Name _____

Computer Engineering 331, Fall 2021 Exam 2

Exam time: 5 pre + 70 minutes exam

Test Value: 30 **pts. Total possible points:** 49 **(max score =** 163+**%)**

Total = /30	P1: /2	P2: /4	P3: /4	P4: /12	P5: /8
	E1: /6	E2: /6	E3: /3	E4: /2	E5: /2

Front Left Neighbor # _____	**Front Neighbor #** _____	**Front Right Neighbor #** _____
Left Neighbor # _____	**Your Name (print clearly):** _____	**Right Neighbor #** _____
Rear Left Neighbor # _____	**Rear Neighbor #** _____	**Rear Right Neighbor #** _____

A. You will have 70 minutes to complete this exam. The exam is **open-note-in-dead-tree-format** unless you have received specific authorization for using electronic notes, in which case you are requested to sit in the first row only. Useful tables have been provided for you on the last sheet of this exam, which can be freely removed once you have started writing – it does not need to be turned in. Additional scratch pages are provided at the end of the exam. Write your name on each page.
B. Please turn off all cell phones, smartwatches, and other mobile devices. Remove all hats & headphones.
C. Place your backpacks, laptops and jackets under your seat. All notes you intend to consult should be already removed from backpacks, etc. before the start of the exam.
D. There may be partial credit for incomplete answers on P1-P5; write as much of the solution as you can. **No partial credit will be given for extra credit problems.**
E. Show all of your work for a problem in the space provided on the exam sheet. If you need additional space, you must place a note with the problem indicating where the additional work is located. Answers (for problems explicitly requesting that work is shown) that lack derivations will not receive credit.
F. Please note that some problems may have multiple sub-problems and that point allocations are not always directly indicative of difficulty or problem solving time. You may wish to solve problems in an order other than that in which they are presented on the exam.

Email: _____

Student ID Number: _____

I, the undersigned, declare the following: All the work presented on this assessment is my own. I had no prior knowledge of the exam contents, nor will I share the contents with others.

SIGN HERE: _____

Name _____

1. (2pts; 0.5 each) **General Knowledge: Multicycle, Pipelining, Branch Prediction**
True or False. Circle T or F.

T F a. The BHT will produce predictions for ADDU instructions

T F b. There is no possible sequence of code for which the degenerate "always not taken" predictor induces fewer stalls than a 1-bit bimodal branch predictor.

T F c. For both pipelined and multicycle designs, the new clock period will be at least as long as the critical path through the slowest indivisible HW resource.

T F d. All read-after-write dependencies in a program will cause hazards in an FDEMW pipeline.

2. (4pts) **Branch Predictor Modeling: Unaliased 2-bit Bimodal BHT**

Assume that the PC for a given static branch instruction FOO maps to 2-bit counter in a bimodal branch predictor, and that the initial state of that counter is T(11).
Given the below table depicting a sequence of outcomes for FOO, fill in the states {`N(00)`,`n(01)`,`t(10)`,`T(11)`} and correct/misprediction entries in the table. Assume that no other branch maps to the same counter during the depicted period.

As indicated by the arrow, the outcome in each column occurs ***after*** the predictor was already in the indicated state in that column, and will affect the state in the next column.

OUTCOME	N	N	T	T	T	N	N	N	T
STATE	T →	t	n	t	T	T	t	n	N
Cor./Mis.	**Mis.**	mis	mis	hit	hit	mis	mis	hit	mis

3) (4 pts) **Multicycle CPI**

Consider a single-cycle MIPS processor with cycle-time of 1000ps and a multi-cycle design that differs from the one seen in lecture (see attached notes at end of exam) in the following fashion:
i) Cycle time is 125ps
ii) Both I and D memory accesses take N cycles, where N is an integer >= 1

If 50% of operations are R types, 10% of operations are stores, 20% are branches, and 20% are loads, what is the largest value of N for which the multicycle design is at least as fast as the single cycle design? Given that value of N, what is the CPI for the multicycle design?

$ET_{SC} = I \cdot 1 \cdot 1000ps \quad ET_{MC} = I \cdot CPI_{MC} \cdot 125ps$

$1000ps \geq CPI_{MC} \cdot 125ps \quad CPI_{MC} \leq 8$

$CPI_{MC} = 50\% \cdot (N+3) + 10\% \cdot (N+2+N) + 20\% (N+2) + 20\% (N+3+N)$

$\frac{5N}{10} + \frac{15}{10} + \frac{2N}{10} + \frac{2}{10} + \frac{2N}{10} + \frac{4}{10} + \frac{4N}{10} + \frac{6}{10} \leq 8$

$\frac{13N}{10} + \frac{27}{10} \leq 8 \quad N \leq \frac{53}{13} \Rightarrow N \leq 4$

$CPI_{N=4} = \frac{52}{10} + \frac{27}{10}$

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4. (12pts; 3, 6, 3). **Dependencies and Pipeline Scheduling**

a)

PC:	Instruction
0x00440000	L0: lw $8, 0($4)
0x00440004	sll $8, $8, 3
0x00440008	lw $9, 0($5)
0x0044000c	add $8, $8, $9
0x00440010	lw $8, 0($8)
0x00440014	lw $9, 0($6)
0x00440018	B0: beq $9, $0, L1
0x0044001c	mul $9, $8, $9
0x00440020	sw $9, 0($6)
0x00440024	L1: addi $4, $4, 4
0x00440028	addi $5, $5, 4
0x0044002c	addi $6, $6, 4
0x00440030	B1: bne $6, $7, L0
0x00440034	jr $ra

Indicate all RAW register dependencies with an arrow from the produced register to each consumed operand, ignoring any dependencies between the current and subsequent iterations (i.e. all dependencies go from an instruction with a smaller PC to an instruction with a larger PC).

b) Given the same code, and assuming an FDEMW pipeline with branch resolution and hazard detection in D, and with all possible forwarding support, schedule the execution of the indicated instructions, assuming that neither B0 nor B1 are taken, and that both are mispredicted. Indicate stalls with lower case letters and completed stages with capitals. Assume that mul operates the same as other ALU operations. The flushes of the misfetched instructions have been given as "FL" in the cycle they were flushed.

CYCLE / INSTRUCTION	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
L0:lw $8, 0($4)	D	E	m	w														f	FL					
sll $8, $8, 3	F	d	D	E	M	w																		
lw $9, 0($5)		f	F	D	E	m	w																	
add $8, $8, $9				F	d	D	E	m	w															
lw $8, 0($8)					f	F	D	E	m	w														
lw $9, 0($6)							F	D	E	m	w													
B0:beq $9, $0, L1								F	d	d	D	E	m	w										
mul $9, $8, $9												F	D	E	m	w								
sw $9, 0($6)													F	D	E	m	w							
L1:addi $4, $4, 4									f	f	FL			F	D	E	m	w						
addi $5, $5, 4															F	D	E	m	w					
addi $6, $6, 4																F	D	E	m	w				
B1:bne $6, $7, L0																	F	d	D	E	m	w		
jr $ra																				F	D	E	m	W

c) draw arrows indicating all forwarding that occurred in the above schedule

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5. (8pts; 6, 1, 1) **Performance analysis**

Consider the following piece of code:

```
addi $s0, $a2, 4096     # initialize loop end condition
LOOP:                   #
lw $t0, 0($a0)          # load from source 1
lw $t1, 0($a1)          # load from source 2
add $t0, $t0, $t1       # sum loaded values
addi $a0, $a0, 4        # source 1 array pointer increment
addi $a1, $a1, 4        # source 2 array pointer increment
addi $a2, $a2, 4        # increment array pointer for destination array
sw $t0, -4($a2)         # store into destination array
bne $a2, $s0, LOOP      # check destination pointer against end condition
addi $v0, $0, 1024      # set return value to number of elements written
```

Assume a single cycle processor HAL with CT=800ps, a multicycle processor MENDICANTBIAS with CT = 100ps and timings {Branch:5, R-Type:5, Store:8, Load:9} cycles, and a pipelined FDEMW processor GLADOS with CT = 200ps.

Assume that the pipelined processor has branch resolution and hazard detection in D, full forwarding, and a 2-bit bimodal branch predictor that already has a BTB entry for the branch and an initial state T=11.

A) Assuming that the above code is the only measured execution, how long does it take for each of HAL, MENDICANTBIAS, and GLADOS to execute? **Assume that, for the pipelined processor, the 1st instruction is counted as taking 5 cycles to complete.** (Please note that, despite the naming convention, we are asking how much time it takes for the computer to execute the above code, not "how long would it take each AI to decide that you need to be executed?") Show work. You do not need to reduce expressions.

B) Set up the equation to find the CT at which MENDICANTBIAS would have the same performance as GLADOS. **Do not solve for CT.**

C) Rank GLADOS, MENDICANTBIAS and HAL from fastest to slowest in executing the given code.