Magnetic storage-
From magnetic tape to HDD

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2016.02.24
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1. Magnetic storage - introduction

- Magnetic storage: Recording & storage of data on a magnetised medium
- A form of „non-volatile” memory
- Data accessed using read/write heads
- Widely used for computer data storage, audio and video applications, magnetic stripe cards etc.
1. Magnetic storage - introduction
2. Magnetic tape

- 1928 Germany: Magnetic tape for audio recording by Fritz Pfleumer
  - Fe2O3 coating on paper stripes, further developed by AEG & BASF
- 1951: UNIVAC - first use of magnetic tape for data storage
  - 12.7 mm Ni-plated brass-phosphorus alloy tape
  - 128 characters /inch data density
  - 7000 ch. /s writing speed
2. Magnetic tape
2. Magnetic tape

- **1950s: IBM** patented magnetic tape technology
  - 12.7 mm wide magnetic tape on a 26.7 cm reel
  - 370-730 m long tapes

- **1980: 1100 m PET** -based tape
  - 18 cm reel for developers
  - 7, 9 stripe tapes (8 bit + parity)
  - Capacity up to 140 MB

- **DEC** -tapes for personal use
2. Magnetic tape

- 2014: Sony & IBM recorded 148 Gbit /squareinch → tape capacity 185 TB!
2. Magnetic tape

- Remanent structural change in a magnetic medium
- Analog or digital recording (binary storage)
- Longitudinal or perpendicular recording
- Ni-Fe-alloy core in tape head
2. Magnetic tape

- Hysteresis in magnetic recording
- 40-150 kHz bias signal applied to the tape to remove its "magnetic history" and "stir" the magnetization
- Each recorded signal will encounter the same magnetic condition
- Current in tape head proportional to the signal to be recorded
2. Magnetic tape

- Fe2O3 & Fe3O4 particles embedded in a plastic binder on a polyester tape
- CrO2 and other metal powders: better signal-to-noise ratio
- 0.5 µm particle size, 10 µm tape thickness
3. Magnetic-core memory

- 1947: First fully developed core system as a digital logic circuit patented by Frederick Viehe (later purchased by IBM)
- 1949: Pulse transfer controlling device by An Wang & Way-Dong Woo
- Magnetic field of the cores can be used as switches in electromechanical systems
- 1953: First core memory was installed on MIT Whirlwind computer
  - 32 x 32 x 16 bit system,
  - 9 microsecs core access time (tube: 25!)
3. Magnetic-core memory

MIT Whirlwind core memory 1953
3. Magnetic-core memory

- Early 1960s: drum memory (inexpensive, low performance) and vacuum tubes (expensive, high performance) replaced by core memory
- 1970s: core memory replaced by integrated semiconductor RAM chips

64 cores hold 8 bytes!
3. Magnetic-core memory

- 1mm toroid ceramic ferrite cores
  - High degree of magnetic remanence (staying highly magnetized)
  - Low coercitivity (less energy to change magnetization direction)
- 1 core = 1 bit
- 2 possible states: 0 & 1 (direction of magnetization)
- 4 types of wires: X, Y, sense (S), inhibit (Z)
- 45° positioning of cores → no stray coupling
3. Magnetic-core memory

- Current in a wire passing through the cores creates magnetic field
- Core polarity changed only by a magnetic field greater than „select” intensity
- Location select: X & Y wires, „half-select” intensity, where these cross
- Resulting induced field
  - magnetic flux of cores forced to circulate clockwise or counterclockwise (0 or 1)
- 1.2 µs switching time
3. Magnetic-core memory

- Reading: ciruity trying to flip the bit to the polarity assigned to the 0 state by driving the appropriate X & Y wires
- If bit 0: no physical change
- If bit 1: core changes magnetic polarity inducing a voltage pulse in „sense” line (after a delay: access time)
- Voltage pulse detected: bit was 0
- No Voltage pulse: bit 1.
3. Magnetic-core memory

- After reading core is set back to 0 has to be rewritten to the original 0/1 state.
- To write a 1 bit: appr. X & Y wires driven, current in the opposite direction as for the reading.
- To write a 0 bit = to inhibit writing a 1 bit. Same amount of current sent through „inhibit” line net current = half of the select current no change of polarity.
4. Bubble memory

- 1960s: Twistor memory by Andrew Bobeck
  - Similar to core memory, magnetic tape in place of "cores"
  - Data stored in relatively large magnetized patches, "domains"
  - Ability to be assembled automatically (core: manual!)

- 1960s Michealis: Magnetic domains
  - can be propagated orthogonally
  - in anisotropic thin permalloy magnetic films

- Orthoferrites: written patch + external magnetic field
  - bubbles! (Bobeck)
4. Bubble memory

- 1977: First commercial bubble memory product by Texas Instruments
- Late 1970s: Intel 7110 1Mbit bubble memory
- 1980s: Hard disk systems introduced, bubble memory development stopped
- Still in use through 1980s (high vibration & harsh environmental applications)
4. Bubble memory

- Uniaxial magnetic anisotropy:
  - Orthomagnetic axis perpendicular to the square surface
  - Tending to form sharply divided areas, N up, S down or the other way around
- Squeezing the domains into small bubbles using an external magnetic field
4. Bubble memory

- External fields can push and pull domains/bubbles in an orthomagnetic sheet
- Driver coils form a steadily rotating magnetic field along the surface of the sheet
- Ferromagnetic guides get magnetized by the coils what coerces the bubbles along the guide pattern
4. Bubble memory

- Left side: pair of coils acting as an electromagnet, launching new bubbles
- Bubbles propagate along the guide track, and turn up at the right side
- Right side: pair of coils act as a „pick-up”

Electric pulse is formed when a bubble arrives → read off the output terminal

- Read operation: bubbles run in circles
- Write operation: direct pulses sent to the launching coils, entering new string of bits as bubbles
4. Bubble memory

- Perfect material for bubbles: garnet
  - Type of silicates, $X_3Y_2(SiO_4)_3$, $X$: (Ca, Mg, Fe, Mn)$^{2+}$, $Y$: (Al, Fe, Cr)$^{3+}$
  - Cubic & rhombic dodecahedron crystal system
  - Bubbles easily formed and pushed towards the ends to be read out
4. Bubble memory

- Memory density: 1Mbit/cm²
- 2μm bubble diameter
- 20000 A/m external „squeezing” field
- 4-6000 A/m rotating magnetic field
- 100 kbit/s data speed
5. Hard disk drive

- 1953: IBM invented hard disk drive
- New level in computer hierarchy: secondary storage
- Slower & less expensive than main memory, faster & more expensive than magnetic tapes
- 1956: first commercial use in IBM 305 RAMAC system
  - 50 pcs 24 inch platters → 3.75 MB
  - Single head assembly, average access time under 1 s!
5. Hard disk drive

- 1961: BCP 4000 Series: 1.8 x 1.3 m, 26 pcs 39 inch platters
  - 205 ms access time, 205 MB capacity
- 1973: IBM 3340 „Winchester“, 2 spindles (35-70 MB each)
- Late 1980s: HDDs standard on almost all PCs
5. Hard disk drive

- Spindle, holding platters
- Platters made from a non-magnetic material (Glass, aluminium alloy, ceramic)
- Platters coated with a 10-20 nm thick magnetic layer and an outer carbon layer (for protection)
- Platters spun at speeds 4200-15000 rpm
- One read-and-write head for each platter on the spindle
5. Hard disk drive

- Read-and-write heads having a flying height in the range of tens of nm-s
- Recording: longitudinal or perpendicular
- Zone-bit recording: more data in the outer tracks
- Superparamagnetic limit: magnetic regions small, their magnetic state might be lost due to thermal effects

- Perpendicular recording or 2 parallel magnetic layers, separated by a 3-atom layer of non-magnetic rhutenium, layers magnetized in the opposite direction, reinforcing each other
5. Hard disk drive

- Data recorded by magnetizing a thin film of ferromagnetic material on a disk
- Binary data bits are represented by sequential changes in the direction of magnetisation
6. Future prospects

- Shingled magnetic recording (SMR)
- Heat-assisted magnetic recording (HAMR)
- Microwave-assisted magnetic recording (MAMR)
- Bit-patterned recording (BPR)
- Giant magnetoresistance heads (GMH)

- Rate of areal density growth dropped above Moore’s law (40% /year)
- Forecast for and beyond 2020: 10-30%
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Thank you for your attention!