

# CS 314 Principles of Programming Languages

## Project 1: A Compiler for the TinyL Language

**THIS IS NOT A GROUP PROJECT!** You may talk about the project and possible solutions in general terms, but must not share code. In this project, you will be asked to write a recursive descent LL(1) parser and code generator for the `tinyL` language as discussed in class. Your compiler will generate RISC machine instructions. You will also write a code optimizer that takes RISC machine instructions as input and implements dead code elimination. The output of the optimizer is a sequence of RISC machine instructions which produces the same results as the original input sequence. To test your generated programs, you can use a virtual machine that can “run” your RISC code programs. The project will require you to manipulate doubly-linked lists of instructions. In order to avoid memory leaks, explicit deallocation of “dead” instructions is necessary.

This document is not a complete specification of the project. You will encounter important design and implementation issues that need to be addressed in your project solution. Identifying these issues is part of the project. As a result, you need to start early, allowing time for possible revisions of your solution.

## 1 Background

### 1.1 The `tinyL` language

`tinyL` is a simple expression language that allows assignments and basic I/O operations.

<code>&lt;program&gt;</code>	<code>::=</code>	<code>&lt;stmt_list&gt; .</code>
<code>&lt;stmt_list&gt;</code>	<code>::=</code>	<code>&lt;stmt&gt; &lt;morestmts&gt;</code>
<code>&lt;morestmts&gt;</code>	<code>::=</code>	<code>; &lt;stmt_list&gt;   <math>\epsilon</math></code>
<code>&lt;stmt&gt;</code>	<code>::=</code>	<code>&lt;assign&gt;   &lt;read&gt;   &lt;print&gt;</code>
<code>&lt;assign&gt;</code>	<code>::=</code>	<code>&lt;variable&gt; = &lt;expr&gt;</code>
<code>&lt;read&gt;</code>	<code>::=</code>	<code>! &lt;variable&gt;</code>
<code>&lt;print&gt;</code>	<code>::=</code>	<code># &lt;variable&gt;</code>
<code>&lt;expr&gt;</code>	<code>::=</code>	<code>+ &lt;expr&gt; &lt;expr&gt;  </code> <code>- &lt;expr&gt; &lt;expr&gt;  </code> <code>* &lt;expr&gt; &lt;expr&gt;  </code> <code>&amp; &lt;expr&gt; &lt;expr&gt;  </code> <code><math>\wedge</math> &lt;expr&gt; &lt;expr&gt;  </code> <code>&lt;variable&gt;  </code> <code>&lt;digit&gt;</code>
<code>&lt;variable&gt;</code>	<code>::=</code>	<code>a   b   c   d   e</code>
<code>&lt;digit&gt;</code>	<code>::=</code>	<code>0   1   2   3   4   5   6   7   8   9</code>

The `&` operator is the bitwise AND operator and the  `$\wedge$`  operator is the bitwise XOR

operator. Here are two examples of valid **tinyL** programs:

```
!a;!b;c+=3*ab;d=&c1;#d.
!a;b=-*+1^2a58;#b.
```

## 1.2 Target Architecture

The target architecture is a simple RISC machine with virtual registers, i.e., with an unbounded number of registers. All registers can only store integer values. A RISC architecture is a load/store architecture where arithmetic instructions operate on registers rather than memory operands (memory addresses). This means that for each access to a memory location, a **load** or **store** instruction has to be generated. Here is the machine instruction set of our RISC target architecture.  $R_x$ ,  $R_y$ , and  $R_z$  represent three arbitrary, but distinct registers.

instr. format	description	semantics
<b>memory instructions</b>		
LOADI $R_x$ #<const>	load constant value #<const> into register $R_x$	$R_x \leftarrow \text{<const>}$
LOAD $R_x$ <id>	load value of variable <id> into register $R_x$	$R_x \leftarrow \text{<id>}$
STORE <id> $R_x$	store value of register $R_x$ into variable <id>	$\text{<id>} \leftarrow R_x$
<b>arithmetic instructions</b>		
ADD $R_x$ $R_y$ $R_z$	add contents of registers $R_y$ and $R_z$ , and store result into register $R_x$	$R_x \leftarrow R_y + R_z$
SUB $R_x$ $R_y$ $R_z$	subtract contents of register $R_z$ from register $R_y$ , and store result into register $R_x$	$R_x \leftarrow R_y - R_z$
MUL $R_x$ $R_y$ $R_z$	multiply contents of registers $R_y$ and $R_z$ , and store result into register $R_x$	$R_x \leftarrow R_y * R_z$
AND $R_x$ $R_y$ $R_z$	Bitwise and contents of registers $R_y$ and $R_z$ , and store result into register $R_x$	$R_x \leftarrow R_y \& R_z$
XOR $R_x$ $R_y$ $R_z$	Bitwise xor contents of registers $R_y$ and $R_z$ , and store result into register $R_x$	$R_x \leftarrow R_y \wedge R_z$
<b>I/O instructions</b>		
READ <id>	read value of variable <id> from standard input	read( <id> )
WRITE <id>	write value of variable <id> to standard output	print( <id> )

## 1.3 Dead Code Elimination

Our tinyL language does not contain any control flow constructs (e.g.: jumps, if-then-else, while). This means that every generated instruction will be executed. However, if the execution of an operation or instruction does not contribute to the input/output behavior of the program, the instruction is considered “dead code” and therefore can be eliminated without changing the semantics of the program. Please note that **READ** instructions may not be eliminated although the read value may have no impact on the outcome of the program.

All **READ** instructions are kept since the overall input/output program behavior needs to be preserved.

Your dead-code eliminator will take a list of RISC instructions as input. For example, in the following code

```
LOADI  $R_x$   $\#c_1$ 
LOADI  $R_y$   $\#c_2$ 
LOADI  $R_z$   $\#c_3$ 
ADD  $R_1$   $R_x$   $R_y$ 
MUL  $R_2$   $R_x$   $R_y$ 
STORE a  $R_1$ 
WRITE a
```

the **MUL** instruction and the third **LOADI** instruction can be deleted without changing the semantics of the program. Therefore, your dead-eliminator should produce the code:

```
LOADI  $R_x$   $\#c_1$ 
LOADI  $R_y$   $\#c_2$ 
ADD  $R_1$   $R_x$   $R_y$ 
STORE a  $R_1$ 
WRITE a
```

## 2 Project Description

The project consists of two parts:

1. Complete the partially implemented recursive descent LL(1) parser that generates RISC machine instructions.
2. Write a dead-code eliminator that recognizes and deletes redundant, i.e., dead RISC machine instructions.

The project represents an entire programming environment consisting of a compiler, an optimizer, and a virtual machine (RISC machine interpreter).

### 2.1 Compiler

The recursive descent LL(1) parser implements a simple code generator. You should follow the main structure of the code as given to you in file **Compiler.c**. As given to you, the file contains code for function **digit**, as well as partial code for function **expr**. As is, the compiler is able to generate code only for expressions that contain “+” operations and constants. You will need to add code in the provided stubs to generate correct RISC machine code for the entire program. Do not change the signatures of the recursive functions. Note: The left-hand and right-hand occurrences of variables are treated differently.

## 2.2 Dead Code Elimination Optimization

The dead code elimination optimizer expects the input file to be provided at the standard input (stdin), and will write the generated code back to standard output (stdout).

The basic algorithm identifies “crucial” instructions. The initial crucial instructions are all **READ** and **WRITE** instructions. For all **WRITE** instruction, the algorithm has to detect all instructions that contribute to the value of the variable that is written out. The first instruction that needs to be found is the one that stores the value into the variable that is written out. This **STORE** instruction is marked as critical and will reference a register. There will be instructions that compute a value for this register, which also need to be marked as critical. This marking process terminates once no more instructions need to be marked as critical. If this basic algorithm is performed for all **WRITE** instructions, the instructions that were not marked critical can be deleted.

Instructions that are deleted as part of the optimization process have to be explicitly deallocated using the C **free** command in order to avoid memory leaks. You will implement your dead code eliminator pass in file **Optimizer.c**. All of your “helper” functions should be implemented in this file.

## 2.3 Virtual Machine

The virtual machine executes a RISC machine program. If a **READ** `<id>` instruction is executed, the user is asked for the value of `<id>` from standard input (stdin). If a **WRITE** `<id>` instruction is executed, the current value of `<id>` is written to standard output (stdout). The virtual machine is implemented in file **Interpreter.c**. **DO NOT MODIFY** this file. It is there only for your convenience so that you may be able to copy the source code of the virtual machine, for instance, to your laptop and compile it there. Note that this is for your convenience only since the project will be graded on the ilab cluster.

The virtual machine assumes that an arbitrary number of registers are available (called virtual registers), and that there are only five memory locations that can be accessed using variable names (`'a' ... 'e'`). In a real compiler, an additional optimization pass maps virtual registers to the limited number of physical registers of a machine. This step is typically called *register allocation*. You do not have to implement register allocation in this project. The virtual machine (RISC machine language interpreter) will report the overall number of executed instructions for a given input program. This allows you to assess the effectiveness of your dead code elimination optimization. You also will be able to check for correctness of your optimization pass.

## 3 Grading

You will submit your versions of files **Optimizer.c** and **Compiler.c**. No other file should be modified, and no additional file(s) may be used. Please make a tarball of these two files: “`tar -cvf proj1_submission.tar Optimizer.c Compiler.c`” and submit the *proj1\_submission.tar* file. Do not submit any executables or any of your test cases.

Your programs will be graded based mainly on functionality. Functionality will be verified through automatic testing on a set of syntactically correct test cases. No error handling is required. The original project distribution contains some test cases. Note that during grading we will use hidden test cases. The distribution also contains executables of reference solutions for the compiler (`compile.sol`) and optimizer (`optimize.sol`). A simple `Makefile` is also provided in the distribution for your convenience. In order to create the compiler, say `make compile` at the Linux prompt, which will generate the executable `compile`.

The provided, initial compiler is able to parse and generate code for very simple programs consisting of a single assignment statement with right-hand side expressions of only additions of numbers, followed by a single print statement. You will need to be able to accept and compile the full `tinyL` language.

The `Makefile` also contains rules to create executables of your optimizer (`make optimize`) and virtual machine (`make run`).

## 4 How To Get Started

Download the code package from sakai, create your own directory on the ilab cluster, and copy the entire provided project folder to your own home directory or any other one of your directories. Make sure that the read, write, and execute permissions for groups and others are disabled (`chmod go-rwx <directory_name>`).

Say `make compile` to generate the compiler. To run the compiler on a test case “test1”, say `./compile test1`. This will generate a RISC machine program in file `tinyL.out`. To create your optimizer, say `make optimize`.

To call your optimizer on a file that contains RISC machine code, for instance file `tinyL.out`, say `./optimize < tinyL.out > optimized.out`. This will generate a new file `optimized.out` containing the output of your optimizer. The operators “<” and “>” are Linux redirection operators for standard input (stdin) and standard output (stdout), respectively. Without those, the optimizer will expect instructions to be entered on the Linux command line, and will write the output to your screen.

You may want to use `valgrind` for memory leak detection. We recommend to use the following flags, in this case to test the optimizer for memory leaks:

```
valgrind --leak-check=full --show-reachable=yes --track-origins=yes ./optimize  
< tinyL.out
```

The RISC virtual machine (RISC machine program interpreter) can be generated by saying `make run`. The distributed version of the VM in `Interpreter.c` is complete and should not be changed. To run a program on the virtual machine, for instance `tinyL.out`, say `./run tinyL.out`. If the program contains `READ` instructions, you will be prompted at the Linux command line to enter a value. Finally, you can define a **tinyL language interpreter** on a single Linux command line as follows:

```
./compile test1; ./optimize < tinyL.out > opt.out; ./run opt.out.
```

The “;” operator allows you to specify a sequence of Linux commands on a single command line.

## 5 Questions

All questions regarding this project should be posted on Sakai forum. Enjoy the project!