Goals

- Understand the different memory technologies.
- Be able to determine the appropriate memory technology for the specific application.

Simple Model of Memory

- Each object is stored in one unique location
- Reads and writes to objects are atomic.
- The system maintains this model for the programmer even though the implementation may be different.

Atomic Actions

- An atomic action is indivisible.
- You can see the state of an object before or after an atomic action, but you cannot see any intermediate states.
- If you atomically change a byte in memory, you will never catch it half way with only some of the bits changed.

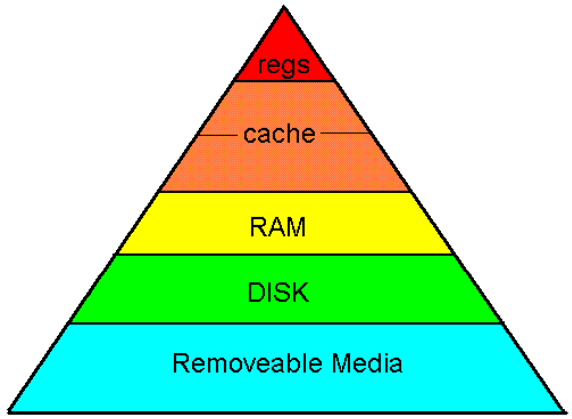
Key Aspects of Memory

- Technology
  - Properties of the underlying hardware
- Organization
  - Way the technology is used to form a working system. How to combine bits into a working system.

Characteristics of Memory

- Primary or secondary
- Random or sequential access
- Granularity of access
- Volatile or nonvolatile
- Read/write or read-only

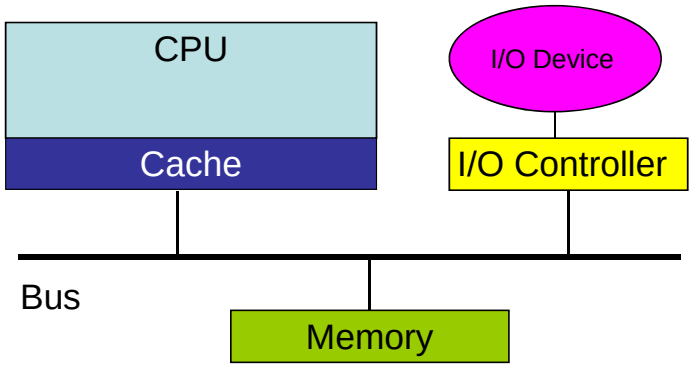
Memory Hierarchy



Primary and Secondary Memory

- Primary memory holds the data and program so that it can be accessed by the processor. It is usually fast and volatile.
  - RAM
  - cache
- Secondary memory is typically used for long term storage. It is usually non-volatile and may be removable.
  - Hard Drive
  - CD

Basic Computer Components



Random Access

- Random access means that it takes the same length of time to read (or write) any data in the system.
- The main computer memory is random access (RAM). The ROM is also random access.
- Some external memory devices, such as tapes, are strictly sequential access.
- Some memory is a combination of random and sequential.

Addressing Granularity

- Some memory types (such as primary RAM) can be addressed by individual bytes.
- Other types of memory can only be accessed in blocks.
  - You cannot read or write less than a block.
  - If you want to change one byte, you must read the block, change the byte and then write the block.
- Rarely can you address individual bits.

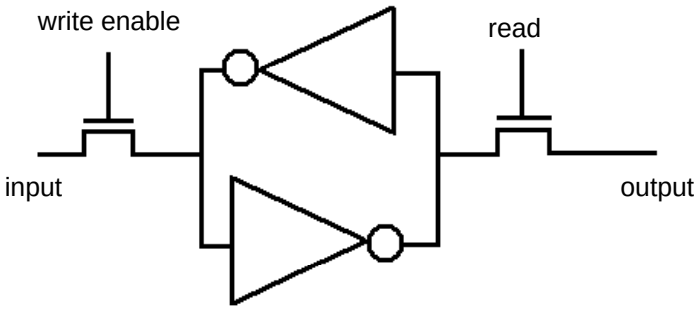
Volatility

- Most RAM in a computer will lose the data when the power is turned off.
- Some memory systems, such as memory sticks or flash memory, can keep the data without power.
- Some memory will maintain its data unless special systems are used.

SRAM Technology

- Static RAM stores data in logic circuitry similar to a flip-flop.
- It takes four to six transistors per bit.
- High speed
- High power consumption and heat
- Frequently used for cache memory

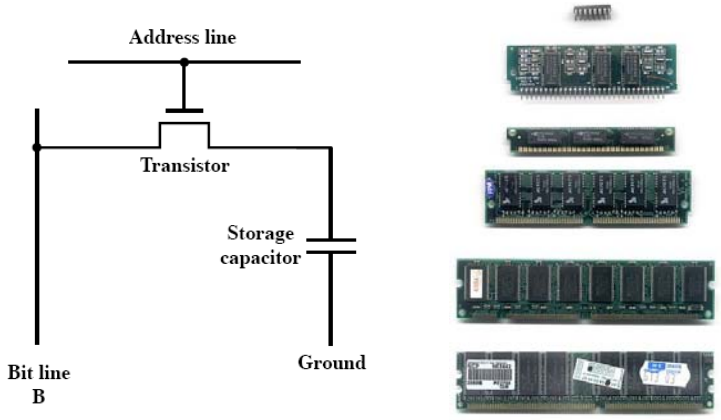
SRAM Design



DRAM Technology

- Dynamic RAM stores the data as a charge in the capacitance of a single transistor.
- Only one transistor is required per bit.
- Slower than SRAM
- Heat and power consumption are less than SRAM
- Data values must be rewritten after reading. Write faster than read.

DRAM Implementation



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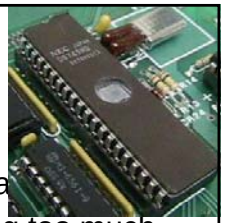
DRAM Refreshing

- A capacitor gradually loses its charge.
- If left alone, the value of a bit in DRAM would be lost in less than a second.
- A refresh circuit periodically reads the data and writes it back to the DRAM.
- The refresh cycle must coordinate with the normal memory operations. The bit cannot change during the refresh cycle.
- Slows down apparent performance

Read-Only Memory

- A Read Only Memory chip (ROM) contains data that cannot be changed by an executing program.
- Most PCs have a Basic Input/Output System (BIOS) program in ROM. This provides a set of functions to perform low level activities and initialization.
- Embedded systems often have all programs in some form of ROM.

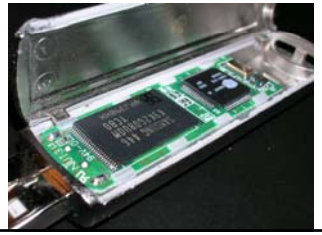
Programming a ROM



- The data in a ROM can be set by:
  - Manufactured to contain specific data
  - Destroying zero value bits by applying too much current to that bit to “blow the fuse”.
  - Some programmable ROMs (PROM) can be changed by special machines that use higher voltages. Some PROMs can be erased by ultraviolet light.
  - Electrically Erasable Programmable ROM (EEPROM) requires special circuitry to write which takes much longer than reading.

Flash Memory

- EEPROM used in thumb drives, cell phones, digital cameras and PDAs.
- Random access read and first write.
- Must be erased in blocks before rewriting.
- All types of flash memory and EEPROM wear out after a certain number of erase operations



Memory Performance

- Latency
  - Time between the initiation of a request until the data is returned.
- Cycle Time
  - Measures how quickly the memory system can handle successive requests.
  - The memory system may require additional time between memory accesses.

Synchronized Memory

- The memory system uses a clock and the CPU uses a different clock.
- The difference in clocks may cause either the CPU or memory to pause briefly.
- Synchronized clock systems align both clocks.
- Synchronized RAM available
  - SDRAM – Synchronized DRAM
  - SSRAM – Synchronized SRAM

Faster Memory Clocks

- Some memory systems run at twice the normal clock rate.
- These memories are known as “Double Data Rate”
- DDR-DRAM – Double Data Rate DRAM
- DDR-SDRAM – Double Data Rate Synchronized DRAM

Summary

Type	Category	Erasure	Byte alterable	Volatile	Typical use
SRAM	Read/write	Electrical	Yes	Yes	Level 2 cache
DRAM	Read/write	Electrical	Yes	Yes	Main memory
ROM	Read-only	Not possible	NO	NO	Large volume appliances
PROM	Read-only	Not possible	NO	NO	Small volume equipment
EPROM	Read-mostly	UV light	NO	NO	Device prototyping
EEPROM	Read-mostly	Electrical	Yes	NO	Device prototyping
Flash	Read/write	Electrical	NO	NO	Film for digital camera

Future Memory Systems

- Nonvolatile memory systems, such as flash memory, are becoming cheaper and bigger.
- Disk drives may be replaced in the future by nonvolatile integrated circuit memory.
- Flash memory wears out faster than a hard drive.