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Computer Science 605.611

Problem Set 1

1. (5) A processor takes 12.8 seconds to execute a certain program. An improvement is made to the processor so that it executes the same program in only 8 seconds. What speedup does this improvement provide for the program?

Before Improvement
Execution time = 12.8 seconds

After Improvement
Execution time = 8 seconds

Performance = 1 / Execution Time

$\text{Performance}_{after}$ = 1/8 seconds
$\text{Performance}_{before}$ = 1/12.8 seconds

$\text{Performance}_{after} / \text{Performance}_{before} = \text{ExecutionTime}_{before} / \text{ExecutionTime}_{after} = n$

12.8 / 8 = 1.6

The improvement provides a speedup of 1.6 for the program.

2. (3) Module 1 describes the three MIPS machine code formats: the R-format, the I-format and the J-format. How does the hardware control unit determine the format of a machine instruction?

The hardware control unit can determine the format of a machine instruction by looking at the opcode. The opcode is always the leftmost 6 bits. Using the opcode, the hardware control unit can determine the format.

R-format: Opcodes with 000000 are in the R-format. We use the 6 right most digits of the machine instructions (funct field) to determine what operation needs to be performed.

I-format: Opcodes that corresponds to instructions with immediate values, are in the I-format. The right most 16 digits of the machine instruction is for the immediate data. An example would be the opcode 001000 or addi insruction.

J-format: Opcodes that correspond to jump instructions are in the J-format. The right most 26 digits are for immediate offset. An example would be the opcode 000010 or the J instruction.

So, by decoding the opcode of the machine instruction, the hardware control unit can distinguish between R-format, I-format and j-format instructions.

3. (7) The MIPS system includes a CPU to handle integer instructions and two coprocessors: CP0, the system coprocessor, records information needed to handle exceptions and interrupts, and CP1 handles floating point instructions. The control unit determines what operation an instruction performs by examining the instruction opcode. For each of the following MIPS instructions, specify whether the instruction is executed by the CPU or by CP1 (coprocessor 1). Based your answers on appendix A of the textbook.

Main difference between the CPU and the CPI, is that the CPU will handle integer instructions, and the CPI will handle floating point instructions.

div
    CPU
mult
    CPU
cvt.w.s
    CP1
mtc1
    CPU
lwc1
    CP1
neg.s
    CP1
swc1
    CP1

4. (12) Indicate whether each of the phrases below applies to a CISC or to a RISC by placing the letter X into one of the two blanks. Base your choice on the information provided in module 1.

| | | |
|---|---|---|
| • supports fewer addressing modes | CISC _____ | RISC___X___ |
| • usually contains fewer CPU registers | CISC __X_ | RISC_______ |
| • arithmetic instructions can't use memory operands | CISC _____ | RISC___X___ |
| • allows variable length machine instructions | CISC __X_ | RISC_______ |
| • more likely to use hardwired control logic | CISC _____ | RISC___X___ |
| • more likely to complete an instruction each cycle | CISC _____ | RISC___X___ |

5. A processor has a clock rate of 2 GHz and executes 150 million instructions from a program with an average CPI of 4.

Three techniques that can be used to improve the performance of the program are:

- Option 1: optimize the program so that only 100 million instructions are executed.
- Option 2: double the clock rate of the processor.
- Option 3: carefully select the instructions in the program so that the average CPI is reduced from 4 to 2.5.

For each of these options used alone, compute the resulting speedup for the program. Recall that speedup is defined as the ratio of the execution time before the change to the execution time after the change.

Speed of the original processor
Clock Rate = 2GHz
Number of Instructions Executed = 150 * 10^6
CPI = 4

Execution time = (Number of Instructions Executed * CPI ) / Clock Rate
Execution time = ( 150 * 10^6 * 4 ) / (2 *10^9) seconds
Execution time = ( 600 * 10^6) / (2*10^9) seconds
Execution time = .3 seconds

The original processor takes .3 seconds to execute the program.

Option 1:
Optimize the program so only 100 million instructions are executed.
Number of Instructions Executed = 100*10^6

Execution time = (Number of Instructions Executed * CPI ) / Clock Rate
Execution time = ( 100 * 10^6 * 4 ) / (2 *10^9) seconds
Execution time = ( 400 * 10^6) / (2*10^9) seconds
Execution time = .2 seconds

N = Execution time before / Execution time after

N = .3/.2 = 1.5

Option 1 leads to 1.5 times speed up

Option 2:
Only double the clock rate. Assume all other variables stay the same.
Clock Rate = 4GHz

Execution time = (Number of Instructions Executed * CPI ) / Clock Rate

Execution time = ( 150 * 10^6 * 4 ) / (4 *10^9) seconds
Execution time = ( 600 * 10^6) / (4*10^9) seconds
Execution time = .15 seconds

N = Execution time before / Execution time after

N = .3/.15 = 2

Option 2 leads to 2 times speed up

Option 3:
CPI is now 2.5

Execution time = (Number of Instructions Executed * CPI ) / Clock Rate
Execution time = ( 150 * 10^6 * 2.5 ) / (2 *10^9) seconds
Execution time = ( 375 * 10^6) / (2*10^9) seconds
Execution time = .1875 seconds

N = Execution time before / Execution time after

N = .3/.1875 = 1.6

Option 3 leads to 1.6 times speed up

(3) Speedup provided by option 1 = 1.5
(3) Speedup provided by option 2 = 2
(3) Speedup provided by option 3 = 1.6

6. A processor with a clock rate of 2.5 GHz requires 0.28 seconds to execute the 175 million instructions contained in a program.

a) (3) What is the average CPI (cycles per instruction) for this program?

Execution time = (Instruction Count * CPI) / Clock Rate
CPI = (Execution time * Clock Rate) / Instruction Count

CPI = (0.28 * 2.5 *10^9) / (175 *10^6)

CPI = 4

b) (3) Suppose the processor's clock rate is increased, but the average CPI for the program rises to 5. With this average CPI of 5, what value is required for the higher clock rate to execute the program's 175 million instructions in 0.175 seconds?

Execution time = (Instruction Count * CPI) / Clock Rate
Clock Rate = (Instruction Count * CPI) / Execution time
Clock Rate = ( 175 * 10^6 * 5 ) / 0.175
Clock Rate = 5*10^9

Clock Rate = 5 GHz

c) (5) Suppose the processor's clock rate remains 2.5 GHz and the CPI remains at 4, but the program is rewritten to reduce the number of instructions executed from 175 million down to 159090910. How many nano-seconds are required to execute the rewritten program? Express your answer in the format ddddddddd.d, where each d is a decimal digit.

Execution time = (Instruction Count * CPI) / Clock Rate
Execution time = (159090910 * 4) / (2.5*10^9)
Execution time = 0.254545454545… seconds
Execution time = 254545454.5454545… nano-seconds

Rewrite into the correct format.
Execution time = 254545454.5 nano-seconds

7. A C++ program is translated into machine code runs on processor A and executes a total of 28 million instructions. The machine code on processor A contains twelve million instructions with CPI = 2, seven million instructions with CPI=3 and nine million instructions with CPI=4.

The same C++ program is translated into machine code that runs on a different processor B. The machine code on processor B executes 32 million instructions. Ten million of the instructions have CPI = 1, seventeen million instructions have CPI=2 and five million instructions have CPI=4. Processor A and processor B both run at a 2 GHz clock rate.

a) (3) What is the peak MIPS rating for the program that runs on processor A? Express your answer to two decimal places.

Best CPI =2.
Total instructions = 28 million
Clock Rate = 2 GHz

Peak MIPS = (Clock Rate) / (CPI * 10^6)
Peak MIPS = (2*10^9) / (2 * 10^6)
Peak MIPS = 1*10^3
Peak MIPS = 1000

b) (3) What is the peak MIPS rating for the program that runs on processor B? Express your answer to two decimal places.

Best CPI =1.
Total instructions = 32 million
Clock Rate = 2 GHz

Peak MIPS = (Clock Rate) / (CPI * 10^6)
Peak MIPS = (2*10^9) / (1 * 10^6)
Peak MIPS = 2*10^3
Peak MIPS = 2000

c) (3) What is the native MIPS rating for the program that runs on processor A? Express your answer to two decimal places.

Clock Rate = 2 GHz
Sequence 1 = 12 million instructions have a CPI of 2
Sequence 2 = 7 million instructions have a CPI of 3
Sequence 3 = 9 million instructions have a CPI of 4
Total Instruction Count = 28 million

Weighted Average CPI = ( (Instruction Count in sequence 1 * CPI of sequence 1) + (Instruction Count in sequence 2 * CPI of sequence 2) + … + (Instruction Count in last sequence * CPI of last sequence) ) / ( Total Instruction Count )
Weighted Average CPI = ( ( (12 *2) + (7*3) + (9*4) ) * 10^6) / (28 *10^6)
Weighted Average CPI = 2.89285714286

Native MIPS = Clock Rate / ( CPI * 10^6)
Native MIPS = (2 *10^9) / ( 2.89285714286 *10^6)
Native MIPS = 691.358024691

Rewrite to round to 2 decimal points
Native MIPS = 691.36

8. (5) The native MIPS rating for a machine code program with an average CPI of 2.5 on processor 1 is 800. Compiling the same program for processor 2 produces a machine code program that executes the same number of machine instructions but with an average CPI of 4. Both processors run at a 2 GHz clock rate. What is the relative MIPS rating for the program running on processor 2 compared to the program running on processor 1?

MIPS of Processor 1 = Clock Rate / ( CPI * million)
MIPS of Processor 1 = (2 * 10^9) / ( 2.5 * 10^6)
MIPS of Processor 1 = 800

MIPS of Processor 2 = Clock Rate / ( CPI * million)
MIPS of Processor 2 = (2 * 10^9) / ( 4 * 10^6)
MIPS of Processor 2 = 500

Relative MIPS = MIPS of Processor 2 / MIPS of Processor 1
Relative MIPS = 500 / 800
Relative MIPS = 0.625

The relative MIPS rating for the program running on processor 2 compared to the program running on processor 1 is 0.625.

9. When a certain program is run, the CPU executes a total of 7 million instructions. The average CPI for the program is 2.5 and the CPU clock rate is 4 GHz.

a) (3) What is the corresponding CPU clock cycle time in nano-seconds?

CPU Time = CPU Clock Cycles * CPU Clock Cycle Time
CPU Time = (IC *CPI) / Clock Rate
CPU Clock Cycles = IC * CPI

CPU Time = (7 *10^6 *2.5) / (4*10^9)
CPU Time = 0.004375 seconds

CPU Clock Cycles = 7 *10^6 * 2.5
CPU Clock Cycles = 17500000

0.004375 = 17500000 * CPU Clock Cycle Time
CPU Clock Cycle Time = 0.004375 / 17500000
CPU Clock Cycle Time = 2.5 *10^-10 seconds

Rewrite in nano seconds
CPU Clock Cycle Time = 0.25 nano-seconds

b) (3) What number is obtained by evaluating the expression: clock_rate / (average_CPI*$10^6$) using the values provided above for clock rate and average CPI?

Clock Rate = 4 GHz
CPI = 2.5

Clock rate / (average CPI *10^6)
= (4*10^9) / (2.5 *10^6)
= 1600

c) (3) What number is obtained by evaluating the expression: IC / (execution_time*$10^6$) for this program using the values provided above for the instruction count (IC), clock rate and average CPI?

IC = 7 *10^6
Clock Rate = 4*10^9
Average CPI = 2.5

Execution time = (IC * CPI) / Clock Rate
Execution time = (7*10^6 * 2.5) / 4*10^9
Execution time = 0.004375 seconds

IC / (execution time *10^6)
= (7 *10^6) / ( 0.004375 * 10^6)
= 1600

10. The sub-module on Computer performance metrics defines the geometric mean, the harmonic mean and the arithmetic mean as techniques for assessing the performance of a group of programs. Some processors, especially those used in laptops or mobile devices, can run at a lower rate to conserve power and extend battery charge.

Suppose one of these processors runs in the slower low power mode and executes 2,520,000 instructions for a program in 14 milli-seconds.
Next the processor switches to the higher speed mode and executes the same program instructions again. This second execution at the higher speed takes only 9 milli-seconds. Answer the following questions and show how you obtained your answer for each:

a) (5) What is the native MIPS rating for the program in the slower low power mode?

Native MIPS = Instruction Count / (Execution Time * 10^6)
Native MIPS = 2,520,000 / ( 14*10^-3 * 10^6)
Native MIPS = 2,520,000 / ( 14*10^3 )
Native MIPS = 180 MIPS

b) (5) What is the native MIPS rating for the program in the higher speed mode?

Native MIPS = Instruction Count / (Execution Time * 10^6)
Native MIPS = 2,520,000 / ( 9*10^-3 * 10^6)
Native MIPS = 2,520,000 / ( 9*10^3 )
Native MIPS = 280 MIPS

c) (5) What is the arithmetic mean of these two native MIPS ratings?

Arithmetic Mean = sum of values / number of values
Arithmetic Mean = ( 180 MIPS + 280 MIPS ) / 2
Arithmetic Mean = ( 180 MIPS + 280 MIPS ) / 2
Arithmetic Mean = 230 MIPS

d) (5) What is the harmonic mean of the two native MIPS ratings?

Harmonic Mean = number of values / sums of reciprocal values
Harmonic Mean = 2 / ((1/180 + (1/280))
Harmonic Mean = 219.130434783

e) (5) What is the geometric mean of the two native MIPS ratings?

Geometric Mean = (products of values )^(1/ number of values)
Geometric Mean = ( 180 * 280 )^(1/ 2)
Geometric Mean = 224.499443206

f) (5) This same program containing 2,520,000 instructions takes time T1 when executed in the slower low power mode and time T2 when executed again in the higher speed mode. Compute the MIPS rating for the combined two executions of the program. Base your answer on the values T1 and T2 and on the total number of instructions executed (2 * 2,520,000).
MIPS rating = 219.130434783 MIPS _

Number of Instructions of one run = 2520000
Execution time of low speed mode = 14 *10^-3 seconds
Execution time of high speed mode = 9 *10^-3 seconds

Total Instructions = 2520000 * 2

MIPS Rating = Total Instructions / (Total Execution Time *10^6)
MIPS Rating = (2520000 * 2) / ( ( 14 *10^-3 + 9 *10^-3 )*10^6)
MIPS Rating = (5040000) / ( ( 2.3*10^-2 )*10^6)
MIPS Rating = (5040000) / ( 2.3*10^4 )
MIPS Rating = 219.130434783 MIPS