Standard computer
I/O Buses and Interfaces
General PC bus architecture
The bus is a critical component of the Computer:

- Buses are shared components that provide the paths for all parts of the computer to communicate with each other
- They can reduce the complexity of communications between computer components
- They contain conduits for data, “addressing”, and timing/control
- They need a protocol that all users use
- They can provide an easy way to evolve a computer system – add components
- They can be a serious bottleneck if not designed and used appropriately
- As systems grow, they need to evolve hierarchically
- They can be parallel or serial
- They can have data widths larger than the computer word length
General Bus types

**Processor-memory bus** (may be proprietary)
- Short and high speed
- Matched to the memory system to maximize the memory-processor bandwidth
- Optimized for cache block transfers

**Backplane bus** (may be industry standard)
- The backplane is an interconnection structure within the chassis
- Used as an intermediary bus connecting I/O busses to the processor-memory bus

**I/O bus** (industry standard, e.g., SCSI, PCI-e, USB, Hypertransport)
- Usually is lengthy and slower
- Needs to accommodate a wide range of I/O devices
- Connects to the processor-memory bus or backplane bus
Bus Characteristics

- Data & Address lines
  - Data, addresses, and complex commands

- Control lines
  - Signal requests and acknowledgments
  - Indicate what type of information is on the data lines

- Bus transaction consists of
  - Master issuing the command (and address) — request
  - Slave receiving (or sending) the data — action
  - Defined by what the transaction does to memory
    - Input – inputs data from the I/O device to the memory
    - Output – outputs data from the memory to the I/O device
Bus design considerations:

Accessibility
Speed
Reliability
Extensibility
Bottle necks
Noise (electrical)
Flexibility
Ease of Interfacing
Power
Sharability
Communication Protocol
Length
Bus Communications

• Bus Protocols
  – Asynchronous
  – Synchronous
  – Memory Read / Writes
  – I/O Read Writes
  – Peer communication – e.g. CPU to CPU
  – Are communications verified?
  – Is there error checking (parity, CRC, etc.)?
Synchronous and Asynchronous Buses

• Synchronous bus (e.g., processor-memory buses)
  – Includes a clock in the control lines and has a fixed protocol for communication that is relative to the clock
  – Advantage: involves very little logic and can run very fast
  – Disadvantages:
    • Every device communicating on the bus must use same clock rate
    • To avoid clock skew, they cannot be long if they are fast

• Asynchronous bus (e.g., I/O buses)
  – It is not clocked, so requires a handshaking protocol and additional control lines (ReadReq, Ack, DataRdy)
  – Advantages:
    • Can accommodate a wide range of devices and device speeds
    • Can be lengthened without worrying about clock skew or synchronization problems
  – Disadvantage: slow(er)
Synchronous Bus

- Clock
- Status lines
- Stable address
- Address enable

Read cycle
- Read
- Data lines
- Valid data in

Write cycle
- Write
- Data lines
- Valid data out
Asynchronous Bus Handshaking Protocol
- Output (read) data from memory to an I/O device

1. Memory sees **ReadReq**, reads **addr** from data lines, and raises **Ack**
2. I/O device sees **Ack** and releases the **ReadReq** and data lines
3. Memory sees **ReadReq** go low and drops **Ack**
4. When memory has data ready, it places it on data lines and raises **DataRdy**
5. I/O device sees **DataRdy**, reads the data from data lines, and raises **Ack**
6. Memory sees **Ack**, releases the data lines, and drops **DataRdy**
7. I/O device sees **DataRdy** go low and drops **Ack**
Asynchronous Bus

(a) System bus read cycle
Interrupt Driven Data Transfer Time estimate

User program halts only during actual transfer

1000 transfers/second:
- 1000 interrupts @ 2 µsec per interrupt => 2 msec
- 1000 interrupt service @ 98 µsec each => 98 msec

100 msec = 0.1 CPU seconds
Direct Memory Access Time estimate

CPU sends a starting address, direction (R/W), and word count to DMAC. Then issues "start".

DMAC provides:
- Peripheral controller ← Handshake signals
- Memory ← Addresses
  ← Handshake signals

Time to do 1000 xfers in 1 msec:
1 DMA set-up sequence: @ 50 µsec
1 interrupt: @ 2 µsec
1 interrupt service sequence: @ 48 µsec

100 µsec
.0001 second of CPU time
Bus Standards

• Expansion buses or “slots”
• Disk interfaces
• External buses
• Communications interfaces
Expansion Buses

• These are “slots” on the motherboard

  – ISA – Industry Standard Architecture (outdated)
  – PCI – Personal Component Interconnect (outdated)
  – EISA – Extended ISA (outdated)
    • SIMM – Single Inline Memory Module (plugs into slot)
    • DIMM – Dual Inline Memory Module (plugs into slot)
  – MCA – Micro-Channel Architecture (outdated)
  – AGP – Accelerated Graphics Port (outdated)
  – VESA – Video Electronics Standards Association (outdated)
  – PCMCIA – Personal Computer Memory Card International Association (outdated)
  – PCI-e – PCI express (Current)
  – HT – Hypertransport (Current)
Disk Interfaces

• Examples
  – ATA – AT Attachment (named after IBM PC-AT) (outdated)
  – IDE – Integrated Drive Electronics (same as ATA) (outdated)
  – Enhanced IDE (outdated)
    • Encompasses several older standards (ST-506/ST-412, IDE, ESDI, ATA-2, ATA-3, ATA-4)
  – Floppy disk (outdated)
  – SCSI – Small Computer Systems Interface (servers) (Current)
  – ESDI – Enhanced Small Device Interface (mid-80s, obsolete) (outdated)
  – PCMCIA (outdated)
  – SATA – serial ATA (Current)
  – Ethernet (used for network drives) (Current)
External Buses

• Examples
  – Parallel – sometimes called LPT (“line printer”) (outdated)
  – Serial – typically RS232C (sometimes RS422) (outdated)
  – PS/2 – for keyboards and mice (outdated)
  – USB – Universal Serial Bus (current)
  – IrDA – Infrared Device Attachment (specialized)
  – FireWire – very high speed, developed by IEEE (outdated)
Communications Buses

• For connecting systems to systems
• Parallel/LPT (outdated)
  – special purpose, e.g., using special software (Laplink) to transfer data between systems
• Serial/RS232C (outdated)
  – To connect a system to a voice-grade modem
• Ethernet (current)
  – To connect a system to a high-speed network
A look at a few of the preceding examples in more detail:

- ISA
- PCI
- AGP
- Serial
- Parallel
- SCSI
- Ethernet
- USB
ISA bus

History
- a computer bus standard for IBM PC compatible computers introduced with the IBM Personal Computer to support its Intel 8088 microprocessor's 8-bit external data bus and extended to 16 bits for the IBM Personal Computer/AT's Intel 80286 processor
  - Configuration
    - Parallel, multi-drop

Advancements
- EISA
- Extended ISA
  - Design by nine IBM competitors (AST, Compaq, Epson, HP, NEC, Olivetti, Tandy, WYSE, Zenith)
  - Intended to compete with IBM’s MCA - EISA is hardware compatible with ISA
- MCA
- Micro Channel Architecture
  - Introduced by IBM in 1987 as a replacement for the AT/ISA bus
  - EISA and MCA have not been successful!
PCI

- **Peripheral Component Interconnect**
  - Also called “Local Bus”

- **History**
  - Developed by Intel (1993)
  - Very successful, widely used
  - Much faster than ISA
  - Gradually replaced ISA

- **Configuration**
  - Parallel, multi-drop

- **Used for...**
  - Just about any peripheral
  - Can support multiple high-performance devices
  - Graphics, full-motion video, SCSI, local area networks, etc.

- **Specifications**
  - 64-bit bus capability
  - Usually implemented as a 32-bit bus
  - Runs at 33 MHz or 66 MHz
  - At 33 MHz and a 32-bit bus, data rate is 133 Mbytes/s
AGP

- **Accelerated Graphics Port**
- **History**
  - First appeared on Pentium II boards
  - Developed just for graphics (especially 3D graphics)
- **Configuration**
  - Parallel, point-to-point (only one AGP port / system)
- **Specifications**
  - Data rates up to 532 Mbytes/s
Serial Interfaces

• On PCs, a “serial interface” implies a “COM port”, or “communications port”
  – COM1, COM2, COM3, etc.
• COM ports conform to the RS-232C interface standard
• History
  – Well-established standard, developed by the EIA (Electronics Industry Association) in 1960s
  – Originally intended as an electrical specification to connect computer terminals to modems
• Defines the interface between a DTE and a DCE
  – DTE = Data Terminal Equipment (terminal)
  – DCE = Data Communications Equipment (modem)
  – A “modem” is sometimes called a “data set”
  – A “terminal” is anything at the “terminus” of the connection
    • VDT (video display terminal), computer, printer, etc.
• Data rate
  – Maximum specified data rate is 20 Kbits/s with a maximum cable length of 15 meters
  – However...
    • It is common to “push” an RS-232C interface to higher data rates
    • Data rates to 1 Mbit/s can be achieved (with short cables!)
• Configuration
  – Serial, point-to-point
Parallel Interfaces

• History
  – In the context of PCs, a “parallel interface” implies a Centronics-compatible printer interface
  – Originally developed by printer company, Centronics
  – Introduced on the IBM PC (1981) as an LPT (“line printer”) port
  – Improvements
    • EPP (Enhanced Parallel Port), development by Intel, Xircom, Xenith
    • Enshrined in the standard IEEE-1284 (1994)
      – “Standard Signaling Method for a Bi-directional Parallel Peripheral Interface for Personal Computers”
      – Includes Centronics/LPT mode, EPP mode, and...
      – ECP mode (Enhanced Capability Port)

• Data Rate
  – 150 Kbytes/s (LPT) to 1.5 Mbytes/s (ECP)

• Configuration
  – Parallel, point-to-point
SCSI

• **Small Computer Systems Interface**

• **History**
  – Originally called Shugart Associates Systems Interface (SASI, pronounced “sasi”)
  – Scaled down version of IBM’s System 360 Selector Channel
  – Became an ANSI standard in 1986

• **Used for...**
  – Disk drives, CD-ROM drives, tape drives, scanners, printers, etc.

• **Configuration**
  – Parallel, daisy chain
  – Requires terminator at end of chain

• **Versions (data width, data rate)**
  – SCSI-1, Narrow SCSI (8 bits, 5 MBps)
  – SCSI-2 (8, bits 10 MBps)
  – SCSI-3 (8, bits, 20 MBps)
  – UltraWide SCSI (16 bits, 40 MBps)
  – Ultra2 SCSI (8 bits 40 MBps)
  – Wide Ultra2 SCSI (16 bits, 80 MBps)
Ethernet

• History
  – In 1980, Xerox, Digital Equipment Corporation (DEC, now Compaq), and Intel published a specification for an “Ethernet” LAN (local area network)
  – Now exists as a standard - IEEE 802.3
    • Physical interface uses either coax cable with BNC connectors or twisted pair cable with RJ-45 connectors (10Base-T)
  – Fast Ethernet
    • Specified in IEEE 802.3u (100Base-TX)

• Data Rate
  – 10 Mbits/s for Ethernet (10Base-T)
  – 100 Mbits/s for Fast Ethernet (100Base-T)
  – 1000 Mbits/s for Gigabit Ethernet (1000Base-T)

• Configuration
  – Serial, multi-point (token ring or token bus)
USB

• History
  – Universal Serial Bus (USB) is an industry standard developed in the mid-1990s
  – Versions = USB 1.x, USB 2.0, USB 3.0, USB 3.1

• Data Rate / Power
  – USB1.x - 1.5 Mbit/s (Low-Bandwidth) and 12 Mbit/s (Full-Bandwidth), / 100 - 500mA
  – USB2.0 - 35 MB/s or 280 Mbit/s, /1.5 up to 5A
  – USB3.0 - up to 4 Gbit/s (500 MB/s), /low power 150 mA and 900 mA, up to hi power 5A.
  – USB3.1 - 10 Gbps, / up to 2 A at 5 V, up to 5 A at either 12 V (60 W) or 20 V (100 W)

• Configuration
  – Serial, hub, tiered star