EEEN 3449
Microprocessor Systems

Compute the Array Sum

Tyler Hurson

Spring 2017

I. INTRODUCTION

1.1 Purpose

The purpose of this experiment is to familiarize oneself with loop constructs in the Assembly language and how to use them to iterate over an array of data.

1.2 Problem

Comparison and branch instructions will be used in order to control program flow and execute a block of code several times. The most common use of looping mechanisms is to iterate over an array of data. An Assembly program that contains comparison and branching instructions that iterates over each element in a 5-byte array will be executed. Six varieties of this program will be executed.

In Program A-1 (Appendix A), the array is located at the end of the program. Two bytes are reserved for the sum and one byte is reserved for the loop counter. The loop counter is initialized to 0 and counts upwards to 5, accessing each element in the array using offset indexed addressing and adding it to the immediate sum.

In Program B-1 (Appendix B), the array is located at the end of the program. The loop counter is initialized to 5 and counts downwards to 0. The array is summed from the first element to the last.

In Program A-2 (Appendix C), the array is located at the end of the program. The loop counter is initialized to 0 and counts upwards to 5. The array is summed from the last element to the first.

In Program B-2 (Appendix D), the array is located at the end of the program. The loop counter is initialized to 5 and counts downwards to 5. The array is summed from the last element to the first.

In Program A-3 (Appendix E), the array is located at the beginning of the program. The loop counter is initialized to 0 and counts upwards to 5. The array is summed from the first element to the last.

In Program B-3 (Appendix F), the array is located at the beginning of the program. The loop counter is initialized to 5 and counts downwards to 0. The array is summed from the first element to the last.

1.3 Scope

The scope of this experiment is limited to the HCS12 microcontroller. Only a few basic instructions will be used from the HCS12 instruction set, including storing and loading instructions, comparison instructions, arithmetic instructions, and branching instructions.

II. TEST AND EVALUATION

2.1 Apparatus

The equipment used in this test includes: Dragon12-Junior development board, USB power cord, and laptop PC with AsmIDE.

2.2 Procedure

1. The development board was connected to the computer.
2. The COM port number was determined under Device Manager on PC. AsmIDE was launched. Under View -> Options -> COM Port, the COM port was set to the device's number. The Terminal Window was enabled. Under Set COM Options, the default values were restored.
3. Program A-1 was opened, and then assembled. After no errors were recorded, program A was downloaded into the development board, by typing `load` in the Terminal Window in AsmIDE, then downloading the program.
4. `br 2007` was typed to set a breakpoint. `g 2000` was typed to execute the program. `t 100` was typed repeatedly to trace the program, line by line, until the program ended. As the program was traced, the immediate sum (Y) was verified correct for each iteration of the loop.
5. Program B-1 was opened, and then assembled. After no errors were recorded, program B-1 was downloaded into the development board.
6. `br 2007` was typed to set a breakpoint. `g 2000` was typed to execute the program. `t 100` was typed repeatedly to trace the program, line by line, until

the program ended. As the program was traced, the immediate sum (Y) was verified correct for each iteration of the loop.

7. Program A-2 was opened, and then assembled. After no errors were recorded, program A-2 was downloaded into the development board.
8. `br 2007` was typed to set a breakpoint. `g 2000` was typed to execute the program. `t 100` was typed repeatedly to trace the program, line by line, until the program ended. As the program was traced, the immediate sum (Y) was verified correct for each iteration of the loop.
9. Program B-2 was opened, and then assembled. After no errors were recorded, program B-2 was downloaded into the development board.
10. `br 2007` was typed to set a breakpoint. `g 2000` was typed to execute the program. `t 100` was typed repeatedly to trace the program, line by line, until the program ended. As the program was traced, the immediate sum (Y) was verified correct for each iteration of the loop.
11. Program A-3 was opened, and then assembled. After no errors were recorded, program A-3 was downloaded into the development board.
12. `br 2007` was typed to set a breakpoint. `g 2000` was typed to execute the program. `t 100` was typed repeatedly to trace the program, line by line, until the program ended. As the program was traced, the immediate sum (Y) was verified correct for each iteration of the loop.
13. Program B-3 was opened, and then assembled. After no errors were recorded, program B-3 was downloaded into the development board.

14. `br 2007` was typed to set a breakpoint. `g 2000` was typed to execute the program. `t 100` was typed repeatedly to trace the program, line by line, until the program ended. As the program was traced, the immediate sum (Y) was verified correct for each iteration of the loop.

III. RESULTS

3.1 Data

For each program, the immediate sum for each iteration was recorded (Table 1). The full line-by-line output of each program is found under its respective Appendix.

Table 1: Immediate Sums of each Program

Program/ Loop Count	A-1	B-1	A-2	B-2	A-3	B-3
1	0B	0B	14	14	0B	0B
2	19	19	25	25	19	19
3	28	28	34	34	28	28
4	39	39	42	42	39	39
5	4D	4D	4D	4D	4D	4D

III. CONCLUSION

4.1 Assessment

This experiment served as an introduction to the basic looping mechanisms of the Assembly language. Six varieties of an Assembly program were tested, each involving differences in the way the loop counter was incremented/decremented and the way the array was added.

APPENDIX A

ASSEMBLY PROGRAM A-1

```
N     equ   5
      org   $1500
sum   rmb   2     ; reserve 2 bytes of memory for sum
i     rmb   1     ; reserve 1 byte of memory for loop counter
      org   $2000 ; program start
      ldaa  #0    ; A = 0
      staa  i     ; i = 0
      staa  sum   ; sum = 0
      staa  sum+1 ; [sum+1] = 0
loop  ldab  i     ; B = i
      cmpb  #N    ; B == 5?
      beq   done  ; branch to done if B == 5
      ldx   #array; load pointer first element in array to X
      abx         ; X = X + B
      ldab  0,X   ; B = [X]
      ldy   sum   ; Y = [sum]
      aby         ; B = B + Y
      sty   sum   ; sum = Y
      inc   i     ; i++
      bra   loop  ; branch back to loop
done  swi         ; loop finished
array dc.b  11,14,15,17,20
      end
```

STAA $1501

PC	SP	X	Y	A	B	SXHI NZVC
2008	3C00	0000	0000	00	00	1001 0100

LDAB $1502

PC	SP	X	Y	A	B	SXHI NZVC
200B	3C00	0000	0000	00	00	1001 0100

CMPB #$05

PC	SP	X	Y	A	B	SXHI NZVC
200E	3C00	0000	0000	00	00	1001 0100

BEQ $2026

PC	SP	X	Y	A	B	SXHI NZVC
2010	3C00	0000	0000	00	00	1001 1001

LDX #$2027

PC	SP	X	Y	A	B	SXHI NZVC
2012	3C00	0000	0000	00	00	1001 1001

1AE5 ABX

PC	SP	X	Y	A	B	SXHI NZVC
2015	3C00	2027	0000	00	00	1001 0001

LDAB 0,X

PC	SP	X	Y	A	B	SXHI NZVC
2017	3C00	2027	0000	00	00	1001 0001

LDY $1500

PC	SP	X	Y	A	B	SXHI NZVC
2019	3C00	2027	0000	00	0B	1001 0001

19ED ABY

PC	SP	X	Y	A	B	SXHI NZVC
201C	3C00	2027	0000	00	0B	1001 0101

STY $1500

PC	SP	X	Y	A	B	SXHI NZVC
201E	3C00	2027	000B	00	0B	1001 0101

INC $1502

PC	SP	X	Y	A	B	SXHI NZVC
2021	3C00	2027	000B	00	0B	1001 0001

BRA $200B

PC	SP	X	Y	A	B	SXHI NZVC
2024	3C00	2027	000B	00	0B	1001 0001

LDAB $1502

PC	SP	X	Y	A	B	SXHI NZVC
200B	3C00	2027	000B	00	0B	1001 0001

CMPB #$05

PC	SP	X	Y	A	B	SXHI NZVC
200E	3C00	2027	000B	00	01	1001 0001

BEQ $2026

PC	SP	X	Y	A	B	SXHI NZVC
2010	3C00	2027	000B	00	01	1001 1001

LDX #$2027

PC	SP	X	Y	A	B	SXHI NZVC
2012	3C00	2027	000B	00	01	1001 1001

1AE5 ABX

PC	SP	X	Y	A	B	SXHI NZVC
2015	3C00	2027	000B	00	01	1001 0001

LDAB 0,X

PC	SP	X	Y	A	B	SXHI NZVC
2017	3C00	2028	000B	00	01	1001 0001

LDY $1500

PC	SP	X	Y	A	B	SXHI NZVC
2019	3C00	2028	000B	00	0E	1001 0001

19ED ABY

PC	SP	X	Y	A	B	SXHI NZVC
201C	3C00	2028	000B	00	0E	1001 0001

STY $1500

PC	SP	X	Y	A	B	SXHI NZVC
201E	3C00	2028	0019	00	0E	1001 0001

INC $1502

PC	SP	X	Y	A	B	SXHI NZVC
2021	3C00	2028	0019	00	0E	1001 0001

BRA $200B

PC	SP	X	Y	A	B	SXHI NZVC
2024	3C00	2028	0019	00	0E	1001 0001

LDAB $1502

PC	SP	X	Y	A	B	SXHI NZVC
200B	3C00	2028	0019	00	0E	1001 0001

CMPB #$05

PC	SP	X	Y	A	B	SXHI NZVC
200E	3C00	2028	0019	00	02	1001 0001

BEQ $2026

PC	SP	X	Y	A	B	SXHI NZVC
2010	3C00	2028	0019	00	02	1001 1001

LDX #$2027

PC	SP	X	Y	A	B	SXHI NZVC
2012	3C00	2028	0019	00	02	1001 1001

1AE5 ABX

PC	SP	X	Y	A	B	SXHI NZVC
2015	3C00	2027	0019	00	02	1001 0001

LDAB 0,X

PC	SP	X	Y	A	B	SXHI NZVC
2017	3C00	2029	0019	00	02	1001 0001

LDY $1500

PC	SP	X	Y	A	B	SXHI NZVC
2019	3C00	2029	0019	00	0F	1001 0001

19ED ABY

PC	SP	X	Y	A	B	SXHI NZVC
201C	3C00	2029	0019	00	0F	1001 0001

STY $1500

PC	SP	X	Y	A	B	SXHI NZVC
201E	3C00	2029	0028	00	0F	1001 0001

INC $1502

PC	SP	X	Y	A	B	SXHI NZVC
2021	3C00	2029	0028	00	0F	1001 0001

BRA $200B

PC	SP	X	Y	A	B	SXHI NZVC
2024	3C00	2029	0028	00	0F	1001 0001

LDAB $1502

PC	SP	X	Y	A	B	SXHI NZVC
200B	3C00	2029	0028	00	0F	1001 0001

CMPB #$05

PC	SP	X	Y	A	B	SXHI NZVC
200E	3C00	2029	0028	00	03	1001 0001

BEQ $2026

PC	SP	X	Y	A	B	SXHI NZVC
2010	3C00	2029	0028	00	03	1001 1001

LDX #$2027

PC	SP	X	Y	A	B	SXHI NZVC
2012	3C00	2029	0028	00	03	1001 1001

1AE5 ABX

PC	SP	X	Y	A	B	SXHI NZVC
2015	3C00	2027	0028	00	03	1001 0001

LDAB 0,X

PC	SP	X	Y	A	B	SXHI NZVC
2017	3C00	202A	0028	00	03	1001 0001

LDY $1500

PC	SP	X	Y	A	B	SXHI NZVC
2019	3C00	202A	0028	00	11	1001 0001

19ED ABY

PC	SP	X	Y	A	B	SXHI NZVC
201C	3C00	202A	0028	00	11	1001 0001

STY $1500

PC	SP	X	Y	A	B	SXHI NZVC
201E	3C00	202A	0039	00	11	1001 0001

INC $1502

PC	SP	X	Y	A	B	SXHI NZVC
2021	3C00	202A	0039	00	11	1001 0001

BRA $200B

PC	SP	X	Y	A	B	SXHI NZVC
2024	3C00	202A	0039	00	11	1001 0001

LDAB $1502

PC	SP	X	Y	A	B	SXHI NZVC
200B	3C00	202A	0039	00	11	1001 0001

CMPB #$05

PC	SP	X	Y	A	B	SXHI NZVC
200E	3C00	202A	0039	00	04	1001 0001

BEQ $2026

PC	SP	X	Y	A	B	SXHI NZVC
2010	3C00	202A	0039	00	04	1001 1001

LDX #$2027

PC	SP	X	Y	A	B	SXHI NZVC
2012	3C00	202A	0039	00	04	1001 1001

1AE5 ABX

PC	SP	X	Y	A	B	SXHI NZVC
2015	3C00	2027	0039	00	04	1001 0001

LDAB 0,X

PC	SP	X	Y	A	B	SXHI NZVC
2017	3C00	202B	0039	00	04	1001 0001

LDY $1500

PC	SP	X	Y	A	B	SXHI NZVC
2019	3C00	202B	0039	00	14	1001 0001

19ED ABY

PC	SP	X	Y	A	B	SXHI NZVC
201C	3C00	202B	0039	00	14	1001 0001

STY $1500

PC	SP	X	Y	A	B	SXHI NZVC
201E	3C00	202B	004D	00	14	1001 0001

INC $1502

PC	SP	X	Y	A	B	SXHI NZVC
2021	3C00	202B	004D	00	14	1001 0001

BRA $200B

PC	SP	X	Y	A	B	SXHI NZVC
2024	3C00	202B	004D	00	14	1001 0001

LDAB $1502

PC	SP	X	Y	A	B	SXHI NZVC
200B	3C00	202B	004D	00	14	1001 0001

CMPB #$05

PC	SP	X	Y	A	B	SXHI NZVC
200E	3C00	202B	004D	00	05	1001 0001

BEQ $2026

PC	SP	X	Y	A	B	SXHI NZVC
2010	3C00	202B	004D	00	05	1001 0100

APPENDIX B

ASSEMBLY PROGRAM B-1

```
N     equ   5
      org   $1500
sum   rmb   2     ; reserve 2 bytes of memory for sum
i     rmb   1     ; reserve 1 byte of memory for loop counter
      org   $2000 ; program start
      ldaa  #0    ; A = 0
      movb  #N, i ; i = 5
      staa  sum   ; sum = 0
      staa  sum+1 ; [sum+1] = 0
      clrb        ; B = 0
loop  ldaa  i     ; A = i
      cmpa  #0    ; A == 0?
      beq   done  ; branch to done if A == 0
      ldx   #array; load pointer first element in array to X
      abx         ; X = X + B
      exg   A, B  ; A = B, B = A
      ldab  0,X   ; B = [X]
      ldy   sum   ; Y = [sum]
      aby         ; B = B + Y
      exg   A, B  ; A = B, B = A
      sty   sum   ; sum = Y
      dec   i     ; i--
      incb        ; B++
      bra   loop  ; branch back to loop
done  swi         ; loop finished
array dc.b  11,14,15,17,20
      end
```

STAA $1500

PC	SP	X	Y	A	B	SXHI NZVC
2007	3C00	0000	0000	00	00	1001 0100

STAA $1501

PC	SP	X	Y	A	B	SXHI NZVC
200A	3C00	0000	0000	00	00	1001 0100

C7 CLRB

PC	SP	X	Y	A	B	SXHI NZVC
200D	3C00	0000	0000	00	00	1001 0100

LDAA $1502

PC	SP	X	Y	A	B	SXHI NZVC
200E	3C00	0000	0000	00	00	1001 0100

CMPA #$00

PC	SP	X	Y	A	B	SXHI NZVC
2011	3C00	0000	0000	05	00	1001 0000

BEQ $202E

PC	SP	X	Y	A	B	SXHI NZVC
2013	3C00	0000	0000	05	00	1001 0000

LDX #$202F

PC	SP	X	Y	A	B	SXHI NZVC
2015	3C00	0000	0000	05	00	1001 0000

1AE5 ABX

PC	SP	X	Y	A	B	SXHI NZVC
2018	3C00	202F	0000	05	00	1001 0000

EXG A,B

PC	SP	X	Y	A	B	SXHI NZVC
201A	3C00	202F	0000	05	00	1001 0000

LDAB 0,X

PC	SP	X	Y	A	B	SXHI NZVC
201C	3C00	202F	0000	00	05	1001 0000

LDY $1500

PC	SP	X	Y	A	B	SXHI NZVC
201E	3C00	202F	0000	00	0B	1001 0000

19ED ABY

PC	SP	X	Y	A	B	SXHI NZVC
2021	3C00	202F	0000	00	0B	1001 0100

EXG A,B

PC	SP	X	Y	A	B	SXHI NZVC
2023	3C00	202F	000B	00	0B	1001 0100

STY $1500

PC	SP	X	Y	A	B	SXHI NZVC
2025	3C00	202F	000B	0B	00	1001 0100

DEC $1502

PC	SP	X	Y	A	B	SXHI NZVC
2028	3C00	202F	000B	0B	00	1001 0000

52 INCB

PC	SP	X	Y	A	B	SXHI NZVC
202B	3C00	202F	000B	0B	00	1001 0000

BRA $200E

PC	SP	X	Y	A	B	SXHI NZVC
202C	3C00	202F	000B	0B	01	1001 0000

LDAA $1502

PC	SP	X	Y	A	B	SXHI NZVC
200E	3C00	202F	000B	0B	01	1001 0000

CMPA #$00

PC	SP	X	Y	A	B	SXHI NZVC
2011	3C00	202F	000B	04	01	1001 0000

BEQ $202E

PC	SP	X	Y	A	B	SXHI NZVC
2013	3C00	202F	000B	04	01	1001 0000

LDX #$202F

PC	SP	X	Y	A	B	SXHI NZVC
2015	3C00	202F	000B	04	01	1001 0000

1AE5 ABX

PC	SP	X	Y	A	B	SXHI NZVC
2018	3C00	202F	000B	04	01	1001 0000

EXG A,B

PC	SP	X	Y	A	B	SXHI NZVC
201A	3C00	2030	000B	04	01	1001 0000

LDAB 0,X

PC	SP	X	Y	A	B	SXHI NZVC
201C	3C00	2030	000B	01	04	1001 0000

LDY $1500

PC	SP	X	Y	A	B	SXHI NZVC
201E	3C00	2030	000B	01	0E	1001 0000

19ED ABY

PC	SP	X	Y	A	B	SXHI NZVC
2021	3C00	2030	000B	01	0E	1001 0000

EXG A,B

PC	SP	X	Y	A	B	SXHI NZVC
2023	3C00	2030	0019	01	0E	1001 0000

STY $1500

PC	SP	X	Y	A	B	SXHI NZVC
2025	3C00	2030	0019	0E	01	1001 0000

DEC $1502

PC	SP	X	Y	A	B	SXHI NZVC
2028	3C00	2030	0019	0E	01	1001 0000

52 INCB

PC	SP	X	Y	A	B	SXHI NZVC
202B	3C00	2030	0019	0E	01	1001 0000

BRA $200E

PC	SP	X	Y	A	B	SXHI NZVC
202C	3C00	2030	0019	0E	02	1001 0000

LDAA $1502

PC	SP	X	Y	A	B	SXHI NZVC
200E	3C00	2030	0019	0E	02	1001 0000

CMPA #$00

PC	SP	X	Y	A	B	SXHI NZVC
2011	3C00	2030	0019	03	02	1001 0000

BEQ $202E

PC	SP	X	Y	A	B	SXHI NZVC
2013	3C00	2030	0019	03	02	1001 0000

LDX #$202F

PC	SP	X	Y	A	B	SXHI NZVC
2015	3C00	2030	0019	03	02	1001 0000

1AE5 ABX

PC	SP	X	Y	A	B	SXHI NZVC
2018	3C00	202F	0019	03	02	1001 0000

EXG A,B

PC	SP	X	Y	A	B	SXHI NZVC
201A	3C00	2031	0019	03	02	1001 0000

LDAB 0,X

PC	SP	X	Y	A	B	SXHI NZVC
201C	3C00	2031	0019	02	03	1001 0000

LDY $1500

PC	SP	X	Y	A	B	SXHI NZVC
201E	3C00	2031	0019	02	0F	1001 0000

19ED ABY

PC	SP	X	Y	A	B	SXHI NZVC
2021	3C00	2031	0019	02	0F	1001 0000

EXG A,B

PC	SP	X	Y	A	B	SXHI NZVC
2023	3C00	2031	0028	02	0F	1001 0000

STY $1500

PC	SP	X	Y	A	B	SXHI NZVC
2025	3C00	2031	0028	0F	02	1001 0000

DEC $1502

PC	SP	X	Y	A	B	SXHI NZVC
2028	3C00	2031	0028	0F	02	1001 0000

52 INCB

PC	SP	X	Y	A	B	SXHI NZVC
202B	3C00	2031	0028	0F	02	1001 0000

BRA $200E

PC	SP	X	Y	A	B	SXHI NZVC
202C	3C00	2031	0028	0F	03	1001 0000

LDAA $1502

PC	SP	X	Y	A	B	SXHI NZVC
200E	3C00	2031	0028	0F	03	1001 0000

CMPA #$00

PC	SP	X	Y	A	B	SXHI NZVC
2011	3C00	2031	0028	02	03	1001 0000

BEQ $202E

PC	SP	X	Y	A	B	SXHI NZVC
2013	3C00	2031	0028	02	03	1001 0000

LDX #$202F

PC	SP	X	Y	A	B	SXHI NZVC
2015	3C00	2031	0028	02	03	1001 0000

1AE5 ABX

PC	SP	X	Y	A	B	SXHI NZVC
2018	3C00	202F	0028	02	03	1001 0000

EXG A,B

PC	SP	X	Y	A	B	SXHI NZVC
201A	3C00	2032	0028	02	03	1001 0000

LDAB 0,X

PC	SP	X	Y	A	B	SXHI NZVC
201C	3C00	2032	0028	03	02	1001 0000

LDY $1500

PC	SP	X	Y	A	B	SXHI NZVC
201E	3C00	2032	0028	03	11	1001 0000

19ED ABY

PC	SP	X	Y	A	B	SXHI NZVC
2021	3C00	2032	0028	03	11	1001 0000

EXG A,B

PC	SP	X	Y	A	B	SXHI NZVC
2023	3C00	2032	0039	03	11	1001 0000

STY $1500

PC	SP	X	Y	A	B	SXHI NZVC
2025	3C00	2032	0039	11	03	1001 0000

DEC $1502

PC	SP	X	Y	A	B	SXHI NZVC
2028	3C00	2032	0039	11	03	1001 0000

52 INCB

PC	SP	X	Y	A	B	SXHI NZVC
202B	3C00	2032	0039	11	03	1001 0000

BRA $200E

PC	SP	X	Y	A	B	SXHI NZVC
202C	3C00	2032	0039	11	04	1001 0000

LDAA $1502

PC	SP	X	Y	A	B	SXHI NZVC
200E	3C00	2032	0039	11	04	1001 0000

CMPA #$00

PC	SP	X	Y	A	B	SXHI NZVC
2011	3C00	2032	0039	01	04	1001 0000

BEQ $202E

PC	SP	X	Y	A	B	SXHI NZVC
2013	3C00	2032	0039	01	04	1001 0000

LDX #$202F

PC	SP	X	Y	A	B	SXHI NZVC
2015	3C00	2032	0039	01	04	1001 0000

1AE5 ABX

PC	SP	X	Y	A	B	SXHI NZVC
2018	3C00	202F	0039	01	04	1001 0000

EXG A,B

PC	SP	X	Y	A	B	SXHI NZVC
201A	3C00	2033	0039	01	04	1001 0000

LDAB 0,X

PC	SP	X	Y	A	B	SXHI NZVC
201C	3C00	2033	0039	04	01	1001 0000

LDY $1500

PC	SP	X	Y	A	B	SXHI NZVC
201E	3C00	2033	0039	04	14	1001 0000

19ED ABY

PC	SP	X	Y	A	B	SXHI NZVC
2021	3C00	2033	0039	04	14	1001 0000

EXG A,B

PC	SP	X	Y	A	B	SXHI NZVC
2023	3C00	2033	004D	04	14	1001 0000

STY $1500

PC	SP	X	Y	A	B	SXHI NZVC
2025	3C00	2033	004D	14	04	1001 0000

DEC $1502

PC	SP	X	Y	A	B	SXHI NZVC
2028	3C00	2033	004D	14	04	1001 0000

52 INCB

PC	SP	X	Y	A	B	SXHI NZVC
202B	3C00	2033	004D	14	04	1001 0100

BRA $200E

PC	SP	X	Y	A	B	SXHI NZVC
202C	3C00	2033	004D	14	05	1001 0000

LDAA $1502

PC	SP	X	Y	A	B	SXHI NZVC
200E	3C00	2033	004D	14	05	1001 0000

CMPA #$00

PC	SP	X	Y	A	B	SXHI NZVC
2011	3C00	2033	004D	00	05	1001 0100

BEQ $202E

PC	SP	X	Y	A	B	SXHI NZVC
2013	3C00	2033	004D	00	05	1001 0100

3F SWI

PC	SP	X	Y	A	B	SXHI NZVC
202E	3C00	2033	004D	00	05	1001 0100

APPENDIX C

ASSEMBLY PROGRAM A-2

```
N     equ   5
      org   $1500
sum   rmb   2     ; reserve 2 bytes of memory for sum
i     rmb   1     ; reserve 1 byte of memory for loop counter
      org   $2000 ; program start
      ldaa  #0    ; A = 0
      ldab  #N-1  ; B = 4
      staa  i     ; i = 0
      staa  sum   ; sum = 0
      staa  sum+1 ; [sum+1] = 0
loop  ldaa  i     ; A = i
      cmpa  #N    ; A == 5?
      beq   done  ; branch to done if A == 5
      ldx   #array; load pointer first element in array to X
      abx         ; X = X + B
      exg   A,B   ; A = B, B = A
      ldab  0,X   ; B = [X]
      ldy   sum   ; Y = [sum]
      aby         ; B = B + Y
      exg   A,B   ; A = B, B = A
      sty   sum   ; sum = Y
      inc   i     ; i++
      decb        ; B--
      bra   loop  ; branch back to loop
done  swi         ; loop finished
array dc.b  11,14,15,17,20
      end
```

STAA $1500

PC	SP	X	Y	A	B	SXHI NZVC
2007	3C00	0000	0000	00	04	1001 0100

STAA $1501

PC	SP	X	Y	A	B	SXHI NZVC
200A	3C00	0000	0000	00	04	1001 0100

LDAA $1502

PC	SP	X	Y	A	B	SXHI NZVC
200D	3C00	0000	0000	00	04	1001 0100

CMPA #$05

PC	SP	X	Y	A	B	SXHI NZVC
2010	3C00	0000	0000	00	04	1001 0100

BEQ $202D

PC	SP	X	Y	A	B	SXHI NZVC
2012	3C00	0000	0000	00	04	1001 1001

LDX #$202E

PC	SP	X	Y	A	B	SXHI NZVC
2014	3C00	0000	0000	00	04	1001 1001

1AE5 ABX

PC	SP	X	Y	A	B	SXHI NZVC
2017	3C00	202E	0000	00	04	1001 0001

EXG A,B

PC	SP	X	Y	A	B	SXHI NZVC
2019	3C00	2032	0000	00	04	1001 0001

LDAB 0,X

PC	SP	X	Y	A	B	SXHI NZVC
201B	3C00	2032	0000	04	00	1001 0001

LDY $1500

PC	SP	X	Y	A	B	SXHI NZVC
201D	3C00	2032	0000	04	14	1001 0001

19ED ABY

PC	SP	X	Y	A	B	SXHI NZVC
2020	3C00	2032	0000	04	14	1001 0101

EXG A,B

PC	SP	X	Y	A	B	SXHI NZVC
2022	3C00	2032	0014	04	14	1001 0101

STY $1500

PC	SP	X	Y	A	B	SXHI NZVC
2024	3C00	2032	0014	14	04	1001 0101

INC $1502

PC	SP	X	Y	A	B	SXHI NZVC
2027	3C00	2032	0014	14	04	1001 0001

53 DECB

PC	SP	X	Y	A	B	SXHI NZVC
202A	3C00	2032	0014	14	04	1001 0001

BRA $200D

PC	SP	X	Y	A	B	SXHI NZVC
202B	3C00	2032	0014	14	03	1001 0001

LDAA $1502

PC	SP	X	Y	A	B	SXHI NZVC
200D	3C00	2032	0014	14	03	1001 0001

CMPA #$05

PC	SP	X	Y	A	B	SXHI NZVC
2010	3C00	2032	0014	01	03	1001 0001

BEQ $202D

PC	SP	X	Y	A	B	SXHI NZVC
2012	3C00	2032	0014	01	03	1001 1001

LDX #$202E

PC	SP	X	Y	A	B	SXHI NZVC
2014	3C00	2032	0014	01	03	1001 1001

1AE5 ABX

PC	SP	X	Y	A	B	SXHI NZVC
2017	3C00	202E	0014	01	03	1001 0001

EXG A,B

PC	SP	X	Y	A	B	SXHI NZVC
2019	3C00	2031	0014	01	03	1001 0001

LDAB 0,X

PC	SP	X	Y	A	B	SXHI NZVC
201B	3C00	2031	0014	03	01	1001 0001

LDY $1500

PC	SP	X	Y	A	B	SXHI NZVC
201D	3C00	2031	0014	03	11	1001 0001

19ED ABY

PC	SP	X	Y	A	B	SXHI NZVC
2020	3C00	2031	0014	03	11	1001 0001

EXG A,B

PC	SP	X	Y	A	B	SXHI NZVC
2022	3C00	2031	0025	03	11	1001 0001

STY $1500

PC	SP	X	Y	A	B	SXHI NZVC
2024	3C00	2031	0025	11	03	1001 0001

INC $1502

PC	SP	X	Y	A	B	SXHI NZVC
2027	3C00	2031	0025	11	03	1001 0001

53 DECB

PC	SP	X	Y	A	B	SXHI NZVC
202A	3C00	2031	0025	11	03	1001 0001

BRA $200D

PC	SP	X	Y	A	B	SXHI NZVC
202B	3C00	2031	0025	11	02	1001 0001

LDAA $1502

PC	SP	X	Y	A	B	SXHI NZVC
200D	3C00	2031	0025	11	02	1001 0001

CMPA #$05

PC	SP	X	Y	A	B	SXHI NZVC
2010	3C00	2031	0025	02	02	1001 0001

BEQ $202D

PC	SP	X	Y	A	B	SXHI NZVC
2012	3C00	2031	0025	02	02	1001 1001

LDX #$202E

PC	SP	X	Y	A	B	SXHI NZVC
2014	3C00	2031	0025	02	02	1001 1001

1AE5 ABX

PC	SP	X	Y	A	B	SXHI NZVC
2017	3C00	202E	0025	02	02	1001 0001

EXG A,B

PC	SP	X	Y	A	B	SXHI NZVC
2019	3C00	2030	0025	02	02	1001 0001

LDAB 0,X

PC	SP	X	Y	A	B	SXHI NZVC
201B	3C00	2030	0025	02	02	1001 0001

LDY $1500

PC	SP	X	Y	A	B	SXHI NZVC
201D	3C00	2030	0025	02	0F	1001 0001

19ED ABY

PC	SP	X	Y	A	B	SXHI NZVC
2020	3C00	2030	0025	02	0F	1001 0001

EXG A,B

PC	SP	X	Y	A	B	SXHI NZVC
2022	3C00	2030	0034	02	0F	1001 0001

STY $1500

PC	SP	X	Y	A	B	SXHI NZVC
2024	3C00	2030	0034	0F	02	1001 0001

INC $1502

PC	SP	X	Y	A	B	SXHI NZVC
2027	3C00	2030	0034	0F	02	1001 0001

53 DECB

PC	SP	X	Y	A	B	SXHI NZVC
202A	3C00	2030	0034	0F	02	1001 0001

BRA $200D

PC	SP	X	Y	A	B	SXHI NZVC
202B	3C00	2030	0034	0F	01	1001 0001

LDAA $1502

PC	SP	X	Y	A	B	SXHI NZVC
200D	3C00	2030	0034	0F	01	1001 0001

CMPA #$05

PC	SP	X	Y	A	B	SXHI NZVC
2010	3C00	2030	0034	03	01	1001 0001

BEQ $202D

PC	SP	X	Y	A	B	SXHI NZVC
2012	3C00	2030	0034	03	01	1001 1001

LDX #$202E

PC	SP	X	Y	A	B	SXHI NZVC
2014	3C00	2030	0034	03	01	1001 1001

1AE5 ABX

PC	SP	X	Y	A	B	SXHI NZVC
2017	3C00	202E	0034	03	01	1001 0001

EXG A,B

PC	SP	X	Y	A	B	SXHI NZVC
2019	3C00	202F	0034	03	01	1001 0001

LDAB 0,X

PC	SP	X	Y	A	B	SXHI NZVC
201B	3C00	202F	0034	01	03	1001 0001

LDY $1500

PC	SP	X	Y	A	B	SXHI NZVC
201D	3C00	202F	0034	01	0E	1001 0001

19ED ABY

PC	SP	X	Y	A	B	SXHI NZVC
2020	3C00	202F	0034	01	0E	1001 0001

EXG A,B

PC	SP	X	Y	A	B	SXHI NZVC
2022	3C00	202F	0042	01	0E	1001 0001

STY $1500

PC	SP	X	Y	A	B	SXHI NZVC
2024	3C00	202F	0042	0E	01	1001 0001

INC $1502

PC	SP	X	Y	A	B	SXHI NZVC
2027	3C00	202F	0042	0E	01	1001 0001

53 DECB

PC	SP	X	Y	A	B	SXHI NZVC
202A	3C00	202F	0042	0E	01	1001 0001

BRA $200D

PC	SP	X	Y	A	B	SXHI NZVC
202B	3C00	202F	0042	0E	00	1001 0101

LDAA $1502

PC	SP	X	Y	A	B	SXHI NZVC
200D	3C00	202F	0042	0E	00	1001 0101

CMPA #$05

PC	SP	X	Y	A	B	SXHI NZVC
2010	3C00	202F	0042	04	00	1001 0001

BEQ $202D

PC	SP	X	Y	A	B	SXHI NZVC
2012	3C00	202F	0042	04	00	1001 1001

LDX #$202E

PC	SP	X	Y	A	B	SXHI NZVC
2014	3C00	202F	0042	04	00	1001 1001

1AE5 ABX

PC	SP	X	Y	A	B	SXHI NZVC
2017	3C00	202E	0042	04	00	1001 0001

EXG A,B

PC	SP	X	Y	A	B	SXHI NZVC
2019	3C00	202E	0042	04	00	1001 0001

LDAB 0,X

PC	SP	X	Y	A	B	SXHI NZVC
201B	3C00	202E	0042	00	04	1001 0001

LDY $1500

PC	SP	X	Y	A	B	SXHI NZVC
201D	3C00	202E	0042	00	0B	1001 0001

19ED ABY

PC	SP	X	Y	A	B	SXHI NZVC
2020	3C00	202E	0042	00	0B	1001 0001

EXG A,B

PC	SP	X	Y	A	B	SXHI NZVC
2022	3C00	202E	004D	00	0B	1001 0001

STY $1500

PC	SP	X	Y	A	B	SXHI NZVC
2024	3C00	202E	004D	0B	00	1001 0001

INC $1502

PC	SP	X	Y	A	B	SXHI NZVC
2027	3C00	202E	004D	0B	00	1001 0001

53 DECB

PC	SP	X	Y	A	B	SXHI NZVC
202A	3C00	202E	004D	0B	00	1001 0001

BRA $200D

PC	SP	X	Y	A	B	SXHI NZVC
202B	3C00	202E	004D	0B	FF	1001 1001

LDAA $1502

PC	SP	X	Y	A	B	SXHI NZVC
200D	3C00	202E	004D	0B	FF	1001 1001

CMPA #$05

PC	SP	X	Y	A	B	SXHI NZVC
2010	3C00	202E	004D	05	FF	1001 0001

BEQ $202D

PC	SP	X	Y	A	B	SXHI NZVC
2012	3C00	202E	004D	05	FF	1001 0100

3F SWI

PC	SP	X	Y	A	B	SXHI NZVC
202D	3C00	202E	004D	05	FF	1001 0100

APPENDIX D

ASSEMBLY PROGRAM B-2

```
N      equ   5
       org   $1500
sum    rmb   2      ; reserve 2 bytes of memory for sum
i      rmb   1      ; reserve 1 byte of memory for loop counter
       org   $2000 ; program start
       ldaa  #0     ; A = 0
       staa  sum    ; sum = 0
       staa  sum+1 ; [sum+1] = 0
       movb  #N,i   ; i = 5
loop   ldab  i      ; B = i
       cmpb  #0     ; B == 0?
       beq   done   ; branch to done if B == 1
       ldx   #array; load pointer to array to X
       decb         ; B = B - 1
       abx          ; X = X + B
       ldab  0,X    ; B = [X]
       ldy   sum    ; Y = [sum]
       aby          ; B = B + Y
       sty   sum    ; sum = Y
       dec   i      ; i--
       bra   loop   ; branch back to loop
done   swi          ; loop finished
array  dc.b  11,14,15,17,20
       end
```

MOVB
#$05,$1502

PC	SP	X	Y	A	B	SXHI NZVC
2008	3C00	0000	0000	00	00	1001 0100

LDAB $1502

PC	SP	X	Y	A	B	SXHI NZVC
200D	3C00	0000	0000	00	00	1001 0100

CMPB #$00

PC	SP	X	Y	A	B	SXHI NZVC
2010	3C00	0000	0000	00	05	1001 0000

BEQ $2029

PC	SP	X	Y	A	B	SXHI NZVC
2012	3C00	0000	0000	00	05	1001 0000

LDX #$202A

PC	SP	X	Y	A	B	SXHI NZVC
2014	3C00	0000	0000	00	05	1001 0000

53 DECB

PC	SP	X	Y	A	B	SXHI NZVC
2017	3C00	202A	0000	00	05	1001 0000

1AE5 ABX

PC	SP	X	Y	A	B	SXHI NZVC
2018	3C00	202A	0000	00	04	1001 0000

LDAB 0,X

PC	SP	X	Y	A	B	SXHI NZVC
201A	3C00	202E	0000	00	04	1001 0000

LDY $1500

PC	SP	X	Y	A	B	SXHI NZVC
201C	3C00	202E	0000	00	14	1001 0000

19ED ABY

PC	SP	X	Y	A	B	SXHI NZVC
201F	3C00	202E	0000	00	14	1001 0100

STY $1500

PC	SP	X	Y	A	B	SXHI NZVC
2021	3C00	202E	0014	00	14	1001 0100

DEC $1502

PC	SP	X	Y	A	B	SXHI NZVC
2024	3C00	202E	0014	00	14	1001 0000

BRA $200D

PC	SP	X	Y	A	B	SXHI NZVC
2027	3C00	202E	0014	00	14	1001 0000

LDAB $1502

PC	SP	X	Y	A	B	SXHI NZVC
200D	3C00	202E	0014	00	14	1001 0000

CMPB #$00

PC	SP	X	Y	A	B	SXHI NZVC
2010	3C00	202E	0014	00	04	1001 0000

BEQ $2029

PC	SP	X	Y	A	B	SXHI NZVC
2012	3C00	202E	0014	00	04	1001 0000

LDX #$202A

PC	SP	X	Y	A	B	SXHI NZVC
2014	3C00	202E	0014	00	04	1001 0000

53 DECB

PC	SP	X	Y	A	B	SXHI NZVC
2017	3C00	202A	0014	00	04	1001 0000

1AE5 ABX

PC	SP	X	Y	A	B	SXHI NZVC
2018	3C00	202A	0014	00	03	1001 0000

LDAB 0,X

PC	SP	X	Y	A	B	SXHI NZVC
201A	3C00	202D	0014	00	03	1001 0000

LDY $1500

PC	SP	X	Y	A	B	SXHI NZVC
201C	3C00	202D	0014	00	11	1001 0000

19ED ABY

PC	SP	X	Y	A	B	SXHI NZVC
201F	3C00	202D	0014	00	11	1001 0000

STY $1500

PC	SP	X	Y	A	B	SXHI NZVC
2021	3C00	202D	0025	00	11	1001 0000

DEC $1502

PC	SP	X	Y	A	B	SXHI NZVC
2024	3C00	202D	0025	00	11	1001 0000

BRA $200D

PC	SP	X	Y	A	B	SXHI NZVC
2027	3C00	202D	0025	00	11	1001 0000

LDAB $1502

PC	SP	X	Y	A	B	SXHI NZVC
200D	3C00	202D	0025	00	11	1001 0000

CMPB #$00

PC	SP	X	Y	A	B	SXHI NZVC
2010	3C00	202D	0025	00	03	1001 0000

BEQ $2029

PC	SP	X	Y	A	B	SXHI NZVC
2012	3C00	202D	0025	00	03	1001 0000

LDX #$202A

PC	SP	X	Y	A	B	SXHI NZVC
2014	3C00	202D	0025	00	03	1001 0000

53 DECB

PC	SP	X	Y	A	B	SXHI NZVC
2017	3C00	202A	0025	00	03	1001 0000

1AE5 ABX

PC	SP	X	Y	A	B	SXHI NZVC
2018	3C00	202A	0025	00	02	1001 0000

LDAB 0,X

PC	SP	X	Y	A	B	SXHI NZVC
201A	3C00	202C	0025	00	02	1001 0000

LDY $1500

PC	SP	X	Y	A	B	SXHI NZVC
201C	3C00	202C	0025	00	0F	1001 0000

19ED ABY

PC	SP	X	Y	A	B	SXHI NZVC
201F	3C00	202C	0025	00	0F	1001 0000

STY $1500

PC	SP	X	Y	A	B	SXHI NZVC
2021	3C00	202C	0034	00	0F	1001 0000

DEC $1502

PC	SP	X	Y	A	B	SXHI NZVC
2024	3C00	202C	0034	00	0F	1001 0000

BRA $200D

PC	SP	X	Y	A	B	SXHI NZVC
2027	3C00	202C	0034	00	0F	1001 0000

LDAB $1502

PC	SP	X	Y	A	B	SXHI NZVC
200D	3C00	202C	0034	00	0F	1001 0000

CMPB #$00

PC	SP	X	Y	A	B	SXHI NZVC
2010	3C00	202C	0034	00	02	1001 0000

BEQ $2029

PC	SP	X	Y	A	B	SXHI NZVC
2012	3C00	202C	0034	00	02	1001 0000

LDX #$202A

PC	SP	X	Y	A	B	SXHI NZVC
2014	3C00	202C	0034	00	02	1001 0000

53 DECB

PC	SP	X	Y	A	B	SXHI NZVC
2017	3C00	202A	0034	00	02	1001 0000

1AE5 ABX

PC	SP	X	Y	A	B	SXHI NZVC
2018	3C00	202A	0034	00	01	1001 0000

LDAB 0,X

PC	SP	X	Y	A	B	SXHI NZVC
201A	3C00	202B	0034	00	01	1001 0000

LDY $1500

PC	SP	X	Y	A	B	SXHI NZVC
201C	3C00	202B	0034	00	0E	1001 0000

19ED ABY

PC	SP	X	Y	A	B	SXHI NZVC
201F	3C00	202B	0034	00	0E	1001 0000

STY $1500

PC	SP	X	Y	A	B	SXHI NZVC
2021	3C00	202B	0042	00	0E	1001 0000

DEC $1502

PC	SP	X	Y	A	B	SXHI NZVC
2024	3C00	202B	0042	00	0E	1001 0000

BRA $200D

PC	SP	X	Y	A	B	SXHI NZVC
2027	3C00	202B	0042	00	0E	1001 0000

LDAB $1502

PC	SP	X	Y	A	B	SXHI NZVC
200D	3C00	202B	0042	00	0E	1001 0000

CMPB #$00

PC	SP	X	Y	A	B	SXHI NZVC
2010	3C00	202B	0042	00	01	1001 0000

BEQ $2029

PC	SP	X	Y	A	B	SXHI NZVC
2012	3C00	202B	0042	00	01	1001 0000

LDX #$202A

PC	SP	X	Y	A	B	SXHI NZVC
2014	3C00	202B	0042	00	01	1001 0000

53 DECB

PC	SP	X	Y	A	B	SXHI NZVC
2017	3C00	202A	0042	00	01	1001 0000

1AE5 ABX

PC	SP	X	Y	A	B	SXHI NZVC
2018	3C00	202A	0042	00	00	1001 0100

LDAB 0,X

PC	SP	X	Y	A	B	SXHI NZVC
201A	3C00	202A	0042	00	00	1001 0100

LDY $1500

PC	SP	X	Y	A	B	SXHI NZVC
201C	3C00	202A	0042	00	0B	1001 0000

19ED ABY

PC	SP	X	Y	A	B	SXHI NZVC
201F	3C00	202A	0042	00	0B	1001 0000

STY $1500

PC	SP	X	Y	A	B	SXHI NZVC
2021	3C00	202A	004D	00	0B	1001 0000

DEC $1502

PC	SP	X	Y	A	B	SXHI NZVC
2024	3C00	202A	004D	00	0B	1001 0000

BRA $200D

PC	SP	X	Y	A	B	SXHI NZVC
2027	3C00	202A	004D	00	0B	1001 0100

LDAB $1502

PC	SP	X	Y	A	B	SXHI NZVC
200D	3C00	202A	004D	00	0B	1001 0100

CMPB #$00

PC	SP	X	Y	A	B	SXHI NZVC
2010	3C00	202A	004D	00	00	1001 0100

BEQ $2029

PC	SP	X	Y	A	B	SXHI NZVC
2012	3C00	202A	004D	00	00	1001 0100

APPENDIX E

ASSEMBLY PROGRAM A-3

```
N     equ   5
      org   $1500
array dc.b  11,14,15,17,20
sum   rmb   2     ; reserve 2 bytes of memory for sum
i     rmb   1     ; reserve 1 byte of memory for loop counter
      org   $2000 ; program start
      ldaa  #0    ; A = 0
      staa  sum   ; sum = 0
      staa  sum+1 ; [sum+1] = 0
      movb  #N,i  ; i = 5
loop  ldab  i     ; B = i
      cmpb  #0    ; B == 0?
      beq   done  ; branch to done if B == 1
      ldx   #array; load pointer to array to X
      decb        ; B = B - 1
      abx         ; X = X + B
      ldab  0,X   ; B = [X]
      ldy   sum   ; Y = [sum]
      aby         ; B = B + Y
      sty   sum   ; sum = Y
      dec   i     ; i--
      bra   loop  ; branch back to loop
done  swi         ; loop finished
      end
```

APPENDIX F

ASSEMBLY PROGRAM B-3

```
N     equ   5
      org   $1500
array dc.b  11,14,15,17,20
sum   rmb   2     ; reserve 2 bytes of memory for sum
i     rmb   1     ; reserve 1 byte of memory for loop counter
      org   $2000 ; program start
      ldaa  #0    ; A = 0
      movb  #N, i ; i = 5
      staa  sum   ; sum = 0
      staa  sum+1 ; [sum+1] = 0
      clrb        ; B = 0
loop  ldaa  i     ; A = i
      cmpa  #0    ; A == 0?
      beq   done  ; branch to done if A == 0
      ldx   #array; load pointer first element in array to X
      abx         ; X = X + B
      exg   A, B  ; A = B, B = A
      ldab  0,X   ; B = [X]
      ldy   sum   ; Y = [sum]
      aby         ; B = B + Y
      exg   A, B  ; A = B, B = A
      sty   sum   ; sum = Y
      dec   i     ; i--
      incb        ; B++
      bra   loop  ; branch back to loop
done  swi         ; loop finished
      end
```