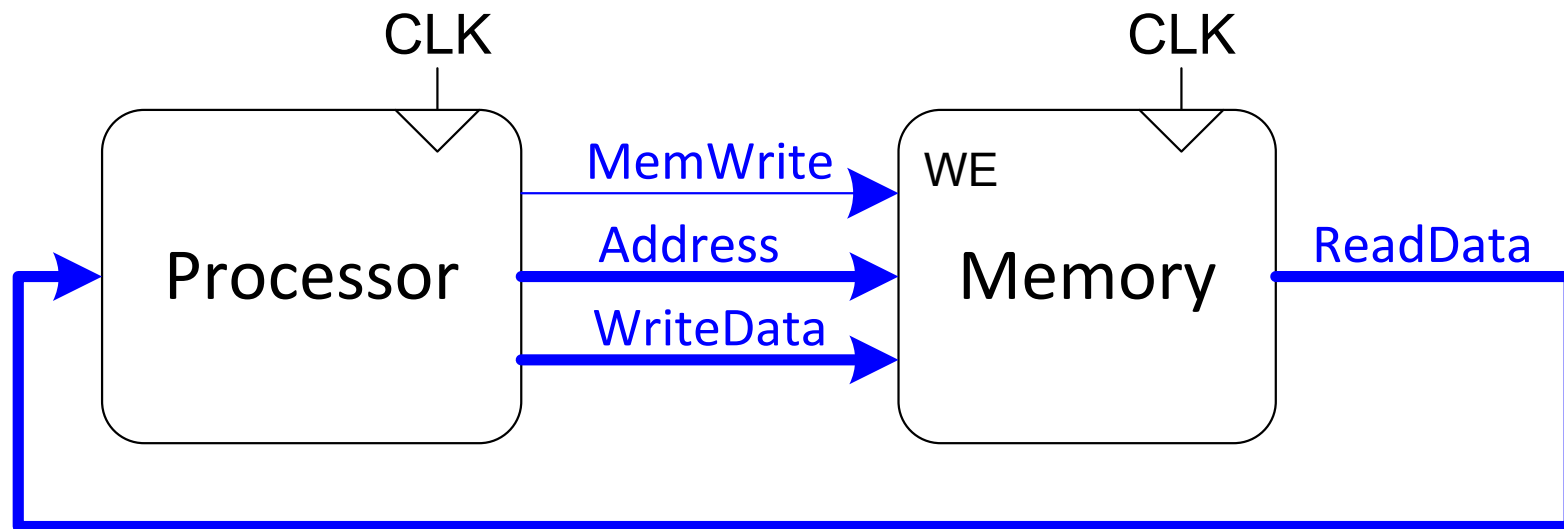


- Provides storage for instructions and data
- Large storage capacity eases the task of developing programs
- Greater speed improves performance and reduces the need to stall the CPU
- Reduced cost makes the overall system more economical
- All of these goals cannot be achieved at the same time
- Techniques such as caching and virtual memory can give the illusion of greater speed and capacity

- There are two basic types of memory
  - Read/write can be changed or updated (RAM)
  - Read-only can be read but not changed (ROM)
- Memory access is a read or write operation
  - Location to access must be specified
  - Read obtains copy of contents
  - Write replaces contents with specified data
- Each location is assigned a unique number (address)
- Any location in RAM or ROM can be accessed directly
- Storage capacity is measured in units of 8-bit bytes

Example: Processor writes to memory by specifying the address, the data, and the write control signal.



The clock signal (CLK) synchronizes the interactions.

- Most systems are “byte addressable”
  - Individual bytes can be accessed
  - Actual transfer size matches bus width
- Multi-byte items usually must reside on proper boundary
  - Word (4 bytes) address must be multiple of 4
  - Half word (2 bytes) address must be even
  - Address of aligned data item is a multiple of its size
  - Unaligned items may require multiple transfers
  - Unaligned accesses cause exceptions on MIPS

- MIPS memory features
  - Employs 32-bit addresses (4 GB address space)
  - Byte-addressable
  - Enforces memory alignment
- Amount of physical memory dictates number of address bits
- Width of pathway (bus) dictates number of bytes in a transfer
- Usually, at most 1 read or write can occur at a time

- “Access time”
  - time between read request and return of data
- “Memory cycle time”
  - minimum time between consecutive reads
  - Includes setup time, access time and recovery time
- Addresses are sent over the address bus
- Data bits are sent over the data bus
- Read/write request signals are sent over the control bus

- There are two types of RAM
  - Dynamic RAM (DRAM)
  - Static RAM (SRAM)
  
- DRAM stores charge to represent 0 or 1
  - Charges leaks off overtime
  - Requires periodic refresh to restore charge
  - Must be charged before a read occurs
  - Reads are destructive (must rewrite to restore)
  - Relatively inexpensive
  - Allows more bits per unit area (more dense)
  - “Volatile” contents lost when power is off

- SRAM uses switches (gates) to store bits
  - Provides much shorter access time than DRAM
  - Contents remain stable as long as power is on
  - Reads are non-destructive
  - More expensive than DRAM
  - Consumes more area per bit than DRAM
  - Used for high speed memory (cache)
  - Volatile, contents lost when power is off



- ROM needs no refresh
  - Used to store permanent or semi-permanent data
  - Contents remains intact even when power is off
  - Reads are non-destructive
  - “Non-volatile” contents persists when power is off
  
- Other memory types
  - PROM (programmable) may be written once
  - EPROM (erasable PROM) exposed to UV to erase
  - EEPROM (electrically erasable) erase/rewrite in-place
  - FLASH (entire blocks must be erased)