

We would like to give credit the lab handout as well as the lab materials from CMU 18-447 Spring 2015 class, which I co-developed with other teaching assistant for Prof. Onur Mutlu's Computer Architecture class.

## Introduction

For this assignment, you will write a C program which is an instruction-level simulator for a limited subset of the MIPS instruction set. This instruction-level simulator will model the behavior of each instruction, and will allow the user to run MIPS programs and see their outputs. In later labs, you will use this simulator as a reference to verify that your later labs execute code correctly.

The simulator will process an input file that contains a MIPS program. Each line of the input file corresponds to a single MIPS instruction written as a hexadecimal string. For example, `2402000a` is the hexadecimal representation of `addiu $0,$zero, 10`. We will provide several input files. But you should also create additional input files in order to test your simulator more comprehensively.

The simulator will execute the input program one instruction at a time. After each instruction, the simulator will modify the MIPS architectural state: values stored in registers and memory. The simulator is partitioned into two main sections: the (1) shell and the (2) simulation routine. Your job is to implement the simulation routine.

The source code for the lab are provided in `lab1-handout.tar`. In the `src` directory, we provide two files (`shell.c` and `shell.h`) that already implement the shell. There is a third file (`sim.c`) where you will implement the simulator routine – this is the only file that you are allowed to change.

## The Shell

The purpose of the shell is to provide the user with commands to control the execution of the simulator. The shell accepts one or more program files as command line arguments and loads them into the memory image. In order to extract information from the simulator, a file named `dumpsim` will be created to hold information requested from the simulator. The shell supports the following commands:

1. `go`: simulates the program until it indicates that the simulator should halt. (As we define below, this is when a `SYSCALL` instruction is executed when the value in `$v0` (register 2) is equal to `0x0A`.)
2. `run <n>`: simulates the execution of the machine for `n` instructions.
3. `mdump <low> <high>`: dumps the contents of memory, from location `low` to location `high` to the screen and the dump file (`dumpsim`).
4. `rdump`: dump the current instruction count, the contents of `R0 – R31`, and the PC to the screen and the dump file (`dumpsim`).
5. `input reg_num reg_val`: set general purpose register `reg_num` to value `reg_val`.
6. `high value`: set the HI register to value.
7. `low value`: set the LO register to value.
8. `?`: print out a list of all shell commands.
9. `quit`: quit the shell.

## The Simulation Routine

The simulation routine carries out the instruction-level simulation of the input MIPS program. During the execution of an instruction, the simulator should take the current architectural state and modify it according to the ISA description of the instruction in the *MIPS R4000 User Manual* (32-bit mode only) that is provided on the course lecture and the course website. The architectural state includes the PC, the general purpose registers, and the memory image. The state is contained in the following global variables:

```
#define MIPS_REGS 32
typedef struct CPU_State {
    uint32_t PC;                /* program counter */
    uint32_t REGS[MIPS_REGS];  /* register file. */
    uint32_t HI, LO;           /* multiplier HI and LO regs. */
} CPU_State;
CPU_State STATE_CURRENT, STATE_NEXT;
int RUN_BIT;
```

Furthermore, the simulator models the simulated system's memory. You need to use the following two functions, which we provide, to access the simulated memory:

```
uint32_t mem_read_32(uint32_t address);
void mem_write_32(uint32_t address, uint32_t value);
```

Note that in MIPS, memory is byte-addressable. Furthermore, we will implement a little-endian architecture. This means that machine words (32 bits) are stored with the least-significant byte at the lowest address, and the most-significant byte at the highest address. To implement loads and stores of 16-bit and 8-bit values, you will need to use these 32-bit memory access primitives (hint: be sure to modify only the appropriate part of a 32-bit word!).

In particular, you should call `mem_read_32` and `mem_write_32` with only 32-bit-aligned addresses (i.e., the bottom two bits of the address should be zero).

The simulator skeleton that we provide includes an empty function named `process_instruction()` in the file `sim.c`. This function is called by the shell to simulate one machine instruction. You have to write the code for `process_instruction()` to simulate the execution of instructions. You can also write additional functions to make the simulation modular. (Keep in mind that you will be using the code that you write in later labs in order to validate your work.) We suggest spending time to make your code easy to read and understand, for your own benefit.

# 1 Your Tasks

## 1.1 Playing with MIPS ISA

To familiarize yourself with the MIPS ISA, we would like you to implement the following functions in MIPS ISA and use the SPIM assembler/simulator to check the results.

1. A function that takes two inputs, and return the addition of the two inputs.
2. A function that returns factorial of the input.
3. A function that takes a value  $n$  and return 0 if  $n$  is not a prime number and return 1 if  $n$  is a prime number.

## 1.2 MIPS Instruction-level Simulator

With the skeleton code, you need to implement the rest of the function `process_instruction()` in `sim.c`. The `process_instruction()` function should be able to simulate the instruction-level execution of the following MIPS instructions:

J	JAL	BEQ	BNE	BLEZ	BGTZ
ADDI	ADDIU	SLTI	SLTIU	ANDI	ORI
XORI	LUI	LB	LH	LW	LBU
LHU	SB	SH	SW	BLTZ	BGEZ
BLTZAL	BGEZAL	SLL	SRL	SRA	SLLV
SRLV	SRAV	JR	JALR	ADD	ADDU
SUB	SUBU	AND	OR	XOR	NOR
SLT	SLTU	MULT	MFHI	MFLO	MTHI
MTLO	MULTU	DIV	DIVU	SYSCALL	

Table 1: List of all the MIPS instructions to be implemented

Note that for the SYSCALL instruction, you only need to implement the following behavior: if the register `$v0` (register 2) has value `0x0A` (decimal 10) when SYSCALL is executed, then the go command should stop its simulation loop and return to the simulator shell's prompt. If `$v0` has any other value, the instruction should have no effect. No registers are modified in either case, except that PC is incremented to the next instruction as usual. The `process_instruction()` function that you write should cause the main simulation loop to terminate by setting the global variable RUN BIT to 0.<sup>1</sup>

The accuracy of your simulator is your main priority. Specifically, make sure the architectural state is correctly updated after the execution of each instruction. We will test your simulator with many input programs (some provided with the handout, some not) in order to ensure that each instruction is simulated correctly. In order to test that your simulator is working correctly, you should run the input programs we provide you with and also write one or more programs using all of the required MIPS instructions that are listed in the table above, and execute them one instruction at a time (run 1). You can use the `rdump` command to verify that the state of the machine is updated correctly after the execution of each instruction.

While the table appears to have many instructions, there are actually only a few unique instruction behaviors with a number of minor variations. You should tackle the instructions in groups: R-type ALU, I-type ALU, LW, SW, Jump, Branch, and so on. The MIPS R4000 User Manual (provided in the tarball) contains the official definition for each instruction in this table (except for SYSCALL, for which we provide a restricted definition above). Please implement only the 32-bit behavior of the instructions (the R4000 also has a 64-bit mode, which we can ignore for the purpose of this and subsequent labs.)

<sup>1</sup>This SYSCALL behavior is consistent with SPIM, which defines a set of syscalls, which you can find on the MIPS 4000 Manual.

**Branch Delay Slot.** Unlike the manual, we will implement our architecture without the branch delay slots, which will be covered later in our lecture. For the purposes of Lab 1, this means that branch instructions can update `NEXT_STATE.PC` directly to the branch target when the branch is taken. Furthermore, “jump-and-link” instructions (JAL, JALR, BLTZAL, BGEZAL) store `PC + 4` in R31, rather than `PC + 8` as specified in the manual in these instructions’ descriptions.

In this lab, you do not need to handle overflow exceptions that can be raised by certain arithmetic instructions (e.g., ADDI). Finally, note that your simulator does not have to handle instructions that we do not include in the table above, or any other invalid instructions. We will only test your simulator with valid code that uses the instructions listed above.

## Lab Files

In the tarball, you will find a source code distribution with two subdirectories `src/` and `inputs/`. In `src/`, we are providing you with the simulator skeleton as described above. You can compile the simulator with the provided Makefile. In `inputs/`, we have written some input files for you. You should write more input files in order to be con

dent that your simulator is correct. Also in `inputs/`, you can find a script that will assemble MIPS code into the hexadecimal format that the simulator requires. The `README` file describes how to assemble a MIPS program with this script and load it into the simulator.

## Hand-in Instructions

To submit this assignment, please follow the steps below:

1. Compress all the files into a tarball or zip format with your name clearly indicated
2. Submit the file on Canvas.
3. We will do a live demo showing the functionality of your code.