CS161: Operating Systems

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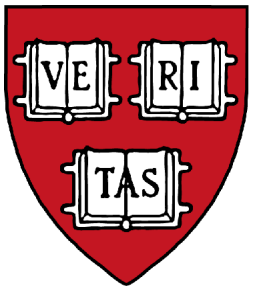


Lecture 14: Filesystem Organization
April 5, 2007

Filesystems

A *filesystem* provides a high-level application access to disk

- *As well as CD, DVD, tape, floppy, etc...*
- Masks the details of low-level sector-based I/O operations
- Provides structured access to data (files and directories)
- Caches recently-accessed data in memory

Hierarchical filesystems: Most common type

- Organized as a tree of directories and files

Byte-oriented vs. record-oriented files

- UNIX, Windows, etc. all provide byte-oriented file access
  - *May read and write files a byte at a time*
- Many older OS's provided only record-oriented files
  - *File composed of a set of records; may only read and write a record at a time*

Versioning filesystems

- Keep track of older versions of files
- e.g., VMS filesystem: Could refer to specific file versions:`foo.txt;1, foo.txt;2`

Filesystem Operations

Filesystems provide a standard interface to files and directories:

- Create a file or directory
- Delete a file or directory
- Open a file or directory – allows subsequent access
- Read, write, append to file contents
- Add or remove directory entries
- Close a file or directory – terminates access

What other features do filesystems provide?

- **Accounting and quotas** – prevent your classmates from hogging the disks
- **Backup** – some filesystems have a "$HOME/.backup" containing automatic snapshots
- **Indexing and search capabilities**
- **File versioning**
- **Encryption**
- **Automatic compression** of infrequently-used files

Should this functionality be part of the filesystem or built on top?

- Classic OS community debate: Where is the best place to put functionality?

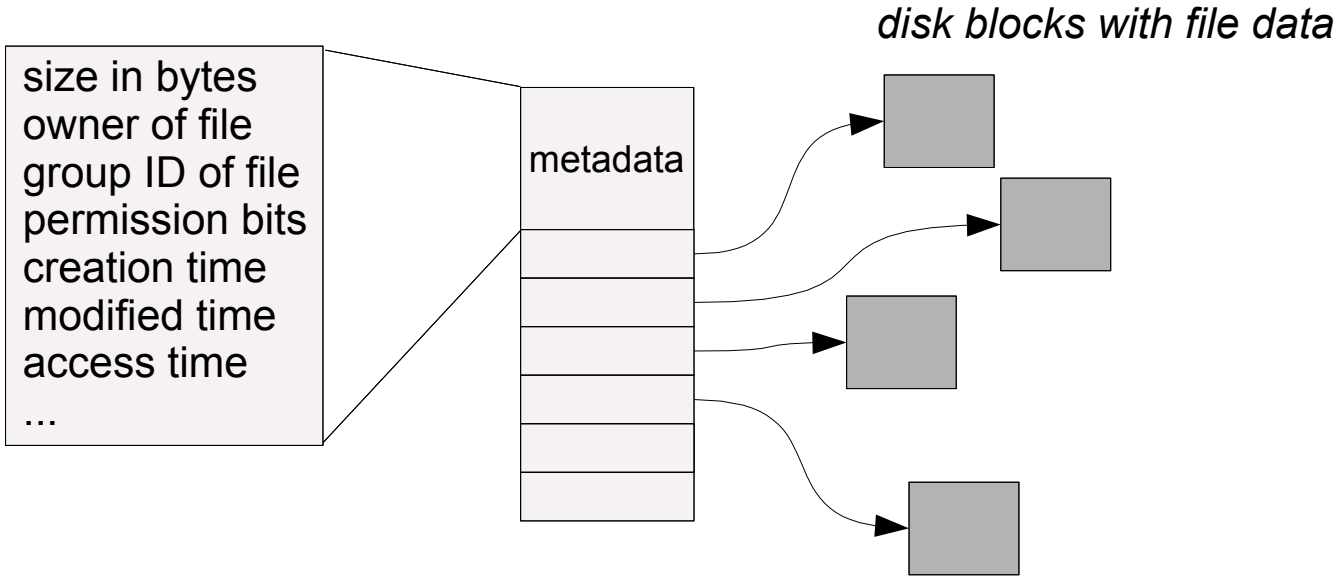
Basic Filesystem Structures

Every file and directory is represented by an **inode**

- Stands for “index node”

Contains two kinds of information:

- 1) Metadata describing the file's owner, access rights, etc.
- 2) Location of the file's blocks on disk



What's one obvious thing missing from the inode metadata?

A word on blocks vs. sectors...

Filesystems generally access data on disk in terms of **blocks**

But, recall the disk can only be accessed one **sector** at a time

Generally, the FS wants to access multiple sectors at once ...

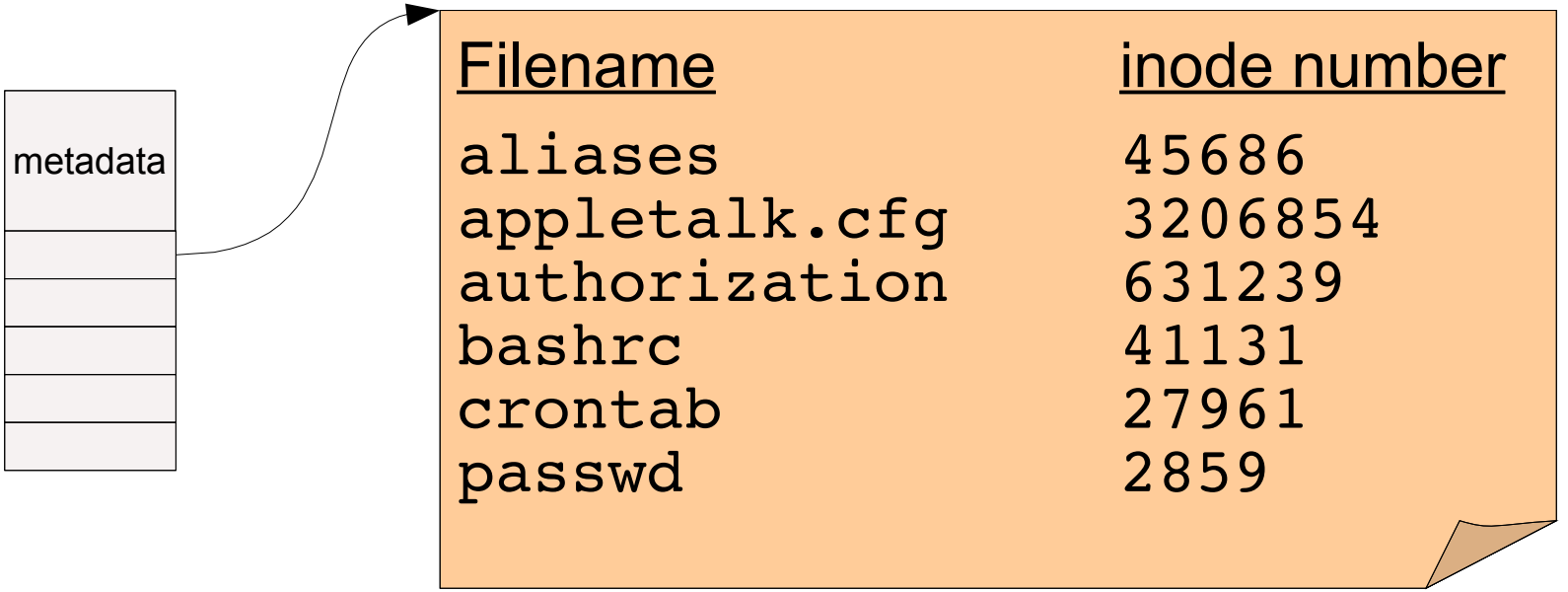
- Why??

Say sector size is 512 bytes, but filesystem block size is 4 KB.

- This means the block consists of 8 *contiguous* sectors on disk
- Translating from block ID to set of sector IDs is pretty trivial:
  - *sectors(block_id) = { block_id*8 , (block_id*8)+1, ... (block_id*8)+7 }*

Directories

A directory is a special kind of file that contains a list of *(filename, inode number)* pairs



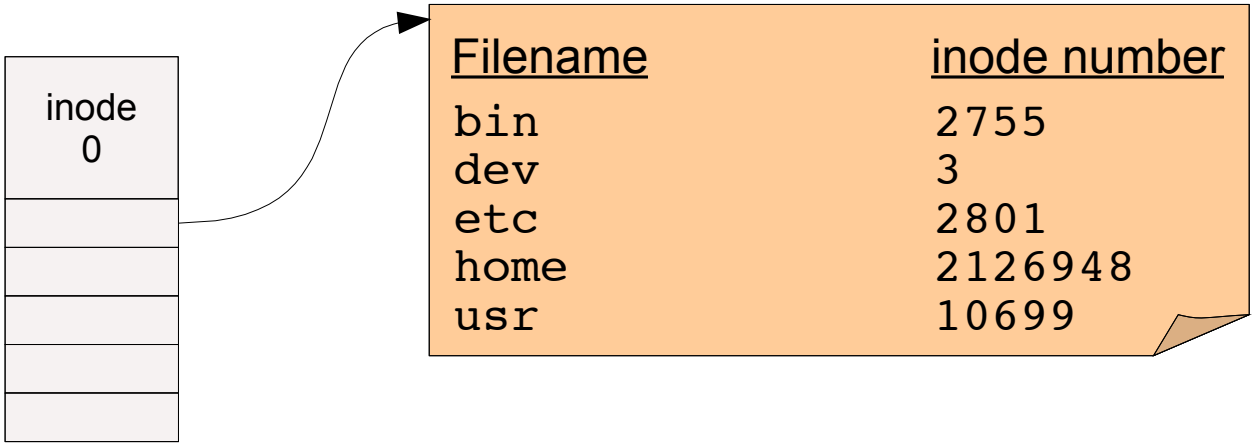
- These are the **contents** of the directory “file data” itself – NOT the directory's inode!
- Filenames (in UNIX) are not stored in the inode at all!

Two open questions:

- How do we find the root directory (“ / “ on UNIX systems)?
- How do we get from an inode number to the location of the inode on disk?

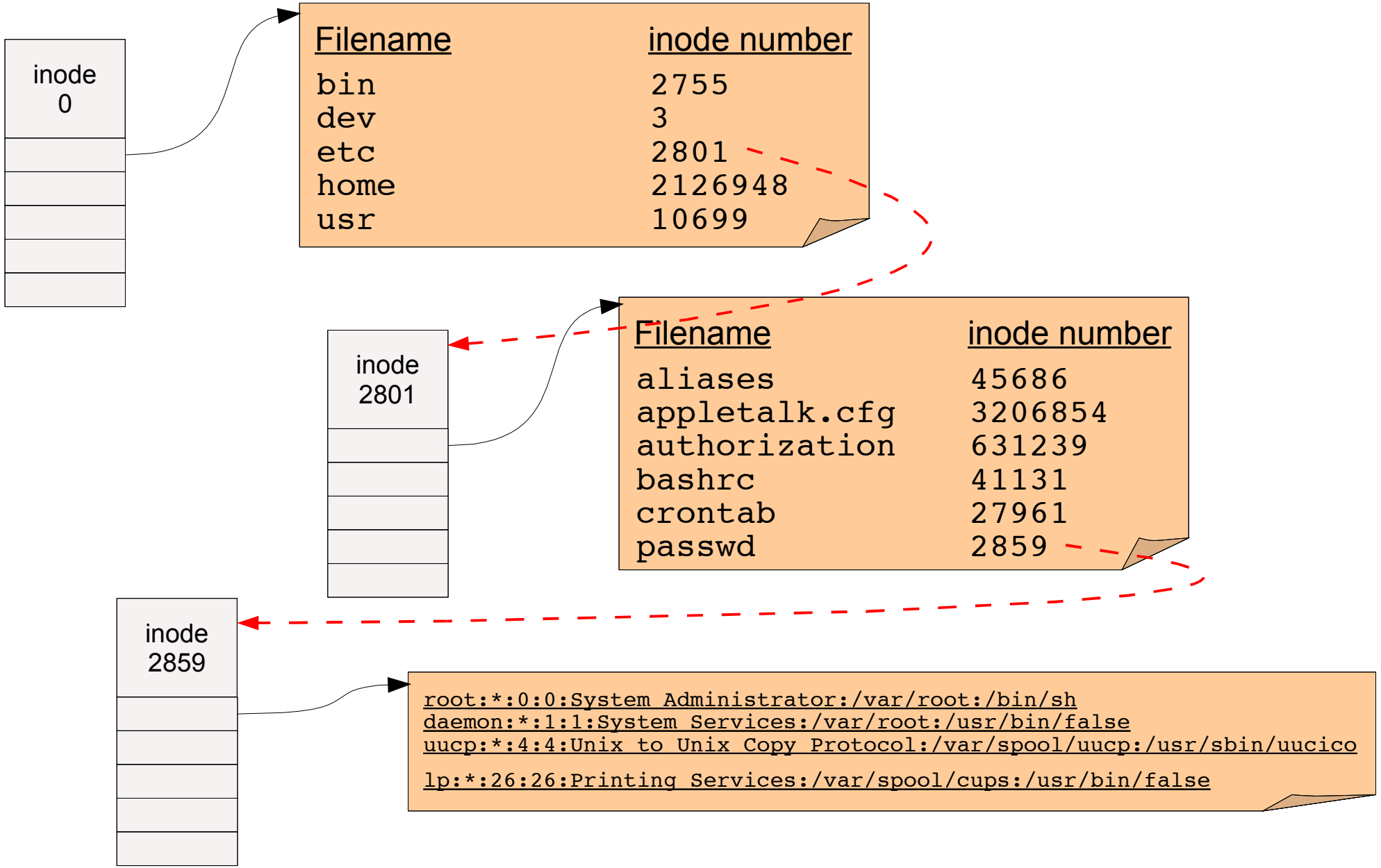
Pathname resolution

- The root directory is a special inode (usually numbered 0 or 1)



Pathname resolution

- To look up a pathname “/etc/passwd”, start at root directory and walk down chain of inodes...



Locating inodes on disk

All right, so directories tell us the *inode number* of a file.
How the heck do we find the inode itself on disk?

Basic idea: Top part of filesystem contains *all* of the inodes!

- inode number is just the “index” of the inode
- Easy to compute the block address of a given inode:
  - *block_addr(inode_num) = block_offset_of_first_inode + (inode_num * inode_size)*
- This implies that a filesystem has a *fixed* number of potential inodes
  - *This number is generally set when the filesystem is created*

- The **superblock** stores important metadata on filesystem layout, list of free blocks, etc.

Stupid directory tricks

Directories map filenames to inode numbers. What does this imply?

We can create multiple pointers to the same inode in *different* directories

- Or even the same directory with different filenames

In UNIX this is called a "hard link" and can be done using "ln"

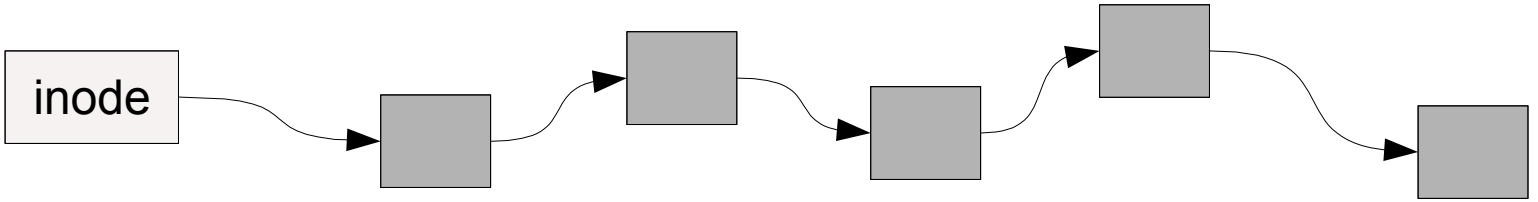
```
bash$ ls -i /home/foo
287663 /home/foo          (This is the inode number of "foo")

bash$ ln /home/foo /tmp/foo

bash$ ls -i /home/foo /tmp/foo
287663 /home/foo
287663 /tmp/foo
```

- "/home/foo" and "/tmp/foo" now refer to the **same file on disk**
  - *Not a copy! You will always see identical data no matter which filename you use to read or write the file.*
- Note: This is not the same as a "symbolic link", which only links one **filename** to another.

How should we organize blocks on disk?

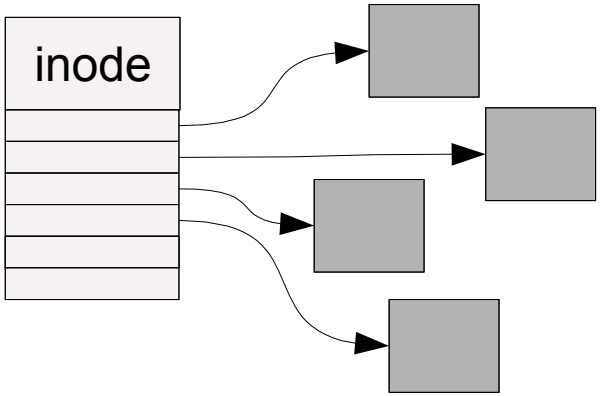
Very simple policy: A file consists of linked blocks

- inode points to the first block of the file
- Each block points to the next block in the file (just a linked list on disk)
  - *What are the advantages and disadvantages??*



Indexed files

- inode contains a list of block numbers containing the file
- Array is allocated when the file is created
  - *What are the advantages and disadvantages??*



Multilevel Indexed Files

inode contains a list of 10-15 *direct block pointers*

- First few blocks of file can be referred to by the inode itself

inode also contains a pointer to a *single indirect*, *double indirect*, and *triple indirect* blocks

- Allows file to grow to be incredibly large!!!