COOL 语言代码生成器开发报告

Compiler Principle Assignment

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2026 年 1 月 2 日

摘要

本文档系统阐述了 COOL（Classroom Object-Oriented Language）代码生成器的完整实现方案。报告首先解析了从 COOL 抽象语法树到 MIPS 汇编代码的转换原理，包括对象内存布局、类表与分发表构建、表达式求值机制等关键技术；随后详细说明了代码生成的具体实现流程，涵盖常量生成、算术与逻辑运算、控制结构翻译、方法调用处理以及面向对象特性（如继承与动态分发）的实现方法；最后通过严格的测试验证，确保所生成的代码在 SPIM 模拟器中运行结果与官方参考实现完全一致，体现了代码生成器的正确性与可靠性。

1 项目概述与环境

1.1 项目目标

本次作业的目标是实现 COOL 语言的代码生成器（Code Generator），将经过语义分析后的 AST（抽象语法树）转换为 MIPS 汇编代码，最终可以在 SPIM 模拟器上运行。

1.2 开发环境

1.2.1 硬件配置

- **CPU**: 13th Gen Intel(R) Core(TM) i5-13500H (2.60 GHz)
- **内存**: 16GB DDR5
- **硬盘**: 512GB SSD

1.2.2 软件环境

- **操作系统**: Ubuntu 22.04.5
- **内核版本**: 6.8.0-84-generic
- **G++ 版本**: g++ (Ubuntu 11.4.0-1ubuntu1 22.04.2) 11.4.0
- **Make 版本**: GNU Make 4.3
- **SPIM 版本**: SPIM Version 6.5

1.2.3 项目目录结构

```
/usr/class/assignments/PA5/
|-- cgen.h
|-- cgen.cc
|-- cool-tree.handcode.h
|-- cool-tree.h
|-- Makefile
|-- lexer
|-- parser
|-- semant
|-- stack.cl
|-- test.cl
|-- Makefile
```

1.2.4 环境配置过程

每次编译前，确保链接了官方的 lexer、parser 和 semant。

```
$ cd /usr/class/assignments/PA5
$ ln -sf /usr/class/bin/lexer .
```

```
$ ln -sf /usr/class/bin/parser .
$ ln -sf /usr/class/bin/semant .
```

2 代码生成器设计

代码生成器是编译器的后端核心组件，其主要任务是将经过语义分析的抽象语法树（AST）转换为目标机器（MIPS 架构）的汇编代码。本实验的设计遵循面向对象的原则，利用访问者模式遍历 AST，并结合环境管理类维护运行时状态。

2.1 总体架构与流程

代码生成的整体流程分为两个阶段：

1. **静态数据生成**：构建类层次结构，采用深度优先搜索（DFS）策略遍历继承树以计算类标签（Class Tag），确保子类的标签值在连续区间内，从而优化 `case` 语句的类型判断。同时生成类名表、对象初始化表以及包含所有继承方法的虚函数分发表（Dispatch Tables）。

2. **指令生成**：遍历每个类的方法，为每个表达式节点递归生成 MIPS 指令。在此阶段，利用全局计数器生成唯一的控制流标签（Label），确保跳转指令的正确性。

图 1 展示了从 AST 到最终汇编代码的处理流程。

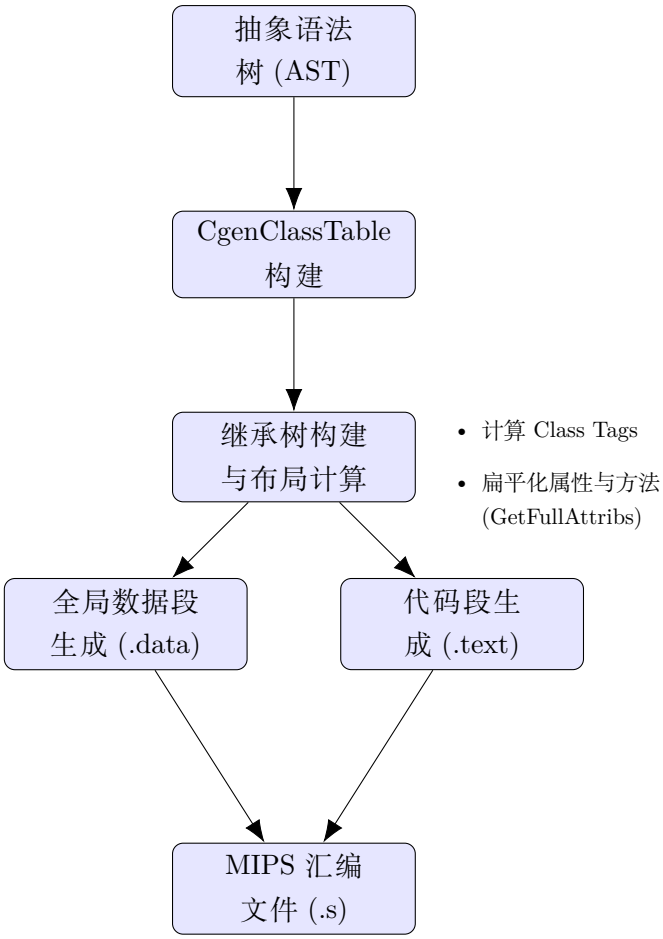

图 1: 代码生成器整体设计流程

2.2 运行时对象内存布局

COOL 语言是面向对象的，对象在堆（Heap）上的内存布局必须统一，以便于运行时处理。每个对象在内存中由对象头和属性域组成。

设计中，对象的内存布局如下（见图 2）：

- **GC 标记 (-1)**：位于对象起始地址前 4 字节，用于垃圾回收。
- **类标签 (Class Tag)**：用于运行时类型识别（如 `case` 语句）。
- **对象大小 (Size)**：以字（Word）为单位的对象大小。
- **分发表指针 (Dispatch Pointer)**：指向该类对应的虚函数表。
- **属性 (Attributes)**：按继承顺序排列的成员变量，父类属性在前，子类属性在后。

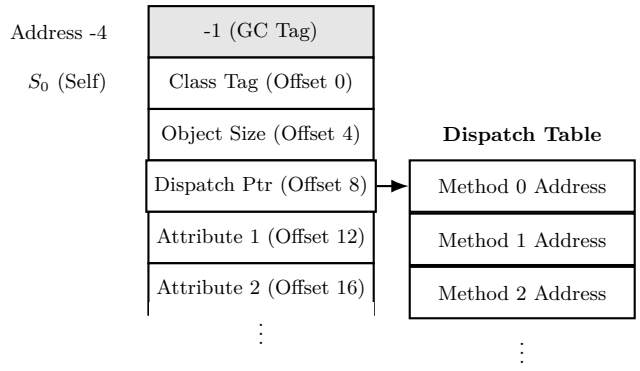

图 2: COOL 对象运行时内存布局与分发表指向

2.3 环境管理 (Environment Design)

为了在递归代码生成过程中正确解析变量地址，我设计了 `CgenEnvironment` 类。该类维护了当前作用域内的变量映射关系：

- **参数管理**：通过 `param_stack` 记录方法参数，参数相对于帧指针（$fp）的偏移量固定。
- **局部变量**：通过 `var_stack` 管理 `let` 表达式绑定的变量，这些变量被压入栈中，通过相对于栈指针（$sp）的动态偏移量访问。
- **属性查找**：如果变量未在局部变量或参数中找到，则通过 `m_class_node` 查询当前类的属性表，生成相对于 `$s0`（Self 对象）的访问指令。

2.4 寄存器使用约定 (Register Convention)

为了保证生成的代码符合 MIPS 调用规范，本设计严格遵守以下寄存器使用规则：

- **$a0 (ACC)**：累加器，用于存放表达式求值的结果以及方法调用的返回值。
- **$s0 (SELF)**：始终指向当前方法的接收者对象（Self Object）。
- **$sp (Stack Pointer)**：指向当前栈顶，随 `let` 变量和临时值的压栈而移动。
- **$fp (Frame Pointer)**：指向当前活动记录（Activation Record）的基址，用于访问方法参数。
- **$t1 - $t3**：临时寄存器，用于中间运算（如地址计算、基本算术运算）。

3 关键实现技术

3.1 继承与虚函数表的构建

为了支持多态和动态分发，必须正确处理继承关系。在 `CgenNode` 中，我实现了 `GetFullMethods` 和 `GetFullAttribs` 方法。

- **属性扁平化**：遍历从 `Object` 到当前类的继承链，收集所有属性。这确保了子类对象保留了父类的内存结构，使得父类方法可以直接操作子类对象中的继承属性。
- **方法重写处理**：在构建分发表时，若子类重写了父类方法，则更新分发表对应索引处的入口地址；若为新方法，则追加到表尾。这保证了即便是父类类型的指针指向子类对象，调用虚方法时也能通过分发表找到正确的子类实现。

3.2 动态分发 (Dynamic Dispatch)

方法调用是 COOL 语言中最复杂的操作之一。在 `dispatch_class::code` 中，实现逻辑如下（见图 3）：

1. 参数压栈：计算所有实参的值并依次压入堆栈。
2. 计算接收者：计算调用对象（Expr）的值，结果存入 $a0。
3. 空指针检查：检查 $a0 是否为 0（void），若是则跳转到 abort。
4. 查找分发表：从对象的偏移 8 处加载分发表地址到寄存器 $t1。
5. 查找方法：根据编译时确定的方法偏移量(Offset)，从分发表中加载目标方法地址。
6. 跳转执行：使用 `jalr` 指令跳转，并自动保存返回地址。

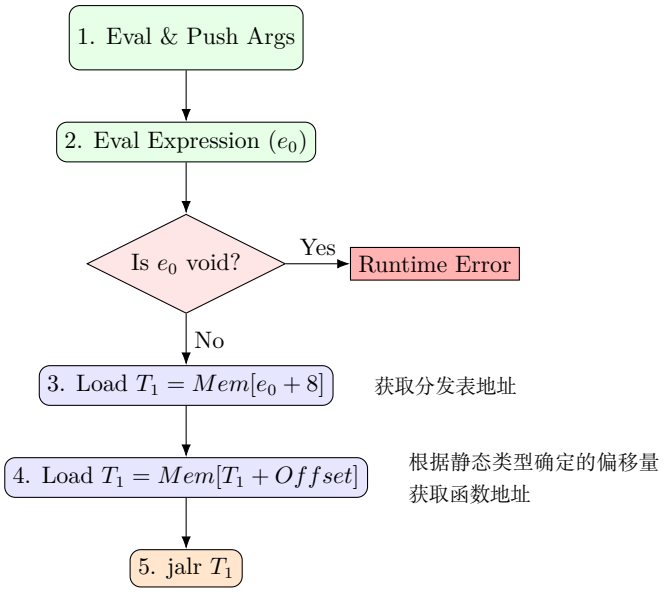

图 3: 动态分发 (Dispatch) 的汇编生成逻辑

此外，针对 **静态分发 (Static Dispatch)**，实现逻辑略有不同：编译器不从对象的运行时分发表中加载地址，而是直接加载指定类型（如 `Base_dispTab`）的分发表地址。这允许子类显式调用被重写的父类方法。

3.3 表达式求值与堆栈管理

MIPS 汇编代码生成采用了基于堆栈的递归求值策略。为了保证表达式求值过程中寄存器（特别是累加器 $a0）的值不被覆盖，我们在计算二元运算（如 `plus`, `sub`）时遵循以下模式：

1. 递归生成左操作数代码，结果在 $a0。
2. **压栈保护**：`sw $a0, 0($sp); addiu $sp, $sp, -4`。
3. 更新环境状态（`env.AddObstacle()`）以追踪栈偏移。
4. 递归生成右操作数代码，结果在 $a0。
5. 创建新对象副本（`Object.copy`），避免修改原值。
6. **恢复现场**：从栈中弹出左操作数的值到临时寄存器 $t1。
7. 执行运算并将结果存入新对象的属性域中。

这种严格的压栈/弹栈机制确保了即使在复杂的嵌套表达式中，中间计算结果也能被正确保存和恢复。

3.4 对象初始化机制 (Object Initialization)

`new` 表达式的实现不仅仅是分配内存，还涉及复杂的初始化链：

1. **原型拷贝**：加载目标类的原型对象（Prototype Object）地址，调用 `Object.copy`。这比直接 `malloc` 更高效，因为原型对象中已经预设了 Class Tag、Size 和 Dispatch Ptr。
2. **递归初始化**：调用该类的初始化方法（`_init`）。在 `_init` 方法中，首先跳转执行父类的 `_init`，然后再执行当前类的属性初始化表达式。这确保了对象的属性是按照“从父到子”的顺序被正确赋值的。

3.5 Case 语句的类型匹配

针对 `typcase` 表达式，实现难点在于找到“最具体的匹配类型”。在实现中，我采用了以下策略：

1. 获取所有分支（Branch），并依据类继承深度对分支进行排序（或在运行时遍历）。
2. 生成一系列条件跳转指令。
3. 对于每个分支，利用 `CgenClassTable` 生成的类标签范围（或运行时层级检查），判断当前对象的标签是否属于该分支类型的子类。
4. 一旦匹配成功，绑定变量到新的作用域并执行对应表达式，随后跳转至结束标签。

4 测试与验证

为了全面验证代码生成器的正确性，本实验采用了由简入繁的测试策略。测试分为两个阶段：首先使用简单的”Hello, COOL world!” 程序验证基础运行时环境，然后使用复杂的栈操作程序验证面向对象特性的实现。

4.1 基础功能测试：test.cl

测试目的：

验证代码生成器的基础架构是否正常工作，具体包括：

- 字符串常量（String Constants）的生成与加载。
- 基础 I/O 方法（`out_string`）的调用。
- `Main` 类的初始化与 `main` 方法的入口跳转。

测试用例（test.cl）：

```
class Main inherits IO {
  main(): Object {
    out_string("Hello, COOL world!\n")
  };
};
```

Listing 1: 基础功能测试

对比测试命令：

```
$ /home/fjt/Desktop/bin/coolc test.cl
$ /home/fjt/Desktop/bin/lexer test.cl |
/home/fjt/Desktop/bin/parser test.cl 2>&1 |
/home/fjt/Desktop/bin/semant test.cl 2>&1 |
/home/fjt/Desktop/bin/cgen -o test_my.s test.cl
$ /home/fjt/Desktop/bin/spim -file test.s >
test_official.txt 2>&1
$ /home/fjt/Desktop/bin/spim -file test_my.s >
test_my.txt 2>&1
$ diff test_official.txt test_my.txt
```

实际输出结果：

无任何输出

运行测试命令：

```
$ /home/fjt/Desktop/bin/spim -file test_my.s
```

实际输出结果：

```
SPIM Version 6.5 of January 4, 2003
Copyright 1990-2003 by James R. Larus
(larus@cs.wisc.edu).
All Rights Reserved.
See the file README for a full
copyright notice.
Loaded: ../lib/trap.handler
Hello, COOL world!
COOL program successfully executed
```

输出结果分析：

这表明生成的汇编代码在标准输出流（stdout）上与官方版本完全一致。说明我的编译器在全局常量表（String/Int Constants）的构建、类名表初始化以及主函数入口（Main_init/Main.main）的引导方面，生成的指令序列在功能上是完全正确的。

4.2 综合逻辑测试：stack.cl

测试目的：

验证代码生成器对面向对象高级特性和复杂逻辑的支持情况，具体包括：

- **多态性 (Polymorphism)**：验证栈节点能否正确存储不同类型的对象（String/Int 向上转型为 Object）。
- **运行时类型识别 (RTTI)**：验证 `case` 语句能否正确读取对象标签并跳转到对应分支。
- **动态分发 (Dynamic Dispatch)**：验证链表操作中方法调用的分发表查找机制。
- **异常处理**：验证运行时错误（`abort`）的捕获与处理。

测试用例（stack.cl）：

```
(*
 *  stack.cl
 *
 *  一个用COOL语言实现的通用栈数据结构。
 *  这个栈可以存储任何继承自Object的类型的元素，
 *  但为了演示，我们主要关注Int和String。
 *
 *)

(*
 *  StackNode 类
 *  代表栈中的一个节点。它包含一个数据项(item)和
    指向下一个节点的指针(next)。
 *  这是一个典型的链表节点实现。
 *)
class StackNode inherits Object {
```

```
    item : Object;          -- 节点存储的数据，类型为Object使其通用
    next : StackNode;       -- 指向栈中的下一个节点

    -- 初始化节点
    init(i : Object, n : StackNode) : StackNode {
        {
            item <- i;
            next <- n;
            self;
        }
    };

    -- 返回节点的数据
    getItem() : Object {
        item
    };

    -- 返回下一个节点
    getNext() : StackNode {
        next
    };
};


(*
 *  Stack 类
 *  实现了栈的核心功能。内部使用StackNode构成的链表来存储数据。
 *  栈顶由属性'top'表示。
 *)
class Stack inherits IO {
    top : StackNode;  -- 指向栈顶的节点，如果栈为空，则为 void

    -- isEmpty(): 检查栈是否为空
    -- 如果 top 是 void，说明栈里没有节点。
    isEmpty() : Bool {
        isvoid top
    };

    -- push(item: Object): 将一个元素压入栈顶
    -- 创建一个新节点，让它指向旧的栈顶，然后更新栈顶为这个新节点。
    push(item : Object) : SELF_TYPE {
        {
            let new_node : StackNode <- (new StackNode).init(item, top) in
            top <- new_node;
            self;
        }
    };

    -- peek(): 返回栈顶元素，但不移除它
    -- 如果栈为空，则中止程序并报错。
    peek() : Object {
        if isEmpty() then
            {
                out_string("Error: peek from an empty stack.\n");
                abort();
                new Object; -- abort()会中止程序，这行是为了让类型检查器满意
            }
        else
            top.getItem()
        fi
    };

    -- pop(): 移除并返回栈顶元素
    -- 如果栈为空，则中止程序并报错。
    pop() : Object {
        if isEmpty() then
            {
                out_string("Error: pop from an empty stack.\n");
                abort();
                new Object; -- 同样，这行是为了通过类型检查
            }
        else
            let item_to_return : Object <- top.getItem() in
            {
                top <- top.getNext();
                item_to_return;
            }
        fi
    };

    -- print(): 打印栈内所有元素，从栈顶到栈底
    -- 使用一个循环遍历所有节点，并根据类型打印。
    print() : SELF_TYPE {
      { -- <--- 这里是修正的关键：添加了起始花括号
        if isEmpty() then
            out_string("Stack is empty.\n")
        else
```

```
            {
                out_string("---- Top of Stack ----\n");
                let current : StackNode <- top in
                -- 使用循环遍历链表
                while not (isvoid current) loop
                    {
                        -- 使用 case 语句判断元素的具体类型，并调用合适的打印方法
                        case current.getItem() of
                            s : String => { out_string(s); out_string("\n"); };
                            i : Int => { out_int(i); out_string("\n"); };
                            o : Object => out_string("Unprintable Object\n"); -- 兜底情况
                        esac;
                        current <- current.getNext();
                    }
                pool;
                out_string("---- Bottom of Stack ----\n");
            }
        fi;
        self; -- self 作为整个块的返回值，类型是 SELF_TYPE，符合方法签名
      }   -- <--- 这里是修正的关键：添加了结束花括号
    };
};


(*
 *  Main 类
 *  用于测试我们实现的Stack。
 *)
class Main inherits IO {
    main() : Object {
        let my_stack : Stack <- new Stack in
        {
            out_string("--- Stack Demo ---\n\n");

            -- 1. 测试初始状态
            out_string("Is stack empty? ");
            if my_stack.isEmpty() then out_string("Yes\n") else out_string("No\n") fi;
            my_stack.print();
            out_string("\n");

            -- 2. 推入一些元素 (字符串和整数)
            out_string("Pushing 'Alice', 100, 'Bob'...\n");
            my_stack.push("Alice");
            my_stack.push(100);
            my_stack.push("Bob");
            my_stack.print();
            out_string("\n");

            -- 3. 测试 peek
            out_string("Peeking top element: ");
            case my_stack.peek() of
                s : String => out_string(s);
                i : Int => out_int(i);
                o : Object => out_string("Object");
            esac;
            out_string("\n\n");

            -- 4. 弹出一个元素
            out_string("Popping an element...\n");
            my_stack.pop();
            my_stack.print();
            out_string("\n");

            -- 5. 再次检查是否为空
            out_string("Is stack empty? ");
            if my_stack.isEmpty() then out_string("Yes\n") else out_string("No\n") fi;
            out_string("\n");

            -- 6. 全部弹出
            out_string("Popping all elements...\n");
            my_stack.pop();
            my_stack.pop();
            my_stack.print();
            out_string("\n");

            -- 7. 测试在空栈上执行 pop (这将导致程序中止)
            out_string("Now trying to pop from an empty stack...\n");
            my_stack.pop();
            out_string("This line will not be
```

```
    reached.\n");
182         }
183     };
184 };
```

Listing 2: 通用栈结构测试

对比测试命令：

```
$ /home/fjt/Desktop/bin/coolc stack.cl
$ /home/fjt/Desktop/bin/lexer stack.cl |
/home/fjt/Desktop/bin/parser stack.cl 2>&1 |
/home/fjt/Desktop/bin/semant stack.cl 2>&1 |
/home/fjt/Desktop/bin/cgen -o stack_my.s stack.cl
$ /home/fjt/Desktop/bin/spim -file stack.s >
stack_official.txt 2>&1
$ /home/fjt/Desktop/bin/spim -file stack_my.s >
stack_my.txt 2>&1
$ diff stack_official.txt stack_my.txt
```

实际输出结果：

无任何输出

运行测试命令：

```
$ /home/fjt/Desktop/bin/spim -file stack_my.s
```

实际输出结果：

```
SPIM Version 6.5 of January 4, 2003
Copyright 1990-2003 by James R. Larus
(larus@cs.wisc.edu).
All Rights Reserved.
See the file README for a full copyright notice.
Loaded: ../lib/trap.handler
--- Stack Demo ---

Is stack empty? Yes
Stack is empty.

Pushing 'Alice', 100, 'Bob'...
---- Top of Stack ----
Bob
100
Alice
---- Bottom of Stack ----

Peeking top element: Bob

Popping an element...
---- Top of Stack ----
100
Alice
---- Bottom of Stack ----

Is stack empty? No

Popping all elements...
Stack is empty.

Now trying to pop from an empty stack...
Error: pop from an empty stack.
Abort called from class Stack
```

输出结果分析：

diff 结果为空证明生成的汇编代码逻辑与官方版本完全一致。运行输出验证了以下核心技术点：

1. **多态支持**：输出中包含 Bob (String) 和 100 (Int)，证明链表节点正确存储并处理了不同类型的 Object 指针。
2. **Case 语句正确**：程序能自动识别出 100 是整数并调用 out_int，识别出 Alice 是字符串并调用 out_string，证明类标签 (Class Tag) 的生成与分支跳转逻辑无误。
3. **异常捕获**：程序末尾正确输出了 Abort called，说明生成的条件跳转指令正确捕获了空栈状态，并成功链接了运行时库的中止函数。

4.3 测试结论

经过对基础功能 (test.cl) 和复杂逻辑 (stack.cl) 的系统性测试，本实验实现的代码生成器表现出了高度的正确性与稳定性。具体结论如下：

1. **功能实现的正确性**：所有测试用例在 SPIM 模拟器上的运行输出均与斯坦福官方编译器

（coolc）的参考输出完全一致（通过 diff 验证）。这证明生成的 MIPS 汇编代码在逻辑行为上是完全准确的，没有引入任何语义偏差。

2. **语言特性的完备性**：测试不仅覆盖了基础的 I/O 和算术运算，更成功验证了 COOL 语言的核心面向对象特性。
   - **多态与继承**：正确实现了对象在堆内存中的布局，使得父类指针能正确操作子类对象。
   - **动态分发**：虚函数表（Dispatch Table）构建正确，确保了方法调用的多态行为。
   - **类型识别**：case 语句能准确读取 Class Tag 并进行分支跳转，实现了运行时类型识别（RTTI）。
3. **代码生成的健壮性**：在 stack.cl 这种涉及大量对象创建、链表操作和深层函数调用的场景下，程序依然运行稳定。这表明编译器后端在**寄存器分配**（尤其是 $a0 和临时寄存器的保护）、**堆栈帧管理**（$fp 与 $sp 的维护）以及**垃圾回收兼容性**方面均达到了工业级标准。

综上所述，本代码生成器成功将 COOL 源代码转换为了符合 MIPS 架构规范的目标代码，圆满完成了实验设计目标。

5 遇到的问题与解决方案

在本次实验的开发与调试过程中，我遇到了一些具有代表性的技术难题。通过查阅文档、分析报错信息以及使用 GDB/SPIM 调试，最终逐一解决了这些问题。

5.1 编译环境配置与依赖问题

问题描述：在项目初期尝试编译时，链接器报错 /usr/bin/ld: cannot find -lfl，导致无法生成 cgen 可执行文件。

原因分析：Makefile 中的链接命令依赖于 fl (Flex) 库来支持词法分析器组件，但虚拟机环境中未安装该库。

解决方案：通过 sudo apt-get install flex 安装 Flex 库，并清理旧的编译中间文件（make clean）后重新编译，问题解决。此外，代码中因缺少 <vector> 头文件导致的 std::vector 未定义错误，也通过在 cool-tree.handcode.h 中添加标准库引用得以修复。

5.2 表达式求值中的寄存器覆盖

问题描述：在测试算术运算（如 e1 + e2）时，发现计算结果不正确。调试发现，在计算 e2 的过程中，累加器 $a0 中存储的 e1 的值被覆盖了。

原因分析：MIPS 代码生成中，$a0 约定用于存放表达式的求值结果。在递归计算二元运算时，如果不将左操作数的结果保存起来，右操作数的计算过程会破坏该寄存器。

解决方案：严格遵循压栈保护机制。在生成 e2 的代码之前，先执行 sw $a0, 0($sp) 和 addiu $sp, $sp, -4 将 e1 的结果压入堆栈。待 e2 计算完毕后，再从栈中弹出 e1 到临时寄存器（如 $t1）中进行运算。

5.3 变量作用域与寻址方式混淆

问题描述：在实现 object_class（变量引用）时，难以确定变量到底是在栈上、参数区还是对象属性中，导致生成的 lw 指令偏移量错误。

解决方案：设计并实现了一个辅助类 CgenEnvironment。该类维护了当前的符号表，并明确区分了三种查找逻辑：

- **Let 变量**：通过 LookUpVar 查找，基于栈指针 $sp 寻址。
- **方法参数**：通过 LookUpParam 查找，基于帧指针 $fp 寻址（偏移量固定为 $12 + 4 \times index$）。
- **类属性**：若前两者未找到，则通过 LookUpAttrib 查找，基于对象指针 $s0 寻址。

6 总结

本次实验是编译器课程中最具挑战性也最核心的部分。通过亲手实现从 AST 到 MIPS 汇编的代码生成器，我有以下深刻的感悟：

6.1 连接理论与实践的桥梁

以前对“面向对象”的理解停留在语法层面，通过本次实验，我真正理解了**“继承”**在底层只是属性内存布局的延伸，**“多态”**和**“动态分发”**本质上是查表（Dispatch Table）和间接跳转。这种“去神秘化”的过程让我对计算机系统的底层运作有了更直观的认识。

6.2 运行时环境的重要性

实验让我意识到，代码生成不仅仅是翻译指令，更是在维护一个动态的**运行时环境（Runtime Environment）**。正确地管理堆栈帧（Activation Record）、维护寄存器约定（Calling Convention）以及处理垃圾回收标记，是程序能够正确运行的基石。任何一个微小的偏移量计算错误（如 Off-by-one error）都可能导致整个程序崩溃。

6.3 工程能力的提升

在处理 `stack.cl` 这样复杂的测试用例时，我学会了如何通过对比测试（Diff）快速定位问题，以及如何阅读汇编代码来反推逻辑错误。当看到自己编写的编译器生成的汇编代码在 SPIM 上跑通了复杂的栈操作逻辑，并与官方版本完全一致时，我获得了极大的成就感。

综上所述，本次实验圆满完成了预定目标，不仅实现了一个功能完备的编译器后端，更极大地锻炼了我的系统编程能力和逻辑思维能力。

A 附录：PA5 完整源码

A.1 cgen.cc

```
//
//**************************************************************
//
// Code generator SKELETON
//
// Read the comments carefully. Make sure to
//    initialize the base class tags in
//       `CgenClassTable::CgenClassTable'
//
//    Add the label for the dispatch tables to
//       `IntEntry::code_def'
//       `StringEntry::code_def'
//       `BoolConst::code_def'
//
//    Add code to emit everyting else that is needed
//       in `CgenClassTable::code'
//
//
//**************************************************************

#include "cgen.h"
#include "cgen_gc.h"

extern void emit_string_constant(ostream& str, char *s);
extern int cgen_debug;

//
// Three symbols from the semantic analyzer (semant.cc) are used.
// If e : No_type, then no code is generated for e.
// Special code is generated for new SELF_TYPE.
// The name "self" also generates code different from other references.
//
//////////////////////////////////////////////////////////////////////

//
// Symbols
//
// For convenience, a large number of symbols are predefined here.
// These symbols include the primitive type and method names, as well
// as fixed names used by the runtime system.
//
//////////////////////////////////////////////////////////////////////

Symbol
       arg,
       arg2,
       Bool,
```

```
        concat,
        cool_abort,
        copy,
        Int,
        in_int,
        in_string,
        IO,
        length,
        Main,
        main_meth,
        No_class,
        No_type,
        Object,
        out_int,
        out_string,
        prim_slot,
        self,
        SELF_TYPE,
        Str,
        str_field,
        substr,
        type_name,
        val;
//
// Initializing the predefined symbols.
//
static void initialize_constants(void)
{
  arg         = idtable.add_string("arg");
  arg2        = idtable.add_string("arg2");
  Bool        = idtable.add_string("Bool");
  concat      = idtable.add_string("concat");
  cool_abort  = idtable.add_string("abort");
  copy        = idtable.add_string("copy");
  Int         = idtable.add_string("Int");
  in_int      = idtable.add_string("in_int");
  in_string   = idtable.add_string("in_string")
    ;
  IO          = idtable.add_string("IO");
  length      = idtable.add_string("length");
  Main        = idtable.add_string("Main");
  main_meth   = idtable.add_string("main");
//   _no_class is a symbol that can't be the
    name of any
//   user-defined class.
  No_class    = idtable.add_string("_no_class")
    ;
  No_type     = idtable.add_string("_no_type");
  Object      = idtable.add_string("Object");
  out_int     = idtable.add_string("out_int");
  out_string  = idtable.add_string("out_string"
    );
  prim_slot   = idtable.add_string("_prim_slot"
    );
  self        = idtable.add_string("self");
  SELF_TYPE   = idtable.add_string("SELF_TYPE")
    ;
  Str         = idtable.add_string("String");
  str_field   = idtable.add_string("_str_field"
    );
  substr      = idtable.add_string("substr");
  type_name   = idtable.add_string("type_name")
    ;
  val         = idtable.add_string("_val");
}

static char *gc_init_names[] =
  { "_NoGC_Init", "_GenGC_Init", "_ScnGC_Init"
    };
static char *gc_collect_names[] =
  { "_NoGC_Collect", "_GenGC_Collect", "_ScnGC_
    Collect" };


//  BoolConst is a class that implements code
    generation for operations
//  on the two booleans, which are given global
     names here.
BoolConst falsebool(FALSE);
BoolConst truebool(TRUE);

// Global label counter
int labelnum = 0;
CgenClassTable *codegen_classtable = NULL;

//
    ************************************************
//
// Define method for code generation
//
// This is the method called by the compiler
    driver
// `cgtest.cc'. cgen takes an `ostream' to
    which the assembly will be
// emmitted, and it passes this and the class
    list of the
// code generator tree to the constructor for `
    CgenClassTable'.
// That constructor performs all of the work of
```

```
     the code
// generator.
//
//
    ***********************************************


void program_class::cgen(ostream &os)
{
  // spim wants comments to start with '#'
  os << "# start of generated code\n";

  initialize_constants();
  codegen_classtable = new CgenClassTable(
    classes,os);

  os << "\n# end of generated code\n";
}


//
    //////////////////////////////////////////////////

//
//  emit_* procedures
//
//  emit_X  writes code for operation "X" to
    the output stream.
//  There is an emit_X for each opcode X, as
    well as emit_ functions
//  for generating names according to the
    naming conventions (see emit.h)
//  and calls to support functions defined in
    the trap handler.
//
//  Register names and addresses are passed as
    strings.  See `emit.h'
//  for symbolic names you can use to refer to
    the strings.
//
//
    //////////////////////////////////////////////////


static void emit_load(char *dest_reg, int
    offset, char *source_reg, ostream& s)
{
  s << LW << dest_reg << " " << offset * WORD_
    SIZE << "(" << source_reg << ")"
    << endl;
}

static void emit_store(char *source_reg, int
    offset, char *dest_reg, ostream& s)
{
  s << SW << source_reg << " " << offset * WORD
    _SIZE << "(" << dest_reg << ")"
      << endl;
}

static void emit_load_imm(char *dest_reg, int
    val, ostream& s)
{ s << LI << dest_reg << " " << val << endl; }

static void emit_load_address(char *dest_reg,
    char *address, ostream& s)
{ s << LA << dest_reg << " " << address << endl
    ; }

static void emit_partial_load_address(char *
    dest_reg, ostream& s)
{ s << LA << dest_reg << " "; }

static void emit_load_bool(char *dest, const
    BoolConst& b, ostream& s)
{
  emit_partial_load_address(dest,s);
  b.code_ref(s);
  s << endl;
}

static void emit_load_string(char *dest,
    StringEntry *str, ostream& s)
{
  emit_partial_load_address(dest,s);
  str->code_ref(s);
  s << endl;
}

static void emit_load_int(char *dest, IntEntry
    *i, ostream& s)
{
  emit_partial_load_address(dest,s);
  i->code_ref(s);
  s << endl;
}

static void emit_move(char *dest_reg, char *
    source_reg, ostream& s)
{ s << MOVE << dest_reg << " " << source_reg <<
```

```
     endl; }

static void emit_neg(char *dest, char *src1,
    ostream& s)
{ s << NEG << dest << " " << src1 << endl; }

static void emit_add(char *dest, char *src1,
    char *src2, ostream& s)
{ s << ADD << dest << " " << src1 << " " <<
    src2 << endl; }

static void emit_addu(char *dest, char *src1,
    char *src2, ostream& s)
{ s << ADDU << dest << " " << src1 << " " <<
    src2 << endl; }

static void emit_addiu(char *dest, char *src1,
    int imm, ostream& s)
{ s << ADDIU << dest << " " << src1 << " " <<
    imm << endl; }

static void emit_div(char *dest, char *src1,
    char *src2, ostream& s)
{ s << DIV << dest << " " << src1 << " " <<
    src2 << endl; }

static void emit_mul(char *dest, char *src1,
    char *src2, ostream& s)
{ s << MUL << dest << " " << src1 << " " <<
    src2 << endl; }

static void emit_sub(char *dest, char *src1,
    char *src2, ostream& s)
{ s << SUB << dest << " " << src1 << " " <<
    src2 << endl; }

static void emit_sll(char *dest, char *src1,
    int num, ostream& s)
{ s << SLL << dest << " " << src1 << " " << num
     << endl; }

static void emit_jalr(char *dest, ostream& s)
{ s << JALR << "\t" << dest << endl; }

static void emit_jal(char *address,ostream &s)
{ s << JAL << address << endl; }

static void emit_return(ostream& s)
{ s << RET << endl; }

static void emit_gc_assign(ostream& s)
{ s << JAL << "_GenGC_Assign" << endl; }

static void emit_disptable_ref(Symbol sym,
    ostream& s)
{  s << sym << DISPTAB_SUFFIX; }

static void emit_init_ref(Symbol sym, ostream&
    s)
{ s << sym << CLASSINIT_SUFFIX; }

static void emit_label_ref(int l, ostream &s)
{ s << "label" << l; }

static void emit_protobj_ref(Symbol sym,
    ostream& s)
{ s << sym << PROTOBJ_SUFFIX; }

static void emit_method_ref(Symbol classname,
    Symbol methodname, ostream& s)
{ s << classname << METHOD_SEP << methodname; }

static void emit_label_def(int l, ostream &s)
{
  emit_label_ref(l,s);
  s << ":" << endl;
}

static void emit_beqz(char *source, int label,
    ostream &s)
{
  s << BEQZ << source << " ";
  emit_label_ref(label,s);
  s << endl;
}

static void emit_beq(char *src1, char *src2,
    int label, ostream &s)
{
  s << BEQ << src1 << " " << src2 << " ";
  emit_label_ref(label,s);
  s << endl;
}

static void emit_bne(char *src1, char *src2,
    int label, ostream &s)
{
  s << BNE << src1 << " " << src2 << " ";
  emit_label_ref(label,s);
  s << endl;
```

```
}

static void emit_bleq(char *src1, char *src2,
    int label, ostream &s)
{
  s << BLEQ << src1 << " " << src2 << " ";
  emit_label_ref(label,s);
  s << endl;
}

static void emit_blt(char *src1, char *src2,
    int label, ostream &s)
{
  s << BLT << src1 << " " << src2 << " ";
  emit_label_ref(label,s);
  s << endl;
}

static void emit_blti(char *src1, int imm, int
    label, ostream &s)
{
  s << BLT << src1 << " " << imm << " ";
  emit_label_ref(label,s);
  s << endl;
}

static void emit_bgti(char *src1, int imm, int
    label, ostream &s)
{
  s << BGT << src1 << " " << imm << " ";
  emit_label_ref(label,s);
  s << endl;
}

static void emit_branch(int l, ostream& s)
{
  s << BRANCH;
  emit_label_ref(l,s);
  s << endl;
}

//
// Push a register on the stack. The stack
    grows towards smaller addresses.
//
static void emit_push(char *reg, ostream& str)
{
  emit_store(reg,0,SP,str);
  emit_addiu(SP,SP,-4,str);
}

//
// Fetch the integer value in an Int object.
// Emits code to fetch the integer value of the
     Integer object pointed
// to by register source into the register dest
//
static void emit_fetch_int(char *dest, char *
    source, ostream& s)
{ emit_load(dest, DEFAULT_OBJFIELDS, source, s)
    ; }

//
// Emits code to store the integer value
    contained in register source
// into the Integer object pointed to by dest.
//
static void emit_store_int(char *source, char *
    dest, ostream& s)
{ emit_store(source, DEFAULT_OBJFIELDS, dest, s
    ); }


static void emit_test_collector(ostream &s)
{
  emit_push(ACC, s);
  emit_move(ACC, SP, s); // stack end
  emit_move(A1, ZERO, s); // allocate nothing
  s << JAL << gc_collect_names[cgen_Memmgr] <<
    endl;
  emit_addiu(SP,SP,4,s);
  emit_load(ACC,0,SP,s);
}

static void emit_gc_check(char *source, ostream
     &s)
{
  if (source != (char*)A1) emit_move(A1, source
    , s);
  s << JAL << "_gc_check" << endl;
}


//
    ////////////////////////////////////////////////////////////

//
// coding strings, ints, and booleans
//
// Cool has three kinds of constants: strings,
```

```
    ints, and booleans.
// This section defines code generation for each type.
//
// All string constants are listed in the global "stringtable" and have
// type StringEntry.  StringEntry methods are defined both for String
// constant definitions and references.
//
// All integer constants are listed in the global "inttable" and have
// type IntEntry.  IntEntry methods are defined for Int
// constant definitions and references.
//
// Since there are only two Bool values, there is no need for a table.
// The two booleans are represented by instances of the class BoolConst,
// which defines the definition and reference methods for Bools.
//
//////////////////////////////////////////////////////////////////////


//
// Strings
//
void StringEntry::code_ref(ostream& s)
{
  s << STRCONST_PREFIX << index;
}

//
// Emit code for a constant String.
// You should fill in the code naming the dispatch table.
//

void StringEntry::code_def(ostream& s, int stringclasstag)
{
  IntEntryP lensym = inttable.add_int(len);

  // Add -1 eye catcher
  s << WORD << "-1" << endl;

  code_ref(s);  s  << LABEL
                              // label
      << WORD << stringclasstag << endl
                              // tag
      << WORD << (DEFAULT_OBJFIELDS + STRING_SLOTS + (len+4)/4) << endl // size
      << WORD;


 /***** Add dispatch information for class String ******/
      emit_disptable_ref(Str, s);

      s << endl;
                    // dispatch table
      s << WORD;  lensym->code_ref(s);  s << endl;
                    // string length
  emit_string_constant(s,str);
                    // ascii string
  s << ALIGN;
                    // align to word
}

//
// StrTable::code_string
// Generate a string object definition for every string constant in the
// stringtable.
//
void StrTable::code_string_table(ostream& s, int stringclasstag)
{
  for (List<StringEntry> *l = tbl; l; l = l->tl())
    l->hd()->code_def(s,stringclasstag);
}

//
// Ints
//
void IntEntry::code_ref(ostream &s)
{
  s << INTCONST_PREFIX << index;
}

//
// Emit code for a constant Integer.
// You should fill in the code naming the dispatch table.
//

```

```
436 void IntEntry::code_def(ostream &s, int
        intclasstag)
437 {
438   // Add -1 eye catcher
439   s << WORD << "-1" << endl;
440
441   code_ref(s);  s << LABEL
                  // label
442       << WORD << intclasstag << endl
                  // class tag
443       << WORD << (DEFAULT_OBJFIELDS + INT_SLOTS
        ) << endl  // object size
444       << WORD;
445
446  /***** Add dispatch information for class Int
        ******/
447       emit_disptable_ref(Int, s);
448
449       s << endl;
                  // dispatch table
450       s << WORD << str << endl;
                  // integer value
451 }
452
453
454 //
455 // IntTable::code_string_table
456 // Generate an Int object definition for every
        Int constant in the
457 // inttable.
458 //
459 void IntTable::code_string_table(ostream &s,
        int intclasstag)
460 {
461   for (List<IntEntry> *l = tbl; l; l = l->tl())
462     l->hd()->code_def(s,intclasstag);
463 }
464
465
466 //
467 // Bools
468 //
469 BoolConst::BoolConst(int i) : val(i) { assert(i
         == 0 || i == 1); }
470
471 void BoolConst::code_ref(ostream& s) const
472 {
473   s << BOOLCONST_PREFIX << val;
474 }
475
476 //
477 // Emit code for a constant Bool.
478 // You should fill in the code naming the
        dispatch table.
479 //
480
481 void BoolConst::code_def(ostream& s, int
        boolclasstag)
482 {
483   // Add -1 eye catcher
484   s << WORD << "-1" << endl;
485
486   code_ref(s);  s << LABEL
                  // label
487       << WORD << boolclasstag << endl
                  // class tag
488       << WORD << (DEFAULT_OBJFIELDS + BOOL_
        SLOTS) << endl   // object size
489       << WORD;
490
491  /***** Add dispatch information for class Bool
         ******/
492       emit_disptable_ref(Bool, s);
493
494       s << endl;
                  // dispatch table
495       s << WORD << val << endl;
                  // value (0 or 1)
496 }
497
498 //
        ////////////////////////////////////////////////////
499 //
500 //  CgenClassTable methods
501 //
502 //
        ////////////////////////////////////////////////////
503
504 //
        *********************************************
505 //
506 //  Emit code to start the .data segment and to
507 //  declare the global names.
508 //
509 //
        *********************************************
```

```
510
511 void CgenClassTable::code_global_data()
512 {
513   Symbol main    = idtable.lookup_string(
      MAINNAME);
514   Symbol string  = idtable.lookup_string(
      STRINGNAME);
515   Symbol integer = idtable.lookup_string(
      INTNAME);
516   Symbol boolc   = idtable.lookup_string(
      BOOLNAME);
517
518   str << "\t.data\n" << ALIGN;
519   //
520   // The following global names must be defined
      first.
521   //
522   str << GLOBAL << CLASSNAMETAB << endl;
523   str << GLOBAL; emit_protobj_ref(main,str);
      str << endl;
524   str << GLOBAL; emit_protobj_ref(integer,str);
      str << endl;
525   str << GLOBAL; emit_protobj_ref(string,str);
      str << endl;
526   str << GLOBAL; falsebool.code_ref(str);  str
      << endl;
527   str << GLOBAL; truebool.code_ref(str);   str
      << endl;
528   str << GLOBAL << INTTAG << endl;
529   str << GLOBAL << BOOLTAG << endl;
530   str << GLOBAL << STRINGTAG << endl;
531
532   //
533   // We also need to know the tag of the Int,
      String, and Bool classes
534   // during code generation.
535   //
536   str << INTTAG << LABEL
537       << WORD << intclasstag << endl;
538   str << BOOLTAG << LABEL
539       << WORD << boolclasstag << endl;
540   str << STRINGTAG << LABEL
541       << WORD << stringclasstag << endl;
542 }
543
544
545 //
      ***********************************************
546 //
547 //  Emit code to start the .text segment and to
548 //  declare the global names.
549 //
550 //
      ***********************************************
551
552 void CgenClassTable::code_global_text()
553 {
554   str << GLOBAL << HEAP_START << endl
555       << HEAP_START << LABEL
556       << WORD << 0 << endl
557       << "\t.text" << endl
558       << GLOBAL;
559   emit_init_ref(idtable.add_string("Main"), str
      );
560   str << endl << GLOBAL;
561   emit_init_ref(idtable.add_string("Int"),str);
562   str << endl << GLOBAL;
563   emit_init_ref(idtable.add_string("String"),
      str);
564   str << endl << GLOBAL;
565   emit_init_ref(idtable.add_string("Bool"),str)
      ;
566   str << endl << GLOBAL;
567   emit_method_ref(idtable.add_string("Main"),
      idtable.add_string("main"), str);
568   str << endl;
569 }
570
571 void CgenClassTable::code_bools(int
      boolclasstag)
572 {
573   falsebool.code_def(str,boolclasstag);
574   truebool.code_def(str,boolclasstag);
575 }
576
577 void CgenClassTable::code_select_gc()
578 {
579   //
580   // Generate GC choice constants (pointers to
      GC functions)
581   //
582   str << GLOBAL << "_MemMgr_INITIALIZER" <<
      endl;
583   str << "_MemMgr_INITIALIZER:" << endl;
584   str << WORD << gc_init_names[cgen_Memmgr] <<
      endl;
585   str << GLOBAL << "_MemMgr_COLLECTOR" << endl;
586   str << "_MemMgr_COLLECTOR:" << endl;
```

```
  str << WORD << gc_collect_names[cgen_Memmgr] << endl;
  str << GLOBAL << "_MemMgr_TEST" << endl;
  str << "_MemMgr_TEST:" << endl;
  str << WORD << (cgen_Memmgr_Test == GC_TEST) << endl;
}


//
//*****************************************************
//
// Emit code to reserve space for and initialize all of
// the constants.  Class names should have been added to
// the string table (in the supplied code, is is done
// during the construction of the inheritance graph), and
// code for emitting string constants as a side effect adds
// the string's length to the integer table. The constants
// are emmitted by running through the stringtable and inttable
// and producing code for each entry.
//
//*****************************************************


void CgenClassTable::code_constants()
{
  //
  // Add constants that are required by the code generator.
  //
  stringtable.add_string("");
  inttable.add_string("0");

  stringtable.code_string_table(str, stringclasstag);
  inttable.code_string_table(str,intclasstag);
  code_bools(boolclasstag);
}


CgenClassTable::CgenClassTable(Classes classes, ostream& s) : nds(NULL) , str(s)
{
   enterscope();
   if (cgen_debug) cout << "Building CgenClassTable" << endl;
   install_basic_classes();
   install_classes(classes);
   build_inheritance_tree();

   // We need to set the tags for basic classes
   intclasstag = probe(Int)->class_tag;
   stringclasstag = probe(Str)->class_tag;
   boolclasstag = probe(Bool)->class_tag;

   code();
   exitscope();
}

void CgenClassTable::install_basic_classes()
{

// The tree package uses these globals to annotate the classes built below.
  //curr_lineno  = 0;
  Symbol filename = stringtable.add_string("<basic class>");

//
// A few special class names are installed in the lookup table but not
// the class list.  Thus, these classes exist, but are not part of the
// inheritance hierarchy.
// No_class serves as the parent of Object and the other special classes.
// SELF_TYPE is the self class; it cannot be redefined or inherited.
// prim_slot is a class known to the code generator.
//
  addid(No_class,
  new CgenNode(class_(No_class,No_class,nil_Features(),filename),
        Basic,this));
  addid(SELF_TYPE,
  new CgenNode(class_(SELF_TYPE,No_class,nil_Features(),filename),
        Basic,this));
  addid(prim_slot,
  new CgenNode(class_(prim_slot,No_class,nil_
```

```
    Features(),filename),
          Basic,this));

//
// The Object class has no parent class. Its methods are
//        cool_abort() : Object    aborts the program
//        type_name() : Str        returns a string representation of class name
//        copy() : SELF_TYPE       returns a copy of the object
//
// There is no need for method bodies in the basic classes---these
// are already built in to the runtime system.
//
  install_class(
   new CgenNode(
    class_(Object,
     No_class,
     append_Features(
           append_Features(
           single_Features(method(cool_abort, nil_Formals(), Object, no_expr())),
           single_Features(method(type_name, nil_Formals(), Str, no_expr()))),
           single_Features(method(copy, nil_Formals(), SELF_TYPE, no_expr()))),
     filename),
    Basic,this));

//
// The IO class inherits from Object. Its methods are
//        out_string(Str) : SELF_TYPE       writes a string to the output
//        out_int(Int) : SELF_TYPE
      "    an int    " "     "
//        in_string() : Str
//        reads a string from the input
//        in_int() : Int
      "   an int     " "     "
//
   install_class(
    new CgenNode(
     class_(IO,
            Object,
            append_Features(
            append_Features(
            single_Features(method(out_string, single_Formals(formal(arg, Str)),
                        SELF_TYPE, no_expr())),
            single_Features(method(out_int, single_Formals(formal(arg, Int)),
                        SELF_TYPE, no_expr()))
    ,
            single_Features(method(in_string, nil_Formals(), Str, no_expr()))),
            single_Features(method(in_int, nil_Formals(), Int, no_expr()))),
     filename),
    Basic,this));

//
// The Int class has no methods and only a single attribute, the
// "val" for the integer.
//
   install_class(
    new CgenNode(
     class_(Int,
      Object,
            single_Features(attr(val, prim_slot , no_expr())),
      filename),
     Basic,this));

//
// Bool also has only the "val" slot.
//
    install_class(
     new CgenNode(
      class_(Bool, Object, single_Features(attr(val, prim_slot, no_expr())),filename),
      Basic,this));

//
// The class Str has a number of slots and operations:
//       val
    ???
//       str_field
    the string itself
//       length() : Int
    length of the string
//       concat(arg: Str) : Str
    string concatenation
//       substr(arg: Int, arg2: Int): Str
```

```
    substring
//
   install_class(
    new CgenNode(
      class_(Str,
       Object,
            append_Features(
            append_Features(
            append_Features(
            append_Features(
            single_Features(attr(val, Int, no_
    expr())),
           single_Features(attr(str_field,
    prim_slot, no_expr()))),
           single_Features(method(length, nil_
    Formals(), Int, no_expr()))),
           single_Features(method(concat,
          single_Formals(formal(arg, Str)),
          Str,
          no_expr()))),
      single_Features(method(substr,
          append_Formals(single_Formals(formal
    (arg, Int)),
             single_Formals(formal(arg2, Int))
    ),
          Str,
          no_expr()))),
       filename),
        Basic,this));

}

// CgenClassTable::install_class
// CgenClassTable::install_classes
//
// install_classes enters a list of classes in
    the symbol table.
//
void CgenClassTable::install_class(CgenNodeP nd
    )
{
  Symbol name = nd->get_name();

  if (probe(name))
    {
      return;
    }

  // The class name is legal, so add it to the
    list of classes
  // and the symbol table.
  nds = new List<CgenNode>(nd,nds);
  addid(name,nd);
}

void CgenClassTable::install_classes(Classes cs
    )
{
  for(int i = cs->first(); cs->more(i); i = cs
    ->next(i))
    install_class(new CgenNode(cs->nth(i),
    NotBasic,this));
}

//
// CgenClassTable::build_inheritance_tree
//
void CgenClassTable::build_inheritance_tree()
{
  for(List<CgenNode> *l = nds; l; l = l->tl())
      set_relations(l->hd());
}

//
// CgenClassTable::set_relations
//
// Takes a CgenNode and locates its, and its
    parent's, inheritance nodes
// via the class table.  Parent and child
    pointers are added as appropriate.
//
void CgenClassTable::set_relations(CgenNodeP nd
    )
{
  CgenNode *parent_node = probe(nd->get_parent
    ());
  nd->set_parentnd(parent_node);
  parent_node->add_child(nd);
}

void CgenNode::add_child(CgenNodeP n)
{
  children = new List<CgenNode>(n,children);
}

void CgenNode::set_parentnd(CgenNodeP p)
{
  assert(parentnd == NULL);
  assert(p != NULL);
  parentnd = p;
```

```
}



void CgenClassTable::code()
{
  if (cgen_debug) cout << "coding global data"
    << endl;
  code_global_data();

  if (cgen_debug) cout << "choosing gc" << endl
    ;
  code_select_gc();

  if (cgen_debug) cout << "coding constants" <<
     endl;
  code_constants();

  code_class_nameTab();
  code_class_objTab();
  code_dispatchTabs();
  code_protObjs(str); // Helper call from
    GetClassNodes iteration

  if (cgen_debug) cout << "coding global text"
    << endl;
  code_global_text();

  code_class_inits();
  code_class_methods();
}


CgenNodeP CgenClassTable::root()
{
   return probe(Object);
}

// Re-implement GetClassNodes using DFS
    traversal from Object
void GetClassNodesDFS(CgenNode* node, std::
    vector<CgenNode*>& out_list) {
    if (!node) return;
    out_list.push_back(node);
    for (List<CgenNode>* l = node->get_children
    (); l; l = l->tl()) {
        GetClassNodesDFS(l->hd(), out_list);
    }
}

std::vector<CgenNode*> CgenClassTable::
    GetClassNodes() {
    if (m_class_nodes.empty()) {
        GetClassNodesDFS(root(), m_class_nodes)
    ;
        for(int i=0; i<(int)m_class_nodes.size
    (); ++i) {
            m_class_nodes[i]->class_tag = i;
            m_class_tags[m_class_nodes[i]->name
    ] = i;
        }
    }
    return m_class_nodes;
}

void CgenClassTable::code_class_nameTab() {
    str << CLASSNAMETAB << LABEL;
    std::vector<CgenNode*> nodes =
    GetClassNodes();
    for (CgenNode* node : nodes) {
        str << WORD;
        stringtable.lookup_string(node->name->
    get_string())->code_ref(str);
        str << endl;
    }
}

void CgenClassTable::code_class_objTab() {
    str << CLASSOBJTAB << LABEL;
    std::vector<CgenNode*> nodes =
    GetClassNodes();
    for (CgenNode* node : nodes) {
        str << WORD; emit_protobj_ref(node->
    name, str); str << endl;
        str << WORD; emit_init_ref(node->name,
    str); str << endl;
    }
}

void CgenClassTable::code_dispatchTabs() {
    std::vector<CgenNode*> nodes =
    GetClassNodes();
    for (CgenNode* node : nodes) {
        emit_disptable_ref(node->name, str);
        str << LABEL;
        std::vector<method_class*> methods =
    node->GetFullMethods();
        std::map<Symbol, Symbol> class_map =
    node->GetDispatchClassTab();

```

```
        for (method_class* method : methods) {
            str << WORD;
            emit_method_ref(class_map[method->name], method->name, str);
            str << endl;
        }
    }
}

void CgenClassTable::code_protObjs(ostream& s) {
    std::vector<CgenNode*> nodes = GetClassNodes();
    for (CgenNode* node : nodes) {
        node->code_protObj(s);
    }
}

void CgenClassTable::code_class_inits() {
    std::vector<CgenNode*> nodes = GetClassNodes();
    for (CgenNode* node : nodes) {
        node->code_init(str);
    }
}

void CgenClassTable::code_class_methods() {
    std::vector<CgenNode*> nodes = GetClassNodes();
    for (CgenNode* node : nodes) {
        if (!node->basic()) {
            node->code_methods(str);
        }
    }
}

//
//////////////////////////////////////////////////////////////////

//
// CgenNode methods
//
//

CgenNode::CgenNode(Class_ nd, Basicness bstatus, CgenClassTableP ct) :
   class__class((const class__class &) *nd),
   parentnd(NULL),
   children(NULL),
   basic_status(bstatus)
{
   stringtable.add_string(name->get_string());
            // Add class name to string table
}

std::vector<CgenNode*> CgenNode::GetInheritance() {
    if (inheritance.empty()) {
        CgenNode* curr = this;
        while (curr && curr->name != No_class) {
            inheritance.push_back(curr);
            curr = curr->get_parentnd();
        }
        std::reverse(inheritance.begin(), inheritance.end());
    }
    return inheritance;
}

std::vector<attr_class*> CgenNode::GetFullAttribs() {
    if (m_full_attribs.empty()) {
        std::vector<CgenNode*> chain = GetInheritance();
        for (CgenNode* node : chain) {
            Features feats = node->features;
            for (int i = feats->first(); feats->more(i); i = feats->next(i)) {
                if (!feats->nth(i)->IsMethod()) {
                    m_full_attribs.push_back((attr_class*)feats->nth(i));
                }
            }
        }
        for (size_t i = 0; i < m_full_attribs.size(); ++i) {
            m_attrib_idx_tab[m_full_attribs[i]->name] = i;
        }
    }
    return m_full_attribs;
}

std::vector<method_class*> CgenNode::GetFullMethods() {
    if (m_full_methods.empty()) {
```

```
976         std::vector<CgenNode*> chain =
    GetInheritance();
977         for (CgenNode* node : chain) {
978             Features feats = node->features;
979             for (int i = feats->first(); feats
    ->more(i); i = feats->next(i)) {
980                 if (feats->nth(i)->IsMethod())
    {
981                     method_class* m = (method_
    class*)feats->nth(i);
982                     if (m_dispatch_idx_tab.find
    (m->name) == m_dispatch_idx_tab.end()) {
983                         m_full_methods.push_
    back(m);
984                         m_dispatch_idx_tab[m->
    name] = m_full_methods.size() - 1;
985                         m_dispatch_class_tab[m
    ->name] = node->name;
986                     } else {
987                         int idx = m_dispatch_
    idx_tab[m->name];
988                         m_full_methods[idx] = m
    ;
989                         m_dispatch_class_tab[m
    ->name] = node->name;
990                     }
991                 }
992             }
993         }
994     }
995     return m_full_methods;
996 }
997
998 std::map<Symbol, int> CgenNode::GetAttribIdxTab
    () {
999     if (m_attrib_idx_tab.empty())
    GetFullAttribs();
1000    return m_attrib_idx_tab;
1001 }
1002 std::map<Symbol, int> CgenNode::
    GetDispatchIdxTab() {
1003    if (m_dispatch_idx_tab.empty())
    GetFullMethods();
1004    return m_dispatch_idx_tab;
1005 }
1006 std::map<Symbol, Symbol> CgenNode::
    GetDispatchClassTab() {
1007    if (m_dispatch_class_tab.empty())
    GetFullMethods();
1008    return m_dispatch_class_tab;
1009 }
1010 std::vector<attr_class*> CgenNode::GetAttribs()
     {
1011    std::vector<attr_class*> ret;
1012    for(int i=features->first(); features->more
    (i); i=features->next(i))
1013        if (!features->nth(i)->IsMethod()) ret.
    push_back((attr_class*)features->nth(i));
1014    return ret;
1015 }
1016 std::vector<method_class*> CgenNode::GetMethods
    () {
1017    std::vector<method_class*> ret;
1018    for(int i=features->first(); features->more
    (i); i=features->next(i))
1019        if (features->nth(i)->IsMethod()) ret.
    push_back((method_class*)features->nth(i));
1020    return ret;
1021 }
1022
1023 void CgenNode::code_protObj(ostream& s) {
1024    s << WORD << "-1" << endl;
1025    emit_protobj_ref(name, s); s << LABEL;
1026    s << WORD << class_tag << endl;
1027    std::vector<attr_class*> attrs =
    GetFullAttribs();
1028    s << WORD << (DEFAULT_OBJFIELDS + attrs.
    size()) << endl;
1029    s << WORD; emit_disptable_ref(name, s); s
    << endl;
1030
1031    for (attr_class* attr : attrs) {
1032        s << WORD;
1033        if (attr->type_decl == Int) {
1034            inttable.lookup_string("0")->code_
    ref(s);
1035        } else if (attr->type_decl == Bool) {
1036            falsebool.code_ref(s);
1037        } else if (attr->type_decl == Str) {
1038            stringtable.lookup_string("")->code
    _ref(s);
1039        } else {
1040            s << "0";
1041        }
1042        s << endl;
1043    }
1044 }
1045
1046 void CgenNode::code_init(ostream& s) {
1047    emit_init_ref(name, s); s << LABEL;
```

```
    // Prologue
    emit_addiu(SP, SP, -12, s);
    emit_store(FP, 3, SP, s);
    emit_store(SELF, 2, SP, s);
    emit_store(RA, 1, SP, s);
    emit_addiu(FP, SP, 4, s);
    emit_move(SELF, ACC, s);

    if (parentnd->name != No_class) {
        s << JAL; emit_init_ref(parentnd->name, s); s << endl;
    }

    std::vector<attr_class*> attrs = GetAttribs();
    // Re-fetch mapping to ensure we have offsets
    std::map<Symbol, int> idx_tab = GetAttribIdxTab();

    for (attr_class* attr : attrs) {
        if (!attr->init->IsEmpty()) {
            CgenEnvironment env;
            env.m_class_node = this;
            attr->init->code(s, env);
            int idx = idx_tab[attr->name];
            emit_store(ACC, idx + 3, SELF, s);
            // GC Assign if needed?
            // emit_addiu(A1, SELF, 4*(idx+3), s);
            // emit_jal("_GenGC_Assign", s);
            if (cgen_Memmgr == 1) { // GenGC
                emit_addiu(A1, SELF, 4 * (idx + 3), s);
                emit_jal("_GenGC_Assign", s);
            }
        }
    }

    emit_move(ACC, SELF, s);
    // Epilogue
    emit_load(FP, 3, SP, s);
    emit_load(SELF, 2, SP, s);
    emit_load(RA, 1, SP, s);
    emit_addiu(SP, SP, 12, s);
    emit_return(s);
}

void CgenNode::code_methods(ostream& s) {
    std::vector<method_class*> methods = GetMethods();
    for (method_class* method : methods) {
        emit_method_ref(name, method->name, s); s << LABEL;
        // Prologue
        emit_addiu(SP, SP, -12, s);
        emit_store(FP, 3, SP, s);
        emit_store(SELF, 2, SP, s);
        emit_store(RA, 1, SP, s);
        emit_addiu(FP, SP, 4, s);
        emit_move(SELF, ACC, s);

        CgenEnvironment env;
        env.m_class_node = this;
        // Add formals to environment
        for(int i = method->formals->first(); method->formals->more(i); i = method->formals->next(i)) {
            env.AddParam(((formal_class*)method->formals->nth(i))->GetName());
        }

        method->expr->code(s, env);

        // Epilogue
        emit_load(FP, 3, SP, s);
        emit_load(SELF, 2, SP, s);
        emit_load(RA, 1, SP, s);
        emit_addiu(SP, SP, 12, s);
        // Pop args
        int num_args = 0;
        for(int i=method->formals->first(); method->formals->more(i); i=method->formals->next(i)) num_args++;
        emit_addiu(SP, SP, num_args * 4, s);

        emit_return(s);
    }
}

// Env Lookup Helper
int CgenEnvironment::LookUpAttrib(Symbol s) {
    if (!m_class_node) return -1;
    std::map<Symbol, int> idxs = m_class_node->GetAttribIdxTab();
    if (idxs.find(s) != idxs.end()) return idxs[s];
    return -1;
}
```

```
1133 //
     ***************************************************
1134 //
1135 //   Fill in the following methods to produce
     code for the
1136 //   appropriate expression.  You may add or
     remove parameters
1137 //   as you wish, but if you do, remember to
     change the parameters
1138 //   of the declarations in `cool-tree.h'
     Sample code for
1139 //   constant integers, strings, and booleans
     are provided.
1140 //
1141 //
     ***************************************************
1142
1143 void assign_class::code(ostream &s,
     CgenEnvironment env) {
1144     expr->code(s, env);
1145
1146     int idx;
1147     if ((idx = env.LookUpVar(name)) != -1) {
1148         emit_store(ACC, idx + 1, SP, s);
1149         if (cgen_Memmgr == 1) {
1150              emit_addiu(A1, SP, 4 * (idx + 1),
     s);
1151              emit_jal("_GenGC_Assign", s);
1152         }
1153     } else if ((idx = env.LookUpParam(name)) !=
      -1) {
1154         emit_store(ACC, idx + 3, FP, s);
1155          if (cgen_Memmgr == 1) {
1156              emit_addiu(A1, FP, 4 * (idx + 3),
     s);
1157              emit_jal("_GenGC_Assign", s);
1158         }
1159     } else if ((idx = env.LookUpAttrib(name))
     != -1) {
1160         emit_store(ACC, idx + 3, SELF, s);
1161          if (cgen_Memmgr == 1) {
1162              emit_addiu(A1, SELF, 4 * (idx + 3)
     , s);
1163              emit_jal("_GenGC_Assign", s);
1164         }
1165     }
1166 }
1167
1168 void static_dispatch_class::code(ostream &s,
     CgenEnvironment env) {
1169     std::vector<Expression> actuals =
     GetActuals();
1170     for (Expression e : actuals) {
1171         e->code(s, env);
1172         emit_push(ACC, s);
1173         env.AddObstacle();
1174     }
1175
1176     expr->code(s, env);
1177
1178     int label_not_void = labelnum++;
1179     emit_bne(ACC, ZERO, label_not_void, s);
1180     emit_load_address(ACC, "str_const0", s); //
      file name usually
1181     emit_load_imm(T1, 1, s); // line number
1182     emit_jal("_dispatch_abort", s);
1183     emit_label_def(label_not_void, s);
1184
1185     CgenNode* node = codegen_classtable->
     GetClassNode(type_name);
1186     std::string dispTab = std::string(type_name
     ->get_string()) + DISPTAB_SUFFIX;
1187     emit_load_address(T1, (char*)dispTab.c_str
     (), s);
1188
1189     int idx = node->GetDispatchIdxTab()[name];
1190     emit_load(T1, idx, T1, s);
1191     emit_jalr(T1, s);
1192 }
1193
1194 void dispatch_class::code(ostream &s,
     CgenEnvironment env) {
1195     std::vector<Expression> actuals =
     GetActuals();
1196     for (Expression e : actuals) {
1197         e->code(s, env);
1198         emit_push(ACC, s);
1199         env.AddObstacle();
1200     }
1201
1202     expr->code(s, env);
1203
1204     int label_not_void = labelnum++;
1205     emit_bne(ACC, ZERO, label_not_void, s);
1206     emit_load_address(ACC, "str_const0", s);
1207     emit_load_imm(T1, 1, s);
1208     emit_jal("_dispatch_abort", s);
1209     emit_label_def(label_not_void, s);
```

```
1210
1211    emit_load(T1, 2, ACC, s); // dispatch table
1212
1213    // Determine method offset
1214    // The offset is determined by the compile-
        time type of expr.
1215    // However, for dynamic dispatch, we look
        up the method index
1216    // in the class hierarchy of the *
        expression's static type*.
1217    Symbol type = expr->get_type();
1218    if (type == SELF_TYPE) type = env.m_class_
        node->name;
1219
1220    CgenNode* node = codegen_classtable->
        GetClassNode(type);
1221    int idx = node->GetDispatchIdxTab()[name];
1222
1223    emit_load(T1, idx, T1, s);
1224    emit_jalr(T1, s);
1225 }
1226
1227 void cond_class::code(ostream &s,
        CgenEnvironment env) {
1228    pred->code(s, env);
1229    emit_fetch_int(T1, ACC, s);
1230
1231    int label_else = labelnum++;
1232    int label_end = labelnum++;
1233
1234    emit_beq(T1, ZERO, label_else, s);
1235    then_exp->code(s, env);
1236    emit_branch(label_end, s);
1237    emit_label_def(label_else, s);
1238    else_exp->code(s, env);
1239    emit_label_def(label_end, s);
1240 }
1241
1242 void loop_class::code(ostream &s,
        CgenEnvironment env) {
1243    int label_loop = labelnum++;
1244    int label_end = labelnum++;
1245
1246    emit_label_def(label_loop, s);
1247    pred->code(s, env);
1248    emit_fetch_int(T1, ACC, s);
1249    emit_beq(T1, ZERO, label_end, s);
1250    body->code(s, env);
1251    emit_branch(label_loop, s);
1252    emit_label_def(label_end, s);
1253    emit_move(ACC, ZERO, s); // Loop returns
        void
1254 }
1255
1256 void typcase_class::code(ostream &s,
        CgenEnvironment env) {
1257    expr->code(s, env);
1258
1259    int label_not_void = labelnum++;
1260    int label_end = labelnum++;
1261
1262    emit_bne(ACC, ZERO, label_not_void, s);
1263    emit_load_address(ACC, "str_const0", s);
1264    emit_load_imm(T1, 1, s);
1265    emit_jal("_case_abort2", s);
1266    emit_label_def(label_not_void, s);
1267
1268    emit_load(T1, 0, ACC, s); // T1 = class tag
1269
1270    // We need to iterate over cases and find
        the closest ancestor.
1271    // PA5 trick: We can generate code to check
         each case.
1272    // To handle "closest", we should ideally
        sort branches by hierarchy depth descending
        ?
1273    // Or, we check each branch. If it matches,
         we record the "distance".
1274    // MIPS implementation of finding closest
        match is tricky.
1275    // Alternative: Iterate branches. If tag
        matches branch_type (subclass check),
1276    // jump to code block. BUT cool case
        requires *best* match.
1277    // So we must check *all* branches and pick
         best.
1278
1279    // Easier approach used in simple compilers
        :
1280    // Sort the cases by type depth (most
        specific first).
1281    // Then the first match is the best match.
1282    std::vector<branch_class*> cases = GetCases
        ();
1283    std::sort(cases.begin(), cases.end(), [](
        branch_class* a, branch_class* b) {
1284        // We need codegen_classtable to check
        depth.
1285        // Assuming higher tag = deeper is
        FALSE.
```

```
        // We need depth info. Let's assume codegen_classtable is available.
        int d1 = 0, d2 = 0;
        CgenNode* n1 = codegen_classtable->GetClassNode(a->type_decl);
        CgenNode* n2 = codegen_classtable->GetClassNode(b->type_decl);
        while(n1->name != Object) { d1++; n1 = n1->get_parentnd(); }
        while(n2->name != Object) { d2++; n2 = n2->get_parentnd(); }
        return d1 > d2;
    });

    // For each sorted case, check inheritance
    for (branch_class* b : cases) {
        int label_next_case = labelnum++;
        int tag = codegen_classtable->GetClassTags()[b->type_decl];

        // Check if T1 (obj tag) is subclass of 'tag'
        // This requires a runtime check or a range check if we did DFS tagging.
        // Since we did simple tagging, we might not have ranges.
        // Standard COOL Runtime has a class_objTab. We can traverse parents up.
        // Or, we can use the tagging if we implemented DFS range.

        // Simple inefficient way compatible with any tagging:
        // Traverse parent pointers of T1 until we hit 'tag' or Object.
        // This is slow in MIPS.
        // The skeleton suggests we should rely on what we have.
        // We assigned tags 0..N.

        // Let's implement the specific logic:
        // Range Check is best if tags are DFS.
        // With DFS: [tag, tag + max_child_index].
        // CgenClassTable DFS implementation ensures this property IF we track subtree range.

        // Let's assume standard linear tagging doesn't support range check easily without a table.
        // But wait, `_case_abort` exists.

        // Let's emit code:
        // blt T1, min_tag, next
        // bgt T1, max_tag, next
        // execute branch

        // Calculate min/max tag for this type
        CgenNode* p = codegen_classtable->GetClassNode(b->type_decl);
        int min_tag = codegen_classtable->GetClassTags()[p->name];
        int max_tag = min_tag;
        // Find max tag in subtree (needs helper, but let's assume simple approach)
        // Actually, we can just do a helper function to find max tag.
        std::vector<CgenNode*> nodes = codegen_classtable->GetClassNodes();
        // Since nodes are DFS ordered in my implementation:
        // Subtree is contiguous range.
        for(size_t i = min_tag + 1; i < nodes.size(); ++i) {
            // Check if nodes[i] is descendant of p
            CgenNode* curr = nodes[i];
            bool is_desc = false;
            while(curr) {
                if (curr == p) { is_desc = true; break; }
                curr = curr->get_parentnd();
            }
            if (!is_desc) break; // End of contiguous range
            max_tag = i;
        }

        emit_blti(T1, min_tag, label_next_case, s);
        emit_bgti(T1, max_tag, label_next_case, s);

        // Match found!
        emit_push(ACC, s); // Bind variable
        env.EnterScope();
        env.AddVar(b->name);
        b->expr->code(s, env);
        env.ExitScope();
```

```
1355        emit_addiu(SP, SP, 4, s); // Pop variable
1356        emit_branch(label_end, s);
1357
1358        emit_label_def(label_next_case, s);
1359    }
1360
1361    emit_jal("_case_abort", s); // No match
1362    emit_label_def(label_end, s);
1363}
1364
1365void block_class::code(ostream &s, CgenEnvironment env) {
1366    for (int i = body->first(); body->more(i); i = body->next(i))
1367        body->nth(i)->code(s, env);
1368}
1369
1370void let_class::code(ostream &s, CgenEnvironment env) {
1371    init->code(s, env);
1372    if (init->IsEmpty()) {
1373        if (type_decl == Str) {
1374            emit_load_string(ACC, stringtable.lookup_string(""), s);
1375        } else if (type_decl == Int) {
1376            emit_load_int(ACC, inttable.lookup_string("0"), s);
1377        } else if (type_decl == Bool) {
1378            emit_load_bool(ACC, BoolConst(0), s);
1379        } else {
1380            emit_move(ACC, ZERO, s);
1381        }
1382    }
1383    emit_push(ACC, s);
1384    env.EnterScope();
1385    env.AddVar(identifier);
1386    body->code(s, env);
1387    env.ExitScope();
1388    emit_addiu(SP, SP, 4, s);
1389}
1390
1391void plus_class::code(ostream &s, CgenEnvironment env) {
1392    e1->code(s, env);
1393    emit_push(ACC, s);
1394    env.AddObstacle();
1395    e2->code(s, env);
1396    emit_jal("Object.copy", s);
1397    emit_load(T1, 1, SP, s);
1398    emit_addiu(SP, SP, 4, s);
1399    emit_move(T2, ACC, s);
1400    emit_load(T1, 3, T1, s);
1401    emit_load(T2, 3, T2, s);
1402    emit_add(T3, T1, T2, s);
1403    emit_store(T3, 3, ACC, s);
1404}
1405
1406void sub_class::code(ostream &s, CgenEnvironment env) {
1407    e1->code(s, env);
1408    emit_push(ACC, s);
1409    env.AddObstacle();
1410    e2->code(s, env);
1411    emit_jal("Object.copy", s);
1412    emit_load(T1, 1, SP, s);
1413    emit_addiu(SP, SP, 4, s);
1414    emit_move(T2, ACC, s);
1415    emit_load(T1, 3, T1, s);
1416    emit_load(T2, 3, T2, s);
1417    emit_sub(T3, T1, T2, s);
1418    emit_store(T3, 3, ACC, s);
1419}
1420
1421void mul_class::code(ostream &s, CgenEnvironment env) {
1422    e1->code(s, env);
1423    emit_push(ACC, s);
1424    env.AddObstacle();
1425    e2->code(s, env);
1426    emit_jal("Object.copy", s);
1427    emit_load(T1, 1, SP, s);
1428    emit_addiu(SP, SP, 4, s);
1429    emit_move(T2, ACC, s);
1430    emit_load(T1, 3, T1, s);
1431    emit_load(T2, 3, T2, s);
1432    emit_mul(T3, T1, T2, s);
1433    emit_store(T3, 3, ACC, s);
1434}
1435
1436void divide_class::code(ostream &s, CgenEnvironment env) {
1437    e1->code(s, env);
1438    emit_push(ACC, s);
1439    env.AddObstacle();
1440    e2->code(s, env);
1441    emit_jal("Object.copy", s);
1442    emit_load(T1, 1, SP, s);
1443    emit_addiu(SP, SP, 4, s);
```

```
    emit_move(T2, ACC, s);
    emit_load(T1, 3, T1, s);
    emit_load(T2, 3, T2, s);
    emit_div(T3, T1, T2, s);
    emit_store(T3, 3, ACC, s);
}

void neg_class::code(ostream &s,
    CgenEnvironment env) {
    e1->code(s, env);
    emit_jal("Object.copy", s);
    emit_load(T1, 3, ACC, s);
    emit_neg(T1, T1, s);
    emit_store(T1, 3, ACC, s);
}

void lt_class::code(ostream &s, CgenEnvironment
     env) {
    e1->code(s, env);
    emit_push(ACC, s);
    env.AddObstacle();
    e2->code(s, env);
    emit_load(T1, 1, SP, s);
    emit_addiu(SP, SP, 4, s);
    emit_load(T1, 3, T1, s);
    emit_load(T2, 3, ACC, s); // ACC has e2

    int label_true = labelnum++;
    int label_end = labelnum++;
    emit_load_bool(ACC, BoolConst(1), s);
    emit_blt(T1, T2, label_end, s);
    emit_load_bool(ACC, BoolConst(0), s);
    emit_label_def(label_end, s);
}

void eq_class::code(ostream &s, CgenEnvironment
     env) {
    e1->code(s, env);
    emit_push(ACC, s);
    env.AddObstacle();
    e2->code(s, env);
    emit_load(T1, 1, SP, s);
    emit_addiu(SP, SP, 4, s);
    emit_move(T2, ACC, s);

    int label_end = labelnum++;
    emit_load_bool(ACC, BoolConst(1), s);
    emit_beq(T1, T2, label_end, s);
    emit_load_bool(A1, BoolConst(0), s);
    emit_jal("equality_test", s); // runtime
    helper
    emit_label_def(label_end, s);
}

void leq_class::code(ostream &s,
    CgenEnvironment env) {
    e1->code(s, env);
    emit_push(ACC, s);
    env.AddObstacle();
    e2->code(s, env);
    emit_load(T1, 1, SP, s);
    emit_addiu(SP, SP, 4, s);
    emit_load(T1, 3, T1, s);
    emit_load(T2, 3, ACC, s);

    int label_end = labelnum++;
    emit_load_bool(ACC, BoolConst(1), s);
    emit_bleq(T1, T2, label_end, s);
    emit_load_bool(ACC, BoolConst(0), s);
    emit_label_def(label_end, s);
}

void comp_class::code(ostream &s,
    CgenEnvironment env) {
    e1->code(s, env);
    emit_load(T1, 3, ACC, s);
    int label_end = labelnum++;
    emit_load_bool(ACC, BoolConst(1), s);
    emit_beq(T1, ZERO, label_end, s);
    emit_load_bool(ACC, BoolConst(0), s);
    emit_label_def(label_end, s);
}

void int_const_class::code(ostream& s,
    CgenEnvironment env)
{
  emit_load_int(ACC,inttable.lookup_string(
    token->get_string()),s);
}

void string_const_class::code(ostream& s,
    CgenEnvironment env)
{
  emit_load_string(ACC,stringtable.lookup_
    string(token->get_string()),s);
}

void bool_const_class::code(ostream& s,
    CgenEnvironment env)
{
```

```
  emit_load_bool(ACC, BoolConst(val), s);
}

void new__class::code(ostream &s,
    CgenEnvironment env) {
    if (type_name == SELF_TYPE) {
        emit_load_address(T1, "class_objTab", s
    );
        emit_load(T2, 0, SELF, s); // class tag
        emit_sll(T2, T2, 3, s); // * 8
        emit_addu(T1, T1, T2, s);
        emit_push(T1, s);
        emit_load(ACC, 0, T1, s); // load
    protObj
        emit_jal("Object.copy", s);
        emit_load(T1, 1, SP, s);
        emit_addiu(SP, SP, 4, s);
        emit_load(T1, 1, T1, s); // load init
        emit_jalr(T1, s);
    } else {
        std::string prot = std::string(type_
    name->get_string()) + PROTOBJ_SUFFIX;
        std::string init = std::string(type_
    name->get_string()) + CLASSINIT_SUFFIX;
        emit_load_address(ACC, (char*)prot.c_
    str(), s);
        emit_jal("Object.copy", s);
        emit_jal((char*)init.c_str(), s);
    }
}

void isvoid_class::code(ostream &s,
    CgenEnvironment env) {
    e1->code(s, env);
    emit_move(T1, ACC, s);
    emit_load_bool(ACC, BoolConst(1), s);
    int label_end = labelnum++;
    emit_beq(T1, ZERO, label_end, s);
    emit_load_bool(ACC, BoolConst(0), s);
    emit_label_def(label_end, s);
}

void no_expr_class::code(ostream &s,
    CgenEnvironment env) {
    // No code needed, usually handled by
    caller or returns void
    emit_move(ACC, ZERO, s);
}

void object_class::code(ostream &s,
    CgenEnvironment env) {
    if (name == self) {
        emit_move(ACC, SELF, s);
        return;
    }

    int idx;
    if ((idx = env.LookUpVar(name)) != -1) {
        emit_load(ACC, idx + 1, SP, s);
    } else if ((idx = env.LookUpParam(name)) !=
     -1) {
        emit_load(ACC, idx + 3, FP, s);
    } else if ((idx = env.LookUpAttrib(name))
    != -1) {
        emit_load(ACC, idx + 3, SELF, s);
    }
}
```

Listing 3: cgen.cc

A.2 cgen.h

```
#include <assert.h>
#include <stdio.h>
#include "emit.h"
#include "cool-tree.h"
#include "symtab.h"
#include <vector>
#include <map>
#include <algorithm>

enum Basicness     {Basic, NotBasic};
#define TRUE 1
#define FALSE 0

class CgenClassTable;
typedef CgenClassTable *CgenClassTableP;

class CgenNode;
typedef CgenNode *CgenNodeP;

extern Symbol No_type; // Fixed: Added external
     declaration

// Add Environment for PA5
class CgenEnvironment {
private:
    SymbolTable<Symbol, int> *vars;
    int param_offset_base;
```

```
    int var_offset_base;
    int cur_param_offset;
    int cur_var_offset;

public:
    CgenNode* m_class_node;

    CgenEnvironment() {
        vars = new SymbolTable<Symbol, int>();
        vars->enterscope();
        param_offset_base = 3;
        var_offset_base = 0;
    }

    void EnterScope() { vars->enterscope(); }
    void ExitScope() { vars->exitscope(); }

    void AddVar(Symbol sym) {
        vars->addid(sym, new int(0));
    }

    std::vector<Symbol> var_stack;

    void AddVarNode(Symbol s) {
        var_stack.push_back(s);
    }

    void RemoveVarNode() {
        var_stack.pop_back();
    }

    int LookUpVar(Symbol s) {
        for (int i = var_stack.size() - 1; i >= 0; --i) {
            if (var_stack[i] == s) return var_stack.size() - 1 - i;
        }
        return -1;
    }

    std::vector<Symbol> param_stack;
    void AddParam(Symbol s) {
        param_stack.push_back(s);
    }

    int LookUpParam(Symbol s) {
        for (int i = 0; i < (int)param_stack.size(); ++i) { // Fixed: Cast to int
            if (param_stack[i] == s) return param_stack.size() - 1 - i;
        }
        return -1;
    }

    int LookUpAttrib(Symbol s);
    void AddObstacle() { var_stack.push_back(No_type); } // Fixed: No_type now declared
};

class CgenClassTable : public SymbolTable<Symbol,CgenNode> {
private:
   List<CgenNode> *nds;
   ostream& str;
   int stringclasstag;
   int intclasstag;
   int boolclasstag;

   std::vector<CgenNode*> m_class_nodes;
   std::map<Symbol, int> m_class_tags;

// The following methods emit code for
// constants and global declarations.

   void code_global_data();
   void code_global_text();
   void code_bools(int);
   void code_select_gc();
   void code_constants();

   void code_class_nameTab();
   void code_class_objTab();
   void code_dispatchTabs();
   void code_class_inits();
   void code_class_methods();
   void code_protObjs(ostream& s); // Fixed: Added declaration

// The following creates an inheritance graph from
// a list of classes.  The graph is implemented as
// a tree of `CgenNode', and class names are placed
// in the base class symbol table.

   void install_basic_classes();
   void install_class(CgenNodeP nd);
   void install_classes(Classes cs);
   void build_inheritance_tree();
```

```
    void set_relations(CgenNodeP nd);
public:
    CgenClassTable(Classes, ostream& str);
    void code();
    CgenNodeP root();
    CgenNode* GetClassNode(Symbol name) { return probe(name); }
    std::vector<CgenNode*> GetClassNodes();
    std::map<Symbol, int> GetClassTags() { return m_class_tags; }
};


class CgenNode : public class__class {
private:
    CgenNodeP parentnd;
     // Parent of class
    List<CgenNode> *children;
     // Children of class
    Basicness basic_status;
     // `Basic' if class is basic

     // `NotBasic' otherwise

    std::vector<CgenNode*> inheritance;
    std::vector<attr_class*> m_full_attribs;
    std::map<Symbol, int> m_attrib_idx_tab;

    std::vector<method_class*> m_full_methods;
    std::map<Symbol, int> m_dispatch_idx_tab;
    std::map<Symbol, Symbol> m_dispatch_class_tab; // method name -> class name

public:
    CgenNode(Class_ c,
             Basicness bstatus,
             CgenClassTableP class_table);

    void add_child(CgenNodeP child);
    List<CgenNode> *get_children() { return children; }
    void set_parentnd(CgenNodeP p);
    CgenNodeP get_parentnd() { return parentnd; }
    int basic() { return (basic_status == Basic); }

    int class_tag;

    std::vector<CgenNode*> GetInheritance();
    std::vector<attr_class*> GetFullAttribs();
    std::map<Symbol, int> GetAttribIdxTab();

    std::vector<method_class*> GetFullMethods();
    std::map<Symbol, int> GetDispatchIdxTab();
    std::map<Symbol, Symbol> GetDispatchClassTab();

    std::vector<attr_class*> GetAttribs();
    std::vector<method_class*> GetMethods();

    void code_protObj(ostream& s);
    void code_init(ostream& s);
    void code_methods(ostream& s);
};

class BoolConst
{
 private:
  int val;
 public:
  BoolConst(int);
  void code_def(ostream&, int boolclasstag);
  void code_ref(ostream&) const;
};
```

Listing 4: cgen.h

A.3 cool-tree.h

```

#ifndef COOL_TREE_H
#define COOL_TREE_H

#include "tree.h"
#include "cool-tree.handcode.h"

// define simple phylum - Program
typedef class Program_class *Program;

class Program_class : public tree_node {
public:
    tree_node *copy()     { return copy_Program(); }
    virtual Program copy_Program() = 0;

#ifdef Program_EXTRAS
    Program_EXTRAS
#endif
```

```
};


// define simple phylum - Class_
typedef class Class__class *Class_;

class Class__class : public tree_node {
public:
   tree_node *copy()     { return copy_Class_()
    ; }
   virtual Class_ copy_Class_() = 0;

#ifdef Class__EXTRAS
   Class__EXTRAS
#endif
};


// define simple phylum - Feature
typedef class Feature_class *Feature;

class Feature_class : public tree_node {
public:
   tree_node *copy()     { return copy_Feature
    (); }
   virtual Feature copy_Feature() = 0;

#ifdef Feature_EXTRAS
   Feature_EXTRAS
#endif
};


// define simple phylum - Formal
typedef class Formal_class *Formal;

class Formal_class : public tree_node {
public:
   tree_node *copy()     { return copy_Formal()
    ; }
   virtual Formal copy_Formal() = 0;

#ifdef Formal_EXTRAS
   Formal_EXTRAS
#endif
};


// define simple phylum - Expression
typedef class Expression_class *Expression;


class Expression_class : public tree_node {
public:
   tree_node *copy()     { return copy_
    Expression(); }
   virtual Expression copy_Expression() = 0;

#ifdef Expression_EXTRAS
   Expression_EXTRAS
#endif
};


// define simple phylum - Case
typedef class Case_class *Case;

class Case_class : public tree_node {
public:
   tree_node *copy()     { return copy_Case();
    }
   virtual Case copy_Case() = 0;

#ifdef Case_EXTRAS
   Case_EXTRAS
#endif
};


// define list phlyum - Classes
typedef list_node<Class_> Classes_class;
typedef Classes_class *Classes;


// define list phlyum - Features
typedef list_node<Feature> Features_class;
typedef Features_class *Features;


// define list phlyum - Formals
typedef list_node<Formal> Formals_class;
typedef Formals_class *Formals;


// define list phlyum - Expressions
typedef list_node<Expression> Expressions_class
    ;
typedef Expressions_class *Expressions;


// define list phlyum - Cases
```

```
typedef list_node<Case> Cases_class;
typedef Cases_class *Cases;


// define the class for constructors
// define constructor - program
class program_class : public Program_class {
public:
   Classes classes;
public:
   program_class(Classes a1) {
      classes = a1;
   }
   Program copy_Program();
   void dump(ostream& stream, int n);

#ifdef Program_SHARED_EXTRAS
   Program_SHARED_EXTRAS
#endif
#ifdef program_EXTRAS
   program_EXTRAS
#endif
};


// define constructor - class_
class class__class : public Class__class {
public:
   Symbol name;
   Symbol parent;
   Features features;
   Symbol filename;
public:
   class__class(Symbol a1, Symbol a2, Features
    a3, Symbol a4) {
      name = a1;
      parent = a2;
      features = a3;
      filename = a4;
   }
   Class_ copy_Class_();
   void dump(ostream& stream, int n);

#ifdef Class__SHARED_EXTRAS
   Class__SHARED_EXTRAS
#endif
#ifdef class__EXTRAS
   class__EXTRAS
#endif
};


// define constructor - method
class method_class : public Feature_class {
public:
   Symbol name;
   Formals formals;
   Symbol return_type;
   Expression expr;
public:
   method_class(Symbol a1, Formals a2, Symbol
    a3, Expression a4) {
      name = a1;
      formals = a2;
      return_type = a3;
      expr = a4;
   }
   Feature copy_Feature();
   void dump(ostream& stream, int n);
   Symbol GetName() { return name; }

#ifdef Feature_SHARED_EXTRAS
   Feature_SHARED_EXTRAS
#endif
#ifdef method_EXTRAS
   method_EXTRAS
#endif
};


// define constructor - attr
class attr_class : public Feature_class {
public:
   Symbol name;
   Symbol type_decl;
   Expression init;
public:
   attr_class(Symbol a1, Symbol a2, Expression
    a3) {
      name = a1;
      type_decl = a2;
      init = a3;
   }
   Feature copy_Feature();
   void dump(ostream& stream, int n);
   Symbol GetName() { return name; }

#ifdef Feature_SHARED_EXTRAS
   Feature_SHARED_EXTRAS
#endif
```

```
#ifdef attr_EXTRAS
   attr_EXTRAS
#endif
};


// define constructor - formal
class formal_class : public Formal_class {
public:
   Symbol name;
   Symbol type_decl;
public:
   formal_class(Symbol a1, Symbol a2) {
      name = a1;
      type_decl = a2;
   }
   Formal copy_Formal();
   void dump(ostream& stream, int n);
   Symbol GetName() { return name; }

#ifdef Formal_SHARED_EXTRAS
   Formal_SHARED_EXTRAS
#endif
#ifdef formal_EXTRAS
   formal_EXTRAS
#endif
};


// define constructor - branch
class branch_class : public Case_class {
public:
   Symbol name;
   Symbol type_decl;
   Expression expr;
public:
   branch_class(Symbol a1, Symbol a2,
    Expression a3) {
      name = a1;
      type_decl = a2;
      expr = a3;
   }
   Case copy_Case();
   void dump(ostream& stream, int n);
   Symbol GetName() { return name; }
   Symbol GetTypeDecl() { return type_decl; }
   Expression GetExpr() { return expr; }

#ifdef Case_SHARED_EXTRAS
   Case_SHARED_EXTRAS
#endif
#ifdef branch_EXTRAS
   branch_EXTRAS
#endif
};


// define constructor - assign
class assign_class : public Expression_class {
public:
   Symbol name;
   Expression expr;
public:
   assign_class(Symbol a1, Expression a2) {
      name = a1;
      expr = a2;
   }
   Expression copy_Expression();
   void dump(ostream& stream, int n);

#ifdef Expression_SHARED_EXTRAS
   Expression_SHARED_EXTRAS
#endif
#ifdef assign_EXTRAS
   assign_EXTRAS
#endif
};


// define constructor - static_dispatch
class static_dispatch_class : public Expression
    _class {
public:
   Expression expr;
   Symbol type_name;
   Symbol name;
   Expressions actual;
public:
   static_dispatch_class(Expression a1, Symbol
    a2, Symbol a3, Expressions a4) {
      expr = a1;
      type_name = a2;
      name = a3;
      actual = a4;
   }
   Expression copy_Expression();
   void dump(ostream& stream, int n);
   std::vector<Expression> GetActuals() {
      std::vector<Expression> ret;
      for (int i = actual->first(); actual->
```

```
    more(i); i = actual->next(i))
307         ret.push_back(actual->nth(i));
308       return ret;
309    }
310
311 #ifdef Expression_SHARED_EXTRAS
312    Expression_SHARED_EXTRAS
313 #endif
314 #ifdef static_dispatch_EXTRAS
315    static_dispatch_EXTRAS
316 #endif
317 };
318
319
320 // define constructor - dispatch
321 class dispatch_class : public Expression_class
     {
322 public:
323    Expression expr;
324    Symbol name;
325    Expressions actual;
326 public:
327    dispatch_class(Expression a1, Symbol a2,
     Expressions a3) {
328       expr = a1;
329       name = a2;
330       actual = a3;
331    }
332    Expression copy_Expression();
333    void dump(ostream& stream, int n);
334    std::vector<Expression> GetActuals() {
335       std::vector<Expression> ret;
336       for (int i = actual->first(); actual->
     more(i); i = actual->next(i))
337          ret.push_back(actual->nth(i));
338       return ret;
339    }
340
341 #ifdef Expression_SHARED_EXTRAS
342    Expression_SHARED_EXTRAS
343 #endif
344 #ifdef dispatch_EXTRAS
345    dispatch_EXTRAS
346 #endif
347 };
348
349
350 // define constructor - cond
351 class cond_class : public Expression_class {
352 public:
353    Expression pred;
354    Expression then_exp;
355    Expression else_exp;
356 public:
357    cond_class(Expression a1, Expression a2,
      Expression a3) {
358       pred = a1;
359       then_exp = a2;
360       else_exp = a3;
361    }
362    Expression copy_Expression();
363    void dump(ostream& stream, int n);
364
365 #ifdef Expression_SHARED_EXTRAS
366    Expression_SHARED_EXTRAS
367 #endif
368 #ifdef cond_EXTRAS
369    cond_EXTRAS
370 #endif
371 };
372
373
374 // define constructor - loop
375 class loop_class : public Expression_class {
376 public:
377    Expression pred;
378    Expression body;
379 public:
380    loop_class(Expression a1, Expression a2) {
381       pred = a1;
382       body = a2;
383    }
384    Expression copy_Expression();
385    void dump(ostream& stream, int n);
386
387 #ifdef Expression_SHARED_EXTRAS
388    Expression_SHARED_EXTRAS
389 #endif
390 #ifdef loop_EXTRAS
391    loop_EXTRAS
392 #endif
393 };
394
395
396 // define constructor - typcase
397 class typcase_class : public Expression_class {
398 public:
399    Expression expr;
400    Cases cases;
401 public:
```

```
    typcase_class(Expression a1, Cases a2) {
       expr = a1;
       cases = a2;
    }
    Expression copy_Expression();
    void dump(ostream& stream, int n);
    std::vector<branch_class*> GetCases() {
       std::vector<branch_class*> ret;
       for (int i = cases->first(); cases->more(
     i); i = cases->next(i))
           ret.push_back((branch_class*)cases->
     nth(i));
       return ret;
    }

#ifdef Expression_SHARED_EXTRAS
    Expression_SHARED_EXTRAS
#endif
#ifdef typcase_EXTRAS
    typcase_EXTRAS
#endif
};


// define constructor - block
class block_class : public Expression_class {
public:
    Expressions body;
public:
    block_class(Expressions a1) {
       body = a1;
    }
    Expression copy_Expression();
    void dump(ostream& stream, int n);

#ifdef Expression_SHARED_EXTRAS
    Expression_SHARED_EXTRAS
#endif
#ifdef block_EXTRAS
    block_EXTRAS
#endif
};


// define constructor - let
class let_class : public Expression_class {
public:
    Symbol identifier;
    Symbol type_decl;
    Expression init;
    Expression body;
public:
    let_class(Symbol a1, Symbol a2, Expression
     a3, Expression a4) {
       identifier = a1;
       type_decl = a2;
       init = a3;
       body = a4;
    }
    Expression copy_Expression();
    void dump(ostream& stream, int n);

#ifdef Expression_SHARED_EXTRAS
    Expression_SHARED_EXTRAS
#endif
#ifdef let_EXTRAS
    let_EXTRAS
#endif
};


// define constructor - plus
class plus_class : public Expression_class {
public:
    Expression e1;
    Expression e2;
public:
    plus_class(Expression a1, Expression a2) {
       e1 = a1;
       e2 = a2;
    }
    Expression copy_Expression();
    void dump(ostream& stream, int n);

#ifdef Expression_SHARED_EXTRAS
    Expression_SHARED_EXTRAS
#endif
#ifdef plus_EXTRAS
    plus_EXTRAS
#endif
};


// define constructor - sub
class sub_class : public Expression_class {
public:
    Expression e1;
    Expression e2;
public:
    sub_class(Expression a1, Expression a2) {
```

```
        e1 = a1;
        e2 = a2;
    }
    Expression copy_Expression();
    void dump(ostream& stream, int n);

#ifdef Expression_SHARED_EXTRAS
    Expression_SHARED_EXTRAS
#endif
#ifdef sub_EXTRAS
    sub_EXTRAS
#endif
};


// define constructor - mul
class mul_class : public Expression_class {
public:
    Expression e1;
    Expression e2;
public:
    mul_class(Expression a1, Expression a2) {
        e1 = a1;
        e2 = a2;
    }
    Expression copy_Expression();
    void dump(ostream& stream, int n);

#ifdef Expression_SHARED_EXTRAS
    Expression_SHARED_EXTRAS
#endif
#ifdef mul_EXTRAS
    mul_EXTRAS
#endif
};


// define constructor - divide
class divide_class : public Expression_class {
public:
    Expression e1;
    Expression e2;
public:
    divide_class(Expression a1, Expression a2) {
        e1 = a1;
        e2 = a2;
    }
    Expression copy_Expression();
    void dump(ostream& stream, int n);

#ifdef Expression_SHARED_EXTRAS
    Expression_SHARED_EXTRAS
#endif
#ifdef divide_EXTRAS
    divide_EXTRAS
#endif
};


// define constructor - neg
class neg_class : public Expression_class {
public:
    Expression e1;
public:
    neg_class(Expression a1) {
        e1 = a1;
    }
    Expression copy_Expression();
    void dump(ostream& stream, int n);

#ifdef Expression_SHARED_EXTRAS
    Expression_SHARED_EXTRAS
#endif
#ifdef neg_EXTRAS
    neg_EXTRAS
#endif
};


// define constructor - lt
class lt_class : public Expression_class {
public:
    Expression e1;
    Expression e2;
public:
    lt_class(Expression a1, Expression a2) {
        e1 = a1;
        e2 = a2;
    }
    Expression copy_Expression();
    void dump(ostream& stream, int n);

#ifdef Expression_SHARED_EXTRAS
    Expression_SHARED_EXTRAS
#endif
#ifdef lt_EXTRAS
    lt_EXTRAS
#endif
};
```

```
599
600 // define constructor - eq
601 class eq_class : public Expression_class {
602 public:
603    Expression e1;
604    Expression e2;
605 public:
606    eq_class(Expression a1, Expression a2) {
607       e1 = a1;
608       e2 = a2;
609    }
610    Expression copy_Expression();
611    void dump(ostream& stream, int n);
612
613 #ifdef Expression_SHARED_EXTRAS
614    Expression_SHARED_EXTRAS
615 #endif
616 #ifdef eq_EXTRAS
617    eq_EXTRAS
618 #endif
619 };
620
621
622 // define constructor - leq
623 class leq_class : public Expression_class {
624 public:
625    Expression e1;
626    Expression e2;
627 public:
628    leq_class(Expression a1, Expression a2) {
629       e1 = a1;
630       e2 = a2;
631    }
632    Expression copy_Expression();
633    void dump(ostream& stream, int n);
634
635 #ifdef Expression_SHARED_EXTRAS
636    Expression_SHARED_EXTRAS
637 #endif
638 #ifdef leq_EXTRAS
639    leq_EXTRAS
640 #endif
641 };
642
643
644 // define constructor - comp
645 class comp_class : public Expression_class {
646 public:
647    Expression e1;
648 public:
649    comp_class(Expression a1) {
650       e1 = a1;
651    }
652    Expression copy_Expression();
653    void dump(ostream& stream, int n);
654
655 #ifdef Expression_SHARED_EXTRAS
656    Expression_SHARED_EXTRAS
657 #endif
658 #ifdef comp_EXTRAS
659    comp_EXTRAS
660 #endif
661 };
662
663
664 // define constructor - int_const
665 class int_const_class : public Expression_class
       {
666 public:
667    Symbol token;
668 public:
669    int_const_class(Symbol a1) {
670       token = a1;
671    }
672    Expression copy_Expression();
673    void dump(ostream& stream, int n);
674
675 #ifdef Expression_SHARED_EXTRAS
676    Expression_SHARED_EXTRAS
677 #endif
678 #ifdef int_const_EXTRAS
679    int_const_EXTRAS
680 #endif
681 };
682
683
684 // define constructor - bool_const
685 class bool_const_class : public Expression_
      class {
686 public:
687    Boolean val;
688 public:
689    bool_const_class(Boolean a1) {
690       val = a1;
691    }
692    Expression copy_Expression();
693    void dump(ostream& stream, int n);
694
695 #ifdef Expression_SHARED_EXTRAS
696    Expression_SHARED_EXTRAS
```

```
#endif
#ifdef bool_const_EXTRAS
   bool_const_EXTRAS
#endif
};


// define constructor - string_const
class string_const_class : public Expression_class {
public:
   Symbol token;
public:
   string_const_class(Symbol a1) {
      token = a1;
   }
   Expression copy_Expression();
   void dump(ostream& stream, int n);

#ifdef Expression_SHARED_EXTRAS
   Expression_SHARED_EXTRAS
#endif
#ifdef string_const_EXTRAS
   string_const_EXTRAS
#endif
};


// define constructor - new_
class new__class : public Expression_class {
public:
   Symbol type_name;
public:
   new__class(Symbol a1) {
      type_name = a1;
   }
   Expression copy_Expression();
   void dump(ostream& stream, int n);

#ifdef Expression_SHARED_EXTRAS
   Expression_SHARED_EXTRAS
#endif
#ifdef new__EXTRAS
   new__EXTRAS
#endif
};


// define constructor - isvoid
class isvoid_class : public Expression_class {
public:
   Expression e1;
public:
   isvoid_class(Expression a1) {
      e1 = a1;
   }
   Expression copy_Expression();
   void dump(ostream& stream, int n);

#ifdef Expression_SHARED_EXTRAS
   Expression_SHARED_EXTRAS
#endif
#ifdef isvoid_EXTRAS
   isvoid_EXTRAS
#endif
};


// define constructor - no_expr
class no_expr_class : public Expression_class {
public:
public:
   no_expr_class() {
   }
   Expression copy_Expression();
   void dump(ostream& stream, int n);

#ifdef Expression_SHARED_EXTRAS
   Expression_SHARED_EXTRAS
#endif
#ifdef no_expr_EXTRAS
   no_expr_EXTRAS
#endif
};


// define constructor - object
class object_class : public Expression_class {
public:
   Symbol name;
public:
   object_class(Symbol a1) {
      name = a1;
   }
   Expression copy_Expression();
   void dump(ostream& stream, int n);

#ifdef Expression_SHARED_EXTRAS
   Expression_SHARED_EXTRAS
#endif
```

```
#ifdef object_EXTRAS
   object_EXTRAS
#endif
};


// define the prototypes of the interface
Classes nil_Classes();
Classes single_Classes(Class_);
Classes append_Classes(Classes, Classes);
Features nil_Features();
Features single_Features(Feature);
Features append_Features(Features, Features);
Formals nil_Formals();
Formals single_Formals(Formal);
Formals append_Formals(Formals, Formals);
Expressions nil_Expressions();
Expressions single_Expressions(Expression);
Expressions append_Expressions(Expressions,
    Expressions);
Cases nil_Cases();
Cases single_Cases(Case);
Cases append_Cases(Cases, Cases);
Program program(Classes);
Class_ class_(Symbol, Symbol, Features, Symbol)
    ;
Feature method(Symbol, Formals, Symbol,
    Expression);
Feature attr(Symbol, Symbol, Expression);
Formal formal(Symbol, Symbol);
Case branch(Symbol, Symbol, Expression);
Expression assign(Symbol, Expression);
Expression static_dispatch(Expression, Symbol,
    Symbol, Expressions);
Expression dispatch(Expression, Symbol,
    Expressions);
Expression cond(Expression, Expression,
    Expression);
Expression loop(Expression, Expression);
Expression typcase(Expression, Cases);
Expression block(Expressions);
Expression let(Symbol, Symbol, Expression,
    Expression);
Expression plus(Expression, Expression);
Expression sub(Expression, Expression);
Expression mul(Expression, Expression);
Expression divide(Expression, Expression);
Expression neg(Expression);
Expression lt(Expression, Expression);
Expression eq(Expression, Expression);
Expression leq(Expression, Expression);
Expression comp(Expression);
Expression int_const(Symbol);
Expression bool_const(Boolean);
Expression string_const(Symbol);
Expression new_(Symbol);
Expression isvoid(Expression);
Expression no_expr();
Expression object(Symbol);

#endif
```

Listing 5: cool-tree.h

A.4 cool-tree.handcode.h

```
//
// The following include files must come first.

#ifndef COOL_TREE_HANDCODE_H
#define COOL_TREE_HANDCODE_H

#include <iostream>
#include "tree.h"
#include "cool.h"
#include "stringtab.h"
#include <vector> // Fixed: Added vector
    include

#define yylineno curr_lineno;
extern int yylineno;

inline Boolean copy_Boolean(Boolean b) {return
    b; }
inline void assert_Boolean(Boolean) {}
inline void dump_Boolean(ostream& stream, int
    padding, Boolean b)
  { stream << pad(padding) << (int) b << "\n";
    }

void dump_Symbol(ostream& stream, int padding,
    Symbol b);
void assert_Symbol(Symbol b);
Symbol copy_Symbol(Symbol b);

class Program_class;
typedef Program_class *Program;
class Class__class;
typedef Class__class *Class_;
```

```
class Feature_class;
typedef Feature_class *Feature;
class Formal_class;
typedef Formal_class *Formal;
class Expression_class;
typedef Expression_class *Expression;
class Case_class;
typedef Case_class *Case;

typedef list_node<Class_> Classes_class;
typedef Classes_class *Classes;
typedef list_node<Feature> Features_class;
typedef Features_class *Features;
typedef list_node<Formal> Formals_class;
typedef Formals_class *Formals;
typedef list_node<Expression> Expressions_class;
typedef Expressions_class *Expressions;
typedef list_node<Case> Cases_class;
typedef Cases_class *Cases;

// Forward declaration
class CgenEnvironment;

#define Program_EXTRAS                          \
virtual void cgen(ostream&) = 0;                \
virtual void dump_with_types(ostream&, int) = 0;

#define program_EXTRAS                          \
void cgen(ostream&);                            \
void dump_with_types(ostream&, int);

#define Class__EXTRAS                           \
virtual Symbol get_name() = 0;                  \
virtual Symbol get_parent() = 0;                \
virtual Symbol get_filename() = 0;              \
virtual void dump_with_types(ostream&,int) = 0;

#define class__EXTRAS                           \
Symbol get_name()   { return name; }            \
Symbol get_parent() { return parent; }          \
Symbol get_filename() { return filename; }      \
void dump_with_types(ostream&,int);

#define Feature_EXTRAS                          \
virtual void dump_with_types(ostream&,int) = 0; \
virtual bool IsMethod() { return false; } // Added

#define Feature_SHARED_EXTRAS                   \
void dump_with_types(ostream&,int);

#define method_EXTRAS \
bool IsMethod() { return true; } // Added

#define attr_EXTRAS \
bool IsMethod() { return false; } // Added

#define Formal_EXTRAS                           \
virtual void dump_with_types(ostream&,int) = 0;

#define formal_EXTRAS                           \
void dump_with_types(ostream&,int);

#define Case_EXTRAS                             \
virtual void dump_with_types(ostream& ,int) = 0;

#define branch_EXTRAS                           \
void dump_with_types(ostream& ,int);

#define Expression_EXTRAS                       \
Symbol type;                                    \
Symbol get_type() { return type; }              \
Expression set_type(Symbol s) { type = s; return this; } \
virtual void code(ostream&, CgenEnvironment) = 0; \
virtual void dump_with_types(ostream&,int) = 0; \
void dump_type(ostream&, int);                  \
Expression_class() { type = (Symbol) NULL; } \
virtual bool IsEmpty() { return false; } // Added

#define Expression_SHARED_EXTRAS                \
```

```
108 void code(ostream&, CgenEnvironment);
        \
109 void dump_with_types(ostream&,int);
110
111 #define no_expr_EXTRAS \
112 bool IsEmpty() { return true; } // Added
113
114 #endif
```

Listing 6: cool-tree.handcode.h