What Computers Can Do

- What computers can do:
  - Deterministically perform or execute instructions to process information
  - The computer must have instructions to follow
- What computers can’t do:
  - No imagination or creativity
  - No intuition
  - No sense of irony, subtlety, proportion, decorum, or humor
  - Are not vindictive or cruel
  - Are not purposeful
  - Have no free will

Anatomy of a Computer

- Computers have five basic parts or subsystems:
  - Memory, control unit, arithmetic/logic unit (ALU), input unit, output unit

Memory

- Memory stores two things:
  - The program(s) that are running
  - The data on which the program(s) operate(s)
- Properties of memory:
  - Discrete locations—each location consists of one byte
  - Addresses—every memory location (byte) has an address (whole numbers starting with zero)
  - Values—memory locations record or store values
  - Finite capacity—limited size; the data may not “fit” in memory location

Memory

- One-byte memory locations can store one ASCII character, or a number less than 256 (0 - 255)
- Programmers use a sequence of memory locations together, ignoring the fact that they all have different addresses
  - Blocks of four bytes are used as a unit so frequently that they are called memory words

Storage Terminology

- Kilobyte (k or kb)—about 1 thousand bytes (1024 bytes)
- Megabyte (mb)—about 1 million bytes (1,048,576 bytes)
- Gigabyte (gb)—about 1 billion bytes (1,073,741,824 bytes)
- Terabyte (tb)—about 1 trillion bytes (1,099,511,627,776 bytes)

Random Access Memory (RAM)

- Temporary holding area for instructions and data before and after processing
  - RAM is volatile—it is reusable and its contents is lost if the electrical power source is removed
  - This is the primary storage unit for modern day computers
- Comprised of millions (or billions) of miniature circuits on a chip (semiconductor memory)

8 Random Access Memory (RAM) (Page 2)
- Random access means the computer can refer to (access) the memory locations in any order
- RAM is often measured in:
  - Megabytes (MB)—millions of bytes, or
  - Gigabytes (GB)—billions of bytes
- A larger memory is preferable because there is more space for programs and data (which usually equates to less I/O)

10 DIMM's (Double In-line Memory Module)
- RAM memory units (DIMM's) are plugged into DIMM banks (slots) on the motherboard
- An earlier technology (SIMM's) was used in 1990’s computers

11 Read Only Memory (ROM)
- Memory chips that store permanent instructions
  - Data in ROM cannot be changed
- Helps the computer start (boot) when power is turned on
- For many personal electronic (computerized) devices, ROM holds basic operating instructions
  - Cell phones, digital watches, TV's, audio players, etc.

12 Complementary Metal Oxide Semiconductor (CMOS)
- Memory chip that holds data about:
  - Computer system configuration
  - The date and time in the system clock
- Data in CMOS can be changed as the computer configuration changes
- Powered by a small battery so that information is not lost when the computer is powered down

13 Central Processing Unit (CPU)
- The “brain” of the computer where processing takes place (also called the processor)
- Consists of the control unit and the ALU (arithmetic/logic unit)

14 Processor Chip
- A microprocessor incorporates most or all of the functions of a central processing unit (CPU) on a single integrated circuit (a chip)

15 Microprocessor
- Single chip that contains the circuitry for both the control unit and the ALU
- History of PC-compatible chips...
  - 8086 & 8088
  - 40286 (or 286)
  - 40386 (or 386)
  - 40486 SX (or 486-SX) & 40486 DX (or 486-DX)
  - Pentium series (most recently the Pentium 4)
  - Intel dual core processor
Integrated Circuits

- Miniaturization:
  - Clock speeds are so high because processor chips are so tiny (electrical signals can travel about 1 foot in a nanosecond—one billionth of a second)
  - Photolithography
    - Uses a printing process (instead of hand-wiring circuits together) in which a photograph of what is wanted is used to etch away the spaces
    - Regardless of how complicated the wiring, cost and amount of work are the same

How Semi-Conductor Technology Works

- Integration:
  - Active components and the wires that connect them are all made together of similar materials in a single process
  - Saves space and produces monolithic part for the whole system, which is more reliable
  - Silicon is a semi-conductor—sometimes it conducts electricity, sometimes not
  - Ability to control when semi-conductor conducts is the main tool in computer construction

The On-Again, Off-Again Behavior of Silicon

- A circuit is set to compute \( x \) and \( y \) for any logical values \( x \) and \( y \)
- If \( x \) is true, the \( x \) circuit conducts electricity and a signal passes to the other end of the wire; if \( x \) is false, no signal passes
- Same process exists for \( y \)
- If both circuits conduct, \( x \) and \( y \) are true—logical AND has been computed

Control Unit

- The control unit is the hardware implementation of the Fetch/Execute Cycle
- Directs and coordinates processing
- Its circuitry:
  - Fetches instructions from memory
  - Decodes the instructions
  - Fetches the operands used in instructions
  - Sends signals to the other parts of the CPU to carry out the instruction tasks

Arithmetic/Logic Unit (ALU) (Page 1)

- Performs arithmetic and logical operations
- A circuit in the ALU can add two numbers (actually only performs binary *addition*)
- There are also circuits for multiplying, comparing (logical operations, i.e. Hours > 40?), etc.

Arithmetic/Logic Unit (ALU) (Page 2)

- Generally does the work during the Instruction Execute step of the cycle
- Data/Operand Fetch step of the cycle gets values that the ALU needs to work on (operands)
- When the ALU completes the operation, Return Result/Store step moves answer from ALU to the destination memory address specified in instruction
23  **System Bus (Motherboard)**
   - The central or main board into which all system components are connected
   - Contains the bus—printed circuits, wires, and/or cables that connect all the internal components

25  **Input Unit and Output Unit (I/O)**
   - The circuits through which information moves into and out of a computer
   - Input and output units (devices) are peripherals that connect to the computer input/output ports ...
     - Not considered part of the computer, but specialized “gadgets” that encode or decode information between computer and physical world

26  **The Peripherals**
   - Keyboard encodes the typed keystrokes into binary form for the computer
   - Monitor decodes information from computer’s memory and displays it on lighted, colored screen
   - Disks drives are used for both input and output
     - Secondary storage devices where computer puts away information when not needed, and can retrieve from when it is needed again

27  **A Device Driver for Every Peripheral**
   - Peripheral devices are “dumb” devices provide basic physical translation to or from binary signals
   - Additional information from the computer is needed to make it operate intelligently, i.e.
     - The computer receives information that the user typed the shift key and the letter “w” at the same time
     - It converts to a capital “W”
   - The software that converts is called the device driver—every peripheral needs driver software for it installed on the computer

28  **Build Your Own PC—Step by Step Guide**
   - [http://www.youtube.com/watch?v=QQQ30QoF_ -8&feature=fvw](http://www.youtube.com/watch?v=QQQ30QoF_ -8&feature=fvw)

29  **PC Ports**
   - Interfaces between the computer and its peripheral devices
   - Physically a port is a specialized outlet on a computer to which a plug or cable connects

30  **Parallel Ports**
   - Type of interface for sending several data signals simultaneously over several parallel channels
   - Also known as a printer port

31  **Serial Ports**
   - An interface through which information transfers in or out one bit at a time
   - Many modern personal computers do not have a serial port

32  **VGA Port**
   - The 15-pin connector is found on many video cards and computer monitors as well as some high definition television sets
- Used for RGB video signals

**33 Ethernet Port**
- A computer networking port for local area network connections
- Often also called an RJ-45 (a larger version of the smaller RJ-11 telephone connector)

**34 USB Ports**
- Universal serial bus connector designed to replace older serial and parallel ports
- Connects computer peripherals such as mice, keyboards, digital cameras, printers, personal media players, flash drives, etc.

**36 Secondary Storage Devices**
- Computer components and recording media that retain digital data used for computing for some interval of time
  - Including after computer has been turned off
  - Technologies include magnetic tape drive, magnetic disk drives, compact disks and flash drives

**37 Magnetic Tape**
- The first truly mass auxiliary storage device was the magnetic tape drive
- The tape was made of a thin magnetizable coating on a long, narrow strip of plastic

**38 Magnetic Disks** (Page 1)
- Storage of data on a magnetized disk
- Uses different patterns of magnetization on a magnetizable material to store data
- History:
  - Floppy disks (refers to flexible disks)
    - 1970 – 8" in diameter
    - Late 1970’s – 5 1/4"
    - Since 1990’s – 3 1/2"
  - Zip drives
  - Today magnetic disk primarily means hard drives

**39 Magnetic Disks** (Page 2)
- Seek time—time it takes for read/write head to be over right track
- Latency—time it takes for sector to spin into position to the read/write head
- Access time—total time it takes to read or write data (sum of seek time and latency)
- Transfer rate—speed at which data is transferred from disk to memory

**41 Compact Disks**
- CD—the compact disk uses a laser to read information stored optically on a plastic disk:
  - CD-ROM read-only memory
  - CD-DA digital audio
  - CD-WORM write once, read many
  - RW or RAM both read from and written to
- Data is evenly distributed around track
- DVD—digital versatile disk is used for storing both audio and video

**43 Flash Drives**
A flash memory data storage device integrated with a USB (Universal Serial Bus) interface
- Typically removable and rewritable, and physically much smaller than a floppy disk
- Most weigh less than one ounce with storage capacities as large as 256 gigabytes
- Additional steady improvements in size and price per capacity expected

Touch Screens
- A computer monitor that can respond to the user touching the screen with a stylus or finger
- Touch screen types include:
  - Resistive
  - Capacitive
  - Infrared
  - Surface acoustic wave (SAW)

Touch Screens
- Resistive touch screen—a screen made up of two layers of electrically conductive material
  - One layer has vertical lines, the other has horizontal lines
  - When the top layer is pressed, it comes in contact with the second layer which allows electrical current to flow
  - The specific vertical and horizontal lines that make contact dictate the location on the screen that was touched

Touch Screens
- Capacitive touch screen—a screen made up of a laminate applied over a glass screen
  - Laminate conducts electricity in all directions; a very small current is applied equally on the four corners
  - When the screen is touched, current flows to the finger or stylus
  - The location of the touch on the screen is determined by comparing how strong the flow of electricity is from each corner

Touch Screens
- Infrared touch screen—a screen with crisscrossing horizontal and vertical beams of infrared light
  - Sensors on opposite sides of the screen detect the beams
  - When the user breaks the beams by touching the screen, the location of the break can be determined

Touch Screens
- Surface acoustic wave (SAW)—a screen with crisscrossing high frequency sound waves across the horizontal and vertical axes
  - When a finger touches the surface, corresponding sensors detect the interruption and determine location of the touch

Word Size
- Number of bits processor can manipulate at one time
- Most instructions have two elements:
  - Opcode—a field which specifies the basic instruction type (such as arithmetic, logical, jump, etc) and the actual operation (such as add or compare)
Operands—address or addresses of data to be processed by the instruction and the location where the result will be stored
- Standard word size for modern computers is 32-bits

Many Simple Operations
- Computers can only perform about 100 different instructions (known as its instruction set)
  - Actually there are only about 20 different kinds of operations (different instructions are needed for adding bytes, words, decimal numbers, etc.)
  - Everything computers do is reduced to some combination of these primitive, hardwired instructions

The Program Counter (Page 1)
- How does the computer determine which step to execute next?
- Address of the next instruction is stored in an area within the control part of the computer
- This register is called the program counter (PC) (or instruction counter).

The Program Counter (Page 2)
- Because instructions use 4 bytes of memory, next instruction must be at PC + 4, four bytes further along in the sequence (in general).
- Computer adds four to the PC, so when the F/E Cycle gets back to Instruction Fetch step, the PC is “pointing at” the next instruction

Branch and Jump Instructions
- Alternatively some instructions may include an address to “go to” next—a JMP (jump) instruction
- This changes the program counter, so instead of going to PC +4 automatically, computer “jumps” or “branches” to the specified location

The Instruction Register
- Part of the control unit in the processor where the current instruction is stored and decoded
- The instruction is “fetched” from memory at the address in memory specified in the PC during the Instruction Fetch step of the Fetch/Execute cycle

The Accumulator
- A register in the control unit of the CPU when intermediate arithmetic and logic results are stored
- Without an accumulator it would be necessary to write the results of each “calculation” back to memory immediately
  - Perhaps only to be read right back again into the control unit for use in the next operation

The Fetch/Execute Cycle
- A five-step cycle (within two major parts):
  - Fetch (instruction time or I-time)
    1. Instruction Fetch (IF)
    2. Instruction Decode (ID)
    3. Data Fetch (DF) / Operand Fetch (OF)
  - Execute (execution time or E-time)
4. Instruction Execution (EX)
5. Result Return (RR) / Store (ST)

**Instruction Interpretation**  (Page 1)
- Process of executing a program—the machine is interpreting commands, but in its own language
  1. Instruction Fetch:
     - Execution begins by moving instruction at the address in memory specified in the program counter (PC) to the instruction register (IR) in the control unit
     - Bits of the instruction are placed into the decoder circuit of the control unit
     - Once instruction is fetched, PC can be incremented making it ready for fetching the next instruction

**Instruction Interpretation**  (Page 2)
2. Instruction Decode:
   - The decoder determines what operation the ALU will perform, and sets it up appropriately
3. Operand Fetch:
   - Decoder finds memory address of the instruction’s data (source operands) ...
   - Most instructions operate on two data values stored in memory (like ADD), so most instructions have addresses for two source operands

**Instruction Interpretation**  (Page 3)
4. Instruction Execution:
   - The actual computation is performed
   - For an ADD instruction, the addition circuit adds the two source operands together to produce their sum
5. Result Return:
   - Result of execution is returned to the location specified by the destination address
   - Once the result is returned, the cycle begins again

**Cycling the F/E Cycle**  (Page 1)
- Computers impressive capabilities come from executing many simple instructions per second
- The computer clock determines rate of F/E cycle measured in gigahertz (GHz), or billions of cycles per second
  - One hertz is one cycle per second
  - Today’s computers operate at between 2-3 GHz

**Cycling the F/E Cycle**  (Page 2)
- Modern computers try to start an instruction on each clock tick
  - Passes off the finishing of an instruction to other circuitry (pipelining)—in this manner up to five instructions can be in processed at the same time
- Does a one-GHz clock really execute a billion instructions per second?
  - Not necessarily a precise measurement ...
  - Computer may not be able to start an instruction on each tick, but sometimes may be able to start more than one instruction at a time

**The “Super Simple CPU” Applet**  (Page 1)
- The “Super Simple CPU” applet is a 16-bit machine (i.e. the word size of a single
instruction is 16 bits)
- It has three registers:
  - PC—the program counter (incremented by 1 after most instructions except JMP which rewrites the PC value)
  - ACC—the accumulator (values are added into it or subtracted from it; also a way station for values coming from input device or going to output device)
  - IR—the instruction register (decoded values of current instruction are displayed below the IR as an alphabetic mnemonic along with the operand in decimal)

### The “Super Simple CPU” Applet (Page 2)

- **OPCODES**
  - Binary Mnemonic Short Explanation
  - 1111 STP Stop the computer (Stops computer until the <Reset> button is clicked)
  - 0001 ADD Add accumulator to operand (Fetch a number from memory as per operand and add it to the contents of the accumulator, replacing the value in the accumulator)
  - 0010 SUB Subtract operand from accumulator (Fetch a number from memory as per operand and subtract it from the contents of the accumulator, replacing the value in the accumulator)

### The “Super Simple CPU” Applet (Page 3)

- **OPCODES (con.)**
  - Binary Mnemonic Short Explanation
  - 0011 LOD Load memory cell into accumulator (Fetch a number from memory as per the operand and store it in the accumulator, replacing the value in the accumulator)
  - 0100 LDI Load immediate into accumulator (Load immediate; the value to be put in the accumulator is the operand—the rightmost 12 bits of the instruction)
  - 0101 STO Store accumulator memory cell (Store the accumulator’s value in memory at the location indicated in operand)

### The “Super Simple CPU” Applet (Page 4)

- **OPCODES (con.)**
  - Binary Mnemonic Short Explanation
  - 0110 INP Input value and store accumulator (Ask the user for one number and store that in the accumulator)
  - 0111 OUT Output value from accumulator (Copy the value in the accumulator to the output area)
  - 1000 JMP Jump to instruction (Put the operand value into the PC, which will cause the next instruction to be taken from that location instead)

### The “Super Simple CPU” Applet (Page 5)

- **OPCODES (con.)**
  - Binary Mnemonic Short Explanation
  - 1001 JNG Jump to instruction if accumulator < 0 (Put the operand value into the PC, which will cause the next instruction to be taken from that location instead, but only if accumulator’s value is negative; otherwise go to the next instruction)
  - 1010 JZR Jump to instruction if accumulator = 0 (Put the operand value into the
PC, which will cause the next instruction to be taken from that location instead, but only if accumulator’s value is zero; otherwise go to the next instruction)

69 [The “Super Simple CPU” Applet  (Page 6)]
- The contents of memory and the CPU’s registers are usually displayed in binary (can be shown in decimal by unchecking the box)
- Numbers are stored as 16-bit values in 2’s complement notation (if number has a 1 in leftmost bit, it is negative)

70 [The “Super Simple CPU” Applet  (Page 7)]
- Each instruction in this super-simple computer has two parts:
  ● opcode—the first four bits which represents the instruction
  ● operand—the last twelve bits which is the data upon which the instruction executes

71 [The “Super Simple CPU” Applet  (Page 8)]
- Operand may be any of the following depending upon the opcode:
  ● It is often the address of a memory cell, used by ADD, SUB, LOD, and STO
  ● If the instruction is LDI (load immediate), the operand is a 12-bit constant that is put directly into the accumulator
  ● The jumping instructions (JMP, JNG, JZR) use the 12-bit operand as the value that is stored in the PC register, thus causing control to jump to that spot in memory
  ● A few instructions (STP, IN, OUT) ignore the operand altogether