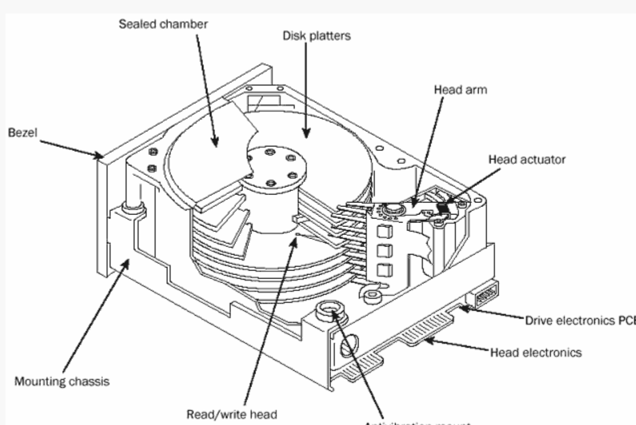
What Disks Look Like

Specifications Configuration	Parallel-ATA	Serial-ATA
Interface	PATA-133	SATA 3.0Gb/s
Capacity (GB) [1]	500 / 400 / 320 / 250	←
Data heads (physical)	6 / 6 / 4 / 4	←
Data disks	3 / 3 / 2 / 2	←
Performance		
Data buffer [2]	8 MB	16 MB / 8 MB
Rotational speed (rpm)	7,200	←
Media transfer rate (max. Mbits/sec)	998	←
Interface transfer rate (max. MB/sec)	133	300
Average seek time (ms) (read, typical) [3]	8.5	←
Reliability		
Error rate (non-recoverable)	1 in 10E14	←
Start/stops (at 40° C)	50,000	←
Availability [4]	24/7	←

Hitachi Deskstar T7K500 SATA

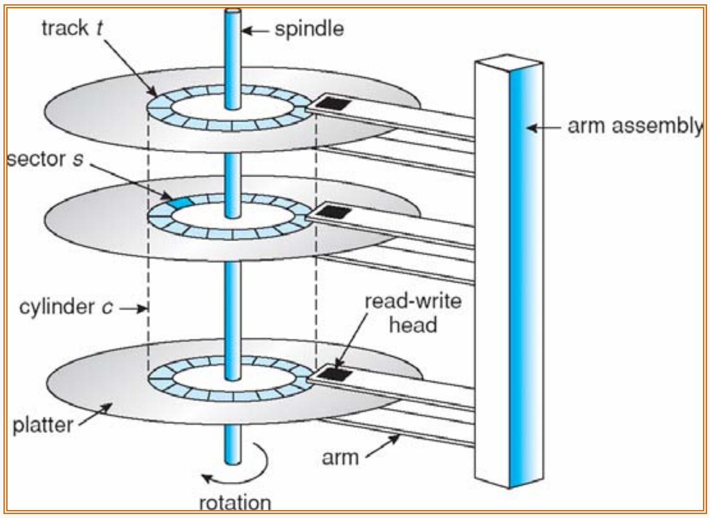
Disk Schematics



See narrated flash animation at
http://cis.poly.edu/cs2214rvs/disk.swf

Source: Micro House PC Hardware Library Volume I: Hard Drives

Tracks, Sectors, Cylinders



Typical Disk Parameters

2-30 heads (2 per platter)
- Modern disks: no more than 4 platters

Diameter: 2.5” – 14”

Capacity: 20MB-500GB

Sector size: 64 bytes to 8K bytes
- Most PC disks: 512 byte sectors

700-20480 tracks per surface

16-1600 sectors per track

The OS perspective

Disks are big & slow - compared to RAM

Access to disk requires
- Seek (move arm to track) – to cross all tracks anywhere from 20-50ms, on average takes 1/3.
- Rotational delay (wait for sector to appear under track) 7,200rpm is 8.3ms per rotation, on average takes ½: 4.15ms rot delay
- Transfer time (fast: 512 bytes at 998 Mbit/s is about 3.91us)

Seek+Rot Delay dominates

Random Access is expensive
- and unlikely to get better

Consequence:
- avoid seeks
- seek to short distances
- amortize seeks by doing bulk transfers

Disk Scheduling

Can use priority scheme

Can reduce avg access time by sending requests to disk controller in certain order
- Or, more commonly, have disk itself reorder requests

SSTF: shortest seek time first
- Like SJF in CPU scheduling, guarantees minimum avg seek time, but can lead to starvation

SCAN: "elevator algorithm"
- Process requests with increasing track numbers until highest reached, then decreasing etc. – repeat

Variations:
- LOOK – don't go all the way to the top without passengers
- C-SCAN: - only take passengers when going up

Accessing Disks

Sector is the unit of atomic access

Writes to sectors should always complete, even if power fails

Consequence of sector granularity:

- Writing a single byte requires read-modify-write

```
void set_byte(off_t off, char b) {
    char buffer[512];
    disk_read(disk, off/DISK_SECTOR_SIZE, buffer);
    buffer[off % DISK_SECTOR_SIZE] = b;
    disk_write(disk, off/DISK_SECTOR_SIZE, buffer);
}
```


Disk Caching – Buffer Cache

How much memory should be dedicated for it?

- In older systems (& Pintos), set aside a portion of physical memory
- In newer systems, integrated into virtual memory system: *e.g.*, page cache in Linux

How should eviction be handled?

How should prefetching be done?

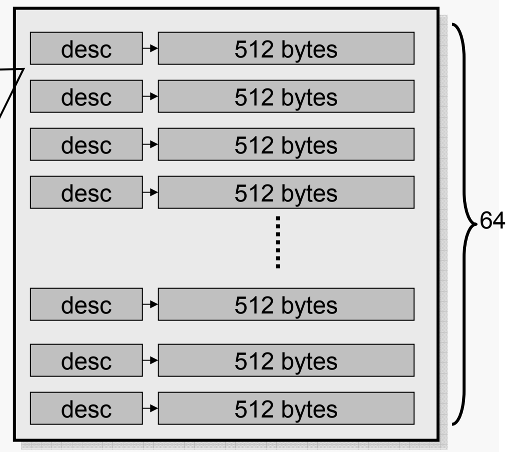
How should concurrent access be mediated (multiple processes may be attempting to write/read to same sector)?

- How is consistency guaranteed? (All accesses must go through buffer cache!)

What write-back strategy should be used?

Buffer Cache in Pintos

Cache Block Descriptor
- disk_sector_id, if in use
- dirty bit
- valid bit
- # of readers
- # of writers
- # of pending read/write requests
- lock to protect above variables
- signaling variables to signal availability changes
- usage information for eviction policy
- data (pointer or embedded)



A Buffer Cache 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 Rationale

Compare to buffer pool assignment in CS2604

Differences:

```
class BufferPool { // (2) Buffer Passing
public:
  virtual void* getblock(int block) = 0;
  virtual void dirtyblock(int block) = 0;
  virtual int blocksize() = 0;
};
```

Do not combine allocating a buffer (a resource management decision) with loading the data into the buffer from file (which is not always necessary)

Provide a way for buffer user to say they're done with the buffer

Provide a way to share buffer between multiple users

More efficient interface (opaque type instead of block idx saves lookup, constant size buffers)

Buffer Cache Sizing

Simple approach

- Set aside part of physical memory for buffer cache/use rest for virtual memory pages as page cache – evict buffer/page from same pool

Disadvantage: can't use idle memory of other pool - usually use unified cache subject to shared eviction policy

Windows allows user to limit buffer cache size

Problem:

- Bad prediction of buffer caches accesses can result in poor VM performance (and vice versa)

Buffer Cache Replacement

Similar to VM Page Replacement, differences:
- Can do exact LRU (because user must call cache_get_block()!)
- But LRU hurts when long sequential accesses – should use MRU (most recently used) instead.

Example reference string: ABCDABCDABCD, can cache 3:
- LRU causes 12 misses, 0 hits, 9 evictions
- How many misses/hits/evictions with MRU?

Also: not all blocks are equally important, benefit from some hits more than from others

Buffer Cache Writeback Strategies

Write-Through:
- Good for floppy drive, USB stick
- Poor performance – every write causes disk access

(Delayed) Write-Back:
- Makes individual writes faster – just copy & set bit
- Absorbs multiple writes
- Allows write-back in batches

Problem: what if system crashes before you've written data back?
- Trade-off: performance in no-fault case vs. damage control in fault case
- If crash occurs, order of write-back can matter

Writeback Strategies (2)

Must write-back on eviction (naturally)

Periodically (every 30 seconds or so)

When user demands:

- fsync(2) writes back all modified data belonging to one file – database implementations use this
- sync(1) writes back entire cache

Some systems guarantee write-back on file close

Buffer Cache Prefetching

Would like to bring next block to be accessed into cache before it's accessed

- Exploit "Spatial locality"

Must be done in parallel

- use daemon thread and producer/consumer pattern

Note: next(n) not always equal to n+1

- although we try for it – via clustering to minimize seek times

Don't initiate read_ahead if next(n) is unknown or would require another disk access to find out

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