Lecture 24: Memory technology

- Memory landscape
- Volatile memories
- Non-volatile memories

Announcements

- HW2 will be assigned this week end
- There will be a quiz on memory next week

Basic categories of memory

- **Read-Only Memory (ROM)**
  - Can only be read (accessed)
  - Cannot be written (modified)
  - Contents are often set before ROM is placed into the system
- **Random-Access Memory (RAM)**
  - Can be read/written
  - Term used for historical reasons
  - Technically, ROMs are also random access

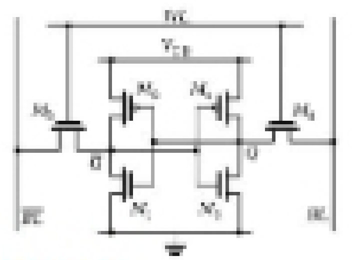
- **Volatile memory**
  - Lose contents when power is lost
  - Often stores program state, stack, and heap
  - In desktop/server systems, also stores program executable
- **Non-volatile memory**
  - Retain contents when power is lost
  - Used for boot code in almost every system

Memory technologies landscape

	Volatile	Non-Volatile
RAM	Static RAM (SRAM) Dynamic RAM (DRAM)	EEPROM Flash Memory Disk PCM, STTRAM, FeRAM…
ROM	n/a	Mask ROM PROM EPROM

Volatile: Static RAM

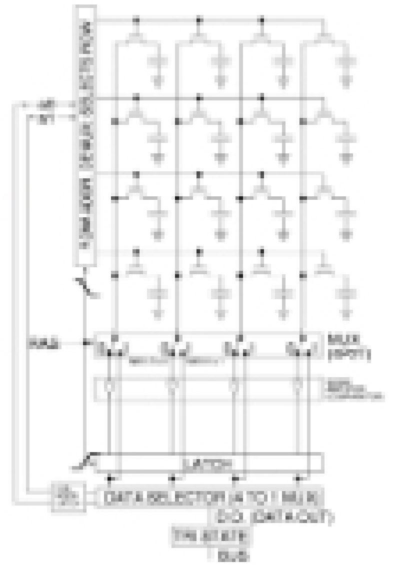
- Basic cell
  - Bistable core
    - 4T: uses pullup resistors for M2, M4
    - 6T: uses P-FET for M2, M4
  - Access transistors
  - BL, BL# are provided to improve noise margin
- 6T is typically used (but has poor density)



- Fast access times O(10 ns)
- Read/write speeds are symmetric
- Read/write granularity is word

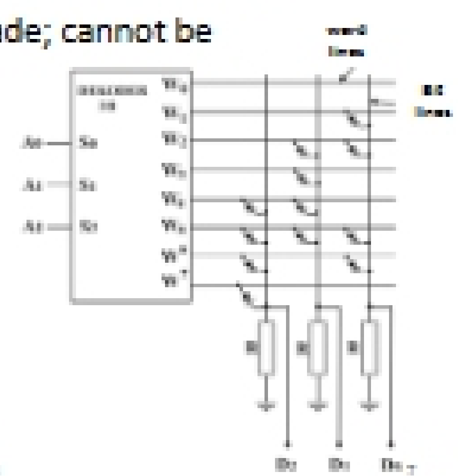
Volatile: Dynamic RAM

- Requires only 1T and 1C per cell
- Outstanding density, low cost, and cost advantage compared to SRAM
- Small charges involved → relatively slow
  - Bit lines must be pre-charged to detect bits
  - Reads are destructive; internal writebacks needed
- Values must be refreshed periodically
  - Prevents charge from leaking away
  - Complicates control circuitry slightly

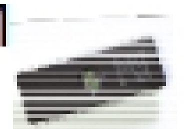


Non-Volatile: Mask ROM

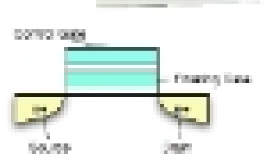
- The "simplest" memory technology
- Presence/absence of diode at each cell denote value
- Pattern of diodes defined by mask used in fab process
- Contents are fixed when chip is made; cannot be changed
- High upfront setup costs
- Small recurring marginal costs
- Good for applications where
  - Cost sensitivity drives design
  - Upgrading contents not an issue
  - e.g. boot ROM, CPU microcode

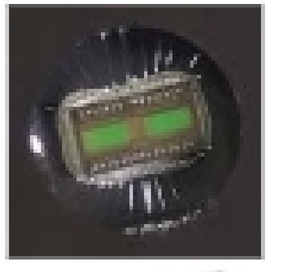


Non-Volatile: EPROM



- Erasable Programmable Read-Only Memory
- Constructed from floating gate FETs
  - Charge trapped on the FG erases cell
  - High voltage (13V +) applied to the control gate
    - "Writes" the cell with a 0
    - Allows FG charge to be dissipated
- Writing means changing from 1 → 0
- Erasing means changing form 0 → 1
  - Uses UV light (not electrically!)
  - Erase unit is the whole device
- Retains data for 10-20 years
- Costly because
  - Use of quartz window (UV transparent)
  - Use of ceramic package
- Not used much these days





Non-Volatile: Flash Storage

- Semiconductor storage
  - 100× – 1000× faster than disk
  - Smaller, lower power, more robust
  - But more $/GB (between disk and DRAM)

Two types:

- NOR flash: bit cell like a NOR gate
  - Random read/write access
  - Used for instruction memory in embedded systems
- NAND flash: bit cell like a NAND gate
  - Denser (bits/area), cheaper per GB, but block-at-a-time access
  - Cheaper Used for USB keys, media storage, …

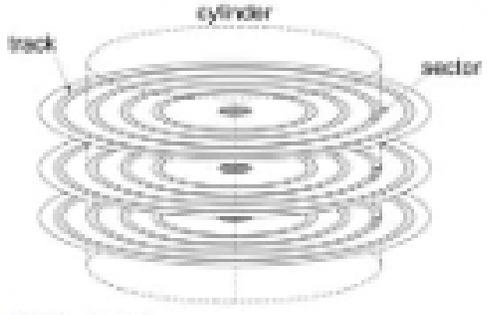
Flash Access

- Electrically erasable (like EEPROM, unlike EPROM)
- **Erase** size is block (not word); can't do byte modifications
- **Reads** are like standard RAM
- Can "**write**" bits/words (actually, change from 1 → 0)
  - Write cycle is O(microseconds)
  - Slower then RAM but faster than EEPROM
  - To (re)write from 0 → 1, must explicitly erase entire block
    - Erase is time consuming O(milliseconds to seconds)
- Floating gate technology
  - Erase/write cycles are limited (10K to 100K, typically)
  - Flash bits wears out after 1000's of accesses
    - *Wear leveling: remap data to less used blocks*

Non-Volatile: Disk Storage

- Rotating magnetic storage

Each sector records
- Sector ID
- Data (512 ~ 4096 bytes)
- Error correcting code (ECC)
  - Hide defects and recording errors
- Synchronization fields and gaps



Disk Access

- Access to a sector involves
  - Queuing delay if other accesses are pending
  - Seek: move the heads
  - Rotational latency
  - Data transfer
  - Controller overhead
- Manufacturers quote average seek time
  - Based on all possible seeks
  - Locality and OS scheduling lead to smaller actual average seek times
- Smart disk controller allocate physical sectors on disk
  - Present logical sector interface to host
- Disk drives include caches
  - Prefetch sectors in anticipation of access
  - Avoid seek and rotational delay