

# PoCSD In-memory file system

## Code overview

# Overview

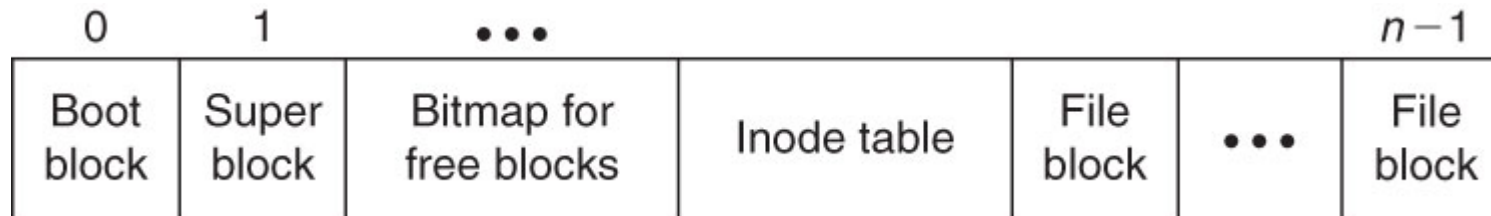
- The in-memory file system is used as a basis for various assignments used in class
- The code implements, in memory, a file system inspired by the design in Chapter 2 of the textbook
- You will progressively add complexity to this design to capture, in practice, concepts that we discuss in class

# Code overview

- The code is written in Python, and maintains data structures that store information and expose methods to perform various functions across the layers of file system
- The data structures are abstracted as classes with methods that implement the majority of the “heavy lifting code” necessary to manipulate them
- This presentation overviews the major data structures and methods, in a “bottom-up” fashion – from the “raw” block layer up

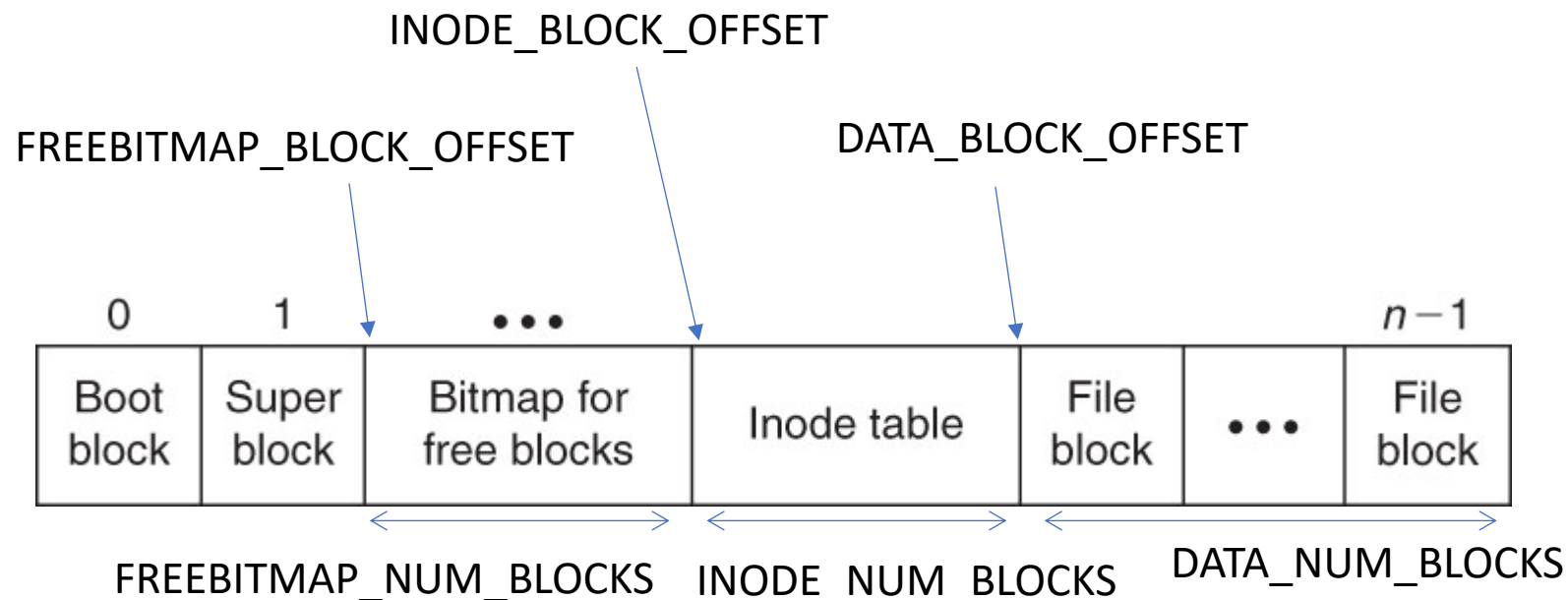
# DiskBlocks()

- This class stores the raw block array
- The blocks are used to store file system data and metadata
  - Boot block – normally this would store boot code; it's unused in our class
  - Superblock() – stores file system constants
  - Bitmap for free blocks: stores an array of bytes, one byte per block, which determines if the block is free (0) or used (1)
  - Inode table: stores a table of inodes
  - File blocks: store file system object data (file contents, directory entries)



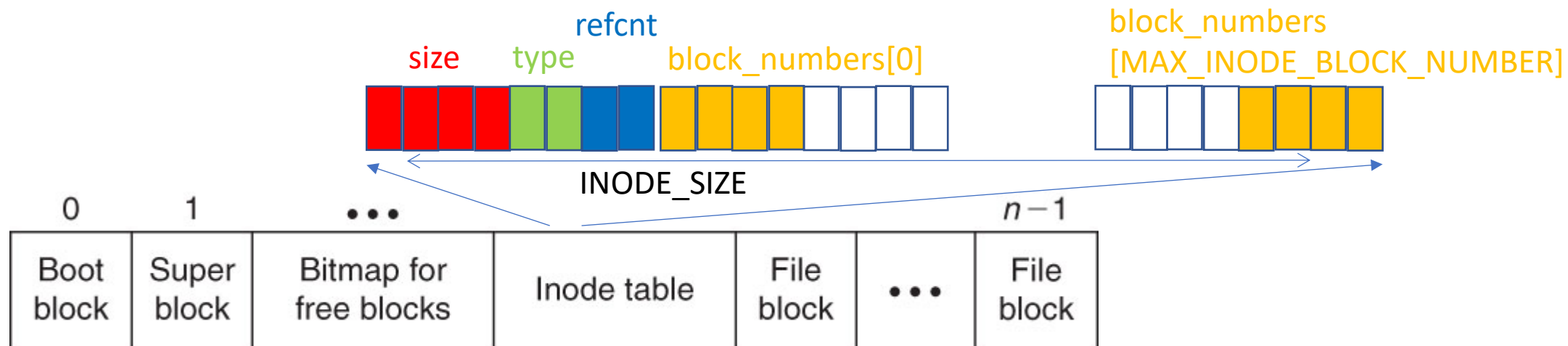
# DiskBlocks()

- File system constants are declared at the beginning of memoryfs.py
  - BLOCK\_SIZE (Bytes), TOTAL\_NUM\_BLOCKS, MAX\_NUM\_INODES, and INODE\_SIZE (the size of each inode, in Bytes)
  - Additional constants used in the code are derived from them, such as:



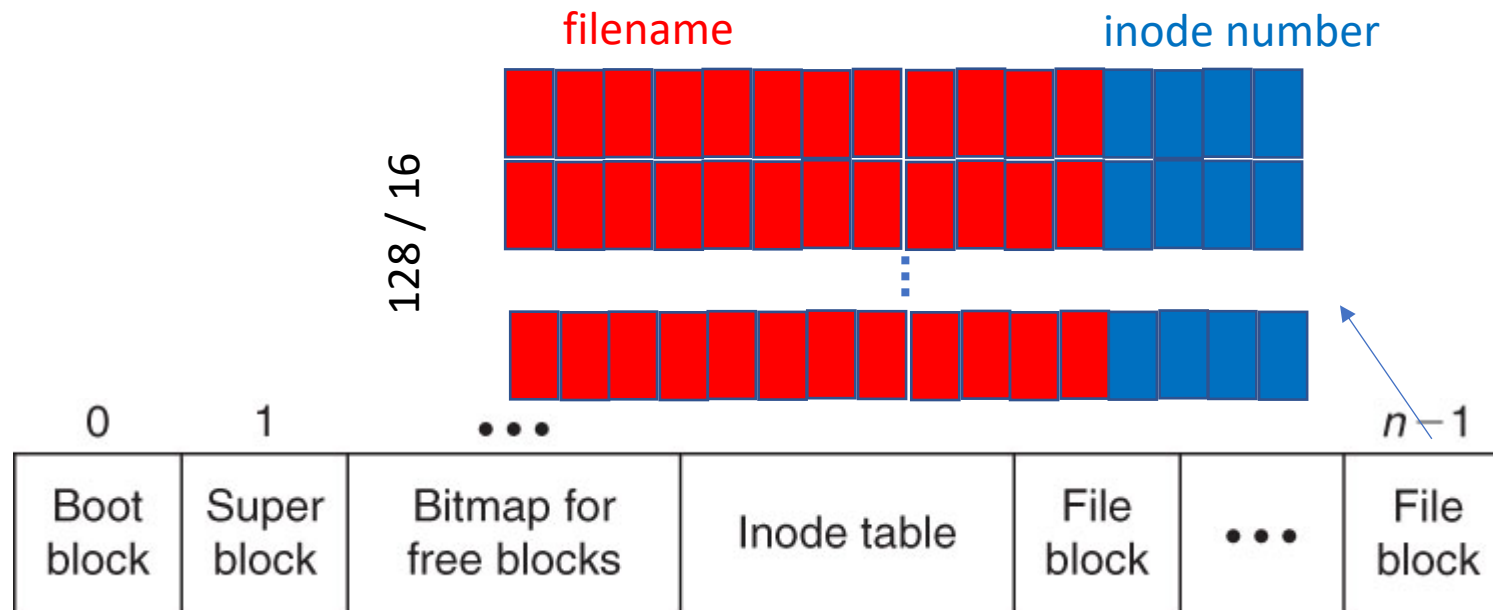
# DiskBlocks() – encoding inodes

- Note: to simplify programming and readability, the following constants used for the inode data structure cannot be changed:
  - 4 Bytes are used to store **size** (hence maximum file size cannot exceed 4GB)
  - 2 Bytes are used to store **type** (plenty; we only have a handful of types)
  - 2 Bytes for **refcnt** (hence a file has at most 65535 references)
  - 4 Bytes for **each index in block\_numbers** (hence at most  $2^{32}$  blocks)



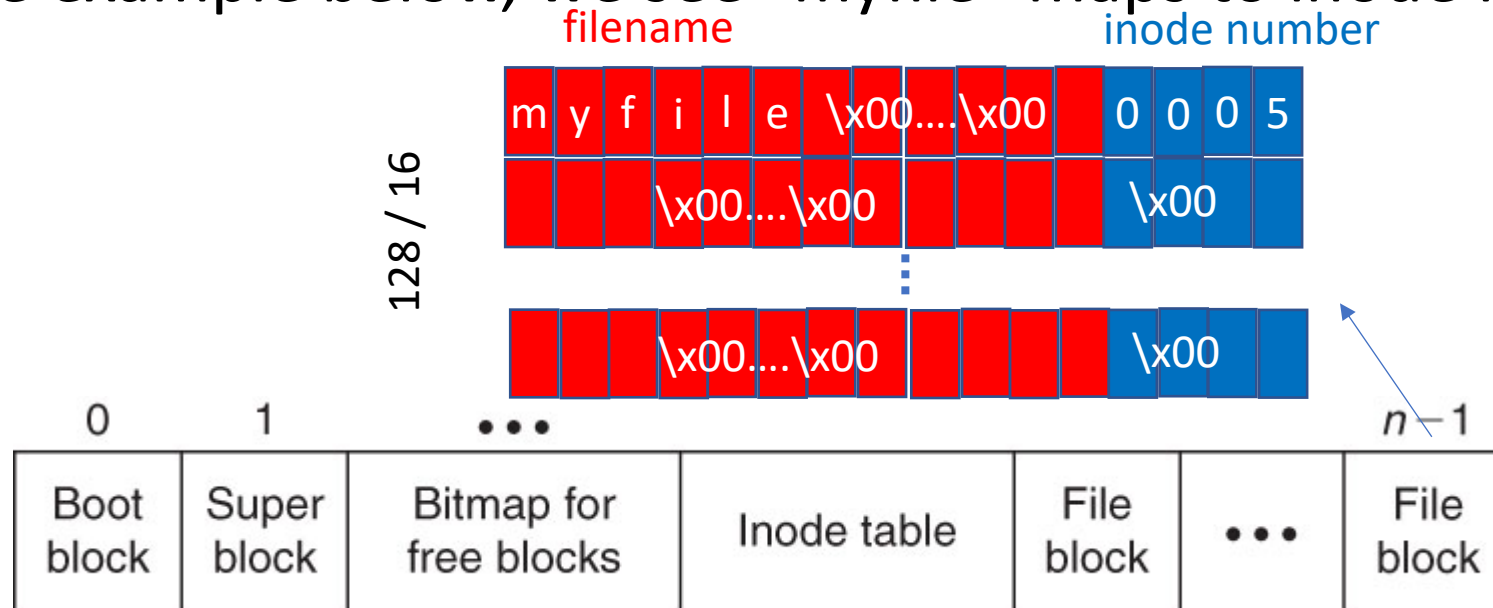
# DiskBlocks() – encoding directory entries

- Each data block storing directory entries is structured as follows:
  - MAX\_FILENAME determines the max **size** (characters) of an object's **name**
  - INODE\_NUMBER\_DIRENTRY\_SIZE determines the **size** of an inode **number**
  - By default, MAX\_FILENAME=12 and INODE\_NUMBER\_DIRENTRY\_SIZE=4
    - Hence, each (name,inode) mapping uses 16 Bytes
    - With default block size 128 Bytes, there are up to 16 directory entries per datablock



# DiskBlocks() – encoding directory entries

- The file name can have any characters, except “/”
  - The code doesn't enforce for encoding
- Unused file name bytes are filled with zeroes ('\x00' in hex)
  - A file name that is all zeroes means that the entry is free
- Inode numbers are encoded as big-endian
- In the example below, we see “myfile” maps to inode number 5





# DiskBlocks()

- The key methods exposed by DiskBlocks() are:
  - Put(number, data)
    - Writes raw data block indexed by block number
    - Data block must be a byte array of up to BLOCK\_SIZE length
      - If it is smaller than BLOCK\_SIZE, Put() pads it with zeroes up to BLOCK\_SIZE
    - Number must be between 0..TOTAL\_NUM\_BLOCKS
  - data = Get(number)
    - Reads from raw block storage indexed by block number
- DiskBlocks() is an in-memory class; two methods are exposed to “dump” the entire raw block storage to disk, and to read from disk
  - This is useful to save/restore the file system state between invocations of memory.py
  - DumpToDisk() and LoadFromDisk() use Python’s “pickle” to serialize the object

# DiskBlocks()

- InitializeBlocks(cleanslate, prefix)
  - This method initializes the raw storage
  - If cleanslate == True, initializes blocks with zeroes, except:
    - Boot block stores the prefix string – can be used as identifier, e.g. your name or a UUID
    - Superblock stores file system constants
  - If cleanslate == False, initialized blocks from a pickled dump file
    - The file name is prefix\_BS\_bbb\_NB\_nnn\_IS\_iii\_MI\_mmm
    - Where bbb is BLOCK\_SIZE, nnn TOTAL\_NUM\_BLOCKS, iii INODE\_SIZE, and mmm MAX\_NUM\_INODES

# DiskBlocks() helper/debugging functions

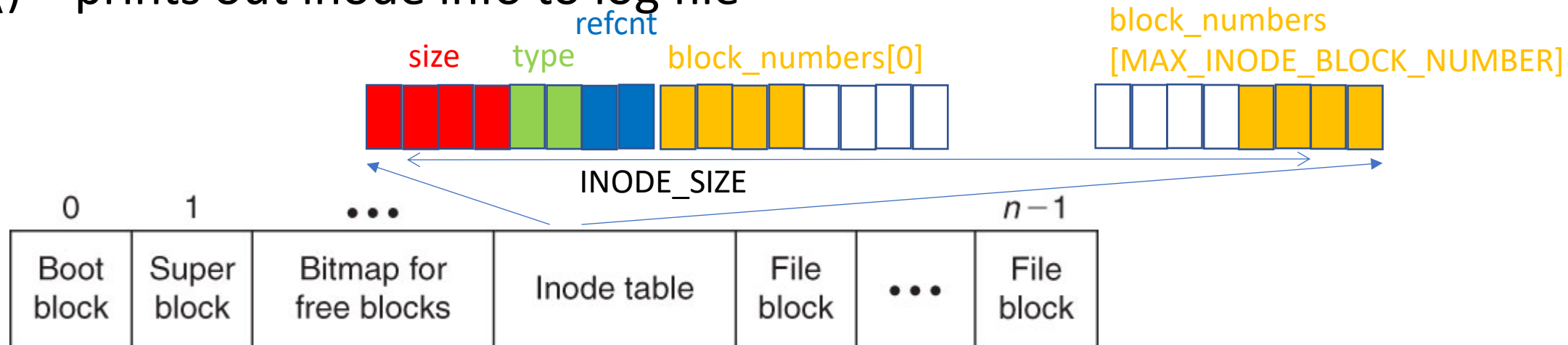
- `PrintFSInfo()`
  - Prints to the log file a summary of file system information
- `PrintBlocks(tag,min,max)`
  - Prints to the log file the contents of blocks in the [min,max] range
  - The “tag” string is also printed to the log, to facilitate debugging
- Example:
  - `RawBlocks = DiskBlocks()`
  - `RawBlocks.InitializeBlocks(True,"my_id")`
  - `RawBlocks.PrintBlocks("Initial state",0,16)`
    - (Some code that changes blocks)
  - `RawBlocks.PrintBlocks("Next state",0,16)`

# Inode()

- This class represents an inode in memory
  - Its type, size, reference count, and array of block\_numbers[]
  - The types supported in the version you start from are:
    - INODE\_TYPE\_INVALID
    - INODE\_TYPE\_FILE
    - INODE\_TYPE\_DIR
- Inodes are initialized as INVALID, size 0, refcnt 0, block\_numbers[] as an array of zeroes

# Inode()

- Helper functions extract/insert inode from table in raw block storage
  - InodeFromByteArray(b)
    - This method loads an inode's type, size, refcnt, block\_numbers[] from a byte array with INODE\_SIZE bytes
  - InodeToBytearray()
    - This method returns a byte array encoding the inode's information
- Print() – prints out inode info to log file

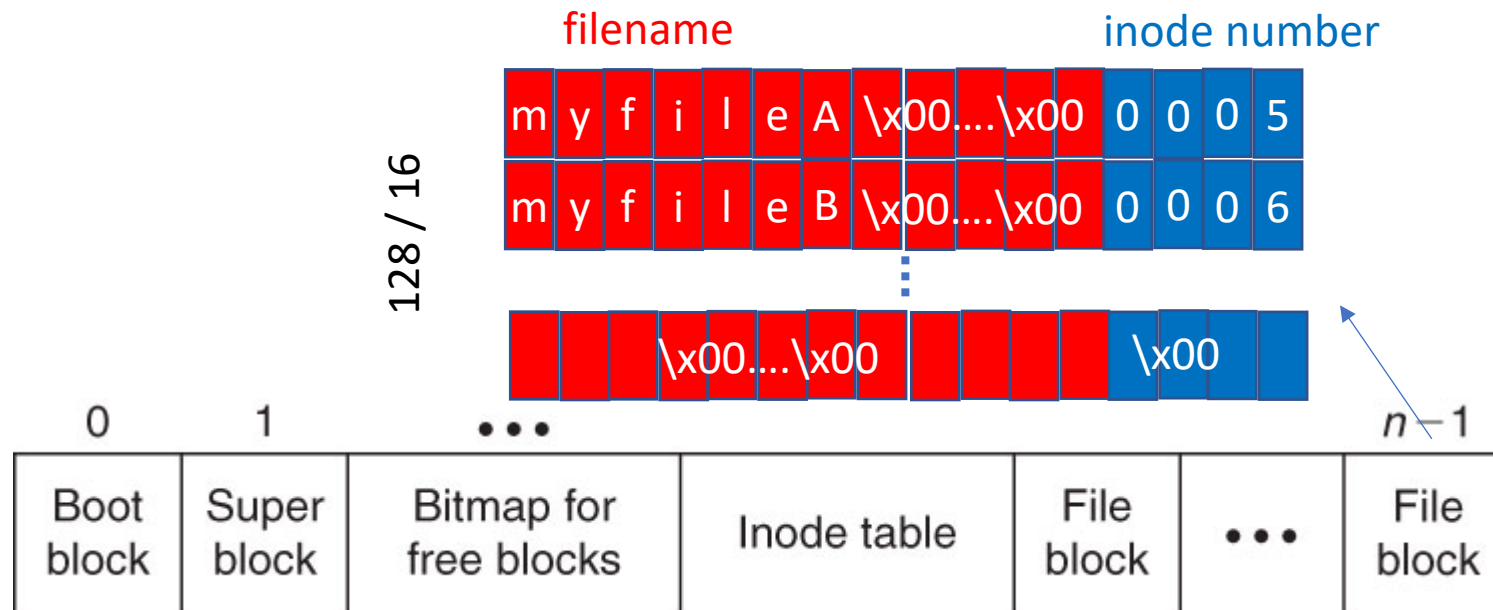


# InodeNumber()

- This class exposes methods that use numbers to identify an inode
  - It holds an Inode() object, the inode's number
  - You need to initialize it with a number, and the object holding disk blocks
- InodeNumberToInode()
  - Load inode structure from raw block storage, given its number
- StoreInode()
  - Store inode structure in raw block storage, given its number
- InodeNumberToBlock(offset)
  - Returns a block of data from raw storage, given its offset; equivalent to textbook's INODE\_NUMBER\_TO\_BLOCK

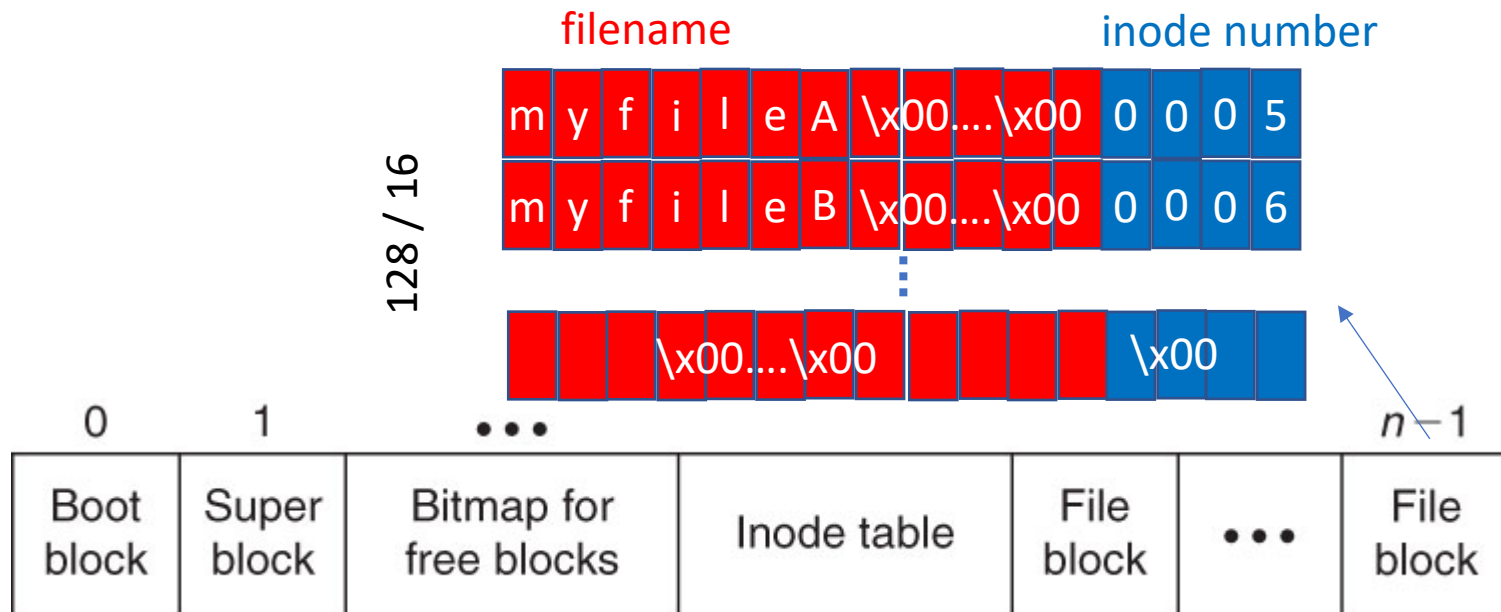
# FileName()

- This class exposes methods at the file layer
  - You need to initialize it with a number, and the object holding disk blocks
- HelperGetFilenameString(block, index)
  - Extract MAX\_FILENAME-size string from bytearray block, using index
  - E.g. with block below, index 0 returns “myfileA”, index 1 returns “myfileB”
    - Padded to the right with “\x00”



# FileName()

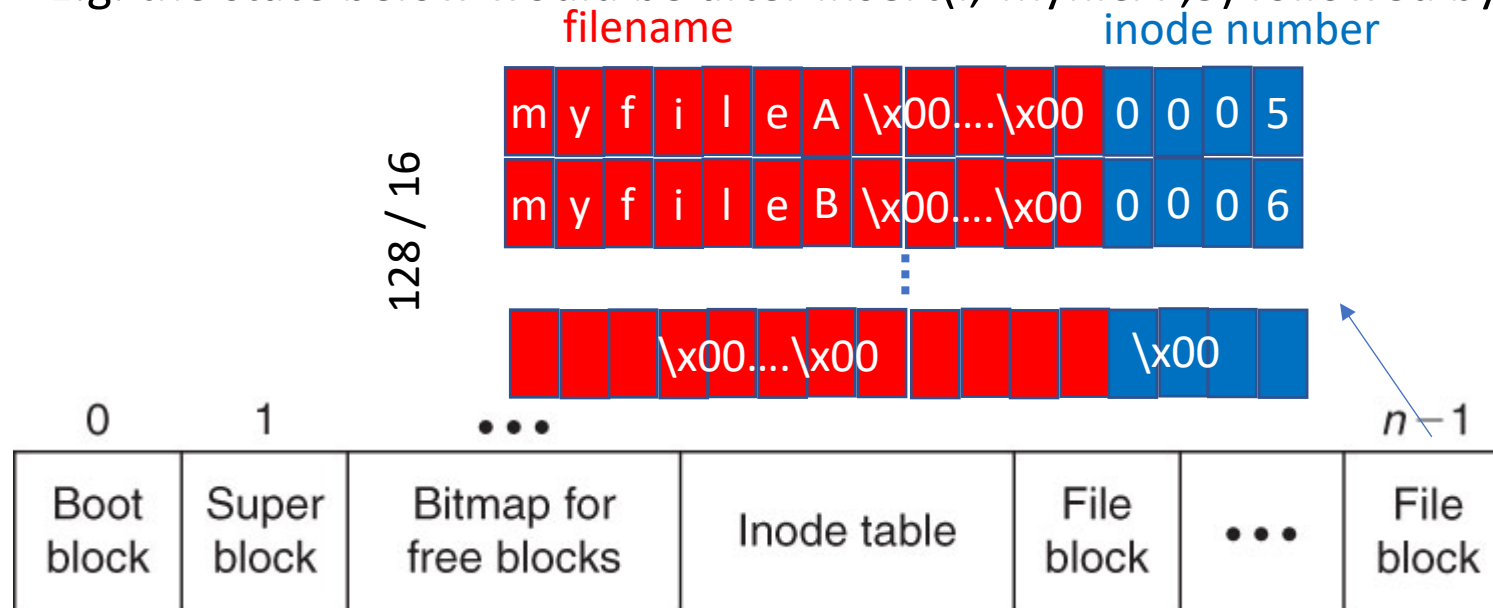
- HelperGetFilenameInodeNumber(block, index)
  - Extract INODE\_NUMBER\_DIRENTRY\_SIZE int from block, using index
  - E.g. with block below, index 0 returns 5, index 1 returns 6





# FileName()

- InsertFileNameInodeNumber(insert\_to, filename, inode number)
  - Inserts a (filename,inode number) entry to a directory's data block
  - insert\_to is an InodeNumber() object - the inode number of the directory that we're inserting this entry
  - This adds an entry to the end of the table (starting from inode.size)
    - Allocates a new block and add to block\_numbers[] if needed
    - E.g. the state below would be after Insert(i,"myfileA",5) followed by Insert(i,"myfileB",6)

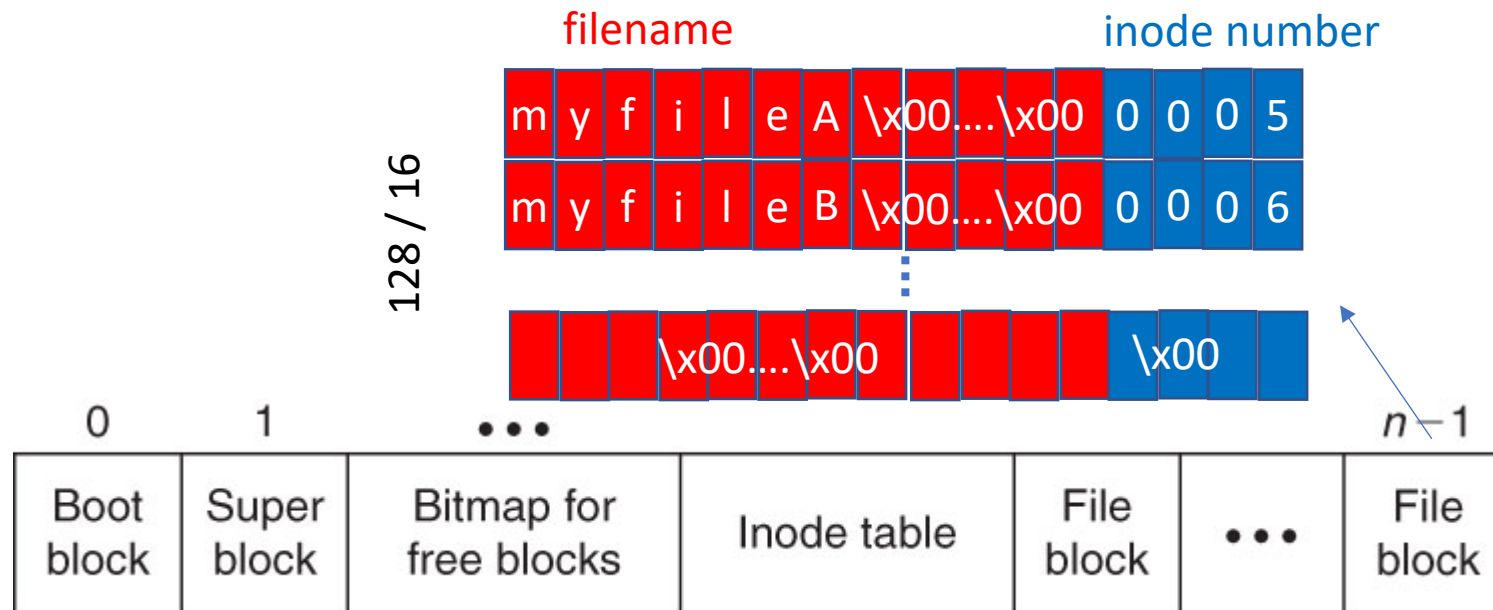


# FileName()

- FindAvailableInode()
  - Scans inode table to find a free inode
  - Used when allocating a new inode as part of Create()
  - An inode is free if its type is INODE\_TYPE\_INVALID
- FindAvailableFileEntry(dir)
  - Finds next available block in a directory's block\_numbers[] array
    - If inode reached maximum size, returns error
  - Used when allocating a new data block for a directory as part of Create()
- AllocateDataBlock()
  - Allocates a new data block from free list; if there is a free block available, update free bitmap, and returns block number

# FileName()

- Lookup(filename, dir)
  - Looks up a file object in a directory – as in the book's LOOKUP
  - dir is an inode number, filename is a string
  - Example, Lookup("myfileA",0) would return 5 for the example below, assuming this is one of the data blocks indexed in the root directory (inode number 0)



# FileName()

- InitRootNode()
  - Initializes root inode (inode number 0), and writes to block storage
  - Also inserts “.” directory entry
- Create(dir, name, type)
  - Create a file system object of given type, in given directory, with given name
    - Allocates a new inode for the object
    - Adds (name,inode\_number) to dir’s entry, allocating new block if needed
    - If type is INODE\_TYPE\_DIR
      - Allocate data block for new directory, and insert “.” and “..” entries
    - If type is INODE\_TYPE\_FILE
      - Create empty file, with size 0 – no data blocks are allocated yet
  - Returns the new object’s inode number

# FileName()

- Write(file\_inode\_number, offset, data)
  - Writes bytearray “data” into file given its inode number, starting at offset
  - file\_inode\_number must index an inode of type INODE\_TYPE\_FILE
  - offset can point to anywhere within the file, and data can be smaller or larger than BLOCK\_SIZE, but:
    - offset cannot be larger than file’s size
    - offset + len(data) cannot exceed MAX\_FILE\_SIZE
  - This method allocates data blocks as needed to accommodate data
  - Partial writes (smaller than a block) only change the bytes to be written
    - The block is first read from raw storage
  - Returns the number of bytes written

