Clock Cycles and CPU Performance

1. Clock Cycles

Computers operate based on a clock signal that runs at a constant rate.

- **Clock Period (T):** The time duration of one clock cycle (in seconds).
- **Clock Rate (f):** The number of clock cycles per second (in Hz).

$$\text{Clock Rate } (f) = \frac{1}{\text{Clock Period } (T)}$$

2. CPU Time

CPU time is the actual time the CPU spends executing instructions of a program.

$$\text{CPU Time} = \text{CPU Clock Cycles} \times \text{Clock Cycle Time}$$

or

$$\text{CPU Time} = \frac{\text{CPU Clock Cycles}}{\text{Clock Rate}}$$

3. CPI (Cycles Per Instruction)

- **Instruction Count (IC):** Total number of instructions executed.
- **CPI:** Average number of clock cycles per instruction.

$$\text{CPI} = \frac{\text{CPU Clock Cycles}}{\text{Instruction Count (IC)}}$$

$$\text{IPC (Instructions Per Clock)} = \frac{1}{\text{CPI}}$$

4. Final CPU Time Formula

$$\text{CPU Time} = \text{Instruction Count} \times \text{CPI} \times \text{Clock Cycle Time}$$

or

$$\text{CPU Time} = \frac{\text{Instruction Count} \times \text{CPI}}{\text{Clock Rate}}$$

$$T = \frac{N \times \text{CPI}}{f}$$

5. Multiple Instruction Classes

If a program uses multiple instruction classes, total CPU cycles can be computed as:

$$\text{CPU Clock Cycles} = \sum_{i=1}^{n} (\text{CPI}_i \times C_i)$$

where:

- CPI_i = Cycles per instruction for class i
- C_i = Number of instructions of class i
- n = Number of instruction classes

6. Comparing Code Sequences

We are comparing two code sequences to evaluate:

- Total number of instructions executed
- Total CPU clock cycles
- Average CPI (Cycles Per Instruction)

Instruction Class CPI

Class	**CPI**
A	1
B	2
C	3

Instruction Counts per Sequence

Sequence	**A**	**B**	**C**	**Total Instructions**
1	2	1	2	5
2	4	1	1	6

CPU Clock Cycles

$$\text{Sequence 1: } (2 \times 1) + (1 \times 2) + (2 \times 3) = 2 + 2 + 6 = 10 \text{ cycles}$$
$$\text{Sequence 2: } (4 \times 1) + (1 \times 2) + (1 \times 3) = 4 + 2 + 3 = 9 \text{ cycles}$$

CPI Calculation

$$\text{CPI}_1 = \frac{10}{5} = 2 \qquad \text{CPI}_2 = \frac{9}{6} = 1.5$$

Conclusion: Sequence 2 is faster and has a lower CPI.

7. Practice Problem: Clock Rate Calculation

Given:

- Computer A runs the program in 10 seconds at 2 GHz
- Computer B should run the same program in 6 seconds
- B needs 1.2 times the clock cycles as A

Calculation

Let clock cycles of A be C:

$$\text{Execution Time}_A = \frac{C}{2 \times 10^9} = 10 \Rightarrow C = 20 \times 10^9$$

$$\text{Execution Time}_B = \frac{1.2 \times C}{f_B} = 6 \Rightarrow f_B = \frac{1.2 \times 20 \times 10^9}{6} = 4 \text{ GHz}$$

Answer: Computer B should have a clock rate of 4 GHz.

8. Factors Affecting CPU Performance

$$\text{CPU Time} = \frac{N \times \text{CPI}}{f}$$

Where:

- N = Instruction Count
- CPI = Cycles Per Instruction
- f = Clock Rate

Performance Influence Table

Component	Affects	Type
Algorithm	Instruction Count	Software
Programming Language	Instruction Count, CPI	Software
Compiler	Instruction Count, CPI	Software
Instruction Set Architecture	Instruction Count, CPI, Clock Rate	Both

9. Speedup Techniques

- **Cache Memory:** Faster access to instructions and data.
- **Pipelined Processing:** Overlapping multiple instruction stages.
- **Superscalar Processing:** Parallel execution of multiple instructions.