ECE 571 – Advanced Microprocessor-Based Design Lecture 21

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Announcements

- HW#10 was posted, ARM readings

Disk Storage

- First disk, IBM, 1950s (size of two refrigerators, 3.75MB), oxide was similar to paint used on golden gate bridge, 1s access time
- At the time already had tape
- Disk vs Disc (usually magnetic vs optical)
- PATA/SATA/SCSI/USB

Disk Storage

- Originally CHS (cylinder/head/sector)
- Now LBA (logical block access)
- Constant linear velocity (mostly CDs) – same speed no matter where track is. More data on outer tracks
- Constant angular velocity – HDD and FDD
- Audio/Video disks often one big spiral track, hard disks usually separate tracks

Magnetic Storage

- Magnetism to store onto drives
- Non-volatile
- Historical
  - Wire recording (early 1900s)
  - Magnetic tape (analog, 1928)
  - Magnetic drum – story of Mel
  - Core memory, Core rope
  - Twistor? Bubble memory?

Magnetism

- Magnetic domains. Start out random, but can be arranged by external field to line up, making much stronger field.
- This is not a minimal energy config, but very stable
- Temperature can cause to disappear, at Curie point

Hard Disk

- Rigid disk, spinning
  Originally aluminum, now more exotic
- Two motors
  - spindle (spins)
  - 4200 to 15k rpm, consumer often 5400 or 7200
  - Want: low vibration, low noise
  - Minimal wobble. Causes Non-Repeatable Runout (NRRO) causing track mis-registration (TMR)
  - Used to have ball bearings, but hard to make them

that good. Recently use fluid dynamic bearings.

  - Constant angular velocity, though recent (since 90s) zone bit recording (store more on outer rim)
    To keep from being really complex, it's not per track but a bunch of different zones, each with different density

- actuator (move arm)
  - Linear or rotary
  - Arm moved using voice coil (stepper motor on old) NIB (niobium Iron Boron) high-flux magnet, coil (sort of like speaker coil) rapidly moves in magnetic field

Reading/Writing

- Read/write head
- Close over surface of disk, often nanometers. Any dirt bad.
- N/S polarity, read as 0/1
- Hard to read 0 or 1, easier to measure transition, so encoding used. This means write a sector at a time, not possible to change an individual bit. NRZI encoding. FM/MFM Run-length limited (RLL) codes
- Magnetic "domains" of grains that can be aligned

- Magnetic dipole forming magnetic field
- Prior to 2005 or so these were horizontal and parallel
- These days, perpendicular (see silly movie)
- Originally iron(III) oxide, now cobalt-based
- Need to resist self-demagnetization
- Writing
  - Early used electromagnet to both read/write
  - Metal in Gap (MIG) and thin film heads later
  - Magnetoresistance
  - Spintronics, "Giant" magnetoresistance
  - Modern, separate read/write heads (close to each

other) read is magneto-resistance, write thin-film inductive
  - write-wide read-narrow
  - Guard band on either side to keep from bleeding (affects directly TPI)
- "servo" or how to I find the track
- A DSP takes the signal from the read head and converts to digital

High Density

- Roughly follow Moore's Law?

Problems with High Density

- superparamagnetic trilemma involving grain size, grain magnetic strength and ability of the head to write
- Data can be lost for thermal reasons
- “superparamagnetic limit”
- Platters covered in two parallel magnetic layers, separated by 3 atoms of ruthenium. Magnetized in opposite directions.
- Perpendicular recording
- exchange spring media

Error Handling

- Without error checking, error of 1 in 10^5 which is pretty high
- ECC, Reed-Solomon Coding
- With ECC drops to 1 in 10^{14} which is better, but more like one per petabyte or so
- Takes up space, 1TB disk might have 93GB of ECC
- Newer, LDPC (low-density parity check)
- Reserve pool, remap bad sectors. SMART
- Sector slipping, sector sparing

- Primary vs Grown defects
- Security – can you recover a drive that is over-written with zeros? Alternating zeros and ones? random? shred?

  Problem with wear leveling/error where might leave behind old data in places that won't get erased

Other Disasters

- Head crash (park first)
  "Landing zone" to park head at power off, needs to be able to spin up with it parked
- Air density – has a filter letting outside air in, stops working at high altitudes
- Physical shock – accelerometer to auto-park heads
- Just noise or vibration, playing loud music can slow speed you get
- Entire disk crash – in old days large glass or metal

platters spinning near speed of sound, shrapnel if break

Ways to Increase Performance

- Helium – less turbulence and friction, can pack tighter
- Perpendicular
- Shingling
- Heat-assisted magnetic recording
- Microwave-assisted magnetic recording
- Two-dimensional magnetic recording
- Bit-pattern recording
- Gigantic-magnetoresistance

Formatting

- Low-level. Logical blocks. Delimited by markers start, end, ECC, space to allow for timing
- Traditionally 512B but by moving to 4k can reduce percentage dedicated to the delimiters (though have to be backwards compatible)
- High-level format is just putting filesystem onto the blocks

Form Factor

- Capacity – 1GB (10**9) vs 1GiB (2**30)
- Desktop – 60GB - 4TB, 5400 - 10k rpm
- Mobile – smaller in size and space, usually spin slower 5400 or 7200
- Enterprise – fast, often 10k or 15k. Sometimes smaller platters (2.5) for faster seek time
- Consumer – often slower, more shock resistant

Performance

- Response time vs Throughput
- Seek time – time to get head to block of interest
  Fast drives today, 4ms
- Rotational latency – head seeks to right track but has to wait for block to spin by
  15k – 2ms, 7200 – 4ms, 5400 – 5ms
- Bits per second – 2010, 7200rpm drive 1Gb/s, depends on which track, rpm,.
  SATA can send about 3Gb/s with 10-bit encoding

SSD

- Solid-state disk
- No moving parts
- Faster, lower-latency, more resistant to shock
- Still more expensive
- Most 3D TLC NAND-based
- SDDs not permanent, will gradually leak and lose data after 2-3 years (faster if worn? trapped electrons leak away)
- Originally was DRAM (battery backed) but these days

NAND flash

- Controller that handles things
  - Bad-block remapping
  - Read scrubbing
  - Wear leveling

SSD Performance

- DRAM-based fastest
- Single NAND relatively slow
- Having lots in parallel helps

SSD Form Factor

- Can be SATA, but SATA while fast enough for magnetic disk cannot keep up with flash
- M.2 (formerly NGFF) – Intel
  Can provide PCIe, SATA 3.0, or USB 3, different keying to keep from plugging in wrong
- NVMe – non volatile memory express – hook up via PCIe

Trim Operation

- On filesystem, erase file, usually just mark as deleted and blocks unused, even though never want the bytes again
- TRIM on flash lets you tell disk you don't want them anymore, and the drive can then reclaim them
- Also, when OS then re-uses freed block, flash sees this as an over-write of the block (expensive) rather than a fresh write to a new block
- Expensive because typically erases in big chunks (512kB)

so over-writing you have to erase a whole big chunk, then do a write back of existing values

NAND vs NOR flash

- ROM, EPROM, EEPROM
- FLASH (NAND/NOR) can have parts erased, not whole thing at once
- Invented at Toshiba in the 1980s
- NOR
  - Long erase
  - Random access
  - 100x - 1000000x erase cycles
  - CF was originally NOR (but NAND cheaper)

- Like a NOR gate, one end to ground
- low read latency, can be used bit-by-bit ROM
- Program by writing at high voltage, Channel turned on, quantum tunneling via "hot electron injection"
- Resetting (actually to all 1 state). Same process, opposite direction, large voltage. Can in theory be individually reset bits but in practice in blocks

- NAND
  - Reduced erase/write times
  - Less chip area (higher density)
  - 10x endurance of NOR

- Must read out in large blocks (not random access)
- Wired in series like a bunch of NAND gates
- Certain amount of errors allowed (unlike NOR)
- Tunnel injection for erasing
- ECC error correction

- Programming
  - Starts as all 1s
  - In general can change any 1 to 0 at any time, but if want to switch from 0 back to 1 have to erase whole block
- Floating-gate transistors

- Each cell like a MOSFET, but with two gates
- Floating gate and control gate. Control to switch, float can trap electrons
- Floating gate raises the Vt by acting as a screen, so detect if 1 or 0 by putting an intermediate voltage

- Charge pumps
  - Need high voltage to write. But usually this is done from single voltage supply
  - In space applications usually the charge pump that fails (so chips can still be read, but no longer write)

Flash Issues

- Memory wear – can only write so many times before wears out. 100k?
- Memory disturb – a bit like rowhammer, write too many times can change nearby
- Xray can reset bits (problem when trying to see if BGA solder went well)

Hybrid Drive

SDD vs HDD comparison

- Data Durability – SDD loses in a few years – HDD lasts longer, but motors/mechanical might fail
- Startup – HDD has to spin up, takes a while
- Random Access – HDD bad, has to spin to location
- Read latency – SDD better
- Bandwidth – SDD often higher
- Read perf – SDD fast but goes down with use
- Noise – SDDs silent
- Heating – both don't like high temps

- Cooling – SDDs can operate at lower temps
- Air – SDDs don’t require air
- Price – SDD cheaper
- Power –SDD usually better
- Storage size – HDD usually better

Compact Flash

SD-card

RAID arrays

Tape