Basic Computer Hardware

INFO/CSE 100, Autumn 2004
Fluency in Information Technology

http://www.cs.washington.edu/100

Readings and References

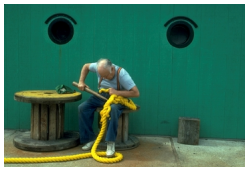
- Reading
  - » *Fluency with Information Technology*
    - Chapter 9, Principles of Computer Operation
- Other References
  - » The Rope and Pulley Wonder, in *The Tinkertoy Computer, A. K. Dewdney*

Overview

- During this quarter, we're looking at the actual workings of computer systems
- Organized as "*layers of abstraction*"
  - » application programs
  - » higher level languages: Javascript, SQL, …
  - » operating system concepts
  - » bits, bytes, assembly language
  - » transistors, electrons, photons

Ogres aren't the only things with layers.

Layers of abstraction



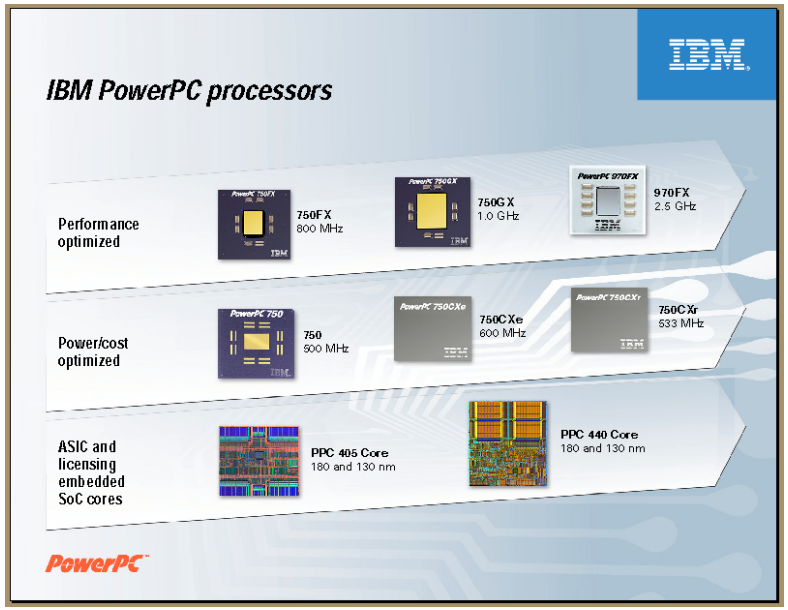
- At any level of abstraction, there are
  - » elements at that level
  - » the building blocks for those elements
- Abstraction
  - » isolates a layer from changes in the layer below
  - » improves developer productivity by reducing detail needed to accomplish a task
  - » helps define a single architecture that can be implemented with more than one organization

Architecture and Organization

- Architecture (the *logical definition*)
  - » defines elements and interfaces between layers
  - » Instruction Set Architecture
    - instructions, registers, addressing
- Organization (the *physical implementation*)
  - » components and connections
  - » how instructions are implemented in hardware
  - » many different organizations can implement a single architecture

Computer Architecture

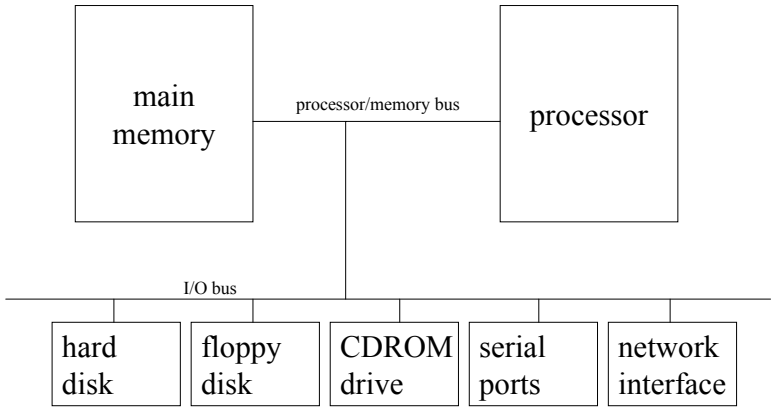
- Specification of how to program a specific computer family
  - » what instructions are available?
  - » how are the instructions formatted into bits?
  - » how many registers and what is their function?
  - » how is memory addressed?
- Some examples architectures
  - » IBM 360, 370, …
  - » PowerPC 601, 603, G5, …
  - » Intel x86 286, 386, 486, Pentium, …
  - » MIPS R2000, R3000, R4000, R5000, ...



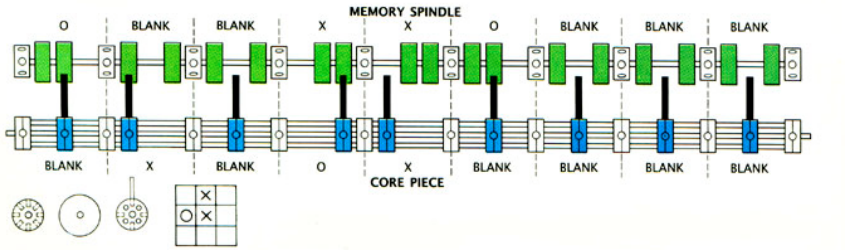
Computer Organization

- Processor
  - » datapath (functional units) manipulate the bits
  - » control controls the manipulation
- Memory
  - » cache memory - smaller, higher speed
  - » main memory - larger, slower speed
- Input / Output
  - » interface to the rest of the world

A typical organization



Many possible implementations



Memory spindle, which encodes the X's and O's of a tic-tac-toe board, prevents the core piece from turning.

COMPUTER RECREATIONS, A Tinkertoy Computer, by A. K. Dewdney
SCIENTIFIC AMERICAN October 1989

Many possible implementations

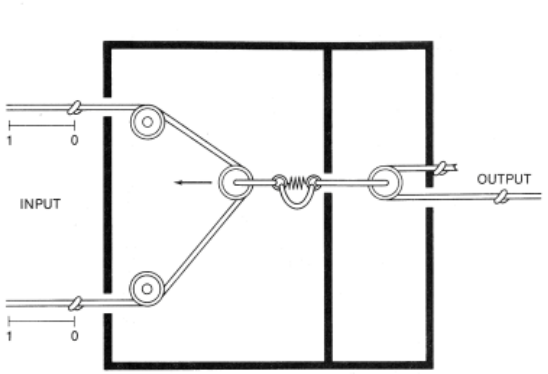


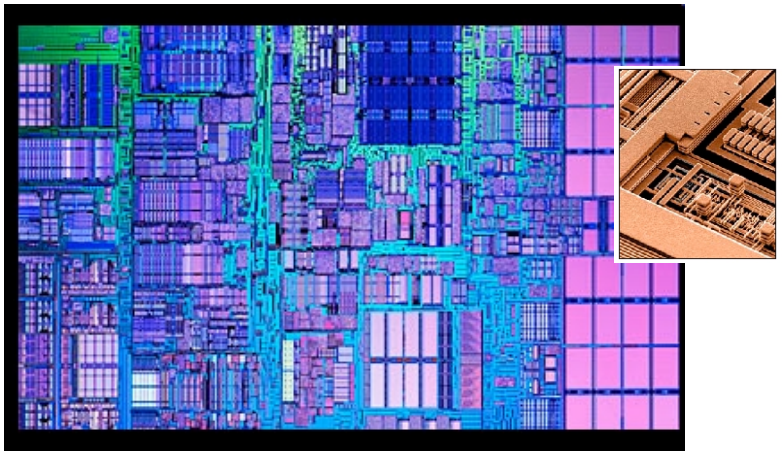
Figure 2.4 The Apraphulian AND gate.

The Tinkertoy Computer and Other Machinations, by A.K. Dewdney

Integrated Circuits

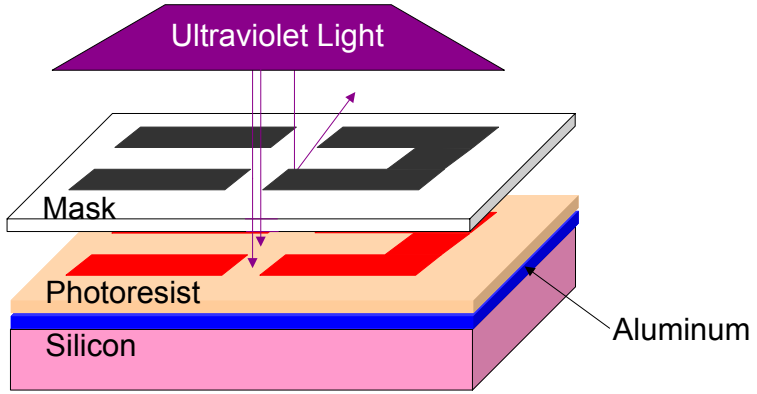
- Integrated circuits (ICs) are the power enabler of the information revolution
  - » When computers were made of discrete parts, wires of every transistor (3), capacitor (2), resistor (2), etc. had to be hand-connected
  - » Labor intensive, expensive, error prone, unreliable, cumbersome, … even with robots!
  - » Integrated circuits solved that by 2 ideas
    - Integration -- circuits built as a unit from like parts
    - Photolithography -- printing process to make chips

Apple / IBM G5 Processor

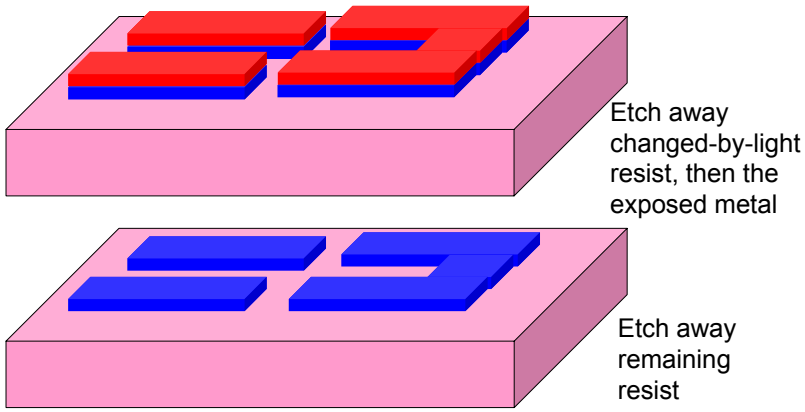


Photolithography

Consider process for depositing "wires"



Remove Resist Material



The cost of the circuit is not directly related to its complexity

Semiconductors

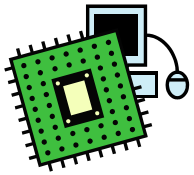
- Silicon, a semiconductor -- sometimes it conducts and sometimes it doesn't
  - » It's possible to control when semiconductors do and don't conduct

    Compute by controlling conductivity
- *Any* signal that can be controlled using the state of one or two other signals can be used to build a computer

Computers ...

- Deterministically execute instructions
  - » "Deterministically" means that when a computer chooses the next instruction to perform it will make the choice the same way each time
  - » Given the program instructions and the current input, you can always predict *exactly* which instruction will be executed next and what it will do

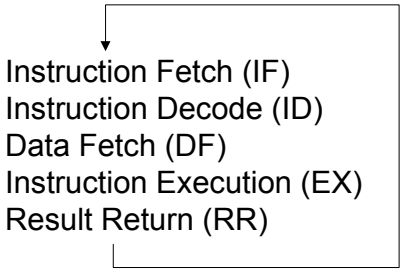
Computers have no free will and they are not random!



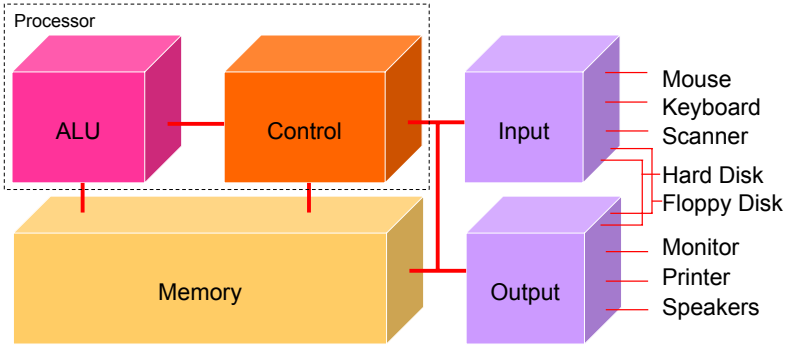
Fetch/Execute Cycle

Computer = instruction execution engine

- » The fetch/execute cycle is the process that executes instructions

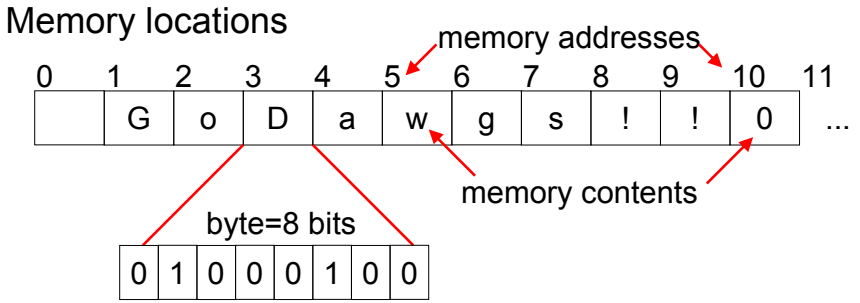


Anatomy of a Computer



Memory ...

Programs and the data they operate on must be in the memory while they are running



Control

- The Fetch/Execute cycle is hardwired into the computer's control, i.e. it is the actual "engine"
- Depending on the Instruction Set Architecture, the instructions say things like
  - » Put in memory location 20 the contents of memory location 10 + contents of memory location 16
  - » The instructions executed have the form ADDB 10, 16, 20

10	11	12	13	14	15	16	17	18	19	20	21
6						12				18	...

ALU

The Arithmetic/Logic Unit does the actual computation

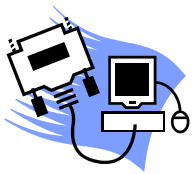
Depending on the Instruction Set Architecture, each type of data has its own separate instructions

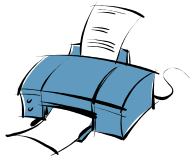
ADDB	: add bytes	ADDBU	: add bytes unsigned
ADDH	: add half words	ADDHU	: add halves unsigned
ADD	: add words	ADDU	: add words unsigned
ADDS	: add short decimal numbers		
ADDD	: add long decimal numbers		

Most computers have only about a 100-150 instructions hard wired

Input/Output

- Input units bring data to memory from outside world; output units send data to outside world from memory
  - » Most peripheral devices are "dumb", meaning that the processor assists in their operation





The PC's PC

- The program counter (PC) tells where the next instruction comes from
  - » In some architectures, instructions are always 4 bytes long, so add 4 to the PC to find the next instruction

Program Counter: 112

112	113	114	115	116	117	118	119	120	121
ADD 210,216,220				AND 414,418,720				OR	...

Clocks Run The Engine

- The rate that a computer "spins around" the Fetch/Execute cycle is controlled by its clock
  - » Current clocks run 2-3 GHz
  - » The computer tries do at least one instruction per cycle, depending on the instruction and the availability of memory contents
  - » Modern processors often try to do more than one instruction per cycle

Clock rate is not a good indicator of speed anymore, because several things are happening every clock cycle