CS 3204
Operating Systems

Project 4 Help Session

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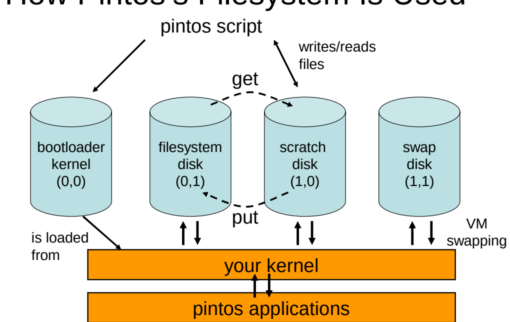
Project 4

- Final Task: Build a simple file system!
  - "Easier than Project 3" – maybe
  - But: definitely more lines of code for complete solution
    - And no room for errors – it's a filesystem, after all!
- Subtasks:
  - Buffer Cache
  - Extensible Files
  - Subdirectories

  } Synchronization
- Again open-ended design problem

How Pintos's Filesystem Is Used



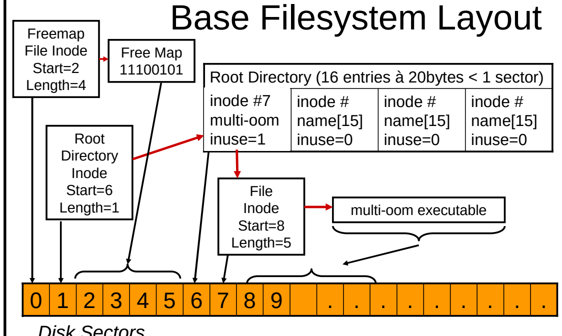
Project Requirements

- Your kernel must
  - Be able to format the disk when asked (write structures for an initial, empty filesystem on it)
  - Be able to copy files onto it when called from fsutil_put() (which happens before process_execute is called for the first time) – and copy files off of it
  - Be able to support required system calls
    - New calls: mkdir, readdir, inumber, isdir, chdir
  - Be able to write data back to persistent storage
  - Be able to copy files from it when called from fsutil_get()

Project Requirements (cont'd)

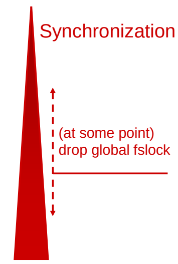
- Only your kernel writes to and reads from your disk
- Don't have to follow any prescribed layout
- Can pick any layout strategy that doesn't suffer from external fragmentation and can grow files
  - recommend Unix-style direct, single indirect, double indirect inode layout – but feel free to be creative
- Can pick any on-disk inode layout (you must design your own, the existing one does not work)
- Can pick any directory layout (although existing directory layout suffices)

Base Filesystem Layout



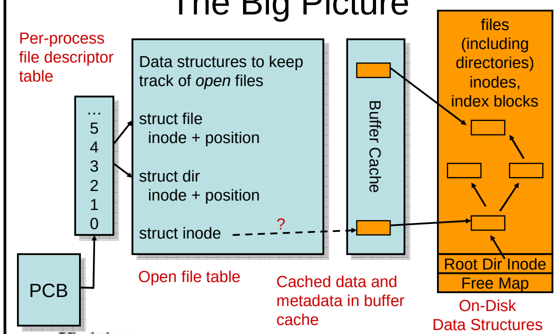
Recommended Order

1. Buffer Cache – implement & pass all regression tests
2. Extensible Files – implement & pass file growth tests
3. Subdirectories
4. Miscellaneous: cache readahead, reader/writer fairness, deletion etc.

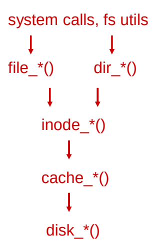


You should think about synchronization throughout

The Big Picture

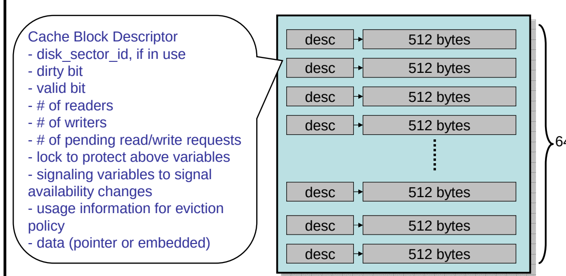


Buffer Cache (1): Overview



- Should cache accessed disk blocks in memory
- Buffer cache should be only interface to disk: all disk accesses should go through it
  - Ensures consistency!

Buffer Cache (2): Design



Buffer Cache (3): Interface

```
// cache.h
struct cache_block;                    // opaque type
// reserve a block in buffer cache dedicated to hold this sector
// possibly evicting some other unused buffer
// either grant exclusive or shared access
struct cache_block * cache_get_block (disk_sector_t sector, bool exclusive);
// release access to cache block
void cache_put_block(struct cache_block *b);
// read cache block from disk, returns pointer to data
void *cache_read_block(struct cache_block *b);
// fill cache block with zeros, returns pointer to data
void *cache_zero_block(struct cache_block *b);
// mark cache block dirty (must be written back)
void cache_mark_block_dirty(struct cache_block *b);
// not shown: initialization, readahead, shutdown
```


Buffer Cache (4): Notes

- Interface is just a suggestion
- Definition as static array of 64 blocks ok
- Use structure hiding (don't export cache_block struct outside cache.c)
- Must have explicit per-block locking (can't use Pintos's lock since they do not allow for multiple readers)
- Should provide solution to multiple reader, single writer synchronization problem that starves neither readers nor writers:
  - Use condition variables!
- Eviction: use LRU (or better)
  - Can use Pintos list_elem to implement eviction policy, such as LRU via stack implementation

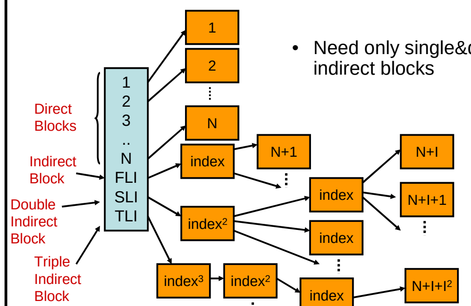
Buffer Cache (5): Prefetching

```
b = cache_get_block(n, _);
cache_read_block(b);
cache_readahead(next(n));
```

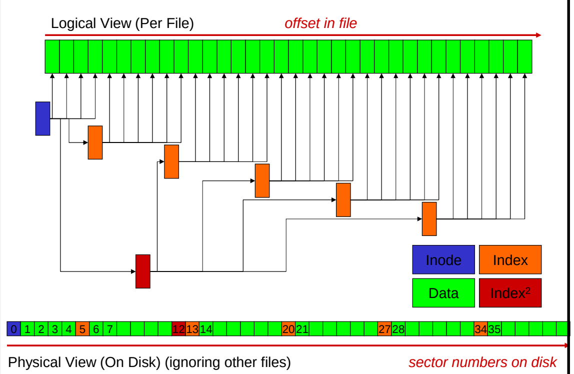
```
queue q;
cache_readahead(sector s) {
   q.lock();
   q.add(request(s));
   qcond.signal();
   q.unlock();
}
cache_readahead_daemon() {
  while (true) {
   q.lock();
   while (q.empty())
     qcond.wait();
   s = q.pop();
   q.unlock();
   read sector(s);
  }
}
```

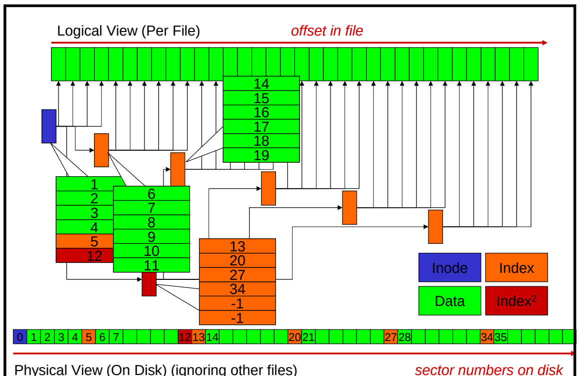
- Would like to bring next block to be accessed into cache before it's accessed
- Must be done in parallel
  - use daemon thread and producer/consumer pattern
- Note: next(n) not always equal to n+1
- Don't initiate read_ahead if next(n) is unknown or would require another disk access to find out

Multi-Level Indices



- Need only single&double indirect blocks





Multi-Level Indices (cont'd)

- How many levels do we need?
- Max Disk size: 8MB = 16,384 Sectors
- Assume sector number takes 2 or 4 bytes, can store 256 or 128 in one sector
- Filesize(using only direct blocks) < 256
- Filesize(direct + single indirect block) < 2*256
- File (direct + single indirect + double indirect) < 2*256 + 256^2 = 66,048

Files vs. Inode vs. Directories

- Offset management in struct file etc. should not need any changes
  - If there's no sharing of struct file/dir instances between processes, then there are no concurrency issues since Pintos's processes are single-threaded!
- You have to completely redesign struct inode_disk to fit your layout
- You will have to change struct inode
  - struct inode are necessarily shared between processes – since they represent files on disk!
  - struct inode can no longer embed struct inode_disk (inode_disk should be stored in buffer cache)

struct inode vs struct inode_disk

redesign for indexed approach

```
struct in
  {
    disk_sector_t start; /* First data sector. */
    off_t length;         /* File size in bytes. */
    unsigned magic;       /* Magic number. */
    uint32_t unused[125];/* Not used. */
  };
```

store in buffer cache

```
/* In-memory inode. */
struct inode
  {
    struct list_elem elem; /* Element in inode list. */
    disk_sector_t sector;  /* Sector number of disk location. */
    int open_cnt;           /* Number of openers. */
    bool removed;           /* True if deleted, false otherwise. */
    int deny_wr             writes ok, >0: deny writes. */
    struct inode_disk data; /* Inode content. */
  };
```


Extending a file

- Seek past end of file & write extends a file
- Space in between is filled with zeros
  - Can extend sparsely (use “nothing here” marker in index blocks)
- Consistency guarantee on file extension:
  - If A extends & B reads, B may read all, some, or none of what A wrote
    - But never something else!
  - Implication: do not update & unlock metadata structures (e.g., inode length) until data is in buffer cache

Subdirectories

- Support nested directories (work as usual)
- Requires:
  - Keeping track of type of file in on-disk inode
  - Distinction between file descriptors in syscall layer – e.g., must reject write() to open directory
- Should only require minor changes to how individual directories are implemented (e.g., as a linear list – should be able to reuse existing code)
  - Must implement “.” and “..” – simple solution is to create the two entries on disk when a directory is created.
  - Must support path names such as ///a/b/../c/./d
  - Path components can remain <= 14 in length
  - Once file growth works, directory growth should work “automatically”
- Implement system calls: readdir, mkdir, rmdir
  - Need a way to test whether directory is empty
  - readdir() should not return . and ..

Subdirectories: Lookup

- Implement absolute & relative paths
- Use strtok_r to split path
  - Recall that strtok_r() destroys its argument - make sure you create copy if necessary
  - Make sure you operate on copied-in string
- Walk hierarchy, starting from root directory (for absolute paths); current directory (for relative paths)
- All components except last must exist & be directories
- Make sure you don’t leak memory, or you fail dir-vine.

Current Directory

- Need to keep track of current directory
  - in struct thread
  - be aware of possible initialization order issues: before first task starts, get/put must work but process_execute hasn’t been called
- When an attempt is made to delete the current directory, or any open directory, either
  - Reject
  - Allow, but don’t allow further use

Synchronization Issues (1)

- Always consider: what lock (or other protection mechanism) protects which field:
  - If lock L protects data D, then all accesses to D must be within lock_acquire(&L); …. Update D …; lock_release(&L);
- Embed locks in objects or define as static variables where appropriate (struct inode)
- For buffer cache entries, must build new synchronization structure (Single Writer/Multiple Reader lock without starvation) on top of existing ones (locks + condition variables)
- For directories, can use lock on underlying inode directly to guarantee exclusive access

Synchronization Issues (2)

- Should be fine-grained: independent operations should proceed in parallel, for example
  - Don't lock entire buffer cache when waiting for read/write access of individual buffer cache entry
  - Example: don't lock entire path resolution component when looking up file along /a/b/c/d
  - Files should support multiple readers & writers
    - Data writes do not require exclusive access to buffer cache block holding the data!
  - Process removing a file in directory A should not wait for removing file in directory B
- For full credit, must have dropped global fs lock
  - Can't see whether any of this works until you have done so

Free Map Management

- Can leave almost unchanged
- Read from disk on startup, flush on shutdown
- Instead of allocating n sectors at file creation time, now allocate 1 sector at a time, and only when file is growing
  - Implement extents for extra performance + credit
- But: must still support creating files that have an initial size greater than 0; easy to do:
  - If **file_create("…", m)** is called with m > 0, simulate **write_at(offset=m, 1byte of data);** to expand to appropriate length
- Don't forget to protect free_map() with lock

Grading Hints

- Extended tests won't fully pass until file growth + subdirectories are sufficiently implemented such that 'tar' works.
- Core parts (majority of credit) of assignment are
  - Buffer cache
  - Extensible files
  - Subdirectories
- For this assignment, credit for regression tests will depend on how many parts (n = 0, 1, 2) of the assignment you've implemented
  - Credit for regression tests = Reported TestScore * n/3
  - Don't get credit for resubmitting P2.
- Tests will not detect
  - If you keep global fslock or not
  - If you have a buffer cache
  - TAs will grade those aspects by inspection/reading your design document
- Good Luck!