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

EE 306, Fall 2017
Yale Patt, Instructor
Stephen Pruett, Siavash Zangeneh, Aniket Deshmukh, Zachary Susskind, Meiling Tang, Jiahan Liu
Exam 2, November 15, 2015

Name:__________________________

Problem 1 (20 points):_______

Problem 2 (20 points):_______

Problem 3 (20 points):_______

Problem 4 (20 points):_______

Problem 5 (20 points):_______

Total (100 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.

I will not cheat on this exam.

____
Signature

GOOD LUCK!

Name:____

Problem 1. (20 points):

Part a. (5 points): Construct the symbol table for the following LC-3 assembly language program:

Symbol Table:

Symbol	Address

```
        .ORIG x4500
        LD    R2,BOBO
        LD    R3,SAM
AGAIN   ADD   R3,R3,R2
        ADD   R2,R2,#-1
        BRnzp SAM
BOBO    .STRINGZ "Why are you asking me this?"
SAM     BRnp  AGAIN
        TRAP  x25
        .BLKW 5
JOE     .FILL x7777
        .END
```

Part b. (5 points): A stack machine executes the following 6 instructions:

```
Push 5
Push 4
ADD
Push 6
MUL
POP
```

What value is popped by the last instruction? [ ]

Assume the stack is empty, with R6 = xFE00. Before the stack machine executes "Push 5", the contents of memory locations xFDFA to xFDFF are shown. Show the contents of memory and R6 after the six operations above are executed.

Address	**Before**	**After**
xFDFA	x0000	
xFDFB	x0000	
xFDFC	x0000	
xFDFD	x0000	
xFDFE	x0000	
xFDFF	x0000	

R6: [ ]

Name:____

Part c. (5 points): We want to move a number from A to B. List all LC-3 opcodes that can be used to accomplish this in one instruction when A,B are as specified at the top of each column. We have provided four slots for each column. Use as many as you need.

A is memory location B is a register R0-R7	A is a register R0-R7 B is a register R0-R7	A is a register R0-R7 B is memory location	A is memory location B is memory location

Part d. (5 points): What is wrong with the following program fragment?

```
          ...
          ...
        LD R0, A
SPIN    LDI R1,KBSR
        BRzp SPIN
        STI R0,KBDR
          ...
          ...
        RET
KBSR    .FILL xFE00
KBDR    .FILL xFE02
A       .FILL x0041
          ...
          ...
```

Name:____

Problem 2. (20 points): Since ASCII codes consist of 8 bits each, we can store two ASCII codes in one word of LC-3 memory. If a user types 2n characters on the keyboard, followed by the <ENTER>key, the subroutine PACK on the next page will store the corresponding ASCII codes into n sequential memory locations, two per memory location, starting at location A.

You may assume that a user never enters an odd number of characters.

Part a. (15 points): Your job: Fill in the blanks in the program.

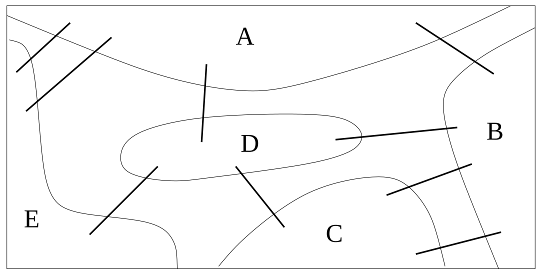
Part b. (5 points): If a user types the string **Please help!** followed by the <ENTER> key, what does the program do?

Name:____

```
         .ORIG x7020
PACK     ST R7, SAVER7
         ST R6, SAVER6
         ST R4, SAVER4
         ST R3, SAVER3
         LEA R6, A      ; R6 is the pointer
         AND R4, R4, #0
         ADD R4, R4, #8 ; R4 is our counter
         AND R3, R3, #0
         LEA R0, PROMPT
         TRAP x22
POLL     
         BRzp POLL
         
         LD R0, NEG_LF
         ADD R0, R7, R0
         
         ADD R4, R4, #0
         BRz NOSHIFT
SHIFT    ADD R7, R7, R7
         ADD R4, R4, #-1
         BRp SHIFT
         ADD R3, R7, #0
         BRnzp POLL
NOSHIFT  ADD R3, R3, R7
         
         ADD R6, R6, #1
         ADD R4, R4, #8
         BRnzp POLL
DONE     LD R7, SAVER7
         LD R6, SAVER6
         LD R4, SAVER4
         LD R3, SAVER3
         LEA R0, A     ; Returns a pointer to the characters
         RET
KBSR     .FILL xFE00
KBDR     .FILL xFE02
NEG_LF   .FILL xFFF6
PROMPT   .STINGZ "Please enter a string: "
A        .BLKW #5
SAVER7   .BLKW #1
SAVER6   .BLKW #1
SAVER4   .BLKW #1
SAVER3   .BLKW #1
         .END
```

Name:____

Problem 3. (20 points): Many cities, like New York City, Stockholm, Konigsberg, etc. consist of several areas, connected by bridges. The figure below shows a map of FiveParts, a city made up of five areas A,B,C,D,E, with the areas connected by 9 bridges as shown.



The following program prompts the user to enter two areas, and then stores the number of bridges from the first area to the second in location x4500. Your job: On the next page, design the data structure for the city of FiveParts that the program below will use to count the number of bridges between two areas.

```
             .ORIG x3000
             LEA R0, FROM
             TRAP x22
             TRAP x20       ; Inputs a char without banner
             NOT R1, R0
             ADD R1, R1, #1
             LEA R0, TO
             TRAP x22
             TRAP x20
             NOT R0, R0
             ADD R0, R0, #1
             AND R5, R5, #0
             LDI R2, HEAD
SEARCH       BRz DONE
             LDR R3, R2, #0
             ADD R7, R1, R3
             BRz FOUND_FROM
             LDR R2, R2, #1
             BRnzp SEARCH
FOUND_FROM   ADD R2, R2, #2
NEXT_BRIDGE  LDR R3, R2, #0
             BRz DONE
             LDR R4, R3, #0
             ADD R7, R0, R4
             BRnp SKIP
             ADD R5, R5, #1  ; Increment Counter
SKIP         ADD R2, R2, #1
             BRnzp NEXT_BRIDGE
DONE         STI R5, ANSWER
             HALT
HEAD         .FILL x3050
ANSWER       .FILL x4500
FROM         .STRINGZ "FROM: "
TO           .STRINGZ "TO: "
             .END
```

Name:____

Your job is to provide the contents of the memory locations that are needed to specify the data structure for the city of FiveParts, which is needed by the program on the previous page. We have given you the HEAD pointer for the data structure and in addition, five memory locations and the contents of those five locations. We have also supplied more than enough sequential memory locations after each of the five to enable you to finish the job. Use as many of these memory locations as you need.

x4000	x0041
x4001	
x4002	
x4003	
x4004	
x4005	
x4006	

x3050	

xA243	x0042
xA244	
xA245	
xA246	
xA247	
xA248	
xA249	

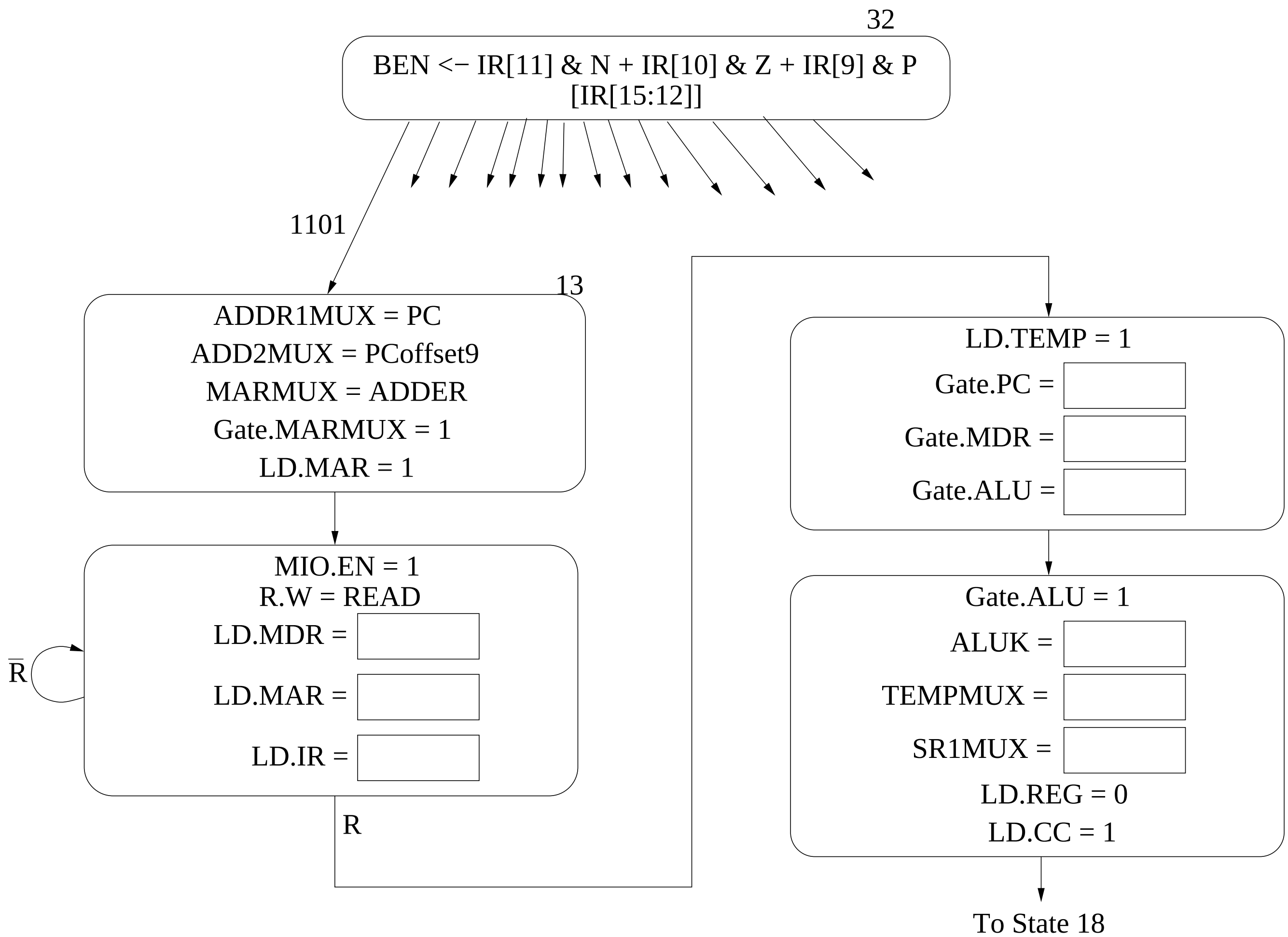
x4100	x0043
x4101	
x4102	
x4103	
x4104	
x4105	
x4106	

xBBBB	x0044
xBBBC	
xBBBD	
xBBBE	
xBBBF	
xBBC0	
xBBC1	

x3100	x0045
x3101	
x3102	
x3103	
x3104	
x3105	
x3106	

Name:____

Problem 4. (20 points): We wish to use the unused opcode 1101 to add a new instruction to the LC-3 ISA. This requires four new states in the state machine (shown below) and additions to the data path (shown on the next page).



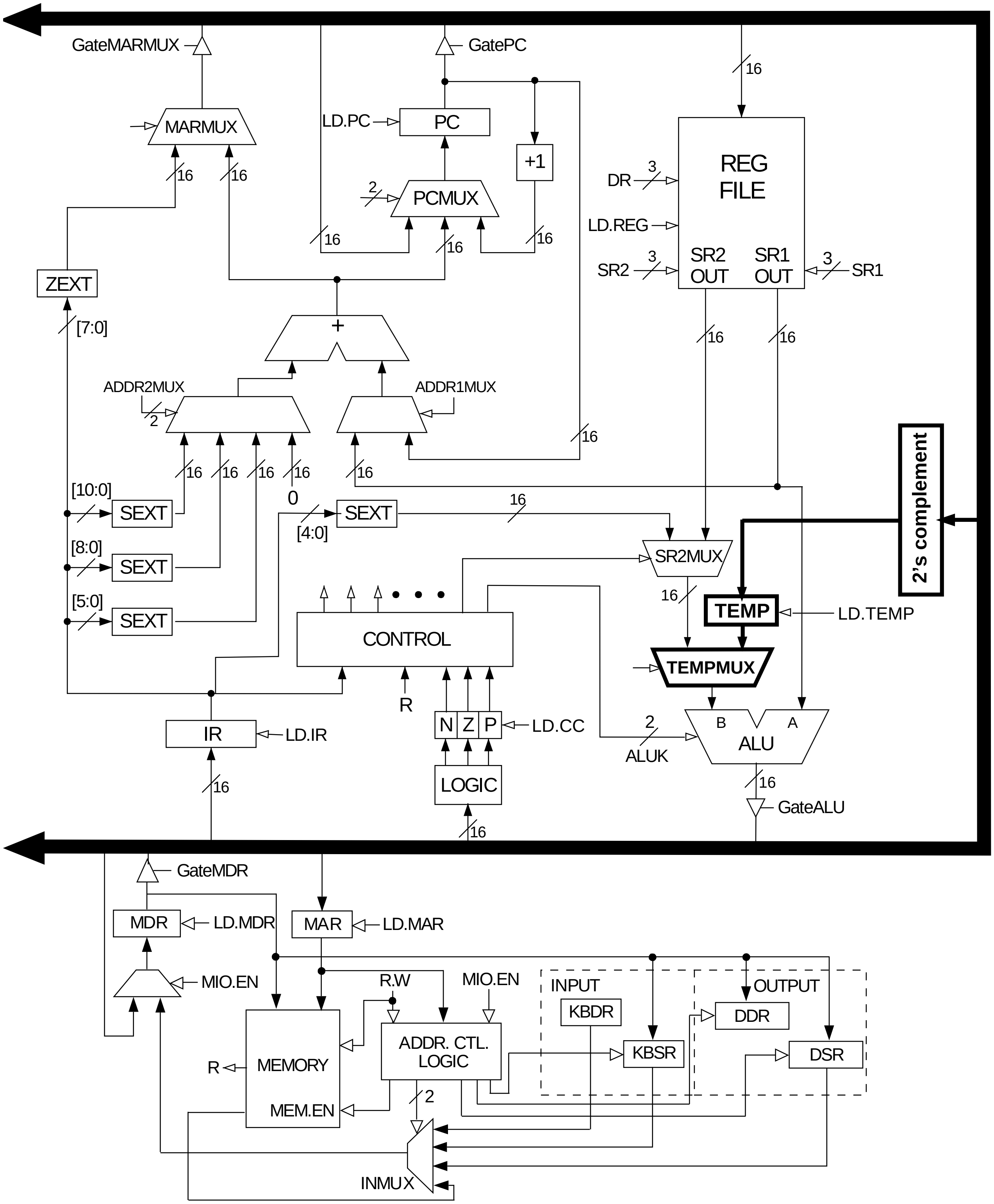
Part a. (5 points): Fill in the missing information in the four states. You can assume all control signals not shown are 0. A table of relevant control signals is included in your exam packet.

Part b. (10 points): What does the new instruction do (in 15 words or fewer)?

Part c. (5 points): Identify the fields of the new instruction. Be sure you indicate clearly the correct bits for each field.

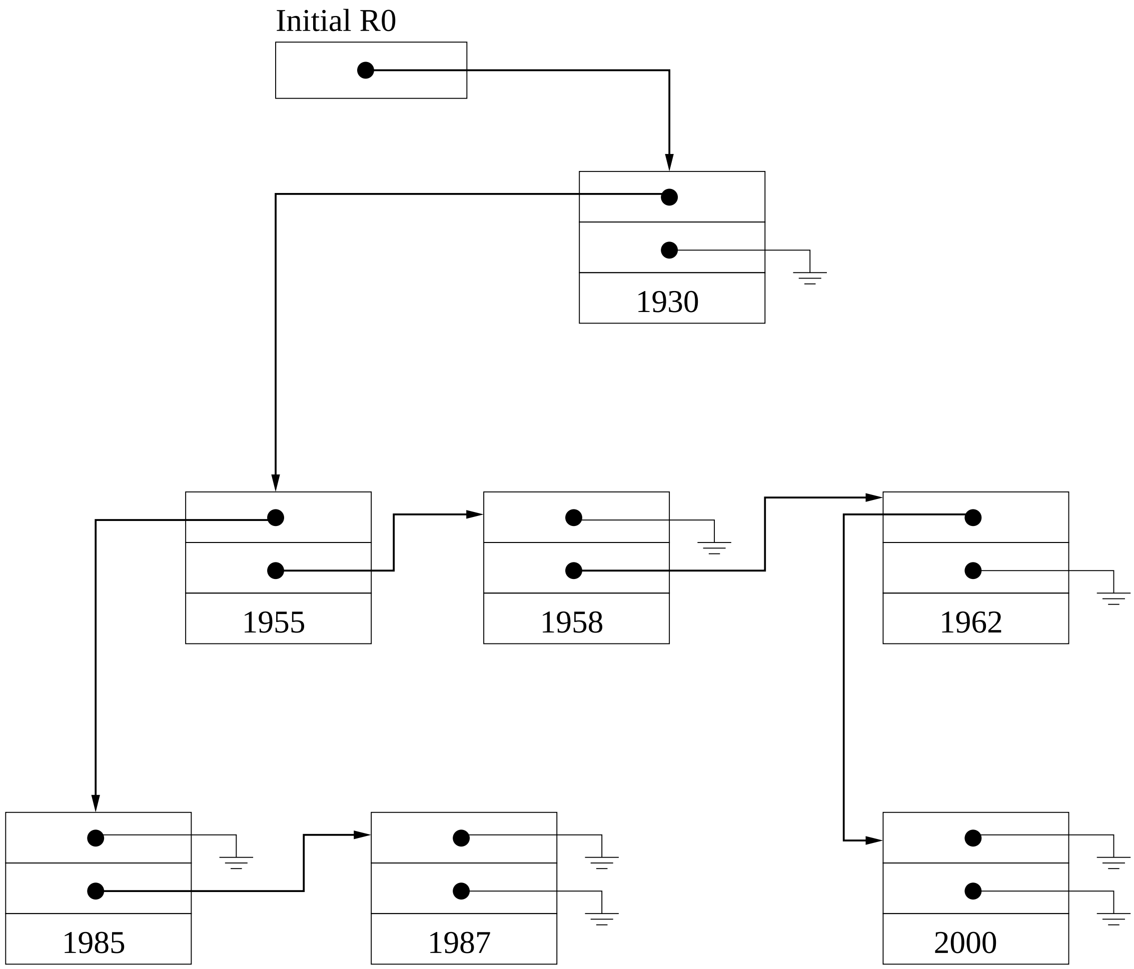
15–12	11	10	9	8	7	6	5	4	3	2	1	0
1101												

Name:____


GateMARMUX
GatePC
MARMUX
LD.PC
PC
16
+1
REG
FILE
DR
3
LD.REG
SR2
SR2
OUT
SR1
OUT
SR1
PCMUX
2
ZEXT
[7:0]
+
ADDR2MUX
ADDR1MUX
[10:0]
SEXT
[8:0]
SEXT
[5:0]
SEXT
0
[4:0]
SEXT
SR2MUX
2's complement
TEMP
LD.TEMP
TEMPMUX
CONTROL
R
IR
LD.IR
N
Z
P
LD.CC
LOGIC
ALUK
B
A
ALU
GateALU
GateMDR
MDR
LD.MDR
MAR
LD.MAR
MIO.EN
R.W
MIO.EN
INPUT
KBDR
OUTPUT
DDR
KBSR
DSR
MEMORY
MEM.EN
ADDR. CTL.
LOGIC
INMUX

Name:____________________________________

Problem 5. (20 points): Information about members of an extended family is stored in a tree. The first two words in each node are pointers to the oldest child and the next younger sibling. That is, the children of a parent are ordered according to age. We use the 3rd word in each node to represent the year the person was born.



Name:____

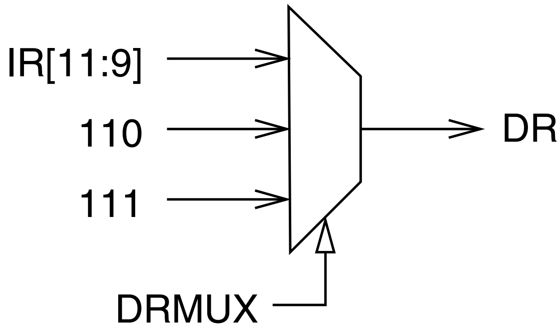
Part a. (15 points): The following recursive subroutine counts the number of family members who are born before 1960. R0 is a pointer to the root of a tree. R1 is the output count. Assume the main program initializes R1 to 0 and R6 to the stack pointer before calling the subroutine. The stack does not overflow during the execution of the subroutine. Fill in the missing instructions.

```
          .ORIG x4000
COUNT     ADD R6, R6, #-1
          [                    ]
          ADD R6, R6, #-1
          [                    ]
          ADD R0, R0, #0
          [                    ]
          [                    ]
          LD R7, NEG_VALUE
          ADD R7, R2, R7
          BRzp SKIP
          ADD R1, R1, #1
SKIP      ADD R2, R0, #0
          LDR R0, R2, #0
          [                    ]
          [                    ]
          [                    ]
          ADD R0, R2, #0
RESTORE   [                    ]
          ADD R6, R6, #1
          [                    ]
          ADD R6, R6, #1
          RET
NEG_VALUE .FILL #-1960
```

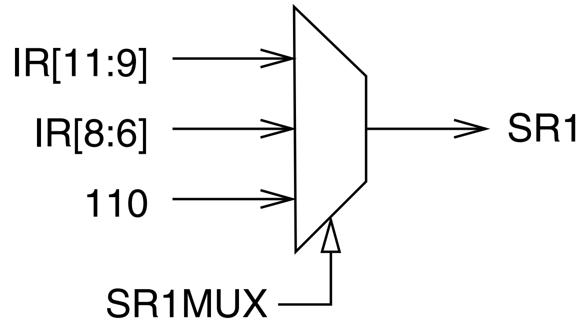
Part b. (5 points): Can we speed up the subroutine by eliminating visits to unnecessary nodes in the tree? How (in 20 words or fewer)?

Data Path Control Signals

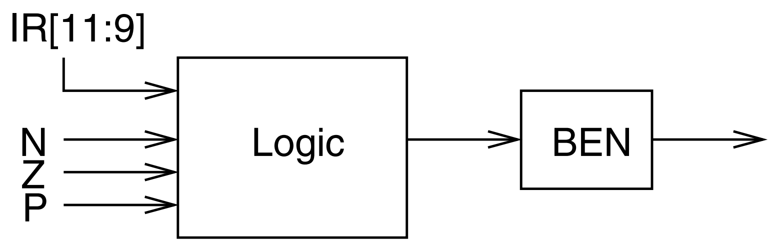
Signal Name	Signal Values
LD.MAR/1:	NO(0), LOAD(1)
LD.MDR/1:	NO(0), LOAD(1)
LD.IR/1:	NO(0), LOAD(1)
LD.REG/1:	NO(0), LOAD(1)
LD.CC/1:	NO(0), LOAD(1)
LD.TEMP/1:	**NO(0), LOAD(1)**
Gate.MARMUX/1:	NO(0), YES(1)
Gate.MDR/1:	NO(0), YES(1)
Gate.PC/1:	NO(0), YES(1)
Gate.ALU/1:	NO(0), YES(1)
ADDR1MUX/1:	PC(0), BaseR(1)
ADDR2MUX/2:	ZERO(00), offset6(01), PCoffset9(10), PCoffset11(11)
MARMUX/1:	IR7.0(0), ADDER(1)
SR1MUX/2:	11.9(00), 8.6(01), SP(10)
TEMPMUX/1:	**OP2(0), TEMP(1)**
ALUK/2:	ADD(00), AND(01), NOT(10), PASSA(11)
MIO.EN/1:	NO(0), YES(1)
R.W/1:	RD(0), WR(1)


IR[11:9]
110
111
DR
DRMUX

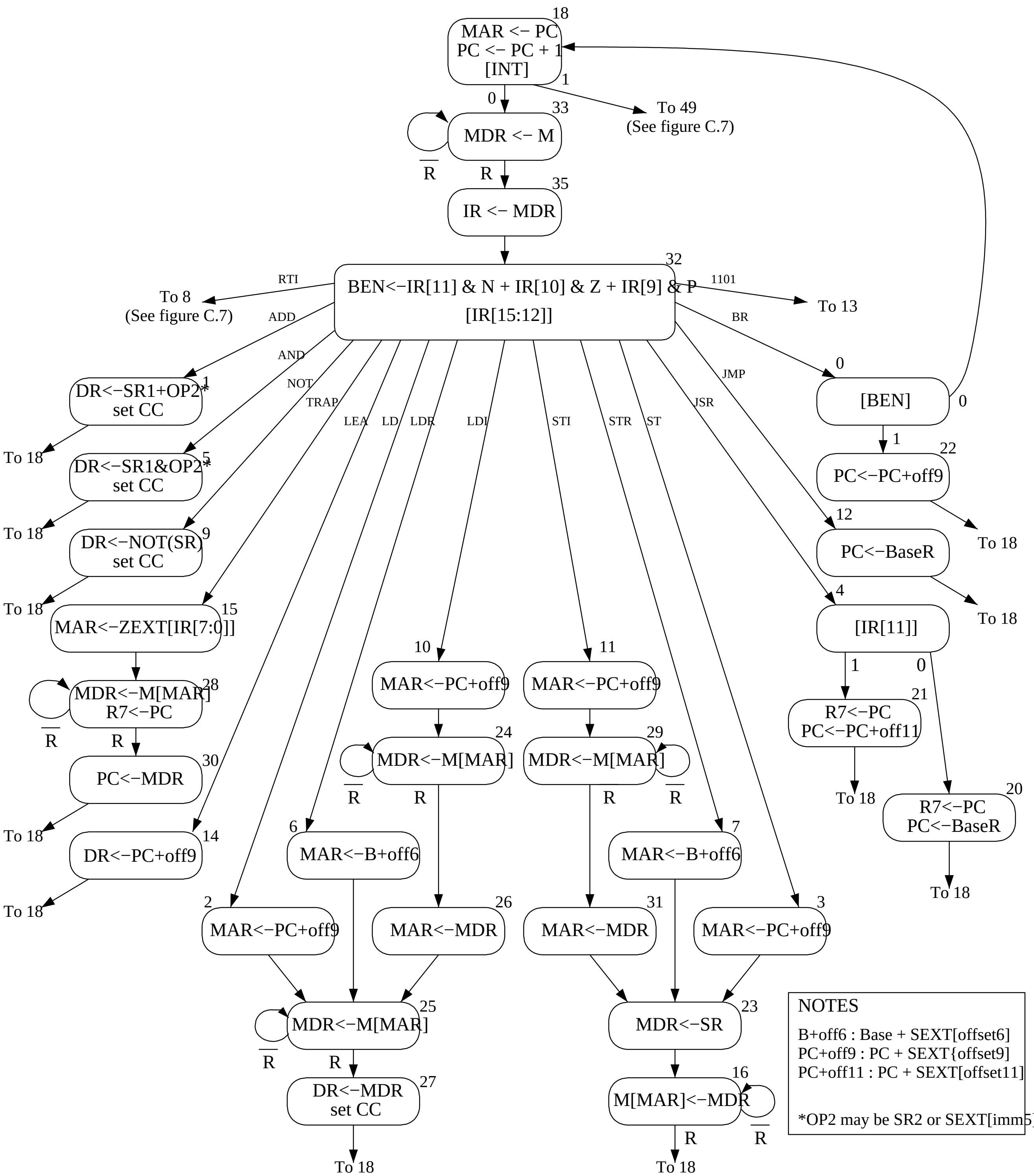
(a)


IR[11:9]
IR[8:6]
110
SR1
SR1MUX

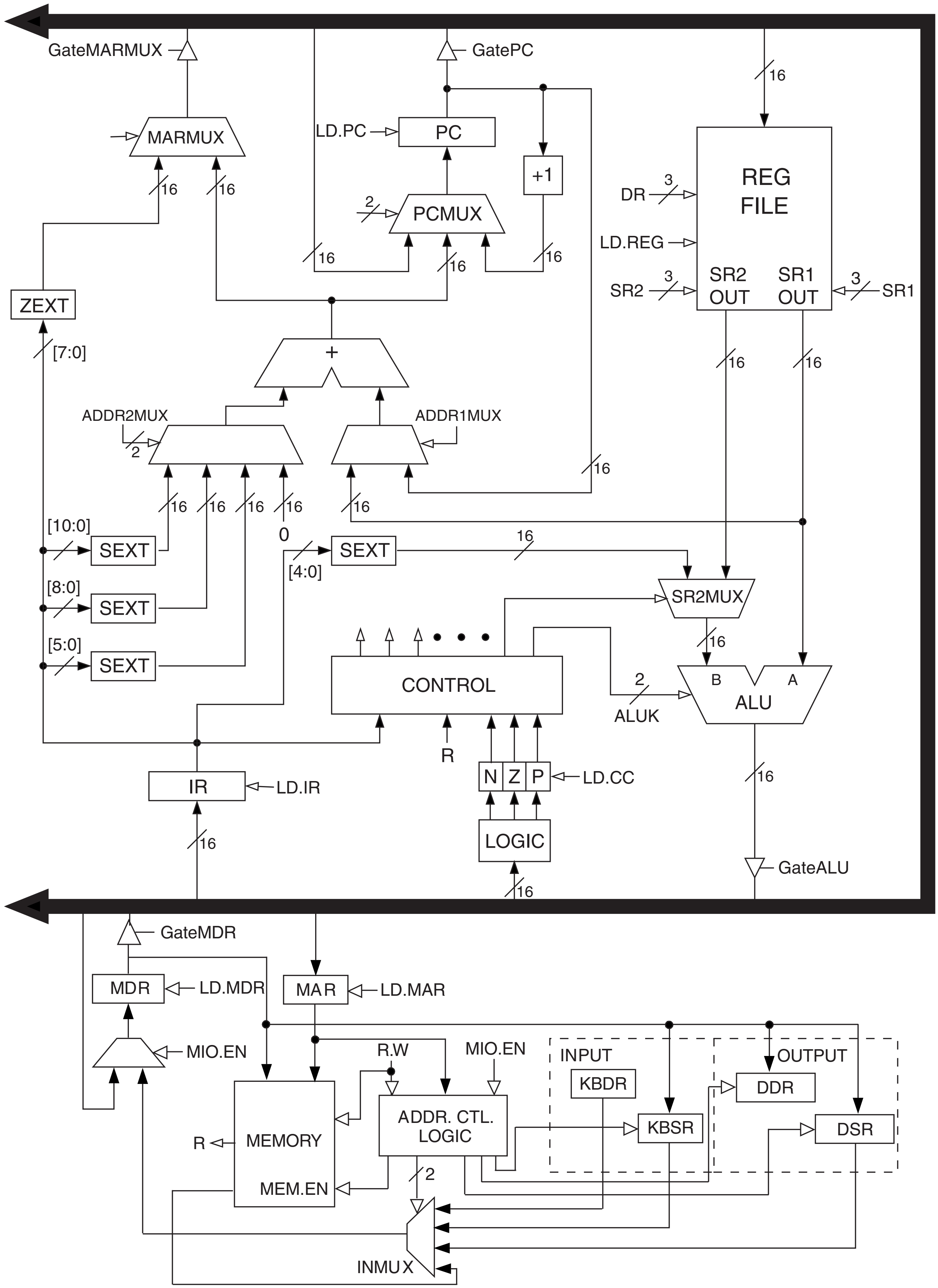
(b)


IR[11:9]
N
Z
P
Logic
BEN

(c)



18
MAR <− PC
PC <− PC + 1
[INT]
1
To 49
(See figure C.7)
0
33
MDR <− M
R
R
35
IR <− MDR
32
BEN<−IR[11] & N + IR[10] & Z + IR[9] & P
[IR[15:12]]
RTI
To 8
(See figure C.7)
1101
To 13
ADD
AND
NOT
TRAP
LEA
LD
LDR
LDI
STI
STR
ST
JSR
JMP
BR
0
[BEN]
0
1
1
DR<−SR1+OP2*
set CC
To 18
5
DR<−SR1&OP2*
set CC
To 18
9
DR<−NOT(SR)
set CC
To 18
15
MAR<−ZEXT[IR[7:0]]
28
MDR<−M[MAR]
R7<−PC
R
R
30
PC<−MDR
To 18
14
DR<−PC+off9
To 18
22
PC<−PC+off9
To 18
12
PC<−BaseR
To 18
4
[IR[11]]
1
0
21
R7<−PC
PC<−PC+off11
To 18
20
R7<−PC
PC<−BaseR
To 18
10
MAR<−PC+off9
11
MAR<−PC+off9
24
MDR<−M[MAR]
R
R
29
MDR<−M[MAR]
R
R
6
MAR<−B+off6
7
MAR<−B+off6
2
MAR<−PC+off9
26
MAR<−MDR
31
MAR<−MDR
3
MAR<−PC+off9
25
MDR<−M[MAR]
R
R
23
MDR<−SR
27
DR<−MDR
set CC
To 18
16
M[MAR]<−MDR
R
R
To 18
NOTES
B+off6 : Base + SEXT[offset6]
PC+off9 : PC + SEXT{offset9]
PC+off11 : PC + SEXT[offset11]
*OP2 may be SR2 or SEXT[imm5]


GateMARMUX
GatePC
16
MARMUX
LD.PC
PC
+1
REG
FILE
DR
3
16
2
PCMUX
LD.REG
ZEXT
SR2
SR1
SR2
OUT
SR1
OUT
[7:0]
+
ADDR2MUX
ADDR1MUX
[10:0]
SEXT
0
[4:0]
[8:0]
[5:0]
SR2MUX
CONTROL
B
A
ALU
ALUK
R
IR
LD.IR
N
Z
P
LD.CC
LOGIC
GateALU
GateMDR
MDR
LD.MDR
MAR
LD.MAR
MIO.EN
R.W
INPUT
OUTPUT
KBDR
DDR
MEMORY
ADDR. CTL.
LOGIC
KBSR
DSR
MEM.EN
INMUX

	15 14 13 12	11 10 9	8 7 6	5	4 3	2 1 0
ADD+	0001	DR	SR1	0	00	SR2
ADD+	0001	DR	SR1	1	imm5	
AND+	0101	DR	SR1	0	00	SR2
AND+	0101	DR	SR1	1	imm5	
BR	0000	n z p	PCoffset9			
JMP	1100	000	BaseR	000000		
JSR	0100	1 PCoffset11				
JSRR	0100	0 00	BaseR	000000		
LD+	0010	DR	PCoffset9			
LDI+	1010	DR	PCoffset9			
LDR+	0110	DR	BaseR	offset6		
LEA	1110	DR	PCoffset9			
NOT+	1001	DR	SR	111111		
RET	1100	000	111	000000		
RTI	1000	000000000000				
ST	0011	SR	PCoffset9			
STI	1011	SR	PCoffset9			
STR	0111	SR	BaseR	offset6		
TRAP	1111	0000	trapvect8			
reserved	1101					

Figure A.2 Format of the entire LC-3 instruction set. **Note:** + indicates instructions that modify condition codes

The Standard ASCII Table

ASCII			ASCII			ASCII			ASCII		
Character	Dec	Hex	Character	Dec	Hex	Character	Dec	Hex	Character	Dec	Hex
nul	0	00	sp	32	20	@	64	40	`	96	60
soh	1	01	!	33	21	A	65	41	a	97	61
stx	2	02	"	34	22	B	66	42	b	98	62
etx	3	03	#	35	23	C	67	43	c	99	63
eot	4	04	$	36	24	D	68	44	d	100	64
enq	5	05	%	37	25	E	69	45	e	101	65
ack	6	06	&	38	26	F	70	46	f	102	66
bel	7	07	'	39	27	G	71	47	g	103	67
bs	8	08	(	40	28	H	72	48	h	104	68
ht	9	09	)	41	29	I	73	49	i	105	69
lf	10	0A	*	42	2A	J	74	4A	j	106	6A
vt	11	0B	+	43	2B	K	75	4B	k	107	6B
ff	12	0C	,	44	2C	L	76	4C	l	108	6C
cr	13	0D	-	45	2D	M	77	4D	m	109	6D
so	14	0E	.	46	2E	N	78	4E	n	110	6E
si	15	0F	/	47	2F	O	79	4F	o	111	6F
dle	16	10	0	48	30	P	80	50	p	112	70
dc1	17	11	1	49	31	Q	81	51	q	113	71
dc2	18	12	2	50	32	R	82	52	r	114	72
dc3	19	13	3	51	33	S	83	53	s	115	73
dc4	20	14	4	52	34	T	84	54	t	116	74
nak	21	15	5	53	35	U	85	55	u	117	75
syn	22	16	6	54	36	V	86	56	v	118	76
etb	23	17	7	55	37	W	87	57	w	119	77
can	24	18	8	56	38	X	88	58	x	120	78
em	25	19	9	57	39	Y	89	59	y	121	79
sub	26	1A	:	58	3A	Z	90	5A	z	122	7A
esc	27	1B	;	59	3B	[	91	5B	{	123	7B
fs	28	1C	<	60	3C	\	92	5C	|	124	7C
gs	29	1D	=	61	3D	]	93	5D	}	125	7D
rs	30	1E	>	62	3E	^	94	5E	~	126	7E
us	31	1F	?	63	3F	_	95	5F	del	127	7F

Table A.2 Trap Service Routines

Trap Vector	Assembler Name	Description
x20	GETC	Read a single character from the keyboard. The character is not echoed onto the console. Its ASCII code is copied into R0. The high eight bits of R0 are cleared.
x21	OUT	Write a character in R0[7:0] to the console display.
x22	PUTS	Write a string of ASCII characters to the console display. The characters are contained in consecutive memory locations, one character per memory location, starting with the address specified in R0. Writing terminates with the occurrence of x0000 in a memory location.
x23	IN	Print a prompt on the screen and read a single character from the keyboard. The character is echoed onto the console monitor, and its ASCII code is copied into R0. The high eight bits of R0 are cleared.
x24	PUTSP	Write a string of ASCII characters to the console. The characters are contained in consecutive memory locations, two characters per memory location, starting with the address specified in R0. The ASCII code contained in bits [7:0] of a memory location is written to the console first. Then the ASCII code contained in bits [15:8] of that memory location is written to the console. (A character string consisting of an odd number of characters to be written will have x00 in bits [15:8] of the memory location containing the last character to be written.) Writing terminates with the occurrence of x0000 in a memory location.
x25	HALT	Halt execution and print a message on the console.

Table A.3 Device Register Assignments

Address	I/O Register Name	I/O Register Function
xFE00	Keyboard status register	Also known as KBSR. The ready bit (bit [15]) indicates if the keyboard has received a new character.
xFE02	Keyboard data register	Also known as KBDR. Bits [7:0] contain the last character typed on the keyboard.
xFE04	Display status register	Also known as DSR. The ready bit (bit [15]) indicates if the display device is ready to receive another character to print on the screen.
xFE06	Display data register	Also known as DDR. A character written in the low byte of this register will be displayed on the screen.
xFFFE	Machine control register	Also known as MCR. Bit [15] is the clock enable bit. When cleared, instruction processing stops.