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

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

```assembly
void swap(int v[], int k) {
    int temp;
    temp = v[k];
    v[k] = v[k+1];
    v[k+1] = temp;
}
```
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 scarce 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>General-Purpose Registers</th>
<th>Special-Purpose Registers</th>
</tr>
</thead>
<tbody>
<tr>
<td>$zero r0</td>
<td>r16 $s0</td>
</tr>
<tr>
<td>$at r1</td>
<td>r17 $s1</td>
</tr>
<tr>
<td>$v0 r2</td>
<td>r18 $s2</td>
</tr>
<tr>
<td>$v1 r3</td>
<td>r19 $s3</td>
</tr>
<tr>
<td>$a0 r4</td>
<td>r20 $s4</td>
</tr>
<tr>
<td>$a1 r5</td>
<td>r21 $s5</td>
</tr>
<tr>
<td>$a2 r6</td>
<td>r22 $s6</td>
</tr>
<tr>
<td>$a3 r7</td>
<td>r23 $s7</td>
</tr>
<tr>
<td>$t0 r8</td>
<td>r24 $t8</td>
</tr>
<tr>
<td>$t1 r9</td>
<td>r25 $t9</td>
</tr>
<tr>
<td>$t2 r10</td>
<td>r26 $k0</td>
</tr>
<tr>
<td>$t3 r11</td>
<td>r27 $k1</td>
</tr>
<tr>
<td>$t4 r12</td>
<td>r28 $gp</td>
</tr>
<tr>
<td>$t5 r13</td>
<td>r29 $sp</td>
</tr>
<tr>
<td>$t6 r14</td>
<td>r30 $fp</td>
</tr>
<tr>
<td>$t7 r15</td>
<td>r31 $ra</td>
</tr>
</tbody>
</table>

~2000 transistors

32 bits

PC

HI LO

CS/CoE0447: Computer Organization and Assembly Language
University of Pittsburgh
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

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?

Instruction description example

<table>
<thead>
<tr>
<th>Add Immediate Word</th>
<th>ADDE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

### Purpose:

- The 16-bit signed immediate is added to the 32-bit value in GPR r5 to produce a 32-bit result.
- If the addition results in 32-bit twos complement 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 r5

### Restrictions:

None

### Operation:

- temp = (16-bit immediate) + GPR[r5].s; sign extend immediate
- If temp is zero, then
  - Set Integer Overflow exception
- Else
  - GPR[r5] = temp

### Exceptions:

- Integer Overflow

Programming Note:

ADDI performs the same arithmetic operation but does not trap on overflow.

A problem has been detected and Windows has been shut down to prevent damage to your computer.

The problem seems to be caused by the following file: SPMDCOM.SYS

PAGE_FAULT_IN_NONPAGED_AREA

If this is the first time you've seen this stop error screen, restart your computer. If this screen appears again, follow these steps:

- check to make sure any new hardware or software is properly installed.
- If this is a new installation, ask your hardware or software manufacturer for any Windows updates you might need.
- If problems continue, disable or remove any newly installed hardware or software. Disable BIOS memory options such as caching or shadowing. If you need to use Safe Mode to remove or disable components, restart your computer, press F8 to select Advanced Startup Options, and then select Safe Mode.

Technical Information:

with path: 0x00000000 (0x00000000, 0x00000000, 0x00000000, 0x00000000)

with SPMDCOM.SYS - Address FFE7617 base at FFE5000, DateStamp 3dec67c
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

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

Memory (DRAM) capacity trend

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

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

Output devices

- 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)

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

3.5-inch floppy disk
1.44MB

Flash SSD - 128GB

Optical storage

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...
Besides classic h/w components…

^Trashcan^