CS433: Computer Architecture – Fall 2022
Homework 1
Total Points: 21 points
All students should solve all problems
Due Date: September 6, 2022 at 10:00 pm CT
(see course information slides for more details)

Directions:

- **All students must write and sign the following statement at the end of their homework submission. "I have read the honor code for this class in the course information handout and have done this homework in conformance with that code. I understand fully the penalty for violating the honor code policies for this class." No credit will be given for a submission that does not contain this signed statement.**
- **On top of the first page of your homework solution, please write your name and NETID, your partner's name and NETID, and whether you are an undergrad or grad student.**
- **Please show all work that you used to arrive at your answer. Answers without justification will not receive credit.**
- **See course information slides for more details**

Problem 0 [4 points]

Choose the correct answer for the following multiple-choice questions:

0.1) You are offered old homework solutions by a student who formerly took this class. You should:

a. Accept the solutions because no one will ever know.
b. Not even look at the solutions because that is the honor code set for this class.
c. Accept the solutions because you don't really want to learn anything in this class. You are simply taking it to fulfill a requirement.

0.2) While working with a partner on a homework assignment, one of your classmates asks if they can also work with you. You should:

a. Tell the other student that you already have a partner for this homework assignment.
b. Agree to work with the other student, but only on the portion of the homework you have not yet completed.
c. Apologize for having found a partner too early and offer to send the other student a completed copy of your homework.

0.3) Suppose you and your partner are overwhelmed with work at the time the homework is due. You should:

a. Have your partner do half the problems, you do the other half, and combine your solutions.
b. Complain about your course load to everyone you meet.

c. Think ahead and email Professor Adve for an extension within 48 hours of when the homework is handed out.

0.4) You and your partner have discussed all the problems and their solutions. You then independently finish writing up your solutions for submission. Your partner texts you that they are running out of time to write up their solutions because there is a midterm the next day and asks you for your writeup as an aid. You should:

a. Give your partner your writeup. After all, you already discussed the solutions with them earlier.
b. Not give your writeup because the honor code requires both partners to independently write the solutions.
c. Not give your writeup, but be available to help your partner as they write up their submission.

Solution: 0.1) b, 0.2) a, 0.3) c, 0.4) b

Grading: 1 point for each answer.

Problem 1 [5 points]:

Part (A) [2 points]

You are developing a new enhancement that provides a 2.5x speedup to certain kinds of instructions. What percentage of a program, as measured by its original execution time, must consist of these instructions if you want to gain an overall speedup of 10%?

Solution:

Let f be the required fraction.

$$\frac{T_{old}}{T_{new}} = 1.1$$

$$\frac{T_{old}}{\left((1-f)+\frac{f}{2.5}\right)\times T_{old}} = 1.1$$

$$\frac{1}{1-\frac{3f}{5}} = 1.1$$

$$\frac{3f}{5} = 1 - \frac{1}{1.1}$$

$$f = 0.152 \text{ or } 15.2\%$$

Grading:

½ point for writing the correct ratio. 1 point for writing the correct equation for Tnew. ½ point for simplification.

Part (B) [1 point]

For the program identified in Part (A), what is the maximum possible speedup if the described enhancement provides infinite speedup?

Solution:

$$Speedup_{infinity} = \frac{1}{1-0.152} = 1.18$$

Grading:

1 point for setup of equation.

Part (C) [2 points]

Two enhancements are proposed: one that can enhance 40% of execution time with a speedup of 1.5, and another that can enhance 25% of execution time with some greater speedup value. Only one of these two can be implemented. How much of a speedup is necessary in the second enhancement to give a better enhancement than the first?

Solution:

$$T_{new1} \geq T_{new2}$$
$$0.6 + \frac{0.4}{1.5} \geq 0.75 + \frac{0.25}{s}$$
$$\frac{7}{60} \geq \frac{0.25}{s}$$
$$s \geq \frac{15}{7} \text{ or } 2.14$$

Grading:

1 point each for writing the correct time for each enhancement.

Problem 2 [3 points]

Several researchers have suggested that adding a register-memory addressing mode to a load-store machine might be useful. The idea is to replace sequences of

```
ld x1, 0(x8)

add x2, x2, x1
```

with

add x2, 0(x8)

Assume that the new instruction will cause the clock cycle time to increase by 5% and will not affect the CPI. Also, assume loads constitute 25.1% of all instructions. What percentage of the loads must be eliminated for the machine with the new instruction to have at least the same performance?

Solution:

Let L be the fraction of loads that are eliminated. This means that $0.251 \times L$ of all instructions are eliminated.

$$CPU\ time_{old} = \#\ of\ instructions \times CPI \times cycle\ time$$
$$CPU\ time_{new} = ((1 - 0.251 \times L) \times \#\ of\ instructions) \times CPI \times ((1 + .05) \times cycle\ time)$$
$$CPU\ time_{new} \leq CPU\ time_{old}$$
$$(1 - 0.251 \times L) \times 1 \times 1.05 \leq 1$$
$$0.251 \times L \geq 1 - \frac{1}{1.05}$$
$$L \geq 0.19\ or\ 19\%$$

Grading:

1 point for the basic time equation. 2 points for setting up the equation correctly to solve the problem. No deductions for calculation mistakes.

Problem 3 [3 points]

Consider a 2.4 cm^2 die for a 64-bit processor manufactured from a 42 cm-diameter wafer costing $9,000. Assume a wafer yield of 99%. Use the defect model from the lecture notes with 0.016 defects per cm^2 and α=10. What is the expected cost per die (before testing)? Ignore edge effect correction.

Solution:

The given equation for die yield is:

$$Die\ yield = Wafer\ yield \times (1 + (Defects\ per\ unit\ area \times Die\ area))^{-\alpha}$$

Plugging in, we get:

$$Die\ yield = 0.99 \times (1 + (0.016 \times 2.4))^{-10} = 0.679$$

Now we need to calculate the number of dies per wafer:

$$Dies\ per\ wafer\ = \frac{\pi \times \left(\frac{wafer\ diameter}{2}\right)^2}{Die\ area}$$

$$Dies\ per\ wafer\ = \frac{\pi \times \left(\frac{42}{2}\right)^2}{2.4} = 577.27\ (round\ down\ to\ 577\ )$$

Finally, we can figure out the cost per die based on the above calculations:

$$Cost\ per\ die\ = \frac{\$9000}{0.679 \times 577} \approx \$22.97$$

Grading:

1 point for setting up the die yield equation properly. 1 point for setting up the dies per wafer equation correctly. 1 point for setting up the cost of die equation correctly. No deductions for calculation mistakes.

Problem 4 [3 points]

Suppose a processor uses 105W of power while operating at 2.7 GHz, of which 3/4 is dynamic power. Suppose we want to run the same processor at a higher frequency which requires increasing the operating voltage proportionally as well. If the maximum dynamic power consumption that can be tolerated is 130W, by how much can the processor frequency be sped up?

Solution:

Total power consumption is broken down into the static and dynamic power components:

$$Power\ = Dynamic\ Power\ +\ Static\ Power$$

From the problem statement, we know that Power = 105 W, and Dynamic Power is ¾ of this:

$$Dynamic\ Power\ = \frac{3}{4} \times\ 105\ W\ =\ 78.75\ W$$

The new dynamic power consumption is 130 W. Since the capacitance is constant, we ignore it in our calculations. Let x be the speedup:

$$F^{'}\ =\ F\ \times\ x$$

$$V^{'}\ =\ V\ \times\ x$$

Using the equation for dynamic power:

$$Dynamic\ Power_{new} = V^{'2} \times F^{'}$$

$$Dynamic\ Power_{new} = (V\ \times\ x)^2 \times\ (F\ \times\ x)$$

$$Dynamic\ Power_{new} = x^3 \times V^2 \times F$$

$$Dynamic\ Power_{new} = x^3 \times\ Dynamic\ Power_{old}$$

$$x^3 = \frac{Dynamic\ Power_{new}}{Dynamic\ Power_{old}}$$

$$x^3 = \frac{130}{78.75} = 1.65$$

$$x = \sqrt[3]{1.65} = 1.182\ or\ 18.2\%$$

Grading:

1 point for finding new dynamic power. 1 point for listing the correct dynamic power equation. 1 point for finding speedup. No deductions for calculation mistakes.

Problem 5 [3 points]

Consider a server farm of 2,700 identical components where a single failure causes the entire system to crash. If each component has an MTTF of 360 days, what is the MTTF of the entire farm? Assume an exponential distribution for component time to failure.

Solution:

FIT of one server = 1/360

FIT of entire farm = $2700 \times \left(\frac{1}{360}\right) = 7.5$

MTTF of entire farm =$\frac{1}{FIT}\ of\ farm = \frac{1}{7.5} days = \frac{1}{7.5} \times 24 \times 60\ minutes = 192\ minutes$

Grading:

1 point for each of the three equations. No deductions for calculation mistakes.