100
Performance

ENGR 3410 – Computer Architecture

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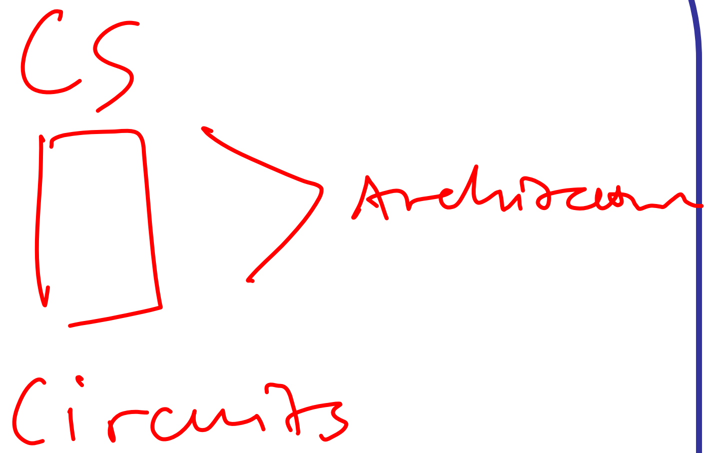
Why are you here?

- (1) Time travel
- (2) Build Computer
- ....
- (4) Profit.
- Structured.

- Required
- Curious
- Mark is $

What is Computer Architecture?

- Transistors



What things are important when buying a computer?

- What features do you look for when buying one?

Speed

price

reliability

Size (mem)

physical size

standards

Logos (flashy ones)

LEDs

Upgradability

noise

Computer “Performance”

- MIPS (Million Instructions Per Second) vs. MHz (Million Cycles Per Second)
- Throughput (jobs/seconds) vs. Latency (time to complete a job)
- Measuring, Metrics, Evaluation – what is “best”?

3.09 GHz
Pentium 4

Hyper
Pipelined
Technology

The PowerBook G4 outguns Pentium III-based notebooks by up to 30 percent.*

* Based on Adobe Photoshop tests comparing a 500MHz PowerBook G4 to 850MHz Pentium III-based portable computers

Performance Example: Planes

Airplane	Passenger Capacity	Cruising Range (miles)	Cruising Speed (mph)	Passenger Throughput (passengermile/hour)
Boeing 777	375	4630	610	228,750
Boeing 747	470	4150	610	286,700
Concorde	132	4000	1350	178,200
Douglas DC8	146	8720	544	79,424

- Which is the “best” plane?
  - Which gets one passenger to the destination first?
  - Which moves the most passengers?
  - Which goes the furthest?
- Which is the “speediest” plane (between Seattle and NY)?
  - Latency: how fast is one person moved?
  - Throughput: number of people per time moved?

Computer Performance

- Primary goal: execution time (time from program start to program completion)

$$Performance = \frac{1}{ExecutionTime}$$

- To compare machines, we say “X is n times faster than Y”

$$n = \frac{Performance_x}{Performance_y} = \frac{ExecutionTime_y}{ExecutionTime_x}$$

- Example: Machine *Orange* and *Grape* run a program
  Orange takes 5 seconds, Grape takes 10 seconds

- Orange is ___2___ times faster than Grape

Execution Time

- Elapsed Time
  - counts everything *(disk and memory accesses, I/O , etc.)*
  - a useful number, but often not good for comparison purposes
- CPU time
  - doesn't count I/O or time spent running other programs
  - can be broken up into system time, and user time

- Example: Unix “time” command

```
fpga.olin.edu> time javac CircuitViewer.java
3.370u 0.570s 0:12.44 31.6%
```

- Our focus: user CPU time
  - time spent executing the lines of code that are "in" our program

CPU Time

CPU execution time for a program = CPU clock cycles for a program * Clock period

CPU execution time for a program = CPU clock cycles for a program * $\frac{1}{\text{Clock rate}}$

- Application example:

  A program takes 10 seconds on computer *Orange*, with a 400MHz clock. Our design team is developing a machine *Grape* with a much higher clock rate, but it will require 1.2 times as many clock cycles. If we want to be able to run the program in 6 seconds, how fast must the clock rate be?

ORANGE: $10\,s = \frac{N \text{ cycles}}{400 \times 10^6 \text{ cycles/s}}$; $N = 4000 \times 10^6$ cycles

Grape: $6\,s = \frac{4000 \times 10^6 \text{ cycles} \cdot 1.2}{X}$

$X = 800$ MHz

CPI

- How do the # of instructions in a program relate to the execution time?

$$\text{CPU clock cycles for a program} = \text{Instructions for a program} * \text{Average Clock Cycles per Instruction } \mathbf{(CPI)}$$

$$\text{CPU execution time for a program} = \text{Instructions for a program} * \text{CPI} * \frac{1}{\text{Clock rate}}$$

CPI Example

- Suppose we have two implementations of the same instruction set (ISA).
- For some program

  Machine A has a clock cycle time of 10 ns. and a CPI of 2.0
  Machine B has a clock cycle time of 20 ns. and a CPI of 1.2

- What machine is faster for this program, and by how much?

$CPU\,Time_A = I \times 2.0 \times 10ns = 20 \times I\,ns$

$CPU\,Time_B = I \times 1.2 \times 20ns = 24 \times I\,ns$

A is $\frac{24}{20}$ ← 1.2 × faster

Computing CPI

- Different types of instructions can take very different amounts of cycles
- Memory accesses, integer math, floating point, control flow

$$CPI = \sum_{types} \left(Cycles_{type} * Frequency_{type} \right)$$

Instruction Type	Type Cycles	Type Frequency	Cycles * Freq
ALU	1	50%	.5
Load	5	20%	1.0
Store	3	10%	.3
Branch	2	20%	.4
		CPI:	2.2

CPI & Processor Tradeoffs

Instruction Type	Type Cycles	Type Frequency
ALU	1	50%
Load	5	20%
Store	3	10%
Branch	2	20%

CPI = 2.2

How much faster would the machine be if:

1. A data cache reduced the average load time to 2 cycles?

OLD 5 x .2 = 1.0
NEW 2 x .2 = .4
CPI ↓ .6 Speedup: $\frac{2.2}{1.6}$ = 1.375x

2. Branch prediction shaved a cycle off the branch time?

OLD 2 x .2 = .4
NEW 1 x .2 = .2
CPI_{new} = 2.0 $\frac{2.2}{2}$ = 1.1x

3. Two ALU instructions could be executed at once?

OLD 1 x .5 = .5
NEW .5 x .5 = .25
$\frac{2.2}{1.95}$ = 1.1... x

Warning 1: Amdahl's Law

- The impact of a performance improvement is limited by what is NOT improved:

$$\text{Execution time after improvement} = \text{Execution time of unaffected} + \text{Execution time affected} * \frac{1}{\text{Amount of improvement}}$$

- Example: Assume a program runs in 100 seconds on a machine, with multiply responsible for 80 seconds of this time. How much do we have to speed up multiply to make the program run 4 times faster?

25s

$$25s = 20s + 80s \times \frac{1}{N}$$

$$N = 80/5 = 16$$

- 5 times faster?

X NO.

Warning 2: MIPs, MHz ≠ Performance

- Higher MHz (clock rate) doesn't always mean better CPU

  Orange computer: 1000 MHz, CPI: 2.5, 1 billion instruction program

  $T = \frac{1B \times 2.5}{1000} = 2.5s$

  Grape computer: 500MHz, CPI: 1.1, 1 billion instruction program

  $T = \frac{1B \times 1.1}{500} = 2.2s$

- Higher MIPs (million instructions per second) doesn't always mean better CPU

  1 MHz machine, with two different compilers

  Compiler A on program X: 10M ALU, 1M Load

  Compiler B on program X: 5M ALU, 1M Load

Execution Time: A 15s B 10s

MIPS: A 11/15 = .73 B 6/10 = .6

Instruction Type	Type Cycles
ALU	1
Load	5
Store	3
Branch	2

Processor Performance Summary

- Machine performance:

$$\text{CPU execution time for a program} = \text{Instructions for a program} * \text{CPI} * \frac{1}{\text{Clock rate}}$$

- Better performance:

  ______ number of instructions to implement computations

  ______ CPI

  ______ Clock rate

- Improving performance must balance each constraint

  Example: RISC vs. CISC