

Project 1--CDA 3101 (Spring 2014)

Worth: 100 points (10% of course grade)

Assigned: Friday, Jan 24, 2014

Due: 1:25 pm, Monday, Feb 24, 2014

1. Purpose

This project is intended to help you understand the instructions of a very simple assembly language and how to assemble programs into machine language.

2. Problem

This project has three parts. In the first part, you will write a program to take an assembly-language program and produce the corresponding machine language. In the second part, you will write a behavioral simulator for the resulting machine code. In the third part, you will write a short assembly-language program to multiply two numbers.

3. LC3101 Instruction-Set Architecture

For this project, you will be developing a simulator and assembler for the LC3101 (Little Computer, used in CDA 3101). The LC3101 is very simple, but it is general enough to solve complex problems. For this project, you will only need to know the instruction set and instruction format of the LC3101.

The LC3101 is an 8-register, 32-bit computer. All addresses are word-addresses (unlike MIPS which is byte-addressed). The LC3101 has 65536 words of memory. By assembly-language convention, register 0 will always contain 0 (i.e. the machine will not enforce this, but no assembly-language program should ever change register 0 from its initial value of 0).

There are 3 instruction formats (bit 0 is the least-significant bit). Bits 31-25 are unused for all instructions, and should always be 0.

R-type instructions (add, nand):

- bits 24-22: opcode
- bits 21-19: reg A
- bits 18-16: reg B
- bits 15-3: unused (should all be 0)
- bits 2-0: destReg

I-type instructions (lw, sw, beq):

4. LC3101 Assembly Language and Assembler (40%)

The first part of this project is to write a program to take an assembly-language program and translate it into machine language. You will

Symbolic addresses refer to labels. For lw or sw instructions, the assembler should compute offsetField to be equal to the address of the label. This could be used with a zero base register to refer to the label, or could be used with a non-zero base register to index into an array starting at the label. For beq instructions, the assembler should translate the label into the numeric offsetField needed to branch to that label.

After the last used field comes more white space, then any comments. The comment field ends at the end of a line. Comments are vital to creating understandable assembly-language programs, because the instructions are rather cryptic.

In addition to LC3101 instructions, an assembly-language program may contain

.fill
(note the leading period). .fill tells the assembler to put a number into the place where the instruction would normally be stored. .fill instructions use

For example, ".fill 32" puts the value 32 where the instruction would normally be stored. .fill with a symbolic address will store the address of the label. In the example below, ".fill start" will store the value 2, because the label "start" is at address 2.

The assembler should make two passes over the assembly-language program. In the first pass, it will calculate the address for every symbolic label. Assume

```
negl .fill -1
stAddr .fill start          will contain the address of start (2)
```

And here is the corresponding machine language:

```
(address 0): 8454151 (hex 0x810007)
(address 1): 9043971 (hex 0x8a0003)
(address 2): 655361 (hex 0xa0001)
(address 3): 16842754 (hex 0x1010002)
(address 4): 16842749 (hex 0x100fffd)
(address 5): 29360128 (hex 0x1c00000)
(address 6): 25165824 (hex 0x1800000)
(address 7): 5 (hex 0x5)
(address 8): -1 (hex 0xffffffff)
(address 9): 2 (hex 0x2)
```

file, one instruction per line. Any deviation from this format (e.g. extra

Any

output) can

Hints: the example assembly-language program above is a good case to include in your test suite, though you'll need to write more test cases to get full

As with the assembler, you will write a suite of test cases to validate the LC3101 simulator.

The test cases for the simulator part of this project will be short assembly-language programs that, after being assembled into machine code, serve as input to a simulator. You will submit your suite of test cases together with your simulator, and we will grade your test suite according to how thoroughly it exercises an LC3101 simulator. Each test case may execute at most 200 instructions on a correct simulator, and your test suite may contain up to 20 test cases. These limits are much larger than needed for full credit (the solution test suite is composed of a couple test cases, each executing less than 40 instructions). See Section 7 for how your test suite will be graded.

5.2. Simulator Hints

Be careful how you handle `offsetField` for `lw`, `sw`, and `beq`. Remember that it's a 2's complement 16-bit number, so you need to convert a negative `offsetField` to a negative 32-bit integer on the Sun workstations (by sign extending it). To do this, use the following function.

```
int
convertNum(int num)
{
    /* convert a 16-bit number into a 32-bit Sun integer */
    if (num & (1<<15) ) {
        num -= (1<<16);
    }
    return(num);
}
```

An example run of the simulator (not for the specified task of multiplication) is included at the end of this posting.

6. Assembly-Language Multiplication (20%)

The third part of this assignment is to write an assembly-language program to multiply two numbers. Input the numbers by reading memory locations called "mcand" and "mplier". The result should be stored in register 1 when the

program halts. You may assume that the two input numbers are at most 15 bits and are positive; this ensures that the (positive) result fits in an LC3101 word. See the algorithm on page 252 of the textbook for how to multiply. Remember that shifting left by one bit is the same as adding the number to itself. Given the LC3101 instruction set, it's easiest to modify the algorithm so that you avoid the right shift. Submit a version of the program that computes $(32766 * 10383)$.

Your multiplication program must be reasonably efficient--it must be at most 50 lines long and execute at most 1000 instructions for any valid numbers (this is several times longer and slower than the solution). To achieve this, you must use a loop and shift algorithm to perform the multiplication; algorithms

You may also choose to not use this fragment.

```
/* Assembler code fragment for LC3101 */

#include <stdlib.h>
#include <stdio.h>
#include <string.h>

#define MAXLINELENGTH 1000

int readAndParse(FILE *, char *, char *, char *, char *, char *);
int isNumber(char *);

int
main(int argc, char *argv[])
{
    char *inFileString, *outFileString;
    FILE *inFilePtr, *outFilePtr;
    char label[MAXLINELENGTH], opcode[MAXLINELENGTH],
    arg0[MAXLINELENGTH],
        arg1[MAXLINELENGTH], arg2[MAXLINELENGTH];

    if (argc != 3) {
```

```

    /* after doing a readAndParse, you may want to do the following to
test the
        opcode */
    if (!strcmp(opcode, "add")) {
        /* do whatever you need to do for opcode "add" */
    }

    return(0);
}

/*
 * Read and parse a line of the assembly-language file. Fields are
returned
 * in label, opcode, arg0, arg1, arg2 (these strings must have memory
already
 * allocated to them).
 *
 * Return values:
 *     0 if reached end of file
 *     1 if all went well
 *
 * exit(1) if line is too long.
 */
int
readAndParse(FILE *inFilePtr, char *label, char *opcode, char *arg0,
             char *arg1, char *arg2)
{
    char line[MAXLINELENGTH];
    char *ptr = line;

    /* delete prior values */
    label[0] = opcode[0] = arg0[0] = arg1[0] = arg2[0] = '\0';

    /* read the line from the assembly-language file */
    if (fgets(line, MAXLINELENGTH, inFilePtr) == NULL) {
        /* reached end of file */
        return(0);
    }

    /* check for line too long (by looking for a \n) */
    if (strchr(line, '\n') == NULL) {
        /* line too long */
        printf("error: line too long\n");
        exit(1);
    }

    /* is there a label? */
    ptr = line;
    if (sscanf(ptr, "%[^\\t\\n ]", label)) {
        /* successfully read label; advance pointer over the label */
        ptr += strlen(label);
    }

    /*

```

```

        * Parse the rest of the line.  Would be nice to have real regular
        * expressions, but scanf will suffice.
        */
        sscanf(ptr, "%*[\t\n ]%[^\\t\\n ]%*[\t\n ]%[^\\t\\n ]%*[\t\n ]%[^\\t\\n
]%^*[\t\n ]%[^\\t\\n ]",
               opcode, arg0, arg1, arg2);
        return(1);
    }

int
isNumber(char *string)
{
    /* return 1 if string is a number */
    int i;
    return( (sscanf(string, "%d", &i)) == 1);
}

```

10. Code Fragment for Simulator

Here is some C code that may help you write the simulator. Again, you should take this merely as a hint. You may have to re-code this to make it do exactly what you want, but this should help you get started. Remember not to change stateStruct or printState.

```

/* instruction-level simulator for LC3101 */

#include <stdio.h>
#include <string.h>

#define NUMMEMORY 65536 /* maximum number of words in memory */
#define NUMREGS 8 /* number of machine registers */
#define MAXLINELENGTH 1000

typedef struct stateStruct {
    int pc;
    int mem[NUMMEMORY];
    int reg[NUMREGS];
    int numMemory;
} stateType;

void printState(stateType *);

int
main(int argc, char *argv[])
{
    char line[MAXLINELENGTH];
    stateType state;
    FILE *filePtr;

    if (argc != 2) {

```


bits. Neither a nor b are changed. E.g. $(25 \gg 2)$ is 6. Note that 25 is 11001 in binary, and 6 is 110 in binary.

3) The value of the expression $(a \ll b)$ is the number "a" shifted left by "b" bits. Neither a nor b are changed. E.g. $(25 \ll 2)$ is 100. Note that 25 is 11001 in binary, and 100 is 1100100 in binary.

4) To find the value of the expression $(a \& b)$, perform a logical AND on each bit of a and b (i.e. bit 31 of a AND'ed with bit 31 of b, bit 30 of a AND'ed with bit 30 of b, etc.). E.g. $(25 \& 11)$ is 9, since:

```
    11001 (binary)
    & 01011 (binary)
    -----
    = 01001 (binary), which is 9 decimal.
```

5) To find the value of the expression $(a | b)$, perform a logical OR on each bit of a and b (i.e. bit 31 of a OR'ed with bit 31 of b, bit 30 of a OR'ed with bit 30 of b, etc.). E.g. $(25 | 11)$ is 27, since:

```
    11001 (binary)
    | 01011 (binary)
    -----
    = 11011 (binary), which is 27 decimal.
```

6) $\sim a$ is the bit-wise complement of a (a is not changed).

Use these operations to create and manipulate machine-code. E.g. to look at bit 3 of the variable a, you might do: $(a \gg 3) \& 0x1$. To look at bits (bits 15-12) of a 16-bit word, you could do: $(a \gg 12) \& 0xF$. To put a 6 into bits 5-3 and a 3 into bits 2-1, you could do: $(6 \ll 3) | (3 \ll 1)$. If you're not sure what an operation is doing, print some intermediate results to help you debug.

12. Example Run of Simulator

```
memory[0]=8454151
memory[1]=9043971
memory[2]=655361
memory[3]=16842754
memory[4]=16842749
memory[5]=29360128
memory[6]=25165824
```

```
memory[7]=5
memory[8]=-1
memory[9]=2
```

```
@@@
```

```
state:
```

```
    pc 0
```

```
    memory:
```

```
        mem[ 0 ] 8454151
        mem[ 1 ] 9043971
        mem[ 2 ] 655361
        mem[ 3 ] 16842754
        mem[ 4 ] 16842749
        mem[ 5 ] 29360128
        mem[ 6 ] 25165824
        mem[ 7 ] 5
        mem[ 8 ] -1
        mem[ 9 ] 2
```

```
    registers:
```

```
        reg[ 0 ] 0
        reg[ 1 ] 0
        reg[ 2 ] 0
        reg[ 3 ] 0
        reg[ 4 ] 0
        reg[ 5 ] 0
        reg[ 6 ] 0
        reg[ 7 ] 0
```

```
end state
```

```
@@@
```

```
state:
```

```
    pc 1
```

```
    memory:
```

```
        mem[ 0 ] 8454151
        mem[ 1 ] 9043971
        mem[ 2 ] 655361
        mem[ 3 ] 16842754
        mem[ 4 ] 16842749
        mem[ 5 ] 29360128
        mem[ 6 ] 25165824
        mem[ 7 ] 5
        mem[ 8 ] -1
        mem[ 9 ] 2
```

```
    registers:
```

```
        reg[ 0 ] 0
        reg[ 1 ] 5
        reg[ 2 ] 0
        reg[ 3 ] 0
        reg[ 4 ] 0
        reg[ 5 ] 0
        reg[ 6 ] 0
        reg[ 7 ] 0
```

```
end state
```



```

@@@
state:
    pc 2
    memory:
        mem[ 0 ] 8454151
        mem[ 1 ] 9043971
        mem[ 2 ] 655361
        mem[ 3 ] 16842754
        mem[ 4 ] 16842749
        mem[ 5 ] 29360128
        mem[ 6 ] 25165824
        mem[ 7 ] 5
        mem[ 8 ] -1
        mem[ 9 ] 2
    registers:
        reg[ 0 ] 0
        reg[ 1 ] 5
        reg[ 2 ] -1
        reg[ 3 ] 0
        reg[ 4 ] 0
        reg[ 5 ] 0
        reg[ 6 ] 0
        reg[ 7 ] 0
end state

```

```

@@@
state:
    pc 3
    memory:
        mem[ 0 ] 8454151
        mem[ 1 ] 9043971
        mem[ 2 ] 655361
        mem[ 3 ] 16842754
        mem[ 4 ] 16842749
        mem[ 5 ] 29360128
        mem[ 6 ] 25165824
        mem[ 7 ] 5
        mem[ 8 ] -1
        mem[ 9 ] 2
    registers:
        reg[ 0 ] 0
        reg[ 1 ] 4
        reg[ 2 ] -1
        reg[ 3 ] 0
        reg[ 4 ] 0
        reg[ 5 ] 0
        reg[ 6 ] 0
        reg[ 7 ] 0
end state

```

```

@@@
state:
    pc 4

```

```

memory:
    mem[ 0 ] 8454151
    mem[ 1 ] 9043971
    mem[ 2 ] 655361
    mem[ 3 ] 16842754
    mem[ 4 ] 16842749
    mem[ 5 ] 29360128
    mem[ 6 ] 25165824
    mem[ 7 ] 5
    mem[ 8 ] -1
    mem[ 9 ] 2
registers:
    reg[ 0 ] 0
    reg[ 1 ] 4
    reg[ 2 ] -1
    reg[ 3 ] 0
    reg[ 4 ] 0
    reg[ 5 ] 0
    reg[ 6 ] 0
    reg[ 7 ] 0
end state

```

@@@

```

state:
    pc 2
    memory:
        mem[ 0 ] 8454151
        mem[ 1 ] 9043971
        mem[ 2 ] 655361
        mem[ 3 ] 16842754
        mem[ 4 ] 16842749
        mem[ 5 ] 29360128
        mem[ 6 ] 25165824
        mem[ 7 ] 5
        mem[ 8 ] -1
        mem[ 9 ] 2
    registers:
        reg[ 0 ] 0
        reg[ 1 ] 4
        reg[ 2 ] -1
        reg[ 3 ] 0
        reg[ 4 ] 0
        reg[ 5 ] 0
        reg[ 6 ] 0
        reg[ 7 ] 0
end state

```

@@@

```

state:
    pc 3
    memory:
        mem[ 0 ] 8454151
        mem[ 1 ] 9043971
        mem[ 2 ] 655361

```

```
        mem[ 3 ] 16842754
        mem[ 4 ] 16842749
        mem[ 5 ] 29360128
        mem[ 6 ] 25165824
        mem[ 7 ] 5
        mem[ 8 ] -1
        mem[ 9 ] 2
    registers:
        reg[ 0 ] 0
        reg[ 1 ] 3
        reg[ 2 ] -1
        reg[ 3 ] 0
        reg[ 4 ] 0
        reg[ 5 ] 0
        reg[ 6 ] 0
        reg[ 7 ] 0
end state
```

```
@@@
state:
    pc 4
    memory:
        mem[ 0 ] 8454151
        mem[ 1 ] 9043971
        mem[ 2 ] 655361
        mem[ 3 ] 16842754
        mem[ 4 ] 16842749
        mem[ 5 ] 29360128
        mem[ 6 ] 25165824
        mem[ 7 ] 5
        mem[ 8 ] -1
        mem[ 9 ] 2
    registers:
        reg[ 0 ] 0
        reg[ 1 ] 3
        reg[ 2 ] -1
        reg[ 3 ] 0
        reg[ 4 ] 0
        reg[ 5 ] 0
        reg[ 6 ] 0
        reg[ 7 ] 0
end state
```

```
@@@
state:
    pc 2
    memory:
        mem[ 0 ] 8454151
        mem[ 1 ] 9043971
        mem[ 2 ] 655361
        mem[ 3 ] 16842754
        mem[ 4 ] 16842749
        mem[ 5 ] 29360128
        mem[ 6 ] 25165824
```

```

        mem[ 7 ] 5
        mem[ 8 ] -1
        mem[ 9 ] 2
    registers:
        reg[ 0 ] 0
        reg[ 1 ] 3
        reg[ 2 ] -1
        reg[ 3 ] 0
        reg[ 4 ] 0
        reg[ 5 ] 0
        reg[ 6 ] 0
        reg[ 7 ] 0
end state

```

@@@

state:

pc 3

memory:

```

        mem[ 0 ] 8454151
        mem[ 1 ] 9043971
        mem[ 2 ] 655361
        mem[ 3 ] 16842754
        mem[ 4 ] 16842749
        mem[ 5 ] 29360128
        mem[ 6 ] 25165824
        mem[ 7 ] 5
        mem[ 8 ] -1
        mem[ 9 ] 2

```

registers:

```

        reg[ 0 ] 0
        reg[ 1 ] 2
        reg[ 2 ] -1
        reg[ 3 ] 0
        reg[ 4 ] 0
        reg[ 5 ] 0
        reg[ 6 ] 0
        reg[ 7 ] 0

```

end state

@@@

state:

pc 4

memory:

```

        mem[ 0 ] 8454151
        mem[ 1 ] 9043971
        mem[ 2 ] 655361
        mem[ 3 ] 16842754
        mem[ 4 ] 16842749
        mem[ 5 ] 29360128
        mem[ 6 ] 25165824
        mem[ 7 ] 5
        mem[ 8 ] -1
        mem[ 9 ] 2

```

registers:

```
        reg[ 0 ] 0
        reg[ 1 ] 2
        reg[ 2 ] -1
        reg[ 3 ] 0
        reg[ 4 ] 0
        reg[ 5 ] 0
        reg[ 6 ] 0
        reg[ 7 ] 0
end state
```

```
@@@
state:
    pc 2
    memory:
        mem[ 0 ] 8454151
        mem[ 1 ] 9043971
        mem[ 2 ] 655361
        mem[ 3 ] 16842754
        mem[ 4 ] 16842749
        mem[ 5 ] 29360128
        mem[ 6 ] 25165824
        mem[ 7 ] 5
        mem[ 8 ] -1
        mem[ 9 ] 2
    registers:
        reg[ 0 ] 0
        reg[ 1 ] 2
        reg[ 2 ] -1
        reg[ 3 ] 0
        reg[ 4 ] 0
        reg[ 5 ] 0
        reg[ 6 ] 0
        reg[ 7 ] 0
```

end state

```
@@@
state:
    pc 3
    memory:
        mem[ 0 ] 8454151
        mem[ 1 ] 9043971
        mem[ 2 ] 655361
        mem[ 3 ] 16842754
        mem[ 4 ] 16842749
        mem[ 5 ] 29360128
        mem[ 6 ] 25165824
        mem[ 7 ] 5
        mem[ 8 ] -1
        mem[ 9 ] 2
    registers:
        reg[ 0 ] 0
        reg[ 1 ] 1
        reg[ 2 ] -1
        reg[ 3 ] 0
```

```
        reg[ 4 ] 0
        reg[ 5 ] 0
        reg[ 6 ] 0
        reg[ 7 ] 0
end state
```

@@@

state:

pc 4

memory:

```
mem[ 0 ] 8454151
mem[ 1 ] 9043971
mem[ 2 ] 655361
mem[ 3 ] 16842754
mem[ 4 ] 16842749
mem[ 5 ] 29360128
mem[ 6 ] 25165824
mem[ 7 ] 5
mem[ 8 ] -1
mem[ 9 ] 2
```

registers:

```
reg[ 0 ] 0
reg[ 1 ] 1
reg[ 2 ] -1
reg[ 3 ] 0
reg[ 4 ] 0
reg[ 5 ] 0
reg[ 6 ] 0
reg[ 7 ] 0
```

end state

@@@

state:

pc 2

memory:

```
mem[ 0 ] 8454151
mem[ 1 ] 9043971
mem[ 2 ] 655361
mem[ 3 ] 16842754
mem[ 4 ] 16842749
mem[ 5 ] 29360128
mem[ 6 ] 25165824
mem[ 7 ] 5
mem[ 8 ] -1
mem[ 9 ] 2
```

registers:

```
reg[ 0 ] 0
reg[ 1 ] 1
reg[ 2 ] -1
reg[ 3 ] 0
reg[ 4 ] 0
reg[ 5 ] 0
reg[ 6 ] 0
reg[ 7 ] 0
```

end state

@@@

state:

pc 3

memory:

mem[0]	8454151
mem[1]	9043971
mem[2]	655361
mem[3]	16842754
mem[4]	16842749
mem[5]	29360128
mem[6]	25165824
mem[7]	5
mem[8]	-1
mem[9]	2

registers:

reg[0]	0
reg[1]	0
reg[2]	-1
reg[3]	0
reg[4]	0
reg[5]	0
reg[6]	0
reg[7]	0

end state

@@@

state:

pc 6

memory:

mem[0]	8454151
mem[1]	9043971
mem[2]	655361
mem[3]	16842754
mem[4]	16842749
mem[5]	29360128
mem[6]	25165824
mem[7]	5
mem[8]	-1
mem[9]	2

registers:

reg[0]	0
reg[1]	0
reg[2]	-1
reg[3]	0
reg[4]	0
reg[5]	0
reg[6]	0
reg[7]	0

end state

machine halted

total of 17 instructions executed

final state of machine:

```
@@@
state:
  pc 7
  memory:
    mem[ 0 ] 8454151
    mem[ 1 ] 9043971
    mem[ 2 ] 655361
    mem[ 3 ] 16842754
    mem[ 4 ] 16842749
    mem[ 5 ] 29360128
    mem[ 6 ] 25165824
    mem[ 7 ] 5
    mem[ 8 ] -1
    mem[ 9 ] 2
  registers:
    reg[ 0 ] 0
    reg[ 1 ] 0
    reg[ 2 ] -1
    reg[ 3 ] 0
    reg[ 4 ] 0
    reg[ 5 ] 0
    reg[ 6 ] 0
    reg[ 7 ] 0
end state
```