Computer Organization and Design

Homework 1 答案与评分细则

Problem 1. (20 points)

Consider three different processors P1, P2, and P3 executing the same instruction set. P1 has a 3 GHz clock rate and a CPI of 1.5. P2 has a 2.5 GHz clock rate and a CPI of 1.0. P3 has a 4.0 GHz clock rate and has a CPI of 2.2.

a. Which processor has the highest performance expressed in instructions per second? (5 points)

Ans: T=CPI×IC/F, thus instructions per second: IC/F=F/CPI,
where T is the execution time, CPI is the cycles per instructions, IC is the instruction counts and F is the clock rate.

$P1: 3GHz/1.5 = 2 \times 10^9$ instructions per second …1 points

$P2: 2.5GHz/1.0 = 2.5 \times 10^9$ instructions per second …1 points

$P3: 4.0GHz/2.2 = 1.82 \times 10^9$ instructions per second …1 points

So P2 has the highest performance among the three. …2 points

反过来求也可:

P1: CPI/F=1.5/3GHz=5×10^{-10} seconds per instruction … 1 points

P2: CPI/F=1.0/2.5GHz=4×10^{-10} seconds per instruction … 1 points

P3: CPI/F=2.2/4GHz=5.5×10^{-10} seconds per instruction … 1 points

So P2 has the highest performance among the three. … 2 points

b. If the processors each execute a program in 10 seconds, find the number of cycles and the number of instructions. (5 points)

Ans: Cycles: Cycles = clock rate × execution time

$P1: 3GHz \times 10 = 3 \times 10^{10}$ cycles

$P2: 2.5GHz \times 10 = 2.5 \times 10^{10}$ cycles

$P3: 4GHz \times 10 = 4 \times 10^{10}$ cycles

Number of instructions: Number of instructions = Cycles/CPI

$P1: 3GHz \times 10/1.5 = 2 \times 10^{10}$ instructions

$P2: 2.5GHz \times 10/1.0 = 2.5 \times 10^{10}$ instructions

$P3: 4GHz \times 10/2.2 = 1.82 \times 10^{10}$ instructions

…结果每个 0.5 points，公式或过程每个 1 points.

c. We are trying to reduce the execution time by 30%, but this leads to an increase of 20% in the CPI. What clock rate should we have to get this time reduction? (10 points)

Ans: Execution time = (Num of instructions $\times$ CPI)/(Clock rate) …3 points
So if we want to reduce the execution time by 30%, and CPI increases by 20%, we have:
Execution time $\times$ 0.7 = (Num of instructions $\times$ CPI $\times$ 1.2)/(New Clock rate)
New Clock rate = Clock rate $\times$ 1.2 / 0.7 = 1.71 $\times$ Clock rate …4 points
New Clock rate for each processor:
P1: $3GHz \times 1.71 = 5.13\ GHz$
P2: $2.5GHz \times 1.71 = 4.27\ GHz$
P3: $4GHz \times 1.71 = 6.84\ GHz$ …3 points, each 1 points

Problem 2. (20 points)
Consider two different implementations of the same instruction set architecture. The instructions can be divided into four classes according to their CPI (classes A, B, C, and D). P1 with a clock rate of 2.5 GHz and CPIs of 1, 2, 3, and 3, and P2 with a clock rate of 3 GHz and CPIs of 2, 2, 2, and 2.
Given a program with a dynamic instruction count of 1.0E6 instructions divided into classes as follows: 10% class A, 20% class B, 50% class C, and 20% class D, which is faster: P1 or P2?

a. What is the global CPI for each implementation? (5 points)

Ans: Counts of all instructions is 1×10^6
Number of instructions for different classes is:
Class A: $1 \times 10^6 \times 10\% = 1 \times 10^5$ instructions
Class B: $1 \times 10^6 \times 20\% = 2 \times 10^5$ instructions
Class C: $1 \times 10^6 \times 50\% = 5 \times 10^5$ instructions
Class D: $1 \times 10^6 \times 20\% = 2 \times 10^5$ instructions

Execution time = (Num of instructions $\times$ CPI)/clock rate
For P1:
Execution time
$=(1 \times 10^5 \times 1 + 2 \times 10^5 \times 2 + 5 \times 10^5 \times 3 + 2 \times 10^5 \times 3)/(2.5 \times 10^9)$
The global CPI for P1 is then:
CPI_{P1}= Execution time $\times$ clock rate / Num of instructions = 2.6 …2.5 points

For P2:
Execution time
$=(1 \times 10^5 \times 2 + 2 \times 10^5 \times 2 + 5 \times 10^5 \times 2 + 2 \times 10^5 \times 2)/(3 \times 10^9)$
The global CPI for P2 is then:
CPI_{P2} = Execution time $\times$ clock rate / Num of instructions = 2 …2.5 points

直接用 CPI 算也可:

For P1: $CPI_{P1}=1 \times 10\% + 2 \times 20\% + 3 \times 50\% + 3 \times 20\% = 2.6$ …2.5 points
For P2: $CPI_{P2}=2 \times 10\% + 2 \times 20\% + 2 \times 50\% + 2 \times 20\% = 2$ …2.5 points

b. Find the clock cycles required in both cases. (5 points)

Ans: Clock cycles = Num of instructions $\times$ global CPI
For P1: Clock cycles=$1 \times 10^6 \times 2.6 = 2.6 \times 10^6$ …(2.5 points)
For P2: Clock cycles=$1 \times 10^6 \times 2 = 2 \times 10^6$ …(2.5 points)

Which is faster? (10 points)
P1: $2.5GHz/2.6 = 0.96 \times 10^9$ instructions per second …4 points
P2: $3GHz/2 = 1.5 \times 10^9$ instructions per second …4 points
So P2 is faster. …2 points

反过来求也可:

P1: $2.6/2.5GHz = 1.04 \times 10^{-9}$ seconds per instruction …4 points
P2: $2/3GHz = 6.67 \times 10^{-10}$ seconds per instruction…4 points
So P2 is faster. …2 points

Problem 3. (30 points)
Compilers can have a profound impact on the performance of an application. Assume that for a program, compiler A results in a dynamic instruction count of1.0E9 and has an execution time of 1.1 s, while compiler B results in a dynamic instruction count of 1.2E9 and an execution time of 1.5 s.

a. Find the average CPI for each program given that the processor has a clock cycle time of 1 ns. (10 points)

Ans: Execution Time = CPI $\times$ Num of instructions / clock rate, so we have:
CPI = Execution Time $\times$ clock rate / Num of instructions …2 points
Complier A: $CPI_A = 1.1s \times 1 \times 10^9 Hz/(1 \times 10^9$ instructions$)=1.1$ …4 points
Complier B: $CPI_B = 1.5s \times 1 \times 10^9 Hz/(1.2 \times 10^9$ instructions$)=1.25$ …4 points

b. Assume the compiled programs run on two different processors. If the execution times on the two processors are the same, how much faster is the clock of the processor running compiler A's code versus the clock of the processor running compiler B's code? (10 points)

Ans: clock rate = CPI $\times$ Num of instructions / Execution Time …3 points
Since the execution times on the two processors are the same, so the speed up is:
$Clock_B/Clock_A$
$=(CPI_B \times$ Num of instructions $_B)/(CPI_A \times$ Num of instructions $_A)$ …5 points
$=(1.25 \times 1.2 \times 10^9)/ (1.1 \times 1 \times 10^9)$

=1.36 …2 points

c. A new compiler is developed that uses only 6.0E8 instructions and has an average CPI of 1.1. What is the speedup of using this new compiler versus using compiler A or B on the original processor? (10 points)

Ans:
Speed up for complier A:
$Clock_A/Clock_{New}$
=(CPI_A × Num of instructions $_A$)/(CPI_{New} × Num of instructions $_{New}$)
…3 points
=$(1.1\times1\times10^9)/(1.1\times6\times10^8)$
=1.67 …2 points

Speed up for complier B:
Clock B/Clock New
=(CPI_B × Num of instructions $_B$)/(CPI_{New} × Num of instructions $_{New}$)
…3 points
=$(1.25\times1.2\times10^9)$ /$(1.1\times6\times10^8)$
=2.27 …2 points

Problem 4. (30 points)
The Pentium 4 Prescott processor, released in 2004, had a clock rate of 3.6 GHz and voltage of 1.25 V. Assume that, on average, it consumed 10 W of static power and 90 W of dynamic power.
The Core i5 Ivy Bridge, released in 2012, had a clock rate of 3.4 GHz and voltage of 0.9 V. Assume that, on average, it consumed 30 W of static power and 40 W of dynamic power.

a. For each processor find the average capacitive loads. (10 points)

Ans: Dynamic Power = $1/2$ × Capacitive load × Voltage^2 × clock rate
So the average capacitive load is
C=2 × Dynamic Power/ (Voltage^2 × clock rate) …6 points
Pentium 4: C=$2\times 90W/((1.25V)^2\times 3.6\times 10^9 Hz) = 3.2\times 10^{-8}F$ …2 points
Core i5 Ivy Bridge: C=$2\times 40W/((0.9V)^2\times 3.4\times 10^9 Hz) = 2.9\times 10^{-8}F$
… 2 points

b. Find the percentage of the total dissipated power comprised by static power and the ratio of static power to dynamic power for each technology. (10 points)

Ans:
Pentium 4:
The percentage of the total dissipated power comprised by static power
=10/100=10% …3 points

The ratio of static power to dynamic power = 10/90 =11.11% …2 points

Core i5 Ivy Bridge:
The percentage of the total dissipated power comprised by static power =30/70=42.86% …3 points
The ratio of static power to dynamic power = 30/40 =75% …2 points

c. If the total dissipated power is to be reduced by 10%, how much should the voltage be reduced to maintain the same leakage current? Note: power is defined as the product of voltage and current. (10 points)

Ans: The total dissipated power is to be reduced by 10%, we have:
$(S_{new} + D_{new})/(S_{old} + D_{old})$=0.9, thus we can get:
$D_{new} = 0.9 \times (S_{old} + D_{old}) - S_{new}$ …(1) …2 points

According to the definition of the dynamic power, we have

$$D_{new} = \frac{1}{2} C \times V_{new}{}^2 \times F$$

Then we get the new voltage by: $V_{new} = [2D_{new}/(C \times F)]^{1/2}$ …(2) … 2points

According to the definition of static power, we have:
$S_{old} = V_{old} \times I$ …(3)
$S_{new} = V_{new} \times I$ …(4)
According to (3) and (4), we derive the new static power by:
$S_{new} = V_{new} \times (S_{old}/V_{old})$ … (5) …2 points

Pentium 4:
$S_{new} = V_{new} \times (10/1.25) = 8V_{new}$
$D_{new} = 0.9 \times 100 - 8V_{new} = 90 - 8V_{new}$
$V_{new} = [2 \times (90 - 8V_{new})/(3.2 \times 10^{-8} \times 3.6 \times 10^9)]^{1/2}$
V_{new} =1.18V … 1points
$\Delta V = V_{old} - V_{new} = 0.07V$ … 1points

Core i5 Ivy Bridge:
$S_{new} = V_{new} \times (30/0.9) = 33.3V_{new}$
$D_{new} = 0.9 \times 70 - 33.3V_{new} = 63 - 33.3V_{new}$
$V_{new} = [2 \times (63 - 33.3V_{new})/(2.9 \times 10^{-8} \times 3.4 \times 10^9)]^{1/2}$
V_{new} =0.83V … 1points
$\Delta V = V_{old} - V_{new} = 0.07V$ … 1points