X86 ARCHITECTURE

CS 16: Assembly Language Programming for the IBM PC and Compatibles
OBJECTIVES

- Discuss the general concepts
- Look at IA-32 processor architecture and memory management
- Dive into 64-bit processors
- Explore the components of an IA-32 microcomputer
- Take a peek at an Input-Output system
GENERAL CONCEPTS

- Basic microcomputer design
- Instruction execution cycle
- Reading from memory
- How programs run
Clock synchronizes CPU operations
Control unit (CU) coordinates sequence of execution steps
Arithmetic logic unit (ALU) performs arithmetic and bitwise processing
- Synchronizes all CPU and BUS operations
- Machine (clock) cycle measures time of a single operation
- Clock is used to trigger events
- Fetch
- Decode
- Fetch operands
- Execute
- Store output
Reading from Memory

- Multiple machine cycles are required when reading from memory because it responds much more slowly than the CPU.

- The steps are:
  - Place the address of the value you want to read on the address bus.
  - Assert (changing the value of) the processor’s RD (read) pin.
  - Wait one clock cycle for the memory chips to respond.
  - Copy the data from the data bus into the destination operand.
CACHE MEMORY

- High-speed expensive static RAM both inside and outside the CPU
  - Level-1 cache: inside the CPU
  - Level-2 cache: outside the CPU
- CACHE HIT: when data to be read is already in cache memory
- CACHE MISS: when data to be read is not in cache memory
IA-32 Processor Architecture

- Modes of operation
- Basic execution environment
- Floating-point unit
- Intel Microprocessor history
Modes of Operation

- Protected mode
  - Native mode (Windows, Linux)

- Real-address mode
  - Native MS-DOS

- System management mode
  - Power management, system security, diagnostics

- Virtual-8086 mode
  - Hybrid of Protected
  - Each program has its own 8086 computer
Addressable memory
General-purpose registers
Index and base registers
Specialized register uses
Status flags
Floating-point, MMX, XMM registers
Addressable Memory

- Protected mode
  - 4 GB
  - 32-bit address

- Real-address and Virtual-8086 modes
  - 1 MB space
  - 20-bit address
Named storage locations inside the CPU, optimized for speed
Use 8-bit name, 16-bit name, or 32-bit name

Applies to EAX, EBX, ECX, and EDX

<table>
<thead>
<tr>
<th>32-bit</th>
<th>16-bit</th>
<th>8-bit (high)</th>
<th>8-bit (low)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EAX</td>
<td>AX</td>
<td>AH</td>
<td>AL</td>
</tr>
<tr>
<td>EBX</td>
<td>BX</td>
<td>BH</td>
<td>BL</td>
</tr>
<tr>
<td>ECX</td>
<td>CX</td>
<td>CH</td>
<td>CL</td>
</tr>
<tr>
<td>EDX</td>
<td>DX</td>
<td>DH</td>
<td>DL</td>
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</tbody>
</table>
Some registers have only a 16-bit name for their lower half.

<table>
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<tr>
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<tbody>
<tr>
<td>ESI</td>
<td>SI</td>
</tr>
<tr>
<td>EDI</td>
<td>DI</td>
</tr>
<tr>
<td>EBP</td>
<td>BP</td>
</tr>
<tr>
<td>ESP</td>
<td>SP</td>
</tr>
</tbody>
</table>
Some Specialized Register Uses

General-Purpose
- EAX: accumulator
- ECX: loop counter
- ESP: stack pointer
- ESI, EDI: index registers
- EBP: extended frame pointer (stack)
Some Specialized Register Uses (2)

- **Segment**
  - CS: code segment
  - DS: data segment
  - SS: stack segment
  - ES, FS, GS: additional segments

- **EIP:** instruction pointer

- **EFLAGS**
  - Status and control flags
  - Each flag is a single binary bit
STATUS FLAGS

- **Carry**
  - Unsigned arithmetic out of range

- **Overflow**
  - Signed arithmetic out of range

- **Sign**
  - Result is negative
Zero
- Result is zero

Auxiliary Carry
- Carry from bit 3 to bit 4

Parity
- Sum of 1 bits is an even number
Eight 80-bit floating-point data registers
- ST(0), ST(1), . . . , ST(7)
- Arranged in a stack
- Used for all floating-point arithmetic

Eight 64-bit MMX registers

Eight 128-bit XMM registers for single-instruction multiple-data (SIMD) operations
IA-32 Memory Management

- Real-address mode
- Calculating linear addresses
- Protected mode
- Multi-segment model
- Paging
PROTECTED MODE

- 4 GB addressable RAM
  - (00000000 to FFFFFFFFh)
- Each program assigned a memory partition which is protected from other programs
- Designed for multitasking
- Supported by Linux & MS-Windows
64-Bit Operation Modes

- Compatibility mode: can run existing 16-bit and 32-bit applications (Windows supports only 32-bit apps in this mode)
- 64-bit mode: Windows 64 uses this

Basic Execution Environment

- Addresses can be 64 bits (48 bits, in practice)
- 16 64-bit general purpose registers
- 64-bit instruction pointer named RIP
32-bit general purpose registers:
- EAX, EBX, ECX, EDX, EDI, ESI, EBP, ESP, R8D, R9D, R10D, R11D, R12D, R13D, R14D, R15D

64-bit general purpose registers:
- RAX, RBX, RCX, RDX, RDI, RSI, RBP, RSP, R8, R9, R10, R11, R12, R13, R14, R15
COMPONENTS OF AN IA-32 MICROCOMPUTER

- Motherboard
- Video output
- Memory
- Input-output ports
Motherboard

- CPU socket
- External cache memory slots
- Main memory slots
- BIOS chips
- Sound synthesizer chip (optional)
Video controller chip (optional)
IDE, parallel, serial, USB, video, keyboard, joystick, network, and mouse connectors
PCI bus connectors (expansion cards)
dynamic RAM
Pentium 4 socket
IDE drive connectors
mouse, keyboard, parallel, serial, and USB connectors
memory controller hub
Pentium 4 socket
dynamic RAM
Power connector
Diskette connector
IDE drive connectors
I/O Controller
Battery
Firmware hub
AGP slot
PCI slots
Audio chip
Video
Video OUTPUT

- Video controller
  - On motherboard, or on expansion card
  - AGP (accelerated graphics port technology)
    - This link may change over time
- Video memory (VRAM)
- Video CRT Display
  - Uses raster scanning
  - Horizontal retrace
  - Vertical retrace
- Direct digital LCD monitors
  - No raster scanning required
128-bit 3D graphics performance powered by RAGE™ 128 PRO
3D graphics performance
Intelligent TV-Tuner with Digital VCR
TV-ON-DEMAND™
Interactive Program Guide
Still image and MPEG-2 motion video capture
Video editing
Hardware DVD video playback
Video output to TV or VCR
MEMORY

 ROM
  □ Read-only memory

 EPROM
  □ Erasable programmable read-only memory

 Dynamic RAM (DRAM)
  □ Inexpensive; must be refreshed constantly

 Static RAM (SRAM)
  □ Expensive; used for cache memory; no refresh required
Video RAM (VRAM)
- Dual ported; optimized for constant video refresh

CMOS RAM
- Complimentary metal-oxide semiconductor
- System setup information

See: Intel platform memory (Intel technology brief: link address may change)
Input-Output Ports: USB

- Intelligent high-speed connection to devices
- Up to 12 megabits/second
- USB hub connects multiple devices
- Enumeration: computer queries devices
- Supports hot connections
SHORT-cable, high speed
Common for printers
Bidirectional, parallel data transfer
Intel 8255 controller chip
RS-232 serial port
One bit at a time
Uses long cables and modems
16550 UART (universal asynchronous receiver transmitter)
Programmable in assembly language
DEVICE INTERFACES

- **ATA host adapters**
  - Intelligent drive electronics (hard drive, CDROM)

- **SATA (Serial ATA)**
  - Inexpensive, fast, bidirectional

- **FireWire**
  - High speed (800 MB/sec), many devices at once

- **Bluetooth**
  - Small amounts of data, short distances, low power usage

- **Wi-Fi (wireless Ethernet)**
  - IEEE 802.11 standard, faster than Bluetooth
Levels of Input-Output

Level 3: High-level language function
- Examples: C++, Java
- Portable, convenient, not always the fastest

Level 2: Operating system
- Application Programming Interface (API)
- Extended capabilities, lots of details to master

Level 1: BIOS
- Drivers that communicate directly with devices
- OS security may prevent application-level code from working at this level
When a HLL program displays a string of characters, the following steps take place:
Assembly language programs can perform input-output at each of the following levels:

- Library (Level 3)
- OS Function (Level 2)
- BIOS Function (Level 1)
- Hardware (Level 0)
SUMMARY

- Central Processing Unit (CPU)
- Arithmetic Logic Unit (ALU)
- Instruction execution cycle
- Multitasking
- Floating Point Unit (FPU)
- Complex Instruction Set
- Real mode and Protected mode
- Motherboard components
- Memory types
- Input/Output and access levels