PoCSD In-memory file system
Code overview

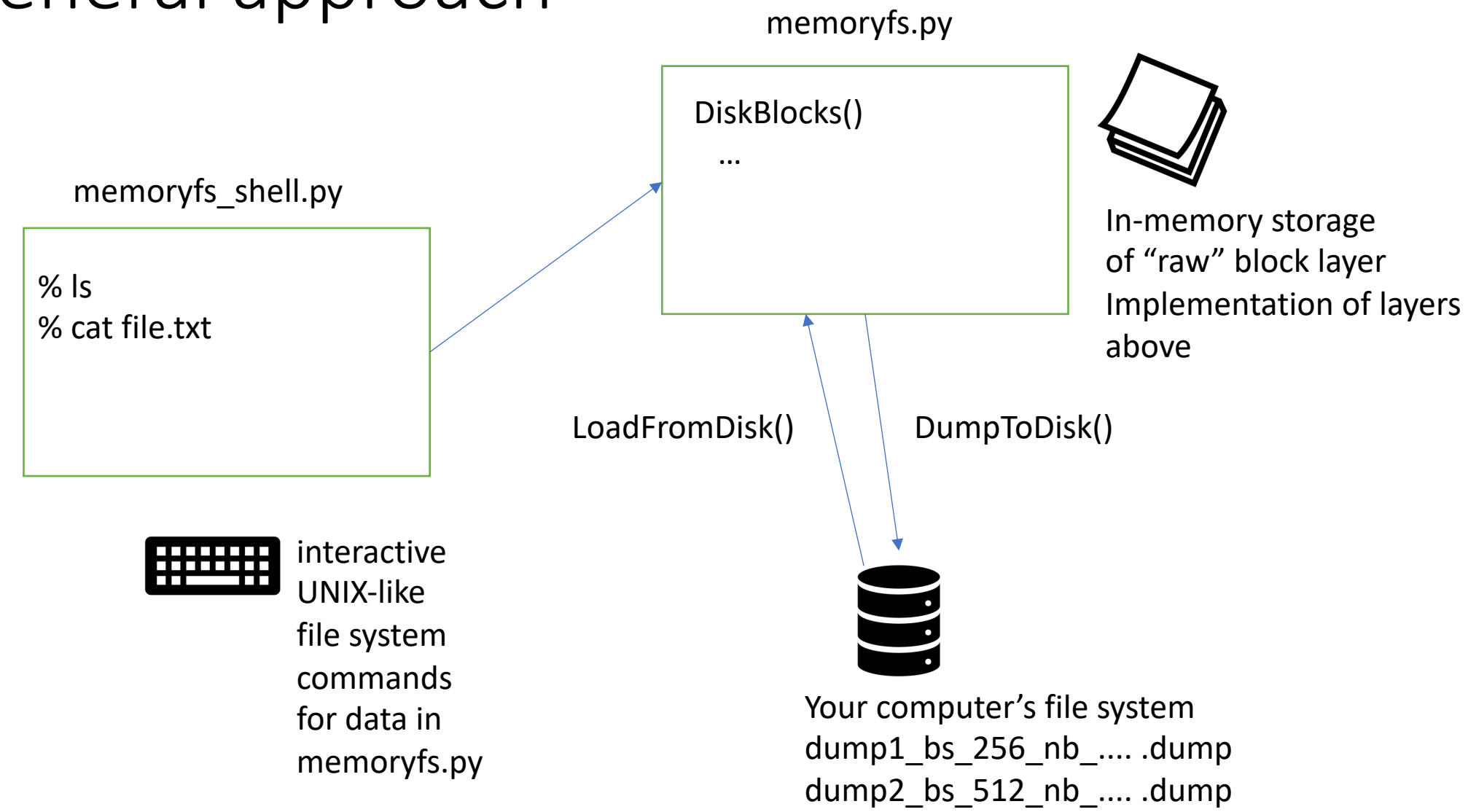
Overview

- 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

General approach



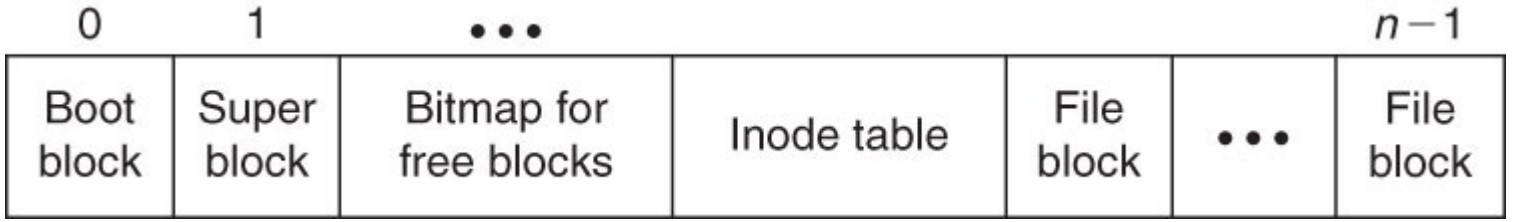
Layering on textbook's discussion

Layer	Purpose	
Symbolic link	Integrate multiple file systems	User-oriented names
Absolute path name layer	Provide a root for naming hierarchies	
Path name layer	Organize files into naming hierarchies	
File name layer	Human-oriented names	User/machine Interface
Inode number layer	Machine-oriented names	Machine-oriented names
File layer	Organize blocks into files	
Block layer	Identify disk blocks	

DiskBlocks()

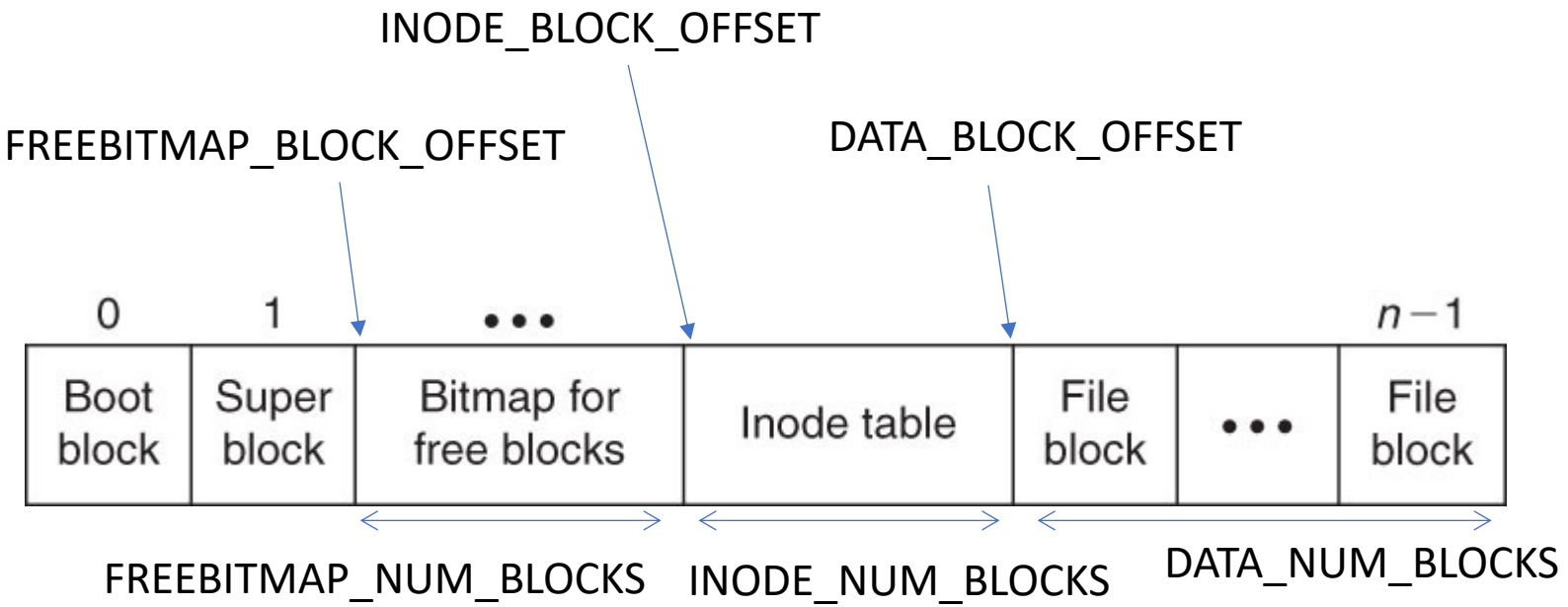
DiskBlocks()

- 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)



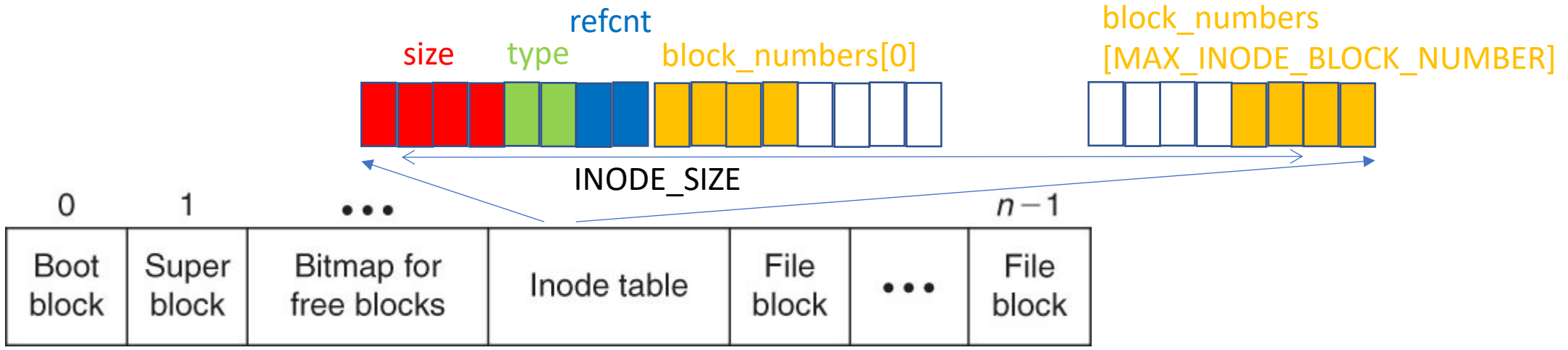
DiskBlocks()

- 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:



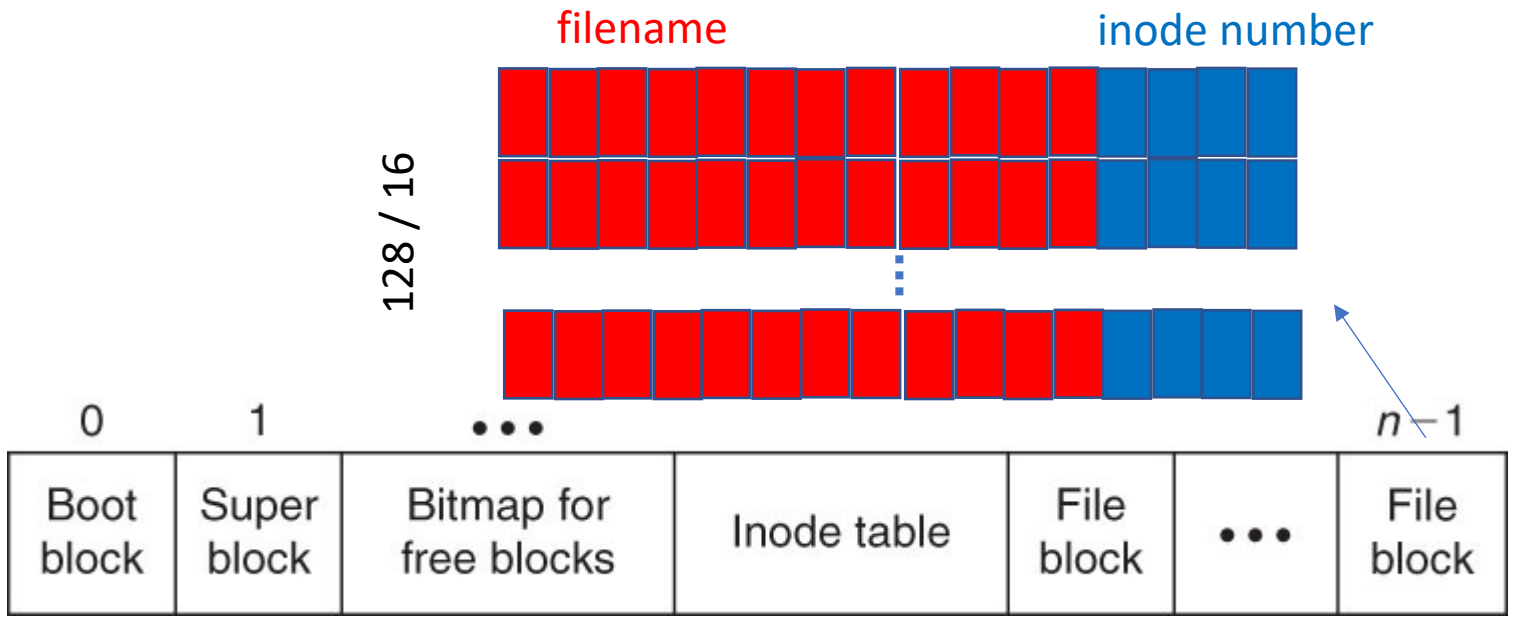
DiskBlocks() – encoding inodes

- 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)



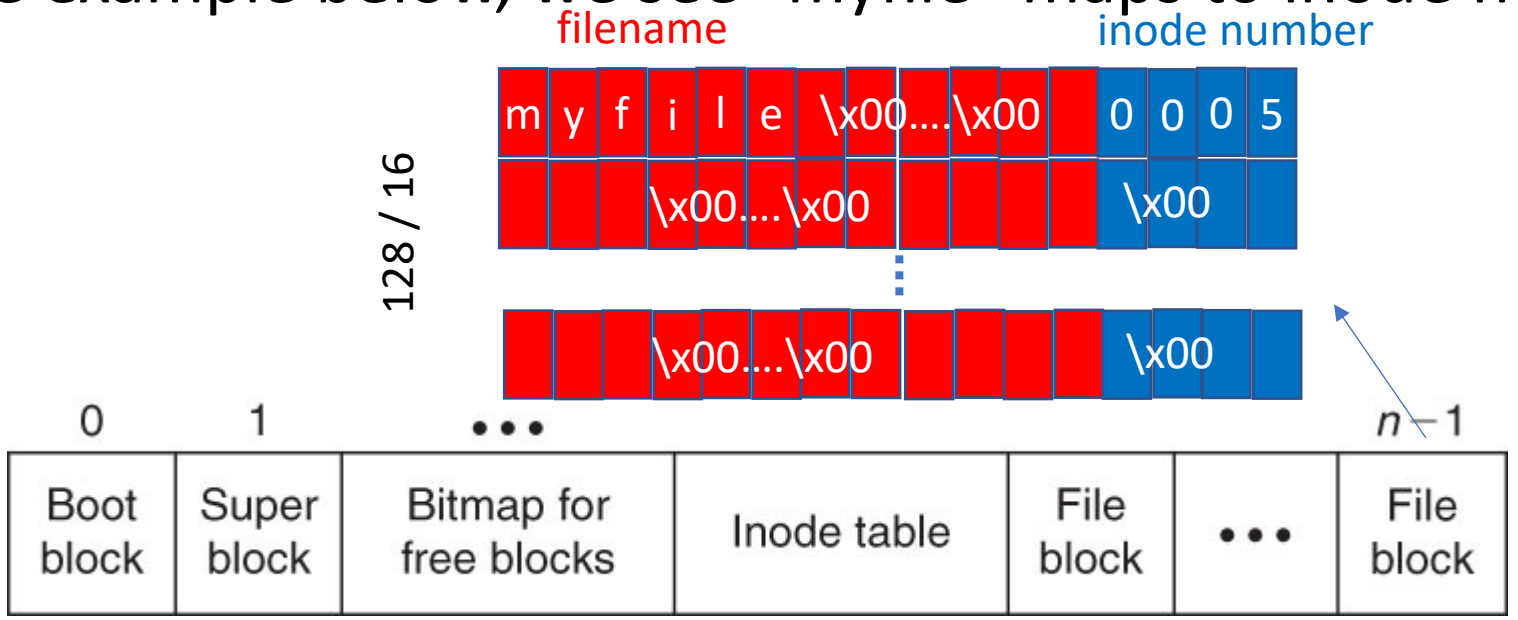
DiskBlocks() – encoding directory entries

- 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 8 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-1
  - 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(self, prefix):
  - This method initializes the raw block storage in memory with zeroes
    - The prefix argument specifies what goes in block #0 – this is unused for now
    - Block #1 is initialized with superblock = [TOTAL_NUM_BLOCKS, BLOCK_SIZE, MAX_NUM_INODES, INODE_SIZE]
- LoadFromDisk(self, filename):
  - This method initializes the raw block storage in memory from a file
    - You will be given examples of “dump files” in HW#1
    - You can create your own “dump files” to checkpoint block storage to disk – see below
- DumpToDisk(self, filename):
  - This method creates a dump file from the raw block contents in memory

Visualizing data in DiskBlocks()

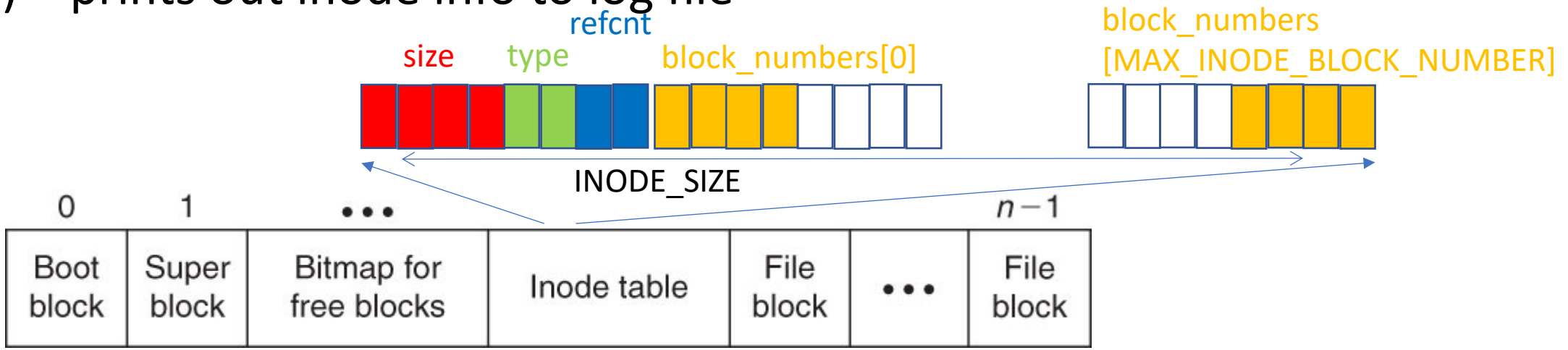
- The file system shell has debugging commands to help you visualize raw block data (and inode info), and get yourself acquainted with how data is stored in blocks:
  - load dumpfile, save dumpfile : load or save dumpfile in disk
  - showfsconfig : displays FS configuration, number of blocks, block size, number of inodes, inode size
  - showblock blockno : displays the contents of raw block number "blockno
  - showblockslice blockno start end : displays a slice of the contents of raw block number "blockno", in hexadecimal format, from byte "start" to byte "end", including byte "end"
  - showinode inodeno : displays the inode data structure for inode number "inodeno"

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

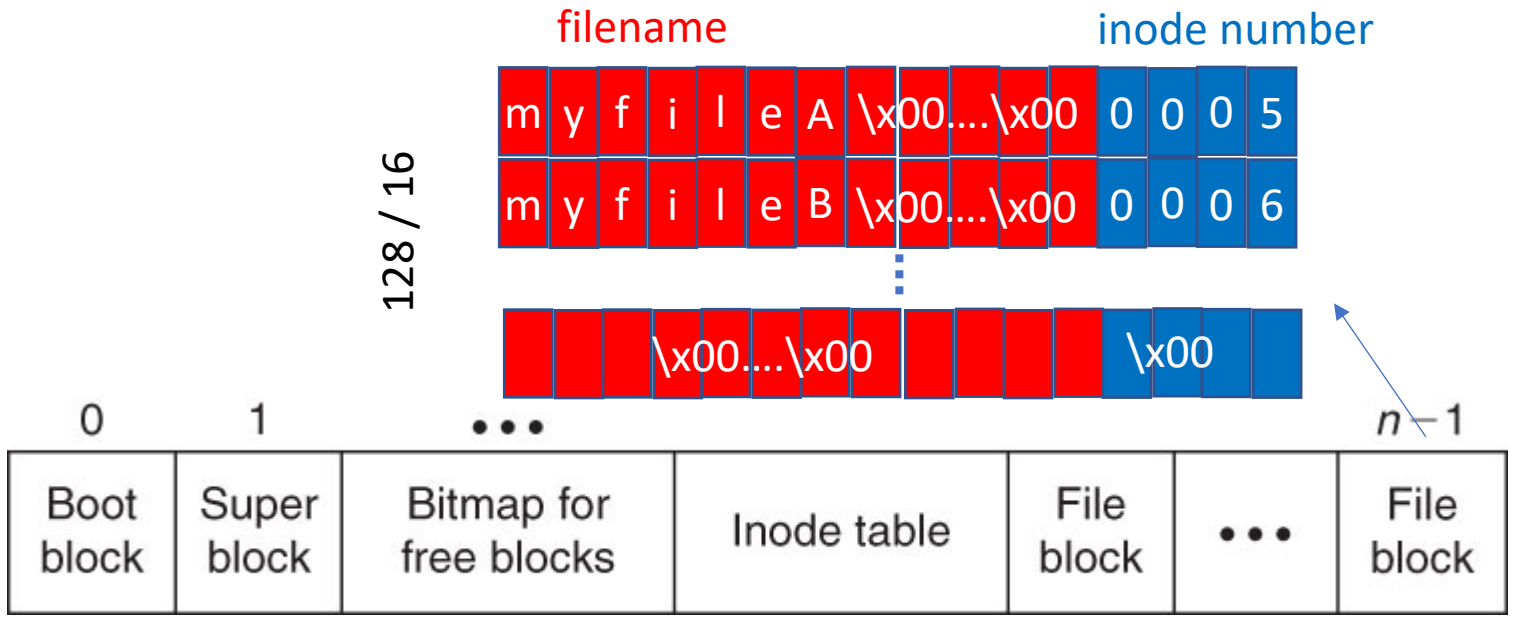


InodeNumber()

- 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

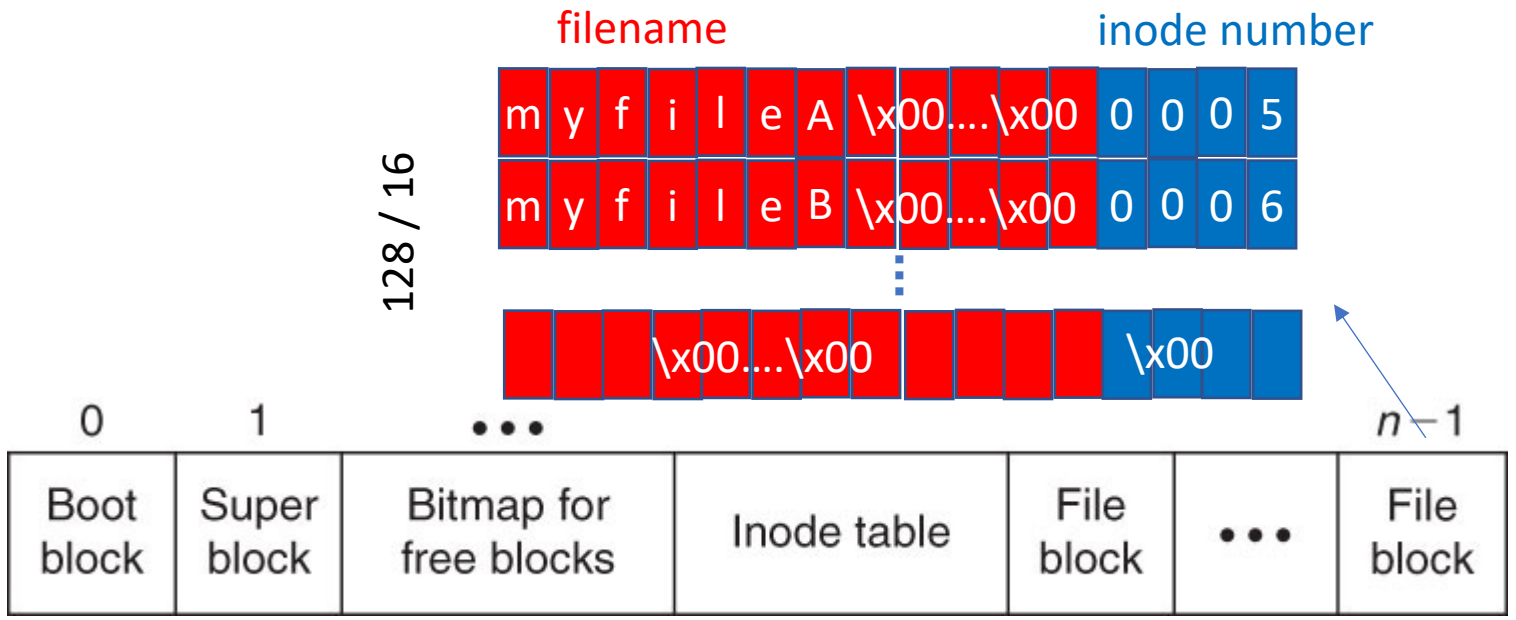
FileName()

- This class exposes methods at the file layer
  - You need to initialize it with 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”



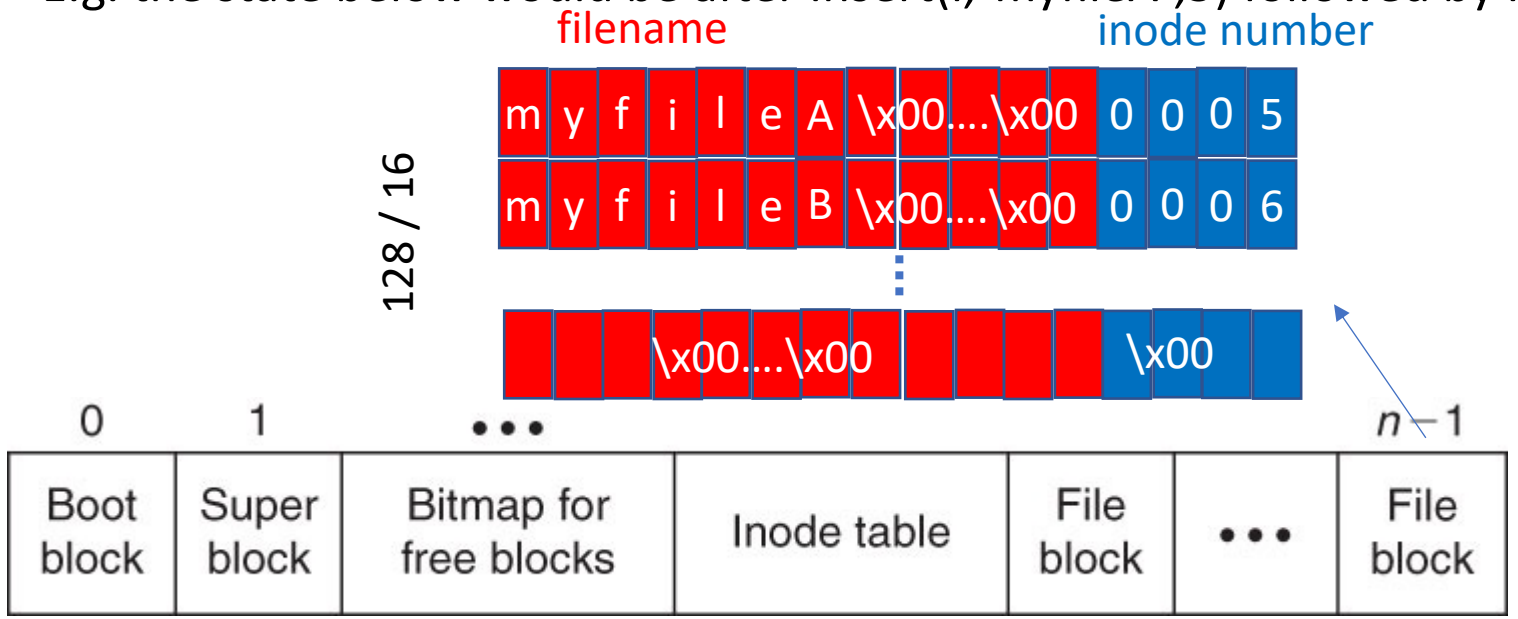
FileName()

- 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, inodenumber)
  - Inserts a (filename,inodenumber) 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)

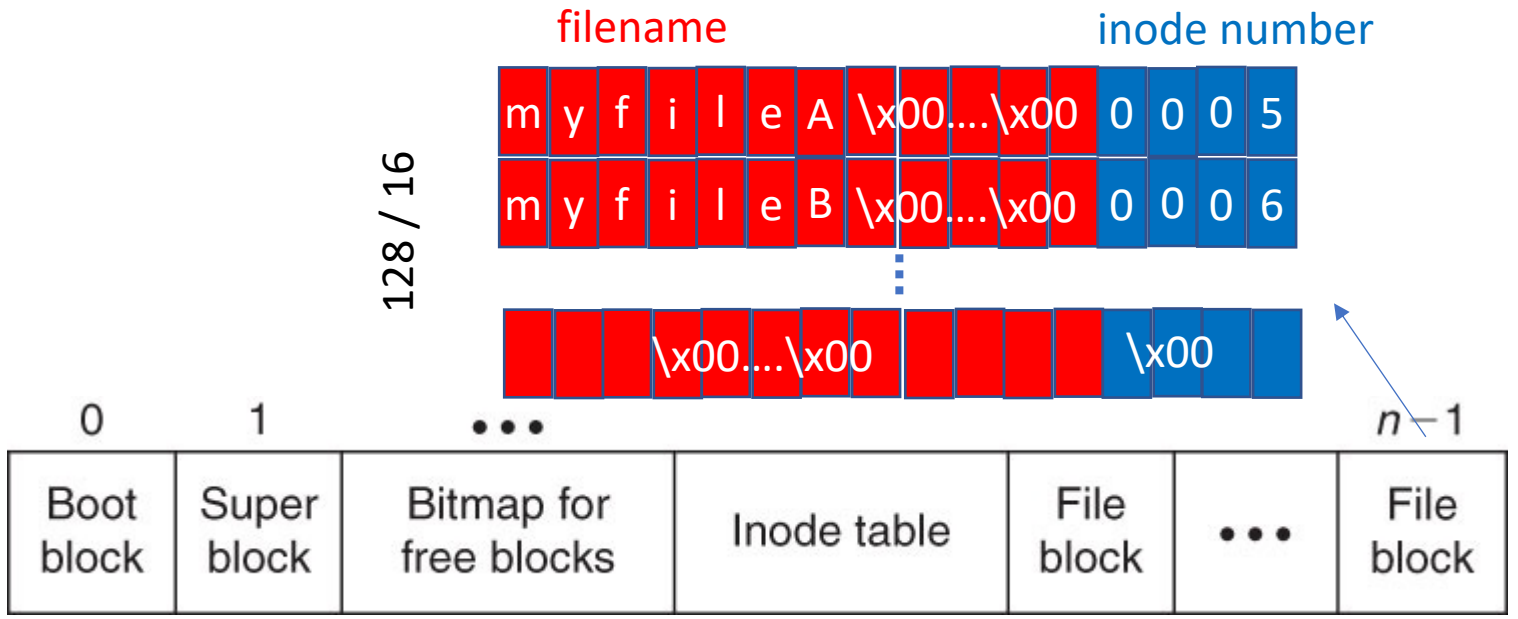


FileName()

- 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()

- InitRootInode()
  - 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

FileName()

- Example:

```
RawBlocks = DiskBlocks()
RawBlocks.InitializeBlocks(True,b’myid’)
file = FileName(RawBlocks)
file.InitRootInode()
file.Create(0, "data", INODE_TYPE_DIR)                    # create “/data” directory
file.Create(0, "foo", INODE_TYPE_DIR)             # create “/foo” directory
file.Create(0, "file1.txt", INODE_TYPE_FILE)      # create “/file1.txt” file
file.Create(2, "file2.txt", INODE_TYPE_FILE)      # create “/foo/file2.txt"
file.Create(1, "file3.txt", INODE_TYPE_FILE)      # create “/data/file3.txt”
f = file.Lookup('file3.txt’,1)                    # Lookup file3.txt in /data
data = bytearray("Contents of file8.txt.","utf-8") # Write a string to file3.txt
offset = file.Write(f, 0, data)
data2 = bytearray("Adding more content to file8.txt.","utf-8")
file.Write(f, offset, data2)                      # Append another string to file3.txt
```