Chapter 1 Exercises

1.11 Assume a 15cm diameter wafer has a cost of 12, contains 84 dies, and has 0.020 defects/cm^2. Assume a 20cm diameter wafer has a cost of 15, contains 100 dies, and has 0.031 defects/cm^2.

1.11.1 Find the yield for both wafers.

$$\text{yield} = \frac{1}{(1 + (\text{Defects per area} \times \text{Die area}))^N}$$

Wafer 1:

- Wafer $\text{area}_1 = \pi r^2 = \pi(\frac{15}{2})^2 = \frac{\pi 225}{4}$
- Die $\text{area}_1 = \frac{\text{Wafer area}}{\text{Dies per wafer}} = \frac{(\pi 225)/4}{84} = \frac{\pi 75}{112}$
- Defects per $\text{area}_1 = 0.020$
- $N_1 = 2$

$$\text{yield}_1 = \frac{1}{(1 + (0.020 \times \frac{\pi 75}{112}))^2} = 0.9208... \Rightarrow 0.92$$

$$\boxed{\text{yield}_1 = 0.92}$$

Wafer 2:

- Wafer $\text{area}_2 = \pi r^2 = \pi(\frac{20cm}{2})^2 = \pi 100$
- Die $\text{area}_2 = \frac{\text{Wafer area}}{\text{Dies per wafer}} = \frac{\pi 100}{100} = \pi$
- Defects per $\text{area}_2 = 0.031$
- $N_2 = 2$

$$\text{yield}_2 = \frac{1}{(1 + (0.031 \times \pi))^2} = 0.8303... \Rightarrow 0.83$$

$$\boxed{\text{yield}_2 = 0.83}$$

1.11.2 Find the cost per die for both wafers.

$$\text{Cost per die} = \frac{\text{Cost per wafer}}{\text{Dies per wafer} \times \text{yield}}$$

Wafer 1:

- Cost per $\text{wafer}_1 = 12$
- Dies per $\text{wafer}_1 = 84$
- $\text{yeild}_1 = 0.9208$

$$\text{Cost per die}_1 = \frac{12}{84 \times 0.9208} = 0.1551... \Rightarrow 0.16$$

$$\boxed{\text{Cost per die}_1 = 0.16}$$

Wafer 2:

- Cost per $\text{wafer}_2 = 15$
- Dies per $\text{wafer}_2 = 100$
- $\text{yeild}_2 = 0.8303$

$$\text{Cost per die}_2 = \frac{15}{100 \times 0.8303} = 0.1806... \Rightarrow 0.18$$

$$\boxed{\text{Cost per die}_2 = 0.18}$$

1.11.3 If the number of dies per wafer is increased by 10% and the defects per area unit increases by 15%, find the die area and yeild.

Wafer 1:

- Dies per $\text{wafer}_1 = 84 + (0.1 \times 84) = 92.4$
- Wafer $\text{area}_1 = \pi r^2 = \pi(\frac{15cm}{2})^2 = \frac{\pi 225}{4}$
- Defects per $\text{area}_1 = 0.020 + (0.15 \times 0.020) = 0.023$
- $N_1 = 2$
- Cost per $\text{wafer}_1 = 12$

$$\text{Die area}_1 = \frac{\text{Wafer area}}{\text{Dies per wafer}} = \frac{(\pi 225)/4}{92.4} = \frac{\pi 375}{616}$$

$$\boxed{\text{Die area}_1 = \frac{\pi 375}{616}}$$

$$\text{yield}_1 = \frac{1}{(1 + (0.023 \times \frac{\pi 375}{616}))^2} = 0.9175... \Rightarrow 0.92$$

$$\boxed{\text{yield}_1 = 0.92}$$

Wafer 2:

- Dies per $\text{wafer}_2 = 100 + (0.1 \times 100) = 110$
- Wafer $\text{area}_2 = \pi r^2 = \pi(\frac{20cm}{2})^2 = \pi 100$

- Defects per $\text{area}_2 = 0.031 + (0.15 \times 0.031) = 0.03565$
- $N_2 = 2$
- Cost per $\text{wafer}_2 = 15$

$$\text{Die area}_2 = \frac{\text{Wafer area}}{\text{Dies per wafer}} = \frac{\pi 100}{110} = \frac{\pi 10}{11}$$

$$\boxed{\text{Die area}_2 = \frac{\pi 10}{11}}$$

$$\text{yield}_2 = \frac{1}{(1 + (0.03565 \times \frac{\pi 10}{11}))^2} = 0.8237... \Rightarrow 0.82$$

$$\boxed{\text{yield}_2 = 0.82}$$

1.15 Assume a program requires the execution of 50×10^6 FP instructions. 110×10^6 INT instructions, 80×10^6 L/S instructions, and 10×10^6 branch instructions. The CPI for each type of instruction is 1, 1, 4, and 2, respectively. Assume the processor has 2GHz clock rate.

1.15.1 By how much must we improve the CPI of FP instructions if we want the program to run two times faster?

Total CPU clock cycles before optimization:

$(50 \times 10^6)(1) + (110 \times 10^6)(1) + (80 \times 10^6)(4) + (16 \times 10^6)(2) = 512 \times 10^6$

Total CPU execution time before optimization:

$\frac{512 \times 10^6}{2\text{GHz}} = 256 \times 10^{-3}\text{s}$

Goal CPU execution time before optimization:

$\frac{256 \times 10^{-3}\text{s}}{2} = 128 \times 10^{-3}\text{s}$

Goal total cycles for FP:

$128 \times 10^{-3}\text{s} \times 2\text{GHz} = 256 \times 10^6$

FP CPI:

$\text{FP CPI} = \frac{256 - 462}{50}$

$\text{FP CPI} = -4.12$

$\boxed{\text{It is not possible to improve the FP CPI to make the program run 2 times faster.}}$

1.15.2 By how much must we improve the CPI of L/S instructions if we want the program to run two times faster?

Goal CPU execution time before optimization:

$\frac{256 \times 10^{-3}\text{s}}{2} = 128 \times 10^{-3}\text{s}$

Goal total cycles for L/S:

$128 \times 10^{-3}\text{s} \times 2\text{GHz} = 256 \times 10^6$

L/S CPI:

$(50 \times 10^6)(1) + (110 \times 10^6)(1) + (80 \times 10^6)(\text{L/S CPI}) + (16 \times 10^6)(2) = 512 \times 10^6$

$\text{L/S CPI} = \frac{256 - 192}{80}$

$\text{FP CPI} = 4.625$

CPI Improvement:

$4/0.8 = 5$

$\boxed{\text{L/S instructions must be 5 times faster}}$

1.15.3 By how much is the execution time of the program improved if the CPI of INT and FP instructions is reduced by 40% and the CPI of L/S and Branch is reduced by 30%?

New CPI

- FP: $(1 - (1) \times 0.4) = 0.6$
- INT: $(1 - (1) \times 0.4) = 0.6$
- L/S: $(4 - (4) \times 0.3) = 2.8$
- Branch: $(2 - (2) \times 0.3) = 1.4$

New total CPU clock cycles

$$(50 \times 10^6)(0.6) + (110 \times 10^6)(0.6) + (80 \times 10^6)(2.8) + (16 \times 10^6)(1.4) = 342.4 \times 10^6$$

New CPU execution time

$$\frac{342.4 \times 10^6}{2\text{GHz}} = 171.2 \times 10^{-3}\text{s}$$

CPU execution time improvement:

$$\frac{256 \times 10^{-3}}{171.2\text{s} \times 10^{-3}\text{s}} \times 100\% = 149.5\%$$

$$\boxed{\text{The execution time is improved by } 149.5\%}$$