F.A.T. File System

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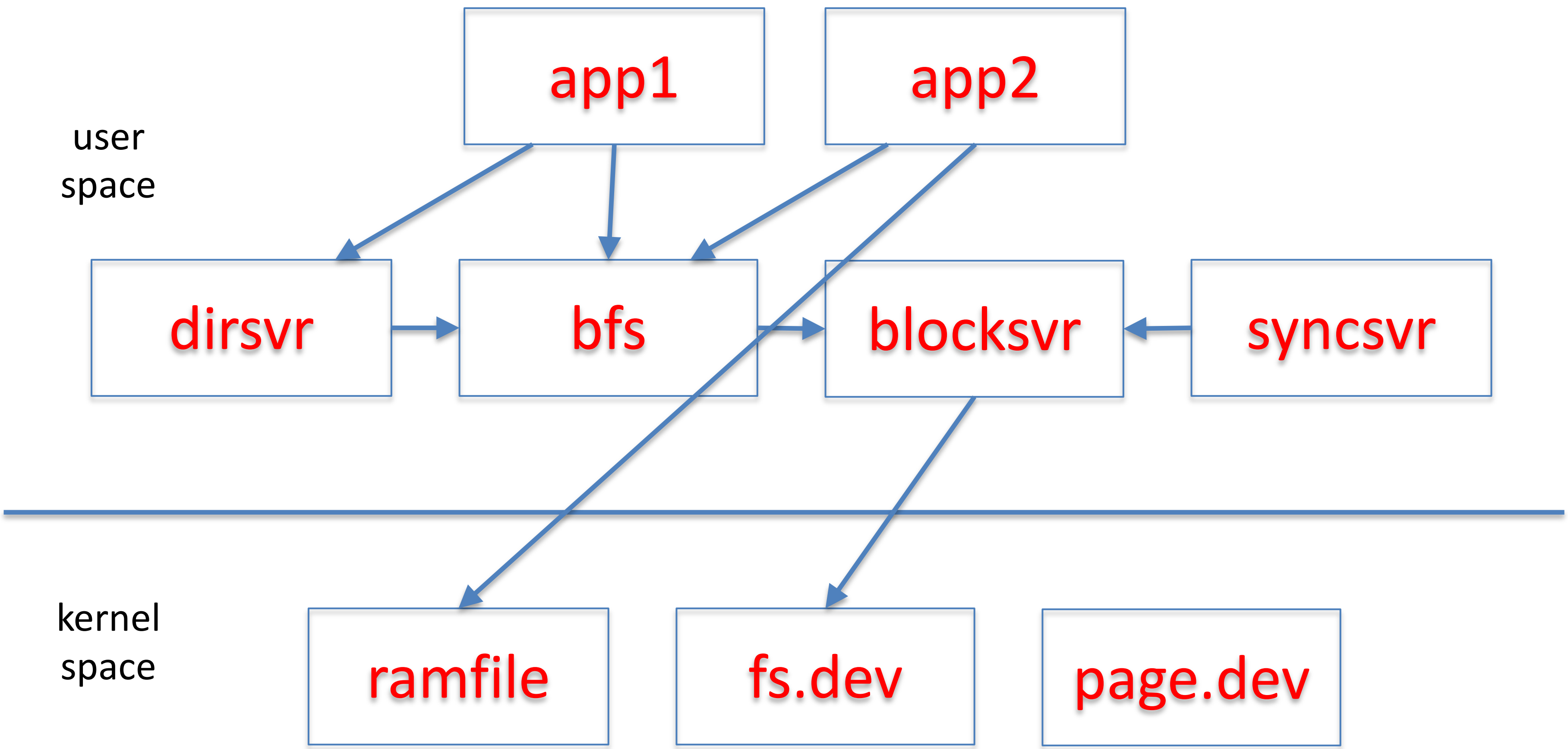
File System

- Mapping a file name to its content and metadata
  - A file may be stored in HDD, SSD, or RAMDISK
  - Metadata like permission, owner, etc

EGOS Storage Architecture



Block Store Abstraction

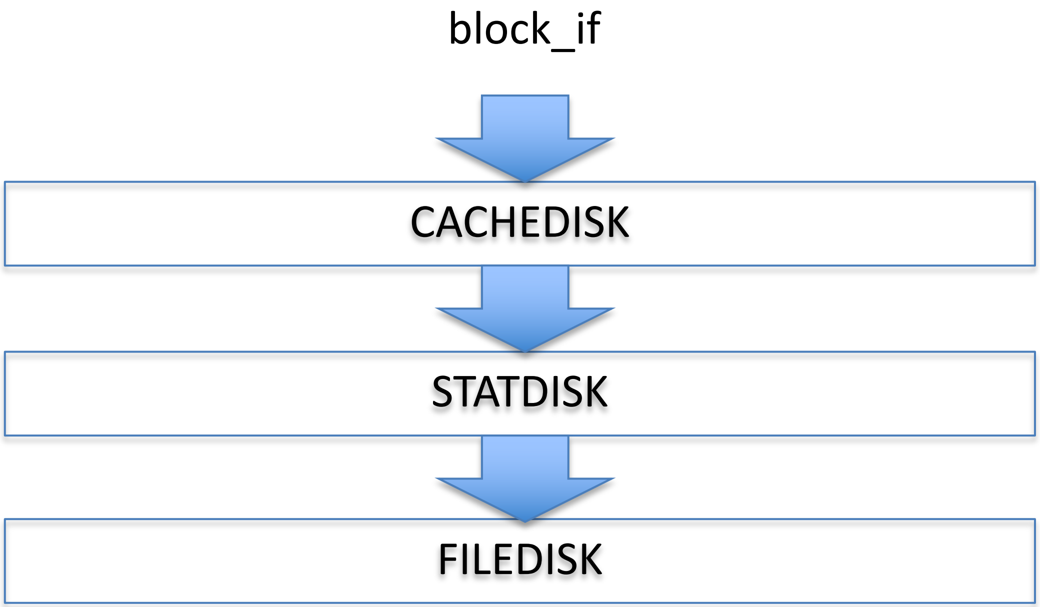
- A block store consists of a collection of *i-nodes*
- Each i-node is a finite sequence of *blocks*
- Simple interface:
  - block_t block
    - block of size BLOCK_SIZE
  - getninodes() → integer
    - returns the number of i-nodes on this block store
  - getsize(inode number) → integer
    - returns the number of of block on the given inode
  - setsize(inode number, nblocks)
    - set the number of blocks on the given inode
  - release()
    - give up reference to the block store

Block Store Abstraction, cont'd

- read(inode, block number) → block
  - returns the contents of the given block number
- write(inode, block number, block)
  - writes the block contents at the given block number
- sync(inode)
  - make sure all blocks are persistent
    - if inode == -1, then all blocks on all inodes

Block Stores can be Layered!

Each layer presents a block_if abstraction



keeps a cache of recently used blocks

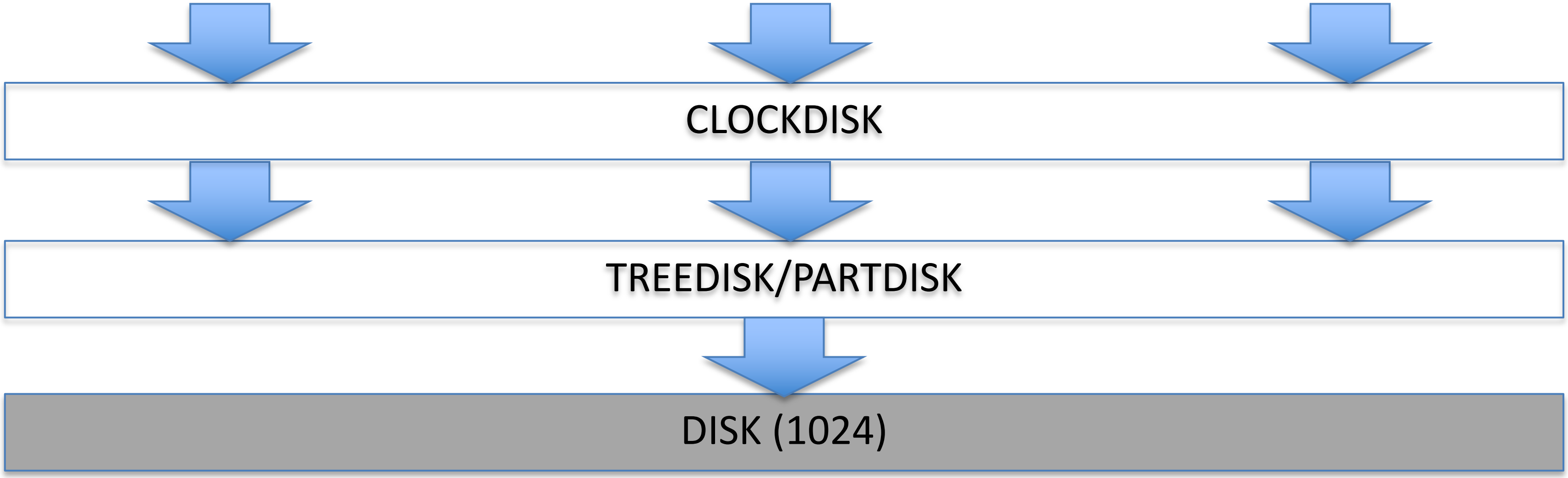
keeps track of #reads and #writes for statistics

keeps blocks in a Posix file

Multiplexing

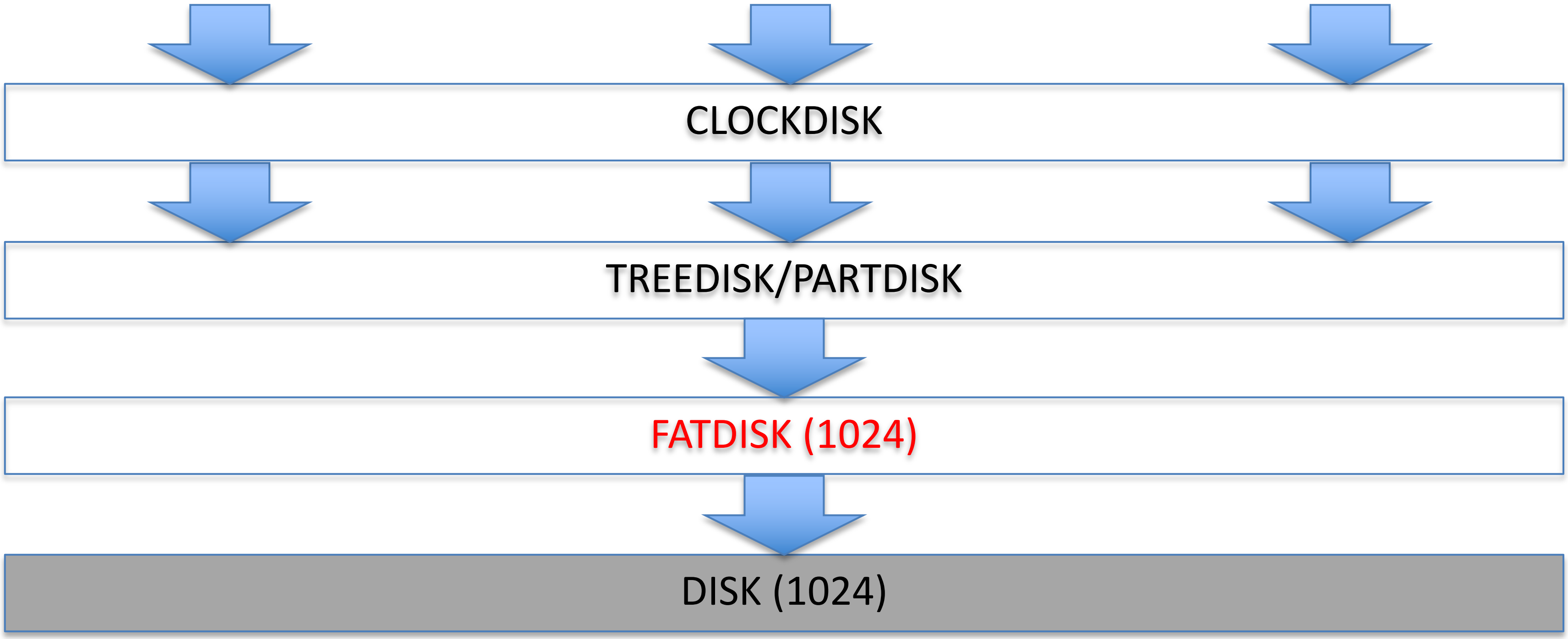
- A single block store can be “multiplexed”, offering multiple virtual block stores
- One way is simply partitioning the underlying block store into multiple disjoint sections
  - Treedisk
  - Partdisk

Partitioning



FAT file system

- Manage a disk using File Allocation Table



FAT file system

- Given an inode, our goal is to read all content (blocks) of that inode.
- All the information needed to locate the blocks belonging to an inode is **stored on disk**.

Linked List Allocation

Each file is stored as linked list of **blocks**

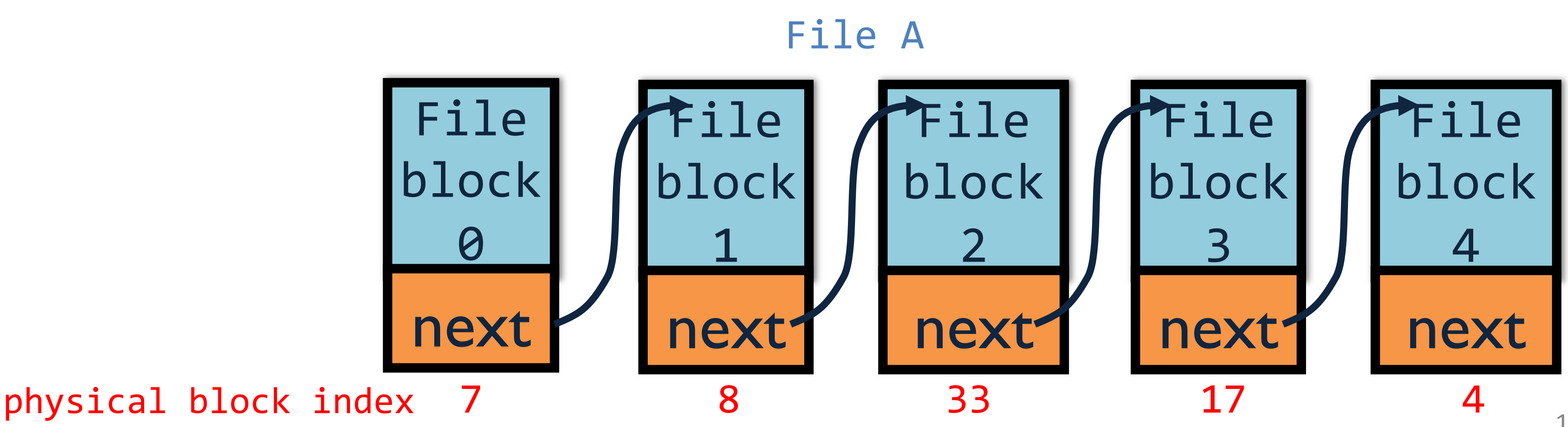
- First word of each block points to next block
- Rest of disk block is file data

+ Space Utilization: no space lost to external fragmentation

+ Simple: only need to find 1st block of each file

– Performance: random access is slow

– Implementation: blocks mix meta-data and data



File Allocation Table (FAT)

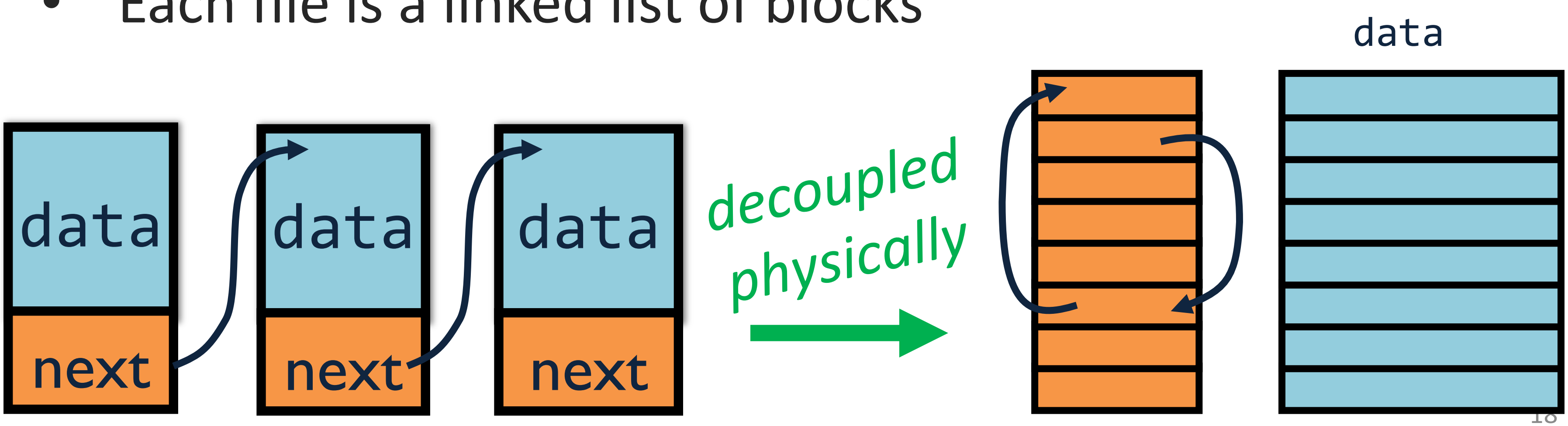
[late 70's]

Microsoft File Allocation Table

- originally: MS-DOS, early version of Windows
- today: still widely used (e.g., CD-ROMs, thumb drives, camera cards)

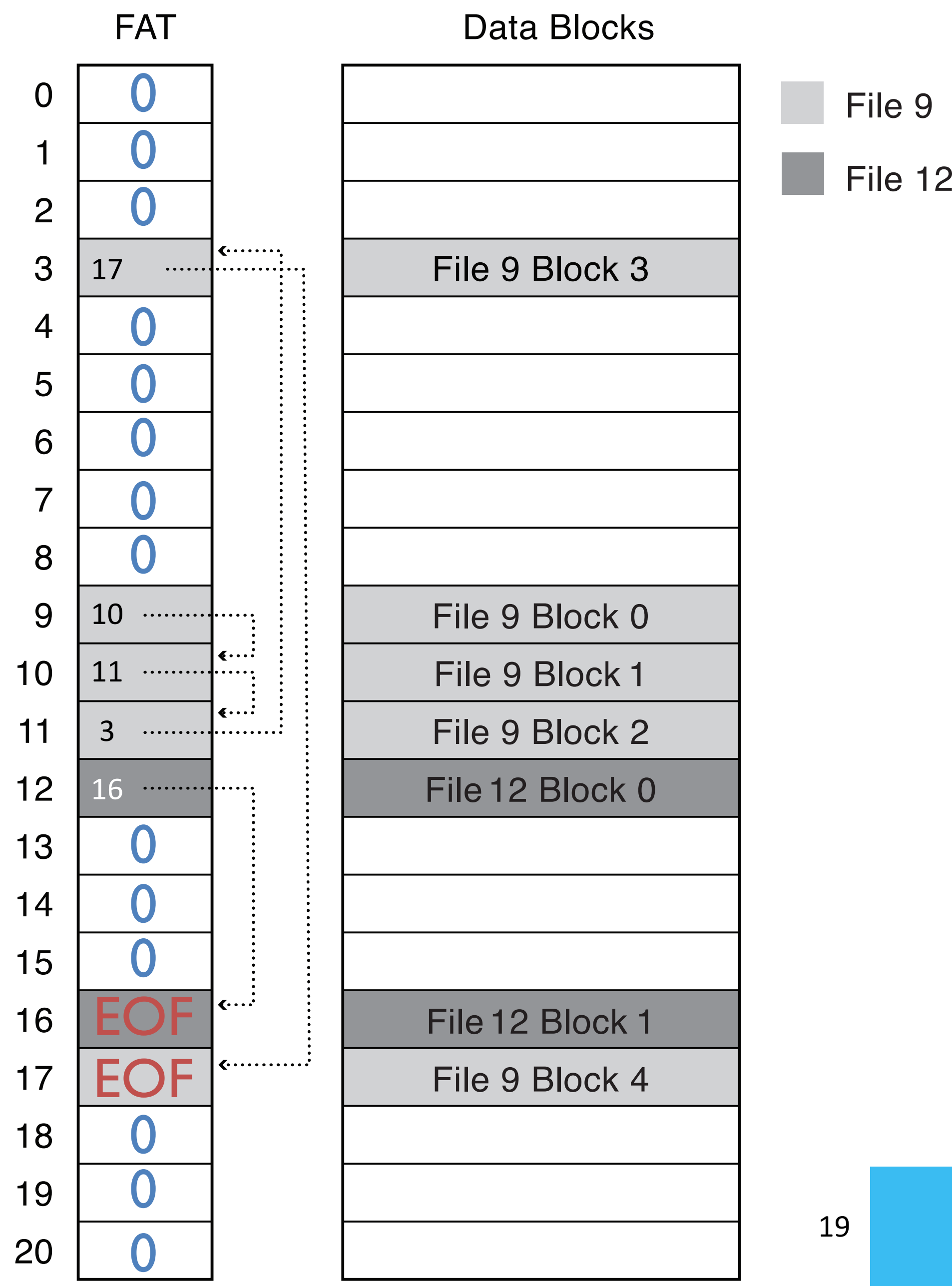
File table:

- Linear map of all blocks on disk
- Each file is a linked list of blocks



FAT File System

- 1 entry per block
- EOF for last block
- 0 indicates free block



What is missing?

At file level
- start index of the file
- size

At disk level
- freelist
- size

P6:FAT disk layout

- fatdisk offers multiple virtual block stores
- The underlying block store is partitioned into four sections:
  1. *superblock*
     - at block #0
  2. a fixed number of *i-node blocks*
     - start at block #1
     - the number is given in the superblock
  3. the FAT table
     - the number of blocks is given in the superblock
  4. the remaining blocks
     - *data blocks, free blocks*

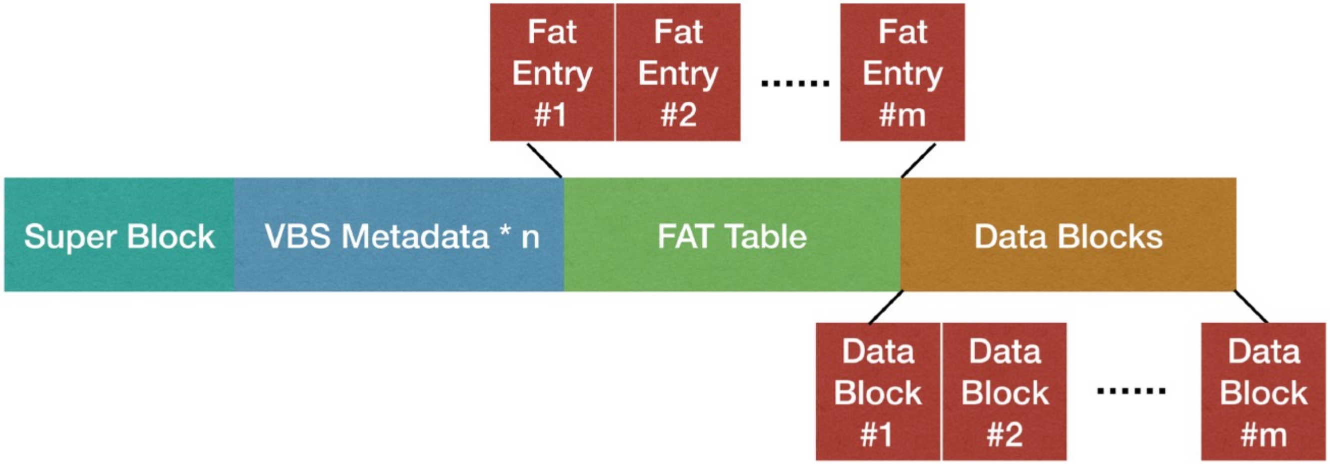
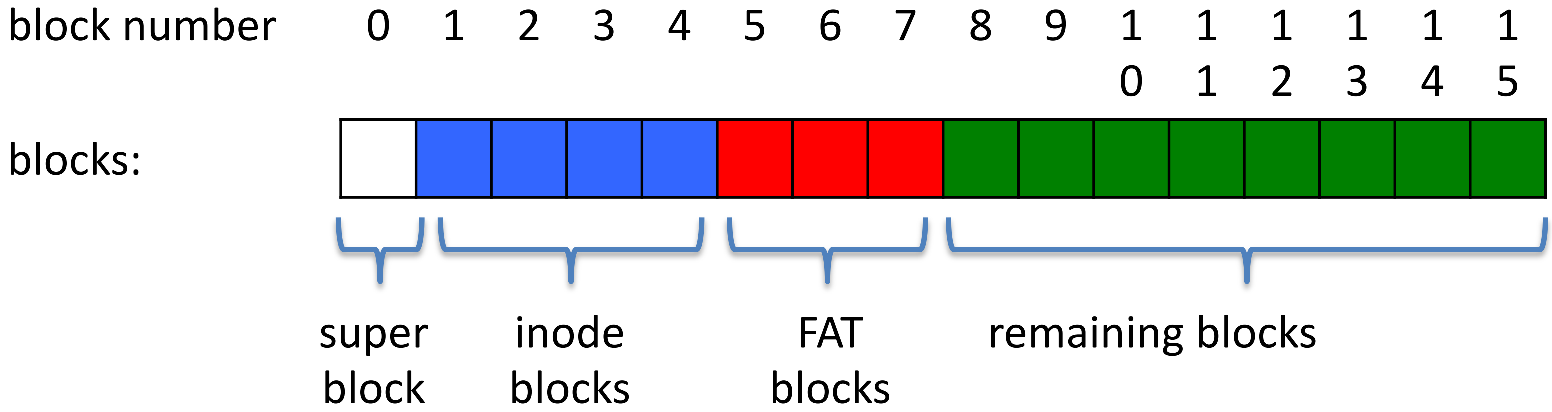


Figure 2: Physical Disk Layout

- **[Super Block]** This is the first block on the physical disk. It stores some metadata such as the number of virtual block stores (i.e. n), the number of data blocks (i.e. m), and information keeping track of unused data blocks (i.e., the *free list*).
- **[VBS Metadata * n]** This region is usually called the *inode table*, where each *inode* stores the metadata of a virtual block store. Each inode contains a pair of integers: the size of the VBS (in number of blocks) and the data block index of the *first* data block in this VBS. For example, (5, 9) means that the VBS contains 5 blocks and the first block is stored in data block #9 of the "Data Blocks" region.
- **[FAT Table]** There are m FAT entries, corresponding to the m data blocks. Each VBS is organized as a linked list of FAT entries, and each FAT entry contains the *next* pointer of the linked list. In Figure 3, the size of VBS #1 is 5, stored in data block #9, #5, #23, #2, #8. In this case, FAT entry #9 would contain integer 5, FAT entry #5 would contain integer 23, etc. FAT entry #8 would contain 0 marking the end of the linked list. One may also use -1 instead of 0.
- **[Data Blocks]** Data blocks store the actual data of each VBS. Some data blocks hold valid data while others are *unused* and contain arbitrary content.


block number
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
blocks:
super block
inode blocks
FAT blocks
remaining blocks

Data structures

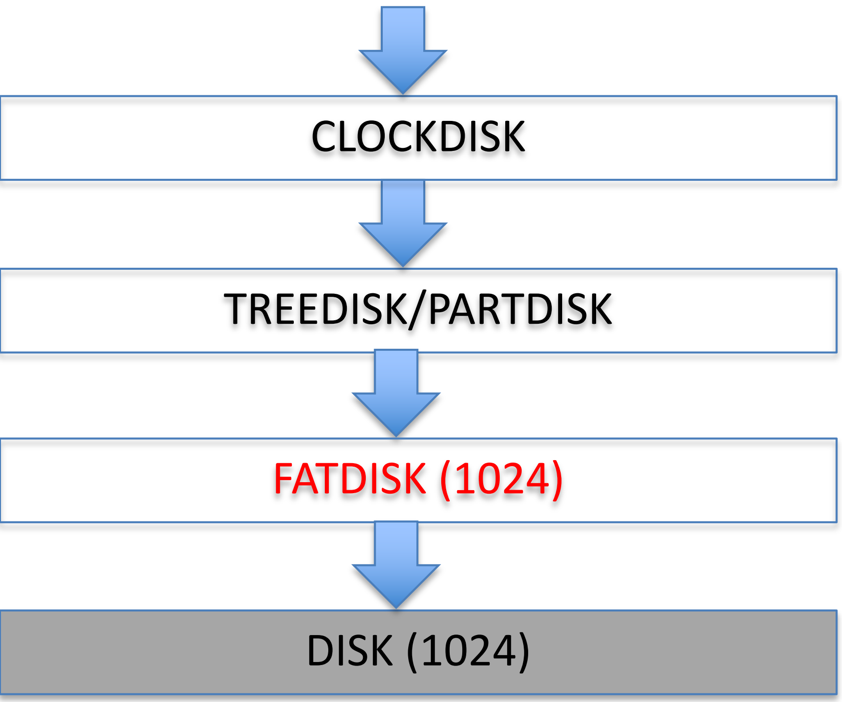
`src/block/fatdisk.h`

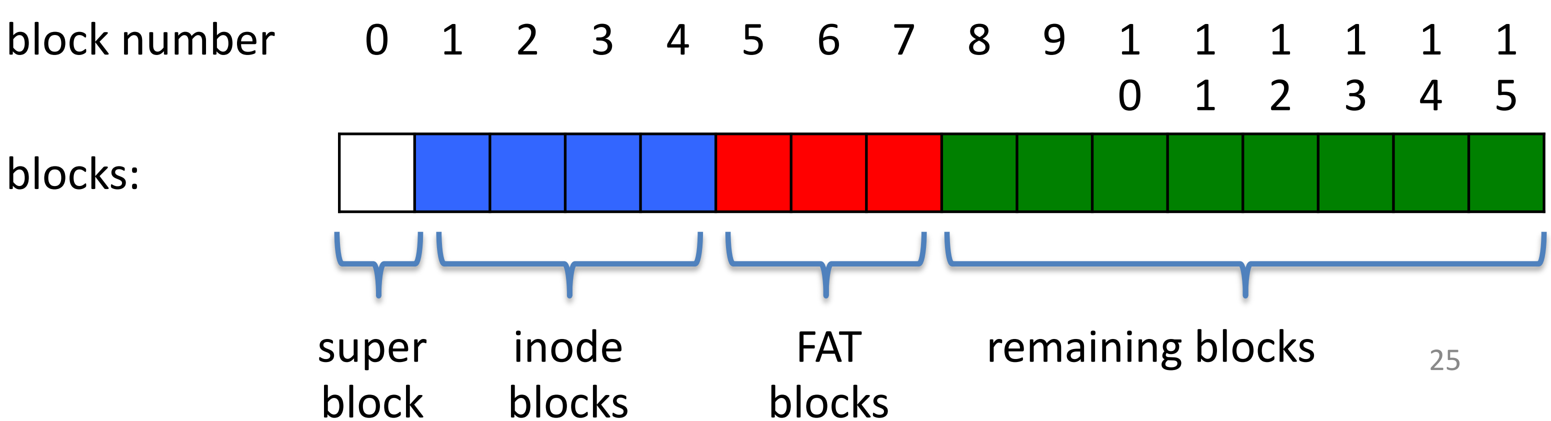
- struct fatdisk_superblock
- struct fatdisk_inode
- struct fatdisk_fatentry
- struct fatdisk_inodeblock
- struct fatdisk_fatblock

Implement 4 functions

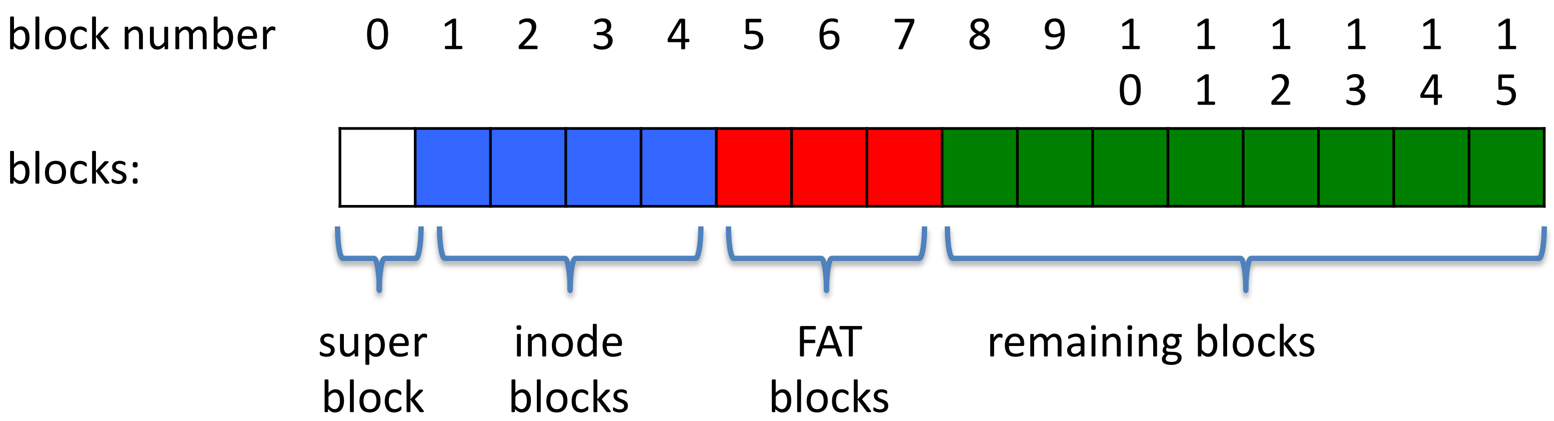
- fatdisk_create(block_if below, unsigned int below_ino, unsigned int ninodes);
  - Use below->getsize(below_ino) to know the capacity of underlying disk.
  - Initialize the FAT layout described before.
- fatdisk_read(block_if this_bs, unsigned int ino, block_no offset, block_t *block);
  - Read content from (ino, offset)
- fatdisk_write(block_if this_bs, unsigned int ino, block_no offset, block_t *block);
  - Write content to (ino, offset)
- fatdisk_free_file(struct fatdisk_snapshot *snapshot, struct fatdisk_state *fs);
  - Free a file and return all its block back to freelist.

below_ino and **ino** are not the same!





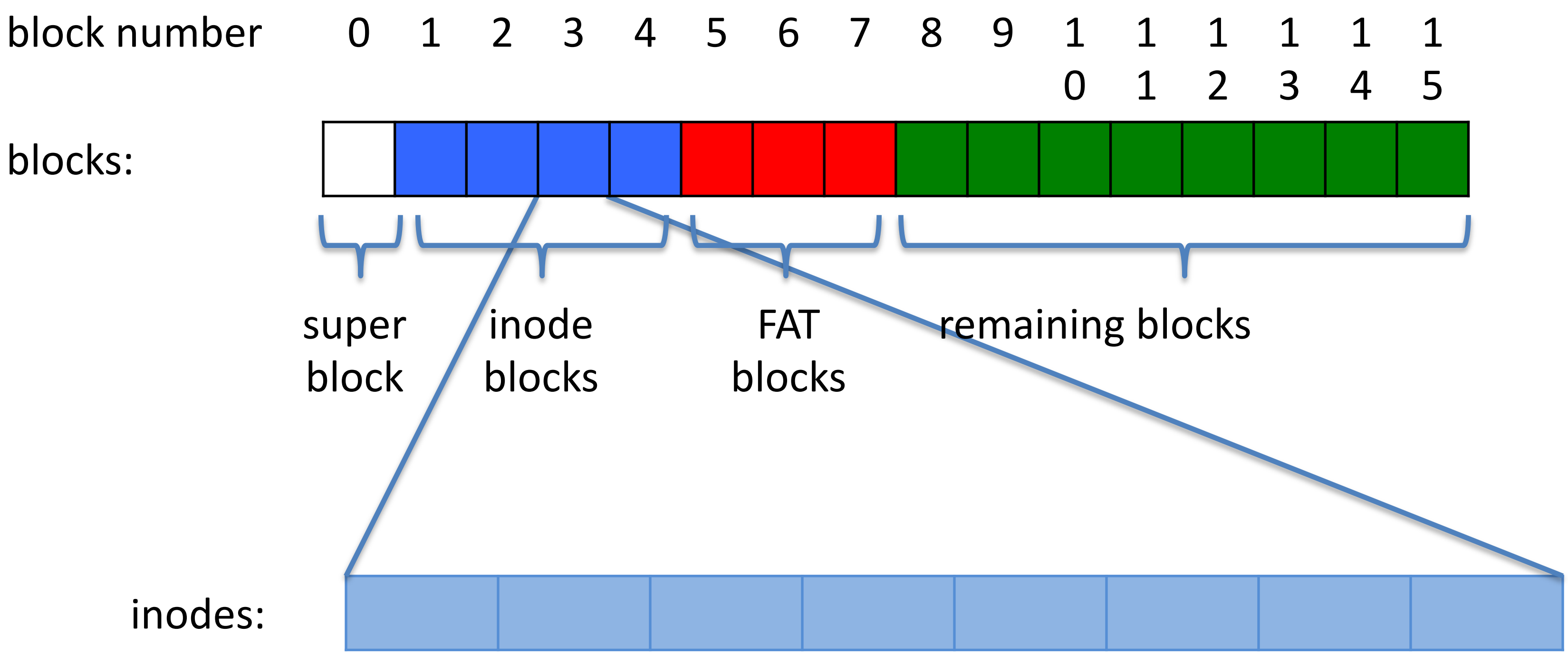
fatdisk: layout



fatdisk superblock

```
struct fatdisk_superblock {
    block_no n_inodeblocks;
         // # blocks containing inodes

    block_no n_fatblocks;
         // # blocks containing fat entries

    block_no fat_free_list;
         // fat index of the first free fat entry};

   …
}
```

fatdisk: i-node blocks



fatdisk i-node

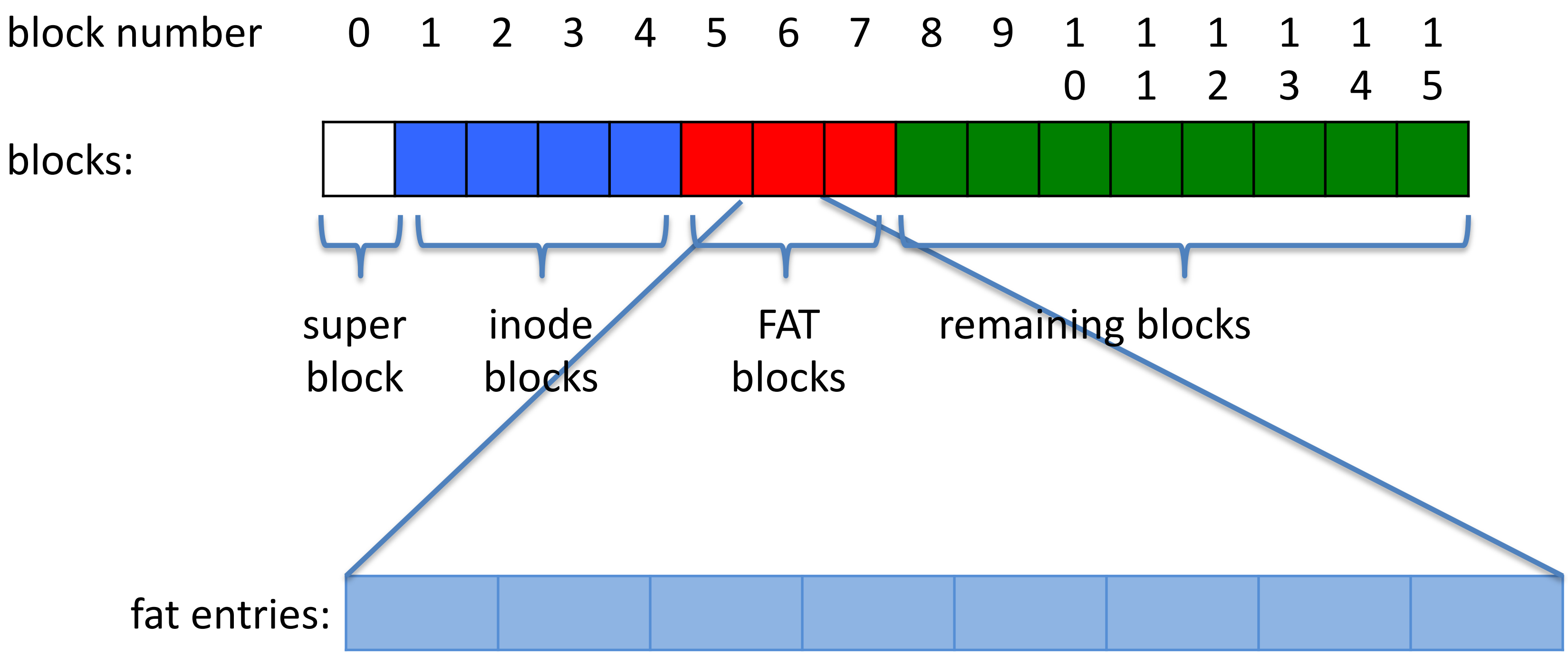
(one per virtual block store)

```
struct fatdisk_inode {
    block_no head;
            // block number of first block
            // should be 0 if nblocks == 0

    block_no nblocks;
            // #blocks in the virtual block store
};
```

fatdisk i-node block

```
#define INODES_PER_BLOCK    (BLOCK_SIZE /
      sizeof(struct fatdisk_inode))

struct fatdisk_inodeblock {
    struct fatdisk_inode inodes[INODES_PER_BLOCK];
};
```

fatdisk: FAT blocks



fatdisk fat-entry
(one per virtual block)

```
struct fatdisk_fatentry {
    block_no next;
      // next entry in the file or in the free list
      // 0 (or -1) for EOF or end of free list
};
```

fatdisk FAT block

```
#define FAT_PER_BLOCK       (BLOCK_SIZE /
             sizeof(struct fatdisk_fatentry))

struct fatdisk_fatblock {
    struct fatdisk_fatentry entries[FAT_PER_BLOCK];
};
```

General purpose block

```
union fatdisk_block {
    struct fatdisk_superblock superblock;
    struct fatdisk_inodeblock inodeblock;
    struct fatdisk_fatblock fatblock;
    block_t datablock;
};
```

snapshot

```
struct fatdisk_snapshot {
    union fatdisk_block superblock;
    union fatdisk_block inodeblock;
    block_no inode_blockno;
    unsigned int inode_no;
    struct fatdisk_inode *inode;
};
```

Read path

*int fatdisk_read(block_store_t *this_bs, unsigned int ino, block_no offset, block_t *block);*

- snapshot = fatdisk_get_snapshot(ino)
- Check if offset < snapshop.inode.size
- target_idx = fatdisk_traverse(snapshot, offset)
- target_blockno = 1 + superblock.n_inodeblocks + superblock.n_fatblocks + **target_idx**
- (*fs->below->read)(fs->below, fs->below_ino, target_bno, block)

fatdisk_traverse(snapshot, offset)

`Given an inode and offset, find the block index.`

- `idx = snapshot->inode->head;`
- `fat_base = 1 + snapshot->superblock.superblock.n_inodeblocks;`
- `for(i=0; i<offset; ++i)`
  - `block_no blockno = fat_base + idx / FAT_PER_BLOCK;`
  - `(*fs->below->read)(fs->below, fs->below_ino, blockno, (block_t *) &fat_block)`
  - `idx = fat_block.entries[idx % FAT_PER_BLOCK].next;`

Write path

*int fatdisk_write(block_store_t *this_bs, unsigned int ino, block_no offset, block_t *block);*

- snapshot = fatdisk_get_snapshot(ino)
- Check if offset < snapshop.inode.size
  - What if not not!
- target_idx = fatdisk_traverse(snapshot, offset)
- target_blockno = 1 + superblock.n_inodeblocks + superblock.n_fatblocks+ **target_idx**
- (*fs->below->write)(fs->below, fs->below_ino, target_bno, block)

Write path

*int fatdisk_write(block_store_t *this_bs, unsigned int ino, block_no offset, block_t *block);*

- snapshot = fatdisk_get_snapshot(ino)
- Check if offset < snapshop.inode.size
  - What if not not!
- target_idx = fatdisk_traverse(snapshot, offset)
- target_blockno = 1 + superblock.n_inodeblocks + superblock.n_fatblocks + target_idx
- (*fs->below->write)(fs->below, fs->below_ino, target_bno, block)

```
fatdisk_alloc(nblocks)
• Allocate new blocks to the given inode
   • Update fat entries
• Update free_list


Update the old fat entry
```

fatdisk_free_file(ino)

- Return blocks, fat entries of the ino back to free list
- Set the ino’s size to 0 in inodeblock

Get started!

- Understand the data structures
- Understand the fatdisk_get_snapshot function
- Know how to assign ninode_blocks, nfat_blocks in fatdisk_init
- Start with read/write with offset=0

Don’t overwrite existing file systems

```
int fatdisk_create(block_store_t *below,
                  unsigned int below_ino, unsigned int ninodes) {
  union fatdisk_block superblock;
  if ((*below->read)(below, below_ino, 0, (block_t *) &superblock) < 0) {
    return -1;
  }
  if (superblock.superblock.n_inodeblocks != 0) {
    printf("fatdisk: one already exists with %lu inodes\n",
      superblock.superblock.n_inodeblocks * INODES_PER_BLOCK);
    return 0;
  }
```