Five classic components

I am like a control tower

I am like a pack of file folders

I am like a conveyor belt + service stations

I exchange information with outside world
Some definitions for 447

- **What is a program?**
  - A file of instructions
  - The program writer had a goal when writing this program
  - Instructions execute on the processor ⇒ a dynamic sequence of instructions

- **What is an algorithm?**
  - A procedure to solve a problem
    - E.g., sort an array

- There was a book titled “Algorithms + Data Structures = Programs”

Machine instructions

```assembly
void swap(int v[], int k)
{
    int temp;
    temp = v[k];
    v[k] = v[k+1];
    v[k+1] = temp;
}
```

```assembly
swa
   muli $2, $5, 4
   add $2, $4, $2
   lw  $15, 0($2)
   lw  $16, 4($2)
   sw  $16, 0($2)
   sw  $15, 4($2)
   jr  $31
```
Instruction set architecture

- A “programmer’s reference manual” (PRM) for a processor will disclose the ISA of the processor

- You are a system software programmer

- Components of ISA in PRM
  - Data types the processor supports
  - Instructions and their definitions
  - Registers and their usage
  - Processor modes
  - Exception mechanism
  - (Compatibility issues)

Register

- It’s a storage in your processor that you can directly address and access in an instruction

- If your processor is 32-bit, your registers are (usually) 32 bits wide

- Depending on the processor, there can be many registers or only a few of those
  - Registers were a scare resource – they occupy chip space
  - Today we can put many registers; the concern is the access time and the power consumption
Early processor example: Intel 4004

- b. 1971
- It’s considered the first microprocessor by many people
- ~2000 transistors
- 4-bit processor
- 1 register – accumulator

MIPS registers

<table>
<thead>
<tr>
<th>32 bits</th>
<th>32 bits</th>
<th>32 bits</th>
</tr>
</thead>
<tbody>
<tr>
<td>$zero</td>
<td>r0</td>
<td>r16</td>
</tr>
<tr>
<td>$at</td>
<td>r1</td>
<td>r17</td>
</tr>
<tr>
<td>$v0</td>
<td>r2</td>
<td>r18</td>
</tr>
<tr>
<td>$v1</td>
<td>r3</td>
<td>r19</td>
</tr>
<tr>
<td>$a0</td>
<td>r4</td>
<td>r20</td>
</tr>
<tr>
<td>$a1</td>
<td>r5</td>
<td>r21</td>
</tr>
<tr>
<td>$a2</td>
<td>r6</td>
<td>r22</td>
</tr>
<tr>
<td>$a3</td>
<td>r7</td>
<td>r23</td>
</tr>
<tr>
<td>$t0</td>
<td>r8</td>
<td>r24</td>
</tr>
<tr>
<td>$t1</td>
<td>r9</td>
<td>r25</td>
</tr>
<tr>
<td>$t2</td>
<td>r10</td>
<td>r26</td>
</tr>
<tr>
<td>$t3</td>
<td>r11</td>
<td>r27</td>
</tr>
<tr>
<td>$t4</td>
<td>r12</td>
<td>r28</td>
</tr>
<tr>
<td>$t5</td>
<td>r13</td>
<td>r29</td>
</tr>
<tr>
<td>$t6</td>
<td>r14</td>
<td>r30</td>
</tr>
<tr>
<td>$t7</td>
<td>r15</td>
<td>r31</td>
</tr>
</tbody>
</table>

General-Purpose Registers
Special-Purpose Registers
Instruction

- Unit of program execution; program consists of instructions
- It describes an operation that the processor understands how to perform
- The amount of work defined for an instruction is usually small; for example,
  - Add two numbers in registers
  - Compare two numbers in registers
  - Make a jump in the program if the first number is smaller than the second number

- Complex instructions may ease your programming…
  - For example, “multiply two numbers from memory location A & B and iterate this 100 times or until you meet two zeros”
  - BUT, your processor implementation can become quite complex

Instruction description example

<table>
<thead>
<tr>
<th>Add Immediate Word</th>
<th>ADDI</th>
</tr>
</thead>
<tbody>
<tr>
<td>31 26 25 21 20 16 15</td>
<td>imm8</td>
</tr>
<tr>
<td>ADDI 00100</td>
<td>$r1</td>
</tr>
<tr>
<td>0</td>
<td>5</td>
</tr>
</tbody>
</table>

Format: ADDI rt, ru, immediate
MP5032

Purpose:
To add a constant to a 16-bit integer. If overflow occurs, then temp.

Description: rt ← rs + immediate
The 16-bit signed immediate is added to the 32-bit value in GPR rt to produce a 32-bit result.
- If the addition results in 32-bit 2’s complement arithmetic overflow, the destination register is not modified and an Integer Overflow exception occurs.
- If the addition does not overflow, the 32-bit result is placed into GPR rt.

Restrictions:
None

Operation:
temp ← (GPR[rs]h | GPR[rs]l) + sign_extend(immediate)
if temp, 2 temp, then
  signal exception: integer overflow
else
  GPR[rt] ← temp
endif

Exceptions:
Integer Overflow

Programming Notes:
ADDIU performs the same arithmetic operation but does not trap on overflow.
### Processor modes

- **“User mode”**
  - Ordinary programs run in this mode
  - Most instructions can be executed in this mode (e.g., add, load)
  - Critical system resources are not directly accessed
  - What about other user’s programs?

- **“Privileged mode”**
  - System software runs in this mode
  - Some instructions can be executed only in this mode
  - Critical system resources are managed by the system software (i.e., OS)

- What happens if the user program tries to access prohibited, privileged system resource?
Switching between modes

- When powered on, a processor will be in its privileged mode.

- When the system boots up and becomes initialized, the system starts to execute user programs or interact with the user.

- The processor switches back and forth between the modes when:
  - There is an instruction-induced exception:
    - Divide-by-zero
    - Access to unallocated memory space
    - System calls
  - There is an interrupt from the I/O system:
    - Clock interrupt
    - Keyboard & mouse

Inside your PC

- Integrated circuits (ICs):
  - CPU (central processing unit), chipsets, memory, peripheral I/O chips (e.g., for USB, IEEE1394, …)

- Printed circuit boards (PCBs):
  - Substrate for ICs and interconnection
  - Distribution of clock, power supply
  - Heat dissipation

- Hard drive

- Optical storage (CD-ROM, DVD-ROM, CD-RW, …)

- Power supply:
  - Converts line AC voltage (100V) to regulated DC low voltage levels
  - GND (0V), +/-12V, +/-5V, …

- Chassis:
  - Holds boards, power supply, and provides physical interface for user and other system components

- Connectors and cables
Integrated circuits

- Primarily crystalline silicon
- 1mm~25mm on a side
- “Feature size”: 45~250nm
- 0.1B~1B transistors
- 3~10 metal “conductive” layers
- CMOS (complementary metal-oxide semiconductor) technology

- Package spreads chip level signal paths to board level
- Provides heat dissipation
Packaging

- Mounting
- Wire bonding
- Packaging material filling & marking

Printed circuit board

- Fiberglass or ceramic
- 1~20 conductive layers
- 1~20 inches on a side
- IC packages are mounted and soldered on a board
Technology trend

2X transistors on a same-size chip every 1.5~2 years!

Memory (DRAM) capacity trend

1.4x/year or 2x every 2 years
8000x since 1980!
Hard drive capacity trend

Exponential technology advances

- Memory
  - DRAM capacity: 2x / 2 years (since ’96)
  - 64x capacity improvement in the last decade

- Processor
  - Speed (in terms of clock frequency): 2x / 1.5 years (since ’85)
    - It slows down these days
  - 100x performance improvement in the last decade

- Disk
  - Capacity: 2x / 1 year (since ’97)
  - 250x capacity improvement in the last decade
My first PC

- My 1st year at college
- CPU: 80286 @~10MHz
  - (No hardware floating-point unit)
- Main memory: 1MB
- Hard drive: 40MB
- 5.25” floppy disk
- No CD-ROM
- 14-inch monitor (not flat)
- Wheel mouse w/ 2 buttons

If I buy a new PC in the future…

- Processor: (something x86) @at least 2~3GHz
  - # of cores in this processor must be 4 or more
- Memory capacity: at least 4GB, probably 8GB
- Disk capacity: several TB
- Optical drive: Blu-ray enabled DVD/CD drive
- New units: Mega to Giga, Giga to Tera, (Tera to Peta, Peta to Exa, Exa to Zetta, Zetta to Yotta)
Input devices

- Accepts input from human

- Desktop computers
  - Keyboard
  - Mouse (touchpad)
  - Joystick
  - ...

- Servers
  - Terminals on network

- Cell phone – embedded computer
  - Keypad
  - Voice recognition

---

Input devices

- Mouse
  - Wheel mouse (hard to find these days)
  - Optical mouse: takes 1,500 “photo shots” of LED (light-emitting diode) reflection to detect and measure movement

- Keyboard or keypad
  - Not many changes so far

- Web camera

- Voice recognition

- New input device?
Output devices

- Passes information to human

- Desktop computers
  - Display (LCD)
  - Sound
  - …

- Servers
  - Terminals on network

- Cell phone – embedded computer
  - Screen
  - Sound
  - Vibration

- Display
  - Transition from CRT to LCD nearly completed
  - LCD size from 10 to ~30 inches

- Sound
  - Simple “tick” to theatre-like effects, 5.1 channels, …
Storage and network

- Storage and network devices are I/O devices like keyboard and graphics card.

- Today, storage and network devices need high bandwidth:
  - Fast data retrieval and storing
  - Fast communication

Main memory

- DRAM (dynamic random access memory) is the choice technology:
  - Large capacity
  - Low price
  - Standard products from multiple vendors

- What is SRAM?
Main memory

- Embedded computers use DRAM or SRAM (or both) depending on applications
  - On-chip SRAM
  - On-chip SDRAM
  - SDRAM
  - Mobile SDRAM (1.8V operation)

![SRAM, SDRAM, FLASH all in a same chip!](www.3G.co.uk)

Storage

- Secondary storage (c.f., main memory)
- Non-volatile
- Stores programs, user-saved data, etc.

- In PC/server domain, magnetic disk (hard disk) is dominant

- In embedded computers, “flash” memory and “ROM” are quite popular

- Due to performance, power, and reliability issues, solid-state disk drives (based on flash memory technology) become increasingly common
Storage

5.25-inch floppy disk
1.2MB

USB drive - ~GBs

Hard disk drive - ~TBs

35-inch floppy disk

1.44MB

Flash SSD – 128GB

Optical storage

CS/CoE0447: Computer Organization and Assembly Language
University of Pittsburgh
Main memory vs. storage

- Differences?
- Volatility
  - Technology used
- Addressability
- Access speed

Computer networks

- Local area network (LAN)
  - Within a limited distance (e.g., inside a building)
  - 100/100/1000Mbps, ...
- Wide area network (WAN)
  - Connecting smaller networks far apart

- At home
  - Modem: 14.4kbps, 28.8kbps, 33.6kbps, 56kbps
  - Cable modem/DSL: several hundred kbps ~ several Mbps
  - Home network

- Proliferation of wireless LAN (IEEE 802.11)
  - 1~100Mbps
A look at ADSL modem

Real stuff: manufacturing Pentium4

- Read your textbook, Chapter 1.4
Besides classic h/w components…
Besides classic h/w components…

^Trashador^