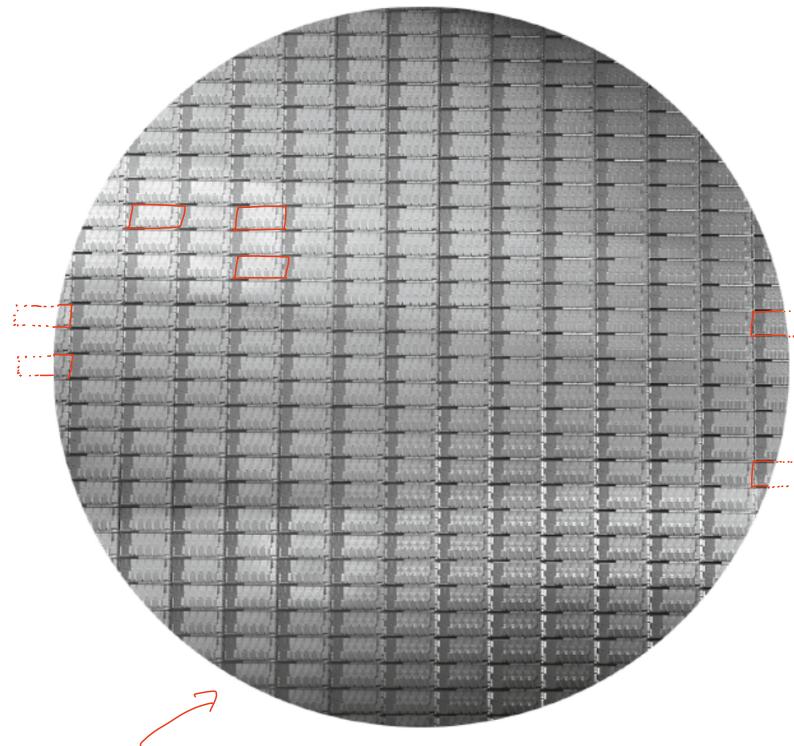
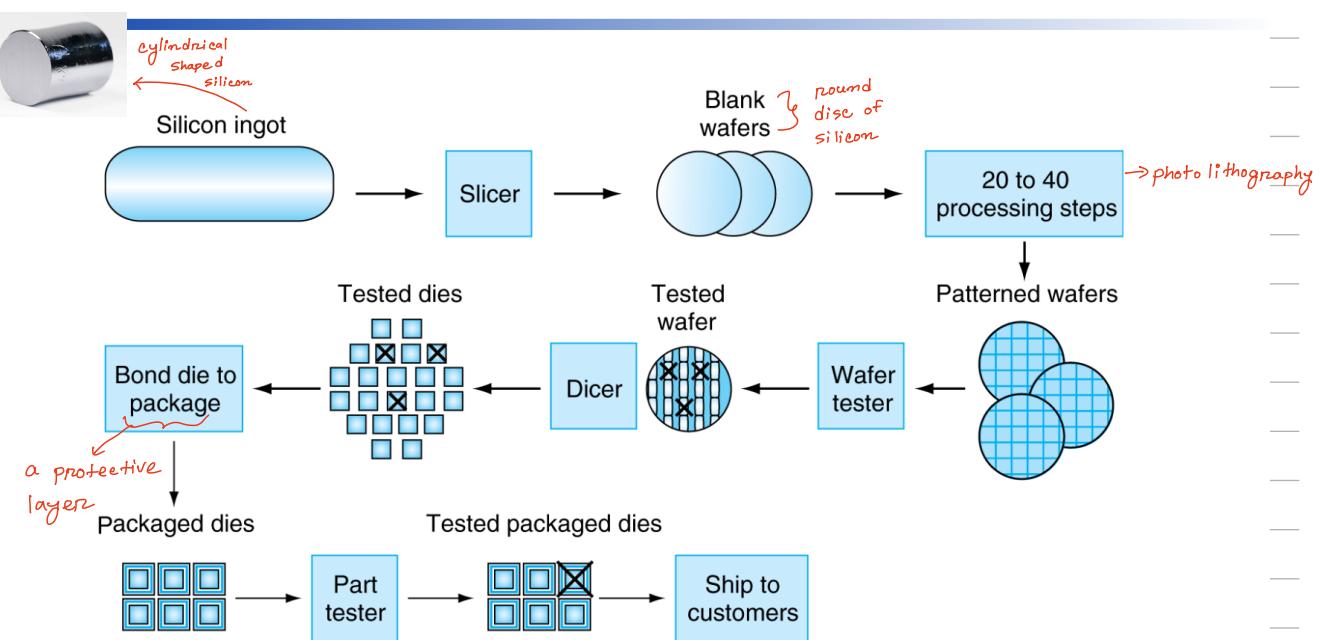


Manufacturing ICs



This is a wafer. As the shape is round,

$$\text{So, Wafer Area} = \pi r^2$$

and, Die can be in rectangular or square shape.

$$\text{Area} = \text{Height} \times \text{Width}$$

$$\text{Dies per Wafer} \approx \frac{\text{Wafer Area}}{\text{Die Area}}$$

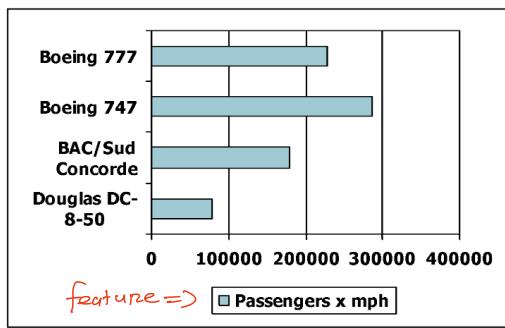
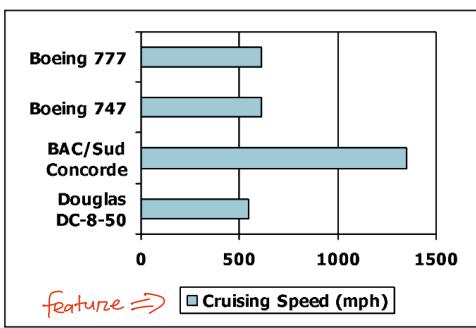
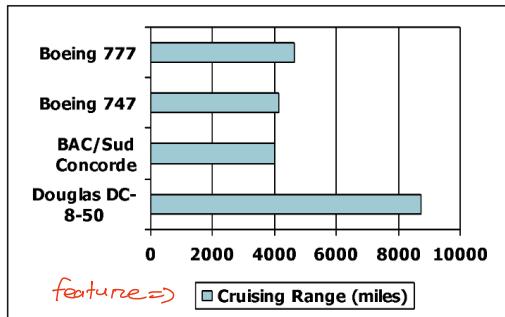
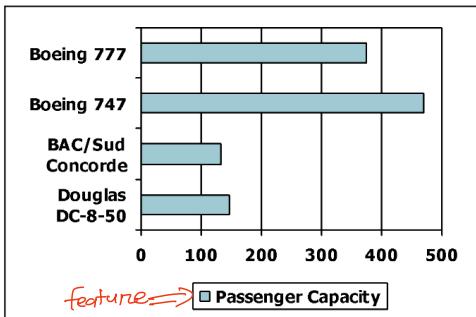
$$\text{Cost per die} = \frac{\text{Cost per Wafer}}{\text{Dies per Wafer} \times \text{Yield}}$$

↑ amount of working dies per wafer.

Defining Performance

whenever we speak of performance, we must mention the feature based on which we calculated the performance.

- Which airplane has the best performance?



lesser response time → better performance

$$\Rightarrow \text{Performance} = \frac{1}{\text{Execution time}}$$

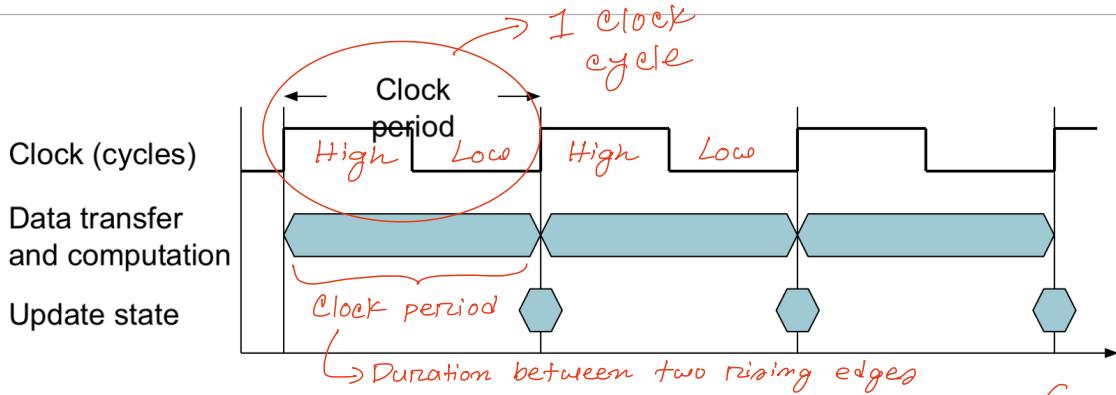
X is n times faster than Y

$$P_X = n \times P_Y$$

$$\Rightarrow \frac{P_X}{P_Y} = n$$

$$\Rightarrow \frac{\frac{1}{E_X}}{\frac{1}{E_Y}} = n$$

$$\Rightarrow \frac{E_Y}{E_X} = n$$



- Clock period: duration of a clock cycle (clock cycle time)
 - e.g., $250\text{ps} = 0.25\text{ns} = 250 \times 10^{-12}\text{s}$
- Clock frequency (rate): cycles per second (clock rate)
 - e.g., $4.0\text{GHz} = 4000\text{MHz} = 4.0 \times 10^9\text{Hz}$

CPU Time Example

- Computer A: 2GHz clock, 10s CPU time
- Designing Computer B
 - Aim for 6s CPU time ✓
 - Can do faster clock, but causes $1.2 \times$ clock cycles A
- How fast must Computer B clock be? → Find the new frequency of B?

$$\text{CPU Time}_B = 6\text{s}$$

$$\text{Clock Cycle}_B = 1.2 \times 20 \times 10^9 \\ = 24 \times 10^9$$

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

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

$$= \frac{24 \times 10^9}{6} \frac{1}{\text{s}}$$

$$= 4 \times 10^9 \text{ s}^{-1}$$

$$= 4 \times 10^9 \text{ Hz} = 4 \text{ GHz}$$

$$\text{Clock Rate}_A = 2 \text{ GHz}$$

$$\text{CPU Time}_A = 10\text{s}$$

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

$$\text{CPU Clock Cycles}_A = \text{CPU Time}_A \times \text{Clock Rate}_A$$

$$= 10 \times 2 \times 10^9$$

$$= 10 \times 2 \times 10^9 \times 10^9 \text{ Hz}$$

$$= 20 \times 10^9 \times 10^9 \text{ Hz}$$

$$= 20 \times 10^9 \text{ Hz}$$

CPU Time = CPU Clock Cycle \times Clock Cycle Time

this is the total number of clock cycles for a single task program

CPI = Clock cycle per instruction ??

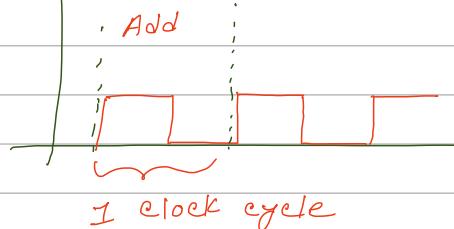
assembly
program
to
add 1 to 4

addi x₂₀, x₀, 1

addi x₂₀, x₂₀, 2

addi x₂₀, x₂₀, 3

addi x₂₀, x₂₀, 4



CPU Clock Cycle = 4 \times 1

Instruction count Clock cycle per instruction (CPI)

CPU Time = CPU Clock Cycle \times Clock Cycle Time

= Instruction count \times CPI \times Clock Cycle Time

Instruction count for a program, determined by program, ISA, compiler

\Rightarrow Suppose two programs were compiled using same ISA, does not mean their instruction count is same. It means rules followed to compile these programs were same.

Avg CPI \Rightarrow Determined by CPU Hardware

CPI Example

- Computer A: Cycle Time = 250ps, CPI = 2.0
- Computer B: Cycle Time = 500ps, CPI = 1.2
- Same ISA \rightarrow to figure out which computer is faster, we run the same program in both computers
- Which is faster, and by how much?

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

$$= 1 \times 2.0 \times 250\text{ps} = 1 \times 500\text{ps}$$

\Rightarrow Same program and u ISA

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

$$= 1 \times 1.2 \times 500\text{ps} = 1 \times 600\text{ps}$$

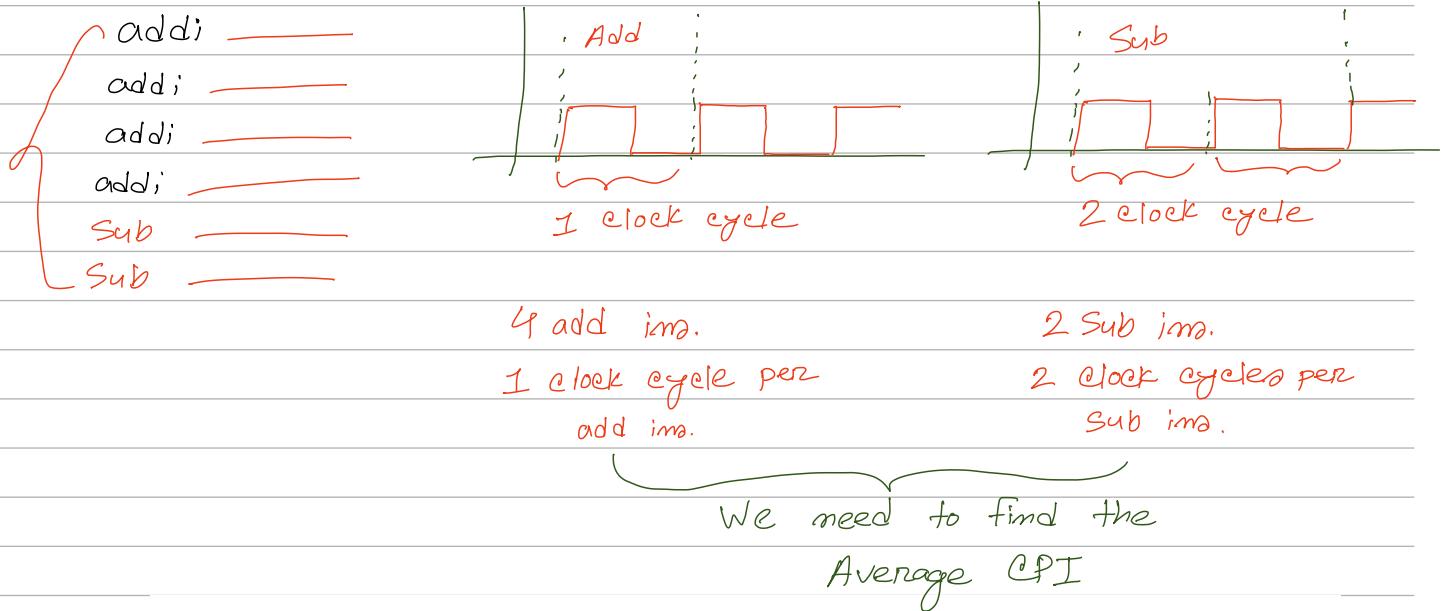
So, Instruction count will be same.

$$\frac{\text{CPU Time}_B}{\text{CPU Time}_A} = \frac{1 \times 600\text{ps}}{1 \times 500\text{ps}} = 1.2$$

...by this much

Lesser time means faster.

Average CPI



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

Weighted average CPI

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

Relative frequency

Class	Add	Sub B	Mul C
CPI for class	1	2	3
IC in sequence 1	2 ✓	1 ✓	2 ✓
IC in sequence 2	4 ✗	1 ✗	1 ✗

$$\text{Total IC} = 5$$

$$\begin{aligned} \text{Clock cycles} &= (2 \times 1) + (1 \times 2 + 2 \times 3) \\ &= 10 \end{aligned}$$

$$\therefore \text{Avg CPI} = \frac{10}{5} = 2$$

$$\text{Total IC} = 6$$

$$\begin{aligned} \text{Clock cycles} &= (4 \times 1 + 1 \times 2 + 1 \times 3) \\ &= 9 \end{aligned}$$

$$\therefore \text{Avg CPI} = \frac{9}{6} = 1.5$$

CPU Time = Instruction

count of a program X

clock cycles per instruction X

Duration of a clock cycle.