Instructions:

- Print your name in the space provided below.
- This examination is closed book and closed notes, aside from the permitted one-page formula sheet. No calculators or other computing devices may be used. The use of any such device will be interpreted as an indication that you are finished with the test and your test form will be collected immediately.
- Answer each question in the space provided. If you need to continue an answer onto the back of a page, clearly indicate that and label the continuation with the question number.
- If you want partial credit, justify your answers, even when justification is not explicitly required.
- There are 7 questions, some with multiple parts, priced as marked. The maximum score is 100.
- When you have completed the test, sign the pledge at the bottom of this page and turn in the test.
- If you brought a fact sheet to the test, write your name on it and turn it in with the test.
- Note that either failing to return this test, or discussing its content with a student who has not taken it is a violation of the Honor Code.

Do not start the test until instructed to do so!

Name Solution

printed

Pledge: On my honor, I have neither given nor received unauthorized aid on this examination.

signed


CHECK IT OUT-OLD COMPUTER SHOPPERS! WOW—IN 1996, $3,000 WOULD GET YOU A 100 MHz PENTIUM SYSTEM WITH A PARALLEL PORT, TWO SERIAL PORTS, A 2MB VIDEO CARD, AND "MS-WINDOWS"
NICE!
MISC
AND $299 WOULD GET YOU A PALM PILOT 1000—16 MHz, 128 KB STORAGE, AND A MEMO PAD, CALENDAR, AND STATE-OF-THE-ART ADDRESS BOOK THAT CAN STORE OVER 100 NAMES!
OOOH!
AND $110 WOULD GET YOU A BULKY TI GRAPHING CALCULATOR WITH AROUND A 10MHz CPU, 24 KB RAM, AND A 96×64-PIXEL B/W DISPLAY!
TIMES SURE HAVE... ...HAVE... UH.
OKAY, WHAT THE HELL, T.I.?
MAYBE THEY COST SO MUCH NOW BECAUSE THERE'S ONLY ONE ENGINEER LEFT WHO REMEMBERS HOW TO MAKE DISPLAYS THAT CRAPPY.

xkcd.com

1. [10 points] Two machines implement support for the same machine language, but have different hardware designs. Aside from the processor, the two machines are identical (RAM, hard drive performance, etc.) Machine A has a substantially higher clock rate than machine B. Nevertheless, execution of a certain machine language program, with the same input, takes substantially less time on machine B than on machine A. Explain how this is possible. Be precise and cite relevant formulas from our discussion of performance.

Execution time is the product of the number of instructions executed, the average CPI for the program, and the reciprocal of the clock rate. Even though machine A has a higher clock rate, it is entirely possible that machine B has a lower average CPI for this program, in which case the program could execute in less time on machine B.

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2. Suppose a program consists of 30% floating point multiply instructions, 20% floating point divide instructions, and the remaining 50% are other instructions. Floating point division, floating point multiplication, and each of the other instructions have the same CPI.

a) [12 points] What speedup can be achieved, for that program, if the execution of a floating point multiplication instruction is made 3/2 times faster and the execution of a floating point division is made 4/3 times faster? Justify your conclusion.

Apply Amdahl's Law: T_after = .50 * T_before + .30 * T_before/(3/2) + .20 * T_before/(4/3)

=.50 * T_before + .20 * T_before + .15 * T_before

= .85 * T_before

So, the speedup is: T_before / (.85 * T_before) = 1 / .85 = 20/17 (about 1.176)

b) [8 points] What is the upper bound on the speedup can be achieved, for the same program, by making the execution of floating point division faster? Justify your conclusion.

Since floating point division makes up only 20% of the instructions, we could not reduce the overall running time to less than 80% of the original time (in fact, we can't even achieve that unless we figure out how to perform a floating point division in time 0).

So, the maximum speedup would be bounded by 1 / .80 = 1.25.

3. [10 points] Computer A has an overall CPI_A of 1.5 and can be run at a clock rate Clk_A of 2.0 GHz. Computer B has a CPI_B of 2.5 and can be run at a clock rate Clk_B of 2.5 GHz. We have a particular program we wish to run. When compiled for computer A, this program will execute exactly I_A = 25,000 instructions.

Set up an algebraic equation (i.e., symbolic) to determine how many instructions would the program need to execute when compiled for Computer B, in order for the two computers to have exactly the same execution time for this program?

Since execution time equals the product of instruction count, average CPI and cycle length, we are asking when would:

$$I_A * CPI_A / Clk_A == I_B * CPI_B / Clk_B$$

which would be true iff

$$I_B = (I_A * CPI_A * Clk_B) / (CPI_B * Clk_A)$$

4. These questions refer to the simplified single-cycle MIPS32 datapath (full diagram supplied with the test). Recall that this datapath supports the following instructions: `add`, `sub`, `and`, `or`, `slt`, `lw`, `sw`, `beq` and `j`.

a) [12 points] Consider the multiplexor, labeled **4a** on the datapath diagram, that is controlled by the ALUSrc signal. Which of the supported instructions could not be executed correctly if ALUSrc was stuck at 0? Why?

If ALUSrc was stuck at 0, the MUX it controls would never pass a sign-extended immediate to the ALU. That would prevent lw and sw from executing correctly, since each of those requires computing an address by adding a sign-extended immediate to a value from a register.

b) [12 points] Consider the Sign extend unit, labeled **4b** on the datapath diagram. Which of the supported instructions depend on this unit for their correct operation? Why is it needed?

The sign-extender is applied to a 16-bit immediate from the instruction itself; this is necessary for lw and sw (as noted above) and also for beq, where the immediate is used in the calculation of an instruction address which will be used if the branch is taken.

c) [10 points] Suppose the MemRead signal was stuck at 0. Which of the supported instructions could not be executed correctly? Why?

If MemRead was stuck at 0, it would be impossible to read a value from the Data memory unit.

The only instruction that requires doing that is lw.

5. [4 points] Why is the single-cycle datapath called the single-cycle datapath?

Because the entire datapath fetches and executes an instruction in one (somewhat long) clock cycle.

6. For some instruction(s), it does not matter whether the MemtoReg signal is set to 0 or 1.

a) [4 points] For which instruction(s) is that true?

sw, beq and j

b) [6 points] The fact that MemtoReg does not matter for some instruction(s) depends upon the presence and correct use of some other feature of the datapath. What is that feature, and how is it relevant to this question?

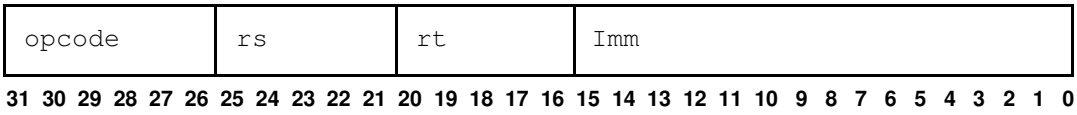
The output from the MUX controlled by MemtoReg goes to the Write data input to the Register file. If an instruction writes a value into the Register file, the correct value must be delivered to the Register file.

If an instruction does not write a value into the Register file, we do not care what value is delivered to the Register file, as long as the value is not written to a register.

To prevent writes to the Register file, we must have the RegWrite signal and set it correctly.

7. [12 points] Consider the following proposed instruction for the simplified single-cycle MIPS32 datapath discussed in class:

```
swpregmem   $rt, Imm($rs)    # GPR[rt] = Mem[GPR[rs] + Imm]
                             # Mem[GP[rs] + Imm] = GPR[rt]
```



The instruction swaps the values in register `$rt` and at memory address `$rs + Imm`. This could be accomplished by using a sequence of `lw` and `sw` (and other) instructions, but that would require three clock cycles and an extra register for temporary storage.

Assume that the Data memory unit is capable of handling a read operation and a write operation, targeting the same memory address, in a single clock cycle, and that the read will be completed before the write occurs. Then, the given single-cycle datapath can be extended to this new instruction, and all that is required is that the Control unit be modified to recognize the opcode for `swpregmem` and set the existing control signals correctly.

Assume we've modified the Control unit to handle `swpregmem`. How should the Control unit set each of the following control signals if a `swpregmem` instruction is being executed? No justification is required.

Control Signal	value for `swpregmem`
RegWrite	1
ALUSrc	1
MemWrite	1
MemRead	1
MemtoReg	1
RegDst	0