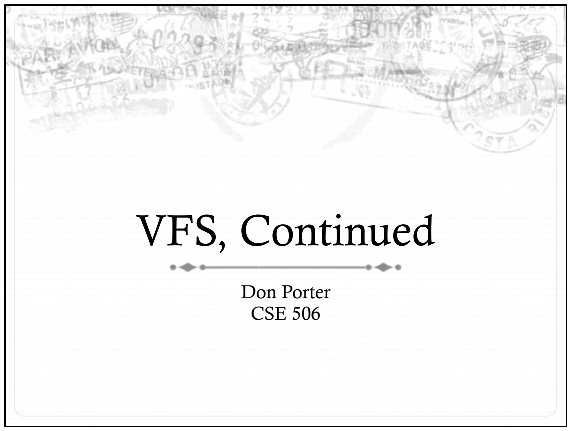
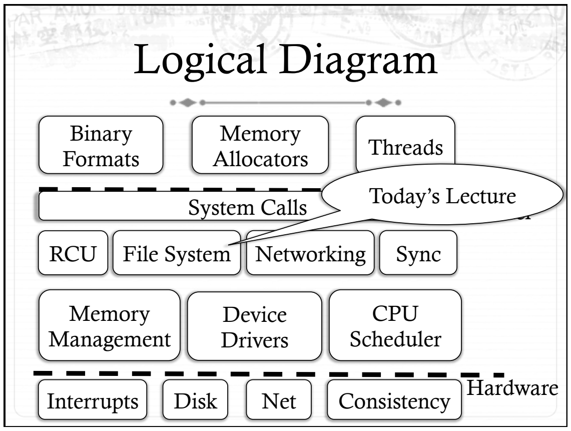


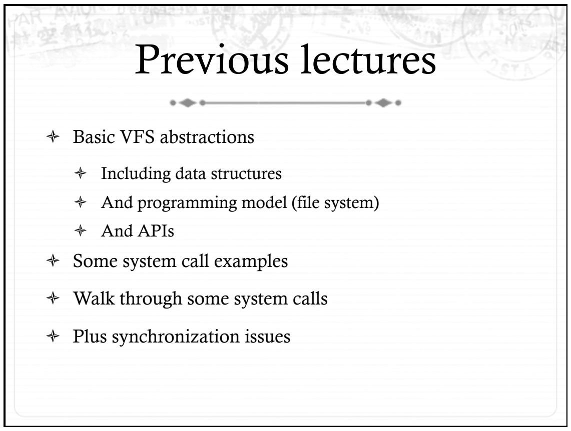
VFS, Continued

Don Porter
CSE 506



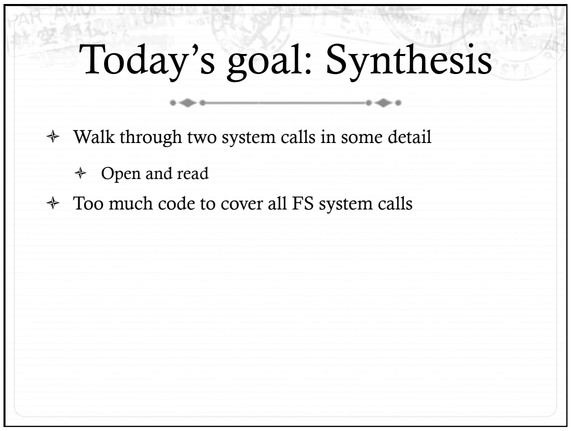
Logical Diagram

Binary Formats
Memory Allocators
Threads
System Calls
Today's Lecture
RCU
File System
Networking
Sync
Memory Management
Device Drivers
CPU Scheduler
Hardware
Interrupts
Disk
Net
Consistency



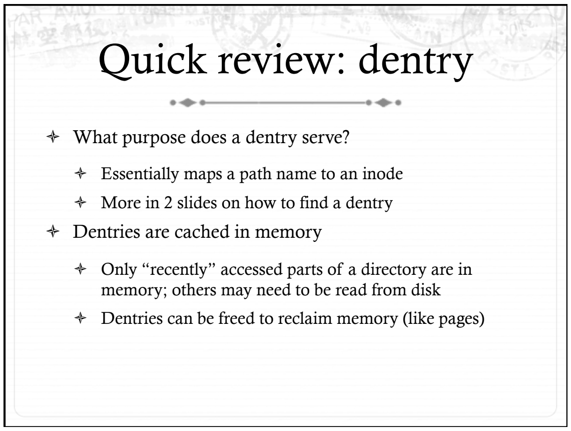
Previous lectures

- Basic VFS abstractions
  - Including data structures
  - And programming model (file system)
  - And APIs
- Some system call examples
- Walk through some system calls
- Plus synchronization issues



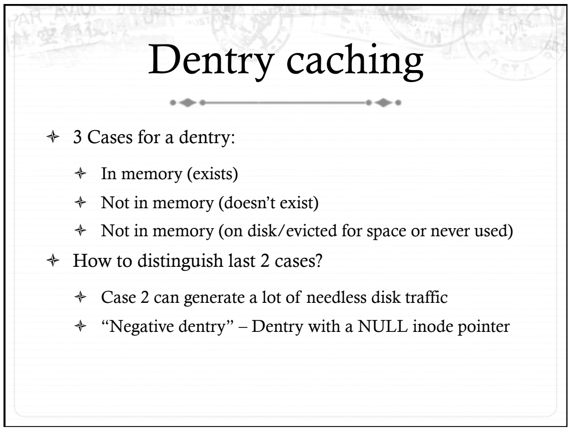
Today's goal: Synthesis

- Walk through two system calls in some detail
  - Open and read
- Too much code to cover all FS system calls



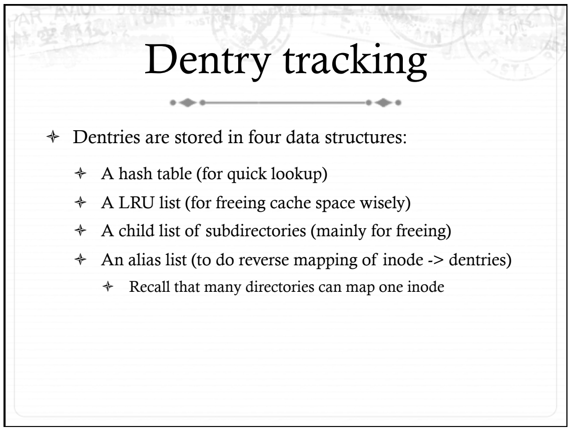
Quick review: dentry

- What purpose does a dentry serve?
  - Essentially maps a path name to an inode
  - More in 2 slides on how to find a dentry
- Dentries are cached in memory
  - Only "recently" accessed parts of a directory are in memory; others may need to be read from disk
  - Dentries can be freed to reclaim memory (like pages)



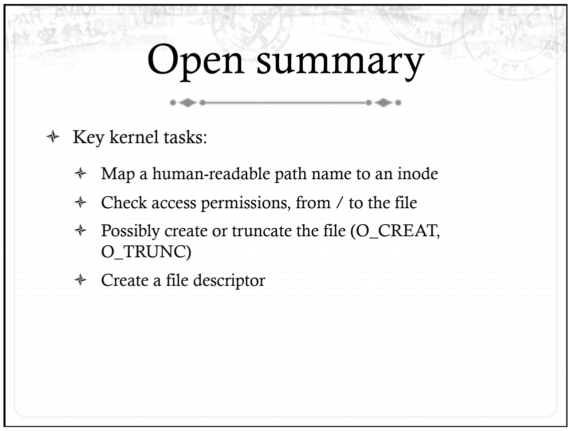
Dentry caching

- 3 Cases for a dentry:
  - In memory (exists)
  - Not in memory (doesn't exist)
  - Not in memory (on disk/evicted for space or never used)
- How to distinguish last 2 cases?
  - Case 2 can generate a lot of needless disk traffic
  - "Negative dentry" – Dentry with a NULL inode pointer



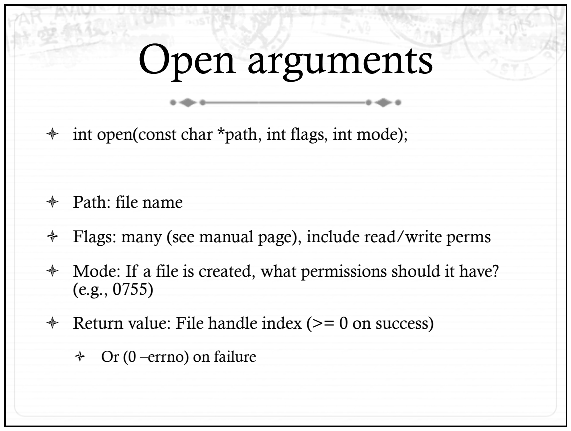
Dentry tracking

- Dentries are stored in four data structures:
  - A hash table (for quick lookup)
  - A LRU list (for freeing cache space wisely)
  - A child list of subdirectories (mainly for freeing)
  - An alias list (to do reverse mapping of inode -> dentries)
    - Recall that many directories can map one inode



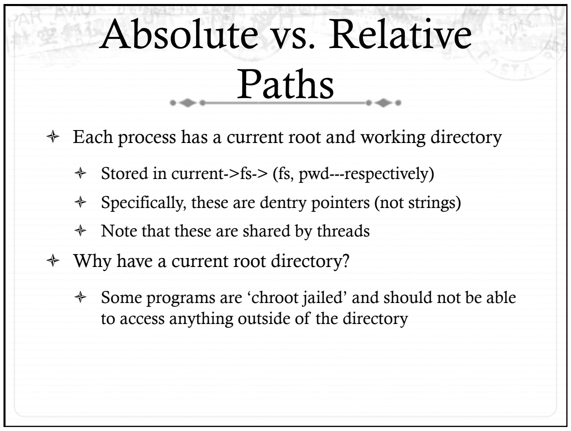
Open summary

- Key kernel tasks:
  - Map a human-readable path name to an inode
  - Check access permissions, from / to the file
  - Possibly create or truncate the file (O_CREAT, O_TRUNC)
  - Create a file descriptor



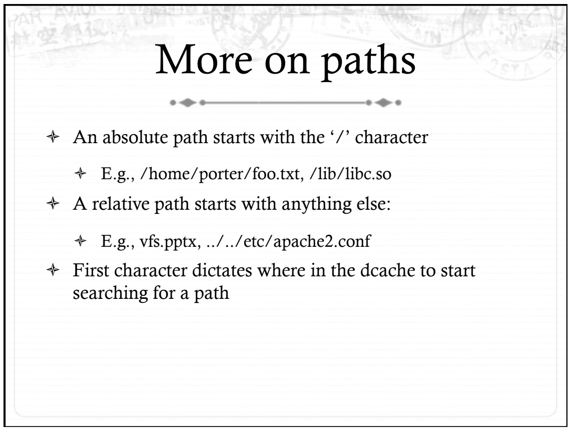
Open arguments

- int open(const char *path, int flags, int mode);
- Path: file name
- Flags: many (see manual page), include read/write perms
- Mode: If a file is created, what permissions should it have? (e.g., 0755)
- Return value: File handle index (>= 0 on success)
  - Or (0 –errno) on failure



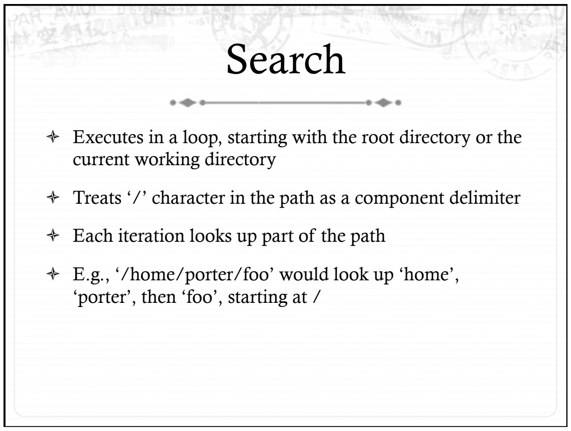
Absolute vs. Relative Paths

- Each process has a current root and working directory
  - Stored in current->fs-> (fs, pwd---respectively)
  - Specifically, these are dentry pointers (not strings)
  - Note that these are shared by threads
- Why have a current root directory?
  - Some programs are 'chroot jailed' and should not be able to access anything outside of the directory



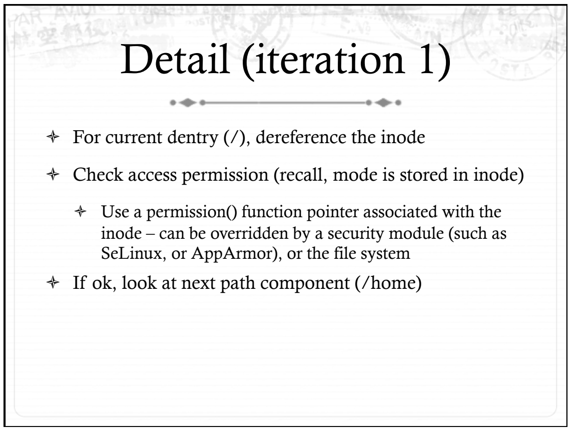
More on paths

- An absolute path starts with the '/' character
  - E.g., /home/porter/foo.txt, /lib/libc.so
- A relative path starts with anything else:
  - E.g., vfs.pptx, ../../etc/apache2.conf
- First character dictates where in the dcache to start searching for a path



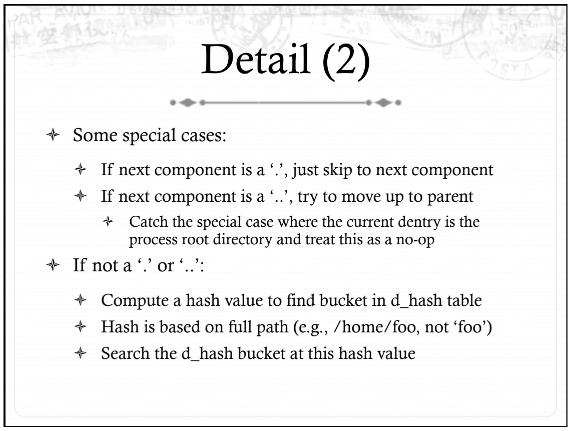
Search

- Executes in a loop, starting with the root directory or the current working directory
- Treats '/' character in the path as a component delimiter
- Each iteration looks up part of the path
- E.g., '/home/porter/foo' would look up 'home', 'porter', then 'foo', starting at /



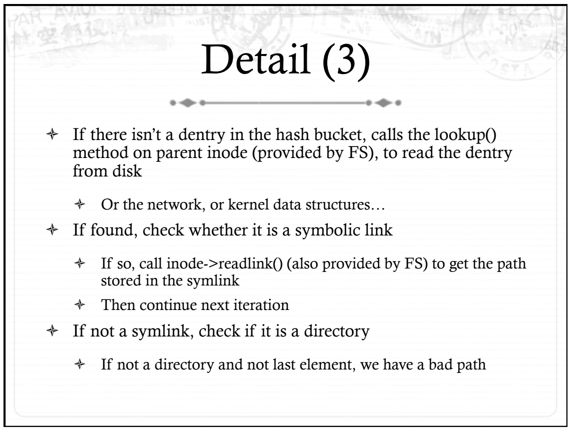
Detail (iteration 1)

- For current dentry (/), dereference the inode
- Check access permission (recall, mode is stored in inode)
  - Use a permission() function pointer associated with the inode – can be overridden by a security module (such as SeLinux, or AppArmor), or the file system
- If ok, look at next path component (/home)



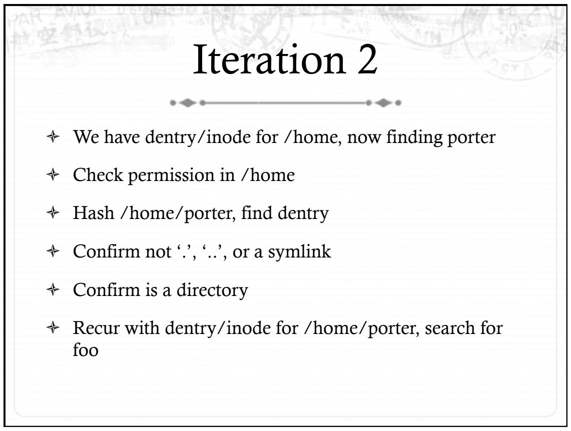
Detail (2)

- Some special cases:
  - If next component is a '.', just skip to next component
  - If next component is a '..', try to move up to parent
    - Catch the special case where the current dentry is the process root directory and treat this as a no-op
- If not a '.' or '..':
  - Compute a hash value to find bucket in d_hash table
  - Hash is based on full path (e.g., /home/foo, not 'foo')
  - Search the d_hash bucket at this hash value



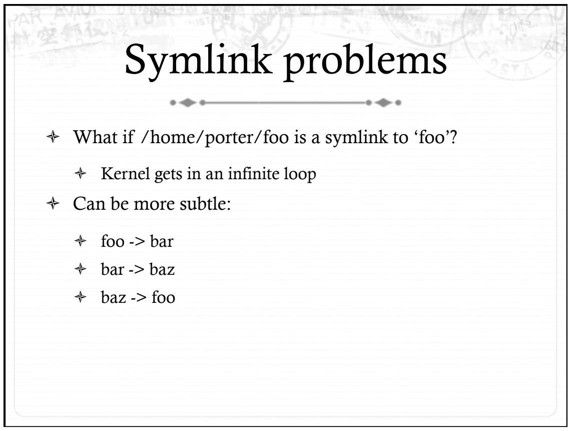
Detail (3)

- If there isn't a dentry in the hash bucket, calls the lookup() method on parent inode (provided by FS), to read the dentry from disk
  - Or the network, or kernel data structures…
- If found, check whether it is a symbolic link
  - If so, call inode->readlink() (also provided by FS) to get the path stored in the symlink
  - Then continue next iteration
- If not a symlink, check if it is a directory
  - If not a directory and not last element, we have a bad path



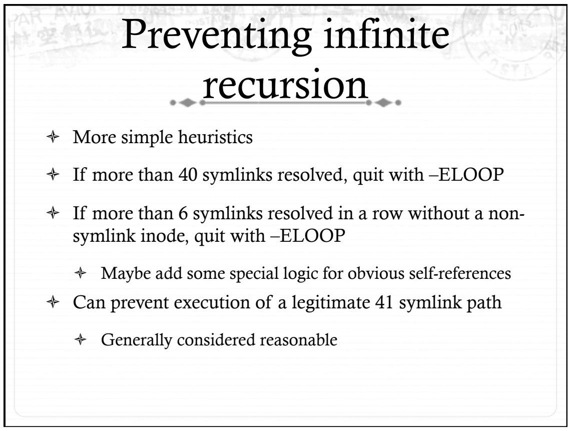
Iteration 2

- We have dentry/inode for /home, now finding porter
- Check permission in /home
- Hash /home/porter, find dentry
- Confirm not '.', '..', or a symlink
- Confirm is a directory
- Recur with dentry/inode for /home/porter, search for foo



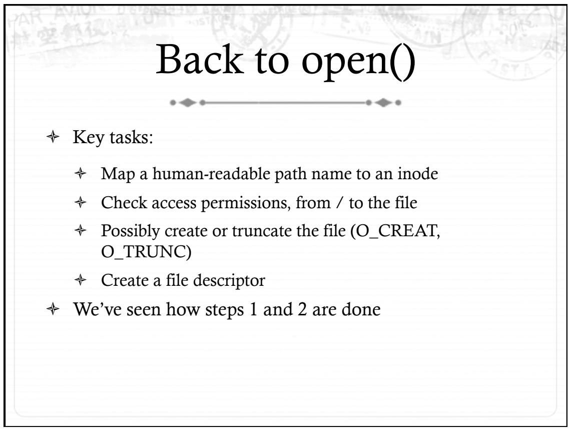
Symlink problems

- What if /home/porter/foo is a symlink to 'foo'?
  - Kernel gets in an infinite loop
- Can be more subtle:
  - foo -> bar
  - bar -> baz
  - baz -> foo



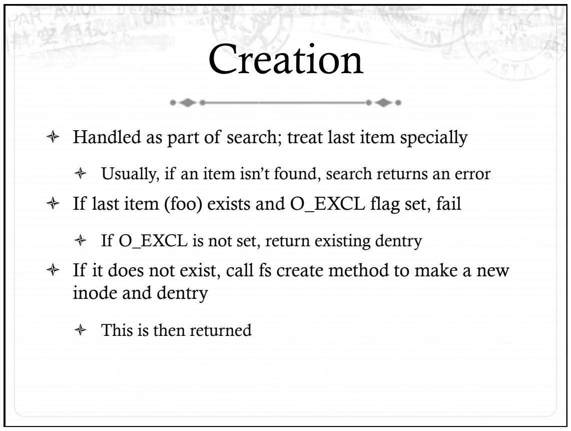
Preventing infinite recursion

- More simple heuristics
- If more than 40 symlinks resolved, quit with –ELOOP
- If more than 6 symlinks resolved in a row without a non-symlink inode, quit with –ELOOP
  - Maybe add some special logic for obvious self-references
- Can prevent execution of a legitimate 41 symlink path
  - Generally considered reasonable



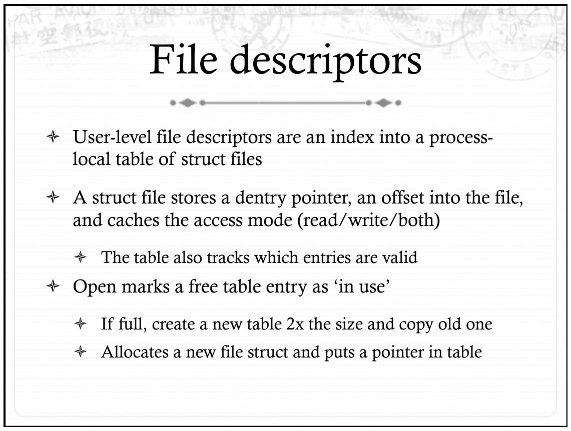
Back to open()

- Key tasks:
  - Map a human-readable path name to an inode
  - Check access permissions, from / to the file
  - Possibly create or truncate the file (O_CREAT, O_TRUNC)
  - Create a file descriptor
- We've seen how steps 1 and 2 are done



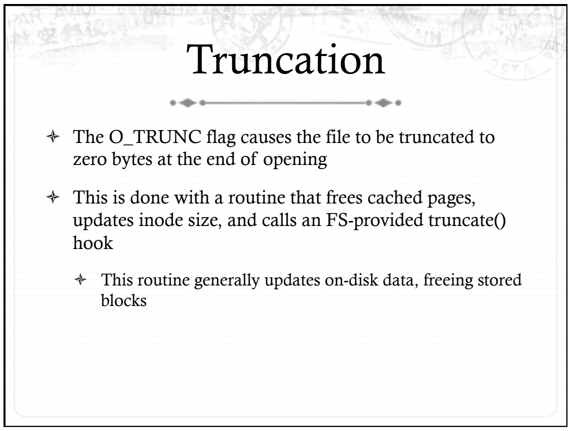
Creation

- Handled as part of search; treat last item specially
  - Usually, if an item isn't found, search returns an error
- If last item (foo) exists and O_EXCL flag set, fail
  - If O_EXCL is not set, return existing dentry
- If it does not exist, call fs create method to make a new inode and dentry
  - This is then returned



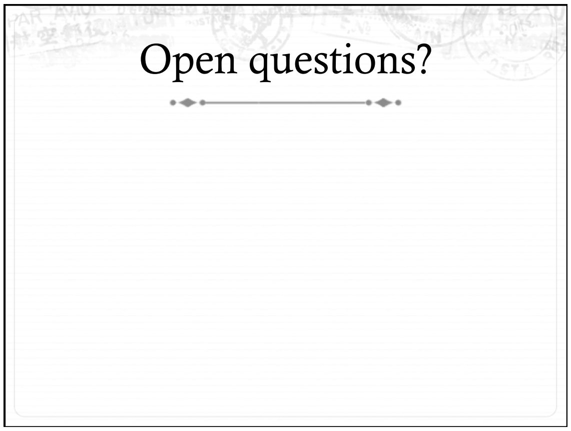
File descriptors

- User-level file descriptors are an index into a process-local table of struct files
- A struct file stores a dentry pointer, an offset into the file, and caches the access mode (read/write/both)
  - The table also tracks which entries are valid
- Open marks a free table entry as 'in use'
  - If full, create a new table 2x the size and copy old one
  - Allocates a new file struct and puts a pointer in table

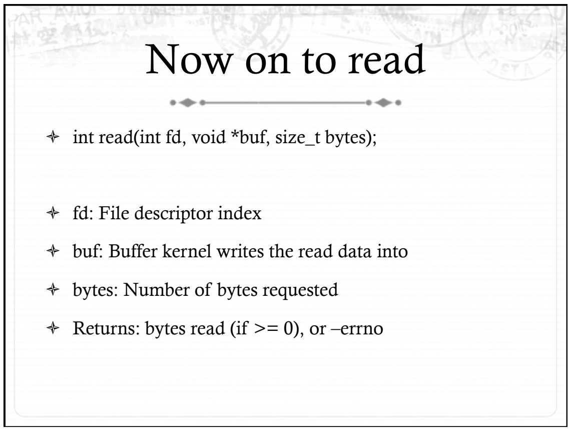


Truncation

- The O_TRUNC flag causes the file to be truncated to zero bytes at the end of opening
- This is done with a routine that frees cached pages, updates inode size, and calls an FS-provided truncate() hook
  - This routine generally updates on-disk data, freeing stored blocks

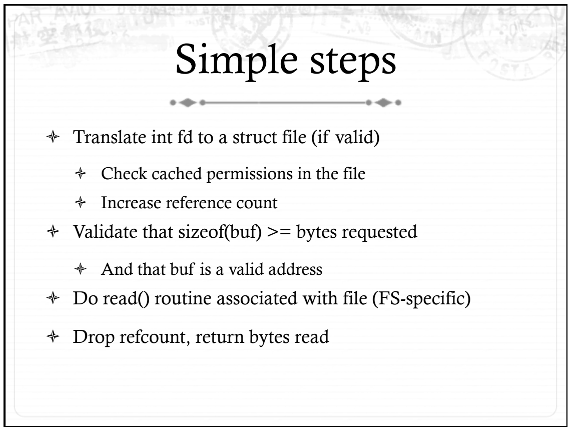


Open questions?



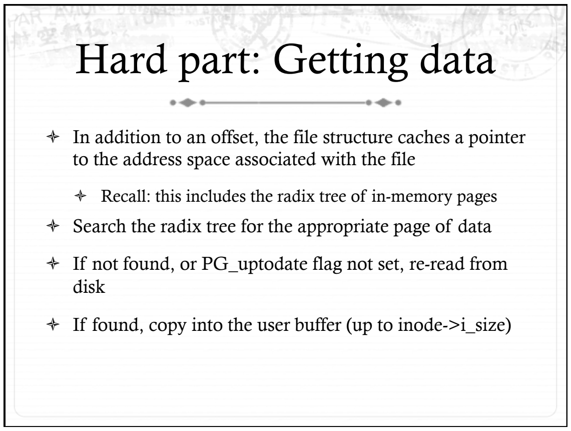
Now on to read

- int read(int fd, void *buf, size_t bytes);
- fd: File descriptor index
- buf: Buffer kernel writes the read data into
- bytes: Number of bytes requested
- Returns: bytes read (if >= 0), or –errno



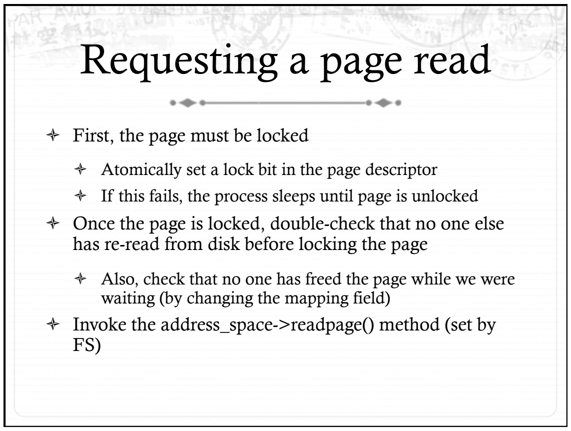
Simple steps

- Translate int fd to a struct file (if valid)
  - Check cached permissions in the file
  - Increase reference count
- Validate that sizeof(buf) >= bytes requested
  - And that buf is a valid address
- Do read() routine associated with file (FS-specific)
- Drop refcount, return bytes read



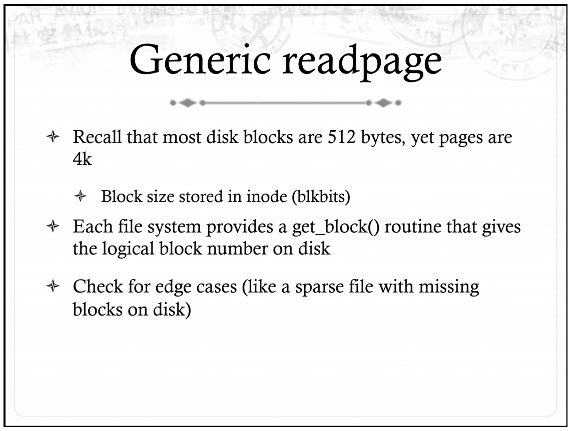
Hard part: Getting data

- In addition to an offset, the file structure caches a pointer to the address space associated with the file
  - Recall: this includes the radix tree of in-memory pages
- Search the radix tree for the appropriate page of data
- If not found, or PG_uptodate flag not set, re-read from disk
- If found, copy into the user buffer (up to inode->i_size)



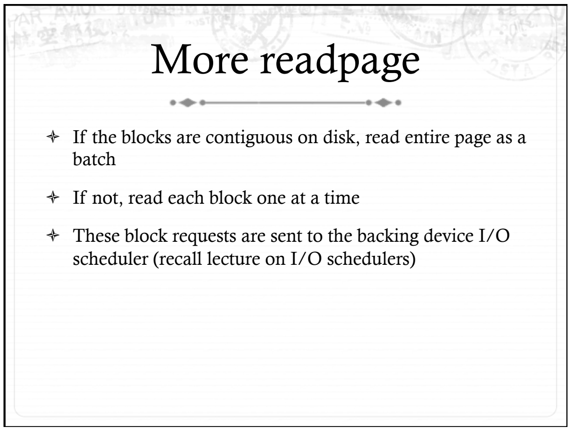
Requesting a page read

- First, the page must be locked
  - Atomically set a lock bit in the page descriptor
  - If this fails, the process sleeps until page is unlocked
- Once the page is locked, double-check that no one else has re-read from disk before locking the page
  - Also, check that no one has freed the page while we were waiting (by changing the mapping field)
- Invoke the address_space->readpage() method (set by FS)



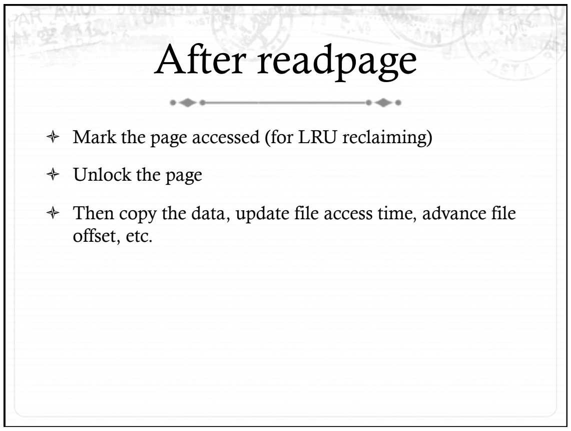
Generic readpage

- Recall that most disk blocks are 512 bytes, yet pages are 4k
  - Block size stored in inode (blkbits)
- Each file system provides a get_block() routine that gives the logical block number on disk
- Check for edge cases (like a sparse file with missing blocks on disk)



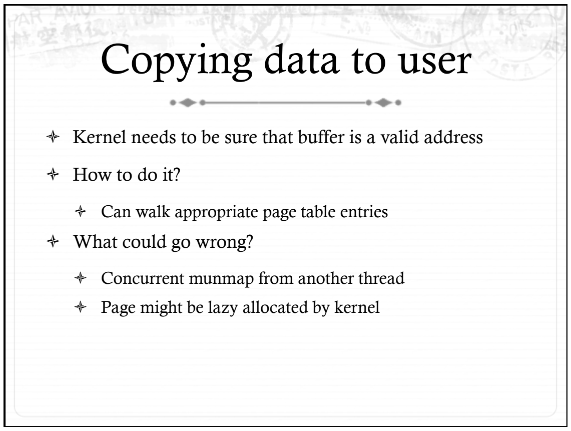
More readpage

- If the blocks are contiguous on disk, read entire page as a batch
- If not, read each block one at a time
- These block requests are sent to the backing device I/O scheduler (recall lecture on I/O schedulers)



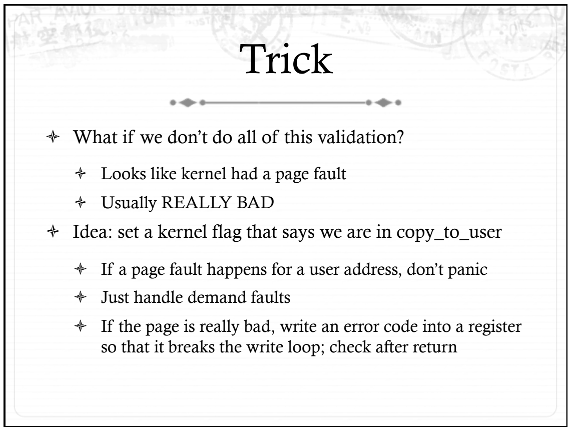
After readpage

- Mark the page accessed (for LRU reclaiming)
- Unlock the page
- Then copy the data, update file access time, advance file offset, etc.



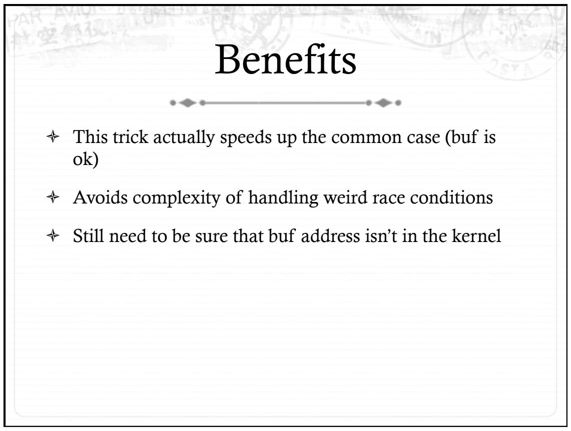
Copying data to user

- Kernel needs to be sure that buffer is a valid address
- How to do it?
  - Can walk appropriate page table entries
- What could go wrong?
  - Concurrent munmap from another thread
  - Page might be lazy allocated by kernel



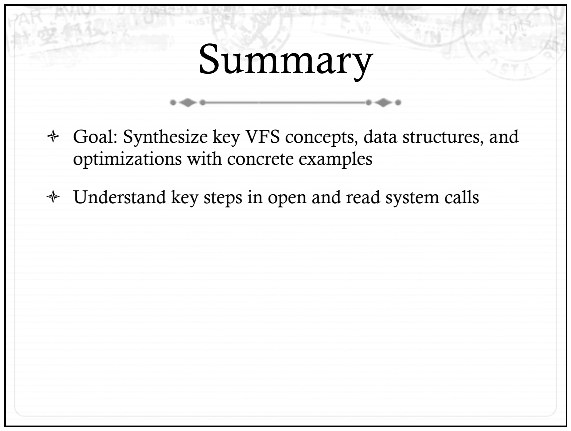
Trick

- What if we don't do all of this validation?
  - Looks like kernel had a page fault
  - Usually REALLY BAD
- Idea: set a kernel flag that says we are in copy_to_user
  - If a page fault happens for a user address, don't panic
  - Just handle demand faults
  - If the page is really bad, write an error code into a register so that it breaks the write loop; check after return



Benefits

- This trick actually speeds up the common case (buf is ok)
- Avoids complexity of handling weird race conditions
- Still need to be sure that buf address isn't in the kernel



Summary

- Goal: Synthesize key VFS concepts, data structures, and optimizations with concrete examples
- Understand key steps in open and read system calls