ECS 150 - Project 4

Joël Porquet

UC Davis - Spring Quarter 2017

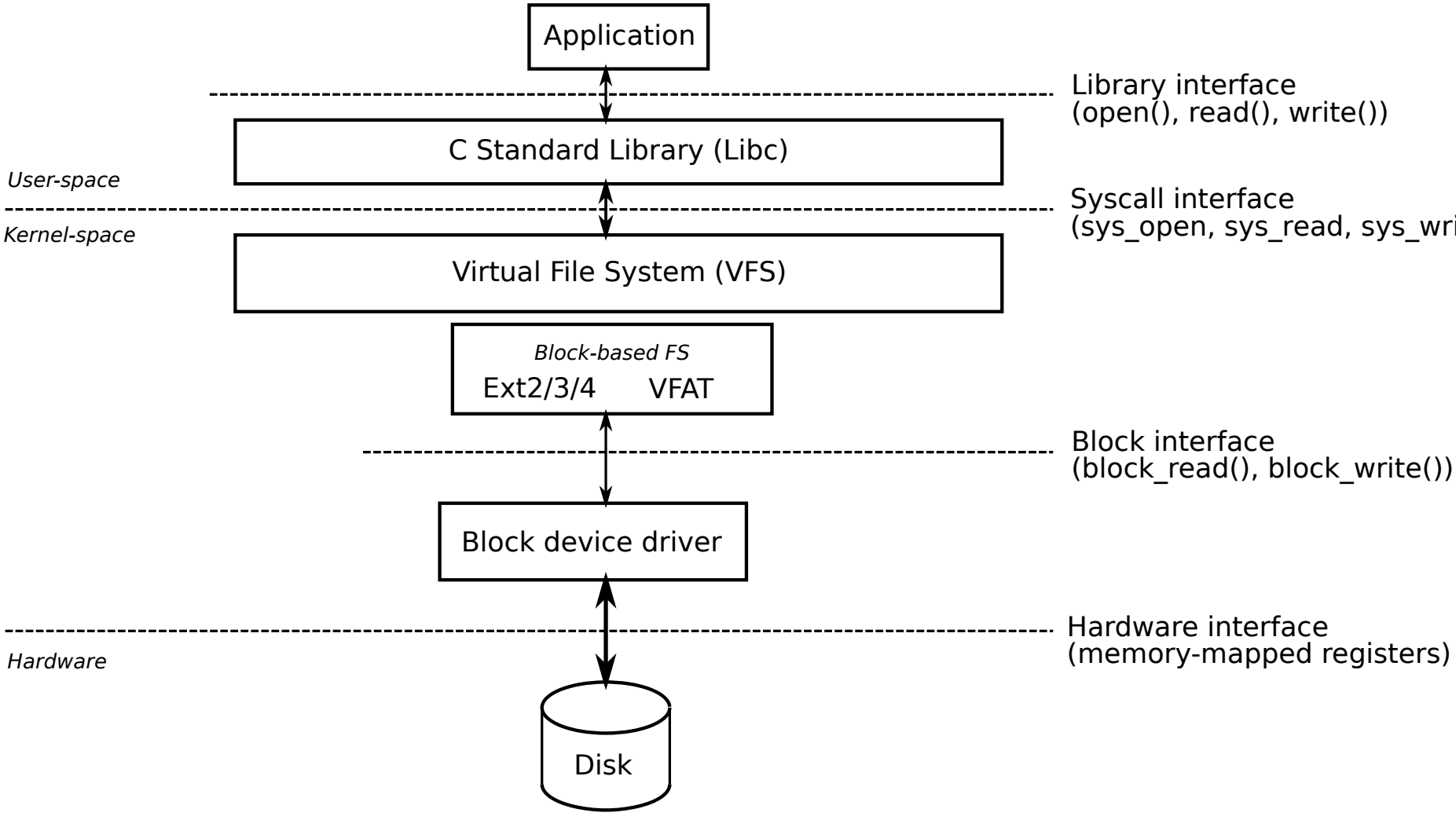
Goal

The goal of this project is to implement the support for a very simple *file system*: **ECS150-FS**.

Applications will have the possibility to read/write files from/to this file system.

```
int fs_mount(const char *diskname);            /* Mounting the file system */
int fs_umount(void);
int fs_info(void);

int fs_create(const char *filename);           /* Creating files */
int fs_delete(const char *filename);
int fs_ls(void);

int fs_open(const char *filename);             /* Opening files */
int fs_close(int fd);
int fs_stat(int fd);
int fs_lseek(int fd, size_t offset);

int fs_write(int fd, void *buf, size_t count); /* Modifying files */
int fs_read(int fd, void *buf, size_t count);
```

Big picture: reality



Problem: the vast majority the file system management is in kernel mode!

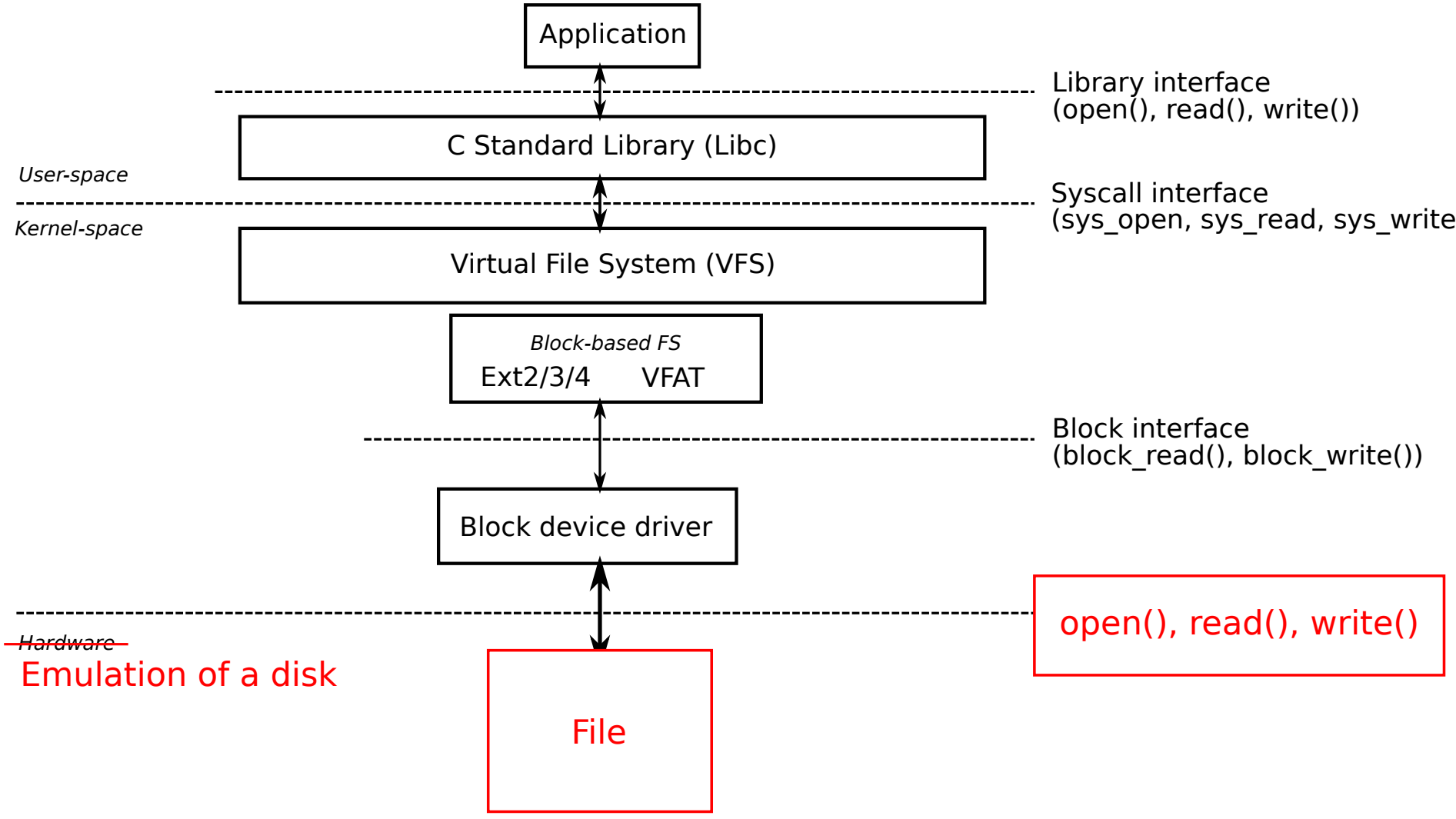
Emulating a disk with a file

A disk, or a partition on a disk, merely represents contiguous binary data storage.

How can we easily emulate any size of contiguous data?... With a file!

```
$ dd if=/dev/zero of=emulated_disk_space bs=4K count=8192

$ ls -l emulated_disk_space
-rw-r--r-- 1 joel joel 32M 2017-03-01 13:52 emulated_disk_space

$ xxd emulated_disk_space
00000000: 0000 0000 0000 0000 0000 0000 0000 0000  ................
00000010: 0000 0000 0000 0000 0000 0000 0000 0000  ................
00000020: 0000 0000 0000 0000 0000 0000 0000 0000  ................
00000030: 0000 0000 0000 0000 0000 0000 0000 0000  ................
00000040: 0000 0000 0000 0000 0000 0000 0000 0000  ................
00000050: 0000 0000 0000 0000 0000 0000 0000 0000  ................
00000060: 0000 0000 0000 0000 0000 0000 0000 0000  ................
00000070: 0000 0000 0000 0000 0000 0000 0000 0000  ................
00000080: 0000 0000 0000 0000 0000 0000 0000 0000  ................
00000090: 0000 0000 0000 0000 0000 0000 0000 0000  ................
...
01fffff0: 0000 0000 0000 0000 0000 0000 0000 0000  ................
```

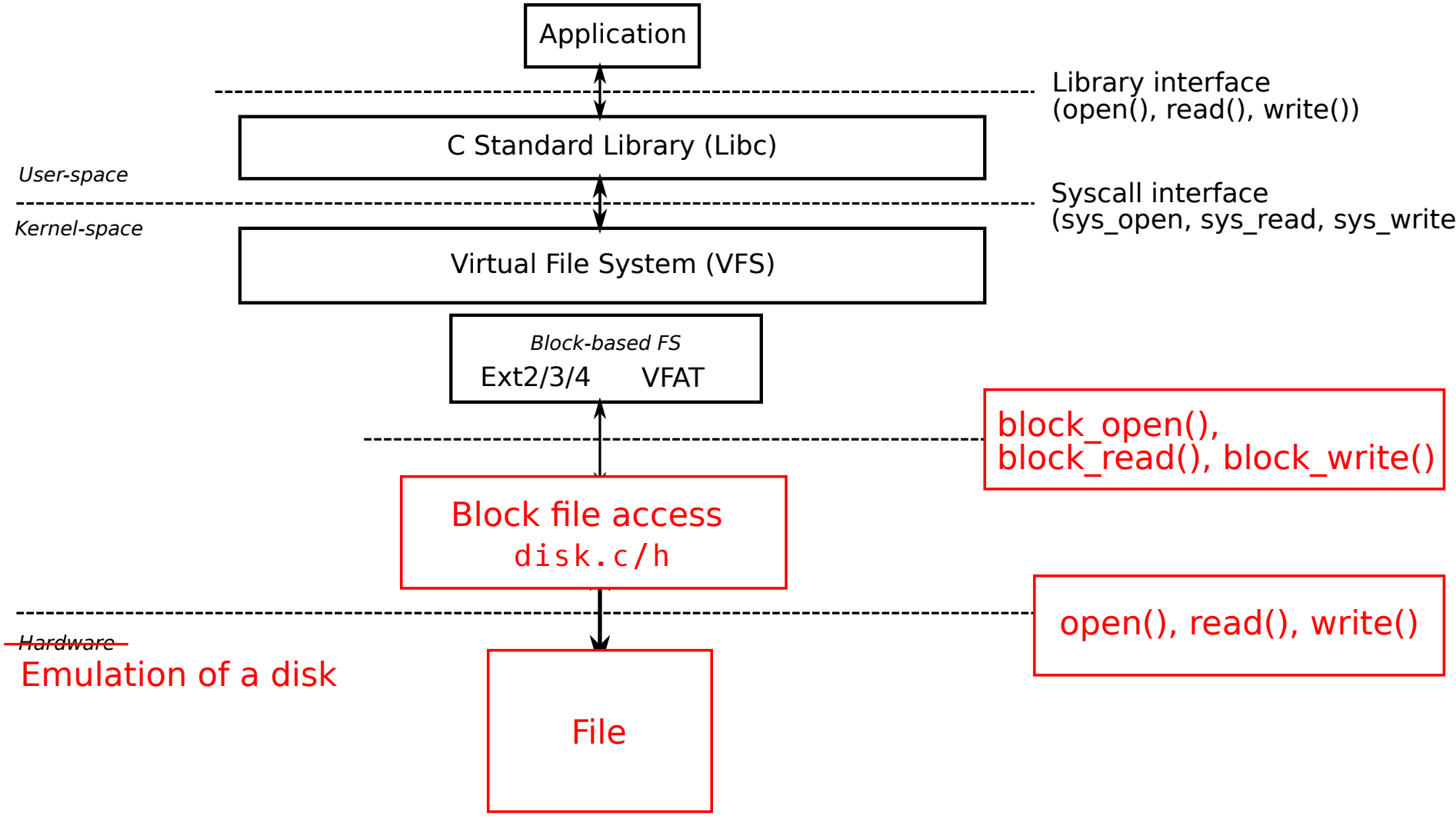
Big picture: replacing the disk



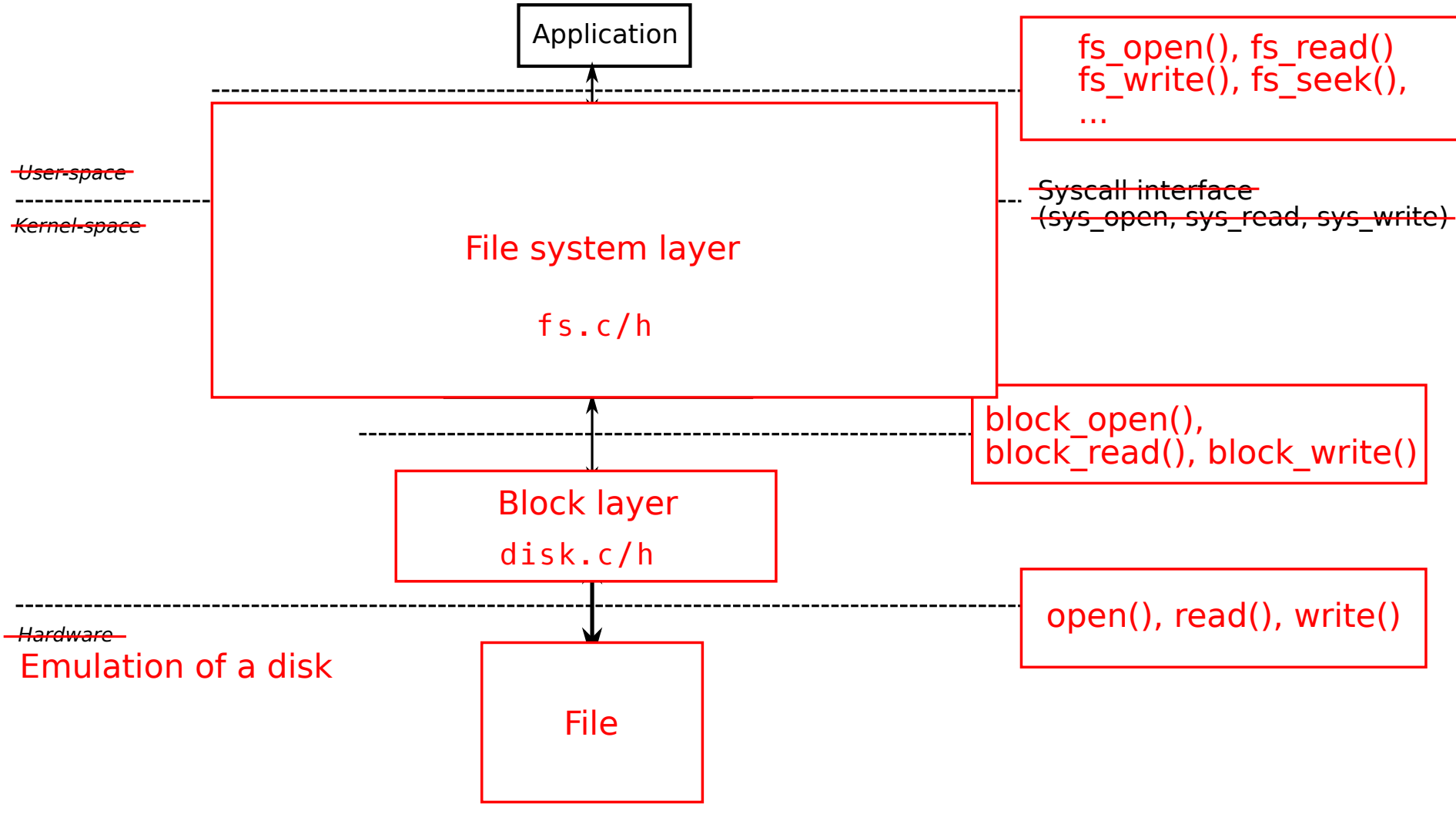
Accessing a file by blocks

```c
#define BLOCK_SIZE 4096

int fd;

int block_open(char *disk_filename)
{
    fd = open(disk_filename, O_RDWR);
}

int block_read(size_t block_nr, void *buf)
{
    lseek(fd, block_nr * BLOCK_SIZE);
    read(fd, buf, BLOCK_SIZE);
}

int block_write(size_t block_nr, void *buf)
{
    lseek(fd, block_nr * BLOCK_SIZE);
    write(fd, buf, BLOCK_SIZE);
}
```

Big picture: replacing the block device driver



Big picture: replacing the libc/vfs/fs drivers



ECS150-FS

Layout

Each block is 4096 bytes.

ECS150-FS

Layout

Each block is 4096 bytes.

Example with file system embedding 8192 data blocks:

- Amount of data blocks: 8192
- Number of blocks for FAT: (8192 * 2) / 4096 = 4
- Total amount of blocks: 1 + 4 + 1 + 8192 = 8198
- Root directory block index: 5
- Data block start index: 6

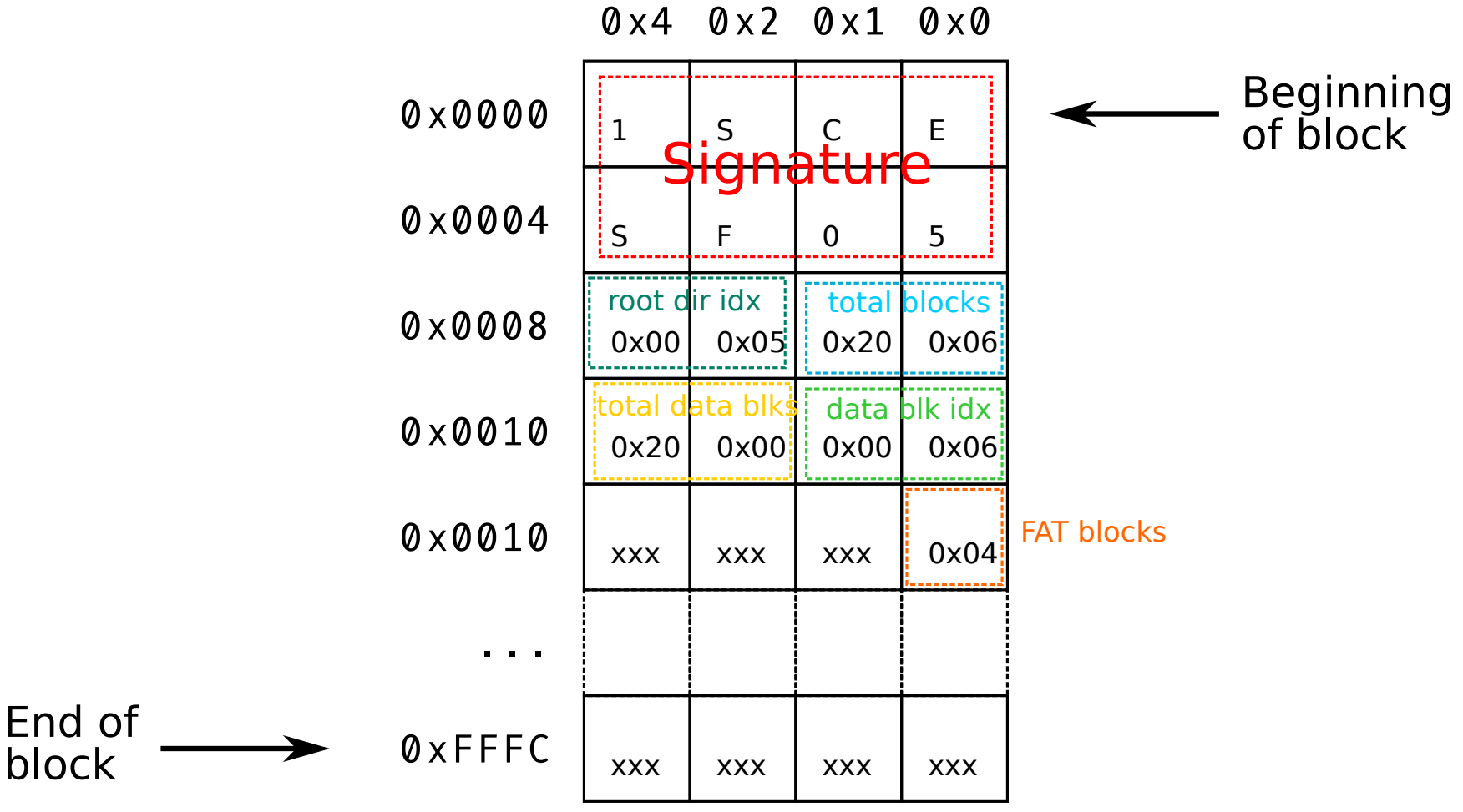
ECS150-FS

Superblock: high-level layout

Offset	Length (bytes)	Description
0x00	8	Signature (must be equal to "ECS150FS")
0x08	2	Total amount of blocks of virtual disk
0x0A	2	Root directory block index
0x0C	2	Data block start index
0x0E	2	Amount of data blocks
0x10	1	Number of blocks for FAT
0x11	4079	Unused/Padding

ECS150-FS

Superblock: at byte level



ECS150-FS

Superblock: C data structure

```
struct superblock{
    ???
};
```

Key points:

- The integer types must match exactly those of the specification
- Careful about alignment

Digression

Integer types

- Is `char` always 8 bits?
- Is `short int` always 16 bits?
- Is `int` always 32 bits?
- Etc.

Digression

Integer types

- Is `char` always 8 bits?
- Is `short int` always 16 bits?
- Is `int` always 32 bits?
- Etc.

Type	Specification
char	"Smallest addressable unit of the machine that can contain basic character set"
short	"Capable of containing *at least* the [−32767, +32767] range; thus, it is *at least* 16 bits in size."
int	"Capable of containing *at least* the [−32767, +32767] range; thus, it is *at least* 16 bits in size."
long	"Capable of containing *at least* the [−2147483647, +2147483647] range; thus, it is *at least* 32 bits in size."

How to guarantee a certain size then?

Digression

Integer types

Use integer types that have exact widths:

```
#include <stdint.h>

int8_t
int16_t
int32_t

uint8_t
uint16_t
uint32_t
```

Digression

Structure alignment

Structure naturally packed:

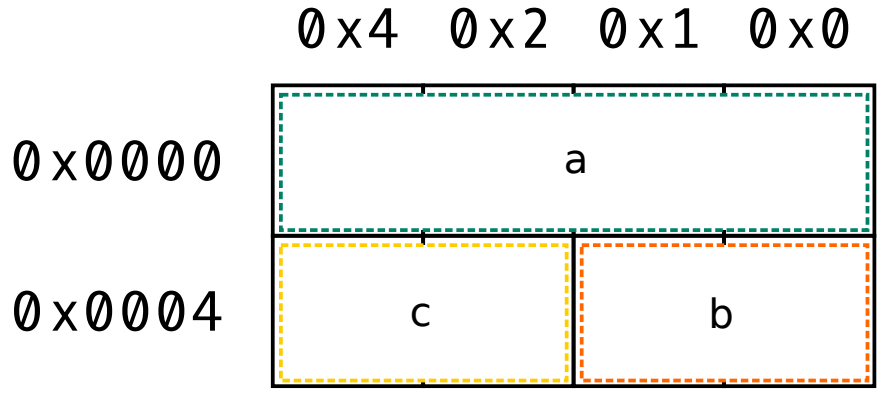
```
struct packed_s
{
  int32_t   a;
  int16_t   b;
  int16_t   c;
};
```

Digression

Structure alignment

Structure naturally packed:

```
struct packed_s
{
  int32_t   a;
  int16_t   b;
  int16_t   c;
};
```



Digression

Structure alignement

Structure fields have to aligned…

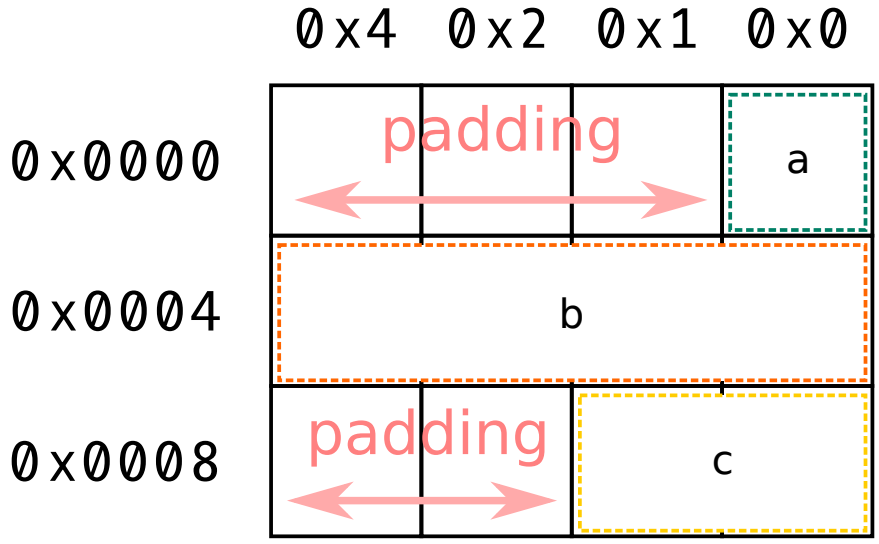
```
struct padded_s
{
  int8_t    a;
  int32_t   b;
  int16_t   c;
};
```

Digression

Structure alignement

Structure fields have to aligned...

```
struct padded_s
{
  int8_t    a;
  int32_t   b;
  int16_t   c;
};
```



Digression

Structure alignement

Force compiler to ignore alignment

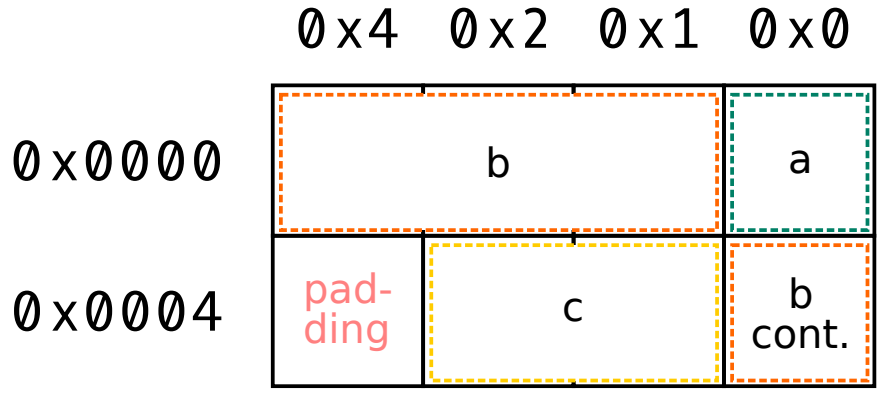
```
struct packed_s
{
  int8_t    a;
  int32_t   b;
  int16_t   c;
} __attribute__((packed));
```

Digression

Structure alignement

Force compiler to ignore alignment

```
struct packed_s
{
  int8_t    a;
  int32_t   b;
  int16_t   c;
} __attribute__((packed));
```



Digression

Structure alignement

Conclusion: when transposing a specification into data structures, always use packing!

- File format
- Network protocol
- Etc.

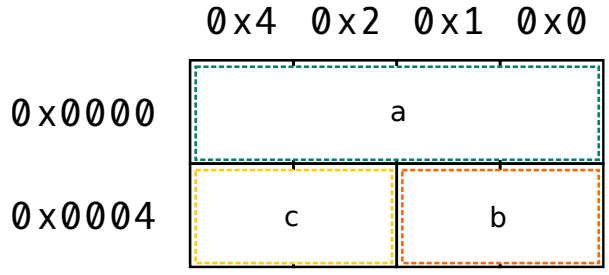
Digression

Reading data structures from a file (or buffer)

Reading data from a file (or whatever blob of data), for which I know the layout. It can easily be type-casted into a structure instance.

```
struct packed_s
{
  int32_t   a;
  int16_t   b;
  int16_t   c;
};
```

```
char* buf[8];

fd = open("file", O_RDWR);
read(bd, buf, 8);

struct packed_s *s = buf;
s->a = 0;

/* or simply */
struct packed_s obj;
read(bd, &obj, sizeof(obj));
obj.a = 0;
```



ECS150-FS

FAT

- Big array of 16-bit entries: linked-list of data blocks composing a file
- Three possible values for each entry:
  - `0`: corresponding data block is available
  - `FAT_EOC`: last data block of a file
  - `!=0 && !=FAT_EOC`: index of next data block

ECS150-FS

FAT

- Big array of 16-bit entries: linked-list of data blocks composing a file
- Three possible values for each entry:
  - `0`: corresponding data block is available
  - `FAT_EOC`: last data block of a file
  - `!=0 && !=FAT_EOC`: index of next data block

Root directory

1 block, 16-byte entry per file: 128 entries total

Offset	Length (bytes)	Description
0x00	16	Filename (including NULL character)
0x10	4	Size of the file (in bytes)
0x14	2	Index of the first data block
0x16	10	Unused/Padding

ECS150-FS

Example: big file, small file, empty file

<test1, 25000, 2>,
<test2, 5000, 1>,
<test3, 0, FAT_EOC>
...

FAT

0	
1	8
2	3
3	4
4	5
5	6
6	7
7	0xFFFF
8	0xFFFF
9	0
10	0

Data blocks

0	
1	test2, block #0
2	test1, block #0
3	test1, block #1
4	test1, block #2
5	test1, block #3
6	test1, block #4
7	test1, block #5
8	test2, block #1
9	
10	

Implementation

Phase 1: Volume mounting

- `fs_mount()`: open the virtual disk, and read the metadata (superblock, fat, root directory)
- `fs_unmount()`: close virtual disk (make sure that virtual disk is up-to-date)
- `fs_info()`: show information about volume

Implementation

Phase 2: File creation/deletion

- `fs_create()`: Create a new file
  - Initially, size is 0 and pointer to first data block is `FAT_EOC`
- `fs_delete()`: Delete an existing file
  - Don't forget to free allocated data blocks
- `fs_ls()`: List all the existing files

Implementation

Phase 3: File descriptor operations

- `fs_open()`: initialize and return file descriptor
  - 32 file descriptors max
  - Can open same file multiple times
  - Contains file's offset (initially 0)
- `fs_close()`: close file descriptor
- `fs_seek()`: move file's offset
- `fs_stat()`: return file's size

None of these function should change the file system…

Implementation

Phase 4: File reading/writing

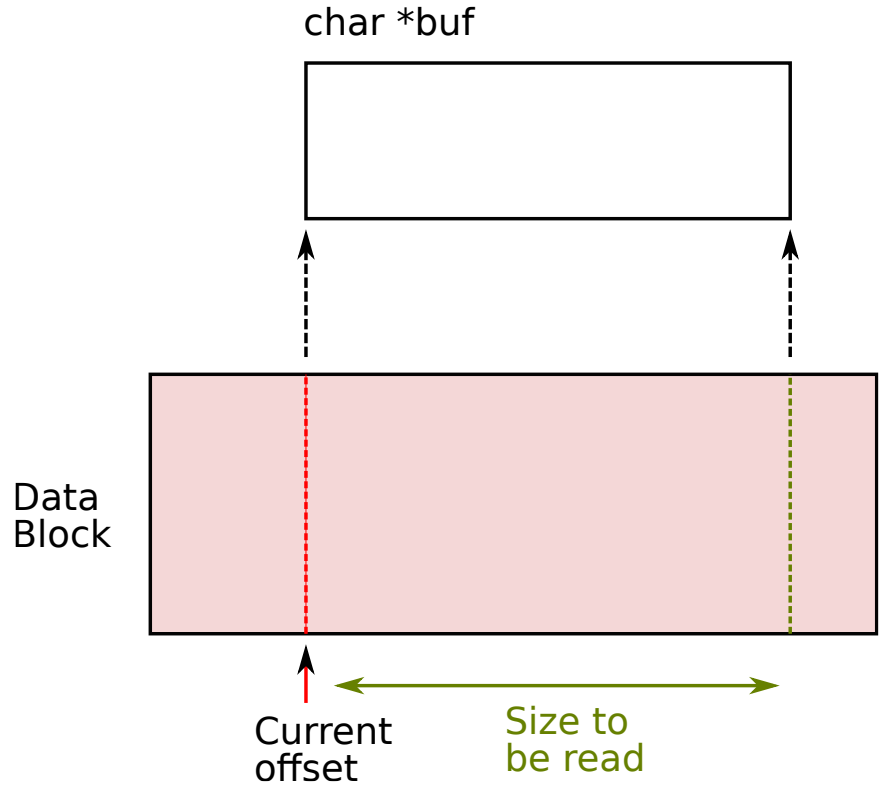
Most complicated phase: might take as much time as all the previous phases combined

- Allocation of new blocks must follow *first-fit* strategy (allocate first free data block from beginning of the FAT).
- Three difficulties:
  - Small operations
  - First/last block on big operations
  - Extending writes

Implementation

Small operation: example

- Current offset is in the middle of the file, not aligned on the beginning of a block
- The size of data to read is smaller than what's remaining in this block

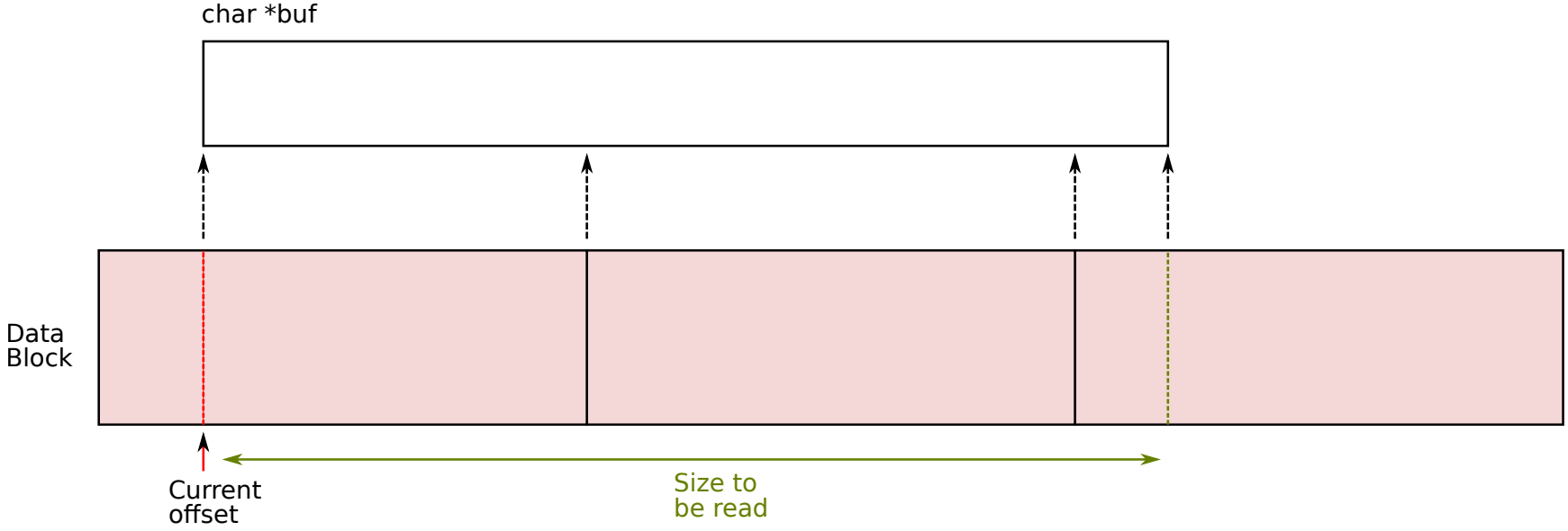


Might want to use a *bounce buffer*

Implementation

Big operation: example

- Current offset is in the middle of the file, not aligned on the beginning of a block
- The size to read spans multiple (non-consecutive) blocks
- The size of data to read is smaller than what's remaining in the last block

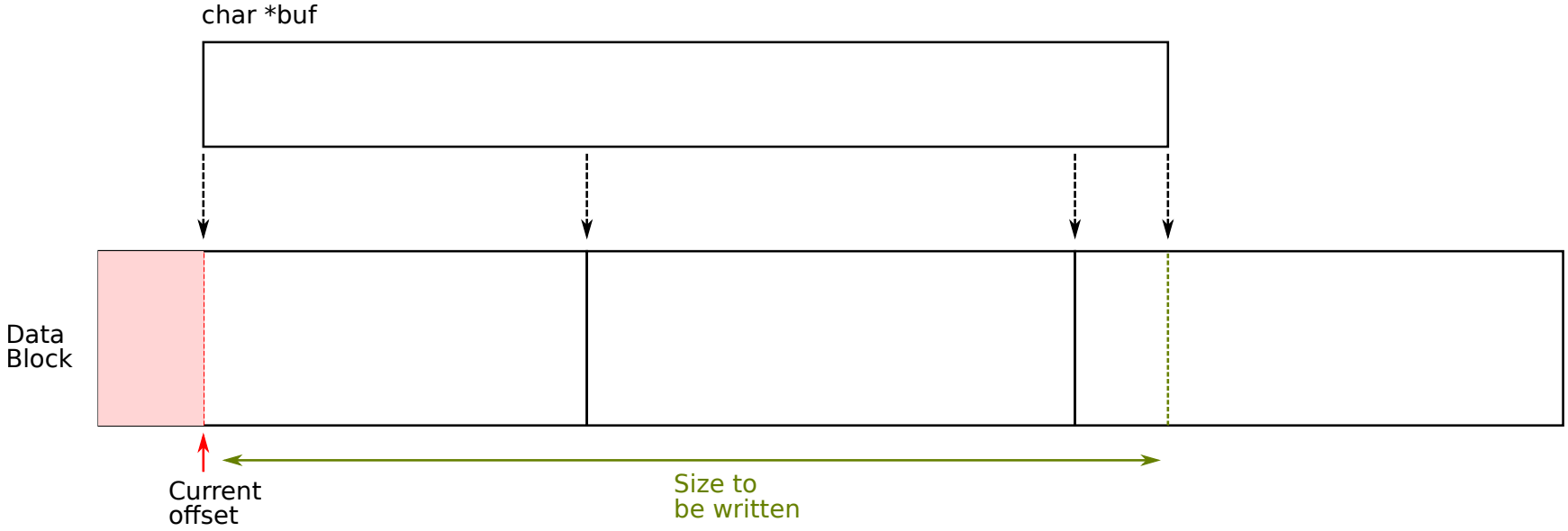


Mix of *bounce buffer* and direct copy

Implementation

Extending write: example

- Write more than what's currently allocated



Implementation

In short

- Think of all the cases: combination of file's offset, file's size, size to be read or written, etc.
- Come up with a way to handle all these combinations in the *most* generic way (ie not one function per case!)