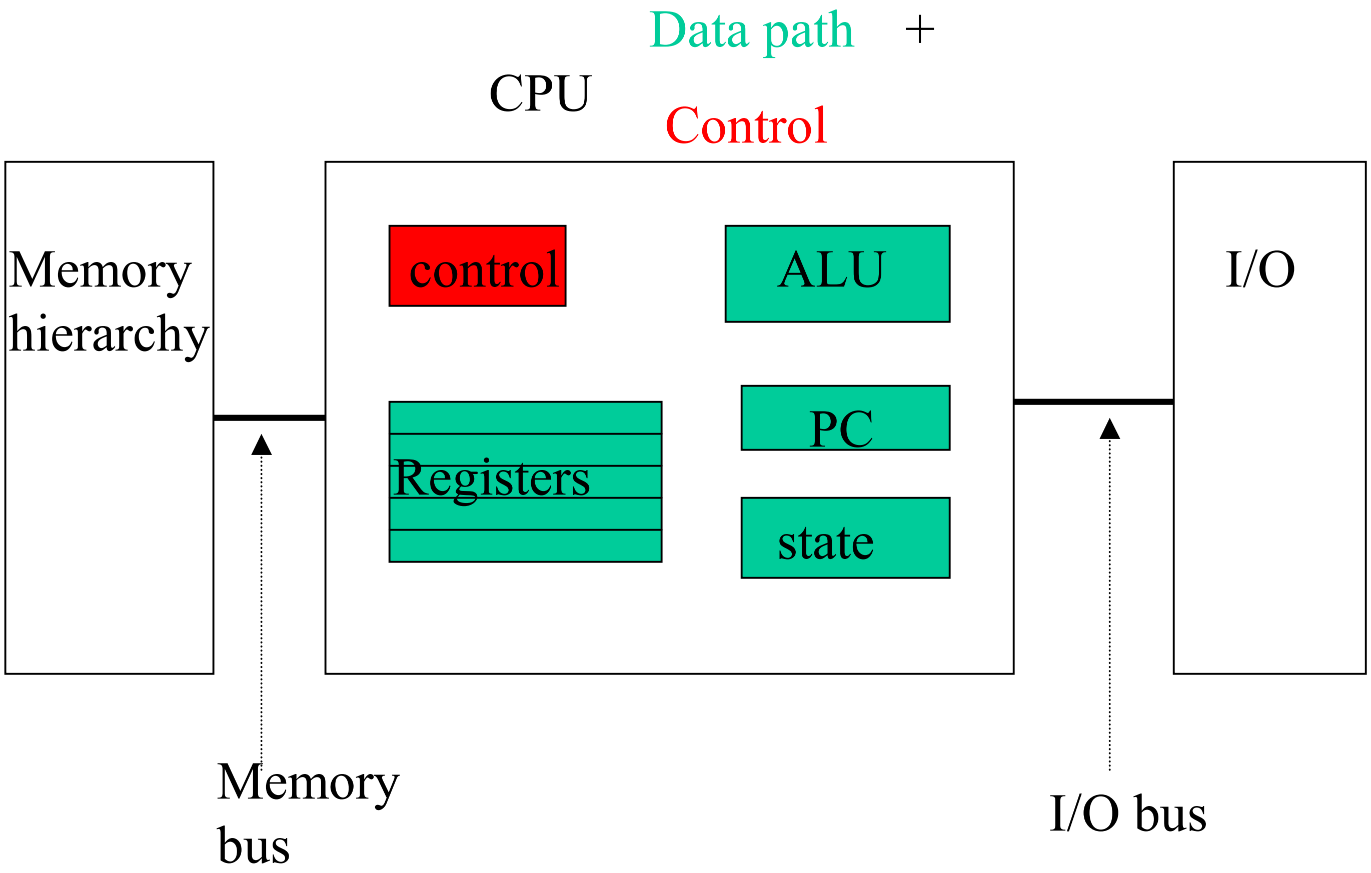
What is Computer Architecture?

- **Structure:** static arrangement of the parts
- **Organization:** dynamic interaction of the parts and their control
- **Implementation**: design of specific building blocks
- **Performance:** behavioral study of the system or of some of its components

Alternate definition: Instruction Set Architecture (ISA)

- Architecture is an **interface** between layers
- ISA is the interface between hardware and software
- ISA is what is visible to the programmer (and ISA might be different for O.S. and applications)
- ISA consists of:
  - instructions (operations and how they are encoded)
  - information units (size, how are they addressed etc.)
  - registers (or more generally processor state)
  - input-output control

Computer structure: Von Neumann model



Computer Organization

- Organization and architecture often used as synonyms
- **Organization** (in this course) refers to:
  - what are the basic blocks of a computer system, more specifically
    - basic blocks of the CPU
    - basic blocks of the memory hierarchy
  - how are the basic blocks designed, controlled, connected?
- Organization used to be transparent to the ISA.
- Today more and more of the ISA is *"exposed"* to the user/compiler.

Advances in technology

Processor technology	Vacuum tubes	Transistors	Integrated circuits	VLSI
Memory technology	Vacuum tubes	Ferrite core	Semi-conductor	Semi-conductor
Processor structure	Single processor	Main frames	Micros and minis	PC's 64-bit arch Superscalar Multithreaded

Some Computer families

- Computers that have the same (or very similar) ISA
  - Compatibility of software between various implementations
- IBM
  - 704, 709, 70xx etc.. From 1955 till 1965
  - 360, 370, 43xx, 33xx From 1965 to the present
  - Power PC
- DEC
  - PDP-11, VAX From 1970 till 1985
  - Alpha (now Compaq, now HP) in 1990's

More computer families

- Intel
  - Early micros 40xx in early 70’s
  - x86 (086,…,486, Pentium, Pentium Pro, Pentium 3, Pentium 4) from 1980 on
  - IA-64 (Itanium) in 2001
- SUN
  - Sparc, Ultra Sparc 1985 0n
- MIPS-SGI
  - Mips 2000, 3000, 4400, 10000 from 1985 on

MIPS is a RISC

- RISC = *R*educed *I*nstruction *S*et *C*omputer
- R could also stand for "regular"
- All arithmetic-logical instructions are of the form

$$R_a \leftarrow R_b \ \text{op} \ R_c$$

- MIPS (as all RISC's) is a *Load-Store* architecture
  - ALU operates only on operands that are in registers
  - The only instructions accessing memory are load and store
- Sloop is also a RISC, load-store architecture

Registers

- Registers are the "*bricks*" of the CPU
- Registers are an essential part of the ISA
  - Visible to the hardware and to the programmer
- Registers are
  - Used for high speed storage for operands. For example, if *a,b,c* are in registers 8,9,10 respectively

    ```
    add $8,$9,$10          # a = b + c
    ```
  - Easy to name (most computer have 32 registers visible to the programmer and their names are 0, 1, 2, …,31)
  - Used for addressing memory

Registers (ct'd)

- Not all registers are "equal'
  - Some are special-purpose (e.g., register 0 in MIPS is wired to the value 0)
  - Some are used for integer and some for floating-point (e.g., 32 of each in MIPS)
  - Some have restricted use by convention (cf. App. A pp A-22-23)
  - Why no more than 32 or 64 registers
    - Well, sometimes there is (SPARC, Itanium, Cray, Tera)
    - Smaller is faster
    - Instruction encoding (names have to be short)
    - There can be more registers but they are invisible to the ISA
      - this is called *register renaming* (see CSE 471)

Memory system

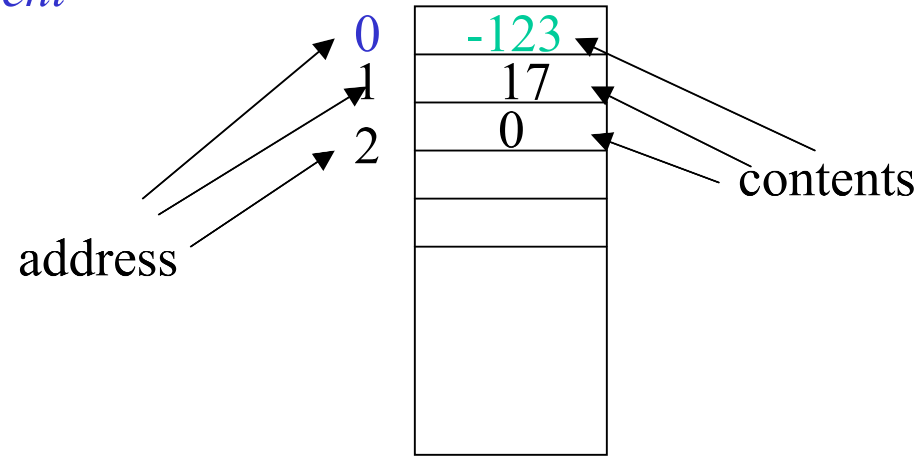
- Memory is a *hierarchy* of devices with faster and more expensive ones closer to CPU
  - Registers
  - Caches (hierarchy: on-chip, off-chip)
  - Main memory (DRAM)
  - Secondary memory (disks)

Information units

- Basic unit is the *bit* (has value 0 or 1)
- Bits are grouped together in information units:
  - Byte = 8 bits
  - Word = 4 bytes
  - Double word = 2 words
  - etc.

Memory addressing

- Memory is an array of information units
  - Each unit has the same size
  - Each unit has its own *address*
  - Address of an unit and contents of the unit at that address are *different*

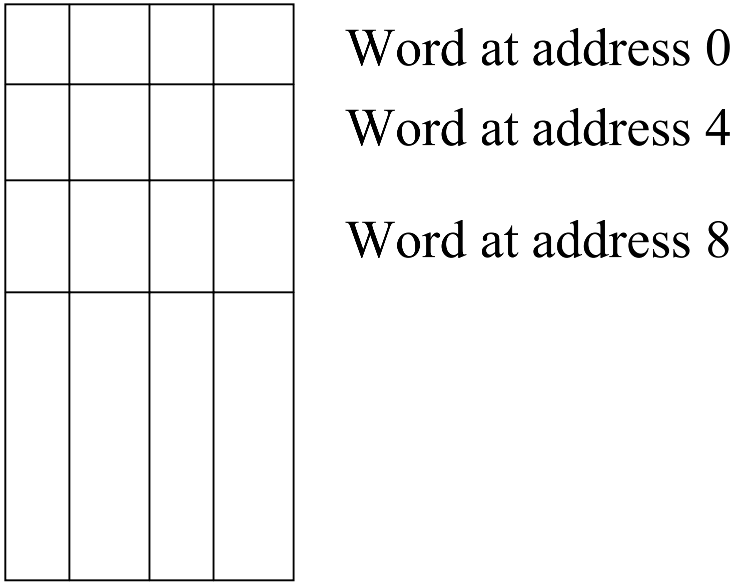


Addressing

- In most of today's computers, the basic I-unit that can be addressed is a byte
  - MIPS is *byte addressable*
- The *address space* is the set of all I-units that a program can reference
  - The address space is tied to the length of the registers
  - MIPS has 32-bit registers. Hence its address space is 4G bytes
  - Older micros (minis) had 16-bit registers, hence 64 KB address space (too small)
  - Some current (Alpha, Itanium,Sparc) machines have 64-bit registers, hence an enormous address space

Addressing words

- Although machines are byte-addressable, words are the most commonly used I-units
- Every word *starts at an address divisible by 4*



Word at address 0

Word at address 4

Word at address 8

Big-endian vs. little endian

- Byte order within a word:

3	2	1	0

Little-endian
(we’ll use this)

0	1	2	3

Big-endian

The CPU - Instruction Execution Cycle

- The CPU executes a program by repeatedly following this cycle
  1. Fetch the next instruction, say instruction *i*
  2. Execute instruction *i*
  3. Compute address of the next instruction, say *j*
  4. Go back to step 1
- Of course we'll optimize this but it's the basic concept

What’s in an instruction?

- An instruction tells the CPU
  - the operation to be performed via the **OPCODE**
  - where to find the operands (source and destination)
- For a given instruction, the ISA specifies
  - what the OPCODE means (semantics)
  - how many operands are required and their types, sizes etc.(syntax)
- Operand is either
  - register (integer, floating-point, PC)
  - a memory address
  - a constant