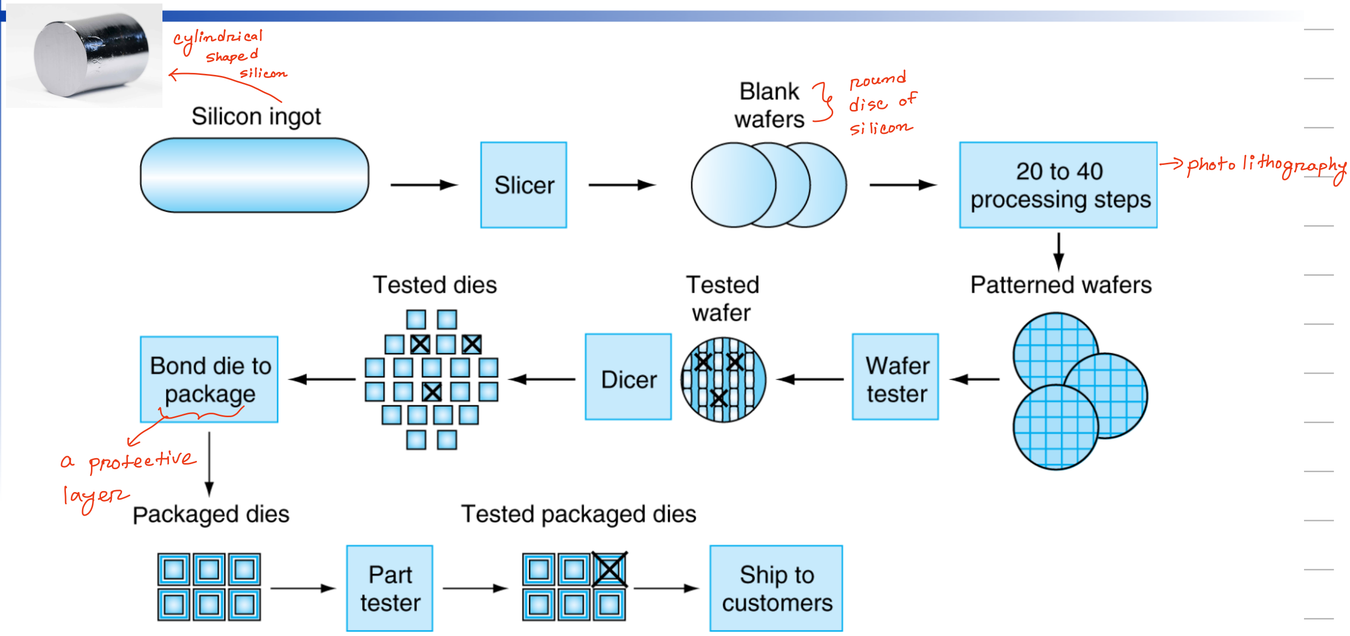
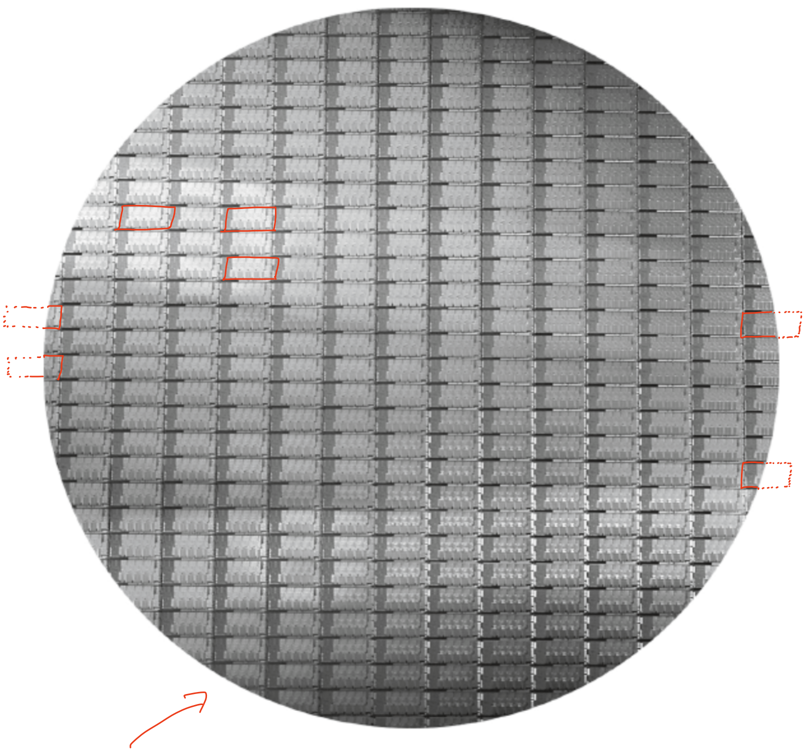
Manufacturing ICs





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

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

↳ amount of working dies per wafer.

this is a wafer. As the shape is round,

So, Wafer Area $= \pi r^2$

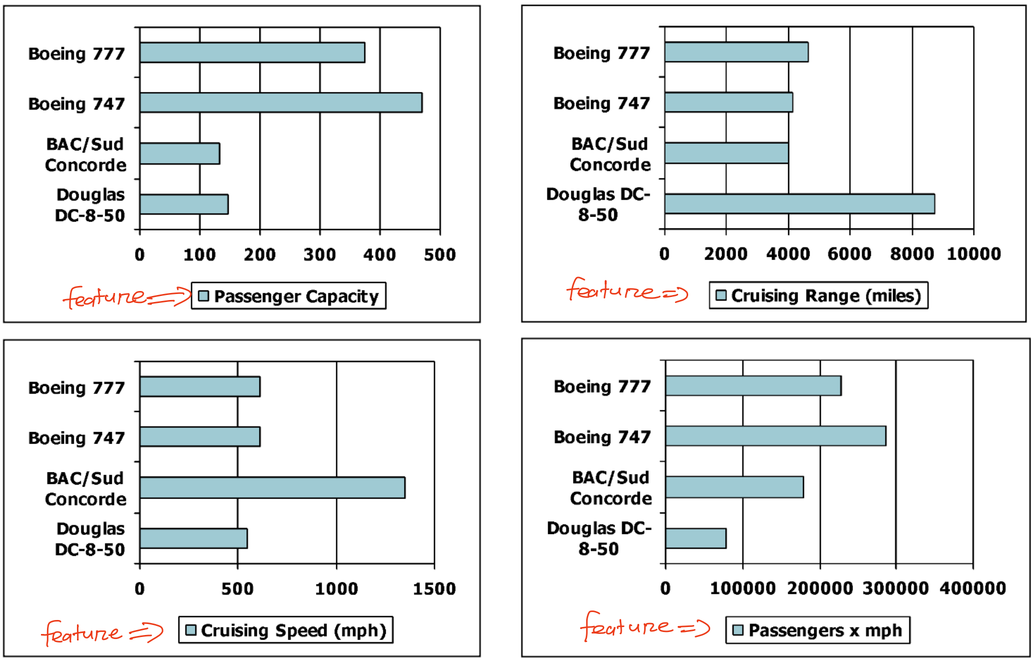
and, Die can be in rectangular or square shape.

Area = Height $\times$ Width

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

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

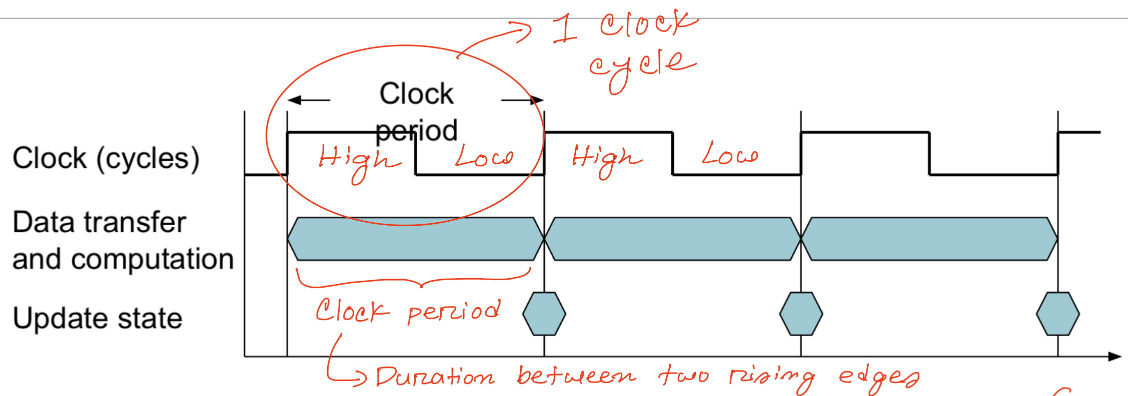
X is n times faster than Y

$$P_X = n \times P_Y$$

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

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

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



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

If a processor performs 1 million cycles in 20s ;

$$\text{frequency} = \frac{1000000}{20} \text{ Hz} = 50{,}000 \text{ Hz} = 50000 \times 10^{-9} \text{ GHz}$$
$$= 5 \times 10^{-5} \text{ GHz}$$

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 × clock cycles$_A$
- How fast must Computer B clock be? → Find the new frequency/ of B? Clock Rate

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

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

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

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

$= \dfrac{24 \times 10^9}{6} \dfrac{1}{s}$
$= 4 \times 10^9 \ s^{-1}$
$= 4 \times 10^9 \text{ Hz} = 4 \text{ GHz}$

$\text{Clock Rate}_A = 2 \text{ GHz}$
$\text{CPU Time}_A = 10s$

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

$\text{CPU Clock Cycles}_A = \text{CPU Time}_A \times \text{Clock Rate}_A$
$= 10s \times 2 \text{GHz}$
$= 10 \times 2 \times 10^9 \times s \times \text{Hz}$
$= 20 \times 10^9 \times \cancel{s} \times \frac{1}{\cancel{s}}$
$= 20 \times 10^9$

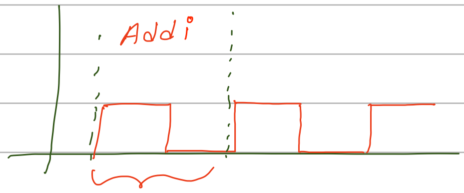
this is the total number of clock cycles for a single task/ program

CPU Time = CPU Clock Cycle × Clock Cycle Time

CPI = Clock Cycle per instruction ??

assembly program to add 1 to 4

addi x_{20}, x_0, 1 → instruction
addi x_{20}, x_{20}, 2
addi x_{20}, x_{20}, 3
addi x_{20}, x_{20}, 4



1 clock cycle

CPU Clock Cycle = 4 × 1

Instruction count (4); clock cycle per instruction (CPI) (1)

CPU Time = CPU Clock Cycle × Clock Cycle Time

= Instruction count × CPI × Clock cycle Time

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

⇒ 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 ⇒ Determined by CPU Hardware

CPI Example

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

$$\text{CPU Time}_A = \text{Instruction Count} \times \text{CPI}_A \times \text{Cycle Time}_A$$
$$= I \times 2.0 \times 250\text{ps} = I \times 500\text{ps}$$

A is faster…

$$\text{CPU Time}_B = \text{Instruction Count} \times \text{CPI}_B \times \text{Cycle Time}_B$$
$$= I \times 1.2 \times 500\text{ps} = I \times 600\text{ps}$$

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

…by this much

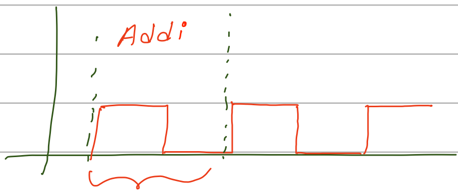
⇒ Same program and " ISA

So, Instruction Count will be same.

Lesser time means faster.

Average CPI

addi
addi
addi
addi
Sub
Sub



4 add ins.
1 clock cycle per add ins.

2 Sub ins.
2 clock cycles per sub ins.

We need to find the Average CPI

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

- Weighted average CPI

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

type of instructions

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 ✓✓

Total IC = 5
Clock cycles = $(2\times1 + 1\times2 + 2\times3)$
$= 10$
$\therefore$ Avg CPI $= \frac{10}{5} = 2$

Total IC = 6
Clock cycles = $(4\times1 + 1\times2 + 1\times3)$
$= 9$
$\therefore$ Avg CPI $= \frac{9}{6} = 1.5$

CPU Time = Instruction count of a program × clock cycles per instruction × Duration of a clock cycle.

- Performance improved by
  - Reducing number of clock cycles → often leads complex design and additional hardware.
  - Increasing clock rate → increasing power consumption & generate more heat.
  - Hardware designer must often trade off clock rate against cycle count