Department of Electrical and Computer Engineering
The University of Texas at Austin

EE 360N, Spring 2007
Yale Patt, Instructor
Chang Joo Lee, Rustam Miftakhutdinov, Poorna Samanta, TAs
Final Exam, May 11, 2007

Name: SOLUTIONS

Problem 1 (30 points):_____

Problem 2 (10 points):_____

Problem 3 (10 points):_____

Problem 4 (15 points):_____

Problem 5 (20 points):_____

Problem 6 (20 points):_____

Problem 7 (20 points):_____

Total (125 points):_____

Note: Please be sure that your answers to all questions (and all supporting work that is required) are contained in the space provided.

Note: Please be sure your name is recorded on each sheet of the exam.

GOOD LUCK!

Name:_____

Problem 1 (30 points)

Part a (4 points): A RAM cell stores one bit of information. That storage is accomplished

in an SRAM cell by A pair of cross-coupled inverters

and in a DRAM cell by charge stored on a capacitor

Part b (5 points): Amdahl's Law says that the maximum speedup I can get on a multiprocessor for

an algorithm that is 95% vectorizable is 20.

To achieve that speedup, I need ∞ processors.

Part c (5 points): Recall that asynchronous I/O with central arbitration requires at least the following bus control signals:

BR_i, BG_i (for all priority levels i), $BBSY$, $SACK$, $MSYN$, $SSYN$

What signal does the PAU receive, indicating that a device controller has accepted being bus master for the next bus cycle?

SACK

What does the PAU do as a result of receiving this signal?

PAU de-asserts the BG signal

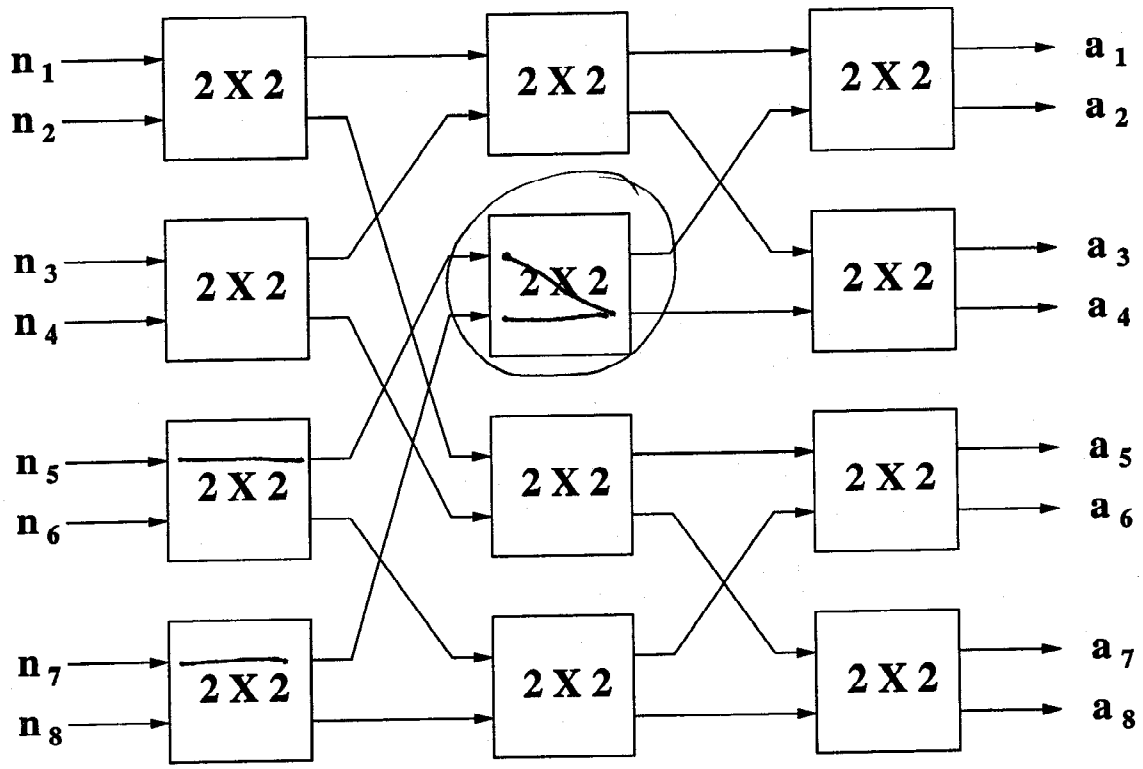
Name:_____

Problem 1 continued:

Part d (6 points): Recall that Omega networks are better than buses with respect to contention

and better than full crossbars with respect to cost.

Suppose n_5 wants to talk to a_3 and n_7 wants to talk to a_4 in the following Omega network in the same cycle. Can they do it? Show how by tracing the paths on the Omega network below, or explain why not in ten words or less in the box provided.



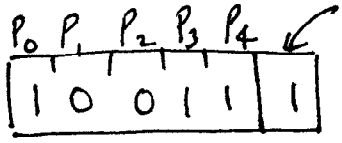
They cannot do it in the same cycle since they collide in the circled switch.

Name:_____

Problem 1 continued:

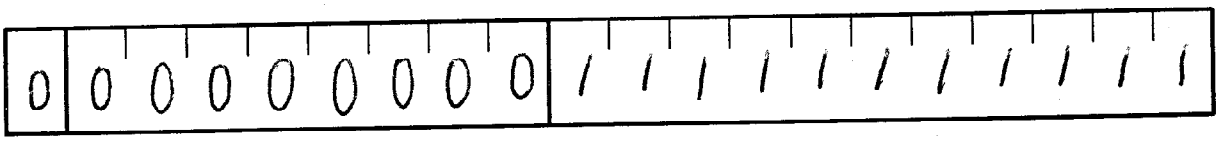
Part e (5 points): A Directory based Cache Coherency scheme has five processors, each with a private cache. Cache line X has directory information as follows: 100111. Processor 2 wants to read a value in this cache line, and takes a cache miss.

What can you tell me about the Cache Coherency logic? Please be specific.



The logic is faulty. The "private" bit can not be set AND more than one processor has the line in its cache.

Part f (5 points): Suppose a new floating point data type is invented, which follows all the insights of the IEEE Standard. The only difference is it has 11 fraction bits and 8 exponent bits. Show below the representation for the largest positive subnormal number, using this format.



Name:_____

Problem 2 (10 points):

We discussed multiplication as a sequence of shifts/adds in EE 316. We extended it to Booth's algorithm (2 bits per iteration) in class. Now, on the exam, we wish to extend it to 3 bits per iteration.

A truth table to describe the combinational logic needed would consist of 4 inputs and 4 outputs. The 4 inputs are the 3 bits of the multiplier and the input borrow bit. The 4 outputs are a left shift of the multiplicand by k_1 bits, an Add or Subtract signal, a subsequent left shift of the multiplicand by k_2 bits, and the output borrow bit.

For the case where the 3 bits of the multiplier are **110** and the input borrow bit is **0**, specify the 4 outputs listed below.

1. Left shift the multiplicand [1] bits to the left.

2. Perform the operation of **Add / Subtract** (circle one) in the ALU.

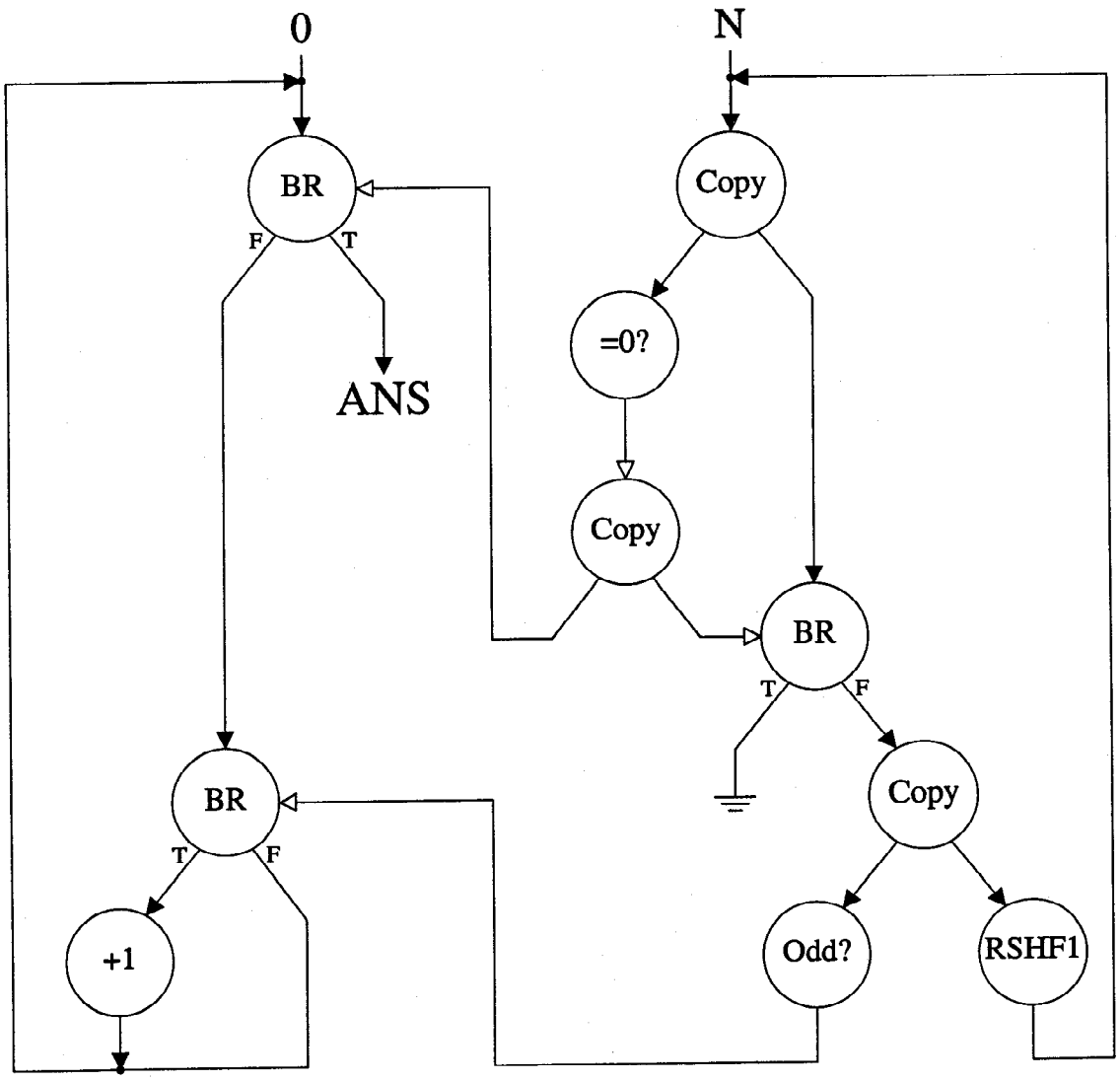
3. Left shift the multiplicand [2] bits to the left.

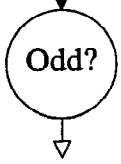
4. Set the Borrow bit to **0 / 1** (circle one).

Name:_____

Problem 3 (10 points)

Consider the following data flow graph:



Note that node  outputs True if its input is odd and False if its input is even.

What does the data flow graph above do?

Answer: Counts the number of ones in the binary representation of N.

Name:_____

Problem 4 (15 points):

An array A consists of 1536 one-byte elements, stored in 1536 consecutive locations of memory, starting at address x4000. (Hint : 1536 = 1024 + 512)

A programmer wishes to add 10 to every 8th element, but does so by the very curious method of adding 1 to every 8th element, and then iterating that process ten times. The C program segment looks like this:

```
for ( i = 0; i < 10; i++ )
{
     for ( index = 0; index < 1536; index = index + 8 )
            A[index] = A[index] + 1;
}
```

Assume that the compiler allocates registers for the loop variables i and index. The processor has a 1 KB, 2-way set associative cache. You may assume that the cache is initially empty. You may leave the answers for the following questions as fractions. Please show your work.

Part a (5 points): For a cache line size of 16 bytes, calculate the miss ratio if the perfect LRU replacement policy is used.

No. of misses per iteration $= \frac{1536}{16}$

Miss ratio: $\frac{\frac{1536}{16} \times 10}{\frac{1536 \times 2 \times 10}{8}} = \frac{1}{4}$

Part b (10 points): Suppose the cache line is 4 bytes. All other parameters remain the same. Circle the replacement policy which would give the least number of misses. Also, calculate the miss ratio for your chosen replacement policy.

FIFO (First In First Out) (LIFO (Last In First Out)) LRU

3 points

For first iteration, no. of misses $= \frac{1536}{8} = 192$

For the other 9 iterations,
no. of misses per iteration $= \frac{1024}{8} = 128$

Miss ratio: $\frac{192 + 128 \times 9}{\frac{1536 \times 2 \times 10}{8}} = \frac{7}{20}$

7 points

Name:_____

Problem 5 (20 points)

An in-order vector processor with 11 cycle memory latency, 16-way interleaved memory and 8 vector registers of length 64 is used to execute the vector code resulting from compiling the following high-level language program segment:

```
for ( i = 0; i < 40; i = i + 2 )
{
        C[i]= A[i] + B[i];
        C[i+1] = A[i+1];
}
```

Part a (5 points): Shown below is the vector code produce by the compiler with some information missing. Your job is to fill in the missing information.

```
MOVI VLEN,  # 20        1 point
MOVI VSTR,  # 2         1 point
VLD  V0, A
VLD  V1, B
VADD V2, V0, V1
VLD V3, A+1             1 point
VST V2, C               1 point
VST V3, C+1             1 point
```

You have available the following vector instructions:

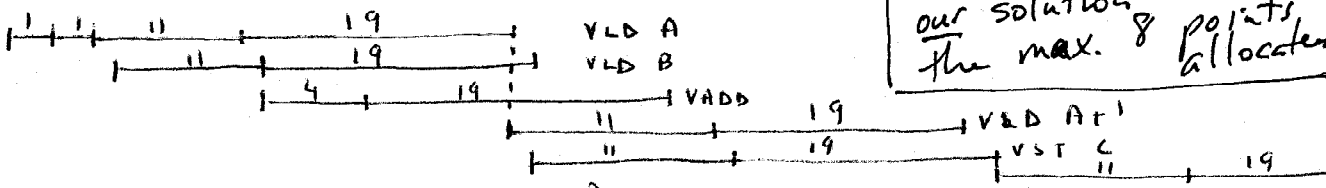
```
MOVI VLEN, #n        ; (1 cycle)
MOVI VSTR, #n        ; (1 cycle)
VADD Vi, Vj, Vk      ; Vi is dest, Vj, Vk are sources (4 staged pipelined adder)
VLD  Vi, A + k       ; Vi gets loaded with contents of memory, starting at A + k
VST  Vi, A + k       ; Contents of Vi gets stored in memory, starting at A + k
```

Name:_____

Problem 5 continued:

Note: Our solution was not optimal. About one dozen students came up with a solution better than ours. They received 10 points on Part c. Those who came up with our solution received the max. 8 points, allocated

Part b (7 points): How many cycles does it take the vector code to execute? Assume that the memory has 2 load ports and 1 store port and the vector processor supports vector chaining. Please show your work.



cycles = 2 + (11+19) + (11+19) + 1 + (11+19)

= 2 + 30 + 30 + 1 + 30 = 93

Answer: 93 Cycles

Part c (8 points): A simple reordering of the instructions will result in improved execution time. Show the new order below which results in **minimal** execution time. How many cycles does the new order take? Please show your work.

4 points

MOVI VLEN, # 20

MOVI VSTR, # 2

VLD V3, A+1

VST V3, C+1

VLD V0, A

VLD V1, B

VADD V2, V0, V1

VST V2, C

+2 Extra credit for solution on the left.

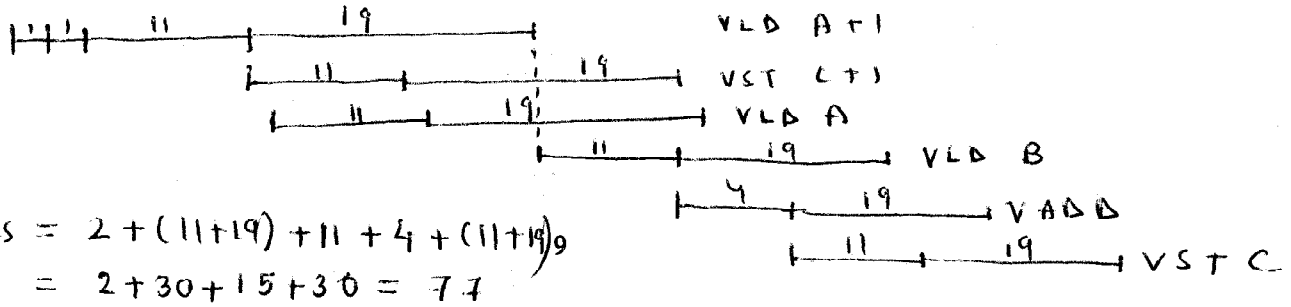
The solution below has also been given credit.

```
MOVI VLEN, # 20
MOVI VSTR, # 2
VLD V0, A
VLD V1, B
VADD V2, V0, V1
VST V2, C
VLD V3, A+1
VST V3, C+1
```

Cycles: 78

Answer: 77 Cycles

4 points



cycles = 2 + (11+19) + 11 + 4 + (11+19)

= 2 + 30 + 15 + 30 = 77

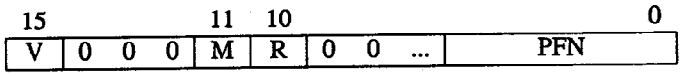
Name:_____

Problem 6 (20 points)

Consider the following **two-level** virtual memory system for the LC-3b. Recall that the user page table is located in the system virtual space:

Virtual Address Space:	64KB	Number of Page Frames:	32
User Space Range:	x0000 to x7FFF	Page Size:	256 bytes
System Space Range:	x8000 to xFFFF	Page Table Entry Size:	2 bytes

The system **does not** include a Translation Lookaside Buffer and a cache. Each Page Table Entry (PTE) contains valid (V), Modified (M), Reference (R) bits and Page Frame Number(PFN). The PTE format is as follows:



Part a (2 points): How many bits are needed for the address bus to the physical memory? Show the computation.

$2^5 \times 2^8 = 2^{13}$ **Answer:** 13

Part b (18 points): The machine stopped at a breakpoint and the following state information was observed:

PC	SBR	UBR	R0	R1	R2	R3	R4	R5	R6	R7
x3010	x0000	xA000	x1234	x5000	x4000	x1000	x4233	x1299	xFEBC	xABCD

Note: SBR is the System Page Table Base Register and UBR is the User Page Table Base Register. Each points to the first entry of the corresponding page table.

After execution resumed, the machine issued the following successive seven physical memory requests, uninterrupted by any page faults, access control violations, or anything else. Note that each entry is incomplete. Your job: complete the seven entries.

Access #	PA	Access	Data	Identity of Item Being Accessed
1	x0040	Read	x8C18	PTE for System Page x20
2	x1860	Read	x8410	PTE for User Page x30
3	x1010	Read	x7E82	The instruction STW R7, R2, #2
4	x0040	Read	x8C18	PTE for System Page x20
5	x1880	Read	x8008	PTE for User Page x40
6	x1880	Write	x8C08	PTE for User Page x40. Set M and R bits
7	x0804	Write	xABCD	Data stored by the STW instruction.

Note: The last column should identify what is being read specifically. For example: "The instruction LDB R0,R1,#0," "The PTE for User Virtual Page 0," "PTE for System Virtual Page 0," etc.

Name:_____

Problem 7 (20 points)

We are designing a 42-bit floating point format similar to the IEEE standard discussed in class. We have decided on the sizes of the exponent and fraction fields as shown below:

S	Exponent	Fraction
1	10	31

However, we have not yet decided on the bias of the exponent. Please use *N* for the bias in your answers to parts a, b, and c below.

Part a (5 points): What is the **smallest positive** number represented by this format (*Min*)?

0, 00000..., 00...0001

$$Min = \boxed{2^{-31}} \times 2^{\boxed{1-N}}$$

Part b (5 points): What is the **largest positive finite** number represented by this format (*Max*)?

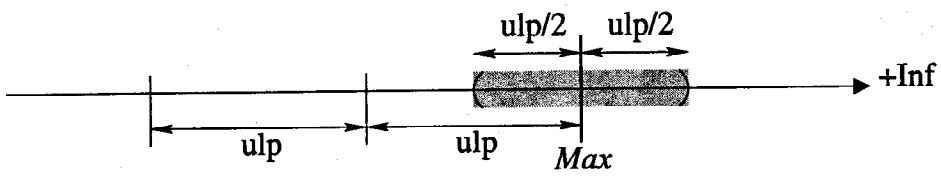
0, 11...10, 11111...11

$$Max = \boxed{(2 - 2^{31})} \times 2^{\boxed{1022-N}}$$

Name:_____

Problem 7 continued:

Part c (5 points): In class, we defined the range of real values rounded to *Min* if the **round to nearest** rounding mode is used. The shaded range in the figure below represents the real values rounded to *Max*. Any number to the right of that range is rounded to positive infinity.



We want to choose the bias (N) so that for any positive finite number x represented exactly by our floating point format, its reciprocal ($1/x$) can also be represented (after rounding to nearest) as a positive finite number.

(1) That means $\frac{1}{Min}$ must be less than $(2-2^{32}) \times 2^{1022-N}$ $(Max + \frac{ULP}{2})$

(2) and, $\frac{1}{Max}$ must be greater than $2^{-32} \times 2^{1-N}$ $(Min - \frac{ULP}{2})$

Part d (5 points): Compute the bias that will allow the results in part c to hold. NOTE: In part c you have created two inequalities in N. Solve those 2 inequalities.

(1) $\frac{1}{2^{-31} \times 2^{1-N}} < (2-2^{-32}) \times 2^{1022-N} \Rightarrow 2^{N+30} < (1-2^{-33}) \times 2^{1023-N}$

$\Rightarrow 2^{N+30} < 2^{1023-N}$ (N is integer)

(2) $2^{-32} \times 2^{1-N} < \frac{1}{(2-2^{-31}) \times 2^{1022-N}} \Rightarrow 2^{N+31} > (1-2^{-32}) \times 2^{1023-N}$

$\Rightarrow 2^{N+31} \geq 2^{1023-N}$ (N is integer)

$\Rightarrow 2^{N+30} < 2^{1023-N} \leq 2^{N+31}$

$\Rightarrow 2^{1023-N} = 2^{N+31}$

$\Rightarrow 1023 - N = N + 31$

$\Rightarrow 2N = 992 \Rightarrow N = 496$

Answer: 496