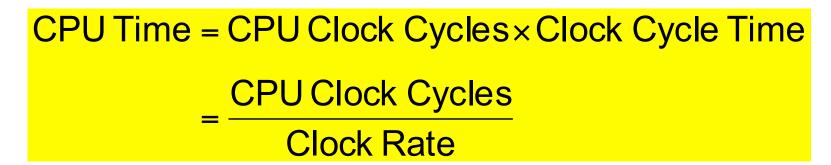
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- Performance can be improved by
 - Reducing number of clock cycles
 - Increasing clock rate
 - Hardware designer must often trade off clock rate against cycle count

Computer A: 2GHz clock, program takes 10s CPU time

CPU time example

- **Designing Computer B**
 - Desire is for 6s CPU time
 - Suppose using a faster clock requires 1.2 × clock cycles
- How fast must Computer B clock be?

Clock Rate_B =
$$\frac{\text{Clock Cycles}_{\text{B}}}{\text{CPU Time}_{\text{B}}} = \frac{1.2 \times \text{Clock Cycles}_{\text{A}}}{6\text{s}}$$

Clock Cycles_A = CPU Time_A × Clock Rate_A

$$= 10\text{s} \times 2\text{GHz} = 20 \times 10^{9}$$

Clock Rate_B = $\frac{1.2 \times 20 \times 10^{9}}{6\text{s}} = \frac{24 \times 10^{9}}{6\text{s}} = 4\text{GHz}$

```
Clock Cycles = Instruction Count \times Cycles per Instruction

CPU Time = Instruction Count \times CPI \times Clock Cycle Time

= \frac{Instruction Count \times CPI}{Clock Rate}
```

- Instruction Count for a program
 - Determined by program, ISA and compiler
- Average cycles per instruction
 - Determined by CPU hardware
 - If different instructions have different CPI
 - Average CPI is affected by instruction mix

- CPI example
- Computer A: Cycle Time = 250ps, CPI = 2.0
- Computer B: Cycle Time = 500ps, CPI = 1.2
- Same ISA
- Which is faster, and by how much?

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With different instruction classes:

Clock Cycles =
$$\sum_{i=1}^{n} (CPI_i \times Instruction Count_i)$$

Weighted average CPI

$$CPI = \frac{Clock Cycles}{Instruction Count} = \sum_{i=1}^{n} \left(CPI_i \times \frac{Instruction Count_i}{Instruction Count} \right)$$

Relative frequency

 Alternative compiled code sequences using instructions in classes A, B, C

Class	А	В	С
CPI for class	1	2	3
IC in sequence 1	2	1	2
IC in sequence 2	4	1	1

- Sequence 1: IC = 5
 - Clock Cycles= 2×1 + 1×2 + 2×3= 10
 - Avg. CPI = 10/5 = 2.0

- Sequence 2: IC = 6
 - Clock Cycles= 4×1 + 1×2 + 1×3= 9
 - Avg. CPI = 9/6 = 1.5

Performance Summary

$$CPU Time = \frac{Instructions}{Program} \times \frac{Clock \ cycles}{Instruction} \times \frac{Seconds}{Clock \ cycle}$$

- Performance depends on
 - Algorithm: affects IC, possibly CPI
 - Programming language: affects IC, CPI
 - Compiler: affects IC, CPI
 - Instruction set architecture: affects IC, CPI, T_c