Midterm Exam S4
Computer Architecture

Duration: 1 hr 30 min

Write answers only on the answer sheet.

Exercise 1 (4 points)

Complete the table shown on the answer sheet. Write down the new values of the registers (except the **PC**) and memory that are modified by the instructions. **Use the hexadecimal representation. Memory and registers are reset to their initial values for each instruction.**

Initial values:

```
D0 = $FFFF0011   A0 = $00005000   PC = $00006000
D1 = $00000004   A1 = $00005008
D2 = $FFFFFFF1   A2 = $00005010

$005000   54 AF 18 B9 E7 21 48 C0
$005008   C9 10 11 C8 D4 36 1F 88
$005010   13 79 01 80 42 1A 2D 49
```

Exercise 2 (3 points)

Complete the table shown on the answer sheet. Give the result of the additions and the values of the **N**, **Z**, **V** and **C** flags.

Exercise 3 (4 points)

Let us consider the following program. Complete the table shown on the answer sheet.

```
Main        move.w  #-256,d7

next1       moveq.l #1,d1
            tst.b   d7
            bpl     next2
            moveq.l #2,d1

next2       moveq.l #1,d2
            cmp.w   #-5,d7
            ble     next3
            moveq.l #2,d2

next3       clr.l   d3
            move.w  #$25A,d0
loop3       addq.l  #1,d3
            subq.b  #1,d0
            bne     loop3

next4       clr.l   d4
            move.w  #$3,d0
loop4       addq.l  #1,d4
            dbra    d0,loop4        ; DBRA = DBF

quit        illegal
```

Exercise 4 (9 points)

All questions in this exercise are independent. **Except for the output registers, none of the data or address registers must be modified when the subroutine returns.** A string of characters always ends with a null character (the value 0). For the whole exercise, we assume that the strings of characters are never empty (they contain at least one character different from the null character) and contain digits or lower case letters only (without any accents).

1. Write down the **`StrRev`** subroutine that reverses a string of characters.
   Inputs: **A0.L** points to a string to be reversed (source string).
   A1.L points to a memory location where the reversed string must be written (destination string).
   Output: The destination string contains the reversed source string.
   (The source string must not be modified.)

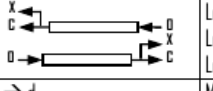
   For instance:
   - If source string = "hello"
   - Then destination string = "olleh"

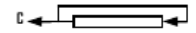
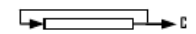
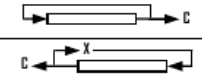
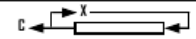
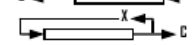
2. Write down the **`IsPal`** subroutine that determines whether a string of characters is palindromic. A string is said to be 'palindromic' when it reads the same backwards as forwards. This subroutine must not use **`StrRev`**.
   Input: **A0.L** points to a string to be tested.
   Output: **D0.L** returns 1 (true) if the string is palindromic.
   D0.L returns 0 (false) if the string is not palindromic.

   For instance:
   - "a", "kayak", "radar", "36544563" are palindromic.
   - "ab", "hello", "123" are not palindromic.

3. By using the **`StrRev`** and **`IsPal`** subroutines, write the **`RevIfNotPal`** subroutine that reverses a non-palindromic string.
   Inputs: **A0.L** points to a string to be reversed (source string).
   A1.L points to a memory location where the reversed string must be written (destination string).
   Outputs: If the source string is not palindromic:
   The destination string contains the reversed source string.
   D0.L returns 0.
   If the source string is palindromic:
   The destination string is not modified (**A1.L** is ignored).
   D0.L returns 1.
   (The source string is never modified.)

EASy68K Quick Reference v1.8 http://www.wowgwep.com/EASy68K.htm

Opcode	Size	Operand	CCR	Effective Address s=source, d=destination, e=either, i=displacement												Operation	Description
	BWL	s,d	XNZVC	Dn	An	(An)	(An)+	-(An)	(i,An)	(i,An,Rn)	abs.W	abs.L	(i,PC)	(i,PC,Rn)	#n		
ABCD	B	Dy,Dx	*U*U*	e	-	-	-	-	-	-	-	-	-	-	-	$Dy_{10} + Dx_{10} + X \rightarrow Dx_{10}$	Add BCD source and eXtend bit to
		-(Ay),-(Ax)		-	-	-	-	e	-	-	-	-	-	-	-	$-(Ay)_{10} + -(Ax)_{10} + X \rightarrow -(Ax)_{10}$	destination, BCD result
ADD [4]	BWL	s,Dn	*****	e	s	s	s	s	s	s	s	s	s	s	s[4]	s + Dn → Dn	Add binary (ADDI or ADDQ is used when
		Dn,d		e	d[4]	d	d	d	d	d	d	d	-	-	-	Dn + d → d	source is #n. Prevent ADDQ with #n.L)
ADDA [4]	WL	s,An	-----	s	e	s	s	s	s	s	s	s	s	s	s	s + An → An	Add address (.W sign-extended to .L)
ADDI [4]	BWL	#n,d	*****	d	-	d	d	d	d	d	d	d	-	-	s	#n + d → d	Add immediate to destination
ADDQ [4]	BWL	#n,d	*****	d	d	d	d	d	d	d	d	d	-	-	s	#n + d → d	Add quick immediate (#n range: 1 to 8)
ADDX	BWL	Dy,Dx	*****	e	-	-	-	-	-	-	-	-	-	-	-	Dy + Dx + X → Dx	Add source and eXtend bit to destination
		-(Ay),-(Ax)		-	-	-	-	e	-	-	-	-	-	-	-	-(Ay) + -(Ax) + X → -(Ax)	
AND [4]	BWL	s,Dn	-**00	e	-	s	s	s	s	s	s	s	s	s	s[4]	s AND Dn → Dn	Logical AND source to destination
		Dn,d		e	-	d	d	d	d	d	d	d	-	-	-	Dn AND d → d	(ANDI is used when source is #n)
ANDI [4]	BWL	#n,d	-**00	d	-	d	d	d	d	d	d	d	-	-	s	#n AND d → d	Logical AND immediate to destination
ANDI [4]	B	#n,CCR	=====	-	-	-	-	-	-	-	-	-	-	-	s	#n AND CCR → CCR	Logical AND immediate to CCR
ANDI [4]	W	#n,SR	=====	-	-	-	-	-	-	-	-	-	-	-	s	#n AND SR → SR	Logical AND immediate to SR (Privileged)
ASL	BWL	Dx,Dy	*****	e	-	-	-	-	-	-	-	-	-	-	-		Arithmetic shift Dy by Dx bits left/right
ASR		#n,Dy		d	-	-	-	-	-	-	-	-	-	-	s		Arithmetic shift Dy #n bits L/R (#n: 1 to 8)
	W	d		-	-	d	d	d	d	d	d	d	-	-	-		Arithmetic shift ds 1 bit left/right (.W only)
Bcc	BW[3]	address[2]	-----	-	-	-	-	-	-	-	-	-	-	-	-	if cc true then	Branch conditionally (cc table on back)
																address → PC	(8 or 16-bit ± offset to address)
BCHG	B L	Dn,d	--*--	e[1]	-	d	d	d	d	d	d	d	-	-	-	NOT(bit number of d) → Z	Set Z with state of specified bit in d then
		#n,d		d[1]	-	d	d	d	d	d	d	d	-	-	s	NOT(bit n of d)→ bit n of d	invert the bit in d
BCLR	B L	Dn,d	--*--	e[1]	-	d	d	d	d	d	d	d	-	-	-	NOT(bit number of d) → Z	Set Z with state of specified bit in d then
		#n,d		d[1]	-	d	d	d	d	d	d	d	-	-	s	0 → bit number of d	clear the bit in d
BRA	BW[3]	address[2]	-----	-	-	-	-	-	-	-	-	-	-	-	-	address → PC	Branch always (8 or 16-bit ± offset to addr)
BSET	B L	Dn,d	--*--	e[1]	-	d	d	d	d	d	d	d	-	-	-	NOT(bit n of d) → Z	Set Z with state of specified bit in d then
		#n,d		d[1]	-	d	d	d	d	d	d	d	-	-	s	1 → bit n of d	set the bit in d
BSR	BW[3]	address[2]	-----	-	-	-	-	-	-	-	-	-	-	-	-	PC → -(SP); address → PC	Branch to subroutine (8 or 16-bit ± offset)
BTST	B L	Dn,d	--*--	e[1]	-	d	d	d	d	d	d	d	d	d	-	NOT(bit Dn of d) → Z	Set Z with state of specified bit in d
		#n,d		d[1]	-	d	d	d	d	d	d	d	d	d	s	NOT(bit #n of d) → Z	Leave the bit in d unchanged
CHK	W	s,Dn	-*UUU	e	-	s	s	s	s	s	s	s	s	s	s	if Dn<0 or Dn>s then TRAP	Compare Dn with 0 and upper bound [s]
CLR	BWL	d	-0100	d	-	d	d	d	d	d	d	d	-	-	-	0 → d	Clear destination to zero
CMP [4]	BWL	s,Dn	-****	e	s[4]	s	s	s	s	s	s	s	s	s	s[4]	set CCR with Dn – s	Compare Dn to source
CMPA [4]	WL	s,An	-****	s	e	s	s	s	s	s	s	s	s	s	s	set CCR with An – s	Compare An to source
CMPI [4]	BWL	#n,d	-****	d	-	d	d	d	d	d	d	d	-	-	s	set CCR with d - #n	Compare destination to #n
CMPM [4]	BWL	(Ay)+,(Ax)+	-****	-	-	-	e	-	-	-	-	-	-	-	-	set CCR with (Ax) - (Ay)	Compare (Ax) to (Ay); Increment Ax and Ay
DBcc	W	Dn,addres[2]	-----	-	-	-	-	-	-	-	-	-	-	-	-	if cc false then { Dn-1 → Dn	Test condition, decrement and branch
																if Dn <> -1 then addr →PC }	(16-bit ± offset to address)
DIVS	W	s,Dn	-***0	e	-	s	s	s	s	s	s	s	s	s	s	±32bit Dn / ±16bit s → ±Dn	Dn= [16-bit remainder, 16-bit quotient]
DIVU	W	s,Dn	-***0	e	-	s	s	s	s	s	s	s	s	s	s	32bit Dn / 16bit s → Dn	Dn= [16-bit remainder, 16-bit quotient]
EOR [4]	BWL	Dn,d	-**00	e	-	d	d	d	d	d	d	d	-	-	s[4]	Dn XOR d → d	Logical exclusive OR Dn to destination
EORI [4]	BWL	#n,d	-**00	d	-	d	d	d	d	d	d	d	-	-	s	#n XOR d → d	Logical exclusive OR #n to destination
EORI [4]	B	#n,CCR	=====	-	-	-	-	-	-	-	-	-	-	-	s	#n XOR CCR → CCR	Logical exclusive OR #n to CCR
EORI [4]	W	#n,SR	=====	-	-	-	-	-	-	-	-	-	-	-	s	#n XOR SR → SR	Logical exclusive OR #n to SR (Privileged)
EXG	L	Rx,Ry	-----	e	e	-	-	-	-	-	-	-	-	-	-	register ← → register	Exchange registers (32-bit only)
EXT	WL	Dn	-**00	d	-	-	-	-	-	-	-	-	-	-	-	Dn.B → Dn.W | Dn.W → Dn.L	Sign extend (change .B to .W or .W to .L)
ILLEGAL			-----	-	-	-	-	-	-	-	-	-	-	-	-	PC→-(SSP); SR→-(SSP)	Generate Illegal Instruction exception
JMP		d	-----	-	-	d	-	-	d	d	d	d	d	d	-	↑d → PC	Jump to effective address of destination
JSR		d	-----	-	-	d	-	-	d	d	d	d	d	d	-	PC → -(SP); ↑d → PC	push PC, jump to subroutine at address d
LEA	L	s,An	-----	-	e	s	-	-	s	s	s	s	s	s	-	↑s → An	Load effective address of s to An
LINK		An,#n	-----	-	-	-	-	-	-	-	-	-	-	-	-	An → -(SP); SP → An;	Create local workspace on stack
																SP + #n → SP	(negative n to allocate space)
LSL	BWL	Dx,Dy	***0*	e	-	-	-	-	-	-	-	-	-	-	-		Logical shift Dy, Dx bits left/right
LSR		#n,Dy		d	-	-	-	-	-	-	-	-	-	-	s		Logical shift Dy, #n bits L/R (#n: 1 to 8)
	W	d		-	-	d	d	d	d	d	d	d	-	-	-		Logical shift d 1 bit left/right (.W only)
MOVE [4]	BWL	s,d	-**00	e	s[4]	e	e	e	e	e	e	e	s	s	s[4]	s → d	Move data from source to destination
MOVE	W	s,CCR	=====	s	-	s	s	s	s	s	s	s	s	s	s	s → CCR	Move source to Condition Code Register
MOVE	W	s,SR	=====	s	-	s	s	s	s	s	s	s	s	s	s	s → SR	Move source to Status Register (Privileged)
MOVE	W	SR,d	-----	d	-	d	d	d	d	d	d	d	-	-	-	SR → d	Move Status Register to destination
MOVE	L	USP,An	-----	-	d	-	-	-	-	-	-	-	-	-	-	USP → An	Move User Stack Pointer to An (Privileged)
		An,USP		-	s	-	-	-	-	-	-	-	-	-	-	An → USP	Move An to User Stack Pointer (Privileged)
	BWL	s,d	XNZVC	Dn	An	(An)	(An)+	-(An)	(i,An)	(i,An,Rn)	abs.W	abs.L	(i,PC)	(i,PC,Rn)	#n		

Opcode	Size	Operand	CCR	Effective Address s=source, d=destination, e=either, i=displacement											Operation	Description
	BWL	s,d	XNZVC	Dn	An	(An)	(An)+	-(An)	(i,An)	(i,An,Rn)	abs.W	abs.L	(i,PC)	(i,PC,Rn)	#n	
MOVEA[4]	WL	s,An	-----	s	e	s	s	s	s	s	s	s	s	s	s	s → An	Move source to An (MOVE s,An use MOVEA)
MOVEM[4]	WL	Rn-Rn,d	-----	-	-	d	-	d	d	d	d	d	-	-	-	Registers → d	Move specified registers to/from memory
		s,Rn-Rn		-	-	s	s	-	s	s	s	s	s	s	-	s → Registers	(.W source is sign-extended to .L for Rn)
MOVEP	WL	Dn,(i,An)	-----	s	-	-	-	-	d	-	-	-	-	-	-	Dn → (i,An)...(i+2,An)...(i+4,A.	Move Dn to/from alternate memory bytes
		(i,An),Dn		d	-	-	-	-	s	-	-	-	-	-	-	(i,An) → Dn...(i+2,An)...(i+4,A.	(Access only even or odd addresses)
MOVEQ[4]	L	#n,Dn	-**00	d	-	-	-	-	-	-	-	-	-	-	s	#n → Dn	Move sign extended 8-bit #n to Dn
MULS	W	s,Dn	-**00	e	-	s	s	s	s	s	s	s	s	s	s	±16bit s * ±16bit Dn → ±Dn	Multiply signed 16-bit; result: signed 32-bit
MULU	W	s,Dn	-**00	e	-	s	s	s	s	s	s	s	s	s	s	16bit s * 16bit Dn → Dn	Multiply unsig'd 16-bit; result: unsig'd 32-bit
NBCD	B	d	*U*U*	d	-	d	d	d	d	d	d	d	-	-	-	$0 - d_{10} - X \rightarrow d$	Negate BCD with eXtend, BCD result
NEG	BWL	d	*****	d	-	d	d	d	d	d	d	d	-	-	-	0 - d → d	Negate destination (2's complement)
NEGX	BWL	d	*****	d	-	d	d	d	d	d	d	d	-	-	-	0 - d - X → d	Negate destination with eXtend
NOP			-----	-	-	-	-	-	-	-	-	-	-	-	-	None	No operation occurs
NOT	BWL	d	-**00	d	-	d	d	d	d	d	d	d	-	-	-	NOT(d) → d	Logical NOT destination (1's complement)
OR[4]	BWL	s,Dn	-**00	e	-	s	s	s	s	s	s	s	s	s	s^4	s OR Dn → Dn	Logical OR
		Dn,d		e	-	d	d	d	d	d	d	d	-	-	-	Dn OR d → d	(ORI is used when source is #n)
ORI[4]	BWL	#n,d	-**00	d	-	d	d	d	d	d	d	d	-	-	s	#n OR d → d	Logical OR #n to destination
ORI[4]	B	#n,CCR	=====	-	-	-	-	-	-	-	-	-	-	-	s	#n OR CCR → CCR	Logical OR #n to CCR
ORI[4]	W	#n,SR	=====	-	-	-	-	-	-	-	-	-	-	-	s	#n OR SR → SR	Logical OR #n to SR (Privileged)
PEA	L	s	-----	-	-	s	-	-	s	s	s	s	s	s	-	↑s → -(SP)	Push effective address of s onto stack
RESET			-----	-	-	-	-	-	-	-	-	-	-	-	-	Assert RESET Line	Issue a hardware RESET (Privileged)
ROL	BWL	Dx,Dy	-**0*	e	-	-	-	-	-	-	-	-	-	-	-		Rotate Dy, Dx bits left/right (without X)
ROR		#n,Dy		d	-	-	-	-	-	-	-	-	-	-	s		Rotate Dy, #n bits left/right (#n: 1 to 8)
	W	d		-	-	d	d	d	d	d	d	d	-	-	-		Rotate d 1-bit left/right (.W only)
ROXL	BWL	Dx,Dy	***0*	e	-	-	-	-	-	-	-	-	-	-	-		Rotate Dy, Dx bits L/R, X used then updated
ROXR		#n,Dy		d	-	-	-	-	-	-	-	-	-	-	s		Rotate Dy, #n bits left/right (#n: 1 to 8)
	W	d		-	-	d	d	d	d	d	d	d	-	-	-		Rotate destination 1-bit left/right (.W only)
RTE			=====	-	-	-	-	-	-	-	-	-	-	-	-	(SP)+ → SR; (SP)+ → PC	Return from exception (Privileged)
RTR			=====	-	-	-	-	-	-	-	-	-	-	-	-	(SP)+ → CCR, (SP)+ → PC	Return from subroutine and restore CCR
RTS			-----	-	-	-	-	-	-	-	-	-	-	-	-	(SP)+ → PC	Return from subroutine
SBCD	B	Dy,Dx	*U*U*	e	-	-	-	-	-	-	-	-	-	-	-	$Dx_{10} - Dy_{10} - X \rightarrow Dx_{10}$	Subtract BCD source and eXtend bit from
		-(Ay),-(Ax)		-	-	-	-	e	-	-	-	-	-	-	-	$-(Ax)_{10} - -(Ay)_{10} - X \rightarrow -(Ax)_{10}$	destination, BCD result
Scc	B	d	-----	d	-	d	d	d	d	d	d	d	-	-	-	If cc is true then 1's → d	If cc true then d.B = 11111111
																else 0's → d	else d.B = 00000000
STOP		#n	=====	-	-	-	-	-	-	-	-	-	-	-	s	#n → SR; STOP	Move #n to SR, stop processor (Privileged)
SUB[4]	BWL	s,Dn	*****	e	s	s	s	s	s	s	s	s	s	s	s^4	Dn - s → Dn	Subtract binary (SUBI or SUBQ used when
		Dn,d		e	d^4	d	d	d	d	d	d	d	-	-	-	d - Dn → d	source is #n. Prevent SUBQ with #n.L)
SUBA[4]	WL	s,An	-----	s	e	s	s	s	s	s	s	s	s	s	s	An - s → An	Subtract address (.W sign-extended to .L)
SUBI[4]	BWL	#n,d	*****	d	-	d	d	d	d	d	d	d	-	-	s	d - #n → d	Subtract immediate from destination
SUBQ[4]	BWL	#n,d	*****	d	d	d	d	d	d	d	d	d	-	-	s	d - #n → d	Subtract quick immediate (#n range: 1 to 8)
SUBX	BWL	Dy,Dx	*****	e	-	-	-	-	-	-	-	-	-	-	-	Dx - Dy - X → Dx	Subtract source and eXtend bit from
		-(Ay),-(Ax)		-	-	-	-	e	-	-	-	-	-	-	-	-(Ax) - -(Ay) – X → -(Ax)	destination
SWAP	W	Dn	-**00	d	-	-	-	-	-	-	-	-	-	-	-	bits[31:16]←→bits[15:0]	Exchange the 16-bit halves of Dn
TAS	B	d	-**00	d	-	d	d	d	d	d	d	d	-	-	-	test d→CCR; 1 →bit7 of d	N and Z set to reflect d, bit7 of d set to 1
TRAP		#n	-----	-	-	-	-	-	-	-	-	-	-	-	s	PC→-(SSP);SR→-(SSP);	Push PC and SR, PC set by vector table #n
																(vector table entry) → PC	(#n range: 0 to 15)
TRAPV			-----	-	-	-	-	-	-	-	-	-	-	-	-	If V then TRAP #7	If overflow, execute an Overflow TRAP
TST	BWL	d	-**00	d	-	d	d	d	d	d	d	d	-	-	-	test d → CCR	N and Z set to reflect destination
UNLK		An	-----	-	d	-	-	-	-	-	-	-	-	-	-	An → SP; (SP)+ → An	Remove local workspace from stack
	BWL	s,d	XNZVC	Dn	An	(An)	(An)+	-(An)	(i,An)	(i,An,Rn)	abs.W	abs.L	(i,PC)	(i,PC,Rn)	#n		

Condition Tests (+ OR, ! NOT, ⊕ XOR; [u] Unsigned, [a] Alternate cc)					
cc	**Condition**	**Test**	**cc**	**Condition**	**Test**
T	true	1	VC	overflow clear	!V
F	false	0	VS	overflow set	V
HI[u]	higher than	!(C + Z)	PL	plus	!N
LS[u]	lower or same	C + Z	MI	minus	N
HS[u], CC[a]	higher or same	!C	GE	greater or equal	!(N ⊕ V)
LO[u], CS[a]	lower than	C	LT	less than	(N ⊕ V)
NE	not equal	!Z	GT	greater than	![(N ⊕ V) + Z]
EQ	equal	Z	LE	less or equal	(N ⊕ V) + Z

Revised by Peter Csaszar, Lawrence Tech University – 2004-2006

An Address register (16/32-bit, n=0-7)
Dn Data register (8/16/32-bit, n=0-7)
Rn any data or address register
s Source, **d** Destination
e Either source or destination
#n Immediate data, **i** Displacement
BCD Binary Coded Decimal
↑ Effective address

SSP Supervisor Stack Pointer (32-bit)
USP User Stack Pointer (32-bit)
SP Active Stack Pointer (same as A7)
PC Program Counter (24-bit)

SR Status Register (16-bit)
CCR Condition Code Register (lower 8-bits of SR)
N negative, **Z** zero, **V** overflow, **C** carry, **X** extend
***** set according to operation's result, ≡ set directly
- not affected, **0** cleared, **1** set, **U** undefined

1 Long only; all others are byte only
2 Assembler calculates offset
3 Branch sizes: **.B** or **.S** -128 to +127 bytes, **.W** or **.L** -32768 to +32767 bytes
4 Assembler automatically uses A, I, Q or M form if possible. Use #n.L to prevent Quick optimization

Last name: ..... First name: ..... Group: .....

ANSWER SHEET TO BE HANDED IN

Exercise 1

Instruction	Memory	Register
Example	`$005000  54 AF 00 40 E7 21 48 C0`	A0 = `$00005004` A1 = `$0000500C`
Example	`$005008  C9 10 11 C8 D4 36 FF 88`	No change
`MOVE.L $5006,(A2)+`		
`MOVE.L #50,10(A1)`		
`MOVE.B 12(A1,D2.L),7(A2)`		
`MOVE.L -2(A1),-17(A2,D0.W)`		

Exercise 2

Operation	Size (bits)	Result (hexadecimal)	N	Z	V	C
`$7F + $7F`	8					
`$7F + $80`	8					
`$7F + $81`	8					

Exercise 3

Values of registers after the execution of the program. **Use the 32-bit hexadecimal representation.**	
D1 = $	**D3** = $
D2 = $	**D4** = $

Exercise 4

```
StrRev
```

```
IsPal
```

```
RevIfNotPal
```