CMSC 411
Homework #2 Solutions

Exercise 2.1(a) For this problem, the average instruction length is

$$AIL = (Percent_0 \times 16) + (Percent_8 \times 24) + (Percent_{16} \times 32)$$

where $Percent_x$ is the percentage of instructions that require x bits for the offset field. From the Figure 2.32 of text, we have the following data:

1. Loads and stores constitute 35% of the instructions and
   (a) 17% need 0 offset bits
   (b) 43% need between 1 and 8 offset bits
   (c) 40% need between 9 and 16 offset bits
2. Branches and jumps constitute 19% of the instructions and
   (a) 0% need 0 offset bits
   (b) 98% need between 1 and 8 offset bits
   (c) 2% need between 9 and 16 offset bits
3. The remaining instructions (assumed to be ALU operations) constitute 46

Therefore, we can AIL as follows:

$$Percent_0 = (.17 \times 35\%) + (.00 \times 19\%) + (46\%) = 52\%$$

$$Percent_8 = (.43 \times 35\%) + (.98 \times 19\%) = 34\%$$

$$Percent_{16} = (.40 \times 35\%) + (.02 \times 19\%) = 14\%$$

$$\begin{aligned} AIL &= (Percent_0 \times 16) + (Percent_8 \times 24) + (Percent_{16} \times 32) \\ &= 21\ bits \end{aligned}$$

Exercise 2.1(b) In this part,

$$AIL = (Percent_8 \times 24) + (Percent_{>8} \times 48)$$

The $Percent_8$ and $Percent_{>8}$ are computed as follows,

$$\begin{aligned} Percent_8 &= 46\% + (.17 \times 35\%) + (.43 \times 35\%) + \\ &\quad (.00 \times 19\%) + (.98 \times 19\%) \\ &= 86\% \end{aligned}$$

$$Percent_{>8} = (.40 \times 35\%) + (.02 \times 19\%) = 14\%$$

Now we get AIL:

$$AIL = (Percent_8 \times 24) + (Percent_{>8} \times 48) = 27\ bits$$

Thus, the variable length instruction format of Exercise 2.1(a) results in fewer instruction bits being required.

Exercise 2.1(c) In this part, since all branch and memory instructions (accounting for 54% of executed instructions) now require exactly 32 bits, our average instruction length will be:

$$AIL = .54 \times 32 + .46 \times 16 = 25\ bits$$

Thus, this compares to 21 bits from Exercise 2.1(a) and 27 bits from Exercise 2.1(b). So this approach fits between the two extremes.

Exercise 2.2(a) For the original configuration,

$$CPU\ Time_{old} = CPI_{old} \times Clk_{old} \times IC_{old}$$

and for the modified configuration:

$$\begin{aligned} CPU\ Time_{new} &= CPI_{new} \times Clk_{new} \times IC_{new} \\ &= CPI_{old} \times (1.10 \times Clk_{old}) \times (IC_{old} - R) \end{aligned}$$

where we assume the new CPI is equal to that of the old, the new clock cycle time is 10% longer than the old one, and the new configuration executes R fewer instructions than the old (due to optimization). To achieve the same performance, set the above equations equal and solve for the ratio of instruction counts:

$$\begin{aligned} CPI_{old} \times Clk_{old} \times IC_{old} &= CPI_{old} \times (1.10 \times Clk_{old}) \times (IC_{old} - R) \\ \frac{IC_{old} - R}{IC_{old}} &= .91 \end{aligned}$$

We get $R = .09(IC_{old})$. Thus 9% of all instructions must be removed to get the same performance. Because loads account for 22.8% of the instruction mix of `gcc` from Figure 2.26, 39.5% of the loads must be replaced with the new load operation combined instruction for the performance of the old and new configurations to be the same.

Exercise 2.10 For each cases, we need the formulas:

$$\begin{aligned} Percent_{data\ access} &= \frac{Number_{data\ access}}{Number_{memory\ access}} \\ Percent_{data\ read} &= \frac{Number_{data\ read}}{Number_{data\ access}} \\ Percent_{memory\ read} &= \frac{Number_{memory\ read}}{Number_{memory\ access}} \end{aligned}$$

We know that each load is one data read, each store is one data write, and each instruction executed is one memory read. The equations below use this information along with the fact that 26% of the instructions are loads and 9% of the instructions are stores (from Figure 2.26 in the text).

$$\begin{aligned} Number_{memory\ access} &= Number_{instructions} \times (1 + .26 + .09) \\ Number_{data\ access} &= Number_{instructions} \times (.26 + .09) \\ Number_{data\ read} &= Number_{instructions} \times (.26) \\ Number_{memory\ read} &= Number_{instructions} \times (1 + .26) \end{aligned}$$

By combining the above results, we get:

$$\begin{aligned} Percent_{data\ access} &= 26\% \\ Percent_{data\ read} &= 74\% \\ Percent_{memory\ read} &= 93\% \end{aligned}$$