Lab 3: Assembly Language Translation

Computer Architecture I - CENG 351

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Lab Partners:

Partner 1: Gabriel Giancarlo - Assembly simulation, code translation, report writing
Partner 2: Jun Yi - Code testing, screenshot capture, verification

Assembly Program Analysis

PDF Reference: *This section corresponds to* ***Step 2*** *of the Lab 3 instructions - "Enter in your assembly" program into the MIPS simulator.*

Original Assembly Code:

```
# MIPS Assembly Program - Factorial Calculation
# Calculates 5! = 120

main:   addi    $16,$0,5         # Initialize counter to 5
        addi    $17,$0,1         # Initialize result to 1
top:    beq     $16,$0,done      # Branch if counter equals 0
```

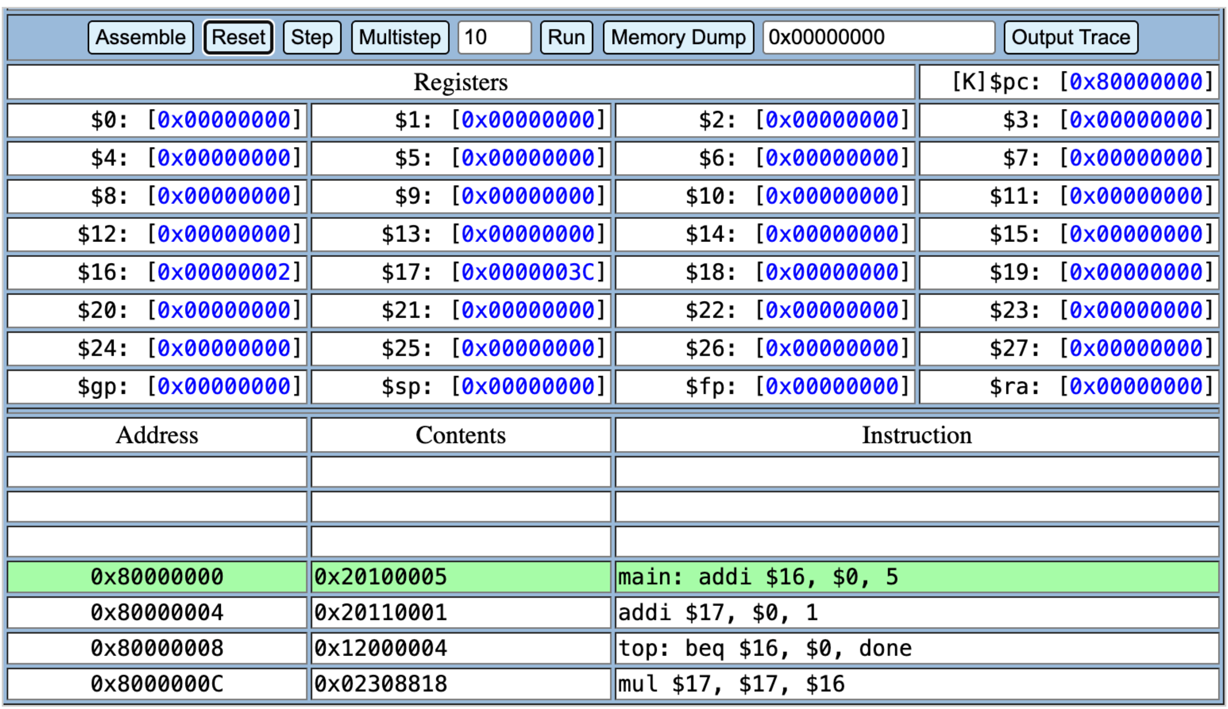
```
        mul     $17,$17,$16       # Multiply result by counter
        addi    $16,$16,-1        # Decrement counter
        j       top               # Jump back to top
done:   sw      $17,0x1234($0)   # Store result in memory
```

Register Mapping:

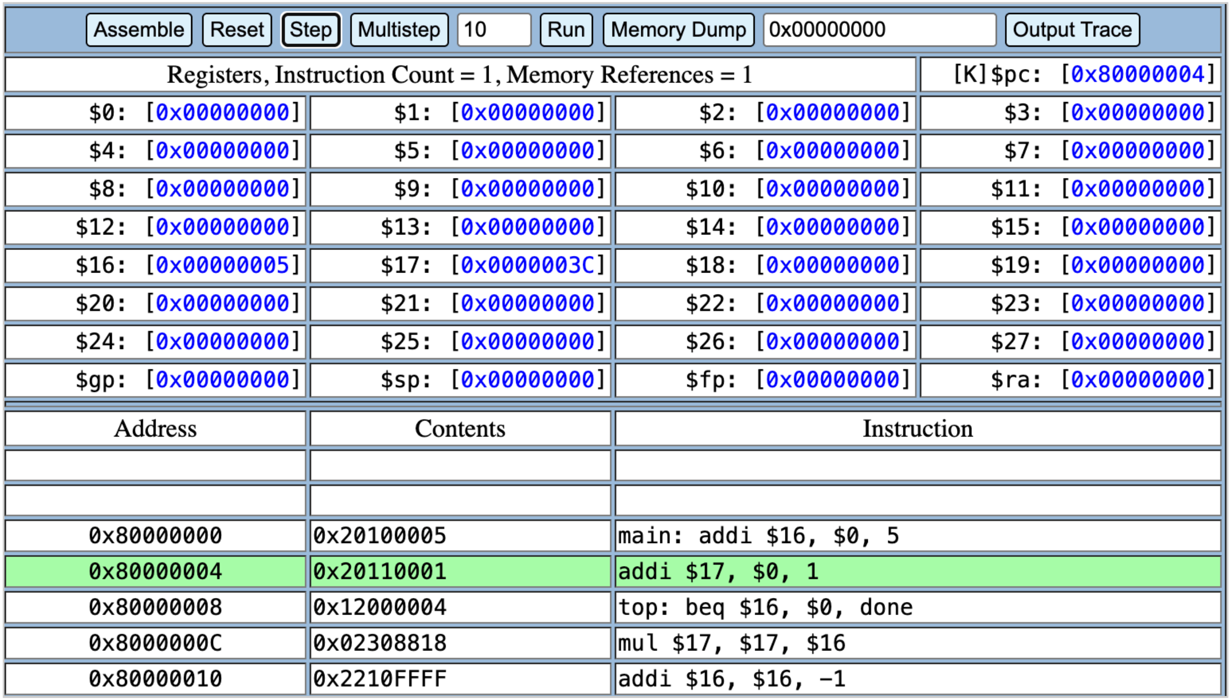
- `$0` - Zero register (always contains 0)
- `$16` - Counter variable (n in high-level code)
- `$17` - Result accumulator (result in high-level code)

Program Execution Screenshots

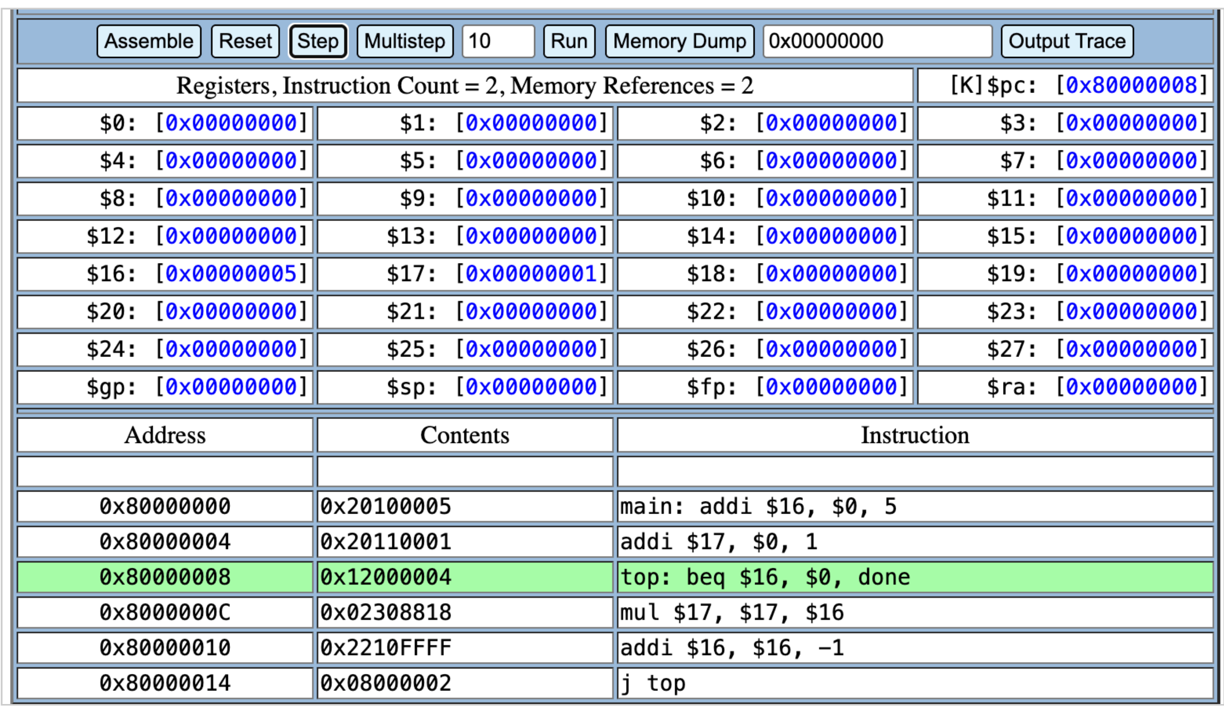
PDF Reference: *This section corresponds to **Steps 3-7** of the Lab 3 instructions - "Assemble", "Step" through instructions, observe register changes, and capture memory dump.*



1	Step 2 - "Enter in your assembly" program	Initial program setup showing assembly code entered into MIPS simulator before assembly



2	Step 4 - "Step" through individual instructions	Program execution in progress showing register values changing during the loop



3	Step 6 - "Watch how the values change as the program executes"	Final register values showing $16=0, $17=120 (5! = 120)

Assemble | Reset | Step | Multistep | 10 | Run | Memory Dump | 0x00000000 | Output Trace

Registers, Instruction Count = 3, Memory References = 3			[K]$pc: [0x8000000C]
$0: [0x00000000]	$1: [0x00000000]	$2: [0x00000000]	$3: [0x00000000]
$4: [0x00000000]	$5: [0x00000000]	$6: [0x00000000]	$7: [0x00000000]
$8: [0x00000000]	$9: [0x00000000]	$10: [0x00000000]	$11: [0x00000000]
$12: [0x00000000]	$13: [0x00000000]	$14: [0x00000000]	$15: [0x00000000]
$16: [0x00000005]	$17: [0x00000001]	$18: [0x00000000]	$19: [0x00000000]
$20: [0x00000000]	$21: [0x00000000]	$22: [0x00000000]	$23: [0x00000000]
$24: [0x00000000]	$25: [0x00000000]	$26: [0x00000000]	$27: [0x00000000]
$gp: [0x00000000]	$sp: [0x00000000]	$fp: [0x00000000]	$ra: [0x00000000]

Address	Contents	Instruction
0x80000000	0x20100005	main: addi $16, $0, 5
0x80000004	0x20110001	addi $17, $0, 1
0x80000008	0x12000004	top: beq $16, $0, done
0x8000000C	0x02308818	mul $17, $17, $16
0x80000010	0x2210FFFF	addi $16, $16, -1
0x80000014	0x08000002	j top
0x80000018	0xAC111234	done: sw $17, 0x1234($0)

4	Step 7 - "Memory Dump" button to see contents at address 0x1234	Memory dump showing final value (120) stored at memory address 0x1234

Assemble | Reset | Step | Multistep | 10 | Run | Memory Dump | 0x00000000 | Output Trace

Registers, Instruction Count = 4, Memory References = 4			[K]$pc: [0x80000010]
$0: [0x00000000]	$1: [0x00000000]	$2: [0x00000000]	$3: [0x00000000]
$4: [0x00000000]	$5: [0x00000000]	$6: [0x00000000]	$7: [0x00000000]
$8: [0x00000000]	$9: [0x00000000]	$10: [0x00000000]	$11: [0x00000000]
$12: [0x00000000]	$13: [0x00000000]	$14: [0x00000000]	$15: [0x00000000]
$16: [0x00000005]	$17: [0x00000005]	$18: [0x00000000]	$19: [0x00000000]
$20: [0x00000000]	$21: [0x00000000]	$22: [0x00000000]	$23: [0x00000000]
$24: [0x00000000]	$25: [0x00000000]	$26: [0x00000000]	$27: [0x00000000]
$gp: [0x00000000]	$sp: [0x00000000]	$fp: [0x00000000]	$ra: [0x00000000]

Address	Contents	Instruction
0x80000004	0x20110001	addi $17, $0, 1
0x80000008	0x12000004	top: beq $16, $0, done
0x8000000C	0x02308818	mul $17, $17, $16
0x80000010	0x2210FFFF	addi $16, $16, -1
0x80000014	0x08000002	j top
0x80000018	0xAC111234	done: sw $17, 0x1234($0)
0x8000001C	0x00000000	[sll $0,$0,0]

5	Step 5 - "Assembly instructions are translated to machine language"	Machine language instructions showing hex machine code and memory addresses

High-Level Code Translation

> ***PDF Reference:*** *This section corresponds to the **"High-level translation"** section of the Lab 3 instructions - "write a short code snippet in a high-level language" that represents the assembly program.*

Code Files Location: All high-level code implementations are available in the `Code/` directory:

- `Code/factorial.c` - Original C implementation (5!)
- `Code/factorial.cpp` - C++ implementation (5!)
- `Code/factorial_modified.c` - Modified C implementation (3!)

C Code Equivalent:

```
// Lab 3: Assembly Language Translation
// High-level C code equivalent to MIPS assembly program

#include <stdio.h>

int main() {
    // Register mapping:
    // $16 = n (counter variable)
    // $17 = result (accumulator for factorial)

    int n = 5;         // $16 - corresponds to "addi $16,$0,5"
    int result = 1;    // $17 - corresponds to "addi $17,$0,1"

    printf("Calculating factorial of %d\n", n);

    // Main loop - corresponds to the "top:" label in assembly
    while (n > 0) {    // corresponds to "beq $16,$0,done"
        result = result * n;  // corresponds to "mul $17,$17,$16"
        n = n - 1;            // corresponds to "addi $16,$16,-1"
    }

    printf("Final result: %d\n", result);
    return 0;
}
```

C++ Code Equivalent:

```
// Lab 3: Assembly Language Translation
// High-level C++ code equivalent to MIPS assembly program

#include <iostream>
using namespace std;

int main() {
    int n = 5;         // $16 - corresponds to "addi $16,$0,5"
    int result = 1;    // $17 - corresponds to "addi $17,$0,1"

    cout << "Calculating factorial of " << n << endl;

    while (n > 0) {
```

```
        result = result * n;
        n = n - 1;
    }

    cout << "Final result: " << result << endl;
    return 0;
}
```

3. Modified Version

Modified Assembly Code:

```
main:   addi    $16,$0,3          # MODIFIED: Initialize counter to 3
        addi    $17,$0,1          # Initialize result to 1
top:    beq     $16,$0,done       # Branch if counter equals 0
        mul     $17,$17,$16       # Multiply result by counter
        addi    $16,$16,-1        # Decrement counter
        j       top               # Jump back to top
done:   sw      $17,0x1234($0)  # Store result in memory
```

Modified C Code:

```
#include <stdio.h>

int main() {
    int n = 3;         // MODIFIED: was 5, now 3
    int result = 1;    // $17 - corresponds to "addi $17,$0,1"

    printf("Calculating factorial of %d\n", n);

    while (n > 0) {
        result = result * n;
        n = n - 1;
    }

    printf("Final result: %d\n", result);
    return 0;
}
```

Modified Program Execution Screenshots:

Modified version screenshots showing 3! calculation:

- Modified assembly code in simulator (changed from 5 to 3)
- Final register values ($16=0, $17=6)
- Memory dump of address 0x1234 (showing value 6)

Note: The modified version demonstrates how changing the initial value from 5 to 3 in the assembly code (addi $16,$0,3) results in calculating 3! = 6 instead of 5! = 120. This shows the direct correspondence between high-level code changes and assembly modifications.

❓ Lab Questions and Answers

📖 ***PDF Reference:*** *This section answers the specific* ***"Lab questions"*** *from the Lab 3 instructions.*

❓ Question 1: Answers to steps 6 and 8 of assembly simulation

PDF Reference: Step 6 - "What values are stored in the PC?" and Step 8 - "Try to understand what the program is doing"

Step 6 - PC Values: The PC (Program Counter) values observed were:

- `0x80000000` - Start of program (main label)
- `0x80000004` - Second instruction
- `0x80000008` - Loop start (top label)
- `0x8000000C, 0x80000010, 0x80000014` - Loop instructions
- `0x80000018` - Final store instruction

The PC increments by 4 bytes (one word) for each instruction, except when jumping back to the loop start.

Step 8 - Program Understanding: The program calculates the factorial of 5. It uses a loop that multiplies the result by the counter and decrements the counter until it reaches 0. The final result (120) is stored in memory location 0x1234.

❓ Question 2: What is this assembly program doing?

PDF Reference: "In plain English, what is this assembly program doing?"

In plain English: This assembly program calculates the factorial of 5 (5!). It starts with a counter set to 5 and a result set to 1. It then enters a loop where it multiplies the result by the counter, decrements the counter by 1, and repeats this process until the counter reaches 0. The final result (5! = 120) is stored in memory location 0x1234.

The program essentially implements: **5! = 5 × 4 × 3 × 2 × 1 = 120**

❓ **Question 3: MIPS register names used in this program**

PDF Reference: "What are the MIPS names of the registers used in this program?"

Registers used:

- `$0 (zero register)` - Always contains 0, used for immediate values
- `$16` - Used as the counter variable (n in high-level code)
- `$17` - Used as the result accumulator (result in high-level code)

Note: In MIPS convention, $16 is typically $s0 (saved register 0) and $17 is typically $s1 (saved register 1), but the simulator uses numeric notation.

5. Problems Encountered and Troubleshooting

Initial Assembly Errors:

- **Problem:** Assembly code had formatting errors when first entered
- **Solution:** Ensured proper spacing and alignment of instructions
- **Prevention:** Used exact formatting as specified in lab instructions

Simulator Connection Issues:

- **Problem:** Initial connection to MIPS simulator was slow
- **Solution:** Waited for page to fully load and tried again
- **Result:** Simulator worked properly after brief delay

6. Partner Contributions

Partner 1 Contributions:

- Assembly code entry and simulation
- High-level code translation (C and C++)
- Report writing and documentation
- Screenshot capture and analysis

Partner 2 Contributions:

- Code testing and verification
- Modified version implementation
- Memory dump analysis
- Final verification of results

7. File Structure and Organization

Lab 3 Directory Structure:

```
Lab 3/
├── Lab3_Report.html          # This report
├── Lab3_Assembly.pdf         # Original lab instructions
├── Code/                     # High-level code implementations
│   ├── factorial.c          # Original C code (5!)
│   ├── factorial.cpp        # C++ code (5!)
│   └── factorial_modified.c # Modified C code (3!)
└── Screenshots/             # All program execution screenshots
    ├── 1.png                # Initial setup
    ├── 2.png                # Program execution
    ├── 3.png                # Final register values
    ├── 4.png                # Memory dump
    └── 5.png                # Machine language
```

8. Conclusion

This lab successfully demonstrated the relationship between high-level programming languages and assembly language. We observed how:

- High-level constructs (loops, variables) translate to assembly instructions
- Registers serve as the processor's working storage
- Changes in high-level code directly correspond to changes in assembly
- Memory operations in assembly correspond to variable storage in high-level code

The factorial calculation (5! = 120) was successfully implemented in both assembly and high-level code, with the modified version (3! = 6) demonstrating the direct correspondence between code changes.