Topic V11

Clock Per Instruction (CPI)

Readings: (Section 1.6)

A trip to the grocery store

Quantity	Item	Cost Per Item	Cost
3	Yogurt	1.50	
5	Apples	0.50	
2	Milk	3.50	

How much did I spend?

A trip to the grocery store

Quantity	Item	Cost Per Item	Cost
3	Yogurt	1.50	4.50
5	Apples	0.50	2.50
2	Milk	3.50	7.00
10			

How many items did I buy?

How much did I spend?

What was the average cost per item?

$$\text{Cost per Item} = \frac{3 \times 1.5 + 5 \times 0.5 + 2 \times 3.5}{3+5+2} = \frac{14.00}{10} = 1.40 \frac{\text{dollars}}{\text{item}}$$

Rendering the Explosion

Quantity	Instruction Class	Cycles Per Instruction	Cycles
300	Branches	2	
500	ALU	1	
200	Load/Store	5	

How many cycles were needed?

Rendering the Explosion

Quantity	Instruction Class	Cycles Per Instruction	Cycles
300	Branches	2	600
500	ALU	1	500
200	Load/Store	5	1000
1000			

How many instructions were executed?

How many cycles were needed?

Rendering the Explosion

Quantity	Instruction Class	Cycles Per Instruction	Cycles
300	Branches	2	600
500	ALU	1	500
200	Load/Store	5	1000
1000		Total	2100

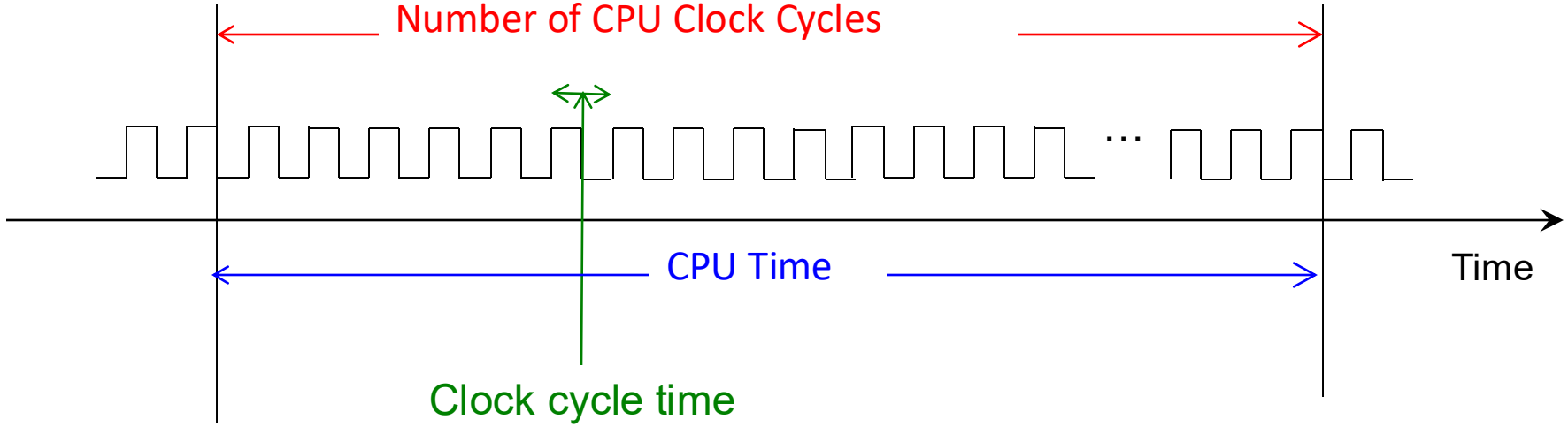
How many instructions were executed?

How many cycles were needed?

What was the average number of cycles per instruction?

CPI

$$\text{Cycle per Instruction} = \frac{300\times2 + 500\times1 + 200\times5}{300+500+200} = \frac{2100}{1000} = 2.10\,\frac{cycles}{\text{instruction}}$$



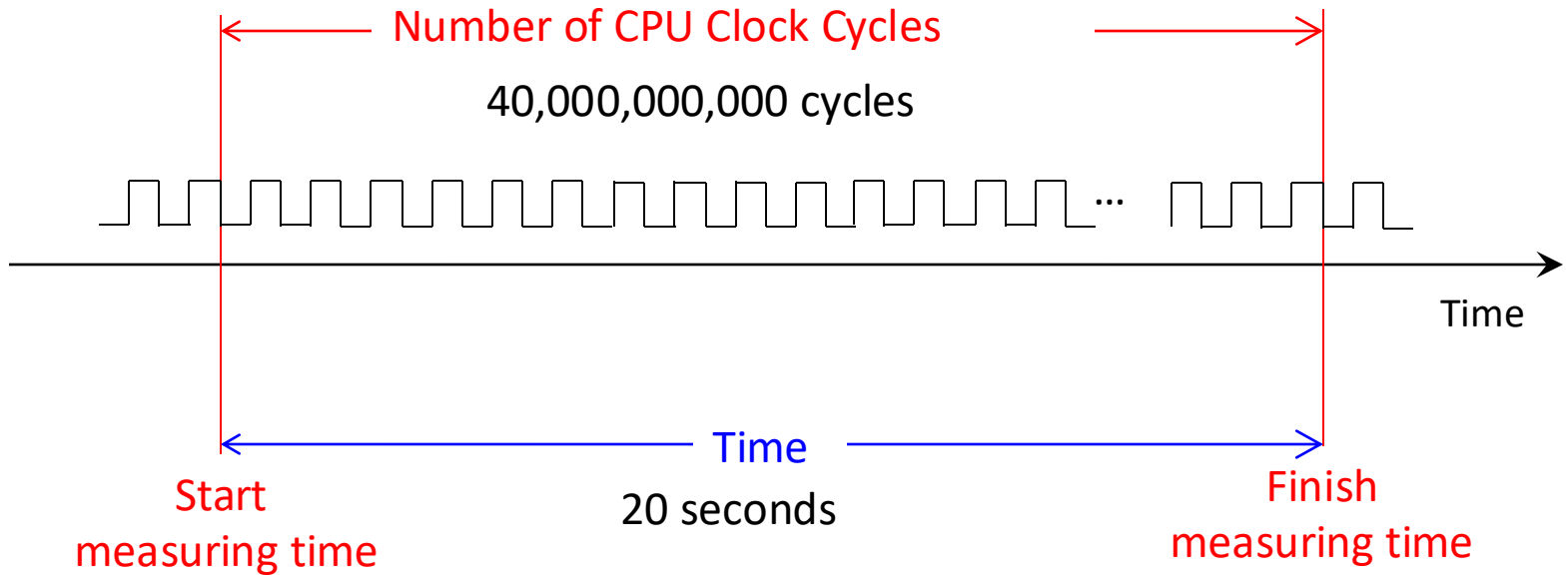
$$\text{CPU Time} = \#\text{Clock Cycles} \times \text{Clock Cycle Time}$$

$$\#\text{Clock Cycles} = \#\text{Instructions} \times \text{CPI}$$

$$\boxed{\text{CPU Time} = \#\text{Instructions} \times \text{CPI} \times \text{Clock Cycle Time}}$$

Frequency

$$\text{Frequency} = \frac{40{,}000{,}000{,}000 \text{ cycles}}{20 \text{ seconds}} = 2 \times 10^9 \frac{\text{cycles}}{\text{seconds}} = 2 \text{ GHz}$$



Frequency: number of clock cycles per seconds

Instruction Count for a program

Determined by program, ISA and compiler

Clock Cycle Time

Determined by ISA and technology

$$\text{CPU Time} = \#\text{Instructions} \times \text{CPI} \times \text{Clock Cycle Time}$$

Average cycles per instruction (CPI)

Determined by CPU hardware

If different instructions have different CPI:

⇒ Average CPI is affected by instruction mix

CPI Example

Same ISA,
same program,
same compiler

Computer A

Cycle time: 250 *ps*
CPI: 2.0

Computer B

Cycle time: 500 *ps*
CPI: 1.2

Which one is faster, and by how much?

$$\text{CPU Time}_A = \#\text{ Instructions} \times \text{CPI}_A \times \text{Cycle Time}_A$$
$$= K \times 2.0 \times 250\text{ ps} = K \times 500\text{ ps}$$

A is faster…

$$\text{CPU Time}_B = \#\text{ Instructions} \times \text{CPI}_B \times \text{Cycle Time}_B$$
$$= K \times 1.2 \times 500\text{ ps} = K \times 600\text{ ps}$$

$$\frac{\text{CPU Time}_B}{\text{CPU Time}_A} = \frac{K \times 600\text{ ps}}{K \times 500\text{ ps}} = 1.2$$

…by this much

CPI in More Detail

If different instruction classes take different numbers of cycles

$$\text{Clock Cycles} = \sum_{k=1}^{n} (\text{CPI}_k \times \text{Instruction Count}_k)$$

CPI is a weighted average:

$$CPI = \frac{ClockCycles}{InstructionCount} = \underbrace{\sum_{k=1}^{n} \left(CPI_k \times \frac{InstructionCount_k}{InstructionCount} \right)}_{\text{Relative frequency}}$$

CPI Example

Two compilers use a different number of instructions of classes A, B, C for a given program. What is the CPI for each version of this program?

Instruction Count

Class	A	B	C

Compiler 1: IC = 5

Clock Cycles
= 2×1 + 1×2 + 2×3
= 10 *cycles*

Avg. CPI = 10/5 = 2.0

Compiler 2: IC = 6

Clock Cycles
= 4×1 + 1×2 + 1×3
= 9 *cycles*

Avg. CPI = 9/6 = 1.5

Performance Summary

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

$$\text{CPU Time} = \text{IC} \times \text{CPI} \times \frac{1}{\text{Frequency}}$$

Performance depends on

- Algorithm: affects IC, possibly CPI
- Programming language: affects IC, CPI
- Compiler: affects IC, CPI
- Instruction set architecture: affects IC, CPI, frequency