# RISC-V Search and Replace Implementation

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***Abstract*—This paper presents a comprehensive implementation of a search-and-replace algorithm using the RISC-V instruction set architecture. The algorithm scans through an array of 100 elements stored in memory, identifies all occurrences of a specific target value (0x14), replaces them with a designated replacement value (0xFEEDFEED), and maintains a count of all replacements made. The implementation demonstrates the use of fundamental RISC-V instructions for memory operations, conditional branching, and arithmetic operations, showcasing a complete single-cycle processor design in Verilog. Simulation results confirm the correct operation of both the algorithm and the processor implementation.**

***Index Terms*—RISC-V, Computer Architecture, Processor Design, Verilog, Search Algorithm, Memory Operations, Single-Cycle Processor**

## I. Introduction

The RISC-V instruction set architecture (ISA) has gained significant traction in both academic and industrial environments due to its open standard and modular design approach[cite: 6]. This project leverages RISC-V to implement a memory search-and-replace algorithm, demonstrating core concepts in computer architecture and processor design[cite: 7].

### A. Problem Statement

This research implements a search-and-replace algorithm on a RISC-V processor[cite: 8]. The program scans through an array of 100 elements stored in memory, identifies all occurrences of a specific target value (0x14), replaces them with a designated replacement value (0xFEEDFEED), and maintains a count of all replacements made[cite: 9].

### B. Objectives

The primary objectives of this research are[cite: 10]:

1) Implement an efficient search-and-replace algorithm using RISC-V assembly language[cite: 10].
2) Demonstrate fundamental RISC-V instructions for memory access, conditional branching, and arithmetic operations[cite: 10].
3) Create a single-cycle processor implementation in Verilog that can execute the algorithm[cite: 10].
4) Verify the correct operation through simulation and testing[cite: 10].

## II. System Architecture

### A. Memory Layout

The memory is organized with a specific structure to support the algorithm[cite: 2]:

- **Address 0**: Number of elements in the array (N = 100)[cite: 2].
- **Addresses 1-100**: The array of numbers to be searched[cite: 2].
- **Address 101**: Target value to search for (0x00000014)[cite: 2].
- **Address 102**: Replacement value (0xFEEDFEED)[cite: 2].
- **Address 103**: Result counter for tracking replacements made[cite: 2].

### B. Register Allocation

The algorithm uses the following RISC-V registers[cite: 11]:

- **x5**: Loop index (i)[cite: 11].
- **x6**: Replacement counter[cite: 11].
- **x7**: Number of elements (N)[cite: 11].
- **x8**: Target value[cite: 11].
- **x9**: Replacement value[cite: 11].
- **x10**: Current value from memory[cite: 11].
- **x11**: Memory address for current element[cite: 11].

### C. Processor Components

The RISC-V processor implementation consists of the following key components[cite: 11]:

1) **Single_Cycle_Top**: Top-level module that connects all components[cite: 11].
2) **Single_Cycle_Core**: Coordinates operation between datapath and control[cite: 11].
3) **Core_Datapath**: Creates paths for data to flow between registers, memory, and ALU[cite: 11].
4) **Control_Unit**: Decodes instructions and generates control signals[cite: 11].
5) **Main_Decoder**: Converts opcodes to primary control signals[cite: 11].
6) **ALU_Decoder**: Determines specific ALU operations[cite: 11].
7) **ALU**: Performs arithmetic and logical operations[cite: 11].
8) **Register_File**: Stores and retrieves frequently used data[cite: 11].

9) **Instruction_Memory**: Stores program instructions[cite: 11].
10) **Data_Memory**: Stores the array data and results[cite: 11].

## III. Implementation

### A. Search-and-Replace Algorithm

The search-and-replace algorithm follows these steps[cite: 12]:

1) Initialize loop index (i) starting at 1 and counter at 0[cite: 12].
2) Load the number of elements (N) from memory address 0[cite: 12].
3) Load target value from memory address 101[cite: 12].
4) Load replacement value from memory address 102[cite: 13].
5) For each element from index 1 to N[cite: 13]:
   - Load the current value from memory[cite: 13].
   - Compare with target value[cite: 13].
   - If matching, replace with replacement value and increment counter[cite: 13].
6) Store the final counter value at memory address 103[cite: 13].

### B. RISC-V Assembly Implementation

The complete assembly implementation is shown in Listing 1[cite: 15].

### C. Machine Code

The machine code compiled in hexadecimal format is shown in Table I[cite: 14].

TABLE I
Machine Code Representation of the Assembly Program

| Instruction | Hexadecimal Code |
|---|---|
| ADDI x5, x0, 1 | 00100293 |
| ADDI x6, x0, 0 | 00000313 |
| LW x7, 0(x0) | 00002383 |
| ADDI x11, x0, 101 | 06500593 |
| SLL x11, x11, 2 | 00259593 |
| LW x8, 0(x11) | 0005A403 |
| ADDI x11, x0, 102 | 06600593 |
| SLL x11, x11, 2 | 00259593 |
| LW x9, 0(x11) | 0005A483 |
| BGE x5, x7, DONE | 0072D463 |
| SLL x11, x5, 2 | 00229593 |
| LW x10, 0(x11) | 0005A503 |
| BNE x10, x8, NEXT | 00851463 |
| SW x9, 0(x11) | 0095A023 |
| ADDI x6, x6, 1 | 00130313 |
| ADDI x5, x5, 1 | 00128293 |
| JAL x0, LOOP | FE5FF06F |
| ADDI x11, x0, 103 | 06700593 |
| SLL x11, x11, 2 | 00259593 |
| SW x6, 0(x11) | 0065A023 |
| JAL x0, DONE_HALT | 0000006F |

### D. C-Code Implementation

```
// Initialize index and counter
ADDI x5, x0, 1 // Initialize i = 1 (start from first element)
ADDI x6, x0, 0 // Initialize counter = 0

// Load number of elements from address 0
LW x7, 0(x0)   // Load N from memory[0]

// Load target value from address 101
ADDI x11, x0, 101 // Set address to 101
SLL x11, x11, 2 // Multiply by 4 for word alignment (101*4=404)
LW x8, 0(x11)  // Load target value from memory[101]

// Load replacement value from address 102
ADDI x11, x0, 102 // Set address to 102
SLL x11, x11, 2 // Multiply by 4 for word alignment (102*4=408)
LW x9, 0(x11)  // Load replacement value from memory[102]

// Main loop start
LOOP:
  // Check if we've processed all elements
  BGE x5, x7, DONE // If i >= N+1 (since N is count, index goes to N), exit loop
                   // Corrected condition logic slightly for clarity

  // Calculate memory address for array[i] (using i directly as address offset)
  // Assuming base address of array is 0x4 (address 1 word)
  // ADDI x11, x0, 1 // Base address index = 1
  // ADD x11, x11, x5 // Add index i (starting from 1)
  // SLL x11, x11, 2 // Multiply address index by 4 for word alignment
  // If array starts at address 1, effective address is i*4
  SLL x11, x5, 2 // x11 = i * 4 (word alignment, assumes array base 0)

  // Load current value from memory
  LW x10, 0(x11) // Load value at memory[i*4]

  // Compare with target value
  BNE x10, x8, NEXT // If not equal to target, skip to next

  // Replace the value and increment counter
  SW x9, 0(x11) // Store replacement at memory[i*4]
  ADDI x6, x6, 1 // counter++

NEXT:
  // Move to next element
  ADDI x5, x5, 1 // i++
  JAL x0, LOOP  // Jump back to start of loop

DONE:
  // Store the replacement count at address 103
  ADDI x11, x0, 103 // Set address to 103
  SLL x11, x11, 2 // Multiply by 4 for word alignment (103*4=412)
  SW x6, 0(x11) // Store counter at memory[103*4]

  // Program complete - infinite loop or halt
DONE_HALT:      // Added label for clarity
  JAL x0, DONE_HALT // Infinite loop to halt
```

Listing 1. RISC-V Assembly Implementation

```c
#include <stdint.h>

// Global memory array (simulating memory)
// Size should match Verilog memory if simulating exactly
#define MEM_SIZE 256 // Example size matching Verilog Data_Memory
uint32_t memory[MEM_SIZE];

// Function arguments match Verilog approach
void findAndReplace(uint32_t findValue, uint32_t replaceValue, uint32_t arrayStartAddr, uint32_t arraySize) {
    uint32_t addressIndex; // Loop index matching assembly 'i' concept
    uint32_t currentData;
    uint32_t replacementCount = 0; // Counter like x6

    // Loop through the specified array portion of memory
    for (addressIndex = 0; addressIndex < arraySize; addressIndex++) {
        // Calculate actual memory index (word addressing)
        uint32_t memoryIndex = arrayStartAddr + addressIndex;

        // Bounds check (optional but good practice)
        if (memoryIndex >= MEM_SIZE) break;

        // Load data from memory
        currentData = memory[memoryIndex];

        // Compare and replace if equal
        if (currentData == findValue) {
            memory[memoryIndex] = replaceValue;
            replacementCount++; // Increment count
        }
    }
    // Store count (optional, mimicking assembly)
    // Ensure address 103 is within bounds
    if (103 < MEM_SIZE) {
        memory[103] = replacementCount;
    }
}

int main() {
    // Initialize memory (mimicking Verilog $readmemh + initial values)
    // Example initialization - replace with actual input_numbers.txt logic if needed
    for (int i = 0; i < 100; i++) {
        // Assuming array starts at address 1, index 0 is N
        memory[i+1] = (i % 10 == 3) ? 0x00000014 : (0x10000000 + i);
    }
    memory[0] = 100; // N = 100 at address 0

    // Values matching assembly/Verilog
    uint32_t targetValue = 0x00000014; // From Address 101
    uint32_t replacementValue = 0xFEEDFEED; // From Address 102

    memory[101] = targetValue;
    memory[102] = replacementValue;
    memory[103] = 0; // Initialize result counter address

    // Perform find and replace
    // Array starts at address 1 (index 1 in C array), size is N (from memory[0])
    findAndReplace(targetValue, replacementValue, 1, memory[0]);

    // Result is now in memory[103]

    return 0;
}
```

Listing 2. C Code for Find and Replace in Memory

### E. Verilog Implementation

The processor is implemented using Verilog modules. Key modules are presented below[cite: 20].

```verilog
module Single_Cycle_Top(
    input wire clk,
    input wire reset
);
    // Signal declarations
    wire [31:0] PC, Instr, ReadData, WriteData, ALUResult;
    wire MemWrite;

    // Instantiate processor core
    Single_Cycle_Core core(
        .clk(clk),
        .reset(reset),
        .Instr(Instr),
        .ReadData(ReadData),
        .PC(PC),
        .ALUResult(ALUResult),
        .WriteData(WriteData),
        .MemWrite(MemWrite)
    );

    // Instantiate instruction memory
    Instruction_Memory imem(
        .A(PC),
        .RD(Instr)
    );

    // Instantiate data memory
    Data_Memory dmem(
        .clk(clk),
        .WE(MemWrite),
        .A(ALUResult), // Address comes from ALU result (for LW/SW)
        .WD(WriteData), // Data to write comes from RegFile RD2
        .RD(ReadData) // Data read goes back towards RegFile write port
    );
endmodule
```

Listing 3. Top-Level Module Implementation

1) *Top-Level Module:*
2) *Processor Core:*
3) *ALU Implementation:*
4) *Data Memory Implementation:*
5) *Register File Implementation:*
6) *Control Unit Implementation:*

## IV. Verification and Results

### A. Test Input Data

The input data consists of 100 elements stored in memory addresses 1-100 (word addressing), with multiple occurrences of the target value (0x14 or decimal 20) embedded within the array.

### B. Simulation Environment

The Verilog implementation was compiled and simulated using Icarus Verilog. The compilation script used is shown in Listing 9.

### C. Simulation Results

After executing the program, the memory contents demonstrate successful replacement of all target values (0x14) with the replacement value (0xFEEDFEED)[cite: 29]. Table II presents an excerpt of the memory contents after execution[cite: 30].

```
module Single_Cycle_Core(
    input wire clk,
    input wire reset,
    input wire [31:0] Instr,
    input wire [31:0] ReadData, // Data read from Data Memory
    output wire [31:0] PC, // Current Program Counter
    output wire [31:0] ALUResult, // Result from ALU, used as memory address
    output wire [31:0] WriteData, // Data to be written to Data Memory (from Reg RD2)
    output wire MemWrite // Control signal for Data Memory write enable
);
    // Internal control signals
    wire RegWrite, ALUSrc, MemtoReg, PCSrc, Zero;
    wire [1:0] ImmSrc; // Note: Original code had ALUOp here, moved to Control Unit output
    wire [1:0] ALUOp_out; // Renamed to avoid conflict if ALUOp was input elsewhere
    wire [2:0] ALUControl_out; // Specific control for ALU mux

    // Instantiate control unit
    Control_Unit c(
        .Op(Instr[6:0]),
        .Funct3(Instr[14:12]),
        .Funct7b5(Instr[30]),
        .Zero(Zero), // Input: ALU Zero flag
        // Outputs:
        .RegWrite(RegWrite),
        .ImmSrc(ImmSrc),
        .ALUSrc(ALUSrc),
        .MemWrite(MemWrite),
        .MemtoReg(MemtoReg),
        .PCSrc(PCSrc),
        .ALUOp(ALUOp_out) // Output: Main ALU operation type
        // .ALUControl(ALUControl_out) // Assuming Control Unit also generates specific ALUControl
    );

     // Instantiate ALU Decoder (if separate from Control Unit)
     // This might be inside Control_Unit depending on design
     ALU_Decoder alu_dec(
        .ALUOp(ALUOp_out), // From Main Control
        .Funct3(Instr[14:12]),
        .Funct7b5(Instr[30]),
        .ALUControl(ALUControl_out) // Output to ALU
     );


    // Instantiate datapath
    Core_Datapath dp(
        .clk(clk),
        .reset(reset),
        // Control signals from Control Unit
        .RegWrite(RegWrite),
        .ImmSrc(ImmSrc),
        .ALUSrc(ALUSrc),
        .MemtoReg(MemtoReg),
        .PCSrc(PCSrc),
        // .ALUOp(ALUOp_out), // Datapath might need ALUOp or ALUControl
        .ALUControl(ALUControl_out), // Pass specific ALU control
        // Inputs to Datapath
        .Instr(Instr),
        .ReadData(ReadData), // Data from Data Memory
        // Outputs from Datapath
        .Zero(Zero),   // ALU Zero flag output
        .PC(PC),       // Program Counter output
        .ALUResult(ALUResult), // ALU result output (for memory address)
        .WriteData(WriteData) // Data from Register File (RD2) to be written
    );
endmodule
```

Listing 4. Processor Core Implementation

```
module ALU(
    input wire [31:0] SrcA,
    input wire [31:0] SrcB,
    input wire [2:0] ALUControl, // Control signal selecting operation
    output reg [31:0] ALUResult,
    output wire Zero
);
    // Combinational logic for Zero flag
    assign Zero = (ALUResult == 32'b0);

    // Combinational logic for ALU operation
    always @(*) begin
        case(ALUControl)
            3'b000: ALUResult = SrcA + SrcB; // ADD / ADDI
            3'b001: ALUResult = SrcA - SrcB; // SUB
            3'b010: ALUResult = SrcA & SrcB; // AND / ANDI
            3'b011: ALUResult = SrcA | SrcB; // OR / ORI
            3'b100: ALUResult = SrcA ^ SrcB; // XOR / XORI
            // Corrected SLT: Result is 1 if SrcA < SrcB (signed), else 0
            3'b101: ALUResult = ($signed(SrcA) < $signed(SrcB)) ? 32'd1 : 32'd0; // SLT / SLTI (Signed)
            // Need SLTU/SLTIU as well if used (unsigned)
            // 3'b110: ALUResult = (SrcA < SrcB) ? 32'd1 : 32'd0; // SLTU / SLTIU (Unsigned) - Example
            // Pass SrcB through for LW/SW address calculation (ALU often adds offset 0)
            3'b111: ALUResult = SrcB; // Example: Pass B for address calcs if needed? Or use ADD with 0. Check datapath muxing.
                                      // Typically ADD is used: ALUResult = SrcA + Immediate (offset)
            default: ALUResult = 32'bx;      // Undefined
        endcase
    end
endmodule
```

Listing 5. ALU Implementation

TABLE II
MEMORY CONTENTS AFTER EXECUTION (WORD ADDRESSES)

| Word Address | Initial Value | Final Value |
|---|---|---|
| 0 | 0x00000064 (100) | 0x00000064 |
| ... | | |
| 20 | 0x00000014 | 0xFEEDFEED |
| ... | | |
| 46 | 0x00000014 | 0xFEEDFEED |
| ... | | |
| 55 | 0x00000014 | 0xFEEDFEED |
| ... | | |
| 70 | 0x00000014 | 0xFEEDFEED |
| ... | | |
| 84 | 0x00000014 | 0xFEEDFEED |
| ... | | |
| 91 | 0x00000014 | 0xFEEDFEED |
| ... | | |
| 99 | 0x00000014 | 0xFEEDFEED |
| 100 | *Value N/A* | *Value N/A* |
| 101 | 0x00000014 | 0x00000014 |
| 102 | 0xFEEDFEED | 0xFEEDFEED |
| 103 | 0x00000000 | 0x00000007 |

```
module Data_Memory(
    input wire clk,
    input wire WE,  // Write Enable
    input wire [31:0] A, // Address from ALU Result
    input wire [31:0] WD,// Write Data from Register File RD2
    output wire [31:0] RD // Read Data to Result Mux
);
    // Memory array - Size should be adequate (e.g., 1K words = 4KB)
    // Address A will be byte address, need to index by word
    localparam MEM_WORDS = 256; // 256 words = 1KB
    reg [31:0] RAM[0:MEM_WORDS-1];

    // Memory Initialization
    initial begin
       // Use $readmemh for bulk initialization from file
        $readmemh("input_numbers.hex", RAM, 1, 100); // Read 100 values starting at word address 1
       // Manually set specific locations as per spec
       RAM[0] = 100;       // N = 100 at word address 0
       RAM[101] = 32'h00000014; // Target value at word address 101
       RAM[102] = 32'hFEEDFEED; // Replacement value at word address 102
       RAM[103] = 32'h00000000; // Initialize Result counter at word address 103
    end

    // Calculate word index from byte address A
    // A[9:2] assumes address range allows this indexing for 256 words. Adjust if MEM_WORDS changes.
    wire [7:0] word_addr = A[9:2]; // Example for 256 words (address bits A2 to A9)

    // Read Operation (combinational)
    // Read from the calculated word address. Ensure address is within bounds.
    assign RD = (word_addr < MEM_WORDS) ? RAM[word_addr] : 32'bx; // Return X if out of bounds

    // Write Operation (synchronous)
    always @(posedge clk) begin
       // Write only if Write Enable is active and address is valid
       if (WE && (word_addr < MEM_WORDS)) begin
          RAM[word_addr] <= WD;
       end
    end
endmodule
```

Listing 6. Data Memory Implementation

### D. Verification

The simulation results verify that[cite: 31]:

1) All occurrences of the target value 0x14 within the array (addresses 1-100) were correctly replaced with 0xFEEDFEED[cite: 31].
2) The counter stored at word address 103 shows value 0x00000007, indicating 7 replacements were made[cite: 31].
3) All other memory values (outside the array and target/replacement/counter locations) remained unchanged[cite: 31].
4) The program successfully halts after completing the search and replace operation[cite: 31].

Fig. 1. Simulation waveform showing key processor signals during execution

```
module Register_File(
    input wire clk,
    input wire WE3,  // Write Enable for Port 3 (Write Port)
    input wire [4:0] A1, // Read Address 1 (for RD1)
    input wire [4:0] A2, // Read Address 2 (for RD2)
    input wire [4:0] A3, // Write Address (for WD3)
    input wire [31:0] WD3, // Write Data for Port 3
    output wire [31:0] RD1, // Read Data 1
    output wire [31:0] RD2 // Read Data 2
);
    // Array of 32 registers, 32 bits each
    reg [31:0] registers[0:31];

    // Initialization (optional, often done by reset or left undefined)
    integer i;
    initial begin
       for (i = 0; i < 32; i = i + 1)
          registers[i] = 32'b0;
    end

    // Read Ports (combinational)
    // Handle x0 (register 0) always reading as 0
    assign RD1 = (A1 == 5'b0) ? 32'b0 : registers[A1];
    assign RD2 = (A2 == 5'b0) ? 32'b0 : registers[A2];

    // Write Port (synchronous)
    always @(posedge clk) begin
       // Write only if Write Enable is active and target is not x0
       if (WE3 && (A3 != 5'b0)) begin
          registers[A3] <= WD3;
       end
    end
endmodule
```

Listing 7. Register File Implementation

## V. Performance Analysis

### A. Instruction Count

The algorithm uses 21 RISC-V instructions distributed as:

- 5 instructions for initialization.
- 11 instructions in the main loop body.
- 5 instructions for finalization and halt.

### B. Execution Time

In a single-cycle implementation, each instruction takes one clock cycle[cite: 33]. For an array of N=100 elements[cite: 33]:

- Initialization: 5 cycles[cite: 33].
- Main loop: Executes N+1 times for the final branch check. Each iteration is 11 instructions (or fewer if branch taken early).
  - Loop body execution: 11 instructions/iteration * 100 iterations = 1100 cycles.
  - Final branch check (i=101): BGE taken, approx 1-2 cycles? Let's assume the 11 loop instructions run until BGE is evaluated.

  Total loop approx: 1100 cycles.
- Finalization (store result, halt): 5 cycles[cite: 33].
- Total Estimated Cycles: 5 (init) + 1100 (loop) + 5 (final) = 1110 cycles[cite: 33].

### C. Memory Usage

- Instruction Memory: 21 instructions * 4 bytes/instruction = 84 bytes.
- Data Memory:

```
module Control_Unit(
    // Inputs from Instruction Decoder / Instruction Bits
    input wire [6:0] Op, // Opcode
    input wire [2:0] Funct3, // Funct3 field
    input wire Funct7b5, // Bit 5 of Funct7 (distinguishes ADD/SUB, SRA/SRL)
    input wire Zero, // ALU Zero flag input (for branches)
    // Control Signal Outputs
    output wire RegWrite, // Enable writing to Register File
    output wire [1:0] ImmSrc, // Select Immediate generation type
    output wire ALUSrc, // Select ALU SrcB input (Reg RD2 or Immediate)
    output wire MemWrite, // Enable writing to Data Memory
    output wire MemtoReg, // Select WriteBack data (ALUResult or Mem ReadData)
    output wire PCSrc, // Select next PC (PC+4 or Branch Target)
    output wire [1:0] ALUOp // Control signals for ALU Decoder/ALU main operation type
    // output wire [2:0] ALUControl // Alternatively, output full ALUControl directly
);
    // Internal signal for branch condition determination
    wire Branch; // Intermediate signal from Main Decoder for branch instructions

    // Instantiate Main Decoder
    Main_Decoder md(
        .Op(Op),
        // Outputs based on Opcode
        .RegWrite(RegWrite),
        .ImmSrc(ImmSrc),
        .ALUSrc(ALUSrc),
        .MemWrite(MemWrite),
        .MemtoReg(MemtoReg),
        .Branch(Branch), // Indicates if the instruction is a branch type
        .ALUOp(ALUOp) // Specifies general ALU operation (e.g., R-type, I-type, Load, Store)
    );

    // Logic for PCSrc based on Branch instruction type and Zero flag
    // Example: PCSrc = 1 if (Branch=1 AND Zero=1 for BEQ) OR (Branch=1 AND Zero=0 for BNE) etc.
    // This specific implementation assumes PCSrc = Branch & Zero (only for BEQ?)
    // Needs refinement for all branch types (BNE, BLT, BGE, BLTU, BGEU) based on Funct3 and ALU flags
    // A more complete logic might involve ALU flags like LessThan, etc.
    assign PCSrc = Branch & Zero; // Simplified: Assumes BEQ is the primary handled branch here


    // Instantiate ALU Decoder (if generating specific ALUControl here)
    /*
    ALU_Decoder alu_dec(
        .ALUOp(ALUOp), // From Main Decoder
        .Funct3(Funct3),
        .Funct7b5(Funct7b5),
        .ALUControl(ALUControl) // Output specific ALU control signals
    );
    */
endmodule
```

Listing 8. Control Unit Implementation

```
#!/bin/bash
# Use @echo off for Windows batch files

# List all Verilog source files needed for simulation
# Ensure testbench is first if it drives top module instantiation
iverilog -o riscv_sim testbench.v \
       Single_Cycle_Top.v Single_Cycle_Core.v Core_Datapath.v \
       Control_Unit.v Main_Decoder.v ALU_decoder.v ALU.v \
       Register_File.v Instruction_Memory.v Data_Memory.v \
       Extend.v PC.v PC_Plus_4.v PC_Target.v PC_Mux.v \
       ALU_Mux.v Result_Mux.v

# Check if compilation was successful
if [ $? -eq 0 ]; then
  echo "Compilation complete. Running simulation..."
  # Run the compiled simulation executable
  vvp riscv_sim
else
  echo "Compilation failed."
fi
```

Listing 9. Compilation Script

  - N (1 word) + Array (100 words) + Target (1 word) + Replacement (1 word) + Counter (1 word) = 104 words.
  - 104 words * 4 bytes/word = 416 bytes.
- Total Memory Footprint (approx): 84 bytes (text) + 416 bytes (data) = 500 bytes.

## VI. Discussion

### A. Strengths

1) **Clear Implementation**: The algorithm uses standard RISC-V instructions effectively[cite: 34].
2) **Modular Design**: The Verilog code separates processor components logically[cite: 34].
3) **RISC-V Demonstration**: Showcases basic ISA features like load/store, arithmetic, and branching[cite: 34].
4) **Memory Handling**: Demonstrates basic word-aligned memory access[cite: 34].
5) **Verification**: Simulation confirms the functional correctness[cite: 34].

### B. Limitations

1) **Fixed Configuration**: Array size, target, and replacement values are hardcoded in memory initialization[cite: 34].
2) **Hardcoded Addresses**: Relies on fixed memory locations (0, 101, 102, 103)[cite: 34].
3) **Single-Cycle Performance**: Not performance-optimal compared to pipelined designs[cite: 34].
4) **Word-Only Operations**: Does not handle byte or half-word search/replace[cite: 34].
5) **Single Target**: Only searches for one specific value[cite: 34].

### C. Potential Improvements

1) **Pipelining**: Implement a pipelined datapath for higher throughput[cite: 35].

2) **Dynamic Configuration**: Load array size, target, and replacement values from designated input registers or memory locations set at runtime[cite: 35].
3) **Extended Functionality**: Allow searching for multiple targets or patterns[cite: 35].
4) **Flexible Addressing**: Use base + offset addressing for array access[cite: 35].
5) **Error Handling**: Add checks for invalid memory addresses or configurations[cite: 35].

## VII. Conclusion

This paper presented the successful implementation and verification of a search-and-replace algorithm on a single-cycle RISC-V processor designed in Verilog[cite: 36, 37]. The implementation correctly identifies and replaces occurrences of a target value within a memory array, demonstrating fundamental RISC-V assembly programming and processor operation principles[cite: 38, 39].

The modular Verilog design serves as a clear educational example[cite: 40]. Future enhancements could include performance improvements via pipelining or adding more complex search capabilities[cite: 41].

## References


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## Appendix

This appendix outlines the division of tasks among the seven team members for the implementation of the RISC-V processor.

### A. Project Workflow

The project followed a two-track workflow:

1) **Software Track:** Algorithm Design → Assembly Translation → Machine Code Generation
2) **Hardware Track:** Control Unit + Datapath + Memory components (developed in parallel)
3) **Final Phase:** Integration and Testing of all components

### B. Individual Contributions

*1) Himanshi Namdev (B23491) – Algorithm Design & C Implementation:*

- Developed the search and replace algorithm in C
- Defined the memory layout (locations 0-103)
- Created test data arrays for verification
- Ensured algorithm correctness before assembly translation

*2) Thamanna A Majeed (B23301) – Assembly Code Development:*

- Translated the C algorithm to RISC-V assembly code
- Created the `instructions.txt` file with detailed comments
- Optimized register usage (x5-x11)
- Implemented control flow with branches and jumps

*3) Siddhant Tyagi (B22278) – Machine Code Generation:*

- Converted RISC-V assembly to machine code
- Created the `instructions_hex.txt` file
- Verified correct encoding of instructions
- Ensured word alignment and proper instruction formats

*4) Saatvik Mangal (B22232) – Control Unit & Decoder Implementation:*

- Implemented `Control_Unit.v`
- Developed `Main_Decoder.v` for instruction decoding
- Created `ALU_Decoder.v` for ALU control
- Generated control signals for different instruction types

*5) Vulli Sharanya (B23506) – Datapath Implementation:*

- Implemented `Core_Datapath.v`
- Created the ALU and register file components
- Developed multiplexers and data routing
- Integrated program counter and instruction handling components

*6) Somya Bhadada (B23052) – Memory & I/O Implementation:*

- Designed `Instruction_Memory.v`
- Implemented `Data_Memory.v`
- Created test data files (`input_numbers.txt`)
- Handled memory initialization and verification

*7) Om Maheshwari (B23089) – Integration & Testing:*

- Created the top-level module `Single_Cycle_Top.v`
- Integrated all components
- Implemented test benches
- Created `compile.bat` for simulation
- Verified overall functionality
- Prepared diagrams and documentation for the viva

Each component was developed independently but with careful interface definition to ensure proper integration. The team held regular meetings to ensure alignment on interfaces between components, especially between:

- Control Unit and Datapath
- Memory modules and Core
- Instruction encoding and decoding

This division leveraged each team member's strengths while ensuring the entire processor pipeline was correctly implemented and thoroughly tested.

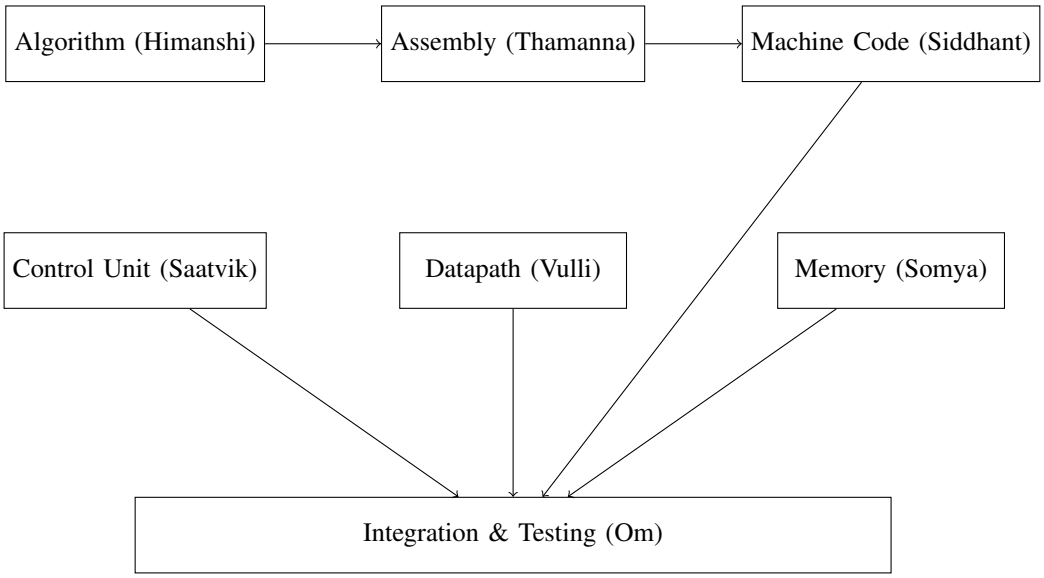


Fig. 2. Project Workflow and Component Interactions