CSCI 592

LAB ASSIGNMENT – 7

Written by

DINESH SEVETI

Date: 03-29-2025

OBJECTIVE

The objective of this project is to implement a simple convolution operation on a 3x3 image matrix using a 2x2 kernel in both Easy68k and RISC-V assembly languages, without utilizing loops. Each element of the result matrix is computed by directly performing the required operations (multiplication and addition) on the image and kernel matrix elements.

TECHNOLOGY USED

- Easy68k Assembly Language: Using the Easy68k simulator to execute the assembly code.
- RISC-V Assembly Language: The program is written for the RISC-V architecture, focusing on optimizing convolution calculations through register-based operations.

PROCEDURE

- Data Representation: Define a 3x3 image matrix and a 2x2 kernel matrix in the data section.
- Multiplication & Summation: Perform element-wise multiplication between the image and kernel matrices, summing the results manually for each element in the output matrix.
- Storing Results: Store the computed convolution results in the result matrix.
- Exit the Program: After all calculations, both programs exit gracefully with a system call.

OPERATIONS

- Matrix Multiplication: Multiply corresponding elements from the image and kernel matrices.
- Addition: Add the products to compute the result for each element of the result matrix.
- Memory Store: Store the resulting values into the result matrix.
- System Exit: Use a system call to exit the program after processing.

ALGORITHM

The algorithm for calculating the convolution in both programs is as follows:

- Initialize the result matrix to store the output values.
- For each element in the result matrix:
- Multiply the corresponding image and kernel elements.
- Sum the results of these multiplications to compute the result.
- Store the result in the result matrix.
- After processing all elements, exit the program.

CODE LISTING

```
      ORG     $1000          ; Start of the program
image:  DC.W    1, 2, 3    ; 3x3 image row 1
        DC.W    4, 5, 6    ; 3x3 image row 2
        DC.W    7, 8, 9    ; 3x3 image row 3
kernel: DC.W    1, 0       ; 2x2 kernel row 1
        DC.W    0, -1      ; 2x2 kernel row 2
result: DS.W    4          ; Space for 2x2 result matrix
   ; Calculate result[0][0]
    MOVE.W  image, D0      ; D0 = image[0][0] = 1
    MOVE.W  kernel, D1     ; D1 = kernel[0][0] = 1
    MULS    D1, D0         ; D0 = D0 * D1 = 1 * 1 = 1
    MOVE.W  image+2, D2    ; D2 = image[0][1] = 2
    MOVE.W  kernel+2, D3   ; D3 = kernel[0][1] = 0
    MULS    D3, D2         ; D2 = D2 * D3 = 2 * 0 = 0
    ADD.W   D2, D0         ; D0 = D0 + D2 = 1 + 0 = 1
    MOVE.W  image+6, D2    ; D2 = image[1][0] = 4
    MOVE.W  kernel+4, D3   ; D3 = kernel[1][0] = 0
    MULS    D3, D2         ; D2 = D2 * D3 = 4 * 0 = 0
    ADD.W   D2, D0         ; D0 = D0 + D2 = 1 + 0 = 1
    MOVE.W  image+8, D2    ; D2 = image[1][1] = 5
    MOVE.W  kernel+6, D3   ; D3 = kernel[1][1] = -1
    MULS    D3, D2         ; D2 = D2 * D3 = 5 * -1 = -5
    ADD.W   D2, D0         ; D0 = D0 + D2 = 1 + (-5) = -4
    MOVE.W  D0, result     ; result[0][0] = -4
    ; Calculate result[0][1]
    MOVE.W  image+2, D0    ; D0 = image[0][1] = 2
    MOVE.W  kernel, D1     ; D1 = kernel[0][0] = 1
    MULS    D1, D0         ; D0 = D0 * D1 = 2 * 1 = 2
    MOVE.W  image+4, D2    ; D2 = image[0][2] = 3
    MOVE.W  kernel+2, D3   ; D3 = kernel[0][1] = 0
    MULS    D3, D2         ; D2 = D2 * D3 = 3 * 0 = 0
    ADD.W   D2, D0         ; D0 = D0 + D2 = 2 + 0 = 2
    MOVE.W  image+8, D2    ; D2 = image[1][1] = 5
    MOVE.W  kernel+4, D3   ; D3 = kernel[1][0] = 0
    MULS    D3, D2         ; D2 = D2 * D3 = 5 * 0 = 0
    ADD.W   D2, D0         ; D0 = D0 + D2 = 2 + 0 = 2

    MOVE.W  image+10, D2   ; D2 = image[1][2] = 6
    MOVE.W  kernel+6, D3   ; D3 = kernel[1][1] = -1
    MULS    D3, D2         ; D2 = D2 * D3 = 6 * -1 = -6
    ADD.W   D2, D0         ; D0 = D0 + D2 = 2 + (-6) = -4
    MOVE.W  D0, result+2   ; result[0][1] = -4
```

```
; Calculate result[1][0]
MOVE.W  image+6, D0    ; D0 = image[1][0] = 4
MOVE.W  kernel, D1     ; D1 = kernel[0][0] = 1
MULS    D1, D0         ; D0 = D0 * D1 = 4 * 1 = 4
MOVE.W  image+8, D2    ; D2 = image[1][1] = 5
MOVE.W  kernel+2, D3   ; D3 = kernel[0][1] = 0
MULS    D3, D2         ; D2 = D2 * D3 = 5 * 0 = 0
ADD.W   D2, D0         ; D0 = D0 + D2 = 4 + 0 = 4

MOVE.W  image+12, D2   ; D2 = image[2][0] = 7
MOVE.W  kernel+4, D3   ; D3 = kernel[1][0] = 0
MULS    D3, D2         ; D2 = D2 * D3 = 7 * 0 = 0
ADD.W   D2, D0         ; D0 = D0 + D2 = 4 + 0 = 4
MOVE.W  image+14, D2   ; D2 = image[2][1] = 8
MOVE.W  kernel+6, D3   ; D3 = kernel[1][1] = -1
MULS    D3, D2         ; D2 = D2 * D3 = 8 * -1 = -8
ADD.W   D2, D0         ; D0 = D0 + D2 = 4 + (-8) = -4
MOVE.W  D0, result+4   ; result[1][0] = -4
; Calculate result[1][1]
MOVE.W  image+8, D0    ; D0 = image[1][1] = 5
MOVE.W  kernel, D1     ; D1 = kernel[0][0] = 1
MULS    D1, D0         ; D0 = D0 * D1 = 5 * 1 = 5

MOVE.W  image+10, D2   ; D2 = image[1][2] = 6
MOVE.W  kernel+2, D3   ; D3 = kernel[0][1] = 0
MULS    D3, D2         ; D2 = D2 * D3 = 6 * 0 = 0
ADD.W   D2, D0         ; D0 = D0 + D2 = 5 + 0 = 5

MOVE.W  image+14, D2   ; D2 = image[2][1] = 8
MOVE.W  kernel+4, D3   ; D3 = kernel[1][0] = 0
MULS    D3, D2         ; D2 = D2 * D3 = 8 * 0 = 0
ADD.W   D2, D0         ; D0 = D0 + D2 = 5 + 0 = 5

MOVE.W  image+16, D2   ; D2 = image[2][2] = 9
MOVE.W  kernel+6, D3   ; D3 = kernel[1][1] = -1
MULS    D3, D2         ; D2 = D2 * D3 = 9 * -1 = -9
ADD.W   D2, D0         ; D0 = D0 + D2 = 5 + (-9) = -4
MOVE.W  D0, result+6   ; result[1][1] = -4

; End of program
SIMHALT                 ; Halt the simulator
```

CODE LISTING

```
.data
image:      .word 1, 2, 3, 4, 5, 6, 7, 8, 9   # image 3x3 matrix
kernel:     .word -1, -2, 0, 1                # kernel 2x2 matrix
result:     .space 16                         # space for result 2x2 matrix
.text
.globl _start
_start:
# Calculate result[0][0]
    # Load image and kernel values into registers
    la   t0, image          # t0 = base address of image
    la   t1, kernel         # t1 = base address of kernel
    lw   t2, 0(t0)
    lw   t3, 0(t1)
    mul  t4, t2, t3
    lw   t2, 4(t0)
    lw   t3, 4(t1)
    mul  t5, t2, t3
    add  t4, t4, t5
    lw   t2, 12(t0)
    lw   t3, 8(t1)
    mul  t5, t2, t3
    add  t4, t4, t5
    lw   t2, 16(t0)
    lw   t3, 12(t1)
    mul  t5, t2, t3
    add  t4, t4, t5
    la   t6, result
    sw   t4, 0(t6)          # Computes 0 and stores at result[0][0]
# Calculate result[0][1]
    lw   t2, 4(t0)
    lw   t3, 0(t1)
    mul  t4, t2, t3
    lw   t2, 8(t0)
    lw   t3, 4(t1)
    mul  t5, t2, t3
    add  t4, t4, t5
    lw   t2, 12(t0)
    lw   t3, 8(t1)
    mul  t5, t2, t3
    add  t4, t4, t5
    lw   t2, 16(t0)
    lw   t3, 12(t1)
    mul  t5, t2, t3
    add  t4, t4, t5
    sw   t4, 4(t6)          # Computes -2 and stores at result[0][1]

# Calculate result[1][0]
    lw   t2, 12(t0)
    lw   t3, 0(t1)
    mul  t4, t2, t3

    lw   t2, 16(t0)
    lw   t3, 4(t1)
    mul  t5, t2, t3
    add  t4, t4, t5

    lw   t2, 24(t0)
    lw   t3, 8(t1)
    mul  t5, t2, t3
    add  t4, t4, t5

    lw   t2, 28(t0)
    lw   t3, 12(t1)
    mul  t5, t2, t3
    add  t4, t4, t5
    sw   t4, 8(t6)          # Computes -6 and stores at result[1][0]
```

```
# Calculate result[1][1]
    lw   t2, 16(t0)
    lw   t3, 0(t1)
    mul  t4, t2, t3
    lw   t2, 20(t0)
    lw   t3, 4(t1)
    mul  t5, t2, t3
    add  t4, t4, t5
    lw   t2, 24(t0)
    lw   t3, 8(t1)
    mul  t5, t2, t3
    add  t4, t4, t5
    lw   t2, 32(t0)
    lw   t3, 12(t1)
    mul  t5, t2, t3
    add  t4, t4, t5
    sw   t4, 12(t6)         # Computes -8 and stores at result[1][1]
    # End of program
    li   a7, 10             # Exit system call
    ecall
```

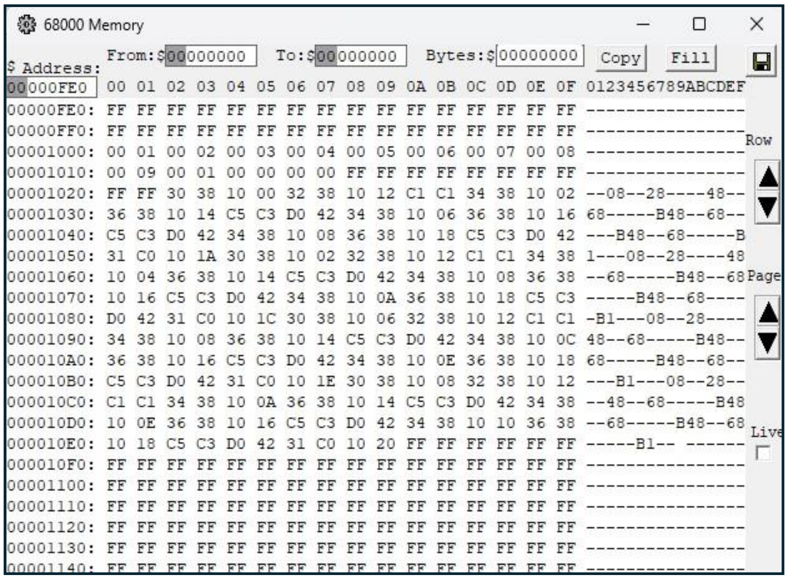
DESCRIPTION

- Easy68k: The Easy68k program calculates the convolution by manually performing element-wise multiplication and addition for each element in the result matrix. No loops are used; instead, each calculation is explicitly coded.
- RISC-V: Similarly, the RISC-V program calculates the convolution manually, without using loops. It performs individual multiplications and additions to compute each element of the result matrix.

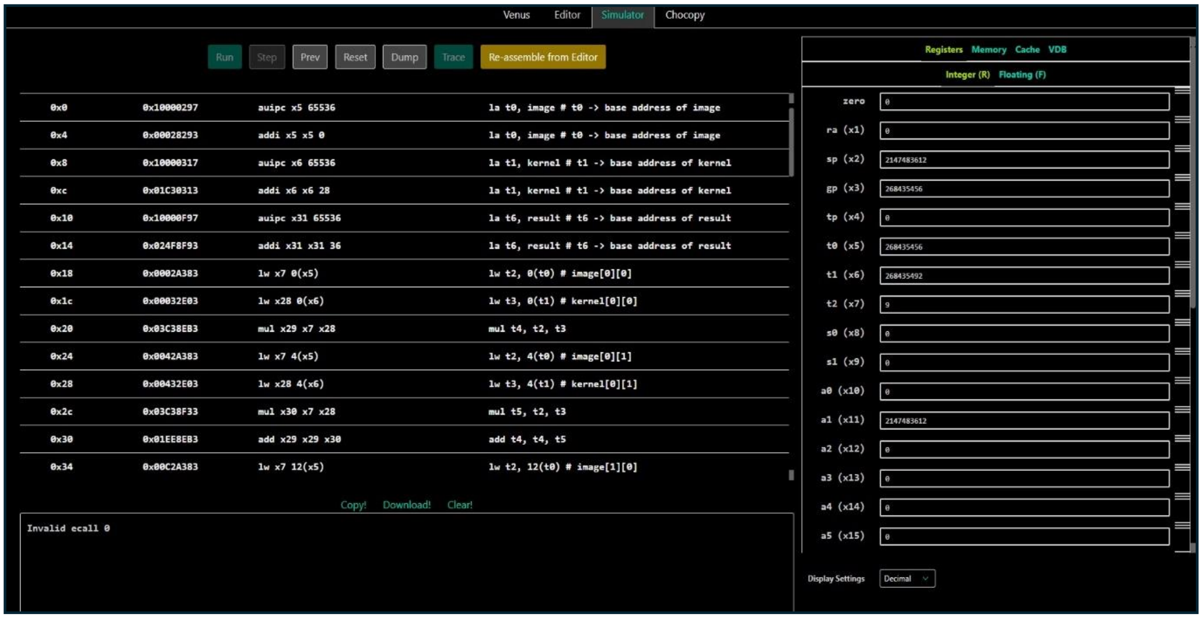
OBSERVATIONS

- Easy68k: This implementation manually handles each element in the result matrix, multiplying corresponding elements from the image and kernel matrices. It does not use loops or iterations.
- RISC-V: The approach is like Easy68k, and while it uses more registers, it still avoids loops and manually processes each element of the result matrix.

RESULTS



```
             From:$00000000   To:$00000000   Bytes:$00000000
$ Address:
00000FE0   00 01 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F 0123456789ABCDEF
00000FE0: FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF ----------------
00000FF0: FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF ----------------
00001000: 00 01 00 02 00 03 00 04 00 05 00 06 00 07 00 08 ----------------
00001010: 00 09 00 01 00 00 00 00 FF FF FF FF FF FF FF FF ----------------
00001020: FF FF 30 38 10 00 32 38 10 12 C1 C1 34 38 10 02 --08--28----48--
00001030: 36 38 10 14 C5 C3 D0 42 34 38 10 06 36 38 10 16 68-----B48--68--
00001040: C5 C3 D0 42 34 38 10 08 36 38 10 18 C5 C3 D0 42 ---B48--68-----B
00001050: 31 C0 10 1A 30 38 10 02 32 38 10 12 C1 C1 34 38 1---08--28----48
00001060: 10 04 36 38 10 14 C5 C3 D0 42 34 38 10 08 36 38 --68-----B48--68
00001070: 10 16 C5 C3 D0 42 34 38 10 0A 36 38 10 18 C5 C3 -----B48--68----
00001080: D0 42 31 C0 10 1C 30 38 10 06 32 38 10 12 C1 C1 -B1---08--28----
00001090: 34 38 10 08 36 38 10 14 C5 C3 D0 42 34 38 10 0C 48--68-----B48--
000010A0: 36 38 10 16 C5 C3 D0 42 34 38 10 0E 36 38 10 18 68-----B48--68--
000010B0: C5 C3 D0 42 31 C0 10 1E 30 38 10 08 32 38 10 12 ---B1---08--28--
000010C0: C1 C1 34 38 10 0A 36 38 10 14 C5 C3 D0 42 34 38 --48--68-----B48
000010D0: 10 0E 36 38 10 16 C5 C3 D0 42 34 38 10 10 36 38 --68-----B48--68
000010E0: 10 18 C5 C3 D0 42 31 C0 10 20 FF FF FF FF FF FF -----B1-- ------
000010F0: FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF ----------------
00001100: FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF ----------------
00001110: FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF ----------------
00001120: FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF ----------------
00001130: FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF ----------------
00001140: FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF ----------------
```



```
0x0     0x10000297   auipc x5 65536     la t0, image # t0 -> base address of image
0x4     0x00028293   addi x5 x5 0       la t0, image # t0 -> base address of image
0x8     0x10000317   auipc x6 65536     la t1, kernel # t1 -> base address of kernel
0xc     0x01C30313   addi x6 x6 28      la t1, kernel # t1 -> base address of kernel
0x10    0x10000F97   auipc x31 65536    la t6, result # t6 -> base address of result
0x14    0x024F8F93   addi x31 x31 36    la t6, result # t6 -> base address of result
0x18    0x0002A383   lw x7 0(x5)        lw t2, 0(t0) # image[0][0]
0x1c    0x00032E03   lw x28 0(x6)       lw t3, 0(t1) # kernel[0][0]
0x20    0x03C38EB3   mul x29 x7 x28     mul t4, t2, t3
0x24    0x0042A383   lw x7 4(x5)        lw t2, 4(t0) # image[0][1]
0x28    0x00432E03   lw x28 4(x6)       lw t3, 4(t1) # kernel[0][1]
0x2c    0x03C38F33   mul x30 x7 x28     mul t5, t2, t3
0x30    0x01EE8EB3   add x29 x29 x30    add t4, t4, t5
0x34    0x00C2A383   lw x7 12(x5)       lw t2, 12(t0) # image[1][0]
```

```
Invalid ecall 0
```

```
zero       0
ra (x1)    0
sp (x2)    2147483612
gp (x3)    268435456
tp (x4)    0
t0 (x5)    268435456
t1 (x6)    268435492
t2 (x7)    9
s0 (x8)    0
s1 (x9)    0
a0 (x10)   0
a1 (x11)   2147483612
a2 (x12)   0
a3 (x13)   0
a4 (x14)   0
a5 (x15)   0
```

Display Settings: Decimal

CONCLUSIONS

In conclusion, both the Easy68k and RISC-V assembly programs effectively perform the convolution operation on a 3x3 image matrix using a 2x2 kernel matrix without utilizing loops, demonstrating a manual approach to matrix operations. By manually calculating the element-wise multiplication and addition for each position in the result matrix, the programs highlight a fundamental understanding of convolution. The results show that despite the absence of loops, the computations are accurate and provide insight into low-level programming techniques for image processing tasks. This approach not only reinforces fundamental assembly programming skills but also showcases the versatility of both Easy68k and RISC-V architectures in handling mathematical operations.