

电子科技大学信息与软件工程学院

# 实 验 报 告

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(实验) 课程名称 代码生成

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# 电子科技大学

## 实验报告

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一、 实验名称：代码生成

二、 实验学时：4h

三、 实验目的：学习中间代码生成的具体实现

四、 实验原理：

LLVM 提供了一套适合编译器系统的中间语言（Intermediate Representation, IR），有大量变换和优化都围绕其实现。经过变换和优化后的中间语言，可以转换为目标平台相关的汇编语言代码。

LLVM 的中间语言与具体的语言、指令集、类型系统无关，其中每条指令都是静态单赋值形式（SSA），即每个变量只能被赋值一次。这有助于简化变量之间的依赖分析。LLVM 允许静态编译代码，或者通过实时编译（JIT）机制将中间表示转换为机器码（类似 Java）。

五、 实验内容：

代码生成

完成算术表达式、逻辑表达式、赋值语句、条件语句、循环语句对应的代码生成，函数命名分别为：

genArithmeticExpr,    genLogicExpr,    genAssignStmt,    genIfStmt,  
genWhileStmt

函数参数都为：

(past node, char\* result)

node 为相关类型的结点

result 为用来保存 LLVM 指令，每行只放一条指令；

注：在生成代码时，生成每个函数对应的代码即可，无需生成其它辅助信息。  
例如，针对下面的源代码：

```
int main() {  
    int a;  
    a = 10;  
    return a % 3;  
}
```

用 clang -emit-llvm -S 生成的 llvm 指令如下：

```
; ModuleID = './20_rem.c'  
source_filename = "./20_rem.c"  
target              datalayout              =  
"e-m:e-p270:32:32-p271:32:32-p272:64:64-i64:64-f80:128-n8:16:32:64-S1  
28"  
target triple = "x86_64-pc-linux-gnu"  
  
; Function Attrs: noinline nounwind optnone uwtable  
define dso_local i32 @main() #0 {  
    %1 = alloca i32, align 4  
    %2 = alloca i32, align 4  
    store i32 0, i32* %1, align 4  
    store i32 10, i32* %2, align 4  
    %3 = load i32, i32* %2, align 4  
    %4 = srem i32 %3, 3  
    ret i32 %4  
}  
  
attributes #0 = { noinline nounwind optnone uwtable  
"frame-pointer"="all" "min-legal-vector-width"="0"  
"no-trapping-math"="true" "stack-protector-buffer-size"="8"
```

```
"target-cpu"="x86-64"
"target-features"="+cx8,+fxsr,+mmx,+sse,+sse2,+x87"
"tune-cpu"="generic" }
```

```
!llvm.module.flags = !{!0, !1, !2, !3, !4}
!llvm.ident = !{!5}
```

```
!0 = !{i32 1, !"wchar_size", i32 4}
!1 = !{i32 7, !"PIC Level", i32 2}
!2 = !{i32 7, !"PIE Level", i32 2}
!3 = !{i32 7, !"uwtable", i32 1}
!4 = !{i32 7, !"frame-pointer", i32 2}
!5 = !{"Ubuntu clang version 14.0.6"}
```

而本实验生成的 llvm 指令只需要 main 函数对应的代码即可，且无需生成 llvm 中的函数修饰符 dso\_local：

```
define i32 @main() {
    %1 = alloca i32, align 4
    %2 = alloca i32, align 4
    store i32 0, i32* %1, align 4
    store i32 10, i32* %2, align 4
    %3 = load i32, i32* %2, align 4
    %4 = srem i32 %3, 3
    ret i32 %4
}
```

## 六、 实验器材（设备、元器件）：无

## 七、 实验步骤：

查看指令手册 LLVMRef.mht

用 clang 学习 llvm 虚拟指令：

编写简单的 C 语言程序 test.c

用 clang -emit-llvm -S ./test.c

生成该文件对应的 llvm 指令

学习示例程序，理解代码生成过程

在实验 3 及示例程序的基础上完成算术表达式、逻辑表达式、赋值语句、条件语句、循环语句对应的代码生成

## 八、 实验结果与分析（含重要数据结果分析或核心代码流程分析）

### 实验结果：

Exp1:

当测试程序为

```
int get_one(int a) {  
    return 1;  
}
```

```
int deepWhileBr(int a, int b) {  
    int c;  
    c = a + b;  
    while (c < 75) {  
        int d;  
        d = 42;  
        if (c < 100) {  
            c = c + d;  
            if (c > 99) {  
                int e;  
                e = d * 2;  
                if (get_one(0) == 1) {  
                    c = e * 2;  
                }  
            }  
        }  
    }  
    return (c);  
}
```

```
int main() {  
    int p;  
    p = 2;  
    p = deepWhileBr(p, p);  
    putint(p);  
    return 0;  
}
```

时，

程序输出为

```
%2 = alloca i32, align 4
store i32 %0, i32* %2, align 4
ret i32 1
}
define i32 @deepWhileBr(i32 %0, i32 %1) {
    %3 = alloca i32, align 4
    %4 = alloca i32, align 4
    %5 = alloca i32, align 4
    %6 = alloca i32, align 4
    %7 = alloca i32, align 4
    store i32 %0, i32* %3, align 4
    store i32 %1, i32* %4, align 4
    %8 = load i32, i32* %3, align 4
    %9 = load i32, i32* %4, align 4
    %10 = add nsw i32 %8, %9
    store i32 %10, i32* %5, align 4
    br label %11
11:
    %12 = load i32, i32* %5, align 4
    %13 = icmp slt i32 %12, 75
    br i1 %13, label %14, label %34
14:
    store i32 42, i32* %6, align 4
    %15 = load i32, i32* %5, align 4
    %16 = icmp slt i32 %15, 100
    br i1 %16, label %17, label %33
17:
    %18 = load i32, i32* %5, align 4
    %19 = load i32, i32* %6, align 4
    %20 = add nsw i32 %18, %19
```

```
define i32 @get_one(i32 %0) {
    %2 = alloca i32, align 4
    store i32 %0, i32* %2, align 4
    ret i32 1
}
define i32 @deepWhileBr(i32 %0, i32 %1) {
    %3 = alloca i32, align 4
    %4 = alloca i32, align 4
    %5 = alloca i32, align 4
    %6 = alloca i32, align 4
    %7 = alloca i32, align 4
    store i32 %0, i32* %3, align 4
    store i32 %1, i32* %4, align 4
    %8 = load i32, i32* %3, align 4
    %9 = load i32, i32* %4, align 4
    %10 = add nsw i32 %8, %9
    store i32 %10, i32* %5, align 4
    br label %11
11:
    %12 = load i32, i32* %5, align 4
    %13 = icmp slt i32 %12, 75
    br i1 %13, label %14, label %34
14:
    store i32 42, i32* %6, align 4
    %15 = load i32, i32* %5, align 4
    %16 = icmp slt i32 %15, 100
    br i1 %16, label %17, label %33
17:
    %18 = load i32, i32* %5, align 4
    %19 = load i32, i32* %6, align 4
```

```

%20 = add nsw i32 %18, %19
store i32 %20, i32* %5, align 4
%21 = load i32, i32* %5, align 4
%22 = icmp sgt i32 %21, 99
br i1 %22, label %23, label %32
23:
%24 = load i32, i32* %6, align 4
%25 = mul nsw i32 %24, 2
store i32 %25, i32* %7, align 4
%26 = call i32 @get_one(i32 0)
%27 = icmp eq i32 %26, 1
br i1 %27, label %28, label %31
28:
%29 = load i32, i32* %7, align 4
%30 = mul nsw i32 %29, 2
store i32 %30, i32* %5, align 4
br label %31
31:
br label %32
32:
br label %33
33:
br label %11, !llvm.loop !6
34:
%35 = load i32, i32* %5, align 4
ret i32 %35
}
define i32 @main() {
%1 = alloca i32, align 4
%2 = alloca i32, align 4
store i32 0, i32* %1, align 4
store i32 2, i32* %2, align 4
%3 = load i32, i32* %2, align 4
%4 = load i32, i32* %2, align 4
%5 = call i32 @deepWhileBr(i32 %3, i32 %4)
store i32 %5, i32* %2, align 4
%6 = load i32, i32* %2, align 4
%7 = call @putint(i32 %6)
ret i32 0
}

```

Exp2:

当测试程序为

```
const int a[5]={0,1,2,3,4};
```

```
int main(){
    return a[4];
}
```

时,

程序输出为:

```
@a = constant [5 x i32] [i32 0, i32 1, i32 2, i32 3, i32 4], align 16
define i32 @main() {
    %1 = alloca i32, align 4
    store i32 0, i32* %1, align 4
    %2 = load i32, i32* getelementptr inbounds ([5 x i32], [5 x i32]* @a, i64 0, i64 4), align 16
    ret i32 %2
}
```

@a = constant [5 x i32] [i32 0, i32 1, i32 2, i32 3, i32 4], align 16

```
define i32 @main() {
    %1 = alloca i32, align 4
    store i32 0, i32* %1, align 4
    %2 = load i32, i32* getelementptr inbounds ([5 x i32], [5 x i32]* @a, i64 0, i64 4), align 16
    ret i32 %2
}
```

Exp3:

当测试程序为

```
int if_ifElse_() {
    int a;
    a = 5;
    int b;
    b = 10;
    if(a == 5){
        if (b == 10)
            a = 25;
        else
            a = a + 15;
    }
    return (a);
}
```

```
int main(){
    return (if_ifElse_());
}
```

时,

程序输出为:



```

1  define i32 @if_IfElse_() {
2    %1 = alloca i32, align 4
3    %2 = alloca i32, align 4
4    store i32 5, i32* %1, align 4
5    store i32 10, i32* %2, align 4
6    %3 = load i32, i32* %1, align 4
7    %4 = icmp eq i32 %3, 5
8    br i1 %4, label %5, label %13
9    5:
10   %6 = load i32, i32* %2, align 4
11   %7 = icmp eq i32 %6, 10
12   br i1 %7, label %8, label %9
13   8:
14   store i32 25, i32* %1, align 4
15   br label %12
16   9:
17   %10 = load i32, i32* %1, align 4
18   %11 = add nsw i32 %10, 15
19   store i32 %11, i32* %1, align 4
20   br label %12
21   12:
22   br label %13
23   13:
24   %14 = load i32, i32* %1, align 4
25   ret i32 %14
26 }

```

```

define i32 @if_IfElse_() {
%1 = alloca i32, align 4
%2 = alloca i32, align 4
store i32 5, i32* %1, align 4
store i32 10, i32* %2, align 4
%3 = load i32, i32* %1, align 4
%4 = icmp eq i32 %3, 5
br i1 %4, label %5, label %13
5:
%6 = load i32, i32* %2, align 4
%7 = icmp eq i32 %6, 10
br i1 %7, label %8, label %9
8:
store i32 25, i32* %1, align 4
br label %12
9:
%10 = load i32, i32* %1, align 4
%11 = add nsw i32 %10, 15
store i32 %11, i32* %1, align 4
br label %12
12:
br label %13
13:
%14 = load i32, i32* %1, align 4
ret i32 %14
}
define i32 @main() {
%1 = alloca i32, align 4
store i32 0, i32* %1, align 4
%2 = call i32 @if_IfElse_()
ret i32 %2
}

```

Exp4:

当测试程序为

```
int main(){
    int a, b;
    a = 10;
    b = -1;
    return a + b;
}
```

时，

程序输出为：

```
define i32 @main() {
    %1 = alloca i32, align 4
    %2 = alloca i32, align 4
    %3 = alloca i32, align 4
    store i32 0, i32* %1, align 4
    store i32 10, i32* %2, align 4
    store i32 -1, i32* %3, align 4
    %4 = load i32, i32* %2, align 4
    %5 = load i32, i32* %3, align 4
    %6 = add nsw i32 %4, %5
    ret i32 %6
}
```

```
define i32 @main() {
    %1 = alloca i32, align 4
    %2 = alloca i32, align 4
    %3 = alloca i32, align 4
    store i32 0, i32* %1, align 4
    store i32 10, i32* %2, align 4
    store i32 -1, i32* %3, align 4
    %4 = load i32, i32* %2, align 4
    %5 = load i32, i32* %3, align 4
    %6 = add nsw i32 %4, %5
    ret i32 %6
}
```

程序从 main.c 的 main 函数开始执行，主要流程如下：

1. main 函数首先处理命令行参数，打开需要编译的源文件。如果没有指定文件，则默认打开"./test.c"。
2. 调用 yyparse() 函数进行语法分析，这个函数会构建抽象语法树 (AST)，并将根节点保存在 astRoot 中。
3. 之后程序调用 genExpr(astRoot) 开始生成 LLVM IR 代码，并用 showAst 显示语法树结构。

在 `ast.c` 中定义了创建各种 AST 节点的函数：

1. `newAstNode()`：基础函数，为节点分配内存并初始化为 0
2. `newNum(int value)`：创建数值节点，存储整数值
3. `newExpr(int oper, past left, past right)`：创建表达式节点，用于算术运算
  - (1) `oper` 存储运算符 (+, -, \*, /)
  - (2) `left` 和 `right` 指向操作数
4. `newDoubleExpr()`：创建逻辑表达式节点，处理比较运算 (==, != 等)
5. `newBasicNode()`：创建基本语句节点，如 `if`、`while` 等控制结构
6. `newNextNode()`：处理语句序列，将多个语句连接成链表
7. `newTypeNode()` 和 `newIDNode()`：分别创建类型节点和标识符节点

`genIvm.c` 实现了代码生成的核心逻辑：

1. `genExpr()` 是主要入口函数，它遍历 AST 并调用 `process()` 处理各类节点
2. `process()` 根据节点类型调用相应的处理函数：
  - (1) `genDeclStmt()`：处理变量声明，生成 `alloca` 和 `store` 指令
  - (2) `genAssignStmt()`：处理赋值语句，生成 `store` 指令
  - (3) `genIfStmt()` 和 `genIfElseStmt()`：处理 `if` 语句，生成条件跳转指令
  - (4) `genWhileStmt()`：处理 `while` 循环，生成循环和跳转指令
  - (5) `genReturnStmt()`：处理 `return` 语句，生成返回指令
3. `genExprStmt()` 处理表达式：

- (1) 算术运算：生成 add、sub、mul、div 指令
- (2) 比较运算：生成 icmp 指令
- (3) 变量访问：生成 load 指令
- 4. checkVariable() 负责查找变量对应的寄存器编号
- 5. addLLVMCodes() 将生成的 LLVM IR 代码输出

整个程序通过维护以下状态来管理代码生成：

- 1. regCount 和 varCount：跟踪寄存器和变量编号
- 2. variables 数组：存储变量名
- 3. variable\_type 数组：记录变量类型
- 4. whilecheckpoint 和 ifcheckpoint：管理控制流标签

以下是完整的代码：

# 完整代码

ast.h:

```
1 #ifndef __AST
2 #define __AST
3
4 #include <stdio.h>
5
6 typedef struct _ast ast;
7 typedef struct _ast *past;
8 struct _ast{
9     int ivalue;
10    char* strValue;
11    char* nodeType;
12    past next;
13    past left;
14    past right;
15 };
16
17 past newAstNode();
18 past newNum(int value);
19 past newExpr(int oper, past left,past right);
20 past newDoubleExpr(char* logic_oper, past left,past right);
21 past newBasicNode(char* nodeType, past left, past right, past next);
22 past newNextNode(char* nodeType, past older, past younger);
23 past newTypeNode(char* strVal);
24 past newIDNode(char* strVal);
25 void showAst(past node, int nest);
26
27 #endif
28
```

ast.c:

```
1 #include "ast.h"
2 #include <stdio.h>
3 #include <stdlib.h>
4 #include <string.h>
```

```

5
6 past newAstNode()
7 {
8     past node = malloc(sizeof(ast));
9     if(node == NULL)
10    {
11        printf("run out of memory.\n");
12        exit(0);
13    }
14    memset(node, 0, sizeof(ast));
15    return node;
16 }
17
18 past newNum(int value)
19 {
20     past var = newAstNode();
21     var->nodeType = "intValue";
22     var->ivalue = value;
23     return var;
24 }
25
26 past newExpr(int oper, past left, past right)
27 {
28     past var = newAstNode();
29     var->nodeType = "expr";
30     var->ivalue = oper;
31     var->left = left;
32     var->right = right;
33     var -> strValue = "@";
34     return var;
35 }
36
37 past newDoubleExpr(char* logic_oper, past left, past right)
38 {
39     past var = newAstNode();
40     var->nodeType = "expr";
41     char *strVal = malloc(sizeof(logic_oper));
42     strcpy(strVal, logic_oper);
43     var -> strValue = strVal;
44     var->left = left;
45     var->right = right;
46     return var;
47 }
48
49 past newBasicNode(char* nodeType, past left, past right, past next)
50 {
51     past root = newAstNode();

```

```

52     char *node_type = malloc(sizeof(nodeType));
53     strcpy(node_type,nodeType);
54     root->nodeType = node_type;
55     root->left = left;
56     root->right = right;
57     root->next = next;
58     return root;
59 }
60
61 past newNode(char* nodeType, past older, past younger)
62 {
63     past root = NULL;
64     //还没有根节点
65     if(strcmp(nodeType, older->nodeType) != 0){
66         root = newAstNode();
67         char *node_type = malloc(sizeof(nodeType));
68         strcpy(node_type,nodeType);
69         root->nodeType = node_type;
70         root->left = older; root->left->next = younger;
71         root->ivalue = 1;
72     }
73     //已经有根节点
74     else{
75         root = older;
76         older = older->left;
77         while(older->next != NULL) older = older->next;
78         older->next = younger;
79         root->ivalue++;
80     }
81     return root;
82 }
83
84 past newTypeNode(char* strVal)
85 {
86     past root = newAstNode();
87     root->nodeType = "type";
88     char *buf = malloc(sizeof(strVal));
89     strcpy(buf,strVal);
90     root->strValue = buf;
91     return root;
92 }
93
94 past newIDNode(char* strVal)
95 {
96     past root = newAstNode();
97     root->nodeType = "parameter";
98     char *buf = malloc(sizeof(strVal));

```

```

99     strcpy(buf, strVal);
100    root->strValue = buf;
101    return root;
102 }
103
104 void showAst(past node, int nest)
105 {
106     if(node == NULL) {
107         //printf("node transfer error\n");
108         return;
109     }
110     int i = 0;
111     for(i = 0; i < nest; i++)
112         printf(" ");
113     if(strcmp(node->nodeType, "expr") == 0){
114         if(strcmp(node->strValue, "@") == 0)
115             printf("%s '%c'\n", node->nodeType, (char)node->ivalue);
116         else
117             printf("%s %s\n", node->nodeType, node->strValue);
118     }
119     else if(strcmp(node->nodeType, "intValue")==0){
120         printf("%s . %d\n", node->nodeType, node->ivalue);
121     }
122     else{
123         if(!node->strValue){
124             if(node->ivalue) printf("%s . %d\n", node->nodeType, node->ivalue);
125             else printf("%s .\n", node->nodeType);
126         }
127         else if(node->ivalue) printf("%s %s %d\n", node->nodeType, node->strValue, node->ivalue);
128         else printf("%s %s .\n", node->nodeType, node->strValue);
129     }
130     showAst(node->left, nest+1);
131     showAst(node->right, nest+1);
132     showAst(node->next, nest);
133 }
134

```

genllvm.h:

```

1  #ifndef GENLLVM_H
2  #define GENLLVM_H
3
4  #include "ast.h"

```



```

5
6 enum {T_INT = 1};
7 #define true 1
8 #define false 0
9
10 int genExpr(past node);
11
12 #endif

```

## genllvm.c:

```

1 #include <stdlib.h>
2 #include <stdio.h>
3 #include <string.h>
4 #include <stdbool.h>
5 #include "genllvm.h"
6
7 int stack_top = 0;
8 int regCount = 1;
9 int varCount = 0;
10 int reg[40];
11 char *variables[40];
12 char *variable_type[40];
13 int whilecheckpoint[10];
14 int ifcheckpoint[10];
15 int if_stack_top = 0;
16 int process(past node, char *result);
17
18 void addLLVMCodes(char *codes)
19 {
20     printf("%s", codes);
21 }
22 int checkVariable(char *variable_name)
23 {
24     int res = 0;
25     for (int i = 1; i < regCount; i++)
26     {
27         if (strcmp(variable_name, variables[i]) == 0)
28         {
29             res = i;
30         }
31     }
32
33     return res;

```

```

34 }
35 int genExprStmt(past node, char *result)
36 {
37     char *key = (char *)malloc(sizeof(char) * 5);
38     char *left = (char *)malloc(sizeof(char) * 5);
39     char *right = (char *)malloc(sizeof(char) * 5);
40     int left_record = 0, right_record = 0;
41     if (strcmp(node->strValue, "@") == 0 || strcmp(node->strValue, "==") == 0
|| strcmp(node->strValue, "!=") == 0 || strcmp(node->strValue, ">=") == 0 ||
strcmp(node->strValue, "<=") == 0)
42     {
43         switch (node->ivalue)
44         {
45             case '+':
46                 sprintf(key, "add");
47                 break;
48             case '-':
49                 sprintf(key, "sub");
50                 break;
51             case '*':
52                 sprintf(key, "mul");
53                 break;
54             case '/':
55                 sprintf(key, "div");
56                 break;
57             default:
58                 sprintf(key, "else");
59                 break;
60         }
61         if (strcmp(node->left->nodeType, "intValue") == 0)
62         {
63             sprintf(left, "%d", node->left->ivalue);
64         }
65         else if (strcmp(node->left->nodeType, "parameter") == 0)
66         {
67             left_record = checkVariable(node->left->strValue);
68             if (left_record != 0)
69             {
70                 ++varCount;
71                 sprintf(left, "%%%d", varCount);
72                 char *tmp = (char *)malloc(sizeof(char) * 200);
73                 sprintf(tmp, "%%%d = load i32, i32* %%%d, align 4\n",
varCount, reg[left_record]);
74                 result = strcat(result, tmp);
75                 free(tmp);
76             }
77         }

```

```

78     else if (strcmp(node->left->nodeType, "expr") == 0)
79     {
80         sprintf(left, "%%%d", genExprStmt(node->left, result));
81     }
82     if (strcmp(node->right->nodeType, "intValue") == 0)
83     {
84         sprintf(right, "%d", node->right->ivalue);
85     }
86     else if (strcmp(node->right->nodeType, "parameter") == 0)
87     {
88         right_record = checkVariable(node->right->strValue);
89         if (right_record != 0)
90         {
91             ++varCount;
92             sprintf(right, "%%%d", varCount);
93             char *tmp = (char *)malloc(sizeof(char) * 200);
94             sprintf(tmp, "%%%d = load i32, i32* %%%d, align 4\n",
varCount, reg[right_record]);
95             result = strcat(result, tmp);
96             free(tmp);
97         }
98     }
99     else if (strcmp(node->right->nodeType, "expr") == 0)
100    {
101        sprintf(right, "%%%d", genExprStmt(node->right, result));
102    }
103    char *tmp = (char *)malloc(sizeof(char) * 200);
104    if (strcmp(key, "else") == 0)
105    {
106        if (strcmp(node->strValue, "@") == 0 && node->ivalue == '>')
107            sprintf(tmp, "%%%d = icmp %s i32 %s, %s\n", ++varCount, "sgt",
left, right);
108        else if (strcmp(node->strValue, "@") == 0 && node->ivalue == '<')
109            sprintf(tmp, "%%%d = icmp %s i32 %s, %s\n", ++varCount, "slt",
left, right);
110        else if (strcmp(node->strValue, "==") == 0)
111            sprintf(tmp, "%%%d = icmp %s i32 %s, %s\n", ++varCount, "eq",
left, right);
112        else if (strcmp(node->strValue, "!=") == 0)
113            sprintf(tmp, "%%%d = icmp %s i32 %s, %s\n", ++varCount, "ne",
left, right);
114        else if (strcmp(node->strValue, ">=") == 0)
115            sprintf(tmp, "%%%d = icmp %s i32 %s, %s\n", ++varCount, "sge",
left, right);
116        else if (strcmp(node->strValue, "<=") == 0)
117            sprintf(tmp, "%%%d = icmp %s i32 %s, %s\n", ++varCount, "sle",
left, right);

```

```

118         strcat(result, tmp);
119         free(tmp);
120         free(key);
121         free(left);
122         free(right);
123         return 0;
124     }
125     sprintf(tmp, "%%%d = %s i32 %s, %s\n", ++varCount, key, left, right);
126     result = strcat(result, tmp);
127
128     free(tmp);
129     free(key);
130     free(left);
131     free(right);
132     return varCount;
133 }
134
135 return 0;
136 }
137 int genDeclStmt(past node, char *result)
138 {
139     if (strcmp(node->left->left->strValue, "int") == 0)
140     {
141         past l = node->left->right->left;
142         for (int i = 0; i < node->left->right->ivalue; i++)
143         {
144             if (strcmp(l->right->nodeType, "intValue") == 0)
145             {
146                 variables[regCount] = l->left->strValue;
147                 variable_type[regCount] = "int";
148                 reg[regCount++] = ++varCount;
149                 char *tmp = malloc(sizeof(char) * 200);
150                 sprintf(tmp, "%c%d = alloca i32, align 4\nstore i32 %d, i32*
151                 %c%d, align 4\n", '%', varCount, l->right->ivalue, '%',
152                 varCount);
153                 strcat(result, tmp);
154                 free(tmp);
155             }
156             l = l->next;
157         }
158         return 0;
159     }
160     int genAssignStmt(past node, char *result)
161     {
162         char *tmp = malloc(sizeof(char) * 200);
163         if (strcmp(node->right->nodeType, "expr") == 0)

```

```

164     {
165         int pos = checkVariable(node->left->strValue);
166         sprintf(tmp, "store i32 %c%d , i32* %c%d, align 4\n", '%',
genExprStmt(node->right, result), '%', reg[pos]);
167         result = strcat(result, tmp);
168         free(tmp);
169         return 0;
170     }
171     else if (strcmp(node->right->nodeType, "intValue") == 0)
172     {
173         int pos = checkVariable(node->left->strValue);
174         sprintf(tmp, "store i32 %d , i32* %c%d, align 4\n", node->right-
>ivalue, '%', reg[pos]);
175         result = strcat(result, tmp);
176         free(tmp);
177         return 0;
178     }
179     else if (strcmp(node->right->nodeType, "parameter") == 0)
180     {
181         char *tmp1 = malloc(sizeof(char) * 200);
182         sprintf(tmp1, "%%d = load i32, i32* %%d, align 4\n", ++varCount,
reg[checkVariable(node->right->strValue)]);
183         result = strcat(result, tmp1);
184         free(tmp1);
185         int pos = checkVariable(node->left->strValue);
186         sprintf(tmp, "store i32 %c%d , i32* %c%d, align 4\n", '%', varCount,
'%', reg[pos]);
187         result = strcat(result, tmp);
188         free(tmp);
189         return 0;
190     }
191     else
192     {
193         free(tmp);
194         result = "";
195         return 0;
196     }
197 }
198 int genIfStmt(past node, char *result)
199 {
200     char *res = (char *)malloc(200);
201     char *tmp = (char *)malloc(200);
202     genExprStmt(node->left, result);
203     char *tmp2 = (char *)malloc(sizeof(char) * 200);
204     sprintf(tmp2, "br i1 %c%d, label %c%d, label %c%d\n; <label>:%d:\n", '%',
varCount, '%', varCount + 1, '%', varCount + 2, varCount + 1);
205     varCount++;

```

```

206     result = strcat(result, tmp2);
207     process(node->right, result);
208     char *tmp3 = (char *)malloc(sizeof(char) * 200);
209     ++varCount;
210     sprintf(tmp3, "br label %c%d\n; <label>:%d:\n", '%', varCount, varCount);
211     result = strcat(result, tmp3);
212     free(tmp);
213     free(res);
214     return 0; // res
215 }
216 int genIfElseStmt(past node, char *result)
217 {
218     char *res = (char *)malloc(200);
219     char *tmp = (char *)malloc(200);
220     genExprStmt(node->left, result);
221     ifcheckpoint[if_stack_top++] = varCount;
222     char *tmp2 = (char *)malloc(sizeof(char) * 200);
223     sprintf(tmp2, "br i1 %c%d, label %c%d, label %c%d\n; <label>:%d:\n", '%',
varCount, '%', varCount + 1, '%', varCount + 2, varCount + 1);
224     varCount++;
225     result = strcat(result, tmp2);
226     process(node->right->left, result);
227     char *tmp3 = (char *)malloc(sizeof(char) * 200);
228     ++varCount;
229     sprintf(tmp3, "br label %c%d\n; <label>:%d:\n", '%', varCount, varCount);
230     result = strcat(result, tmp3);
231     process(node->right->left->next, result);
232     char *tmp4 = (char *)malloc(sizeof(char) * 200);
233     ++varCount;
234     sprintf(tmp4, "br label %c%d\n; <label>:%d:\n", '%', varCount, varCount);
235     result = strcat(result, tmp4);
236     free(tmp);
237     free(res);
238     return 0; // res
239 }
240 int genWhileStmt(past node, char *result)
241 {
242     char *res = (char *)malloc(200);
243     char *tmp = (char *)malloc(200);
244     sprintf(res, "br label %c%d\n", '%', ++varCount);
245     whilecheckpoint[stack_top++] = varCount;
246     sprintf(tmp, "; <label>:%d:\n", varCount);
247     res = strcat(res, tmp);
248     result = strcat(result, res);
249     genExprStmt(node->left, result);
250     char *tmp2 = (char *)malloc(sizeof(char) * 200);

```

```

251     sprintf(tmp2, "br i1 %c%d, label %c%d, label %c%d\n; <label>:%d:\n", '%',
varCount - 1, '%', varCount, '%', varCount + 1, varCount + 1);
252     varCount++;
253     result = strcat(result, tmp2);
254     process(node->right, result);
255     char *tmp3 = (char *)malloc(sizeof(char) * 200);
256     sprintf(tmp3, "br label %c%d\n; <label>:%d:\n", '%',
whilecheckpoint[stack_top - 1], ++varCount);
257     result = strcat(result, tmp3);
258     free(tmp);
259     free(res);
260     return 0;
261 }
262 int genReturnStmt(past node, char *result)
263 {
264     char *tmp = (char *)malloc(sizeof(char) * 200);
265     if (strcmp(node->left->nodeType, "expr") == 0)
266     {
267         sprintf(tmp, "ret i32 %c%d\n", '%', genExprStmt(node->left, result));
268         result = strcat(result, tmp);
269         free(tmp);
270         return 0;
271     }
272     else if (strcmp(node->left->nodeType, "intValue") == 0)
273     {
274         sprintf(tmp, "ret i32 %d\n", node->left->ivalue);
275         result = strcat(result, tmp);
276         free(tmp);
277         return 0;
278     }
279     else if (strcmp(node->left->nodeType, "parameter") == 0)
280     {
281         char *tmp = (char *)malloc(sizeof(char) * 200);
282         sprintf(tmp, "%%%d = load i32, i32* %%%%d, align 4\n", ++varCount,
reg[checkVariable(node->left->strValue)]);
283         result = strcat(result, tmp);
284         free(tmp);
285         char *tmp2 = (char *)malloc(sizeof(char) * 200);
286         sprintf(tmp2, "ret i32 %c%d\n", '%', varCount++);
287         result = strcat(result, tmp2);
288         free(tmp2);
289         return 0;
290     }
291     else
292     {
293         free(tmp);
294         result = "";

```

```

295         return 0;
296     }
297 }
298
299 int process(past node, char *result)
300 {
301     if (strcmp(node->nodeType, "Decl") == 0)
302     {
303         genDeclStmt(node, result);
304     }
305     else if (strcmp(node->nodeType, "DeclList") == 0)
306     {
307         process(node->left, result);
308         process(node->left->next, result);
309     }
310     else if (strcmp(node->nodeType, "Assign_Stmt") == 0)
311     {
312         genAssignStmt(node, result);
313     }
314     else if (strcmp(node->nodeType, "Block_list") == 0)
315     {
316         past l = node->left;
317         for (int i = 0; i < node->ivalue; i++)
318         {
319             process(l, result);
320             l = l->next;
321         }
322     }
323     else if (strcmp(node->nodeType, "While_Stmt") == 0)
324     {
325         genWhileStmt(node, result);
326     }
327     else if (strcmp(node->nodeType, "Return_Stmt") == 0)
328     {
329         genReturnStmt(node, result);
330     }
331     else if (strcmp(node->nodeType, "If_Stmt") == 0)
332     {
333         genIfStmt(node, result);
334     }
335     else if (strcmp(node->nodeType, "IfElse_Stmt") == 0)
336     {
337         genIfElseStmt(node, result);
338     }
339 }
340 int genExpr(past node)
341 {

```



```

342     if (node == NULL)
343         return -1;
344
345     if (strcmp(node->nodeType, "Block_list") == 0)
346     {
347         char *result = (char *)malloc(sizeof(char) * 2000);
348         process(node, result);
349         addLLVMCodes(result);
350     }
351     else
352     {
353         if (node->left != NULL)
354         {
355             genExpr(node->left);
356         }
357         if (node->right != NULL)
358         {
359             genExpr(node->right);
360         }
361     }
362
363     return -1;
364 }
365

```

## main.c:

```

1  #include "ast.h"
2  #include "genllvm.h"
3  #include <stdio.h>
4
5  extern int yyparse();
6  extern FILE *yyin;
7  past astRoot;
8  void yyerror(char *s)
9  {
10     printf("%s\n", s);
11 }
12
13 int main(int argc, char **argv)
14 {
15     if (argc > 2)
16     {
17         printf("args too many!.\n");

```

```

18         return 0;
19     }
20     if (argc == 2)
21     {
22         yyin = fopen(argv[1], "r");
23     }
24     else
25     {
26         yyin = fopen("./test.c", "r");
27     }
28
29     // printf("before yyparse\n");
30     yyparse();
31     fclose(yyin);
32     // printf("before show & after yyparse\n");
33     genExpr(astRoot);
34     showAst(astRoot, 0);
35     // printf("after show\n");
36
37     return 0;
38 }
39

```

`lrlex.l`:

```

1  %{
2
3  #include "ast.h"
4  #include <string.h>
5  #include "lrparser.tab.h"
6
7  %}
8
9  INTERGER    [0-9]
10 OCTALCONS   0[0-7]+
11 HEXCONS     0[xX][0-9a-fA-F]+
12 NOTE_S      \\/(.)*\n
13 NOTE_M      \\/(.*)*\n
14 IDENTIFIER  [_a-zA-Z][_a-zA-Z0-9]*
15
16 %%
17
18 "("         {return '(';}
19 ")"         {return ')';}

```

```

20 "{" {return '{';}
21 "}" {return '}';}
22 "[" {return '['; }
23 "]" {return ']';}
24 "," {return ','; }
25 ";" {return ';';}
26 "+" {return '+'; }
27 "-" {return '-';}
28 "*" {return '*';}
29 "/" {return '/';}
30 "%" {return '%';}
31 "<" {return '<';}
32 ">" {return '>';}
33 "!" {return '!';}
34 "=" {return '='; }
35
36 "int" {return INT;}
37 "continue" {return CONTINUE;}
38 "const" {return CONST;}
39 "else" {return ELSE;}
40 "if" {return IF;}
41 "return" {return RETURN;}
42 "void" {return VOID;}
43 "while" {return WHILE;}
44 "break" {return BREAK;}
45
46 "<=" {return LESSEQ;}
47 ">=" {return GREATEQ;}
48 "!=" {return NOTEQ;}
49 "==" {return EQ;}
50 "&&" {return AND;}
51 "||" {return OR;}
52
53 " " { /*no action and no return*/ }
54 "\t" { /*no action and no return*/ }
55 "\n" { /*no action and no return*/ }
56 {NOTE_S}* { /*no action and no return*/ }
57 {NOTE_M}* { /*no action and no return*/ }
58
59 {INTERGER}+"."*{INTERGER}* |
60 {OCTALCONS} |
61 {HEXCONS} {yyval.number = atoi(yytext); return NUMBER;}
62
63 {IDENTIFIER} {strcpy(yyval.strValue, yytext); return ID;}
64
65 %%
66

```

```

67 int yywrap(){
68     return 1;
69 }
70

```

## lrparser.y:

```

1  %{
2
3  #include "ast.h"
4  #include <stdio.h>
5
6  void yyerror(char *);
7  int yylex(void);
8  extern char* yytext;
9  extern past astRoot;
10 %}
11
12 %union{
13     int          number;
14     char         strValue[50];
15     past         pAst;
16 };
17
18 %token          IF
19 %token          ELSE
20 %token          INT
21 %token          VOID
22 %token          CONST
23 %token          WHILE
24 %token          BREAK
25 %token          RETURN
26 %token          CONTINUE
27 %token          LESSEQ
28 %token          GREATEQ
29 %token          NOTEQ
30 %token          EQ
31 %token          AND
32 %token          OR
33 %token          <strValue>  ID
34 %token          <number>    NUMBER
35 %type           <pAst>      CompUnit CompUnits Decl ConstDecl ConstDef
                             ConstInitVal VarDecl VarDef InitVal FuncDef FuncFParams FuncFParam Block
                             BlockItem Stmt Exp Cond LVal PrimaryExp Number UnaryExp FuncRParams MulExp

```

```

AddExp RelExp EqExp LAndExp LOrExp ConstExp ConstDeclMul ConstDefMul
ConstInitValMul VarDeclMul VarDefMul InitValMul BlockMul LValMul
36
37 %%
38
39 CompUnits: CompUnit                                {$$ = newNextNode("CompUnit", $1,
NULL); astRoot = $$;}
40     | CompUnits CompUnit                            {$$ = newNextNode("CompUnit", $1,
$2); astRoot = $$;}
41     ;
42
43 CompUnit: Decl                                    {$$ = $1;}
44     | FuncDef                                    {$$ = $1;}
45     ;
46
47 Decl: ConstDecl                                {$$ = newBasicNode("Decl", $1, NULL, NULL);}
48     | VarDecl                                {$$ = newBasicNode("Decl", $1, NULL, NULL);}
49     ;
50
51 ConstDeclMul: ConstDef                            {$$ = newNextNode("ConstDecl_list",
$1, NULL);}
52     | ConstDeclMul ',' ConstDef                {$$ = newNextNode("ConstDecl_list",
$1, $3);}
53     ;
54
55 ConstDecl: CONST INT ConstDeclMul ';'            {$$ =
newBasicNode("ConstDecl",newTypeNode("const_int"), $3, NULL);}
56     ;
57
58 ConstDefMul: '[' ConstExp ']'                    {$$ =
newNextNode("ConstDef_list", $2, NULL);}
59     | ConstDefMul '[' ConstExp ']'                {$$ =
newNextNode("ConstDef_list", $1, $3);}
60     ;
61
62 ConstDef: ID '=' ConstInitVal                    {$$ =
newBasicNode("ConstDef",newIDNode($1),$3,NULL);}
63     | ID ConstDefMul '=' ConstInitVal            {$$ =
newBasicNode("ConstDef",newNextNode("ConstDef_para", newIDNode($1), $2), $4,
NULL);}
64     ;
65
66 ConstInitValMul: ConstInitVal                    {$$ =
newNextNode("ConstInitVal_list", $1, NULL);}
67     | ConstInitValMul ',' ConstInitVal            {$$ =
newNextNode("ConstInitVal_list", $1, $3);}
68     ;

```

```

69
70 ConstInitVal: ConstExp          {$$ = $1;}
71   | '{' '}'                     {$$ =
newBasicNode("ConstInitVal_empty",NULL, NULL, NULL);}
72   | '{' ConstInitValMul '}'     {$$ = $2;}
73   ;
74
75 VarDeclMul: VarDef              {$$ = newNextNode("VarDecl_list", $1,
NULL);}
76   | VarDeclMul ',' VarDef       {$$ = newNextNode("VarDecl_list", $1,
$3);}
77   ;
78
79 VarDecl: INT VarDeclMul ';'     {$$ = newBasicNode("VarDecl",
newTypeNode("int"), $2, NULL);}
80   ;
81
82 VarDefMul: '[' ConstExp ']'     {$$ = newNextNode("VarDef_list", $2,
NULL);}
83   | VarDefMul '[' ConstExp ']' {$$ = newNextNode("VarDef_list", $1,
$3);}
84   ;
85
86 VarDef: ID                      {$$ = newBasicNode("VarDef",
newIDNode(yylval.strValue), NULL,NULL);}
87   | ID '=' InitVal             {$$ = newBasicNode("VarDef",
newIDNode($1), $3, NULL);}
88   | ID VarDefMul              {$$ =
newBasicNode("VarDef",newNextNode("VarDef_para", newIDNode($1), $2), NULL,
NULL);}
89   | ID VarDefMul '=' InitVal   {$$ =
newBasicNode("VarDef",newNextNode("VarDef_para", newIDNode($1), $2), $4,
NULL);}
90   ;
91
92 InitValMul: InitVal            {$$ = newNextNode("InitVal_list", $1,
NULL);}
93   | InitValMul ',' InitVal     {$$ = newNextNode("InitVal_list", $1,
$3);}
94   ;
95
96 InitVal: Exp                   {$$ = $1;}
97   | '{' '}'                   {$$ = newBasicNode("InitVal_empty",
NULL, NULL, NULL);}
98   | '{' InitValMul '}'        {$$ = $2;}
99   ;
100

```

[illegible]

```

129
130 Stmt: LVal '=' Exp ';'          {$$ =
    newBasicNode("Assign_Stmt", $1, $3, NULL);}
131     | Exp ';'                  {$$ = $1;}
132     | ';'                      {$$ =
    newBasicNode("Stmt_empty", NULL, NULL, NULL);}
133     | Block                    {$$ = $1;}
134     | IF '(' Cond ')' Stmt      {$$ = newBasicNode("If_Stmt",
    $3, $5, NULL);}
135     | IF '(' Cond ')' Stmt ELSE Stmt {$$ =
    newBasicNode("IfElse_Stmt", $3, newNextNode("If_Else", $5, $7), NULL);}
136     | WHILE '(' Cond ')' Stmt  {$$ =
    newBasicNode("While_Stmt", $3, $5, NULL);}
137     | BREAK ';'               {$$ =
    newBasicNode("Break_Stmt", NULL, NULL, NULL);}
138     | CONTINUE ';'            {$$ =
    newBasicNode("Continue_Stmt", NULL, NULL, NULL);}
139     | RETURN Exp ';'          {$$ =
    newBasicNode("Return_Stmt", $2, NULL, NULL);}
140     | RETURN ';'              {$$ =
    newBasicNode("Return_Stmt", NULL, NULL, NULL);}
141     ;
142
143 Exp: AddExp                      {$$ = $1;}
144     ;
145
146 Cond: LOrExp                    {$$ = $1;}
147     ;
148
149 LValMul: '[' Exp ']'            {$$ = newNextNode("Exp_list", $2, NULL);}
150     | LValMul '[' Exp ']'      {$$ = newNextNode("Exp_list", $1, $3);}
151     ;
152
153 LVal: ID                        {$$ = newIDNode(yylval.strValue);}
154     | ID LValMul               {$$ = newBasicNode("LVal_SEG", newIDNode($1), $2,
    NULL);}
155     ;
156
157 PrimaryExp: '(' Exp ')'         {$$ = $2;}
158     | LVal                     {$$ = $1;}
159     | Number                   {$$ = $1;}
160     ;
161
162 Number: NUMBER                  {$$ = newNum(yylval.number);}
163     ;
164
165 UnaryExp: PrimaryExp           {$$ = $1;}

```



```

166 | ID '(' ')' {$$ = newBasicNode("UnaryExp",
newIDNode($1), NULL, NULL);}
167 | ID '(' FuncRParams ')' {$$ = newBasicNode("UnaryExp",
newIDNode($1), $3, NULL);}
168 | '+' UnaryExp {$$ = newBasicNode("UnaryExp",
newExpr('+', NULL, $2), NULL, NULL);}
169 | '-' UnaryExp {$$ = newBasicNode("UnaryExp", newExpr('-',
', NULL, $2), NULL, NULL);}
170 | '!' UnaryExp {$$ = newBasicNode("UnaryExp",
newExpr('!', NULL, $2), NULL, NULL);}
171 ;
172
173 FuncRParams: Exp {$$ =
newNextNode("FuncRParams_list", $1, NULL);}
174 | FuncRParams ',' Exp {$$ =
newNextNode("FuncRParams_list", $1, $3);}
175 ;
176
177 MulExp: UnaryExp {$$ = $1;}
178 | MulExp '*' UnaryExp {$$ = newExpr('*', $1, $3);}
179 | MulExp '/' UnaryExp {$$ = newExpr('/', $1, $3);}
180 | MulExp '%' UnaryExp {$$ = newExpr('%', $1, $3);}
181 ;
182
183 AddExp: MulExp {$$ = $1;}
184 | AddExp '+' MulExp {$$ = newExpr('+', $1, $3);}
185 | AddExp '-' MulExp {$$ = newExpr('-', $1, $3);}
186 ;
187
188 RelExp: AddExp {$$ = $1;}
189 | RelExp '<' AddExp {$$ = newExpr('<', $1, $3);}
190 | RelExp LESSEQ AddExp {$$ = newDoubleExpr("<=", $1, $3);}
191 | RelExp GREATEQ AddExp {$$ = newDoubleExpr(">=", $1, $3);}
192 | RelExp '>' AddExp {$$ = newExpr('>', $1, $3);}
193 ;
194
195 EqExp: RelExp {$$ = $1;}
196 | EqExp EQ RelExp {$$ = newDoubleExpr("==", $1, $3);}
197 | EqExp NOTEQ RelExp {$$ = newDoubleExpr("!=", $1, $3);}
198 ;
199
200 LAndExp: EqExp {$$ = $1;}
201 | LAndExp AND EqExp {$$ = newDoubleExpr("&&", $1, $3);}
202 ;
203
204 LOrExp: LAndExp {$$ = $1;}
205 | LOrExp OR LAndExp {$$ = newDoubleExpr("||", $1, $3);}

```

```
206         ;
207
208 ConstExp: AddExp          {$$ = $1;}
209         ;
210
211 %%
212
```

## Makefile:

```
1 all: lrparser.tab.c lex.yy.c ast.c main.c genllvm.c
2     gcc -o genllvm lrparser.tab.c lex.yy.c ast.c genllvm.c main.c
3
4 lrparser.tab.c : lrparser.y
5     bison -d lrparser.y
6
7 lex.yy.c : lrlex.l
8     flex lrlex.l
```

## 九、 总结及心得体会：

(1)编写代码之前需要写出递归下降翻译器的伪代码，重点就是要找到对于每个非终结符的属性哪些是继承属性，哪些是综合属性。然后将继承属性作为参数，综合属性作为返回值，进行计算。利用实验二所写的递归下降分析器的伪代码做出改写，加入参数返回值以及一些初始化。

(2)编写代码的时候，需要用到实验一和实验二的代码，写实验一代码的时候没考虑到后面会用到，直接将结果输出并没有保存中间结果，以至于自己在编码的时候需要先将实验一的结果存放在一个自定义的结构体中，里面包含词法分析的两个因素：值和类型。而分析器分析的时候，直接调取这个结构体的内容，四元式的结果也会放在一个特殊的结构体，里面记录了四元式的四个值，方便输出。如果是数字运算式，可以模拟计算器对于这四个值进行计算，并且需要数组和判定运算符函数来判断是数字还是辅助变量，根据对应符号进行运算。

(3)通过这次实验，从词法分析到语法分析到语义分析的知识点有了大致的回顾，并且重点回顾了每个阶段输入什么，输出什么，这些信息怎么存储，用什么算法来计算。还需要进一步优化自己的代码，比如在这次的实验代码过程中，需要改进的是将词法分析和语法分析合并，降低时间复杂度，提高执行效率。

(4)通过这四次的实验过程，让我对于编译原理这门课有了比较清晰的认识，可能理论课当时听懂了，过一会可能会遗忘。但实验课不一样，花费了很久时间然后又是动手敲代码，又是写实验报告梳理思路更加深了对于这门课的理解。通过学习编译原理，感觉用到了数据结构，算法等思维理解，又需要对于许多概念的理解记忆。这也是这门课的难点所在。通过这次学习，懂得更要注重对于基础科目的掌握，不断加强和拓展自己的计算机思维。

通过完成这个实验，我能够更好地理解和实现编译过程中的关键步骤，尤其是中间代码生成这一重要技术。这项实验对于提升我的编程能力和培养良好的程序设计风格非常有帮助。同时，通过这个实验，我进一步加深了对编译技术中的中间代码生成算法的理解，并学会了使用中间代码生成的方法来根据给定的文法分析程序，并生成相应的中间代码表示。

此外，通过参与这个实验，我也获得了开发和调试编译程序的经验，对中间代码的生成过程有了更深入的理解。这个实验让我更加熟悉整个编译过程，并为我未来在编译器开发领域的学习和实践奠定了坚实的基础。

## 十、 对本实验过程及方法、手段的改进建议：无

**报告评分：**

**指导教师签字：**