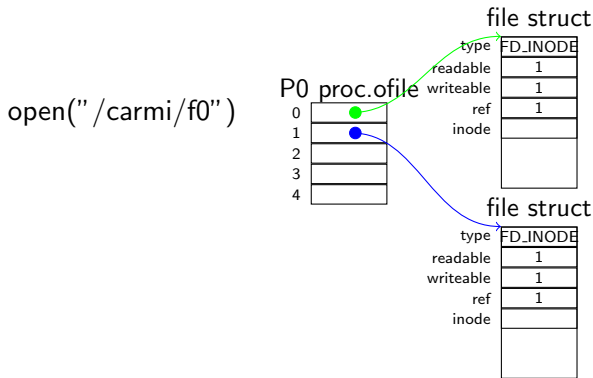
0	
1	
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ofile and file structures relation

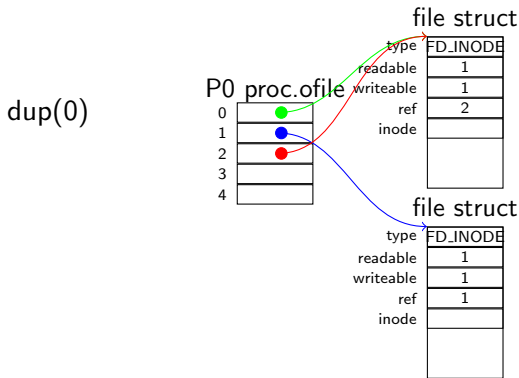
`open("/carimi/f0")`



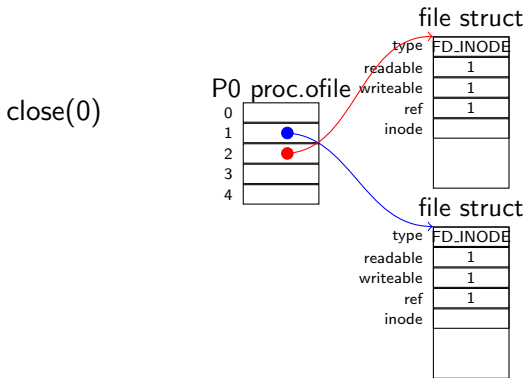
ofile and file structures relation



ofile and file structures relation

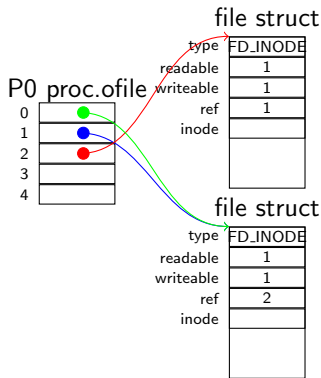


ofile and file structures relation



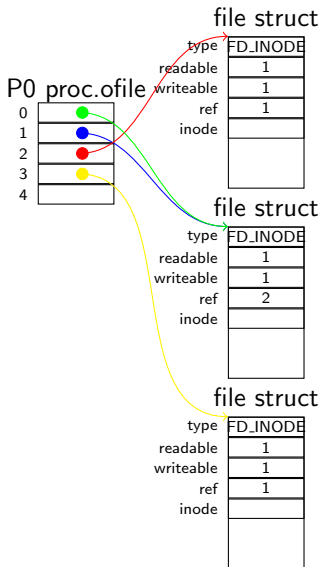
ofile and file structures relation

dup(1)



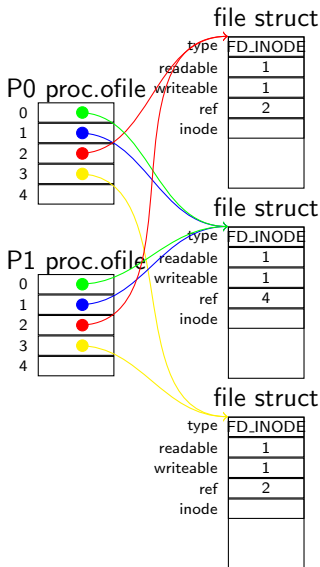
ofile and file structures relation

open("/console")



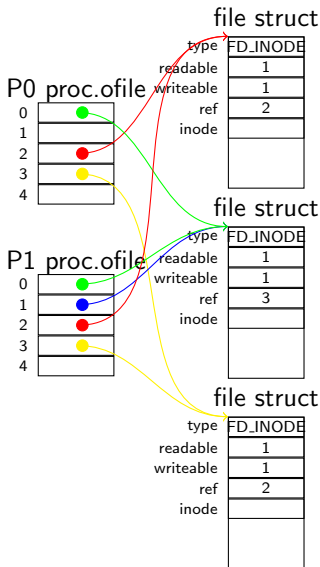
ofile and file structures relation

fork()

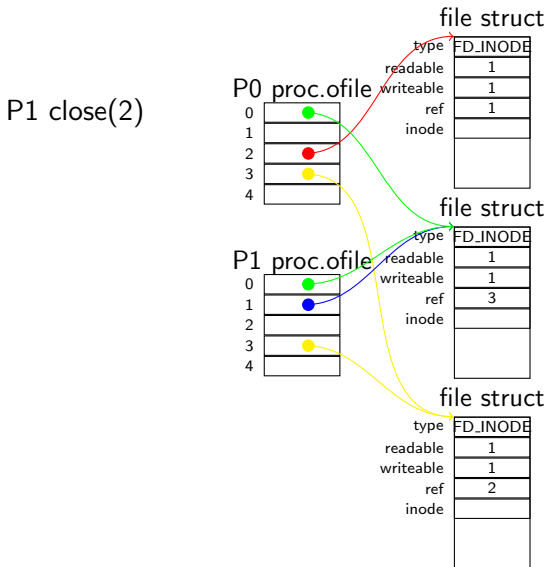


ofile and file structures relation

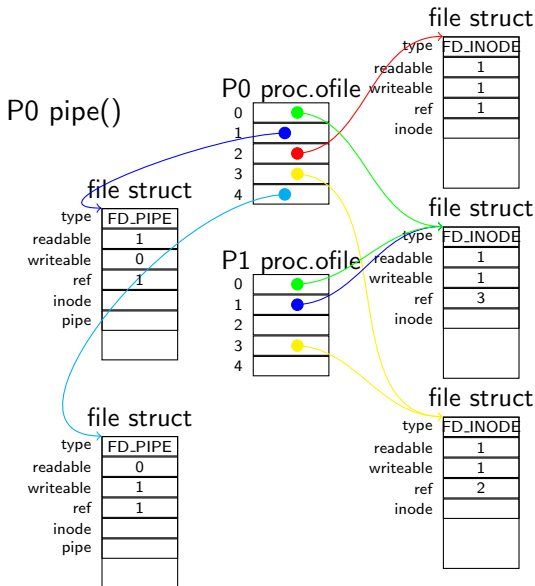
P0 close(1)



ofile and file structures relation



ofile and file structures relation



I/O subsystems

- FD_PIPE.
- FD_INODE:
 - T_FILE.
 - T_DIR.
 - T_DEV.

Each I/O subsystem is defined by a structure and a set of operations.

FD_PIPE

```
6762 struct pipe {  
    struct spinlock lock;  
    char data[PIPESIZE];  
    uint nread; // number of bytes read  
    uint nwrite; // number of bytes written  
    int readopen; // read fd is still open  
    int writeopen; // write fd is still open  
};
```

- pipalloc.
- pipeclose.
- piperead.
- pipewrite.

FD_INODE

```
4162 struct inode {  
    uint dev; // Device number  
    uint inum; // Inode number  
    int ref; // Reference count  
    struct sleeplock lock; // protects everything below  
    int valid;  
  
    short type; // copy of disk inode  
    short major;  
    short minor;  
    short nlink;  
    uint size;  
    uint addrs[NDIRECT+1];  
};
```

FD_INODE methods

Listing 1: T_FILE or T_DIR

```
namei  
create  
ilock  
readi  
writei  
stati  
iunlock  
iput
```

Listing 2: T_DEV (example)

```
consoleread  
consolewrite
```

System calls referencing the file layer

- `sys_dup`.
- `sys_read`.
- `sys_write`.
- `sys_fstat`.
- `sys_close`.

file layer functions used by fd system calls

```
struct file *filedup(struct file *f)
```

```
fileread(struct file *f, char *buf, int len);
```

```
filewrite(struct file *f, char *buf, int len);
```

```
filestat(struct file *f, struct stat *s);
```

```
fileclose(struct file *f);
```

fdalloc: Getting an ofile slot

- fdalloc returns the minimally numbered free slot.

```
6103 static int fdalloc(struct file *f) {  
    int fd;  
  
    for (fd = 0; fd < NOFILE; fd++) {  
        if (myproc()->ofile[fd] == 0) {  
            myproc()->ofile[fd] = f;  
            return fd;  
        }  
    }  
    return -1;  
}
```

sys_dup

```
6118 sys_dup(void) {  
    struct file *f;  
    int fd;  
  
    if (argfd(0, 0, &f) < 0)  
        return -1;  
    if ((fd=falloc(f)) < 0)  
        return -1;  
    filedup(f);  
    return fd;  
}
```

sys_read

```
6132 int sys_read(void) {  
    struct file *f;  
    int n;  
    char *p;  
  
    if (argfd(0, 0, &f) < 0 || argint(2, &n) < 0 ||  
        argptr(1, &p, n) < 0)  
        return -1;  
    return fileread(f, p, n);  
}
```

sys_write

```
6151 int sys_write(void) {  
    struct file *f;  
    int n;  
    char *p;  
  
    if (argfd(0, 0, &f) < 0 || argint(2, &n) < 0 ||  
        argptr(1, &p, n) < 0)  
        return -1;  
    return filewrite(f, p, n);  
}
```

sys_fstat

```
6176 int sys_fstat(void) {  
    struct file *f;  
    struct stat *st;  
  
    if (argfd(0, 0, &f) < 0 || argptr(1, (void*)&st,  
        sizeof(*st)) < 0)  
        return -1;  
    return filestat(f, st);  
}
```

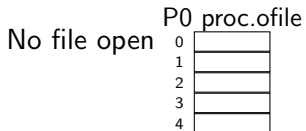
sys_close

```
6163 int sys_close(void) {  
    int fd;  
    struct file *f;  
  
    if (argfd(0, &fd, &f) < 0)  
        return -1;  
    myproc()->ofile[fd] = 0;  
    fileclose(f);  
    return 0;  
}
```

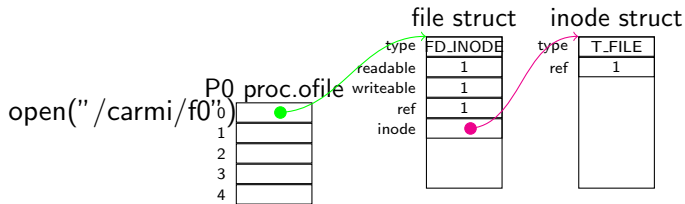
fie layer implementation:

- filedup.
- fileread.
- filewrite.
- filestat.
- fileclose.

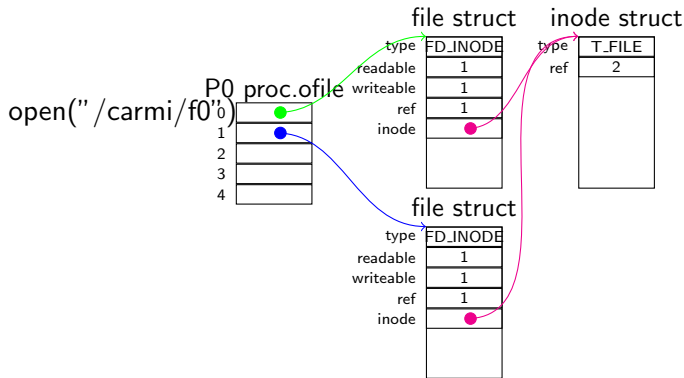
ofile/file/inode/pipe structures relation



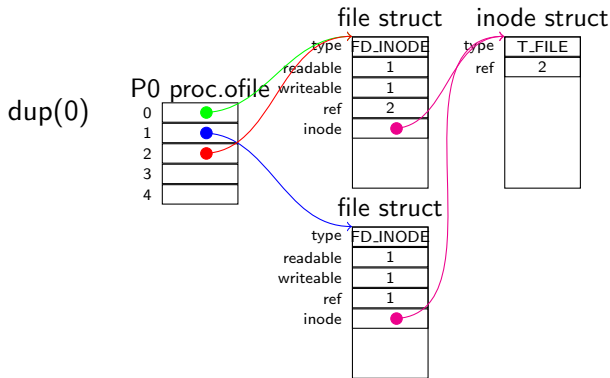
ofile/file/inode/pipe structures relation



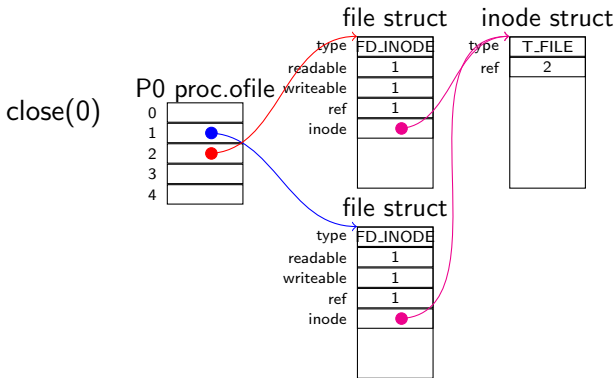
ofile/file/inode/pipe structures relation



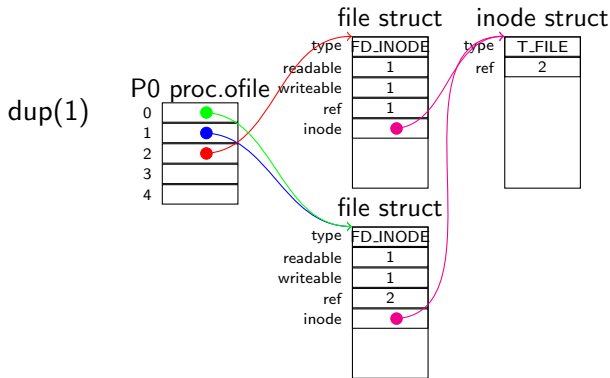
ofile/file/inode/pipe structures relation



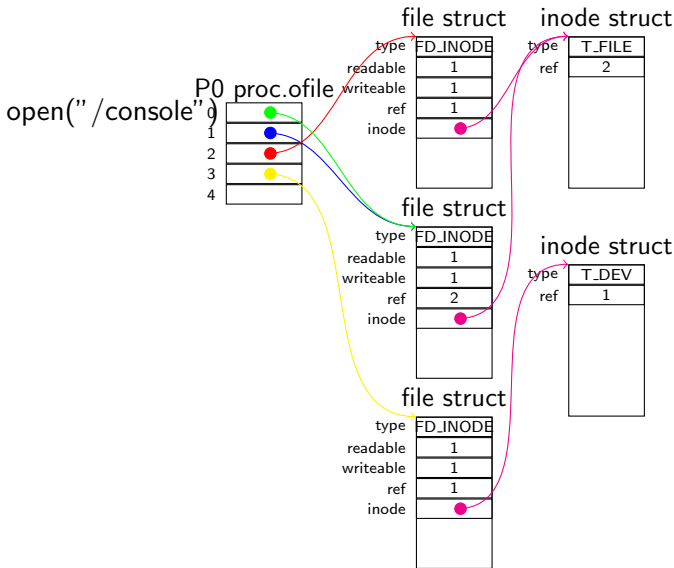
ofile/file/inode/pipe structures relation



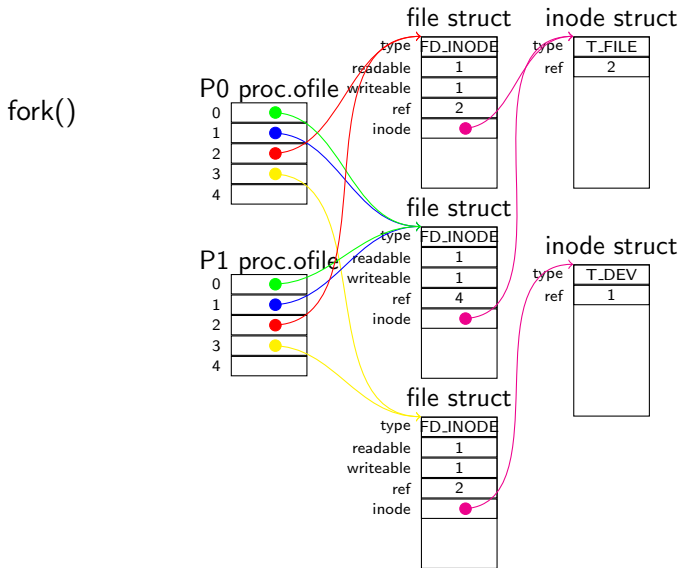
ofile/file/inode/pipe structures relation



ofile/file/inode/pipe structures relation

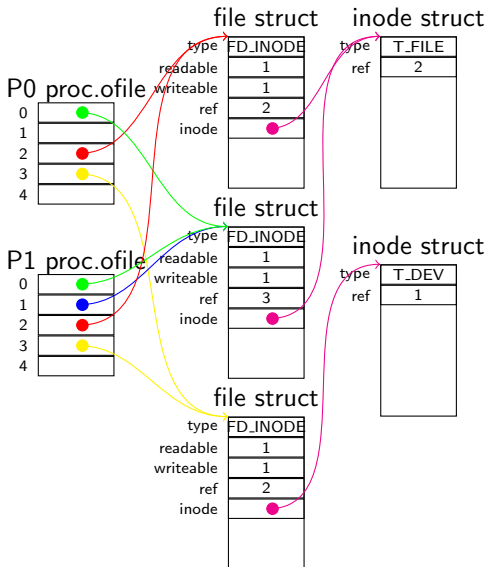


ofile/file/inode/pipe structures relation



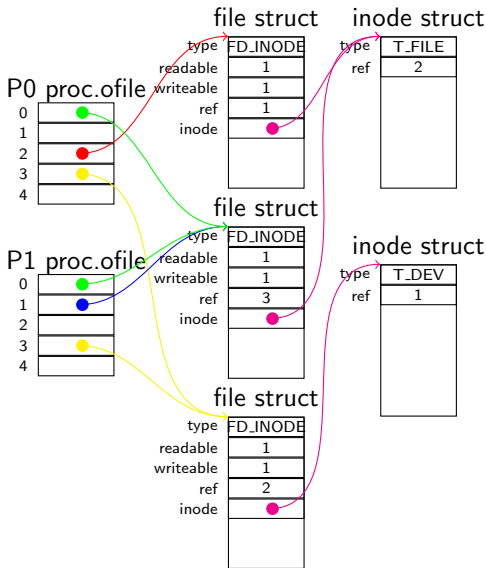
ofile/file/inode/pipe structures relation

P0 close(1)

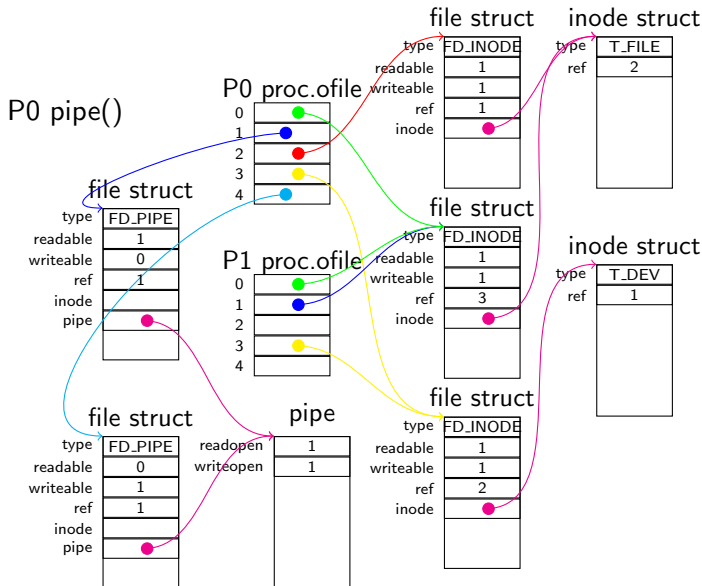


ofile/file/inode/pipe structures relation

P1 close(2)



ofile/file/inode/pipe structures relation



file layer dispatching

The file layer dispatches to one of the following subsystems:

1. pipe.
2. inode.

functions used, from pipe subsystem and inode layer

Pipe subsystem:

- `piperead(pipe *p, char *addr, int len);`
- `pipewrite(pipe *p, char *addr, int len);`
- `pipeclose(pipe *, int writeside);`

inode subsystem:

- `ilock(inode *ip);`
- `iunlock(inode *ip);`
- `readi(inode *ip, char *adr, int len);`
- `writei(inode *ip, char *adr, int len);`
- `iput(inode *ip);`
- `stati(inode *ip, stat *stat);`
- `begin_trans();`
- `commit_trans();`

filedup

```
5902 struct file *filedup(struct file *f) {  
    acquire(&ftable.lock);  
    if (f->ref < 1)  
        panic("filedup");  
    f->ref++;  
    release(&ftable.lock);  
    return f;  
}
```

fileread explanation

- According to the type, fileread delegates the read to one of:
 - piperead.
 - readi.
- For FD_INODE type the file position is handled.

fileread

```
5965 int fileread(struct file *f, char *addr, int n) {  
    int r;  
  
    if (f->readable == 0)  
        return -1;  
    if (f->type == FD_PIPE)  
        return piperead(f->pipe, addr, n);  
    if (f->type == FD_INODE) {  
        ilock(f->ip);  
        if ((r = readi(f->ip, addr, f->off, n)) > 0)  
            f->off += r;  
        iunlock(f->ip);  
        return r;  
    }  
    panic("fileread");  
}
```


filewrite logic

- According to the type, filewrite delegates the write to one of:
 - `pipewrite`.
 - `writei`.
- For `FD_INODE` type the file position is handled.
- The logic around `writei` is due to the limited log file size.

filewrite

6002

```
int filewrite(struct file *f, char *addr, int n) {
    if (f->writable == 0) return -1;
    if (f->type == FD_PIPE) return pipewrite(f->pipe, addr,
    if (f->type == FD_INODE) {
        int max = ((LOGSIZE-1-1-2) / 2) * 512;
        for (int i=0; i < n; ) {
            int n1 = n - i;
            if (n1 > max) n1 = max;
            begin_op(); ilock(f->ip);
            if ((r = writei(f->ip, addr + i, f->off, n1)) > 0)
                f->off += r;
            iunlock(f->ip); end_op();
            if (r < 0) break;
            if (r != n1) panic("short_filewrite");
            i += r;
        }
        return i == n ? n : -1;
    }
    panic("filewrite");
}
```

close logic

- Reference count is updated.
- If reference count drops to zero we delegate to one of:
 - `pipeclose`.
 - `iput`.
- Note due to `iput` we have to release `asquaire`, hence the need to copy the file structure.

filestat

```
5952 int filestat(struct file *f, struct stat *st) {  
    if (f->type == FD_INODE) {  
        ilock(f->ip);  
        stati(f->ip, st);  
        iunlock(f->ip);  
        return 0;  
    }  
    return -1;  
}
```

fileclose

```
5914 void fileclose(struct file *f) {  
    acquire(&ftable.lock);  
    if (f->ref < 1) panic("fileclose");  
    if (--f->ref > 0) {  
        release(&ftable.lock);  
        return;  
    }  
    struct ff = *f;  
    f->ref = 0;  
    f->type = FD_NONE;  
    release(&ftable.lock);  
    if (ff.type == FD_PIPE)  
        pipeclose(ff.pipe, ff.writable);  
    else if (ff.type == FD_INODE) {  
        begin_op();    iput(ff.ip);    end_op();  
    }  
}
```

file structures pool

- There is no dynamic allocation for file structures.
- There is a vector with all file structures, protected with a spinlock.
- A slot is free if the ref field is zero.

```
5863 struct {  
    struct spinlock lock;  
    struct file file[NFILE];  
} ftable;
```

- Allocation is done in `sys_open()` and `sys_pipe()`.

filealloc: Allocating file struct from pool

```
5876 struct file *filealloc(void) {  
    struct file *f;  
  
    acquire(&ftable.lock);  
    for (f = ftable.file; f < ftable.file + NFILE; f++) {  
        if (f->ref == 0) {  
            f->ref = 1;  
            release(&ftable.lock);  
            return f;  
        }  
    }  
    release(&ftable.lock);  
    return 0;  
}
```

Who sets values in the file structure

One of:

- `sys_open()`, by calling the inode layer.
- `sys_pipe()`, by calling the pipe layer.

pipe logic

- Delegate to `pipealloc`.
- Hide the returned file pointers in the `ofile` vector.
- (I tend to think `pipealloc` should just returned pipe pointer and it is our function job to allocate the file structure.

sys_pipe

```
6551 int sys_pipe(void) {  
    int *fd;  
    struct file *rf, *wf;  
    int fd1;  
    if (argptr(0, (void*)&fd, 2*sizeof(fd[0])) < 0) return  
    if (pipealloc(&rf, &wf) < 0) return -1;  
    int fd0 = -1;  
    if((fd0=fdalloc(rf)) < 0 || (fd1=fdalloc(wf)) < 0) {  
        if (fd0 >= 0)  
            myproc()->ofile[fd0] = 0;  
        fileclose(rf);  
        fileclose(wf);  
        return -1;  
    }  
    fd[0] = fd0;  
    fd[1] = fd1;  
    return 0;  
}
```