ISTANBUL TECHNICAL UNIVERSITY

COMPUTER ENGINEERING DEPARTMENT

BLG 222E

COMPUTER ORGANIZATION
PROJECT REPORT

PROJECT NO : 4

DUE DATE : 13.07.2020

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SPRING 2020

Contents

1 INTRODUCTION

Control Unit(CU) is the part of the computer's central processing unit (CPU). It directs the flow of data between the computer's memory and the several peripherals. There are two major categories of CU:

- Hardwired-control unit

- Microprogrammable control unit

We already designed hardwired control unit in the previous project. In this project , we designed a software-based (microprogrammed) control unit of basic computer using the structure shown in Figure 1 .

Figure 1: Slightly Modified Version of Project 2

2 MATERIALS AND METHODS

There are two types of instructions as described below.
(1) Instructions with address reference has the format as a given below :

- The OPCODE is a 5-bit field .

- The REGSEL is a 2-bit field .

- The ADDRESSING MODE is a 1-bit field .

- The ADDRESS is 8 bits .

OPCODE	REGSEL	ADDRESSING MODE	ADDRESS

Figure 2: Instructions with an address reference

(2) Instructions without address reference has the format as a given below :

- The OPCODE is a 5-bit field

- DESTREG is a 3-bit field which specifies the destination register .

- SRCREG1 is a 3-bit field which specifies the first source register .

- SRCREG2 is a 3-bit field which specifies the second source register .

- The least significant two bits are unused and have the value 00.

OPCODE	DESTREG	SRCREG1	SRCREG2	00

Figure 3: Instructions without an address reference

- Operations

In this project CU can perform 18 different operations in the Figure 2.

Figure 2: OPCODE field and symbols for operations and their descriptions

OPCODE (HEX)	SYMB	ADDRESSING MODE	DESCRIPTION
0x00	LD	IM, D	Rx ← Value (Value is described in Table 3)
0x01	ST	D	Value ← Rx
0x02	MOV	N/A	DESTREG ← SRCREG1
0x03	PSH	N/A	M[SP] ← Rx, SP ← SP - 1
0x04	PUL	N/A	SP ← SP + 1, Rx ← M[SP]
0x05	ADD	N/A	DESTREG ← SRCREG1 + SRCREG2
0x06	SUB	N/A	DESTREG ← SRCREG2 - SRCREG1
0x07	DEC	N/A	DESTREG ← SRCREG1 - 1
0x08	INC	N/A	DESTREG ← SRCREG1 + 1
0x09	AND	N/A	DESTREG ← SRCREG1 AND SRCREG2
0x0A	OR	N/A	DESTREG ← SRCREG1 OR SRCREG2
0x0B	NOT	N/A	DESTREG ← NOT SRCREG1
0x0C	LSL	N/A	DESTREG ← LSL SRCREG1
0xOD	LSR	N/A	DESTREG ← LSR SRCREG1
0x0E	BRA	IM	PC ← Value
0x0F	BEQ	IM	IF Z=1 THEN PC ← Value
0x10	BNE	IM	IF Z=0 THEN PC ← Value
0x11	CALL	IM	M[SP] ← PC, SP ← SP − 1, PC ← Value
0x12	RET	N/A	SP ← SP + 1, PC ← M[SP]

Figure 3: REGSEL (Left) and DESTREG/SRCREG1/SRCREG2 (Right) select the register of interest for a particular instruction

REGSEL	REGISTER
00	R0
01	R1
10	R2
11	R3

DESTREG/SRCREG1/SRCREG2	REGISTER
000	R0
001	R1
010	R2
011	R3
100	PC
101	PC
110	AR
111	SP

Figure 4: Addressing modes

ADDRESSING MODE	MODE	SYMB	Value
0	Immediate	IM	ADDRESS Field
1	Direct	D	M[AR]

In the microprogrammed control unit, we have a ROM that stores all the possible operations that can be executed by our control unit. These instructions and the fields they contain generate the control signals that make everything possible. Choosing the next address of ROM to go to is one of the main issues in microprogrammed control unit. For the next address, we can choose between the address that comes from the current microinstruction, the one that comes as a result of mapping, incrementing the current address, and the return address stored when we have a subroutine call and have to return to where we left it off. We have 2 registers in this part of the circuit, CAR (Control Address Register) and SBR (Subroutine Address Register). We have a logic which chooses between these options by using the condition and type of branching that was specified.

For each of the instructions that we have to perform with our control unit, we have specified the contents of the control memory (the ROM), the mapping logic and the control signals that should be generated.

Microinstruction format: F1 F2 F3 F4 CD BR NextAddress

F1 (5 bits) - Taken by the opcode of the instruction

F2 (3 bits) - Most of the time comes from DESTREG F3 (3 bits) - Most of the time comes from SRCREG1 F4 (3 bits) - Most of the time comes from SRCREG2 CD - the condition to check

(00 - condition always 1, 01 - Z, 10 - Z', 11 - S)

BR - the type of branching

(00 - jump, 01 - subroutine call, 10 - subroutine return, 11 - map)

Next address (13 bits) - where to go after this

0 LD Rx ← Value

Has 2 addressing modes

Next address – fetch for all

00000 000 000 00: 00000 101 101 101 00 00 10011 000 000 00 – just jump to fetch

hex: 0000: 02DA1300

00000 000 000 01: 00000 000 000 000 00 00 10011 000 000 00 R0 ← Address field

hex: 0001: 00001300

00000 000 000 10: 00000 000 000 000 00 00 10011 000 000 00 R0 ← M[AR]

hex: 0002: 00001300

00000 001 000 01: 00000 001 000 000 00 00 10011 000 000 00 R1 ← Address field

hex: 0021: 00801300

00000 001 000 10: 00000 001 000 000 00 00 10011 000 000 00 R1 ← M[AR]

hex: 0022: 00801300

00000 010 000 01: 00000 010 000 000 00 00 10011 000 000 00 R2 ← Address field

hex: 0041: 01001300

00000 010 000 10: 00000 010 000 000 00 00 10011 000 000 00 R2 ← M[AR]

hex: 0042: 01001300

00000 011 000 01: 00000 011 000 000 00 00 10011 000 000 00 R3 ← Address field

hex: 0061: 01801300

00000 011 000 10: 00000 011 000 000 00 00 10011 000 000 00 R3 ← M[AR]

hex: 0062: 01801300

Mapping: Opcode 0 Rx 000 A A'

A=0: MuxASel=00 (SelectIR(7-0))

RegSelRegister – depends on Rx – feed the decoded Rx: 00 → 0001 (will activate R0)

01 → 0010, 10 → 0100, 11 → 1000 FunSelReg → Load = 01

A = 1: OutDSel = 01 (should show AR)

RAM – Sel = 1, MuxDSel = 0, LD = 1

MuxASel = 01

RegSelRegister – decode Rx and FunSelReg = 01 (Load) - the same

1 ST Value ← Rx

With address: Mode only direct here - Value is M[AR]

Will use the 2 LSB of the destination register location

00001 000 000 00: 00001 000 000 000 00 00 10011 000 000 00 M[AR]← R0

hex: 0100: 04001300

00001 001 000 00: 00001 001 000 000 00 00 10011 000 000 00 M[AR]← R1

hex: 0120: 04801300

00001 010 000 00: 00001 010 000 000 00 00 10011 000 000 00 M[AR]← R2

hex: 0140: 05001300

00001 011 000 00: 00001 011 000 000 00 00 10011 000 000 00 M[AR]← R3

hex: 0160: 05801300

Mapping: Opcode 0 Rx 00000

OutBSel – Rx , FunSelAlu – 0001 (forward B to OutALU),

OutDSel = 01 (AR) (the value stored in AR is being sent to the address input in the RAM)

RAM: Sel = 1, Str = 1

2 MOV F2 ← F3

R0: 00010 000 000 00: 00010 000 000 000 00 00 10011 000 000 00 R0← R0

hex: 0200: 08001300

00010 000 000 01: 00010 000 000 000 00 10 10011 000 000 00 - this is a special case, when we make a subroutine call to here and then want to return

hex: 0201: 08005300

00010 000 001 00: 00010 000 001 000 00 00 10011 000 000 00 R0 ← R1

hex: 0204: 08101300

00010 000 001 01: 00010 000 001 000 00 10 10011 000 000 00

hex: 0205: 08105300

00010 000 010 00: 00010 000 010 000 00 00 10011 000 000 00 R0 ← R2

hex: 0208: 08201300

00010 000 010 01: 00010 000 010 000 00 10 10011 000 000 00

hex: 0209: 08205300

00010 000 011 00: 00010 000 011 000 00 00 10011 000 000 00 R0 ← R3

hex: 020C: 08301300

00010 000 011 01: 00010 000 011 000 00 10 10011 000 000 00

hex: 020D: 08305300

00010 000 100 00: 00010 000 100 000 00 00 10011 000 000 00 R0 ← PC

hex: 0210: 08401300

00010 000 100 01: 00010 000 100 000 00 10 10011 000 000 00

hex: 0211: 08405300

00010 000 110 00: 00010 000 110 000 00 00 10011 000 000 00 R0 ← AR

hex: 0218: 08601300

00010 000 110 01: 00010 000 110 000 00 10 10011 000 000 00

hex: 0219: 08605300

00010 000 111 00: 00010 000 111 000 00 00 10011 000 000 00 R0 ← SP

hex: 021C: 08701300

00010 000 111 01: 00010 000 111 000 00 10 10011 000 000 00

hex: 021D: 08705300

R1:

00010 001 000 00: 00010 001 000 000 00 00 10011 000 000 00 R1 ← R0

hex: 0220: 08801300

00010 001 000 01: 00010 001 000 000 00 10 10011 000 000 00

hex: 0221: 08805300

00010 001 001 00: 00010 001 001 000 00 00 10011 000 000 00 R1 ← R1

hex: 0224: 08901300 00010 001 001 01: 00010 001 001 000 00 10 10011 000 000 00

hex: 0225: 08905300

00010 001 010 00: 00010 001 010 000 00 00 10011 000 000 00 R1 ← R2

hex: 0228: 08A01300

00010 001 010 01: 00010 001 010 000 00 10 10011 000 000 00

hex: 0229: 08A05300

00010 001 011 00: 00010 001 011 000 00 00 10011 000 000 00 R1 ← R3

hex: 022C: 08B01300

00010 001 011 01: 00010 001 011 000 00 10 10011 000 000 00

hex: 022D: 08B05300 00010 001 100 00: 00010 001 100 000 00 00 10011 000 000 00 R1 ← PC

hex: 0230: 08C01300

00010 001 100 01: 00010 001 100 000 00 10 10011 000 000 00

hex: 0231: 08C05300

00010 001 110 00: 00010 001 110 000 00 00 10011 000 000 00 R1 ← AR

hex: 0238: 08E01300

00010 001 110 01: 00010 001 110 000 00 10 10011 000 000 00

hex: 0239: 08E05300

00010 001 111 00: 00010 001 111 000 00 00 10011 000 000 00 R1 ← SP

hex: 023C: 08F01300

00010 001 111 01: 00010 001 111 000 00 10 10011 000 000 00

hex: 023D: 08F05300

R2:

00010 010 000 00: 00010 010 000 000 00 00 10011 000 000 00 R2 ← R0

hex: 0240: 09001300

00010 010 000 01: 00010 010 000 000 00 10 10011 000 000 00

hex: 0241: 09005300

00010 010 001 00: 00010 010 001 000 00 00 10011 000 000 00 R2 ← R1

hex: 0244: 09101300

00010 010 001 01: 00010 010 001 000 00 10 10011 000 000 00

hex: 0245: 09105300

00010 010 010 00: 00010 010 010 000 00 00 10011 000 000 00 R2 ← R2

hex: 0248: 09201300

00010 010 010 01: 00010 010 010 000 00 10 10011 000 000 00

hex: 0249: 09205300

00010 010 011 00: 00010 010 011 000 00 00 10011 000 000 00 R2 ← R3

hex: 024C: 09301300

00010 010 011 01: 00010 010 011 000 00 10 10011 000 000 00

hex: 024D: 09305300

00010 010 100 00: 00010 010 100 000 00 00 10011 000 000 00 R2 ← PC

hex: 0250: 09401300

00010 010 100 01: 00010 010 100 000 00 10 10011 000 000 00

hex: 0251: 09405300

00010 010 110 00: 00010 010 110 000 00 00 10011 000 000 00 R2 ← AR

hex: 0258: 09601300

00010 010 110 01: 00010 010 110 000 00 10 10011 000 000 00

hex: 0259: 09605300

00010 010 111 00: 00010 010 111 000 00 00 10011 000 000 00 R2 ← SP

hex: 025C: 09701300

00010 010 111 01: 00010 010 111 000 00 10 10011 000 000 00

hex: 025D: 09705300

R3:

00010 011 000 00: 00010 011 000 000 00 00 10011 000 000 00 R3 ← R0

hex: 0260: 09801300

00010 011 000 01: 00010 011 000 000 00 10 10011 000 000 00

hex: 0261: 09805300

00010 011 001 00: 00010 011 001 000 00 00 10011 000 000 00 R3 ← R1

hex: 0264: 09901300

00010 011 001 01: 00010 011 001 000 00 10 10011 000 000 00

hex: 0265: 09905300

00010 011 010 00: 00010 011 010 000 00 00 10011 000 000 00 R3 ← R2

hex: 0268: 09A01300

00010 011 010 01: 00010 011 010 000 00 10 10011 000 000 00

hex: 0269: 09A05300

00010 011 011 00: 00010 011 011 000 00 00 10011 000 000 00 R3 ← R3

hex: 026C: 09B01300

00010 011 011 01: 00010 011 011 000 00 10 10011 000 000 00

hex: 026D: 09B05300

00010 011 100 00: 00010 011 100 000 00 00 10011 000 000 00 R3 ← PC

hex: 0270: 09C01300

00010 011 100 01: 00010 011 100 000 00 10 10011 000 000 00

hex: 0271: 09C05300

00010 011 110 00: 00010 011 110 000 00 00 10011 000 000 00 R3 ← AR

hex: 0278: 09E01300

00010 011 110 01: 00010 011 110 000 00 10 10011 000 000 00

hex: 0279: 09E05300

00010 011 111 00: 00010 011 111 000 00 00 10011 000 000 00 R3 ← SP

hex: 027C: 09F01300

00010 011 111 01: 00010 011 111 000 00 10 10011 000 000 00

hex: 027D: 09F05300

PC:

00010 100 000 00: 00010 100 000 000 00 00 10011 000 000 00 PC ← R0

hex: 0280: 0A001300

00010 100 000 01: 00010 100 000 000 00 10 10011 000 000 00

hex: 0281: 0A005300

00010 100 001 00: 00010 100 001 000 00 00 10011 000 000 00 PC ← R1

hex: 0284: 0A101300

00010 100 001 01: 00010 100 001 000 00 10 10011 000 000 00

hex: 0285: 0A105300

00010 100 010 00: 00010 100 010 000 00 00 10011 000 000 00 PC ← R2

hex: 0288: 0A201300

00010 100 010 01: 00010 100 010 000 00 10 10011 000 000 00

hex: 0289: 0A205300

00010 100 011 00: 00010 100 011 000 00 00 10011 000 000 00 PC ← R3

hex: 028C: 0A301300

00010 100 011 01: 00010 100 011 000 00 10 10011 000 000 00

hex: 028D: 0A305300

00010 100 100 00: 00010 100 100 000 00 00 10011 000 000 00 PC ← PC

hex:0290: 0A401300

00010 100 100 01: 00010 100 100 000 00 10 10011 000 000 00

hex:0291: 0A405300

00010 100 110 00: 00010 100 110 000 00 00 10011 000 000 00 PC ← AR

hex: 0298: 0A601300

00010 100 110 01: 00010 100 110 000 00 10 10011 000 000 00

hex:0299: 0A605300

00010 100 111 00: 00010 100 111 000 00 00 10011 000 000 00 PC ← SP

hex: 029C: 0A701300

00010 100 111 01: 00010 100 111 000 00 10 10011 000 000 00

hex: 029D: 0A705300

AR:

00010 110 000 00: 00010 110 000 000 00 00 10011 000 000 00 AR ← R0

hex: 02C0: 0B001300

00010 110 000 01: 00010 110 000 000 00 10 10011 000 000 00

hex: 02C1: 0B005300

00010 110 001 00: 00010 110 001 000 00 00 10011 000 000 00 AR ← R1

hex: 02C4: 0B101300

00010 110 001 01: 00010 110 001 000 00 10 10011 000 000 00

hex: 02C5: 0B105300

00010 110 010 00: 00010 110 010 000 00 00 10011 000 000 00 AR ← R2

hex: 02C8: 0B201300

00010 110 010 01: 00010 110 010 000 00 10 10011 000 000 00

hex: 02C9: 0B205300

00010 110 011 00: 00010 110 011 000 00 00 10011 000 000 00 AR ← R3
hex: 02CC: 0B301300
00010 110 011 01: 00010 110 011 000 00 10 10011 000 000 00
hex: 02CD: 0B305300
00010 110 100 00: 00010 110 100 000 00 00 10011 000 000 00 AR ← PC
hex: 02D0: 0B401300
00010 110 100 01: 00010 110 100 000 00 10 10011 000 000 00
hex: 02D1: 0B405300
00010 110 110 00: 00010 110 110 000 00 00 10011 000 000 00 AR ← AR
hex: 02D8: 0B601300
00010 110 110 01: 00010 110 110 000 00 10 10011 000 000 00
hex: 02D9: 0B605300
00010 110 111 00: 00010 110 111 000 00 00 10011 000 000 00 AR ← SP
hex: 02DC: 0B701300
00010 110 111 01: 00010 110 111 000 00 10 10011 000 000 00
hex: 02DD: 0B705300

SP:
00010 111 000 00: 00010 111 000 000 00 00 10011 000 000 00 SP ← R0
hex: 02E0: 0B801300
00010 111 000 01: 00010 111 000 000 00 10 10011 000 000 00
hex: 02E1: 0B805300
00010 111 001 00: 00010 111 001 000 00 00 10011 000 000 00 SP ← R1
hex: 02E4: 0B901300
00010 111 001 01: 00010 111 001 000 00 10 10011 000 000 00
hex: 02E5: 0B905300
00010 111 010 00: 00010 111 010 000 00 00 10011 000 000 00 SP ← R2
hex: 02E8: 0BA01300
00010 111 010 01: 00010 111 010 000 00 10 10011 000 000 00
hex: 02E9: 0BA05300
00010 111 011 00: 00010 111 011 000 00 00 10011 000 000 00 SP ← R3
hex: 02EC: 0BB01300
00010 111 011 01: 00010 111 011 000 00 10 10011 000 000 00
hex: 02ED: 0BB05300
00010 111 100 00: 00010 111 100 000 00 00 10011 000 000 00 SP ← PC
hex: 02F0: 0BC01300
00010 111 100 01: 00010 111 100 000 00 10 10011 000 000 00

hex: 02F1: 0BC05300

00010 111 110 00: 00010 111 110 000 00 00 10011 000 000 00 SP ← AR

hex: 02F8: 0BE01300

00010 111 110 01: 00010 111 110 000 00 10 10011 000 000 00

hex: 02F9: 0BE05300

00010 111 111 00: 00010 111 111 000 00 00 10011 000 000 00 SP ← SP

hex: 02FC: 0BF01300

00010 111 111 01: 00010 111 111 000 00 10 10011 000 000 00

hex: 02FD: 0BF05300

Put a Mux – when DESTREG is 101 it will forward 100 – this is what we use in our microinstructions.

The select for this MUX is DR(2) AND DR(1)' AND DR(0) - this gives 1 only when the 101 combo is present and for select = 1 it will forward 100, for select = 0 it will forward whatever DESTREG is.

(To avoid complications will only use 100 for PC - make sure 101 from outside is converted to 100)

When refering to DESTREG, SRCREG1, SRCREG2 in the mapping from now on, we will be referring to their modified versions.

Mapping – Opcode DESTREG SRCREG1 00

(DESTREG and RCREG1 – will be modified)

Control Signals:

- F2 and F3 both belong to RegisterFile

OutBSel – the 2 LSB of F3, FunSelALU – 0001 (buffer B)

MuxASel = 11,

RegSelReg =decode F2 and take the 4 LSB outputs of the decoder

FunSelRegister = 01 (Load)

- F2 and F3 both belong to AddressRegister

OutCSel – depends on F3

OutCSel:

$$\begin{array}{c|c} \text{00-PC} & \text{F3: 100-PC} \\ \text{01-AR} & \text{110-AR} \\ \text{10-SP} & \text{111-SP} \end{array}$$

We can decode the F3.

Decoder 100: 00010000, 101: 00100000, 110: 01000000, 111: 10000000

Will take Bit 7, 6 of the output of the decoder and send to OutCSel The 101 combination as a select for the decoder – will not appear

MuxCSel = 0 (the OutCSel will be forwarded to the A input of the ALU)

FunSelALU = 0000 (forward A)

MuxBSel = 11 (the OutALU)

RegSelAdd:

$$\begin{array}{c|c} \text{001-PC} & \text{F2: 100-PC} \\ \text{010-AR} & \text{110-AR} \\ \text{100-SP} & \text{111-SP} \end{array}$$

Can decode the F2

Decoder 100: 00010000, 101: 00100000, 110: 01000000, 111: 10000000

Take bits 7,6,4 of the output of the decoder and send as RegSelAddress

FunSelAddress = 01 (load)

- F2 – AddressRegister, F3 – RegisterFile

OutBSel = the 2 LSB of F3 , FunSelALU = 0001

MuxBSel = 11,

RegSelAdd – decode the F2 and take bits 7, 6, 4 of the output of the decoder

FunSelAddress = 01 (load)

- F2 – RegisterFile, F3 – AddressRegister

OutCSel – decode the F3 and take bits 7, 6 of the output of the decoding

MuxASel = 10, RegSelR – decode F2 and take the 4 LSB outputs of the decoder, FunSelReg = 01

3 PSH M[SP] ← Rx, SP ← SP − 1

CD BR and then Address of SP ← SP − 1, just need to jump to here

Just make sure that when the PSH operation comes into the IR – make the check here, it does not make the S bit = 1 otherwise when it goes to SP ← SP -1 will treat it as a subroutine and not a jump

00011 000 000 00: 00011 000 000 000 00 00 00111 111 000 01 M[SP] ← R0 and jump to SP ← SP - 1

hex: 0300: 0C0007E1

00011 001 000 00: 00011 001 000 000 00 00 00111 111 000 01 M[SP] ← R1 and jump to SP ← SP - 1

hex: 0320: 0C8007E1

00011 010 000 00: 00011 010 000 000 00 00 00111 111 000 01 M[SP] ← R2 and jump to SP ← SP - 1

hex: 0340: 0D0007E1

00011 011 000 00: 00011 011 000 000 00 00 00111 111 000 01 M[SP] ← R3 and jump to SP ← SP - 1

hex: 0360: 0D8007E1

00011 100 000 00: 00011 100 000 000 00 00 00111 111 000 01 M[SP] ← PC and jump to SP ← SP – 1

hex: 0380: 0E0007E1

M[SP] ← PC is also used as a subroutine-

so instead just for this one:

May do a conditional jump to the return from subroutine part –

If not the case will move on to the next address which holds the jump to decrement SP

What about (00011 100 000 000 11 00 10100 000 000 00)? (hex: 0E019400)

NOP : 101 101 101 – this combination!

101 won't appear in any of the instructions that deal with F3 F4 and F2

• Have modified it to go to 100 (PC) if that combination comes

(00011 100 000 01: 00011 101 101 101 00 00 00111 111 000 01 should hold an unconditional jump to SP ← SP – 1)

hex: 0381: 0EDA07E1

00011 110 000 00: 00011 110 000 000 00 00 00111 111 000 01 M[SP] ← AR and jump to SP ← SP - 1

hex: 03C0: 0F0007E1

00011 111 000 00: 00011 111 000 000 00 00 00111 111 000 01 M[SP] ← SP and jump to SP ← SP - 1

hex: 03E0: 0F8007E1

Here we finish after decrementing SP so we don't need to call it as a subroutine but can only jump to it (unconditional jump to decrement SP).

Afterwards branch to subroutine where SP ← SP – 1 : it is saved in the decrement part

Mapping: Opcode DESTREG (modified) 00000

- F2 – is from the RegisterFile

OutDSel = 10, Str = 1, Sel = 1

OutBSel – the 2 LSB of F2, FunSelALU = 0001 (buffer B)

- F2 – Address File

OutDSel = 10, Str = 1, Sel =1

OutCSel = the 2 MSB (bit 7, 6) of decoding of F2

MuxCSel = 0, FunSelALU = 0000 (buffer A)

4 PUL SP ← SP + 1, Rx ← M[SP]

First branch to the subroutine which increment SP – it is in the increment part

Then continue

We call the subroutine but it must be able to return

00100 000 000 00: 00100 101 101 101 00 01 01000 111 000 01 - subroutine call SP ← SP + 1

hex: 0400:12DA28E1

CD = 00 (condition is 1, unconditional), BR = 01 – subroutine call, Address of SP ← SP + 1

Should i be representing NOP like this – with 101 101?

?(00100 101 101 00 00 01 01000 111 000 01) (hex: 12D05161)

00100 000 000 01: 00100 000 000 000 00 00 10011 000 000 00 R0 ← M[SP]

hex: 0401: 10001300

00100 001 000 00: 00100 101 101 101 00 01 01000 111 000 01 - subroutine call SP ← SP + 1

hex: 0420: 12DA28E1

00100 001 000 01: 00100 001 000 000 00 00 10011 000 000 00 R1 ← M[SP]

hex: 0421: 10801300

00100 010 000 00: 00100 101 101 101 00 01 01000 111 000 01 - subroutine call SP ← SP + 1

hex: 0440: 12DA28E1

00100 010 000 01: 00100 010 000 000 00 00 10011 000 000 00 R2 ← M[SP]

hex: 0441: 11001300

00100 011 000 00: 00100 101 101 101 00 01 01000 111 000 01 - subroutine call SP ← SP + 1

hex: 0460: 12DA28E1

00100 011 000 01: 00100 011 000 000 00 00 10011 000 000 00 R3 ← M[SP]

hex: 0461: 11801300

00100 100 000 00: 00100 101 101 101 00 01 01000 111 000 01 - subroutine call SP ← SP + 1

hex: 0480: 12DA28E1

00100 100 000 01: 00100 100 000 000 00 00 10011 000 000 00 PC ← M[SP]

hex: 0481: 12001300

00100 110 000 00: 00100 101 101 101 00 01 01000 111 000 01 - subroutine call SP ← SP + 1

hex: 04C0: 12DA28E1

00100 110 000 01: 00100 110 000 000 00 00 10011 000 000 00 AR ← M[SP]

hex: 04C1: 13001300

00100 111 000 00: 00100 101 101 101 00 01 01000 111 000 01 - subroutine call SP ← SP + 1

hex: 04E0: 12DA28E1

00100 111 000 01: 00100 111 000 000 00 00 10011 000 000 00 SP ← M[SP]

hex: 04E1: 13801300

Mapping: Opcode DESTREG 000 00

- F2 – RegisterFile

OutDSel = 10 (SP), LD = 1, Sel = 1 (MuxDSel = 0)

MuxASel = 01, RegSelReg = decode F2 and take the 4 LSB outputs of the decoder

FunSel = 01

- F2 – AddressRegister

OutDSel = 10, LD = 1, Sel = 1, (MuxDSel = 0)

MuxBSel = 10,

RegSelAdd = like above – bits 7,6, 0 of the output of decoding the 2 LSB of F2

FunSelAdd = 01 (Load)

5 ADD F2 ← F3 + F4

R0:

00101 000 000 00: 00101 000 000 000 00 00 10011 000 000 00 R0 ← R0 + R0 next address
fetch

hex: 0500: 14001300

00101 000 000 01: 00101 000 000 001 00 00 10011 000 000 00 R0←R0 + R1 next address
fetch

hex: 0501: 14021300

00101 000 000 10: 00101 000 000 010 00 00 10011 000 000 00 R0←R0 + R2

hex: 0502: 14041300

00101 000 000 11: 00101 000 000 011 00 00 10011 000 000 00 R0←R0 + R3

hex: 0503: 14061300

00101 000 001 00: 00101 000 000 100 00 00 10011 000 000 00 R0←R0 + PC

hex: 0504: 14081300

00101 000 001 10: 00101 000 000 110 00 00 10011 000 000 00 R0←R0 + AR

hex: 0506: 140C1300

00101 000 001 11: 00101 000 000 111 00 00 10011 000 000 00 R0←R0 + SP

hex: 0507: 140E1300

00101 000 010 01: 00101 000 001 001 00 00 10011 000 000 00 R0←R1 + R1

hex: 0509: 14121300

00101 000 010 10: 00101 000 001 010 00 00 10011 000 000 00 R0←R1 + R2

hex: 050A: 14141300

00101 000 010 11: 00101 000 001 011 00 00 10011 000 000 00 R0←R1 + R3

hex: 050B: 14161300

00101 000 011 00: 00101 000 001 100 00 00 10011 000 000 00 R0←R1 +PC

hex: 050C: 14181300

00101 000 011 10: 00101 000 001 110 00 00 10011 000 000 00 R0←R1 + AR

hex: 050E: 141C1300

00101 000 011 11: 00101 000 001 111 00 00 10011 000 000 00 R0←R1 + SP

hex: 050F: 141E1300

00101 000 100 10: 00101 000 010 010 00 00 10011 000 000 00 R0←R2 + R2

hex: 0512: 14241300

00101 000 100 11: 00101 000 010 011 00 00 10011 000 000 00 R0←R2 + R3

hex: 0513: 14261300

00101 000 101 00: 00101 000 010 100 00 00 10011 000 000 00 R0←R2 + PC

hex: 0514: 14281300

00101 000 101 10: 00101 000 010 110 00 00 10011 000 000 00 R0←R2 + AR

hex: 0516: 142C1300

00101 000 101 11: 00101 000 010 111 00 00 10011 000 000 00 R0←R2 + SP

hex: 0517: 142E1300

00101 000 110 11: 00101 000 011 011 00 00 10011 000 000 00 R0←R3 + R3

hex: 051B: 14361300

00101 000 111 00: 00101 000 011 100 00 00 10011 000 000 00 R0←R3 + PC

hex: 051C: 14381300

00101 000 111 10: 00101 000 011 110 00 00 10011 000 000 00 R0←R3 + AR

hex: 051E: 143C1300

00101 000 111 11: 00101 000 011 111 00 00 10011 000 000 00 R0←R3 + SP

hex: 051F: 143E1300

22 instructions for first case

R1:

Address given like that to display the mapping

00101 001 00 000: 00101 001 000 000 00 00 10011 000 000 00 R1←R0 + R0

hex: 0520: 14801300

00101 001 00 001: 00101 001 000 001 00 00 10011 000 000 00 R1←R0 + R1

hex: 0521: 14821300

00101 001 00 010: 00101 001 000 010 00 00 10011 000 000 00 R1←R0 + R2

hex: 0522: 14841300

00101 001 00 011: 00101 001 000 011 00 00 10011 000 000 00 R1←R0 + R3

hex: 0523: 14861300

00101 001 00 100: 00101 001 000 100 00 00 10011 000 000 00 R1←R0 + PC

hex: 0524: 14881300

00101 001 00 110: 00101 001 000 110 00 00 10011 000 000 00 R1←R0 + AR

hex: 0526: 148C1300

00101 001 00 111: 00101 001 000 111 00 00 10011 000 000 00 R1←R0 + SP

hex: 0527: 148E1300

00101 001 010 01: 00101 001 001 001 00 00 10011 000 000 00 R1←R1 + R1

hex: 0529: 14921300

00101 001 010 10: 00101 001 001 010 00 00 10011 000 000 00 R1←R1 + R2
hex: 052A: 14941300

00101 001 010 11: 00101 001 001 011 00 00 10011 000 000 00 R1←R1 + R3
hex: 052B: 14961300

00101 001 011 00: 00101 001 001 100 00 00 10011 000 000 00 R1←R1 +PC
hex: 052C: 14981300

00101 001 011 10: 00101 001 001 110 00 00 10011 000 000 00 R1←R1 + AR
hex: 052e: 149C1300

00101 001 011 11: 00101 001 001 111 00 00 10011 000 000 00 R1←R1 + SP
hex: 052f: 149E1300

00101 001 100 10: 00101 001 010 010 00 00 10011 000 000 00 R1←R2 + R2
hex: 0532: 14A41300

00101 001 100 11: 00101 001 010 011 00 00 10011 000 000 00 R1←R2 + R3
hex: 0533: 14A61300

00101 001 101 00: 00101 001 010 100 00 00 10011 000 000 00 R1←R2 + PC
hex: 0534: 14A81300

00101 001 101 10: 00101 001 010 110 00 00 10011 000 000 00 R1←R2 + AR
hex: 0536: 14AC1300

00101 001 101 11: 00101 001 010 111 00 00 10011 000 000 00 R1←R2 + SP
hex: 0537: 14AE1300

00101 001 110 11: 00101 001 011 011 00 00 10011 000 000 00 R1←R3 + R3
hex: 053B: 14B61300

00101 001 111 00: 00101 001 011 100 00 00 10011 000 000 00 R1←R3 + PC
hex: 053C: 14B81300

00101 001 111 10: 00101 001 011 110 00 00 10011 000 000 00 R1←R3 + AR
hex: 053E: 14BC1300

00101 001 111 11: 00101 001 011 111 00 00 10011 000 000 00 R1←R3 + SP
hex: 053F: 14BE1300

R2:

00101 010 000 00: 00101 010 000 000 00 00 10011 000 000 00 R2←R0 + R0
hex: 0540: 15001300

00101 010 000 01: 00101 010 000 001 00 00 10011 000 000 00 R2←R0 + R1

hex: 0541: 15021300

00101 010 000 10: 00101 010 000 010 00 00 10011 000 000 00 R2←R0 + R2

hex: 0542: 15041300

00101 010 000 11: 00101 010 000 011 00 00 10011 000 000 00 R2←R0 + R3

hex: 0543: 15061300

00101 010 001 00: 00101 010 000 100 00 00 10011 000 000 00 R2←R0 + PC

hex: 0544: 15081300

00101 010 001 10: 00101 010 000 110 00 00 10011 000 000 00 R2←R0 + AR

hex: 0546: 150C1300

00101 010 001 11: 00101 010 000 111 00 00 10011 000 000 00 R2←R0 + SP

hex: 0547: 150E1300

00101 010 010 01: 00101 010 001 001 00 00 10011 000 000 00 R2←R1 + R1

hex: 0549: 15121300

00101 010 010 10: 00101 010 001 010 00 00 10011 000 000 00 R2←R1 + R2

hex: 054A: 15141300

00101 010 010 11: 00101 010 001 011 00 00 10011 000 000 00 R2←R1 + R3

hex: 054B: 15161300

00101 010 011 00: 00101 010 001 100 00 00 10011 000 000 00 R2←R1 +PC

hex: 054C: 15181300

00101 010 011 10: 00101 010 001 110 00 00 10011 000 000 00 R2←R1 + AR

hex: 054E: 151C1300

00101 010 011 11: 00101 010 001 111 00 00 10011 000 000 00 R2←R1 + SP

hex: 054F: 151E1300

00101 010 100 10: 00101 010 010 010 00 00 10011 000 000 00 R2←R2 + R2

hex: 0552: 15241300

00101 010 100 11: 00101 010 010 011 00 00 10011 000 000 00 R2←R2 + R3

hex: 0553: 15261300

00101 010 101 00: 00101 010 010 100 00 00 10011 000 000 00 R2←R2 + PC

hex: 0554: 15281300

00101 010 101 10: 00101 010 010 110 00 00 10011 000 000 00 R2←R2 + AR

hex: 0556: 152C1300

00101 010 101 11: 00101 010 010 111 00 00 10011 000 000 00 R2←R2 + SP

hex: 0557: 152E1300

00101 010 110 11: 00101 010 011 011 00 00 10011 000 000 00 R2←R3 + R3

hex: 055B: 15361300

00101 010 111 00: 00101 010 011 100 00 00 10011 000 000 00 R2←R3 + PC

hex: 055C: 15381300

00101 010 111 10: 00101 010 011 110 00 00 10011 000 000 00 R2←R3 + AR

hex: 055E: 153C1300

00101 010 111 11: 00101 010 011 111 00 00 10011 000 000 00 R2←R3 + SP

hex: 055F: 153E1300

R3:

00101 011 000 00: 00101 011 000 000 00 00 10011 000 000 00 R3←R0 + R0

hex: 0560: 15801300

00101 011 000 01: 00101 011 000 001 00 00 10011 000 000 00 R3←R0 + R1

hex: 0561: 15821300

00101 011 000 10: 00101 011 000 010 00 00 10011 000 000 00 R3←R0 + R2

hex: 0562: 15841300

00101 011 000 11: 00101 011 000 011 00 00 10011 000 000 00 R3←R0 + R3

hex: 0563: 15861300

00101 011 001 00: 00101 011 000 100 00 00 10011 000 000 00 R3←R0 + PC

hex: 0564: 15881300

00101 011 001 10: 00101 011 000 110 00 00 10011 000 000 00 R3←R0 + AR

hex: 0566: 158C1300

00101 011 001 11: 00101 011 000 111 00 00 10011 000 000 00 R3←R0 + SP

hex: 0567: 158E1300

00101 011 010 01: 00101 011 001 001 00 00 10011 000 000 00 R3←R1 + R1

hex: 0569: 15921300

00101 011 010 10: 00101 011 001 010 00 00 10011 000 000 00 R3←R1 + R2

hex: 056A: 15941300

00101 011 010 11: 00101 011 001 011 00 00 10011 000 000 00 R3←R1 + R3

hex: 056B: 15961300

00101 011 011 00: 00101 011 001 100 00 00 10011 000 000 00 R3←R1 + PC

hex: 056C: 15981300

00101 011 011 10: 00101 011 001 110 00 00 10011 000 000 00 R3←R1 + AR

hex: 056E: 159C1300

00101 011 011 11: 00101 011 001 111 00 00 10011 000 000 00 R3←R1 + SP

hex: 056F: 159E1300

00101 011 100 10: 00101 011 010 010 00 00 10011 000 000 00 R3←R2 + R2
hex: 0572: 15A41300
00101 011 100 11: 00101 011 010 011 00 00 10011 000 000 00 R3←R2 + R3
hex: 0573: 15A61300
00101 011 101 00: 00101 011 010 100 00 00 10011 000 000 00 R3←R2 + PC
hex: 0574: 15A81300
00101 011 101 10: 00101 011 010 110 00 00 10011 000 000 00 R3←R2 + AR
hex: 0576: 15AC1300
00101 011 101 11: 00101 011 010 111 00 00 10011 000 000 00 R3←R2 + SP
hex: 0577: 15AE1300

00101 011 110 11: 00101 011 011 011 00 00 10011 000 000 00 R3←R3 + R3
hex: 057B: 15B61300
00101 011 111 00: 00101 011 011 100 00 00 10011 000 000 00 R3←R3 + PC
hex: 057C: 15B81300
00101 011 111 10: 00101 011 011 110 00 00 10011 000 000 00 R3←R3 + AR
hex: 057E: 15BC1300
00101 011 111 11: 00101 011 011 111 00 00 10011 000 000 00 R3←R3 + SP
hex: 057F: 15BE1300

PC:
00101 100 000 00: 00101 100 000 000 00 00 10011 000 000 00 PC←R0 + R0
hex: 0580: 16001300
00101 100 000 01: 00101 100 000 001 00 00 10011 000 000 00 PC←R0 + R1
hex: 0581: 16021300
00101 100 000 10: 00101 100 000 010 00 00 10011 000 000 00 PC←R0 + R2
hex: 0582: 16041300
00101 100 000 11: 00101 100 000 011 00 00 10011 000 000 00 PC←R0 + R3
hex: 0583: 16061300
00101 100 001 00: 00101 100 000 100 00 00 10011 000 000 00 PC←R0 + PC
hex: 0584: 16081300
00101 100 001 10: 00101 100 000 110 00 00 10011 000 000 00 PC←R0 + AR
hex: 0586: 160C1300
00101 100 001 11: 00101 100 000 111 00 00 10011 000 000 00 PC←R0 + SP
hex: 0587: 160E1300

00101 100 010 01: 00101 100 001 001 00 00 10011 000 000 00 PC←R1 + R1

hex: 0589: 16121300

00101 100 010 10: 00101 100 001 010 00 00 10011 000 000 00 PC←R1 + R2
hex: 058A: 16141300

00101 100 010 11: 00101 100 001 011 00 00 10011 000 000 00 PC←R1 + R3
hex: 058B: 16161300

00101 100 011 00: 00101 100 001 100 00 00 10011 000 000 00 PC←R1 +PC
hex: 058C: 16181300

00101 100 011 10: 00101 100 001 110 00 00 10011 000 000 00 PC←R1 + AR
hex: 058E: 161C1300

00101 100 011 11: 00101 100 001 111 00 00 10011 000 000 00 PC←R1 + SP
hex: 058F: 161E1300

00101 100 100 10: 00101 100 010 010 00 00 10011 000 000 00 PC←R2 + R2
hex: 0592: 16241300

00101 100 100 11: 00101 100 010 011 00 00 10011 000 000 00 PC←R2 + R3
hex: 0593: 16261300

00101 100 101 00: 00101 100 010 100 00 00 10011 000 000 00 PC←R2 + PC
hex: 0594: 16281300

00101 100 101 10: 00101 100 010 110 00 00 10011 000 000 00 PC←R2 + AR
hex: 0596: 162C1300

00101 100 101 11: 00101 100 010 111 00 00 10011 000 000 00 PC ← R2 + SP
hex: 0597: 162E1300

00101 100 110 11: 00101 100 011 011 00 00 10011 000 000 00 PC←R3 + R3
hex: 059B: 16361300

00101 100 111 00: 00101 100 011 100 00 00 10011 000 000 00 PC←R3 + PC
hex: 059C: 16381300

00101 100 111 10: 00101 100 011 110 00 00 10011 000 000 00 PC←R3 + AR
hex: 059E: 163C1300

00101 100 111 11: 00101 100 011 111 00 00 10011 000 000 00 PC←R3 + SP
hex: 059F: 163E1300

AR:

00101 110 000 00: 00101 110 000 000 00 00 10011 000 000 00 AR←R0 + R0
hex: 05C0: 17001300

00101 110 000 01: 00101 110 000 001 00 00 10011 000 000 00 AR←R0 + R1
hex: 05C1: 17021300

00101 110 000 10: 00101 110 000 010 00 00 10011 000 000 00 AR←R0 + R2
hex: 05C2: 17041300
00101 110 000 11: 00101 110 000 011 00 00 10011 000 000 00 AR←R0 + R3
hex: 05C3: 17061300
00101 110 001 00: 00101 110 000 100 00 00 10011 000 000 00 AR←R0 + PC
hex: 05C4: 17081300
00101 110 001 10: 00101 110 000 110 00 00 10011 000 000 00 AR←R0 + AR
hex: 05C6: 170C1300
00101 110 001 11: 00101 110 000 111 00 00 10011 000 000 00 AR←R0 + SP
hex: 05C7: 170E1300

00101 110 010 01: 00101 110 001 001 00 00 10011 000 000 00 AR←R1 + R1
hex: 05C9: 17121300
00101 110 010 10: 00101 110 001 010 00 00 10011 000 000 00 AR←R1 + R2
hex: 05CA: 17141300
00101 110 010 11: 00101 110 001 011 00 00 10011 000 000 00 AR←R1 + R3
hex: 05CB: 17161300
00101 110 011 00: 00101 110 001 100 00 00 10011 000 000 00 AR←R1 +PC
hex: 05CC: 17181300
00101 110 011 10: 00101 110 001 110 00 00 10011 000 000 00 AR←R1 + AR
hex: 05CE: 171C1300
00101 110 011 11: 00101 110 001 111 00 00 10011 000 000 00 AR←R1 + SP
hex: 05CF: 171E1300

00101 110 100 10: 00101 110 010 010 00 00 10011 000 000 00 AR←R2 + R2
hex: 05D2: 17241300
00101 110 100 11: 00101 110 010 011 00 00 10011 000 000 00 AR←R2 + R3
hex: 05D3: 17261300
00101 110 101 00: 00101 110 010 100 00 00 10011 000 000 00 AR←R2 + PC
hex: 05D4: 17281300
00101 110 101 10: 00101 110 010 110 00 00 10011 000 000 00 AR←R2 + AR
hex: 05D6: 172C1300
00101 110 101 11: 00101 110 010 111 00 00 10011 000 000 00 AR←R2 + SP
hex: 05D7: 172E1300

00101 110 110 11: 00101 110 011 011 00 00 10011 000 000 00 AR←R3 + R3
hex: 05DB: 17361300

00101 110 111 00: 00101 110 011 100 00 00 10011 000 000 00 AR←R3 + PC
hex: 05DC: 17381300
00101 110 111 10: 00101 110 011 110 00 00 10011 000 000 00 AR←R3 + AR
hex: 05DE: 173C1300
00101 110 111 11: 00101 110 011 111 00 00 10011 000 000 00 AR←R3 + SP
hex: 05DF: 173E1300

SP:
00101 111 000 00: 00101 111 000 000 00 00 10011 000 000 00 SP←R0 + R0
Hex: 05E0: 17801300
00101 111 000 01: 00101 111 000 001 00 00 10011 000 000 00 SP←R0 + R1
Hex: 05E1: 17821300
00101 111 000 10: 00101 111 000 010 00 00 10011 000 000 00 SP←R0 + R2
Hex: 05E2: 17841300
00101 111 000 11: 00101 111 000 011 00 00 10011 000 000 00 SP←R0 + R3
Hex: 05E3: 17861300
00101 111 001 00: 00101 111 000 100 00 00 10011 000 000 00 SP←R0 + PC
Hex: 05E4: 17881300
00101 111 001 10: 00101 111 000 110 00 00 10011 000 000 00 SP←R0 + AR
Hex: 05E6: 178C1300
00101 111 001 11: 00101 111 000 111 00 00 10011 000 000 00 SP←R0 + SP
Hex: 05E7: 178E1300

00101 111 010 01: 00101 111 001 001 00 00 10011 000 000 00 SP←R1 + R1
Hex: 05E9: 17921300
00101 111 010 10: 00101 111 001 010 00 00 10011 000 000 00 SP←R1 + R2
Hex: 05EA: 17941300
00101 111 010 11: 00101 111 001 011 00 00 10011 000 000 00 SP←R1 + R3
Hex: 05EB: 17961300
00101 111 011 00: 00101 111 001 100 00 00 10011 000 000 00 SP←R1 +PC
Hex: 05EC: 17981300
00101 111 011 10: 00101 111 001 110 00 00 10011 000 000 00 SP←R1 + AR
Hex: 05EE: 179C1300
00101 111 011 11: 00101 111 001 111 00 00 10011 000 000 00 SP←R1 + SP
Hex: 05EF: 179E1300

00101 111 100 10: 00101 111 010 010 00 00 10011 000 000 00 SP←R2 + R2

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Hex: 05F2: 17A41300

00101 111 100 11: 00101 111 010 011 00 00 10011 000 000 00 SP←R2 + R3

Hex: 05F3: 17A61300

00101 111 101 00: 00101 111 010 100 00 00 10011 000 000 00 SP←R2 + PC

Hex: 05F4: 17A81300

00101 111 101 10: 00101 111 010 110 00 00 10011 000 000 00 SP←R2 + AR

Hex: 05F6: 17AC1300

00101 111 101 11: 00101 111 010 111 00 00 10011 000 000 00 SP←R2 + SP

Hex: 05F7: 17AE1300

00101 111 110 11: 00101 111 011 011 00 00 10011 000 000 00 SP←R3 + R3

Hex: 05FB: 17B61300

00101 111 111 00: 00101 111 011 100 00 00 10011 000 000 00 SP←R3 + PC

Hex: 05FC: 17B81300

00101 111 111 10: 00101 111 011 110 00 00 10011 000 000 00 SP←R3 + AR

Hex: 05FE: 17BC1300

00101 111 111 11: 00101 111 011 111 00 00 10011 000 000 00 SP←R3 + SP

Hex: 05FF: 17BE1300

Opcode - DESTREG - 2 LSB of new SRCREG1 - new SRCREG2

We make a different modification here. It has to do with the design and the microinstruction saved in ROM.in addition we may switch the places of the operands but it is still the same operation. For this reason, we only keep one order of the combination in ROM, and find the new SRCREG1 and SRCREG2 so we can map correctly, no matter the order in which they are given in the instruction.

New SRCREG1 – the smallest between SRCREG1 and SRCREG2
New SRCREG1 – the largest

In the microinstruction in ROM for addition, SRCREG1 is always smaller (the binary code which symbolizes it), than SRCREG2.

- F2 – RegisterFile , F3 – RegisterFile, F4 – RegisterFile

OutASel = 2 LSB of F3, MuxCSel = 1, OutBSel = 2 LSB of F4
FunSelALU = 0100, MuxASel = 11,
RegSelR = decode F2 and take the 4 LSB outputs of the decoder
FunSelRegister = 01 (Load)

- F2 – RegFile, F3 – RegFile, F4 – AddressFile

OutCSel = the 2 MSB (bit 7, 6) of decoding F4, MuxCSel = 0
OutBSel = the 2 LSB of F3, FunSelALU = 0100,
MuxASel = 11,
RegSelR = decode F2 and take the 4 LSB outputs of the decoder
FunSelR = 01

- F2 – AddressFile , F3 – RegisterFile, F4 – RegisterFile

OutASel = the 2 LSB of F3, MuxCSel = 1, OutBSel = the 2 LSB of F4
FunSelALU = 0100, MuxBSel = 11,
RegSelAdd = bits 7,6, 4 of the output of decoding F2
FunSelAdd = 01

- F2 – AddressFile , F3 – RegisterFile, F4 – AddressFile

OutCSel = the 2 MSB (bit 7, 6) of decoding F4
MuxCSel = 0,
OutBSel = the 2 LSB of F3
FunSelALU = 0100, MuxBSel = 11,
RegSelAdd = bits 7, 6, 4 of the output of decoding F2
FunSelAdd = 01

6 SUB F2 ← F3 - F4
R0:
00110 000 000 00: 00110 000 000 000 00 00 10011 000 000 00 R0 ← R0 − R0
Hex: 0600: 18001300
00110 000 000 01: 00110 000 000 001 00 00 10011 000 000 00 R0 ← R0 − R1
Hex: 0601: 18021300
00110 000 000 10: 00110 000 000 010 00 00 10011 000 000 00 R0 ← R0 − R2
Hex: 0602: 18041300
00110 000 000 11: 00110 000 000 011 00 00 10011 000 000 00 R0 ← R0 − R3
Hex: 0603: 18061300

00110 000 001 00: 00110 000 001 000 00 00 10011 000 000 00 R0 ← R1 − R0
Hex: 0604: 18101300

00110 000 001 01: 00110 000 001 001 00 00 10011 000 000 00 R0 ← R1 − R1

Hex: 0605: 18121300

00110 000 001 10: 00110 000 001 010 00 00 10011 000 000 00 R0 ← R1 − R2

Hex: 0606: 18141300

00110 000 001 11: 00110 000 001 011 00 00 10011 000 000 00 R0 ← R1 − R3

Hex: 0607: 18161300

00110 000 010 00: 00110 000 010 000 00 00 10011 000 000 00 R0 ← R2 − R0

Hex: 0608: 18201300

00110 000 010 01: 00110 000 010 001 00 00 10011 000 000 00 R0 ← R2 − R1

Hex: 0609: 18221300

00110 000 010 10: 00110 000 010 010 00 00 10011 000 000 00 R0 ← R2 − R2

Hex: 060A: 18241300

00110 000 010 11: 00110 000 010 011 00 00 10011 000 000 00 R0 ← R2 − R3

Hex: 060B: 18261300

00110 000 011 00: 00110 000 011 000 00 00 10011 000 000 00 R0 ← R3 − R0

Hex: 060C: 18301300

00110 000 011 01: 00110 000 011 001 00 00 10011 000 000 00 R0 ← R3 − R1

Hex: 060D: 18321300

00110 000 011 10: 00110 000 011 010 00 00 10011 000 000 00 R0 ← R3 − R2

Hex: 060E: 18341300

00110 000 011 11: 00110 000 011 011 00 00 10011 000 000 00 R0 ← R3 − R3

Hex: 060F: 18361300

00110 000 100 00: 00110 000 100 000 00 00 10011 000 000 00 R0 ← PC − R0

Hex: 0610: 18401300

00110 000 100 01: 00110 000 100 001 00 00 10011 000 000 00 R0 ← PC − R1

Hex: 0611: 18421300

00110 000 100 10: 00110 000 100 010 00 00 10011 000 000 00 R0 ← PC − R2

Hex: 0612: 18441300

00110 000 100 11: 00110 000 100 011 00 00 10011 000 000 00 R0 ← PC − R3

Hex: 0613: 18461300

For simplicity in mapping

00110 000 110 00: 00110 000 110 000 00 00 10011 000 000 00 R0 ← AR − R0

Hex: 0618: 18601300

00110 000 110 01: 00110 000 110 001 00 00 10011 000 000 00 R0 ← AR − R1

Hex: 0619: 18621300

00110 000 110 10: 00110 000 110 010 00 00 10011 000 000 00 R0 ← AR − R2

Hex: 061A: 18641300

00110 000 110 11: 00110 000 110 011 00 00 10011 000 000 00 R0 ← AR − R3

Hex: 061B: 18661300

00110 000 111 00: 00110 000 111 000 00 00 10011 000 000 00 R0 ← SP − R0

Hex: 061C: 18701300

00110 000 111 01: 00110 000 111 001 00 00 10011 000 000 00 R0 ← SP − R1

Hex: 061D: 18721300

00110 000 111 10: 00110 000 111 010 00 00 10011 000 000 00 R0 ← SP − R2

Hex: 061E: 18741300

00110 000 111 11: 00110 000 111 011 00 00 10011 000 000 00 R0 ← SP − R3

Hex: 061F: 18761300

Opcode F2 F3 F4 – the 2 LSB (it can only be a R0 − R3)

28 operations

R1:

00110 001 000 00: 00110 001 000 000 00 00 10011 000 000 00 R1 ← R0 − R0

Hex: 0620: 18801300

00110 001 000 01: 00110 001 000 001 00 00 10011 000 000 00 R1 ← R0 − R1

Hex: 0621: 18821300

00110 001 000 10: 00110 001 000 010 00 00 10011 000 000 00 R1 ← R0 − R2

Hex: 0622: 18841300

00110 001 000 11: 00110 001 000 011 00 00 10011 000 000 00 R1 ← R0 − R3

Hex: 0623: 18861300

00110 001 001 00: 00110 001 001 000 00 00 10011 000 000 00 R1 ← R1 − R0

Hex: 0624: 18901300

00110 001 001 01: 00110 001 001 001 00 00 10011 000 000 00 R1 ← R1 − R1

Hex: 0625: 18921300

00110 001 001 10: 00110 001 001 010 00 00 10011 000 000 00 R1 ← R1 − R2

Hex: 0626: 18941300

00110 001 001 11: 00110 001 001 011 00 00 10011 000 000 00 R1 ← R1 − R3

Hex: 0627: 18961300

00110 001 010 00: 00110 001 010 000 00 00 10011 000 000 00 R1 ← R2 − R0
Hex: 0628: 18A01300
00110 001 010 01: 00110 001 010 001 00 00 10011 000 000 00 R1 ← R2 − R1
Hex: 0629: 18A21300
00110 001 010 10: 00110 001 010 010 00 00 10011 000 000 00 R1 ← R2 − R2
Hex: 062A: 18A41300
00110 001 010 11: 00110 001 010 011 00 00 10011 000 000 00 R1 ← R2 − R3
Hex: 062B: 18A61300

00110 001 011 00: 00110 001 011 000 00 00 10011 000 000 00 R1 ← R3 − R0
Hex: 062C: 18B01300
00110 001 011 01: 00110 001 011 001 00 00 10011 000 000 00 R1 ← R3 − R1
hex: 062D: 18B21300
00110 001 011 10: 00110 001 011 010 00 00 10011 000 000 00 R1 ← R3 − R2
Hex: 062E: 18B41300
00110 001 011 11: 00110 001 011 011 00 00 10011 000 000 00 R1 ← R3 − R3
Hex: 062F: 18B61300

00110 001 100 00: 00110 001 100 000 00 00 10011 000 000 00 R1 ← PC − R0
Hex: 0630: 18C01300
00110 001 100 01: 00110 001 100 001 00 00 10011 000 000 00 R1 ← PC − R1
Hex: 0631: 18C21300
00110 001 100 10: 00110 001 100 010 00 00 10011 000 000 00 R1 ← PC − R2
Hex: 0632: 18C41300
00110 001 100 11: 00110 001 100 011 00 00 10011 000 000 00 R1 ← PC − R3
Hex: 0633: 18C61300

00110 001 110 00: 00110 001 110 000 00 00 10011 000 000 00 R1 ← AR − R0
Hex: 0638: 18E01300
00110 001 110 01: 00110 001 110 001 00 00 10011 000 000 00 R1 ← AR − R1
Hex: 0639: 18E21300
00110 001 110 10: 00110 001 110 010 00 00 10011 000 000 00 R1 ← AR − R2
Hex: 063A: 18E41300
00110 001 110 11: 00110 001 110 011 00 00 10011 000 000 00 R1 ← AR − R3
Hex: 063B: 18E61300

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00110 001 111 00: 00110 001 111 000 00 00 10011 000 000 00 R1 ← SP − R0
Hex: 063C: 18F01300
00110 001 111 01: 00110 001 111 001 00 00 10011 000 000 00 R1 ← SP − R1
Hex: 063D: 18F21300
00110 001 111 10: 00110 001 111 010 00 00 10011 000 000 00 R1 ← SP − R2
Hex: 063E: 18F41300
00110 001 111 11: 00110 001 111 011 00 00 10011 000 000 00 R1 ← SP − R3
Hex: 063F: 18F61300

R2:
00110 010 000 00: 00110 010 000 000 00 00 10011 000 000 00 R2 ← R0 − R0
Hex: 0640: 19001300
00110 010 000 01: 00110 010 000 001 00 00 10011 000 000 00 R2 ← R0 − R1
Hex: 0641: 19021300
00110 010 000 10: 00110 010 000 010 00 00 10011 000 000 00 R2 ← R0 − R2
Hex: 0642: 19041300
00110 010 000 11: 00110 010 000 011 00 00 10011 000 000 00 R2 ← R0 − R3
Hex: 0643: 19061300

00110 010 001 00: 00110 010 001 000 00 00 10011 000 000 00 R2 ← R1 − R0
Hex: 0644: 19101300
00110 010 001 01: 00110 010 001 001 00 00 10011 000 000 00 R2 ← R1 − R1
Hex: 0645: 19121300
00110 010 001 10: 00110 010 001 010 00 00 10011 000 000 00 R2 ← R1 − R2
Hex: 0646: 19141300
00110 010 001 11: 00110 010 001 011 00 00 10011 000 000 00 R2 ← R1 − R3
Hex: 0647: 19161300

00110 010 010 00: 00110 010 010 000 00 00 10011 000 000 00 R2 ← R2 − R0
Hex: 0648: 19201300
00110 010 010 01: 00110 010 010 001 00 00 10011 000 000 00 R2 ← R2 − R1
Hex: 0649: 19221300
00110 010 010 10: 00110 010 010 010 00 00 10011 000 000 00 R2 ← R2 − R2
Hex: 064A: 19241300
00110 010 010 11: 00110 010 010 011 00 00 10011 000 000 00 R2 ← R2 − R3
Hex: 064B: 19261300

00110 010 011 00: 00110 010 011 000 00 00 10011 000 000 00 R2 ← R3 − R0
Hex: 064C: 19301300
00110 010 011 01: 00110 010 011 001 00 00 10011 000 000 00 R2 ← R3 − R1
Hex: 064D: 19321300
00110 010 011 10: 00110 010 011 010 00 00 10011 000 000 00 R2 ← R3 − R2
Hex: 064E: 19341300
00110 010 011 11: 00110 010 011 011 00 00 10011 000 000 00 R2 ← R3 − R3
Hex: 064F: 19361300

00110 010 100 00: 00110 010 100 000 00 00 10011 000 000 00 R2 ← PC − R0
Hex: 0650: 19401300
00110 010 100 01: 00110 010 100 001 00 00 10011 000 000 00 R2 ← PC − R1
Hex: 0651: 19421300
00110 010 100 10: 00110 010 100 010 00 00 10011 000 000 00 R2 ← PC − R2
Hex: 0652: 19441300
00110 010 100 11: 00110 010 100 011 00 00 10011 000 000 00 R2 ← PC − R3
Hex: 0653: 19461300

00110 010 110 00: 00110 010 110 000 00 00 10011 000 000 00 R2 ← AR − R0
Hex: 0658: 19601300
00110 010 110 01: 00110 010 110 001 00 00 10011 000 000 00 R2 ← AR − R1
Hex: 0659: 19621300
00110 010 110 10: 00110 010 110 010 00 00 10011 000 000 00 R2 ← AR − R2
Hex: 065A: 19641300
00110 010 110 11: 00110 010 110 011 00 00 10011 000 000 00 R2 ← AR − R3
Hex: 065B: 19661300

00110 010 111 00: 00110 010 111 000 00 00 10011 000 000 00 R2 ← SP − R0
Hex: 065C: 19701300
00110 010 111 01: 00110 010 111 001 00 00 10011 000 000 00 R2 ← SP − R1
Hex: 065D: 19721300
00110 010 111 10: 00110 010 111 010 00 00 10011 000 000 00 R2 ← SP − R2
Hex: 065E: 19741300
00110 010 111 11: 00110 010 111 011 00 00 10011 000 000 00 R2 ← SP − R3
Hex: 065F: 19761300

R3:

00110 011 000 00: 00110 011 000 000 00 00 10011 000 000 00 R3 ← R0 − R0
Hex: 0660: 19801300
00110 011 000 01: 00110 011 000 001 00 00 10011 000 000 00 R3 ← R0 − R1
Hex: 0661: 19821300
00110 011 000 10: 00110 011 000 010 00 00 10011 000 000 00 R3 ← R0 − R2
Hex: 0662: 19841300
00110 011 000 11: 00110 011 000 011 00 00 10011 000 000 00 R3 ← R0 − R3
Hex: 0663: 19861300

00110 011 001 00: 00110 011 001 000 00 00 10011 000 000 00 R3 ← R1 − R0
Hex: 0664: 19901300
00110 011 001 01: 00110 011 001 001 00 00 10011 000 000 00 R3 ← R1 − R1
Hex: 0665: 19921300
00110 011 001 10: 00110 011 001 010 00 00 10011 000 000 00 R3 ← R1 − R2
Hex: 0666: 19941300
00110 011 001 11: 00110 011 001 011 00 00 10011 000 000 00 R3 ← R1 − R3
Hex: 0667: 19961300

00110 011 010 00: 00110 011 010 000 00 00 10011 000 000 00 R3 ← R2 − R0
Hex: 0668: 19A01300
00110 011 010 01: 00110 011 010 001 00 00 10011 000 000 00 R3 ← R2 − R1
Hex: 0669: 19A21300
00110 011 010 10: 00110 011 010 010 00 00 10011 000 000 00 R3 ← R2 − R2
Hex: 066A: 19A41300
00110 011 010 11: 00110 011 010 011 00 00 10011 000 000 00 R3 ← R2 − R3
Hex: 066B: 19A61300

00110 011 011 00: 00110 011 011 000 00 00 10011 000 000 00 R3 ← R3 − R0
Hex: 066C: 19B01300
00110 011 011 01: 00110 011 011 001 00 00 10011 000 000 00 R3 ← R3 − R1
Hex: 066D: 19B21300
00110 011 011 10: 00110 011 011 010 00 00 10011 000 000 00 R3 ← R3 − R2
Hex: 066E: 19B41300
00110 011 011 11: 00110 011 011 011 00 00 10011 000 000 00 R3 ← R3 − R3
Hex: 066F: 19B61300

00110 011 100 00: 00110 011 100 000 00 00 10011 000 000 00 R3 ← PC − R0

Hex: 0670: 19C01300

00110 011 100 01: 00110 011 100 001 00 00 10011 000 000 00 R3 ← PC − R1
Hex: 0671: 19C21300

00110 011 100 10: 00110 011 100 010 00 00 10011 000 000 00 R3 ← PC − R2
Hex: 0672: 19C41300

00110 011 100 11: 00110 011 100 011 00 00 10011 000 000 00 R3 ← PC − R3
Hex: 0673: 19C61300

00110 011 110 00: 00110 011 110 000 00 00 10011 000 000 00 R3 ← AR − R0
Hex: 0678: 19E01300

00110 011 110 01: 00110 011 110 001 00 00 10011 000 000 00 R3 ← AR − R1
Hex: 0679: 19E21300

00110 011 110 10: 00110 011 110 010 00 00 10011 000 000 00 R3 ← AR − R2
Hex: 067A: 19E41300

00110 011 110 11: 00110 011 110 011 00 00 10011 000 000 00 R3 ← AR − R3
Hex: 067B: 19E61300

00110 011 111 00: 00110 011 111 000 00 00 10011 000 000 00 R3 ← SP − R0
Hex: 067C: 19F01300

00110 011 111 01: 00110 011 111 001 00 00 10011 000 000 00 R3 ← SP − R1
Hex: 067D: 19F21300

00110 011 111 10: 00110 011 111 010 00 00 10011 000 000 00 R3 ← SP − R2
Hex: 067E: 19F41300

00110 011 111 11: 00110 011 111 011 00 00 10011 000 000 00 R3 ← SP − R3
Hex: 067F: 19F61300

PC:
00110 100 000 00: 00110 100 000 000 00 00 10011 000 000 00 PC ← R0 − R0
Hex: 0680: 1A001300

00110 100 000 01: 00110 100 000 001 00 00 10011 000 000 00 PC ← R0 − R1
Hex: 0681: 1A021300

00110 100 000 10: 00110 100 000 010 00 00 10011 000 000 00 PC ← R0 − R2
Hex: 0682: 1A041300

00110 100 000 11: 00110 100 000 011 00 00 10011 000 000 00 PC ← R0 − R3
Hex: 0683: 1A061300

00110 100 001 00: 00110 100 001 000 00 00 10011 000 000 00 PC ← R1 − R0

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Hex: 0684: 1A101300

00110 100 001 01: 00110 100 001 001 00 00 10011 000 000 00 PC ← R1 – R1

Hex: 0685: 1A121300

00110 100 001 10: 00110 100 001 010 00 00 10011 000 000 00 PC ← R1 – R2

Hex: 0686: 1A141300

00110 100 001 11: 00110 100 001 011 00 00 10011 000 000 00 PC ← R1 – R3

Hex: 0687: 1A161300

00110 100 010 00: 00110 100 010 000 00 00 10011 000 000 00 PC ← R2 – R0

Hex: 0688: 1A201300

00110 100 01001: 00110 100 010 001 00 00 10011 000 000 00 PC ← R2 – R1

Hex: 0689: 1A221300

00110 100 010 10: 00110 100 010 010 00 00 10011 000 000 00 PC ← R2 – R2

Hex: 068A: 1A241300

00110 100 010 11: 00110 100 010 011 00 00 10011 000 000 00 PC ← R2 – R3

Hex: 068B: 1A261300

00110 100 011 00: 00110 100 011 000 00 00 10011 000 000 00 PC ← R3 – R0

Hex: 068C: 1A301300

00110 100 011 01: 00110 100 011 001 00 00 10011 000 000 00 PC ← R3 – R1

Hex: 068D: 1A321300

00110 100 011 10: 00110 100 011 010 00 00 10011 000 000 00 PC ← R3 – R2

Hex: 068E: 1A341300

00110 100 011 11: 00110 100 011 011 00 00 10011 000 000 00 PC ← R3 – R3

Hex: 068F: 1A361300

00110 100 100 00: 00110 100 100 000 00 00 10011 000 000 00 PC ← PC – R0

Hex: 0690: 1A401300

00110 100 100 01: 00110 100 100 001 00 00 10011 000 000 00 PC ← PC – R1

Hex: 0691: 1A421300

00110 100 100 10: 00110 100 100 010 00 00 10011 000 000 00 PC ← PC – R2

Hex: 0692: 1A441300

00110 100 100 11: 00110 100 100 011 00 00 10011 000 000 00 PC ← PC – R3

Hex: 0693: 1A461300

00110 100 110 00: 00110 100 110 000 00 00 10011 000 000 00 PC ← AR – R0

Hex: 0698: 1A601300

00110 100 110 01: 00110 100 110 001 00 00 10011 000 000 00 PC ← AR − R1
Hex: 0699: 1A621300
00110 100 110 10: 00110 100 110 010 00 00 10011 000 000 00 PC ← AR − R2
Hex: 069A: 1A641300
00110 100 110 11: 00110 100 110 011 00 00 10011 000 000 00 PC ← AR − R3
Hex: 069B: 1A661300

00110 100 111 00: 00110 100 111 000 00 00 10011 000 000 00 PC ← SP − R0
Hex: 069C: 1A701300
00110 100 111 01: 00110 100 111 001 00 00 10011 000 000 00 PC ← SP − R1
Hex: 069D: 1A721300
00110 100 111 10: 00110 100 111 010 00 00 10011 000 000 00 PC ← SP − R2
Hex: 069E: 1A741300
00110 100 111 11: 00110 100 111 011 00 00 10011 000 000 00 PC ← SP − R3
Hex: 069F: 1A761300

AR:
00110 110 000 00: 00110 110 000 000 00 00 10011 000 000 00 AR ← R0 − R0
Hex: 06C0: 1B001300
00110 110 000 01: 00110 110 000 001 00 00 10011 000 000 00 AR ← R0 − R1
Hex: 06C1: 1B021300
00110 110 000 10: 00110 110 000 010 00 00 10011 000 000 00 AR ← R0 − R2
Hex: 06C2: 1B041300
00110 110 000 11: 00110 110 000 011 00 00 10011 000 000 00 AR ← R0 − R3
Hex: 06C3: 1B061300

00110 110 001 00: 00110 110 001 000 00 00 10011 000 000 00 AR ← R1 − R0
Hex: 06C4: 1B101300
00110 110 001 01: 00110 110 001 001 00 00 10011 000 000 00 AR ← R1 − R1
Hex: 06C5: 1B121300
00110 110 001 10: 00110 110 001 010 00 00 10011 000 000 00 AR ← R1 − R2
Hex: 06C6: 1B141300
00110 110 001 11: 00110 110 001 011 00 00 10011 000 000 00 AR ← R1 − R3
Hex: 06C7: 1B161300

00110 110 010 00: 00110 110 010 000 00 00 10011 000 000 00 AR ← R2 − R0
Hex: 06C8: 1B201300

00110 110 010 01: 00110 110 010 001 00 00 10011 000 000 00 AR ← R2 − R1
Hex: 06C9: 1B221300
00110 110 010 10: 00110 110 010 010 00 00 10011 000 000 00 AR ← R2 − R2
Hex: 06CA: 1B241300
00110 110 010 11: 00110 110 010 011 00 00 10011 000 000 00 AR ← R2 − R3
Hex: 06CB: 1B261300

   00110 110 011 00: 00110 110 011 000 00 00 10011 000 000 00 AR ← R3 − R0
Hex: 06CC: 1B301300
00110 110 011 01: 00110 110 011 001 00 00 10011 000 000 00 AR ← R3 − R1
Hex: 06CD: 1B321300
00110 110 011 10: 00110 110 011 010 00 00 10011 000 000 00 AR ← R3 − R2
Hex: 06CE: 1B341300
00110 110 011 11: 00110 110 011 011 00 00 10011 000 000 00 AR ← R3 − R3
Hex: 06CF: 1B361300

   00110 110 100 00: 00110 110 100 000 00 00 10011 000 000 00 AR ← PC − R0
Hex: 06D0: 1B401300
00110 110 100 01: 00110 110 100 001 00 00 10011 000 000 00 AR ← PC − R1
Hex: 06D1: 1B421300
00110 110 100 10: 00110 110 100 010 00 00 10011 000 000 00 AR ← PC − R2
Hex: 06D2: 1B441300
00110 110 100 11: 00110 110 100 011 00 00 10011 000 000 00 AR ← PC − R3
Hex: 06D3: 1B461300

   00110 110 110 00: 00110 110 110 000 00 00 10011 000 000 00 AR ← AR − R0
Hex: 06D8: 1B601300
00110 110 110 01: 00110 110 110 001 00 00 10011 000 000 00 AR ← AR − R1
Hex: 06D9: 1B621300
00110 110 110 10: 00110 110 110 010 00 00 10011 000 000 00 AR ← AR − R2
Hex: 06DA: 1B641300
00110 110 110 11: 00110 110 110 011 00 00 10011 000 000 00 AR ← AR − R3
Hex: 06DB: 1B661300

   00110 110 111 00: 00110 110 111 000 00 00 10011 000 000 00 AR ← SP − R0
Hex: 06DC: 1B701300
00110 110 111 01: 00110 110 111 001 00 00 10011 000 000 00 AR ← SP − R1

Hex: 06DD: 1B721300

00110 110 111 10: 00110 110 111 010 00 00 10011 000 000 00 AR ← SP − R2

Hex: 06DE: 1B741300

00110 110 111 11: 00110 110 111 011 00 00 10011 000 000 00 AR ← SP − R3

Hex: 06DF: 1B761300

   SP:

00110 111 000 00: 00110 111 000 000 00 00 10011 000 000 00 SP ← R0 − R0

Hex: 06E0: 1B801300

00110 111 000 01: 00110 111 000 001 00 00 10011 000 000 00 SP ← R0 − R1

Hex: 06E1: 1B821300

00110 111 000 10: 00110 111 000 010 00 00 10011 000 000 00 SP ← R0 − R2

Hex: 06E2: 1B841300

00110 111 000 11: 00110 111 000 011 00 00 10011 000 000 00 SP ← R0 − R3

Hex: 06E3: 1B861300

   00110 111 001 00: 00110 111 001 000 00 00 10011 000 000 00 SP ← R1 − R0

Hex: 06E4: 1B901300

00110 111 001 01: 00110 111 001 001 00 00 10011 000 000 00 SP ← R1 − R1

Hex: 06E5: 1B921300

00110 111 001 10: 00110 111 001 010 00 00 10011 000 000 00 SP ← R1 − R2

Hex: 06E6: 1B941300

00110 111 001 11: 00110 111 001 011 00 00 10011 000 000 00 SP ← R1 − R3

Hex: 06E7: 1B961300

   00110 111 010 00: 00110 111 010 000 00 00 10011 000 000 00 SP ← R2 − R0

Hex: 06E8: 1BA01300

00110 111 010 01: 00110 111 010 001 00 00 10011 000 000 00 SP ← R2 − R1

Hex: 06E9: 1BA21300

00110 111 010 10: 00110 111 010 010 00 00 10011 000 000 00 SP ← R2 − R2

Hex: 06EA: 1BA41300

00110 111 010 11: 00110 111 010 011 00 00 10011 000 000 00 SP ← R2 − R3

Hex: 06EB: 1BA61300

   00110 111 011 00: 00110 111 011 000 00 00 10011 000 000 00 SP ← R3 − R0

Hex: 06EC: 1BB01300

00110 111 011 01: 00110 111 011 001 00 00 10011 000 000 00 SP ← R3 − R1

Hex: 06ED: 1BB21300

00110 111 011 10: 00110 111 011 010 00 00 10011 000 000 00 SP ← R3 – R2

Hex: 06EE: 1BB41300

00110 111 011 11: 00110 111 011 011 00 00 10011 000 000 00 SP ← R3 – R3

Hex: 06EF: 1BB61300

00110 111 100 00: 00110 111 100 000 00 00 10011 000 000 00 SP ← PC – R0

Hex: 06F0: 1BC01300

00110 111 100 01: 00110 111 100 001 00 00 10011 000 000 00 SP ← PC – R1

Hex: 06F1: 1BC21300

00110 111 100 10: 00110 111 100 010 00 00 10011 000 000 00 SP ← PC – R2

Hex: 06F2: 1BC41300

00110 111 100 11: 00110 111 100 011 00 00 10011 000 000 00 SP ← PC – R3

Hex: 06F3: 1BC61300

00110 111 110 00: 00110 111 110 000 00 00 10011 000 000 00 SP ← AR – R0

Hex: 06F8: 1BE01300

00110 111 110 01: 00110 111 110 001 00 00 10011 000 000 00 SP ← AR – R1

Hex: 06F9: 1BE21300

00110 111 110 10: 00110 111 110 010 00 00 10011 000 000 00 SP ← AR – R2

Hex: 06FA: 1BE41300

00110 111 110 11: 00110 111 110 011 00 00 10011 000 000 00 SP ← AR – R3

Hex: 06FB: 1BE61300

00110 111 111 00: 00110 111 111 000 00 00 10011 000 000 00 SP ← SP – R0

Hex: 06FC: 1BF01300

00110 111 111 01: 00110 111 111 001 00 00 10011 000 000 00 SP ← SP – R1

Hex: 06FD: 1BF21300

00110 111 111 10: 00110 111 111 010 00 00 10011 000 000 00 SP ← SP – R2

Hex: 06FE: 1BF41300

00110 111 111 11: 00110 111 111 011 00 00 10011 000 000 00 SP ← SP – R3

Hex: 06FF: 1BF61300

Mapping: Opcode - DESTREG - SRCREG1 - the 2 LSB of SRCREG2 (it can only be a R0 – R3)

- F2 – RegisterFile , F3 – RegisterFile, F4 – RegisterFile

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OutASel = 2 LSB of F3, MuxCSel = 1, OutBSel = 2 LSB of F4

FunSelALU = 0110, MuxASel = 11,

RegSelR = decode F2 and take the 4 LSB outputs of the decoder

FunSelRegister = 01 (Load)

- F2 – RegFile, F3 – AddressFile, F4 – RegFile

OutCSel = the 2 MSB (bit 7, 6) of decoding the F3, MuxCSel = 0

OutBSel = the 2 LSB of F4, FunSelALU = 0110,

MuxASel = 11,

RegSelR = decode F2 and take the 4 LSB outputs of the decoder

FunSelR = 01

- F2 – AddressFile , F3 – RegisterFile, F4 – RegisterFile

OutASel = the 2 LSB of F3, MuxCSel = 1, OutBSel = the 2 LSB of F4

FunSelALU = 0110, MuxBSel = 11,

RegSelAdd = bits 7,6, 4 of the output of decoding the F2

FunSelAdd = 01

- F2 – AddressFile , F3 – AddressFile, F4 – RegisterFile

OutCSel = the 2 MSB (bit 7, 6) of decoding the F3

MuxCSel = 0,

OutBSel = the 2 LSB of F4

FunSelALU = 0110, MuxBSel = 11,

RegSelAdd = bits 7,6, 4 of the output of decoding of F2

FunSelAdd = 01

7 DEC F3 ← F3 − 1

2 clock cycles – first F2 ← F3, then decrement F2

Can already used previous microinstructions

R0:

00111 000 000 00: 00111 101 101 101 00 01 00010 000 000 01 Subroutine to R0 ← R0

Hex: 0700: 1EDA2201

00111 000 000 01: 00111 000 000 000 00 00 10011 000 000 00 R0 ← R0 − 1

Hex: 0701: 1C001300

00111 000 001 00: 00111 101 101 101 00 01 00010 000 001 01 Subroutine to R0 ← R1

Hex: 0704: 1EDA2205

00111 000 001 01: 00111 000 000 000 00 00 10011 000 000 00

- they hold the same thing Hex: 0705: 0705 00111 000 010 00: 00111 101 101 101 00 01 00010 000 010 01 Subroutine to R0 ← R2

Hex: 0708: 1C001300

00111 000 010 01: 00111 000 000 000 00 00 10011 000 000 00

0709: 1C001300

00111 000 011 00: 00111 101 101 101 00 01 00010 000 011 01 Subroutine to R0 ← R3

Hex: 070C: 1EDA220D

00111 000 011 01: 00111 000 000 000 00 00 10011 000 000 00

070D: 1C001300

00111 000 100 00: 00111 101 101 101 00 01 00010 000 100 01 Subroutine to R0 ← PC

Hex: 0710: 1EDA2211

00111 000 100 01: 00111 000 000 000 00 00 10011 000 000 00

0711: 1C001300

00111 000 110 00: 00111 101 101 101 00 01 00010 000 110 01 Subroutine to R0 ← AR

Hex: 0718: 1EDA2219

00111 000 110 01: 00111 000 000 000 00 00 10011 000 000 00

0719: 1C001300

00111 000 111 00: 00111 101 101 101 00 01 00010 000 111 01 Subroutine to R0 ← SP

Hex: 071C: 1EDA221D

00111 000 111 01: 00111 000 000 000 00 00 10011 000 000 00

071D: 1C001300

R1:

00111 001 000 00: 00111 101 101 101 00 01 00010 001 000 01 Subroutine to R1 ← R0

Hex: 0720: 1EDA2221

00111 001 000 01: 00111 001 001 000 00 00 10011 000 000 00 R1 ← R1 − 1

Hex: 0721: 1C901300

00111 001 001 00: 00111 101 101 101 00 01 00010 001 001 01 Subroutine to R1 ← R1

Hex: 0724: 1EDA2225

00111 001 001 01: 00111 001 001 000 00 00 10011 000 000 00

0725: 1C901300

00111 001 010 00: 00111 101 101 101 00 01 00010 001 010 01 Subroutine to R1 ← R2

Hex: 0728: 1EDA2229

00111 001 010 01: 00111 001 001 000 00 00 10011 000 000 00

0729: 1C901300

00111 001 011 00: 00111 101 101 101 00 01 00010 001 011 01 Subroutine to R1 ← R3

Hex: 072C: 1EDA222D

00111 001 011 01: 00111 001 001 000 00 00 10011 000 000 00

072D: 1C901300

00111 001 100 00: 00111 101 101 101 00 01 00010 001 100 01 Subroutine to R1 ← PC

Hex: 0730: 1EDA2231

00111 001 100 01: 00111 001 001 000 00 00 10011 000 000 00

0731: 1C901300

00111 001 110 00: 00111 101 101 101 00 01 00010 001 110 01 Subroutine to R1 ← AR

Hex: 0738: 1EDA2239

00111 001 110 01: 00111 001 001 000 00 00 10011 000 000 00

0739: 1C901300

00111 001 111 00: 00111 101 101 101 00 01 00010 001 111 01 Subroutine to R1 ← SP

Hex: 073C: 1EDA223D

00111 001 111 01: 00111 001 001 000 00 00 10011 000 000 00

073D: 1C901300

R2:

00111 010 000 00: 00111 101 101 101 00 01 00010 010 000 01 Subroutine to R2 ← R0

Hex: 0740: 1EDA2241

00111 010 000 01: 00111 010 010 000 00 00 10011 000 000 00 R2 ← R2 − 1

Hex: 0741: 1D201300

00111 010 001 00: 00111 101 101 101 00 01 00010 010 001 01 Subroutine to R2 ← R1

Hex: 0744: 1EDA2245

00111 010 001 01: 00111 010 010 000 00 00 10011 000 000 00

0745: 1D201300

00111 010 010 00: 00111 101 101 101 00 01 00010 010 010 01 Subroutine to R2 ← R2

0748: 1EDA2249

00111 010 010 01: 00111 010 010 000 00 00 10011 000 000 00

0749: 1D201300

00111 010 011 00: 00111 101 101 101 00 01 00010 010 011 01 Subroutine to R2 ← R3

Hex: 074C: 1EDA224D

00111 010 011 01: 00111 010 010 000 00 00 10011 000 000 00

074D: 1D201300

00111 010 100 00: 00111 101 101 101 00 01 00010 010 100 01 Subroutine to R2 ← PC

Hex: 0750: 1EDA2251

00111 010 100 01: 00111 010 010 000 00 00 10011 000 000 00

0751: 1D201300

00111 010 110 00: 00111 101 101 101 00 01 00010 010 110 01 Subroutine to R2 ← AR

Hex: 0758: 1EDA2259

00111 010 110 01: 00111 010 010 000 00 00 10011 000 000 00

0759: 1D201300

00111 010 111 00: 00111 101 101 101 00 01 00010 010 111 01 Subroutine to R2 ← SP

Hex: 075C: 1EDA225D

00111 010 111 01: 00111 010 010 000 00 00 10011 000 000 00

075D: 1D201300

R3:

00111 011 000 00: 00111 101 101 101 00 01 00010 011 000 01 Subroutine to R3 ← R0

Hex: 0760: 1EDA2261

00111 011 000 01: 00111 011 011 000 00 00 10011 000 000 00 R3 ← R3 - 1

Hex: 0761: 1DB01300

00111 011 001 00: 00111 101 101 101 00 01 00010 011 001 01 Subroutine to R3 ← R1

Hex: 0764: 1EDA2265

00111 011 001 01: 00111 011 011 000 00 00 10011 000 000 0

0765: 1DB01300

00111 011 010 00: 00111 101 101 101 00 01 00010 011 010 01 Subroutine to R3 ← R2

Hex: 0768: 1EDA2269

00111 011 010 01: 00111 011 011 000 00 00 10011 000 000 0

0769: 1DB01300

00111 011 011 00: 00111 101 101 101 00 01 00010 011 011 01 Subroutine to R3 ← R3

Hex: 076C: 1EDA226D

00111 011 011 01: 00111 011 011 000 00 00 10011 000 000 0

076D: 1DB01300

00111 011 100 00: 00111 101 101 101 00 01 00010 011 100 01 Subroutine to R3 ← PC

Hex: 0770: 1EDA2271

00111 011 100 01: 00111 011 011 000 00 00 10011 000 000 0

0771: 1DB01300

00111 011 110 00: 00111 101 101 101 00 01 00010 011 110 01 Subroutine to R3 ← AR

Hex: 0778: 1EDA2279

00111 011 110 01: 00111 011 011 000 00 00 10011 000 000 0

0779: 1DB01300

00111 011 111 00: 00111 101 101 101 00 01 00010 011 111 01 Subroutine to R3 ← SP

Hex: 077C: 1EDA227D

00111 011 111 01: 00111 011 011 000 00 00 10011 000 000 0

077D: 1DB01300

PC:

00111 100 000 00: 00111 101 101 101 00 01 00010 100 000 01 Subroutine to PC ← R0

Hex: 0780: 1EDA2281

00111 100 000 01: 00111 100 100 000 00 00 10011 000 000 00 PC ← PC - 1

Hex: 0781: 1E401300

00111 100 001 00: 00111 101 101 101 00 01 00010 100 001 01 Subroutine to PC ← R1

Hex: 0784: 1EDA2285

00111 100 001 01: 00111 100 100 000 00 00 10011 000 000 00

0785: 1E401300

00111 100 010 00: 00111 101 101 101 00 01 00010 100 010 01 Subroutine to PC ← R2

Hex: 0788: 1EDA2289

00111 100 010 01: 00111 100 100 000 00 00 10011 000 000 00

0789: 1E401300

00111 100 011 00: 00111 101 101 101 00 01 00010 100 011 01 Subroutine to PC ← R3

Hex: 078C: 1EDA228D

00111 100 011 01: 00111 100 100 000 00 00 10011 000 000 00

078D: 1E401300

00111 100 100 00: 00111 101 101 101 00 01 00010 100 100 01 Subroutine to PC ← PC

Hex: 0790: 1EDA2291

00111 100 100 01: 00111 100 100 000 00 00 10011 000 000 00

0791: 1E401300

00111 100 110 00: 00111 101 101 101 00 01 00010 100 110 01 Subroutine to PC ← AR

Hex: 0798: 1EDA2299

00111 100 110 01: 00111 100 100 000 00 00 10011 000 000 00

0799: 1E401300

00111 100 111 00: 00111 101 101 101 00 01 00010 100 111 01 Subroutine to PC ← SP

Hex: 079C: 1EDA229D

00111 100 111 01: 00111 100 100 000 00 00 10011 000 000 00

079D: 1E401300

AR:

00111 110 000 00: 00111 101 101 101 00 01 00010 110 000 01 Subroutine to AR ← R0

Hex: 07C0: 1EDA22C1

00111 110 000 01: 00111 110 110 000 00 00 10011 000 000 00 AR ← AR − 1

Hex: 07C1: 1F601300

00111 110 001 00: 00111 101 101 101 00 01 00010 110 001 01 Subroutine to AR ← R1

Hex: 07C4: 1EDA22C5

00111 110 001 01: 00111 110 110 000 00 00 10011 000 000 00

07C5: 1F601300

00111 110 010 00: 00111 101 101 101 00 01 00010 110 010 01 Subroutine to AR ← R2

Hex: 07C8: 1EDA22C9

00111 110 010 01: 00111 110 110 000 00 00 10011 000 000 00

07C9: 1F601300

00111 110 011 00: 00111 101 101 101 00 01 00010 110 011 01 Subroutine to AR ← R3

Hex: 07CC: 1EDA22CD

00111 110 011 01: 00111 110 110 000 00 00 10011 000 000 00

07CD: 1F601300

00111 110 100 00: 00111 101 101 101 00 01 00010 110 100 01 Subroutine to AR ← PC

Hex: 07D0: 1EDA22D1

00111 110 100 01: 00111 110 110 000 00 00 10011 000 000 00

07D1: 1F601300

00111 110 110 00: 00111 101 101 101 00 01 00010 110 110 01 Subroutine to AR ← AR

Hex: 07D8: 1EDA22D9

00111 110 110 01: 00111 110 110 000 00 00 10011 000 000 00

07D9: 1F601300

00111 110 111 00: 00111 101 101 101 00 01 00010 110 111 01 Subroutine to AR ← SP

Hex: 07DC: 1EDA22DD

00111 110 111 01: 00111 110 110 000 00 00 10011 000 000 00

07DD : 1EDA22DD

SP:

00111 111 000 00: 00111 101 101 101 00 01 00010 111 000 01 Subroutine to SP ← R0

07E0: 1EDA22E1

00111 111 000 01: 00111 111 111 000 00 00 10100 000 000 00 SP ¡- SP − 1

Hex: 07E1: 1FF01400– goes to check subroutine part

00111 111 001 00: 00111 101 101 101 00 01 00010 111 001 01 Subroutine to SP ← R1

Hex: 07E4: 1EDA22E5

00111 111 001 01: 00111 101 101 101 00 01 00010 111 001 01

07E5: 1FF01400

00111 111 010 00: 00111 101 101 101 00 01 00010 111 010 01 Subroutine to SP ← R2

Hex: 07E8: 1EDA22E9

00111 111 010 01: 00111 101 101 101 00 01 00010 111 001 01

07E9: 1FF01400

00111 111 011 00: 00111 101 101 101 00 01 00010 111 011 01 Subroutine to SP ← R3

Hex: 07EC: 1EDA22ED

00111 111 011 01: 00111 101 101 101 00 01 00010 111 001 01

07ED: 1FF01400

00111 111 100 00: 00111 101 101 101 00 01 00010 111 100 01 Subroutine to SP ← PC

Hex: 07F0: 1EDA22F1

00111 111 100 01: 00111 101 101 101 00 01 00010 111 001 01

07F1: 1FF01400

00111 111 110 00: 00111 101 101 101 00 01 00010 111 110 01 Subroutine to SP ← AR

Hex: 07F8: 1EDA22F9

00111 111 110 01: 00111 101 101 101 00 01 00010 111 001 01

07F9: 1FF01400

00111 111 111 00: 00111 101 101 101 00 01 00010 111 111 01 Subroutine to SP ← SP

Hex: 07FC: 1EDA22FD

00111 111 111 01: 00111 101 101 101 00 01 00010 111 001 01

07FD: 1FF01400

Mapping: Opcode DESTREG SRCREG1 00

- F2 – RegFile

RegSelRegister = decode F2 and take the 4 LSB outputs of the decoder
FunSelR = 11 (decrement)

- F2 – AddressFile

RegSelAddress = bits 7,6, 4 of the output of decoding F2
FunSelAdd= 11

8 INC F2 ← F3 + 1

2 clock cycles – first F2 ← F3, then increment F2

Can already used previous microinstructions

R0:

01000 000 000 00: 01000 101 101 101 00 01 00010 000 000 01 Subroutine to R0 ← R0

Hex: 0800: 22DA2201

01000 000 000 01: 01000 000 000 000 00 00 10011 000 000 00 R0 ← R0 + 1

Hex: 0801: 20001300

01000 000 001 00: 01000 101 101 101 00 01 00010 000 001 01 Subroutine to R0 ← R1

Hex: 0804: 22DA2205

01000 000 001 01: 01000 000 000 000 00 00 10011 000 000 00

hex: 0805: 20001300

01000 000 010 00: 01000 101 101 101 00 01 00010 000 010 01 Subroutine to R0 ← R2

Hex: 0808: 22DA2209

01000 000 010 01: 01000 000 000 000 00 00 10011 000 000 00

hex: 0809: 20001300

01000 000 011 00: 01000 101 101 101 00 01 00010 000 011 01 Subroutine to R0 ← R3

Hex: 080C: 22DA220D

01000 000 011 01: 01000 000 000 000 00 00 10011 000 000 00

hex: 080D: 20001300

01000 000 100 00: 01000 101 101 101 00 01 00010 000 100 01 Subroutine to R0 ← PC

Hex: 0810: 22DA2211

01000 000 100 01: 01000 000 000 000 00 00 10011 000 000 00

hex: 0811: 20001300

01000 000 110 00: 01000 101 101 101 00 01 00010 000 110 01 Subroutine to R0 ← AR

Hex: 0818: 22DA2219

01000 000 110 01: 01000 000 000 000 00 00 10011 000 000 00

hex: 0819: 20001300

01000 000 111 00: 01000 101 101 101 00 01 00010 000 111 01 Subroutine to R0 ← SP

Hex: 081C: 22DA221D

01000 000 111 01: 01000 000 000 000 00 00 10011 000 000 00

hex: 081D: 20001300

R1:

01000 001 000 00: 01000 101 101 101 00 01 00010 001 000 01 Subroutine to R1 ← R0

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Hex: 0820: 22DA2221

01000 001 000 01: 01000 001 001 000 00 00 10011 000 000 00 R1 ← R1 + 1

Hex: 0821: 20901300

01000 001 001 00: 01000 101 101 101 00 01 00010 001 001 01 Subroutine to R1 ← R1

Hex: 0824: 22DA2225

01000 001 001 01: 01000 001 001 000 00 00 10011 000 000 00

hex: 0825: 20901300

01000 001 010 00: 01000 101 101 101 00 01 00010 001 010 01 Subroutine to R1 ← R2

Hex: 0828: 22DA2229

01000 001 010 01: 01000 001 001 000 00 00 10011 000 000 00

hex: 0829: 20901300

01000 001 011 00: 01000 101 101 101 00 01 00010 001 011 01 Subroutine to R1 ← R3

Hex: 082C: 22DA222D

01000 001 011 01: 01000 001 001 000 00 00 10011 000 000 00

hex: 082D: 20901300

01000 001 100 00: 01000 101 101 101 00 01 00010 001 100 01 Subroutine to R1 ← PC

Hex: 0830: 22DA2231

01000 001 100 01: 01000 001 001 000 00 00 10011 000 000 00

hex: 0831: 20901300

01000 001 110 00: 01000 101 101 101 00 01 00010 001 110 01 Subroutine to R1 ← AR

Hex: 0838: 22DA2239

01000 001 110 01: 01000 001 001 000 00 00 10011 000 000 00

hex: 0839: 20901300

01000 001 111 00: 01000 101 101 101 00 01 00010 001 111 01 Subroutine to R1 ← SP

Hex: 083C: 22DA223D

01000 001 111 01: 01000 001 001 000 00 00 10011 000 000 00

hex: 083D: 20901300

R2:

01000 010 000 00: 01000 101 101 101 00 01 00010 010 000 01 Subroutine to R2 ← R0

Hex: 0840: 22DA2241

01000 010 000 01: 01000 010 010 000 00 00 10011 000 000 00 R2 ← R2 + 1

Hex: 0841: 21201300

01000 010 001 00: 01000 101 101 101 00 01 00010 010 001 01 Subroutine to R2 ← R1

Hex: 0844: 22DA2245

01000 010 001 01: 01000 010 010 000 00 00 10011 000 000 00

hex: 0845: 21201300

01000 010 010 00: 01000 101 101 101 00 01 00010 010 010 01 Subroutine to R2 ← R2

Hex: 0848: 22DA2249

01000 010 010 01: 01000 010 010 000 00 00 10011 000 000 00

hex: 0849: 21201300

01000 010 011 00: 01000 101 101 101 00 01 00010 010 011 01 Subroutine to R2 ← R3

Hex: 084C: 22DA224D

01000 010 011 01: 01000 010 010 000 00 00 10011 000 000 00

hex: 084D: 21201300

01000 010 100 00: 01000 101 101 101 00 01 00010 010 100 01 Subroutine to R2 ← PC

Hex: 0850: 22DA2251

01000 010 100 01:01000 010 010 000 00 00 10011 000 000 00

hex: 0851: 21201300

01000 010 110 00: 01000 101 101 101 00 01 00010 010 110 01 Subroutine to R2 ← AR

Hex: 0858: 22DA2259

01000 010 110 01: 01000 010 010 000 00 00 10011 000 000 00

hex: 0859: 21201300

01000 010 111 00: 01000 101 101 101 00 01 00010 010 111 01 Subroutine to R2 ← SP

Hex: 085C: 22DA225D

01000 010 111 01: 01000 010 010 000 00 00 10011 000 000 00

hex: 085D: 21201300

R3:

01000 011 000 00: 01000 101 101 101 00 01 00010 011 000 01 Subroutine to R3 ← R0

Hex: 0860: 22DA2261

01000 011 000 01: 01000 011 011 000 00 00 10011 000 000 00 R3 ← R3 + 1

Hex: 0861: 21B01300

01000 011 001 00: 01000 101 101 101 00 01 00010 011 001 01 Subroutine to R3 ← R1

Hex: 0864: 22DA2265

01000 011 001 01: 01000 011 011 000 00 00 10011 000 000 00

hex: 0865: 21B01300

01000 011 010 00: 01000 101 101 101 00 01 00010 011 010 01 Subroutine to R3 ← R2

Hex: 0868: 22DA2269

01000 011 010 01: 01000 011 011 000 00 00 10011 000 000 00

hex: 0869: 21B01300

01000 011 011 00: 01000 101 101 101 00 01 00010 011 011 01 Subroutine to R3 ← R3

Hex: 086C: 22DA226D

01000 011 011 01: 01000 011 011 000 00 00 10011 000 000 00

hex: 086D: 21B01300

01000 011 100 00: 01000 101 101 101 00 01 00010 011 100 01 Subroutine to R3 ← PC

Hex: 0870: 22DA2271

01000 011 100 01: 01000 011 011 000 00 00 10011 000 000 00

hex: 0871: 21B01300

01000 011 110 00: 01000 101 101 101 00 01 00010 011 110 01 Subroutine to R3 ← AR

Hex: 0878: 22DA2279

01000 011 110 01: 01000 011 011 000 00 00 10011 000 000 00

hex: 0879: 21B01300

01000 011 111 00: 01000 101 101 101 00 01 00010 011 111 01 Subroutine to R3 ← SP

Hex: 087C: 22DA227D

01000 011 111 01: 01000 011 011 000 00 00 10011 000 000 00

hex: 087D: 21B01300

PC:

01000 100 000 00: 01000 101 101 101 00 01 00010 100 000 01 Subroutine to PC ← R0

Hex: 0880: 22DA2281

01000 100 000 01: 01000 100 100 000 00 00 10011 000 000 00 PC ← PC + 1

Hex: 0881: 22401300

Could add a new address and hold the special PC ← PC + 1 that is used as a subroutine:

01000 100 000 10: 01000 100 100 000 00 10 10011 000 000 00

Hex: 0882: 22405300

01000 100 001 00: 01000 101 101 101 00 01 00010 100 001 01 Subroutine to PC ← R1

Hex: 0884: 22DA2285

01000 100 001 01: 01000 100 100 000 00 10 10011 000 000 00

hex: 0885: 22401300

01000 100 010 00: 01000 101 101 101 00 01 00010 100 010 01 Subroutine to PC ← R2

Hex: 0888: 22DA2289

01000 100 010 01: 01000 100 100 000 00 10 10011 000 000 00

hex: 0889: 22401300

01000 100 011 00: 01000 101 101 101 00 01 00010 100 011 01 Subroutine to PC ← R3

Hex: 088C: 22DA228D

01000 100 011 01: 01000 100 100 000 00 10 10011 000 000 00

hex: 088D: 22401300

01000 100 100 00: 01000 101 101 101 00 01 00010 100 100 01 Subroutine to PC ← PC

Hex: 0890: 22DA2291

01000 100 100 01: 01000 100 100 000 00 10 10011 000 000 00

hex: 0891: 22401300

01000 100 110 00: 01000 101 101 101 00 01 00010 100 110 01 Subroutine to PC ← AR

Hex: 0898: 22DA2299

01000 100 110 01: 01000 100 100 000 00 10 10011 000 000 00

hex: 0899: 22401300

01000 100 111 00: 01000 101 101 101 00 01 00010 100 111 01 Subroutine to PC ← SP

Hex: 089C: 22DA229D

01000 100 111 01: 01000 100 100 000 00 10 10011 000 000 00

hex: 089D: 22401300

AR:

01000 110 000 00: 01000 101 101 101 00 01 00010 110 000 01 Subroutine to AR ← R0

Hex: 08C0: 22DA22C1

01000 110 000 01: 01000 110 110 000 00 00 10011 000 000 00 AR ← AR + 1

Hex: 08C1: 23601300

01000 110 001 00: 01000 101 101 101 00 01 00010 110 001 01 Subroutine to AR ← R1

Hex: 08C4: 22DA22C5

01000 110 001 01: 01000 110 110 000 00 00 10011 000 000 00

hex: 08C5: 23601300

01000 110 010 00: 01000 101 101 101 00 01 00010 110 010 01 Subroutine to AR ← R2

Hex: 08C8: 22DA22C9

01000 110 010 01: 01000 110 110 000 00 00 10011 000 000 00

hex: 08C9: 23601300

01000 110 011 00: 01000 101 101 101 00 01 00010 110 011 01 Subroutine to AR ← R3

Hex: 08CC: 22DA22CD

01000 110 011 01: 01000 110 110 000 00 00 10011 000 000 00

hex: 08CD: 23601300

01000 110 100 00: 01000 101 101 101 00 01 00010 110 100 01 Subroutine to AR ← PC

Hex: 08D0: 22DA22D1

01000 110 100 01: 01000 110 110 000 00 00 10011 000 000 00

hex: 08D1: 23601300

01000 110 110 00: 01000 101 101 101 00 01 00010 110 110 01 Subroutine to AR ← AR

Hex: 08D8: 22DA22D9

01000 110 110 01: 01000 110 110 000 00 00 10011 000 000 00

hex: 08D9: 23601300

01000 110 111 00: 01000 101 101 101 00 01 00010 110 111 01 Subroutine to AR ← SP

Hex: 08DC: 22DA22DD

01000 110 111 01: 01000 110 110 000 00 00 10011 000 000 00

hex: 08DD: 23601300

need to jump to the subroutine return check when for SP ← SP + 1

SP:

01000 111 000 00: 01000 101 101 101 00 01 00010 111 000 01 Subroutine to SP ← R0

Hex: 08E0: 22DA22E1

01000 111 000 01: 01000 111 111 000 00 00 10100 000 000 00 SP ← SP + 1

Hex: 08E1: 23F01400

01000 111 001 00: 01000 101 101 101 00 01 00010 111 001 01 Subroutine to SP ← R1

Hex: 08E4: 22DA22E5

01000 111 001 01: 01000 111 111 000 00 00 10100 000 000 00

hex: 08E5: 23F01400

01000 111 010 00: 01000 101 101 101 00 01 00010 111 010 01 Subroutine to SP ← R2

Hex: 08E8: 22DA22E9

01000 111 010 01: 01000 111 111 000 00 00 10100 000 000 00

hex: 08E9: 23F01400

01000 111 011 00: 01000 101 101 101 00 01 00010 111 011 01 Subroutine to SP ← R3

Hex: 08EC: 22DA22ED

01000 111 011 01: 01000 111 111 000 00 00 10100 000 000 00

hex: 08ED: 23F01400

01000 111 100 00: 01000 101 101 101 00 01 00010 111 100 01 Subroutine to SP ← PC

Hex: 08F0: 22DA22F1

01000 111 100 01: 01000 111 111 000 00 00 10100 000 000 00

hex: 08F1: 23F01400

01000 111 110 00: 01000 101 101 101 00 01 00010 111 110 01 Subroutine to SP ← AR

Hex: 08F8: 22DA22F9

01000 111 110 01: 01000 111 111 000 00 00 10100 000 000 00

hex: 08F9: 23F01400

01000 111 111 00: 01000 101 101 101 00 01 00010 111 111 01 Subroutine to SP ← SP

Hex: 08FC: 22DA22FD

01000 111 111 01: 01000 111 111 000 00 00 10100 000 000 00

hex: 08FD: 23F01400

Mapping: Opcode DESTREG SRCREG1 00

- F2 – RegFile

RegSelRegister = decode F2 and take the 4 LSB outputs of the decoder
FunSelR = 10 (increment)

- F2 – AddressFile

RegSelAddress = bits 7, 6, 4 of the output of decoding F2
FunSelAdd= 10

9 F2 ← F3 AND F4

R0:

01001 000 000 00: 01001 000 000 000 00 00 10011 000 000 00 R0 ← R0 AND R0
Hex: 0900: 24001300

01001 000 000 01: 01001 000 000 001 00 00 10011 000 000 00 R0 ← R0 AND R1
Hex: 0901: 24021300

01001 000 000 10: 01001 000 000 010 00 00 10011 000 000 00 R0 ← R0 AND R2
Hex: 0902: 24041300

01001 000 000 11: 01001 000 000 011 00 00 10011 000 000 00 R0 ← R0 AND R3
Hex: 0903: 24061300

01001 000 001 00: 01001 000 000 100 00 00 10011 000 000 00 R0 ← R0 AND PC
Hex: 0904: 24081300

01001 000 001 10: 01001 000 000 110 00 00 10011 000 000 00 R0 ← R0 AND AR
Hex: 0906: 240C1300

01001 000 001 11: 01001 000 000 111 00 00 10011 000 000 00 R0 ← R0 AND SP
Hex: 0907: 240E1300

01001 000 010 01: 01001 000 001 001 00 00 10011 000 000 00 R0 ← R1 AND R1
Hex: 0909: 24121300

01001 000 010 10: 01001 000 001 010 00 00 10011 000 000 00 R0 ← R1 AND R2
Hex: 090A: 24141300

01001 000 010 11: 01001 000 001 011 00 00 10011 000 000 00 R0 ← R1 AND R3
Hex: 090B: 24161300

01001 000 011 00: 01001 000 001 100 00 00 10011 000 000 00 R0 ← R1 AND PC
Hex: 090C: 24181300

01001 000 011 10: 01001 000 001 110 00 00 10011 000 000 00 R0 ← R1 AND AR
Hex: 090E: 241C1300

01001 000 011 11: 01001 000 001 111 00 00 10011 000 000 00 R0 ← R1 AND SP

Hex: 090F: 241E1300

01001 000 100 10: 01001 000 010 010 00 00 10011 000 000 00 R0 ← R2 AND R2

Hex: 0912: 24241300

01001 000 100 11: 01001 000 010 011 00 00 10011 000 000 00 R0 ← R2 AND R3

Hex: 0913: 24261300

01001 000 101 00: 01001 000 010 100 00 00 10011 000 000 00 R0 ← R2 AND PC

Hex: 0914: 24281300

01001 000 101 10: 01001 000 010 110 00 00 10011 000 000 00 R0 ← R2 AND AR

Hex: 0916: 242C1300

01001 000 101 11: 01001 000 010 111 00 00 10011 000 000 00 R0 ← R2 AND SP

Hex: 0917: 242E1300

01001 000 110 11: 01001 000 011 011 00 00 10011 000 000 00 R0 ← R3 AND R3

Hex: 091B: 24361300

01001 000 111 00: 01001 000 011 100 00 00 10011 000 000 00 R0 ← R3 AND PC

Hex: 091C: 24381300

01001 000 111 10: 01001 000 011 110 00 00 10011 000 000 00 R0 < − ← R3 AND AR

Hex: 091E: 243C1300

01001 000 111 11: 01001 000 011 111 00 00 10011 000 000 00 R0 ← R3 AND SP

Hex: 091F: 243E1300

22 instructions for first case

R1:

01001 001 000 00: 01001 001 000 000 00 00 10011 000 000 00 R1 ← R0 AND R0

Hex: 0920: 24801300

01001 001 000 01: 01001 001 000 001 00 00 10011 000 000 00 R1 ← R0 AND R1

Hex: 0921: 24821300

01001 001 000 10: 01001 001 000 010 00 00 10011 000 000 00 R1 ← R0 AND R2

Hex: 0922: 24841300

01001 001 000 11: 01001 001 000 011 00 00 10011 000 000 00 R1 ← R0 AND R3

Hex: 0923: 24861300

01001 001 001 00: 01001 001 000 100 00 00 10011 000 000 00 R1 ← R0 AND PC

Hex: 0924: 24881300

01001 001 001 10: 01001 001 000 110 00 00 10011 000 000 00 R1 ← R0 AND AR

Hex: 0926: 248C1300

01001 001 001 11: 01001 001 000 111 00 00 10011 000 000 00 R1 ← R0 AND SP
Hex: 0927: 248E1300

01001 001 010 01: 01001 001 001 001 00 00 10011 000 000 00 R1 ← R1 AND R1
Hex: 0929: 24921300
01001 001 010 10: 01001 001 001 010 00 00 10011 000 000 00 R1 ← R1 AND R2
Hex: 092A: 24941300
01001 001 010 11: 01001 001 001 011 00 00 10011 000 000 00 R1 ← R1 AND R3
Hex: 092B: 24961300
01001 001 011 00: 01001 001 001 100 00 00 10011 000 000 00 R1 ← R1 AND PC
Hex: 092C: 24981300
01001 001 011 10: 01001 001 001 110 00 00 10011 000 000 00 R1 ← R1 AND AR
Hex: 092E: 249C1300
01001 001 011 11: 01001 001 001 111 00 00 10011 000 000 00 R1 ← R1 AND SP
Hex: 092F: 249E1300

01001 001 100 10: 01001 001 010 010 00 00 10011 000 000 00 R1 ← R2 AND R2
Hex: 0932: 24A41300
01001 001 100 11: 01001 001 010 011 00 00 10011 000 000 00 R1 ← R2 AND R3
Hex: 0933: 24A61300
01001 001 101 00: 01001 001 010 100 00 00 10011 000 000 00 R1 ← R2 AND PC
Hex: 0934: 24A81300
01001 001 101 10: 01001 001 010 110 00 00 10011 000 000 00 R1 ← R2 AND AR
Hex: 0936: 24AC1300
01001 001 101 11: 01001 001 010 111 00 00 10011 000 000 00 R1 ← R2 AND SP
Hex: 0937: 24AE1300

01001 001 110 11: 01001 001 011 011 00 00 10011 000 000 00 R1 ← R3 AND R3
Hex: 093B: 24B61300
01001 001 111 00: 01001 001 011 100 00 00 10011 000 000 00 R1 ← R3 AND PC
Hex: 093C: 24B81300
01001 001 111 10: 01001 001 011 110 00 00 10011 000 000 00 R1 ← R3 AND AR
Hex: 093E: 24BC1300
01001 001 111 11: 01001 001 011 111 00 00 10011 000 000 00 R1 ← R3 AND SP
Hex: 093F: 24BE1300

R2:

01001 010 000 00: 01001 010 000 000 00 00 10011 000 000 00 R2 ← R0 AND R0
Hex: 0940: 25001300
01001 010 000 01: 01001 010 000 001 00 00 10011 000 000 00 R2 ← R0 AND R1
Hex: 0941: 25021300
01001 010 000 10: 01001 010 000 010 00 00 10011 000 000 00 R2 ← R0 AND R2
Hex: 0942: 25041300
01001 010 000 11: 01001 010 000 011 00 00 10011 000 000 00 R2 ← R0 AND R3
Hex: 0943: 25061300
01001 010 001 00: 01001 010 000 100 00 00 10011 000 000 00 R2 ← R0 AND PC
Hex: 0944: 25081300
01001 010 001 10: 01001 010 000 110 00 00 10011 000 000 00 R2 ← R0 AND AR
Hex: 0946: 250C1300
01001 010 001 11: 01001 010 000 111 00 00 10011 000 000 00 R2 ← R0 AND SP
Hex: 0947: 250E1300

01001 010 010 01: 01001 010 001 001 00 00 10011 000 000 00 R2 ← R1 AND R1
Hex: 0949: 25121300
01001 010 010 10: 01001 010 001 010 00 00 10011 000 000 00 R2 ← R1 AND R2
Hex: 094A: 25141300
01001 010 010 11: 01001 010 001 011 00 00 10011 000 000 00 R2 ← R1 AND R3
Hex: 094B: 25161300
01001 010 011 00: 01001 010 001 100 00 00 10011 000 000 00 R2 ← R1 AND PC
Hex: 094C: 25181300
01001 010 011 10: 01001 010 001 110 00 00 10011 000 000 00 R2 ← R1 AND AR
Hex: 094E: 251C1300
01001 010 011 11: 01001 010 001 111 00 00 10011 000 000 00 R2 ← R1 AND SP
Hex: 094F: 251E1300

01001 010 100 10: 01001 010 010 010 00 00 10011 000 000 00 R2 ← R2 AND R2
Hex: 0952: 25241300
01001 010 100 11: 01001 010 010 011 00 00 10011 000 000 00 R2 ← R2 AND R3
Hex: 0953: 25261300
01001 010 101 00: 01001 010 010 100 00 00 10011 000 000 00 R2 ← R2 AND PC
Hex: 0954: 25281300
01001 010 101 10: 01001 010 010 110 00 00 10011 000 000 00 R2 ← R2 AND AR
Hex: 0956: 252C1300
01001 010 101 11: 01001 010 010 111 00 00 10011 000 000 00 R2 ← R2 AND SP

Hex: 0957: 252E1300

01001 010 110 11: 01001 010 011 011 00 00 10011 000 000 00 R2 ← R3 AND R3
Hex: 095B: 25361300
01001 010 111 00: 01001 010 011 100 00 00 10011 000 000 00 R2 ← R3 AND PC
Hex: 095C: 25381300
01001 010 111 10: 01001 010 011 110 00 00 10011 000 000 00 R2 ← R3 AND AR
Hex: 095E: 253C1300
01001 010 111 11: 01001 010 011 111 00 00 10011 000 000 00 R2 ← R3 AND SP
Hex: 095F: 253E1300

Remember – we cant have 2 address file registers on the right hand side – only 1

R3:
01001 011 000 00: 01001 011 000 000 00 00 10011 000 000 00 R3 ← R0 AND R0
Hex: 0960: 25801300
01001 011 000 01: 01001 011 000 001 00 00 10011 000 000 00 R3 ← R0 AND R1
Hex: 0961: 25821300
01001 011 000 10: 01001 011 000 010 00 00 10011 000 000 00 R3 ← R0 AND R2
Hex: 0962: 25841300
01001 011 000 11: 01001 011 000 011 00 00 10011 000 000 00 R3 ← R0 AND R3
Hex: 0963: 25861300
01001 011 001 00: 01001 011 000 100 00 00 10011 000 000 00 R3 ← R0 AND PC
Hex: 0964: 25881300
01001 011 001 10: 01001 011 000 110 00 00 10011 000 000 00 R3 ← R0 AND AR
Hex: 0966: 258C1300
01001 011 001 11: 01001 011 000 111 00 00 10011 000 000 00 R3 ← R0 AND SP
Hex: 0967: 258E1300

01001 011 010 01: 01001 011 001 001 00 00 10011 000 000 00 R3 ← R1 AND R1
Hex: 0969: 25921300
01001 011 010 10: 01001 011 001 010 00 00 10011 000 000 00 R3 ← R1 AND R2
Hex: 096A: 25941300
01001 011 010 11: 01001 011 001 011 00 00 10011 000 000 00 R3 ← R1 AND R3
Hex: 096B: 25961300
01001 011 011 00: 01001 011 001 100 00 00 10011 000 000 00 R3 ← R1 AND PC

Hex: 096C: 25981300

01001 011 011 10: 01001 011 001 110 00 00 10011 000 000 00 R3 ← R1 AND AR

Hex: 096E: 259C1300

01001 011 011 11: 01001 011 001 111 00 00 10011 000 000 00 R3 ← R1 AND SP

Hex: 096F: 259E1300

01001 011 100 10: 01001 011 010 010 00 00 10011 000 000 00 R3 ← R2 AND R2

Hex: 0972: 25A41300

01001 011 100 11: 01001 011 010 011 00 00 10011 000 000 00 R3 ← R2 AND R3

Hex: 0973: 25A61300

01001 011 101 00: 01001 011 010 100 00 00 10011 000 000 00 R3 ← R2 AND PC

Hex: 0974: 25A81300

01001 011 101 10: 01001 011 010 110 00 00 10011 000 000 00 R3 ← R2 AND AR

Hex: 0976: 25AC1300

01001 011 101 11: 01001 011 010 111 00 00 10011 000 000 00 R3 ← R2 AND SP

Hex: 0977: 25AE1300

01001 011 110 11: 01001 011 011 011 00 00 10011 000 000 00 R3 ← R3 AND R3

Hex: 097B: 25B61300

01001 011 111 00: 01001 011 011 100 00 00 10011 000 000 00 R3 ← R3 AND PC

Hex: 097C: 25B81300

01001 011 111 10: 01001 011 011 110 00 00 10011 000 000 00 R3 ← R3 AND AR

Hex: 097E: 25BC1300

01001 011 111 11: 01001 011 011 111 00 00 10011 000 000 00 R3 ← R3 AND SP

Hex: 097F: 25BE1300

PC:

01001 100 000 00: 01001 100 000 000 00 00 10011 000 000 00 PC ← R0 AND R0

Hex: 0980: 26001300

01001 100 000 01: 01001 100 000 001 00 00 10011 000 000 00 PC ← R0 AND R1

Hex: 0981: 26021300

01001 100 000 10: 01001 100 000 010 00 00 10011 000 000 00 PC ← R0 AND R2

Hex: 0982: 26041300

01001 100 000 11: 01001 100 000 011 00 00 10011 000 000 00 PC ← R0 AND R3

Hex: 0983: 26061300

01001 100 001 00: 01001 100 000 100 00 00 10011 000 000 00 PC ← R0 AND PC

Hex: 0984: 26081300

01001 100 001 10: 01001 100 000 110 00 00 10011 000 000 00 PC ← R0 AND AR

Hex: 0986: 260C1300

01001 100 001 11: 01001 100 000 111 00 00 10011 000 000 00 PC ← R0 AND SP

Hex: 0987: 260E1300

01001 100 010 01: 01001 100 001 001 00 00 10011 000 000 00 PC ← R1 AND R1

Hex: 0989: 26121300

01001 100 010 10: 01001 100 001 010 00 00 10011 000 000 00 PC ← R1 AND R2

Hex: 098A: 26141300

01001 100 010 11: 01001 100 001 011 00 00 10011 000 000 00 PC ← R1 AND R3

Hex: 098B: 26161300

01001 100 011 00: 01001 100 001 100 00 00 10011 000 000 00 PC ← R1 AND PC

Hex: 098C: 26181300

01001 100 011 10: 01001 100 001 110 00 00 10011 000 000 00 PC ← R1 AND AR

Hex: 098E: 261C1300

01001 100 011 11: 01001 100 001 111 00 00 10011 000 000 00 PC ← R1 AND SP

Hex: 098F: 261E1300

01001 100 100 10: 01001 100 010 010 00 00 10011 000 000 00 PC ← R2 AND R2

Hex: 0992: 26241300

01001 100 100 11: 01001 100 010 011 00 00 10011 000 000 00 PC ← R2 AND R3

Hex: 0993: 26261300

01001 100 101 00: 01001 100 010 100 00 00 10011 000 000 00 PC ← R2 AND PC

Hex: 0994: 26281300

01001 100 101 10: 01001 100 010 110 00 00 10011 000 000 00 PC ← R2 AND AR

Hex: 0996: 262C1300

01001 100 101 11: 01001 100 010 111 00 00 10011 000 000 00 PC ← R2 AND SP

Hex: 0997: 262E1300

01001 100 110 11: 01001 100 011 011 00 00 10011 000 000 00 PC ← R3 AND R3

Hex: 099B: 26361300

01001 100 111 00: 01001 100 011 100 00 00 10011 000 000 00 PC ← R3 AND PC

Hex: 099C: 26381300

01001 100 111 10: 01001 100 011 110 00 00 10011 000 000 00 PC ← R3 AND AR

Hex: 099E: 263C1300

01001 100 111 11: 01001 100 011 111 00 00 10011 000 000 00 PC ← R3 AND SP

Hex: 099F: 263E1300

AR:

01001 110 000 00: 01001 110 000 000 00 00 10011 000 000 00 AR ← R0 AND R0
Hex: 09C0: 27001300
01001 110 000 01: 01001 110 000 001 00 00 10011 000 000 00 AR ← R0 AND R1
Hex: 09C1: 27021300
01001 110 000 10: 01001 110 000 010 00 00 10011 000 000 00 AR ← R0 AND R2
Hex: 09C2: 27041300
01001 110 000 11: 01001 110 000 011 00 00 10011 000 000 00 AR ← R0 AND R3
Hex: 09C3: 27061300
01001 110 001 00: 01001 110 000 100 00 00 10011 000 000 00 AR ← R0 AND PC
Hex: 09C4: 27081300
01001 110 001 10: 01001 110 000 110 00 00 10011 000 000 00 AR ← R0 AND AR
Hex: 09C6: 270C1300
01001 110 001 11: 01001 110 000 111 00 00 10011 000 000 00 AR ← R0 AND SP
Hex: 09C7: 270E1300

01001 110 010 01: 01001 110 001 001 00 00 10011 000 000 00 AR ← R1 AND R1
Hex: 09C9: 27121300
01001 110 010 10: 01001 110 001 010 00 00 10011 000 000 00 AR ← R1 AND R2
Hex: 09CA: 27141300
01001 110 010 11: 01001 110 001 011 00 00 10011 000 000 00 AR ← R1 AND R3
Hex: 09CB: 27161300
01001 110 011 00: 01001 110 001 100 00 00 10011 000 000 00 AR ← R1 AND PC
Hex: 09CC: 27181300
01001 110 011 10: 01001 110 001 110 00 00 10011 000 000 00 AR ← R1 AND AR
Hex: 09CE: 271C1300
01001 110 011 11: 01001 110 001 111 00 00 10011 000 000 00 AR ← R1 AND SP
Hex: 09CF: 271E1300

01001 110 100 10: 01001 110 010 010 00 00 10011 000 000 00 AR ← R2 AND R2
Hex: 09D2: 27241300
01001 110 100 11: 01001 110 010 011 00 00 10011 000 000 00 AR ← R2 AND R3
Hex: 09D3: 27261300
01001 110 101 00: 01001 110 010 100 00 00 10011 000 000 00 AR ← R2 AND PC
Hex: 09D4: 27281300
01001 110 101 10: 01001 110 010 110 00 00 10011 000 000 00 AR ← R2 AND AR

Hex: 09D6: 272C1300

01001 110 101 11: 01001 110 010 111 00 00 10011 000 000 00 AR ← R2 AND SP
Hex: 09D7: 272E1300

01001 110 110 11: 01001 110 011 011 00 00 10011 000 000 00 AR ← R3 AND R3
Hex: 09DB: 27361300

01001 110 111 00: 01001 110 011 100 00 00 10011 000 000 00 AR ← R3 AND PC
Hex: 09DC: 27381300

01001 110 111 10: 01001 110 011 110 00 00 10011 000 000 00 AR ← R3 AND AR
Hex: 09DE: 273C1300

01001 110 111 11: 01001 110 011 111 00 00 10011 000 000 00 AR ← R3 AND SP
Hex: 09DF: 273E1300

SP:

01001 111 000 00: 01001 111 000 000 00 00 10011 000 000 00 SP ← R0 AND R0
Hex: 09E0: 27801300

01001 111 000 01: 01001 111 000 001 00 00 10011 000 000 00 SP ← R0 AND R1
Hex: 09E1: 27821300

01001 111 000 10: 01001 111 000 010 00 00 10011 000 000 00 SP ← R0 AND R2
Hex: 09E2: 27841300

01001 111 000 11: 01001 111 000 011 00 00 10011 000 000 00 SP ← R0 AND R3
Hex: 09E3: 27861300

01001 111 001 00: 01001 111 000 100 00 00 10011 000 000 00 SP ← R0 AND PC
Hex: 09E4: 27881300

01001 111 001 10: 01001 111 000 110 00 00 10011 000 000 00 SP ← R0 AND AR
Hex: 09E6: 278C1300

01001 111 001 11: 01001 111 000 111 00 00 10011 000 000 00 SP ← R0 AND SP
Hex: 09E7: 278E1300

01001 111 010 01: 01001 111 001 001 00 00 10011 000 000 00 SP ← R1 AND R1
Hex: 09E9: 27921300

01001 111 010 10: 01001 111 001 010 00 00 10011 000 000 00 SP ← R1 AND R2
Hex: 09EA: 27941300

01001 111 010 11: 01001 111 001 011 00 00 10011 000 000 00 SP ← R1 AND R3
Hex: 09EB: 27961300

01001 111 011 00: 01001 111 001 100 00 00 10011 000 000 00 SP ← R1 AND PC
Hex: 09EC: 27981300

01001 111 011 10: 01001 111 001 110 00 00 10011 000 000 00 SP ← R1 AND AR

Hex: 09EE: 279C1300

01001 111 011 11: 01001 111 001 111 00 00 10011 000 000 00 SP ← R1 AND SP

Hex: 09EF: 279E1300

01001 111 100 10: 01001 111 010 010 00 00 10011 000 000 00 SP ← R2 AND R2

Hex: 09F2: 27A41300

01001 111 100 11: 01001 111 010 011 00 00 10011 000 000 00 SP ← R2 AND R3

Hex: 09F3: 27A61300

01001 111 101 00: 01001 111 010 100 00 00 10011 000 000 00 SP ← R2 AND PC

Hex: 09F4: 27A81300

01001 111 101 10: 01001 111 010 110 00 00 10011 000 000 00 SP ← R2 AND AR

Hex: 09F6: 27AC1300

01001 111 101 11: 01001 111 010 111 00 00 10011 000 000 00 SP ← R2 AND SP

Hex: 09F7: 27AE1300

01001 111 110 11: 01001 111 011 011 00 00 10011 000 000 00 SP ← R3 AND R3

Hex: 09FB: 27B61300

01001 111 111 00: 01001 111 011 100 00 00 10011 000 000 00 SP ← R3 AND PC

Hex: 09FC: 27B81300

01001 111 111 10: 01001 111 011 110 00 00 10011 000 000 00 SP ← R3 AND AR

Hex: 09FE: 27BC1300

01001 111 111 11: 01001 111 011 111 00 00 10011 000 000 00 SP ← R3 AND SP

Hex: 09FF: 27BE1300

Mapping the same as the AND:

Opcode - DESTREG - 2 LSB of new SRCREG1 - new SRCREG2

- F2 – RegisterFile , F3 – RegisterFile, F4 – RegisterFile

OutASel = 2 LSB of F3, MuxCSel = 1, OutBSel = 2 LSB of F4

FunSelALU = 0111, MuxASel = 11,

RegSelR = decode F2 and take the 4 LSB outputs of the decoder

FunSelRegister = 01 (Load)

- F2 – RegFile, F3 – RegFile, F4 – AddressFile

OutCSel = the 2 MSB (bit 7, 6) of decoding F4, MuxCSel = 0

OutBSel = the 2 LSB of F3, FunSelALU = 0111,

MuxASel = 11,

RegSelR = decode F2 and take the 4 LSB outputs of the decoder FunSelR = 01

- F2 – AddressFile , F3 – RegisterFile, F4 – RegisterFile

OutASel = the 2 LSB of F3, MuxCSel = 1, OutBSel = the 2 LSB of F4

FunSelALU = 0111, MuxBSel = 11,

RegSelAdd = bits 7,6, 4 of the output of decoding F2

FunSelAdd = 01

- F2 – AddressFile , F3 – RegisterFile, F4 – AddressFile

OutCSel = the 2 MSB (bit 7, 6) of decoding F4

MuxCSel = 0,

OutBSel = the 2 LSB of F3

FunSelALU = 0111, MuxBSel = 11,

RegSelAdd = bits 7,6, 4 of the output of decoding the 2 LSB of F2

FunSelAdd = 01

A OR F2 ← F3 OR F4

R0:

01010 000 000 00: 01010 000 000 000 00 00 10011 000 000 00 R0 ← R0 OR R0

Hex: 0A00: 28001300

01010 000 000 01: 01010 000 000 001 00 00 10011 000 000 00 R0 ← R0 OR R1

Hex: 0A01: 28021300

01010 000 000 10: 01010 000 000 010 00 00 10011 000 000 00 R0 ← R0 OR R2

Hex: 0A02: 28041300

01010 000 000 11: 01010 000 000 011 00 00 10011 000 000 00 R0 ← R0 OR R3

Hex: 0A03: 28061300

01010 000 001 00: 01010 000 000 100 00 00 10011 000 000 00 R0 ← R0 OR PC

Hex: 0A04: 28081300

01010 000 001 10: 01010 000 000 110 00 00 10011 000 000 00 R0 ← R0 OR AR

Hex: 0A06: 280C1300

01010 000 001 11: 01010 000 000 111 00 00 10011 000 000 00 R0 ← R0 OR SP
Hex: 0A07: 280E1300

    01010 000 010 01: 01010 000 001 001 00 00 10011 000 000 00 R0 ← R1 OR R1
Hex: 0A09: 28121300
01010 000 010 10: 01010 000 001 010 00 00 10011 000 000 00 R0 ← R1 OR R2
Hex: 0A0A: 28141300
01010 000 010 11: 01010 000 001 011 00 00 10011 000 000 00 R0 ← R1 OR R3
Hex: 0A0B: 28161300
01010 000 011 00: 01010 000 001 100 00 00 10011 000 000 00 R0 ← R1 OR PC
Hex: 0A0C: 28181300
01010 000 011 10: 01010 000 001 110 00 00 10011 000 000 00 R0 ← R1 OR AR
Hex: 0A0E: 281C1300
01010 000 011 11: 01010 000 001 111 00 00 10011 000 000 00 R0 ← R1 OR SP
Hex: 0A0F: 281E1300

    01010 000 100 10: 01010 000 010 010 00 00 10011 000 000 00 R0 ← R2 OR R2
Hex: 0A12: 28241300
01010 000 100 11: 01010 000 010 011 00 00 10011 000 000 00 R0 ← R2 OR R3
Hex: 0A13: 28261300
01010 000 101 00: 01010 000 010 100 00 00 10011 000 000 00 R0 ← R2 OR PC
Hex: 0A14: 28281300
01010 000 101 10: 01010 000 010 110 00 00 10011 000 000 00 R0 ← R2 OR AR
Hex: 0A16: 282C1300
01010 000 101 11: 01010 000 010 111 00 00 10011 000 000 00 R0 ← R2 OR SP
Hex: 0A17: 282E1300

    01010 000 110 11: 01010 000 011 011 00 00 10011 000 000 00 R0 ← R3 OR R3
Hex: 0A1B: 28361300
01010 000 111 00: 01010 000 011 100 00 00 10011 000 000 00 R0 ← R3 OR PC
Hex: 0A1C: 28381300
01010 000 111 10: 01010 000 011 110 00 00 10011 000 000 00 R0 ← R3 OR AR
Hex: 0A1E: 283C1300
01010 000 111 11: 01010 000 011 111 00 00 10011 000 000 00 R0 ← R3 OR SP
Hex: 0A1F: 283E1300

22 instructions for first case

R1:

01010 001 000 00: 01010 001 000 000 00 00 10011 000 000 00 R1 ← R0 OR R0
Hex: 0A20: 28801300
01010 001 000 01: 01010 001 000 001 00 00 10011 000 000 00 R1 ← R0 OR R1
Hex: 0A21: 28821300
01010 001 000 10: 01010 001 000 010 00 00 10011 000 000 00 R1 ← R0 OR R2
Hex: 0A22: 28841300
01010 001 000 11: 01010 001 000 011 00 00 10011 000 000 00 R1 ← R0 OR R3
Hex: 0A23: 28861300
01010 001 001 00: 01010 001 000 100 00 00 10011 000 000 00 R1 ← R0 OR PC
Hex: 0A24: 28881300
01010 001 001 10: 01010 001 000 110 00 00 10011 000 000 00 R1 ← R0 OR AR
Hex: 0A26: 288C1300
01010 001 001 11: 01010 001 000 111 00 00 10011 000 000 00 R1 ← R0 OR SP
Hex: 0A27: 288E1300

01010 001 010 01: 01010 001 001 001 00 00 10011 000 000 00 R1 ← R1 OR R1
Hex: 0A29: 28921300
01010 001 010 10: 01010 001 001 010 00 00 10011 000 000 00 R1 ← R1 OR R2
Hex: 0A2A: 28941300
01010 001 010 11: 01010 001 001 011 00 00 10011 000 000 00 R1 ← R1 OR R3
Hex: 0A2B: 28961300
01010 001 011 00: 01010 001 001 100 00 00 10011 000 000 00 R1 ← R1 OR PC
Hex: 0A2C: 28981300
01010 001 011 10: 01010 001 001 110 00 00 10011 000 000 00 R1 ← R1 OR AR
Hex: 0A2E: 289C1300
01010 001 011 11: 01010 001 001 111 00 00 10011 000 000 00 R1 ← R1 OR SP
Hex: 0A2F: 289E1300

01010 001 100 10: 01010 001 010 010 00 00 10011 000 000 00 R1 ← R2 OR R2
Hex: 0A32: 28A41300
01010 001 100 11: 01010 001 010 011 00 00 10011 000 000 00 R1 ← R2 OR R3
Hex: 0A33: 28A61300
01010 001 101 00: 01010 001 010 100 00 00 10011 000 000 00 R1 ← R2 OR PC
Hex: 0A34: 28A81300
01010 001 101 10: 01010 001 010 110 00 00 10011 000 000 00 R1 ← R2 OR AR

Hex: 0A36: 28AC1300

01010 001 101 11: 01010 001 010 111 00 00 10011 000 000 00 R1 ← R2 OR SP
Hex: 0A37: 28AE1300

   01010 001 110 11: 01010 001 011 011 00 00 10011 000 000 00 R1 ← R3 OR R3
Hex: 0A3B: 28B61300

01010 001 111 00: 01010 001 011 100 00 00 10011 000 000 00 R1 ← R3 OR PC
Hex: 0A3C: 28B81300

01010 001 111 10: 01010 001 011 110 00 00 10011 000 000 00 R1 ← R3 OR AR
Hex: 0A3E: 28BC1300

01010 001 111 11: 01010 001 011 111 00 00 10011 000 000 00 R1 ← R3 OR SP
Hex: 0A3F: 28BE1300

R2:

01010 010 000 00: 01010 010 000 000 00 00 10011 000 000 00 R2 ← R0 OR R0
Hex: 0A40: 29001300

01010 010 000 01: 01010 010 000 001 00 00 10011 000 000 00 R2 ← R0 OR R1
Hex: 0A41: 29021300

01010 010 000 10: 01010 010 000 010 00 00 10011 000 000 00 R2 ← R0 OR R2
Hex: 0A42: 29041300

01010 010 000 11: 01010 010 000 011 00 00 10011 000 000 00 R2 ← R0 OR R3
Hex: 0A43: 29061300

01010 010 001 00: 01010 010 000 100 00 00 10011 000 000 00 R2 ← R0 OR PC
Hex: 0A44: 29081300

01010 010 001 10: 01010 010 000 110 00 00 10011 000 000 00 R2 ← R0 OR AR
Hex: 0A46: 290C1300

01010 010 001 11: 01010 010 000 111 00 00 10011 000 000 00 R2 ← R0 OR SP
Hex: 0A47: 290E1300

   01010 010 010 01: 01010 010 001 001 00 00 10011 000 000 00 R2 ← R1 OR R1
Hex: 0A49: 29121300

01010 010 010 10: 01010 010 001 010 00 00 10011 000 000 00 R2 ← R1 OR R2
Hex: 0A4A: 29141300

01010 010 010 11: 01010 010 001 011 00 00 10011 000 000 00 R2 ← R1 OR R3
Hex: 0A4B: 29161300

01010 010 011 00: 01010 010 001 100 00 00 10011 000 000 00 R2 ← R1 OR PC
Hex: 0A4C: 29181300

01010 010 011 10: 01010 010 001 110 00 00 10011 000 000 00 R2 ← R1 OR AR
Hex: 0A4E: 291C1300
01010 010 011 11: 01010 010 001 111 00 00 10011 000 000 00 R2 ← R1 OR SP
Hex: 0A4F: 291E1300

01010 010 100 10: 01010 010 010 010 00 00 10011 000 000 00 R2 ← R2 OR R2
Hex: 0A52: 29241300
01010 010 100 11: 01010 010 010 011 00 00 10011 000 000 00 R2 ← R2 OR R3
Hex: 0A53: 29261300
01010 010 101 00: 01010 010 010 100 00 00 10011 000 000 00 R2 ← R2 OR PC
Hex: 0A54: 29281300
01010 010 101 10: 01010 010 010 110 00 00 10011 000 000 00 R2 ← R2 OR AR
Hex: 0A56: 292C1300
01010 010 101 11: 01010 010 010 111 00 00 10011 000 000 00 R2 ← R2 OR SP
Hex: 0A57: 292E1300

01010 010 110 11: 01010 010 011 011 00 00 10011 000 000 00 R2 ← R3 OR R3
Hex: 0A5B: 29361300
01010 010 111 00: 01010 010 011 100 00 00 10011 000 000 00 R2 ← R3 OR PC
Hex: 0A5C: 29381300
01010 010 111 10: 01010 010 011 110 00 00 10011 000 000 00 R2 ← R3 OR AR
Hex: 0A5E: 293C1300
01010 010 111 11: 01010 010 011 111 00 00 10011 000 000 00 R2 ← R3 OR SP
Hex: 0A5F: 293E1300

R3:
01010 011 000 00: 01010 011 000 000 00 00 10011 000 000 00 R3 ← R0 OR R0
hex: 0A60: 29801300
01010 011 000 01: 01010 011 000 001 00 00 10011 000 000 00 R3 ← R0 OR R1
Hex: 0A61: 29821300
01010 011 000 10: 01010 011 000 010 00 00 10011 000 000 00 R3 ← R0 OR R2
Hex: 0A62: 29841300
01010 011 000 11: 01010 011 000 011 00 00 10011 000 000 00 R3 ← R0 OR R3
Hex: 0A63: 29861300
01010 011 001 00: 01010 011 000 100 00 00 10011 000 000 00 R3 ← R0 OR PC
Hex: 0A64: 29881300
01010 011 001 10: 01010 011 000 110 00 00 10011 000 000 00 R3 ← R0 OR AR

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Hex: 0A66: 298C1300

01010 011 001 11: 01010 011 000 111 00 00 10011 000 000 00 R3 ← R0 OR SP
Hex: 0A67: 298E1300

01010 011 010 01: 01010 011 001 001 00 00 10011 000 000 00 R3 ← R1 OR R1
Hex: 0A69: 29921300

01010 011 010 10: 01010 011 001 010 00 00 10011 000 000 00 R3 ← R1 OR R2
Hex: 0A6A: 29941300

01010 011 010 11: 01010 011 001 011 00 00 10011 000 000 00 R3 ← R1 OR R3
Hex: 0A6B: 29961300

01010 011 011 00: 01010 011 001 100 00 00 10011 000 000 00 R3 ← R1 OR PC
Hex: 0A6C: 29981300

01010 011 011 10: 01010 011 001 110 00 00 10011 000 000 00 R3 ← R1 OR AR
Hex: 0A6E: 299C1300

01010 011 011 11: 01010 011 001 111 00 00 10011 000 000 00 R3 ← R1 OR SP
Hex: 0A6F: 299E1300

01010 011 100 10: 01010 011 010 010 00 00 10011 000 000 00 R3 ← R2 OR R2
Hex: 0A72: 29A41300

01010 011 100 11: 01010 011 010 011 00 00 10011 000 000 00 R3 ← R2 OR R3
Hex: 0A73: 29A61300

01010 011 101 00: 01010 011 010 100 00 00 10011 000 000 00 R3 ← R2 OR PC
Hex: 0A74: 29A81300

01010 011 101 10: 01010 011 010 110 00 00 10011 000 000 00 R3 ← R2 OR AR
Hex: 0A76: 29AC1300

01010 011 101 11: 01010 011 010 111 00 00 10011 000 000 00 R3 ← R2 OR SP
Hex: 0A77: 29AE1300

01010 011 110 11: 01010 011 011 011 00 00 10011 000 000 00 R3 ← R3 OR R3
Hex: 0A7B: 29B61300

01010 011 111 00: 01010 011 011 100 00 00 10011 000 000 00 R3 ← R3 OR PC
Hex: 0A7C: 29B81300

01010 011 111 10: 01010 011 011 110 00 00 10011 000 000 00 R3 ← R3 OR AR
Hex: 0A7E: 29BC1300

01010 011 111 11: 01010 011 011 111 00 00 10011 000 000 00 R3 ← R3 OR SP
Hex: 0A7F: 29BE1300

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PC:

01010 100 000 00: 01010 100 000 000 00 00 10011 000 000 00 PC ← R0 OR R0
Hex: 0A80: 2A001300
01010 100 000 01: 01010 100 000 001 00 00 10011 000 000 00 PC ← R0 OR R1
Hex: 0A81: 2A021300
01010 100 000 10: 01010 100 000 010 00 00 10011 000 000 00 PC ← R0 OR R2
Hex: 0A82: 2A041300
01010 100 000 11: 01010 100 000 011 00 00 10011 000 000 00 PC ← R0 OR R3
Hex: 0A83: 2A061300
01010 100 001 00: 01010 100 000 100 00 00 10011 000 000 00 PC ← R0 OR PC
Hex: 0A84: 2A081300
01010 100 001 10: 01010 100 000 110 00 00 10011 000 000 00 PC ← R0 OR AR
Hex: 0A86: 2A0C1300
01010 100 001 11: 01010 100 000 111 00 00 10011 000 000 00 PC ← R0 OR SP
Hex: 0A87: 2A0E1300

01010 100 010 01: 01010 100 001 001 00 00 10011 000 000 00 PC ← R1 OR R1
Hex: 0A89: 2A121300
01010 100 010 10: 01010 100 001 010 00 00 10011 000 000 00 PC ← R1 OR R2
Hex: 0A8A: 2A141300
01010 100 010 11: 01010 100 001 011 00 00 10011 000 000 00 PC ← R1 OR R3
Hex: 0A8B: 2A161300
01010 100 011 00: 01010 100 001 100 00 00 10011 000 000 00 PC ← R1 OR PC
Hex: 0A8C: 2A181300
01010 100 011 10: 01010 100 001 110 00 00 10011 000 000 00 PC ← R1 OR AR
Hex: 0A8E: 2A1C1300
01010 100 011 11: 01010 100 001 111 00 00 10011 000 000 00 PC ← R1 OR SP
Hex: 0A8F: 2A1E1300

01010 100 100 10: 01010 100 010 010 00 00 10011 000 000 00 PC ← R2 OR R2
Hex: 0A92: 2A241300
01010 100 100 11: 01010 100 010 011 00 00 10011 000 000 00 PC ← R2 OR R3
Hex: 0A93: 2A261300
01010 100 101 00: 01010 100 010 100 00 00 10011 000 000 00 PC ← R2 OR PC
Hex: 0A94: 2A281300
01010 100 101 10: 01010 100 010 110 00 00 10011 000 000 00 PC ← R2 OR AR
Hex: 0A96: 2A2C1300

01010 100 101 11: 01010 100 010 111 00 00 10011 000 000 00 PC ← R2 OR SP
Hex: 0A97: 2A2E1300

01010 100 110 11: 01010 100 011 011 00 00 10011 000 000 00 PC ← R3 OR R3
Hex: 0A9B: 2A361300
01010 100 111 00: 01010 100 011 100 00 00 10011 000 000 00 PC ← R3 OR PC
Hex: 0A9C: 2A381300
01010 100 111 10: 01010 100 011 110 00 00 10011 000 000 00 PC ← R3 OR AR
Hex: 0A9E: 2A3C1300
01010 100 111 11: 01010 100 011 111 00 00 10011 000 000 00 PC ← R3 OR SP
Hex: 0A9F: 2A3E1300

AR:
01010 110 000 00: 01010 110 000 000 00 00 10011 000 000 00 AR ← R0 OR R0
Hex: 0AC0: 2B001300
01010 110 000 01: 01010 110 000 001 00 00 10011 000 000 00 AR ← R0 OR R1
Hex: 0AC1: 2B021300
01010 110 000 10: 01010 110 000 010 00 00 10011 000 000 00 AR ← R0 OR R2
Hex: 0AC2: 2B041300
01010 110 000 11: 01010 110 000 011 00 00 10011 000 000 00 AR ← R0 OR R3
Hex: 0AC3: 2B061300
01010 110 001 00: 01010 110 000 100 00 00 10011 000 000 00 AR ← R0 OR PC
Hex: 0AC4: 2B081300
01010 110 001 10: 01010 110 000 110 00 00 10011 000 000 00 AR ← R0 OR AR
Hex: 0AC6: 2B0C1300
01010 110 001 11: 01010 110 000 111 00 00 10011 000 000 00 AR ← R0 OR SP
Hex: 0AC7: 2B0E1300

01010 110 010 01: 01010 110 001 001 00 00 10011 000 000 00 AR ← R1 OR R1
Hex: 0AC9: 2B121300
01010 110 010 10: 01010 110 001 010 00 00 10011 000 000 00 AR ← R1 OR R2
Hex: 0ACA: 2B141300
01010 110 010 11: 01010 110 001 011 00 00 10011 000 000 00 AR ← R1 OR R3
Hex: 0ACB: 2B161300
01010 110 011 00: 01010 110 001 100 00 00 10011 000 000 00 AR ← R1 OR PC
Hex: 0ACC: 2B181300
01010 110 011 10: 01010 110 001 110 00 00 10011 000 000 00 AR ← R1 OR AR

Hex: 0ACE: 2B1C1300

01010 110 011 11: 01010 110 001 111 00 00 10011 000 000 00 AR ← R1 OR SP
Hex: 0ACF: 2B1E1300

01010 110 100 10: 01010 110 010 010 00 00 10011 000 000 00 AR ← R2 OR R2
Hex: 0AD2: 2B241300
01010 110 100 11: 01010 110 010 011 00 00 10011 000 000 00 AR ← R2 OR R3
Hex: 0AD3: 2B261300
01010 110 101 00: 01010 110 010 100 00 00 10011 000 000 00 AR ← R2 OR PC
Hex: 0AD4: 2B281300
01010 110 101 10: 01010 110 010 110 00 00 10011 000 000 00 AR ← R2 OR AR
Hex: 0AD6: 2B2C1300
01010 110 101 11: 01010 110 010 111 00 00 10011 000 000 00 AR ← R2 OR SP
Hex: 0AD7: 2B2E1300

01010 110 110 11: 01010 110 011 011 00 00 10011 000 000 00 AR ← R3 OR R3
Hex: 0ADB: 2B361300
01010 110 111 00: 01010 110 011 100 00 00 10011 000 000 00 AR ← R3 OR PC
Hex: 0ADC: 2B381300
01010 110 111 10: 01010 110 011 110 00 00 10011 000 000 00 AR ← R3 OR AR
Hex: 0ADE: 2B3C1300
01010 110 111 11: 01010 110 011 111 00 00 10011 000 000 00 AR ← R3 OR SP
Hex: 0ADF: 2B3E1300

SP:
01010 111 000 00: 01010 111 000 000 00 00 10011 000 000 00 SP ← R0 OR R0
Hex: 0AE0: 2B801300
01010 111 000 01: 01010 111 000 001 00 00 10011 000 000 00 SP ← R0 OR R1
Hex: 0AE1: 2B821300
01010 111 000 10: 01010 111 000 010 00 00 10011 000 000 00 SP ← R0 OR R2
Hex: 0AE2: 2B841300
01010 111 000 11: 01010 111 000 011 00 00 10011 000 000 00 SP ← R0 OR R3
Hex: 0AE3: 2B861300
01010 111 001 00: 01010 111 000 100 00 00 10011 000 000 00 SP ← R0 OR PC
Hex: 0AE4: 2B881300
01010 111 001 10: 01010 111 000 110 00 00 10011 000 000 00 SP ← R0 OR AR
Hex: 0AE6: 2B8C1300

01010 111 001 11: 01010 111 000 111 00 00 10011 000 000 00 SP ← R0 OR SP
Hex: 0AE7: 2B8E1300

01010 111 010 01: 01010 111 001 001 00 00 10011 000 000 00 SP ← R1 OR R1
Hex: 0AE9: 2B921300
01010 111 010 10: 01010 111 001 010 00 00 10011 000 000 00 SP ← R1 OR R2
Hex: 0AEA: 2B941300
01010 111 010 11: 01010 111 001 011 00 00 10011 000 000 00 SP ← R1 OR R3
Hex: 0AEB: 2B961300
01010 111 011 00: 01010 111 001 100 00 00 10011 000 000 00 SP ← R1 OR PC
Hex: 0AEC: 2B981300
01010 111 011 10: 01010 111 001 110 00 00 10011 000 000 00 SP ← R1 OR AR
Hex: 0AEE: 2B9C1300
01010 111 011 11: 01010 111 001 111 00 00 10011 000 000 00 SP ← R1 OR SP
Hex: 0AEF: 2B9E1300

01010 111 100 10: 01010 111 010 010 00 00 10011 000 000 00 SP ← R2 OR R2
Hex: 0AF2: 2BA41300
01010 111 100 11: 01010 111 010 011 00 00 10011 000 000 00 SP ← R2 OR R3
Hex: 0AF3: 2BA61300
01010 111 101 00: 01010 111 010 100 00 00 10011 000 000 00 SP ← R2 OR PC
Hex: 0AF4: 2BA81300
01010 111 101 10: 01010 111 010 110 00 00 10011 000 000 00 SP ← R2 OR AR
Hex: 0AF6: 2BAC1300
01010 111 101 11: 01010 111 010 111 00 00 10011 000 000 00 SP ← R2 OR SP
Hex: 0AF7: 2BAE1300

01010 111 110 11: 01010 111 011 011 00 00 10011 000 000 00 SP ← R3 OR R3
Hex: 0AFB: 2BB61300
01010 111 111 00: 01010 111 011 100 00 00 10011 000 000 00 SP ← R3 OR PC
Hex: 0AFC: 2BB81300
01010 111 111 10: 01010 111 011 110 00 00 10011 000 000 00 SP ← R3 OR AR
Hex: 0AFE: 2BBC1300
01010 111 111 11: 01010 111 011 111 00 00 10011 000 000 00 SP ← R3 OR SP
Hex: 0AFF: 2BBE1300

Mapping: Opcode - DESTREG - 2 LSB of new SRCREG1 - new SRCREG2

Just like AND

- F2 – RegisterFile , F3 – RegisterFile, F4 – RegisterFile

OutASel = 2 LSB of F3, MuxCSel = 1, OutBSel = 2 LSB of F4
FunSelALU = 1000, MuxASel = 11,
RegSelR = decode F2 and take the 4 LSB outputs of the decoder
FunSelRegister = 01 (Load)

- F2 – RegFile, F3 – RegFile, F4 – AddressFile

OutCSel = the 2 MSB (bit 7, 6) of decoding F4, MuxCSel = 0
OutBSel = the 2 LSB of F3, FunSelALU = 1000,
MuxASel = 11,
RegSelR = decode F2 and take the 4 LSB outputs of the decoder
FunSelR = 01

- F2 – AddressFile , F3 – RegisterFile, F4 – RegisterFile

OutASel = the 2 LSB of F3, MuxCSel = 1, OutBSel = the 2 LSB of F4
FunSelALU = 1000, MuxBSel = 11,
RegSelAdd = bits 7,6, 4 of the output of decoding F2
FunSelAdd = 01

- F2 – AddressFile , F3 – RegisterFile, F4 – AddressFile

OutCSel = the 2 MSB (bit 7, 6) of decoding F4
MuxCSel = 0, OutBSel = the 2 LSB of F3
FunSelALU = 1000, MuxBSel = 11,
RegSelAdd = bits 7,6, 4 of the output of decoding F2
FunSelAdd = 01

B NOT F2 ← NOT F3
R0:
01011 000 000 00: 01011 000 000 000 00 00 10011 000 000 00 R0 ← NOT R0
Hex: 0B00: 2C001300

01011 000 001 00: 01011 000 001 000 00 00 10011 000 000 00 R0 ← NOT R1
Hex: 0B04: 2C101300
01011 000 010 00: 01011 000 010 000 00 00 10011 000 000 00 R0 ← NOT R2
Hex: 0B08: 2C201300
01011 000 011 00: 01011 000 011 000 00 00 10011 000 000 00 R0 ← NOT R3
Hex: 0B0C: 2C301300
01011 000 100 00: 01011 000 100 000 00 00 10011 000 000 00 R0 ← NOT PC
Hex: 0B10: 2C401300
01011 000 110 00: 01011 000 110 000 00 00 10011 000 000 00 R0 ← NOT AR
Hex: 0B18: 2C601300
01011 000 111 00: 01011 000 111 000 00 00 10011 000 000 00 R0 ← NOT SP
Hex: 0B1C: 2C701300

R1:
01011 001 000 00: 01011 001 000 000 00 00 10011 000 000 00 R1 ← NOT R0
Hex: 0B20: 2C801300
01011 001 001 00: 01011 001 001 000 00 00 10011 000 000 00 R1 ← NOT R1
Hex: 0B24: 2C901300
01011 001 010 00: 01011 001 010 000 00 00 10011 000 000 00 R1 ← NOT R2
Hex: 0B28: 2CA01300
01011 001 011 00: 01011 001 011 000 00 00 10011 000 000 00 R1 ← NOT R3
Hex: 0B2C: 2CB01300
01011 001 100 00: 01011 001 100 000 00 00 10011 000 000 00 R1 ← NOT PC
Hex: 0B30: 2CC01300
01011 001 110 00: 01011 001 110 000 00 00 10011 000 000 00 R1 ← NOT AR
Hex: 0B38: 2CE01300
01011 001 111 00: 01011 001 111 000 00 00 10011 000 000 00 R1 ← NOT SP
Hex: 0B3C: 2CF01300

R2:
01011 010 000 00: 01011 010 000 000 00 00 10011 000 000 00 R2 ← NOT R0
Hex: 0B40: 2D001300
01011 010 001 00: 01011 010 001 000 00 00 10011 000 000 00 R2 ← NOT R1
Hex: 0B44: 2D101300
01011 010 010 00: 01011 010 010 000 00 00 10011 000 000 00 R2 ← NOT R2
Hex: 0B48: 2D201300
01011 010 011 00: 01011 010 011 000 00 00 10011 000 000 00 R2 ← NOT R3

Hex: 0B4C: 2D301300

01011 010 100 00: 01011 010 100 000 00 00 10011 000 000 00 R2 ← NOT PC
Hex: 0B50: 2D401300

01011 010 110 00: 01011 010 110 000 00 00 10011 000 000 00 R2 ← NOT AR
Hex: 0B58: 2D601300

01011 010 111 00: 01011 010 111 000 00 00 10011 000 000 00 R2 ← NOT SP
Hex: 0B5C: 2D701300

R3:
01011 011 000 00: 01011 011 000 000 00 00 10011 000 000 00 R3 ← NOT R0
Hex: 0B60: 2D801300

01011 011 001 00: 01011 011 001 000 00 00 10011 000 000 00 R3 ← NOT R1
Hex: 0B64: 2D901300

01011 011 010 00: 01011 011 010 000 00 00 10011 000 000 00 R3 ← NOT R2
Hex: 0B68: 2DA01300

01011 011 011 00: 01011 011 011 000 00 00 10011 000 000 00 R3 ← NOT R3
Hex: 0B6C: 2DB01300

01011 011 100 00: 01011 011 100 000 00 00 10011 000 000 00 R3 ← NOT PC
Hex: 0B70: 2DC01300

01011 011 110 00: 01011 011 110 000 00 00 10011 000 000 00 R3 ← NOT AR
Hex: 0B78: 2DE01300

01011 011 111 00: 01011 011 111 000 00 00 10011 000 000 00 R3 ← NOT SP
Hex: 0B7C: 2DF01300

PC:
01011 100 000 00: 01011 100 000 000 00 00 10011 000 000 00 PC ← NOT R0
Hex: 0B80: 2E001300

01011 100 001 00: 01011 100 001 000 00 00 10011 000 000 00 PC ← NOT R1
Hex: 0B84: 2E101300

01011 100 010 00: 01011 100 010 000 00 00 10011 000 000 00 PC ← NOT R2
Hex: 0B88: 2E201300

01011 100 011 00: 01011 100 011 000 00 00 10011 000 000 00 PC ← NOT R3
Hex: 0B8C: 2E301300

01011 100 100 00: 01011 100 100 000 00 00 10011 000 000 00 PC ← NOT PC
Hex: 0B90: 2E401300

01011 100 110 00: 01011 100 110 000 00 00 10011 000 000 00 PC ← NOT AR
Hex: 0B98: 2E601300

01011 100 111 00: 01011 100 111 000 00 00 10011 000 000 00 PC ← NOT SP
Hex: 0B9C: 2E701300

AR:
01011 110 000 00: 01011 110 000 000 00 00 10011 000 000 00 AR ← NOT R0
Hex: 0BC0: 2F001300
01011 110 001 00: 01011 110 001 000 00 00 10011 000 000 00 AR ← NOT R1
Hex: 0BC4: 2F101300
01011 110 010 00: 01011 110 010 000 00 00 10011 000 000 00 AR ← NOT R2
Hex: 0BC8: 2F201300
01011 110 011 00: 01011 110 011 000 00 00 10011 000 000 00 AR ← NOT R3
Hex: 0BCC: 2F301300
01011 110 100 00: 01011 110 100 000 00 00 10011 000 000 00 AR ← NOT PC
Hex: 0BD0: 2F401300
01011 110 110 00: 01011 110 110 000 00 00 10011 000 000 00 AR ← NOT AR
Hex: 0BD8: 2F601300
01011 110 111 00: 01011 110 111 000 00 00 10011 000 000 00 AR ← NOT SP
Hex: 0BDC: 2F701300

SP:
01011 111 000 00: 01011 111 000 000 00 00 10011 000 000 00 SP ← NOT R0
Hex: 0BE0: 2F801300
01011 111 001 00: 01011 111 001 000 00 00 10011 000 000 00 SP ← NOT R1
Hex: 0BE4: 2F901300
01011 111 010 00: 01011 111 010 000 00 00 10011 000 000 00 SP ← NOT R2
Hex: 0BE8: 2FA01300
01011 111 011 00: 01011 111 011 000 00 00 10011 000 000 00 SP ← NOT R3
Hex: 0BEC: 2FB01300
01011 111 100 00: 01011 111 100 000 00 00 10011 000 000 00 SP ← NOT PC
Hex: 0BF0: 2FC01300
01011 111 110 00: 01011 111 110 000 00 00 10011 000 000 00 SP ← NOT AR
Hex: 0BF8: 2FE01300
01011 111 111 00: 01011 111 111 000 00 00 10011 000 000 00 SP ← NOT SP
Hex: 0BFC: 2FF01300

Mapping: Opcode DESTREG SRCREG1 00
Similar to MOV but not quite (the last case - need to pass through the ALU)

- F2 and F3 both belong to RegisterFile

OutBSel – the 2 LSB of F3, FunSelALU – 0011 not B)

MuxASel = 11,

RegSelReg = decode F2 and take the 4 LSB outputs of the decoder

FunSelRegister = 01 (Load)

- F2 and F3 both belong to AddressRegister

OutCSel = the 2 MSB (bit 7, 6) of decoding F3

MuxCSel = 0(OutCSel will be forwarded to the A input of the ALU)

FunSelALU = 0010 (not A)

MuxBSel = 11 (the OutALU)

RegSelAdd = like above – bits 7,6, 4 of the output of decoding F2

FunSelAddress = 01 (load)

- F2 – AddressRegister, F3 – RegisterFile

OutBSel = the 2 LSB of F3 , FunSelALU = 0011(not B)

MuxBSel = 11,

RegSelAdd = like above – bits 7,6, 4 of the output of decoding F2

FunSelAddress = 01 (load)

- F2 – RegisterFile, F3 – AddressRegister

OutCSel = the 2 MSB (bit 7, 6) of decoding F3

MuxCSel = 0, FunSelALU = 0010 (not A)

MuxASel = 11,

RegSelR – decode F2 and take the 4 LSB outputs of the decoder

FunSelReg = 01

C LSL F2 ← LSL F3

R0:

01100 000 000 00: 01100 000 000 000 00 00 10011 000 000 00 R0 ← LSL R0

Hex: 0C00: 30001300

01100 000 001 00: 01100 000 001 000 00 00 10011 000 000 00 R0 ← LSL R1

Hex: 0C04: 30101300

01100 000 010 00: 01100 000 010 000 00 00 10011 000 000 00 R0 ← LSL R2

Hex: 0C08: 30201300

01100 000 011 00: 01100 000 011 000 00 00 10011 000 000 00 R0 ← LSL R3

Hex: 0C0C: 30301300

01100 000 100 00: 01100 000 100 000 00 00 10011 000 000 00 R0 ← LSL PC

Hex: 0C10: 30401300

01100 000 110 00: 01100 000 110 000 00 00 10011 000 000 00 R0 ← LSL AR

Hex: 0C18: 30601300

01100 000 111 00: 01100 000 111 000 00 00 10011 000 000 00 R0 ← LSL SP

Hex: 0C1C: 30701300

R1:

01100 001 000 00: 01100 001 000 000 00 00 10011 000 000 00 R1 ← LSL R0

Hex: 0C20: 30801300

01100 001 001 00: 01100 001 001 000 00 00 10011 000 000 00 R1 ← LSL R1

Hex: 0C24: 30901300

01100 001 010 00: 01100 001 010 000 00 00 10011 000 000 00 R1 ← LSL R2

Hex: 0C28: 30A01300

01100 001 011 00: 01100 001 011 000 00 00 10011 000 000 00 R1 ← LSL R3

Hex: 0C2C: 30B01300

01100 001 100 00: 01100 001 100 000 00 00 10011 000 000 00 R1 ← LSL PC

Hex: 0C30: 30C01300

01100 001 110 00: 01100 001 110 000 00 00 10011 000 000 00 R1 ← LSL AR

Hex: 0C38: 30E01300

01100 001 111 00: 01100 001 111 000 00 00 10011 000 000 00 R1 ← LSL SP

Hex: 0C3C: 30F01300

R2:

01100 010 000 00: 01100 010 000 000 00 00 10011 000 000 00 R2 ← LSL R0

Hex: 0C40: 31001300

01100 010 001 00: 01100 010 001 000 00 00 10011 000 000 00 R2 ← LSL R1

Hex: 0C44: 31101300

01100 010 010 00: 01100 010 010 000 00 00 10011 000 000 00 R2 ← LSL R2

Hex: 0C48: 31201300

01100 010 011 00: 01100 010 011 000 00 00 10011 000 000 00 R2 ← LSL R3

Hex: 0C4C: 31301300

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01100 010 100 00: 01100 010 100 000 00 00 10011 000 000 00 R2 ← LSL PC
Hex: 0C50: 31401300
01100 010 110 00: 01100 010 110 000 00 00 10011 000 000 00 R2 ← LSL AR
Hex: 0C58: 31601300
01100 010 111 00: 01100 010 111 000 00 00 10011 000 000 00 R2 ← LSL SP
Hex: 0C5C: 31701300

R3:
01100 011 000 00: 01100 011 000 000 00 00 10011 000 000 00 R3 ← LSL R0
Hex: 0C60: 31801300
01100 011 001 00: 01100 011 001 000 00 00 10011 000 000 00 R3 ← LSL R1
Hex: 0C64: 31901300
01100 011 010 00: 01100 011 010 000 00 00 10011 000 000 00 R3 ← LSL R2
Hex: 0C68: 31A01300
01100 011 011 00: 01100 011 011 000 00 00 10011 000 000 00 R3 ← LSL R3
Hex: 0C6C: 31B01300
01100 011 100 00: 01100 011 100 000 00 00 10011 000 000 00 R3 ← LSL PC
Hex: 0C70: 31C01300
01100 011 110 00: 01100 011 110 000 00 00 10011 000 000 00 R3 ← LSL AR
Hex: 0C78: 31E01300
01100 011 111 00: 01100 011 111 000 00 00 10011 000 000 00 R3 ← LSL SP
Hex: 0C7C: 31F01300

PC:
01100 100 000 00: 01100 100 000 000 00 00 10011 000 000 00 PC ← LSL R0
Hex: 0C80: 32001300
01100 100 001 00: 01100 100 001 000 00 00 10011 000 000 00 PC ← LSL R1
Hex: 0C84: 32101300
01100 100 010 00: 01100 100 010 000 00 00 10011 000 000 00 PC ← LSL R2
Hex: 0C88: 32201300
01100 100 011 00: 01100 100 011 000 00 00 10011 000 000 00 PC ← LSL R3
Hex: 0C8C: 32301300
01100 100 100 00: 01100 100 100 000 00 00 10011 000 000 00 PC ← LSL PC
Hex: 0C90: 32401300
01100 100 110 00: 01100 100 110 000 00 00 10011 000 000 00 PC ← LSL AR
Hex: 0C98: 32601300
01100 100 111 00: 01100 100 111 000 00 00 10011 000 000 00 PC ← LSL SP

Hex: 0C9C: 32701300

AR:

01100 110 000 00: 01100 110 000 000 00 00 10011 000 000 00 AR ← LSL R0
Hex: 0CC0: 33001300
01100 110 001 00: 01100 110 001 000 00 00 10011 000 000 00 AR ← LSL R1
Hex: 0CC4: 33101300
01100 110 010 00: 01100 110 010 000 00 00 10011 000 000 00 AR ← LSL R2:
Hex: 0CC8: 33201300
01100 110 011 00: 01100 110 011 000 00 00 10011 000 000 00 AR ← LSL R3
Hex: 0CCC: 33301300
01100 110 100 00: 01100 110 100 000 00 00 10011 000 000 00 AR ← LSL PC
Hex: 0CD0: 33401300
01100 110 110 00: 01100 110 110 000 00 00 10011 000 000 00 AR ← LSL AR
Hex: 0CD8: 33601300
01100 110 111 00: 01100 110 111 000 00 00 10011 000 000 00 AR ← LSL SP
Hex: 0CDC: 33701300

SP: 01100 111 000 00: 01100 111 000 000 00 00 10011 000 000 00 SP ← LSL R0
Hex: 0CE0: 33801300
01100 111 001 00: 01100 111 001 000 00 00 10011 000 000 00 SP ← LSL R1
Hex: 0CE4: 33901300
01100 111 010 00: 01100 111 010 000 00 00 10011 000 000 00 SP ← LSL R2
Hex: 0CE8: 33A01300
01100 111 011 00: 01100 111 011 000 00 00 10011 000 000 00 SP ← LSL R3
Hex: 0CEC: 33B01300
01100 111 100 00: 01100 111 100 000 00 00 10011 000 000 00 SP ← LSL PC
Hex: 0CF0: 33C01300
01100 111 110 00: 01100 111 110 000 00 00 10011 000 000 00 SP ← LSL AR
Hex: 0CF8: 33E01300
01100 111 111 00: 01100 111 111 000 00 00 10011 000 000 00 SP ← LSL SP
Hex: 0CFC: 33F01300

Opcode DESTREG SRCREG1 00

Like not – change ALU operation and make sure that SRCREG1 is at input A of ALU
(we can perform LSL and LSR only on A)

- F2 and F3 both belong to RegisterFile

OutASel – the 2 LSB of F3, MuxCSel = 1, FunSelALU – 1010 (LSL A)
MuxASel = 11,
RegSelReg = decode F2 and take the 4 LSB outputs of the decoder
FunSelRegister = 01 (Load)

- F2 and F3 both belong to AddressRegister

OutCSel = the 2 MSB (bit 7, 6) of decoding F3
MuxCSel = 0 (the OutCSel will be forwarded to the A input of the ALU)
FunSelALU = 1010 (LSL A)
MuxBSel = 11 (the OutALU)
RegSelAdd = like above – bits 7,6, 4 of the output of decoding F2
FunSelAddress = 01 (load)

- F2 – AddressRegister, F3 – RegisterFile

OutASel = the 2 LSB of F3 , MuxCSel = 1, FunSelALU = 1010 (LSL A)
MuxBSel = 11,
RegSelAdd = like above – bits 7,6, 4 of the output of decoding F2
FunSelAddress = 01 (load)

- F2 – RegisterFile, F3 – AddressRegister

OutCSel = the 2 MSB (bit 7, 6) of decoding F2
MuxCSel = 0, FunSelALU = 1010 (LSL A)
MuxASel = 11,
RegSelR – decode F2 and take the 4 LSB outputs of the decoder
FunSelReg = 01

D LSR F2 ← LSR F3 R0:
01101 000 000 00: 01101 000 000 000 00 00 10011 000 000 00 R0 ← LSR R0
Hex: 0D00: 34001300
01101 000 001 00: 01101 000 001 000 00 00 10011 000 000 00 R0 ← LSR R1

Hex: 0D04: 34101300

01101 000 010 00: 01101 000 010 000 00 00 10011 000 000 00 R0 ← LSR R2
Hex: 0D08: 34201300

01101 000 011 00: 01101 000 011 000 00 00 10011 000 000 00 R0 ← LSR R3
Hex: 0D0C: 34301300

01101 000 100 00: 01101 000 100 000 00 00 10011 000 000 00 R0 ← LSR PC
Hex: 0D10: 34401300

01101 000 110 00: 01101 000 110 000 00 00 10011 000 000 00 R0 ← LSR AR
Hex: 0D18: 34601300

01101 000 111 00: 01101 000 111 000 00 00 10011 000 000 00 R0 ← LSR SP
Hex: 0D1C: 34701300

R1:

01101 001 000 00: 01101 001 000 000 00 00 10011 000 000 00 R1 ← LSR R0
Hex: 0D20: 34801300

01101 001 001 00: 01101 001 001 000 00 00 10011 000 000 00 R1 ← LSR R1
Hex: 0D24: 34901300

01101 001 010 00: 01101 001 010 000 00 00 10011 000 000 00 R1 ← LSR R2
Hex: 0D28: 34A01300

01101 001 011 00: 01101 001 011 000 00 00 10011 000 000 00 R1 ← LSR R3
Hex: 0D2C: 34B01300

01101 001 100 00: 01101 001 100 000 00 00 10011 000 000 00 R1 ← LSR PC
Hex: 0D30: 34C01300

01101 001 110 00: 01101 001 110 000 00 00 10011 000 000 00 R1 ← LSR AR
Hex: 0D38: 34E01300

01101 001 111 00: 01101 001 111 000 00 00 10011 000 000 00 R1 ← LSR SP
Hex: 0D3C: 34F01300

R2:

01101 010 000 00: 01101 010 000 000 00 00 10011 000 000 00 R2 ← LSR R0
Hex: 0D40: 35001300

01101 010 001 00: 01101 010 001 000 00 00 10011 000 000 00 R2 ← LSR R1
Hex: 0D44: 35101300

01101 010 010 00: 01101 010 010 000 00 00 10011 000 000 00 R2 ← LSR R2
Hex: 0D48: 35201300

01101 010 011 00: 01101 010 011 000 00 00 10011 000 000 00 R2 ← LSR R3
Hex: 0D4C: 35301300

01101 010 100 00: 01101 010 100 000 00 00 10011 000 000 00 R2 ← LSR PC
Hex: 0D50: 35401300
01101 010 110 00: 01101 010 110 000 00 00 10011 000 000 00 R2 ← LSR AR
Hex: 0D58: 35601300
01101 010 111 00: 01101 010 111 000 00 00 10011 000 000 00 R2 ← LSR SP
Hex: 0D5C: 35701300

R3:
01101 011 000 00: 01101 011 000 000 00 00 10011 000 000 00 R3 ← LSR R0
Hex: 0D60: 35801300
01101 011 001 00: 01101 011 001 000 00 00 10011 000 000 00 R3 ← LSR R1
Hex: 0D64: 35901300
01101 011 010 00: 01101 011 010 000 00 00 10011 000 000 00 R3 ← LSR R2
Hex: 0D68: 35A01300
01101 011 011 00: 01101 011 011 000 00 00 10011 000 000 00 R3 ← LSR R3
Hex: 0D6C: 35B01300
01101 011 100 00: 01101 011 100 000 00 00 10011 000 000 00 R3 ← LSR PC
Hex: 0D70: 35C01300
01101 011 110 00: 01101 011 110 000 00 00 10011 000 000 00 R3 ← LSR AR
Hex: 0D78: 35E01300
01101 011 111 00: 01101 011 111 000 00 00 10011 000 000 00 R3 ← LSR SP
Hex: 0D7C: 35F01300

PC:
01101 100 000 00: 01101 100 000 000 00 00 10011 000 000 00 PC ← LSR R0
Hex: 0D80: 36001300
01101 100 001 00: 01101 100 001 000 00 00 10011 000 000 00 PC ← LSR R1
Hex: 0D84: 36101300
01101 100 010 00: 01101 100 010 000 00 00 10011 000 000 00 PC ← LSR R2
Hex: 0D88: 36201300
01101 100 011 00: 01101 100 011 000 00 00 10011 000 000 00 PC ← LSR R3
Hex: 0D8C: 36301300
01101 100 100 00: 01101 100 100 000 00 00 10011 000 000 00 PC ← LSR PC
Hex: 0D90: 36401300
01101 100 110 00: 01101 100 110 000 00 00 10011 000 000 00 PC ← LSR AR
Hex: 0D98: 36601300
01101 100 111 00: 01101 100 111 000 00 00 10011 000 000 00 PC ← LSR SP

Hex: 0D9C: 36701300

AR:

01101 110 000 00: 01101 110 000 000 00 00 10011 000 000 00 AR ← LSR R0
Hex: 0DC0: 37001300
01101 110 001 00: 01101 110 001 000 00 00 10011 000 000 00 AR ← LSR R1
Hex: 0DC4: 37101300
01101 110 010 00: 01101 110 010 000 00 00 10011 000 000 00 AR ← LSR R2
Hex: 0DC8: 37201300
01101 110 011 00: 01101 110 011 000 00 00 10011 000 000 00 AR ← LSR R3
Hex: 0DCC: 37301300
01101 110 100 00: 01101 110 100 000 00 00 10011 000 000 00 AR ← LSR PC
Hex: 0DD0: 37401300
01101 110 110 00: 01101 110 110 000 00 00 10011 000 000 00 AR ← LSR AR
Hex: 0DD8: 37601300
01101 110 111 00: 01101 110 111 000 00 00 10011 000 000 00 AR ← LSR SP
Hex: 0DDC: 37701300

SP:

01101 111 000 00: 01101 111 000 000 00 00 10011 000 000 00 SP ← LSR R0
Hex: 0DE0: 37801300
01101 111 001 00: 01101 111 001 000 00 00 10011 000 000 00 SP ← LSR R1
Hex: 0DE4: 37901300
01101 111 010 00: 01101 111 010 000 00 00 10011 000 000 00 SP ← LSR R2
Hex: 0DE8: 37A01300
01101 111 011 00: 01101 111 011 000 00 00 10011 000 000 00 SP ← LSR R3
Hex: 0DEC: 37B01300
01101 111 100 00: 01101 111 100 000 00 00 10011 000 000 00 SP ← LSR PC
Hex: 0DF0: 37C01300
01101 111 110 00: 01101 111 110 000 00 00 10011 000 000 00 SP ← LSR AR
Hex: 0DF8: 37E01300
01101 111 111 00: 01101 111 111 000 00 00 10011 000 000 00 SP ← LSR SP
Hex: 0DFC: 37F01300

Opcode DESTREG SRCREG1 00
Like not – change ALU operation and make sure that SRCREG1 is at input A of ALU

- F2 and F3 both belong to RegisterFile

OutASel – the 2 LSB of F3, MuxCSel = 1, FunSelALU – 1011 (LSR A)
MuxASel = 11,
RegSelReg = decode F2 and take the 4 LSB outputs of the decoder
FunSelRegister = 01 (Load)

- F2 and F3 both belong to AddressRegister

OutCSel = the 2 MSB (bit 7, 6) of decoding F3
MuxCSel = 0 (the OutCSel will be forwarded to the A input of the ALU)
FunSelALU = 1011 (LSR A)
MuxBSel = 11 (the OutALU)
RegSelAdd = like above – bits 7,6, 4 of the output of decoding F2
FunSelAddress = 01 (load)

- F2 – AddressRegister, F3 – RegisterFile

OutASel = the 2 LSB of F3, MuxCSel = 1, FunSelALU = 1011 (LSR A)
MuxBSel = 11,
RegSelAdd = like above – bits 7,6, 4 of the output of decoding F2
FunSelAddress = 01 (load)

- F2 – RegisterFile, F3 – AddressRegister

OutCSel = the 2 MSB (bit 7, 6) of decoding F3
MuxCSel = 0, FunSelALU = 1011 (LSR A)
MuxASel = 11,
RegSelR – decode F2 and take the 4 LSB outputs of the decoder
FunSelReg = 01

E BRA IM PC ← VALUE
- value is the address field of the instruction

01110 000 000 00: 01110 000 000 000 00 00 10011 000 000 00 PC ← VALUE (address field of the instruction)

Hex: 0E00: 38001300

Mapping: Opcode 000 000 00

MuxBSel = 01, RegSelAddress = 001 (PC), FunSelAdd = 01 (Load)

F BEQ IM – check condition if Z = 1 then PC ← VALUE

Address in control memory of PC ← Value

01111 000 000 00: 01111 000 000 000 01 00 01110 000 000 00 Check condition Z and if true (= 1) – jump to the PC ← Value

Hex: 0F00: 3C008E00

Mapping: Opcode 000 000 00

10 BNE IM – check condition if Z = 0 then PC ← VALUE

10000 000 000 00: 10000 000 000 000 10 00 01110 000 000 00 Check condition Z and if = 0, jump to PC ← Value

Hex: 1000: 40010E00

Z' is a separate status bit – Z' = 1 means that Z = 0

Mapping: Opcode 000 000 00

11 CALL IM M[SP] ← PC, SP ← SP − 1, PC ← VALUE

- IM so that its address field of the microinstruction

10001 000 000 00: 10001 000 000 000 (00 01 00011 100 000 00)- go to subroutine M[SP] ← PC, (use subroutine call and return)

Hex: 1100: 44002380

(can make the subroutine call to that address only with the modifications on Push routine which makes the M[SP] ← PC)

10001 000 000 01: 10001 101 101 101 00 01 00111 111 000 01 - unconditional subroutine call

Hex: 1101: 46DA27E1

Go to SP ← SP − 1 subroutine

10001 000 000 10: NOP 00 00 01110 000 000 00 Go to PC ← VALUE

Hex: 1102: 46DA0E00

Mapping: Opcode 000 000 00

12 RET SP ← SP + 1, PC ← M[SP]

Or maybe it should store no operation and then make the unconditional jump to subroutine

10010 000 000 00: 10010 101 101 101 00 01 01000 111 000 01– go to subroutine SP ← SP + 1

Hex: 1200: 4ADA28E1

10010 000 000 01: 10010 101 101 101 00 00 00100 100 000 01 Jump PC ← M[SP] – unconditional jump

Hex: 1201: 4ADA0481

Mapping: Opcode 000 000 00

FETCH SUBROUTINE

10011 000 000 00: 10011 000 000 000 00 00 10011 000 000 01 IR (15 − 8) ← M[AR] (15 − 8) - unconditional jump to next address Hex: 1300: 4C001301

10011 000 000 01: 10011 000 000 001 00 00 10011 000 000 10 – jump to next address, so we have time to load the whole instruction – if we jumped directly loading the instruction into IR didn't happen correctly Hex: 1301: 4C021302

10011 000 000 10: 10011 101 101 101 00 01 01000 100 000 10 -NOP and jump to PC ← PC + 1 (the special one, that acts as a subroutine) Hex: 1302: 4EDA2882

10011 000 000 11: 10011 101 101 101 00 11 10011 000 000 00 - NOP and MAP according to the instruction code Hex: 1303: 4EDA7300

Last bit = 0

OutDSel = 00 (PC), Sel = 1 , LD = 1

MuxDSel = 1 (the higher bits)

L/H = 1, FunSelIR = 11, E = 1

FunSelIR will always be 1 – we only load to it – if its not enabled nothing will be changed

Last bit = 1

OutDSel = 00 (PC), Sel = 1 , LD = 1

MuxDSel = 0 (the lower bits)

L/H = 0, FunSelIR = 11, E = 1

SUBROUTINE RETURN CHECK ROUTINE

10100 000 000 00: 10100 101 101 101 11 00 10100 000 000 11 – NOP jump to this address if S is 1 - to the address that makes the subroutine return.

1400: 52DB9403

S is a special status bit, used to show whether we the instruction that we are performing has a subroutine call.

There are certain routines stored in ROM which may either be used on their own or as subroutine calls, and their next address changes according to the situation If it was a subroutine call, it returns from the subroutine, to the address stored in the SBR (Subroutine Register). If not it goes to fetch.

If BR is 10 – it does not depend on the condition bit, it will make the return anyway, this first instruction is to check the condition.

If the S status bit is 0 – means this was not a subroutine call and we come to the next address which realizes a jump to fetch.

10100 000 000 01: 10100 101 101 101 00 00 10011 000 000 00 - NOP and go to fetch 1401: 52DA1300

If we came here make the return from subroutine – the next address won't be used but we put the address of fetch just to make sure that we aren't reaching a place we shouldn't if there is some mistake. We don't care about the value of the condition bit 10100 000 000 11: 10100 101 101 101 11 10 10011 000 000 00 - NOP and return from subroutine 1403: 52DBD300

3   RESULTS

We tried to implement the example program that was given in the file. First of all, we converted the instructions into hex code and decided the address in RAM where they should be written.

Table 1: Example Program

Address in memory	Instruction in hex	Instruction description
0x00	7020	ORG 0x20 (BRA instruction)
0x20	0005	LD R0 IM 0x05
0x21	0200	LD R1 IM 0x00
0x22	04A0	LD R2 IM 0xA0
0x23	1640	MOV AR R2
0x24	0500	LD R2 D (LABEL)
0x25	46C0	INC AR AR
0x26	2928	ADD R1 R1 R2
0x27	3800	DEC R0 R0
0x28	8024	BNE IM LABEL
0x29	0b00	ST R1 D

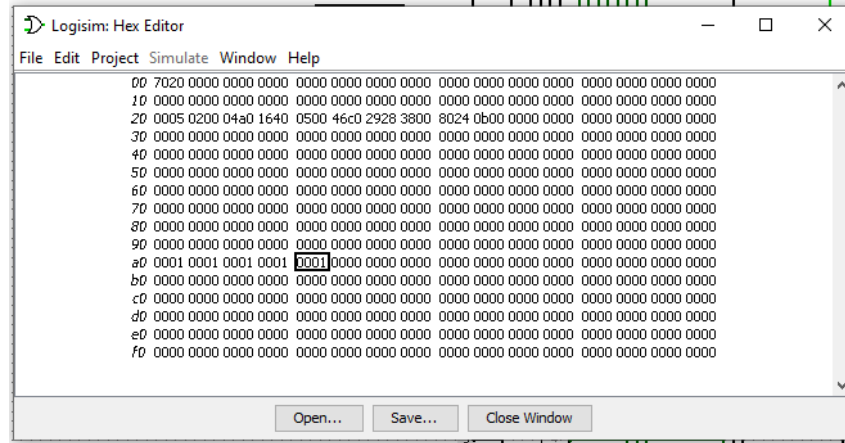As displayed in the following figure, We wrote them into RAM according to table 1.

Figure 5: Entering the program into RAM

The aim of the program is to perform $M[A0] + M[A1] + M[A2] + M[A3] + M[A4]$ and store it at $M[A5]$. We chose some arbitrary values for $M[A0 - A4]$. In our case we wrote a 0x01 value in all those memory addresses of the RAM. When executing their sum, 0x05 was computed and it was successfully stored in memory address A5, as displayed in the figure 6.
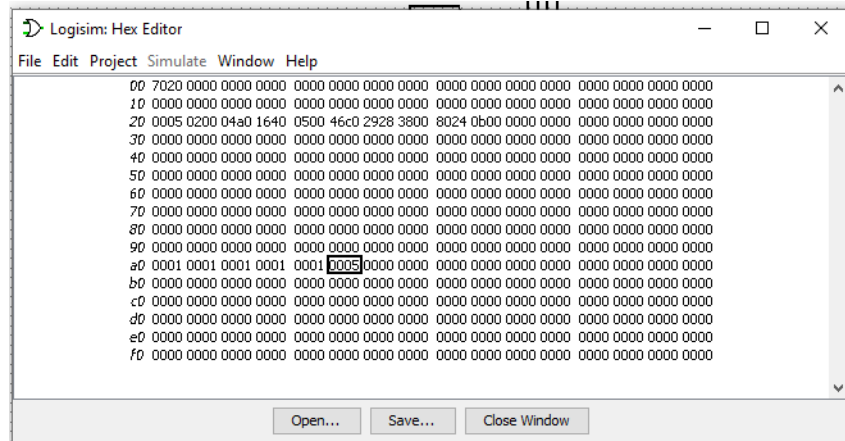

Figure 6: The result of executing the program

4 DISCUSSION

Microprogram consists of microinstructions and it is program stored in memory that generates all the control signals required to execute the instruction set correctly. Microinstruction contains a control word and a sequencing word. In this project we designed microprogrammed control unit. CPU gives instructions to the control unit and control unit performs the actual physical transfer of data. The microinstructions stored in the

ROM will be the same for the different programs that we may try to implement. The programs will be loaded in the RAM and will be executed accordingly.

Generally , our team tried to complete the requirements flawlessly in the most effective way as much as possible without any complex design.

5   CONCLUSION

By doing last 2 projects we are more familiar with Control Unit (CU) design which is a component of a computer's central processing unit (CPU) . CPU is one of the most important parts of computer , so we can say that CU is also an important component of the basic computer. CU which we designed can perform 18 different operations. All in all , we gained experience on software-based implementing of CU .

REFERENCES

[1] BLG 222E - Computer Organization Course. Slide week 9-10.
Available : https://ninova.itu.edu.tr/Sinif/3557.42763/SinifDosyalari?g1827319