# September 2

- Performance
- Read 3.1 through 3.4 for Tuesday
- Only 4 classes before 1st Exam!
- Old Fashioned Farmer's Days

**Which of these airplanes has the best performance?**

| Airplane | Passengers | Range(mi) | Speed | Throughput |
|---|---|---|---|---|
| 777 | 375 | 4630 | 610 | 228,750 |
| 747 | 470 | 4150 | 610 | 286,700 |
| Concorde | 132 | 4000 | 1350 | 178,200 |
| DC-8-50 | 146 | 8720 | 544 | 79,424 |

## Which communications network is best?

- 56kb modem (56k bits / second, WW)
- Road Runner (1.5M bits / second, WW)
- USB Memory + Sneakers (2G bits / 5 minutes, feet)
- DLT (Digital Linear Tape) + FedEx
  (1T bit/12 hours)

# TIME is THE measure!

- **Response Time (latency)**
  - **— How long does it take for my job to run?**
  - **— How long does it take to execute a job?**
  - **— How long must I wait for the database query?**
- **Throughput**
  - **— How many jobs can the machine run at once?**
  - **— What is the average execution rate?**
  - **— How much work is getting done?**

*If we upgrade a machine with a new processor what do we increase?*

*If we add a new machine to the lab what do we increase?*

# What kind of time?

•**Wall-clock Time**

  –**counts everything** ***(disk and memory accesses, I/O , etc.)***

  –**a useful number, but sometimes not good for comparison or analysis purposes**

•**CPU time**

  –**doesn't count I/O or time spent running other programs**

  –**can be broken up into system time, and user time**

•**Our focus: user CPU time**

  –**time spent executing the lines of code that are "in" our program**

# DANGER Will Robinson!

- **Focus on CPU time can SERIOUSLY distort our world view…**
- **SYSTEM designers (as opposed to CPU designers) must focus on the USER EXPERIENCE.**

## “Performance”

- For some program running on machine X,

  $\text{Performance}_X = 1 / \text{Execution time}_X$

- "X is n times faster than Y“

  $\text{Performance}_X \; / \; \text{Performance}_Y = n$

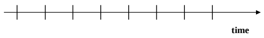
Problem:
- **machine A runs a program in 20 seconds**
- **machine B runs the same program in 25 seconds**

## Cycles

- **Instead of reporting execution time in seconds, we often use cycles**

$$\frac{\text{seconds}}{\text{program}} = \frac{\text{cycles}}{\text{program}} \times \frac{\text{seconds}}{\text{cycle}}$$

- **Clock “ticks” indicate when to start activities (one abstraction):**




- **cycle time = time between ticks = seconds per cycle**
- **clock rate (frequency) = cycles per second (1 Hertz. = 1 cycle/sec)**

**A 200 MHz clock has a** $\frac{1}{200 \times 10^6} = 5\ \text{nanoseconds cycle time}$

## How to improve performance?

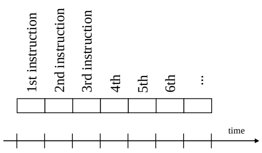
$$\frac{\text{seconds}}{\text{program}} = \frac{\text{cycles}}{\text{program}} \times \frac{\text{seconds}}{\text{cycle}}$$

**So, to improve performance (everything else being equal) you can either**

**________ the # of required cycles for a program, or**
**________ the clock cycle time or, said another way,**
**________ the clock rate.**

## How many cycles are required for a program?

- Could assume that # of cycles = # of instructions

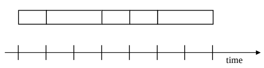



***WRONG!***

***different instructions take different amounts of time on different machines.***

***WHY?***

## Instructions take differing numbers of cycles




- **Division takes more time than addition**
- **Floating point operations take longer than integer ones**
- **Accessing memory takes more time than accessing registers**

- ***Important point: changing the cycle time often changes the number of cycles required for various instructions (more later)***

## Now that we understand cycles…

- **A given program will require**
  - **some number of instructions (machine instructions)**
  - **some number of cycles**
  - **some number of seconds**
- **We have a vocabulary that relates these quantities:**
  - **cycle time (seconds per cycle)**
  - **clock rate (cycles per second)**
  - **CPI (cycles per instruction)** ***a floating point intensive application might have a higher CPI***
  - **MIPS (millions of instructions per second)** ***this would be higher for a program using simple instructions***

## Do any of these equal performance?

**# of cycles to execute program?**

**# of instructions in program?**

**# of cycles per second?**

**average # of cycles per instruction?**

**average # of instructions per second?**

**Common pitfall: thinking one of the variables is indicative of performance when it really isn't.**

## CPI Example

**Suppose we have two implementations of the same instruction set architecture (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**

**Which machine is faster for this program, and by how much?**

***If two machines have the same ISA which of our quantities (e.g., clock rate, CPI, execution time, # of instructions, MIPS) will always be identical?***

## # of instructions example

**A compiler designer is trying to decide between two code sequences for a particular machine. Based on the hardware implementation, there are three different classes of instructions: Class A, Class B, and Class C, and they require one, two, and three cycles (respectively).**

**The first code sequence has 5 instructions:**
**2 of A, 1 of B, and 2 of C**

**The second sequence has 6 instructions:**
**4 of A, 1 of B, and 1 of C.**

***Which sequence will be faster? How much?***
***What is the CPI for each sequence?***

## MIPS example

- **Two different compilers are being tested for a 100 MHz. machine with three different classes of instructions: Class A, Class B, and Class C, which require one, two, and three cycles (respectively). Both compilers are used to produce code for a large piece of software.**

  **The first compiler's code uses 5 million Class A, 1 million Class B, and 1 million Class C instructions.**

  **The second compiler's code uses 10 million Class A, 1 million Class B, and 1 million Class C instructions.**

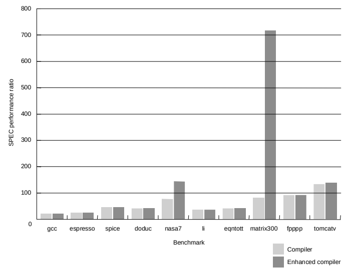
- **Which sequence will be faster according to MIPS?**
- **Which sequence will be faster according to execution time?**

## Benchmarks

- Performance best determined by running a real application
  - Use programs typical of expected workload
  - Or, typical of expected class of applications
    e.g., compilers/editors, scientific applications, graphics, etc.
- Synthetic benchmarks (Dhrystone, Whetstone)
  - nice for architects and designers
  - easy to standardize
  - Easy to abuse
- SPEC (System Performance Evaluation Cooperative)
  - companies have agreed on a set of real program and inputs
  - can still be abused
  - valuable indicator of performance (and compiler technology)

## SPEC '89

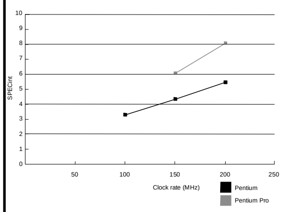
- Compiler "enhancements" and performance

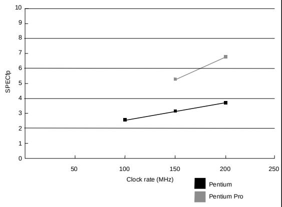


## SPEC '95

Does doubling the clock rate double the performance?

Can a machine with a slower clock rate have better performance?




## Amdahl's Law

Execution Time After Improvement =
Execution Time Unaffected +
Execution Time Affected /
Amt of Improvement

$$T_I = T_U + \frac{T_A}{I}$$

## Amdahl's law Example

Suppose a program runs in 100 seconds on a machine, with multiply responsible for 80 seconds of this time. How much do we have to improve the speed of multiplication if we want the program to run 4 times faster?

$$\frac{100}{4} = 20 + \frac{80}{n} \quad \rightarrow \; n = 16$$

***How about 5 times faster?***

## Amdahl's Law

$$T_I = T_U + \frac{T_A}{I}$$

- ***Principle: Make the common case fast***
- Parallel machines, VLSI algorithms, GPU

## Example

Suppose we enhance a machine making all floating-point instructions run five times faster. If the execution time of some benchmark before the floating-point enhancement is 10 seconds, what will the speedup be if half of the 10 seconds is spent executing floating-point instructions?

speedup = old/new =
10 / (0.5*10 + 0.5*10/5) = 1.67

## Example

We are looking for a benchmark to show off the new floating-point unit described above, and want the overall benchmark to show a speedup of 3. One benchmark we are considering runs for 100 seconds with the old floating-point hardware. How much of the execution time would floating-point instructions have to account for in this program in order to yield our desired speedup on this benchmark?

100/3 = 100*f/5 + 100*(1-f); f = 5/6

## Remember

- Performance is specific to particular programs
  - Total execution time is a consistent summary of performance
- For a given architecture performance increases come from:
  - increases in clock rate (without adverse CPI affects)
  - improvements in processor organization that lower CPI
  - compiler enhancements that lower CPI and/or instruction count
- Pitfall: expecting improvement in one aspect of a machine's performance to affect the total performance