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Computer Systems Organization

Lecture 15-16: Systems Hardware

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This Lecture

What is inside your computer?
How to decipher the different specs?
What Happens When You Turn-On Your Computer?
Booting Sequence

• BIOS starts
  – checks how much RAM
  – keyboard
  – other basic devices
• PnP (Plug-And-Play) initialized
• BIOS determines boot Device
  – By reading the Master Boot Record (MBR)
• The first sector in boot device is read into memory and executed to determine active partition
  – This first sector contains the boot loader.
• Secondary boot loader is loaded from that partition.
• This loader loads the OS from the active partition and starts it.
BIOS

• Basic Input/Output System
• Flash memory
• Resides on your motherboard.
• A standardized communication interface between the computer’s hardware and the operating system.
• The BIOS also reads the Extended System Configuration Data (ESCD) for configuration information on existing PnP devices.
BIOS and PnP

For PnP to work properly the system needs:

- PnP BIOS: reads Extended System Configuration Data (ESCD), which is a file that contains information about installed PnP devices.
- PnP OS
- PnP enabled device (almost all devices these days are like that).
BIOS and PnP

Example: we connect a sound card to the PCI bus:

1. The BIOS initiates the PnP BIOS.
2. The PnP BIOS scans the PCI bus for hardware by sending out a signal to any device connected to the bus, asking the device who it is.
3. The sound card responds by identifying itself. The device ID is sent back across the bus to the BIOS.
4. The PnP BIOS checks the ESCD to see if the configuration data for the sound card is already present.
5. The PnP BIOS assigns IRQ, DMA, memory address and I/O settings to the sound card and saves the data in the ESCD.
6. When the OS boots, it will read the info in ESCD and install required driver.
Anatomy of A Computer System
Anatomy of A Motherboard

- **Chipset**: handles communication between the processor and the other parts of your computer.
- **CPU slot** (socket)
- **Buses**: connection on the motherboard that carries data between the various parts of the motherboard (chipset, memory, processor, ...)
- **Expansion slots**: for connecting expansion cards
- **Memory slots**
- **Power connector**: to supply power to motherboard and to help motherboard supply power to some devices
- **Others**: like graphics and sound (integrated)
- **Clock generator**
Chipset
Chipset

- Designed for use with a specific family of processors.
- **Northbridge**: connects the CPU to high-speed components like RAM.
- **Southbridge**: connects to slower peripheral devices like PCI slots, USB, IDE, … .
- Example: Intel southbridge connects to northbridge with 266MB/s. Other chipsets are faster.
- Both bridges are essentially routers. They route data traffic from one bus to another.
Chipset

South Bridge

North Bridge

source: http://static.ddmcdn.com/gif/motherboard-bridges.jpg
Buses

- To ensure interoperability of different devices with different buses, there must be well-defined rules about how the bus works, and which all attached devices must obey → bus protocol

- A bus has address, data, and control lines.

- There is not necessarily a one-to-one mapping between CPU pins and bus lines.
  - A decoder chip between CPU and bus would be needed in this case.
Buses

• A synchronous bus has a line driven by a crystal oscillator.
  – The signal on this line consists of a square wave
  – All bus activities take an integral number of these cycles, called bus cycles.

• The asynchronous bus does not have a master clock.
  – Handshaking
Disadvantage of Synchronous Buses

• Everything works in multiples of the bus clock.
  – Example: if a CPU and memory can complete a transfer in 3.1 cycles they have to stretch it to 4.0 because fractional cycles are forbidden.

• Once a bus cycle has been chosen, and memory and I/O cards have been built for it, it is difficult to take advantage of future improvements in technology.

• The bus has to be geared to the slowest devices on the bus.
Bus Example: PCI-e

- Developed by Intel
- Peripheral Component Interconnect
- PCI Express architecture is a high performance, IO interconnect for peripherals.
- A serial point-to-point interconnect between two devices
- PCI-Express slots also accepts older PCI cards
- Data sent in packets
- Synchronous
- No shared bus but a shared switch
Bus Example: PCI-e

<table>
<thead>
<tr>
<th>Link Width</th>
<th>x1</th>
<th>x2</th>
<th>x4</th>
<th>x8</th>
<th>x12</th>
<th>x16</th>
<th>x32</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregate BW (GBytes/s)</td>
<td>0.5</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>8</td>
<td>16</td>
</tr>
</tbody>
</table>
PCIe Card

- Is any device connected to PCIe bus

Graphics card PCIe (x16)
Source: National Instrument
Bus Example: USB

- Universal Serial Bus
- Asynchronous → clockless
- Industry standard developed in the 1990s
- Communicates data and power
- USB 3.0
  - Introduced 2008
  - Backward compatible
  - Increase the data transfer rate (up to 5 Gbit/s)
  - Decrease power consumption
  - Increase power output
- USB 3.1 releases July 2013
Bus Example: USB

- **Host**: Initiates all transactions and bandwidth usage. The host controls most of the protocol complexity → allowing for cheaper slave devices to be produced.

- **Slave**: A peripheral USB device

- **Hub**: A device that contains multiple ports.
  - There will always be a root hub. This is the hub that contains the ports connected to the host.
  - We can have a tree of hubs till 5 levels.
Example: USB

- Host
- Root Hub
- HUB
- Keyboard
- Disk
- Speaker
- Printer

Diagram:

- Host connects to Root Hub
- Root Hub connects to two HUBs
- HUBs connect to various devices: Keyboard, Disk, Speaker, Printer
Example: USB

- Once you plug your device in, a process called **enumeration** starts.
- The host initiates enumeration as follows:
  1. Send a reset signal to the device
  2. Determine its speed
  3. Read the device’s information
  4. Assign a unique 7 bit address to the device
Example: USB

Host

Status Change
Query Change
Port Enable
Reset Device
Get Device Descriptor via default Pipe and Address
Assign a Unique Address
Read all Configuration Information
Configure and Assign Configuration Value

Hub

Connect Cable

Device

Attached
Powered
Default
Addressed
Configured

Source: ATMEL
Cooling
Cooling: Air

- **Case fans** come in a variety of sizes.
  - Most cases are designed to use 80 mm, 90 mm, and 120 mm fans.
- **CPU's, video cards, power supply, and other components** often use their own dedicated fan(s).
- **Heatsinks** are normally constructed from copper and/or aluminum and directly contact microchips on a circuit board.
- A fan blows air across the heatsink which transfers heat absorbed from the CPU into the air.
Cooling: Air

Case Fans
Cooling: Air

CPU Heatsinks and Fans
What’s Bad About Air Cooling

• Fans can be loud.
• Air cooling is will not cool as well as the other methods such as liquid cooling.
• You have to clean the fans.
• Needs a basic understanding of thermodynamics to be efficient.
Cooling: Water

• Uses water pushed through a radiator to cool computer components via a pump, reservoir, and tubing.
• Used to cool high end servers, desktops, and super computers like the Cray systems.
• Can be made to a single component or to all components such as the north and south bridge chipsets.
• Around 34% more efficient than air cooling.
Sockets
Processor Socket

• Compatible with specific type(s) of microprocessors.
• How chips are attached to a motherboard (more on that later)
# Motherboards Based on Packaging

<table>
<thead>
<tr>
<th>Type</th>
<th>For</th>
</tr>
</thead>
<tbody>
<tr>
<td>LGA 1156</td>
<td>Intel Core i3, i5, and i7</td>
</tr>
<tr>
<td>AM3</td>
<td>AMD Phenom II and AMD Athlon II</td>
</tr>
<tr>
<td>LGA 775</td>
<td>Intel Core 2 Duo, Intel Core 2 Quad and Intel Xeon processor</td>
</tr>
<tr>
<td>939</td>
<td>AMD Athlon 64, Athlon 64 FX, Athlon 64 X2 and Opteron</td>
</tr>
</tbody>
</table>
How Chips Are Mounted on Motherboards

- Packaging technology
- PGA (Pin-Grid-Array):
  - Pins are arranged in a regular array on the underside of the package.
  - Chip mounted on the board using the through hole method or inserted into a socket.
  - Used in most AMD processors
- LGA (Land-Grid-Array):
  - Pins on the socket rather than the chip
  - Newer Intel processors and many AMD Opteron
Intel Pentium MMX

Source: http://www.cpu-world.com/CPUs/Pentium/
Source: http://www.computer-hardware-explained.com/images/CPU-socket.jpg
LGA

LGA 1156

Source: http://www.anandtech.com/show/2832/2
# Motherboards Based on Dimensions

<table>
<thead>
<tr>
<th>Type of Motherboard</th>
<th>Description</th>
</tr>
</thead>
</table>
| AT                  | - Oldest type of motherboard still used in some systems  
                     - Uses P8 and P9 power connections (see Figure 5-1)  
                     - Measures 30.5 cm × 33 cm (12 inches × 13 inches)  |
| Baby AT             | - Smaller version of AT. Small size is possible because motherboard logic is stored on a smaller chip set.  
                     - Uses P8 and P9 power connections  
                     - Measures 33 cm × 22 cm (12 inches × 8.7 inches)  |
| ATX                 | - Developed by Intel for Pentium systems  
                     - Has a more conveniently accessible layout than AT boards  
                     - Includes a power-on switch that can be software-enabled and extra power connections for extra fans  
                     - Uses a P1 connector (see Figure 5-1)  
                     - Measures 30.5 cm × 24.4 cm (12 inches × 9.6 inches)  |
| Mini ATX            | - An ATX board with a more compact design  
                     - Measures 28.4 cm × 20.8 cm (11.2 inches × 8.2 inches)  |
What to Look for in Motherboards?

- Form-factor
- Socket
- Chipset
  - Latest from Intel: Z77, Z79, Z87
  - Latest from AMD: A85X, 990X, and 990FX
- SLI/Crossfire support
  - If you want to connect more than one video card.
- Ports
- Slots
  - Must be careful whether all are enabled
  - Example: PCIe can be x16 in length but x8 electrically.
- Backup BIOS (nice to have!)
- POST LED (displays POST code while booting)
CPU
What Do You Look For?

• **Socket**
  – If you plan to upgrade, don’t pick the socket with least amount of life left.
  – Example: for Intel: pick LGA1150 or LGA1156 instead of LGA1155
  – Example: for AMD: AM3+ is nice from budget dual-core up to eight-core chips.

• **Core count**
  – Better than frequency these days as a measure of potential performance
  – More cores are better if you can use them.
What to Look For?

- **Clock frequency**
  - Good only for comparing processors of the same family

- **Cache**
  - In many cases, chips are the same! That is: an chip 6MB of L2 cache is usually the same as 8MB cache but the 2MB are either defective or turned off!
  - How good a large cache is depends on the workload.

- **Integrated graphics**
  - Much slower than the discrete GPUs
Processor Numbering System:
Intel As Example

Processor Numbering System: AMD Opteron as Example

- AMD Opteron processors are described by a three-digit model number.
- The first number indicates the maximum scalability of the processor.
  - AMD Opteron 100 vs AMD Opteron 800
- The second two digits indicate relative performance within the series.
  - Dual-Core AMD Opteron processor Model 880 outperforms a Dual-Core AMD Opteron processor Model 875.
GPU
Figure 1.1. Enlarging Performance Gap between GPUs and CPUs.

Multiprocessor CPU
Many-core GPU

Courtesy: John Owens
GPUs Today

• Are general purpose and not only for graphics
• Discrete
  – separate chip on-board like all Nvidia GPUs and AMD Radeo
• Integrated
  – With the CPU on the same chip like the GPU in Intel Sandy Bridge and Ivy Bridge
What to Look for?

• The amount of GPU memory
  – Also called frame-buffer
  – The larger the memory the higher the resolution the GPU can handle.
  – Ranges from 1GB in low-end to 6GB in high-end
  – Example: you will need 3GB–4GB memory for 2560x1600 with decent frame rates
  – Anti-Aliasing (AA): smoothing out edges → may require more memory for lower rendered resolution.

• How many cores?
  – Cores here are simpler than cores in a multicore chips
  – Called stream processors by AMD and CUDA cores by Nvidia

• The two big players: Nvidia and AMD
  – built on different architectures so we cannot compare them
  – This means more cores on an AMD GPU than Nvidia GPU does not necessarily mean the former is faster.
What to Look for?

• **Memory bus**
  – Path between GPU itself and the video card memory
  – **Bus width and speed of memory → bandwidth (GB/s) → more is better**
  – Example:
    • GTX 680: 6GHz memory and 256-bit interface → 192.2 GB/s
    • GTX Titan: 6GHz memory and 384-bit interface → 288.4 GB/s
  – Since most modern gaming GPUs use 6GHz memory, the bus width is the one that makes the difference.
What to Look for?

• Power requirements
  – Most GPUs use PCIe power connectors (6-pin or 8-pin)
  – Most high-end cards will draw 100-200W of power under load → you may need 500-650W PSU (power supply unit) for your entire computer system.

• Display connectors
  – Connects GPU to the display
  – Example:
    • DVI: single-link and dual-link
    • HDMI: versions 1.-, 1.2, 1.3, and 1.4 → for higher resolutions

• The architecture: Fermi and Kepler (latest)
Example: Nvidia Kepler Architecture

Example: Nvidia Chip GK110 Based on Kepler Architecture

- 7.1 billion transistors
- More then 1 TFlop of double precision throughput
  - 3x performance per watt of Fermi
- New capabilities:
  - Dynamic parallelism
  - Hyper-Q
  - Nvidia GPUDirect
Example: From a website:
How to Read Specs?

• **General**
  – Brand: NVIDIA
  – Model TESLA K20 (900-22081-2220-000)

• **Interface:** PCI Express 2.0 x16

• **Chipset**
  – GPU GK110 Core
  – Clock 706MHz
  – CUDA Cores 2496

• **Memory**
  – Memory Clock 2.6GHz
  – Memory Size 5GB
  – Interface 320-bit
  – Memory Type GDDR5

• **Power and Cooling**
  – Cooler: Passive heat sink
  – System Requirements
  – Board power: 225W
    – Idle power: 25W
  – Auxiliary Power Connector: 6 Pin / 8 Pin
System Memory

Dual in-line memory module (DIMM)
System Memory

- We usually call it DRAM but in the near future this technology may change.
- It is the main bottleneck of performance in most computer systems.
What to look for?

- **Capacity**
- **Clock speed**
  - in MHz (e.g. DDR3/1866 runs at 1.866MHz)
  - DDR → double data rate: DDR2, 3, and 4
- **Registered DIMMs (aka Buffered DIMMs)**
  - Extra chip on the module to take some load off the memory controller
- **ECC RAM: Error-Correcting Control**
  - Make sure the CPU supports it if you want to use ECC RAM.
Storage

- **SSD (Solid-State Disks)**
  - Usually using NAND flash
  - SLC, MLC, or TLC (Single, Multi, Triple-level cell) → how many values it can hold in a cell at one time → cost vs capacity
  - Performance depends on the controller that:
    - Reads and writes data from flash
    - Optimizes the drive
    - Performs routing garbage collection
    - Comes from: LSI Sandforce, Samsung, OCZ, ...
  - Over-provisioning = size taken from total capacity for drive maintenance
    - Example: If your drive is listed as 240GB then it has 16GB reserved for over-provisioning
Storage

- HDD (Hard-Disk Drives)
  - capacity
  - RPM (Rotation-per-Minute)
  - Cache size
    - Small memory with the disk (standard: 64MB)
    - Used as buffer
  - Platters
    - HDD stores data on several platters where data is stored on both-sides
    - Highest density platter = 1TB
    - The higher the density the better the performance of the disk
  - NCQ Technology
    - Native command queuing
    - help the drive priorities data requests for efficient processing
Conclusions

• After this lecture you can now understand the different components that make a computer systems and how they interact.

• The overall performance of a computer system as well as its power consumption depends on much more than CPUs and GPUs.