Compiler Principle

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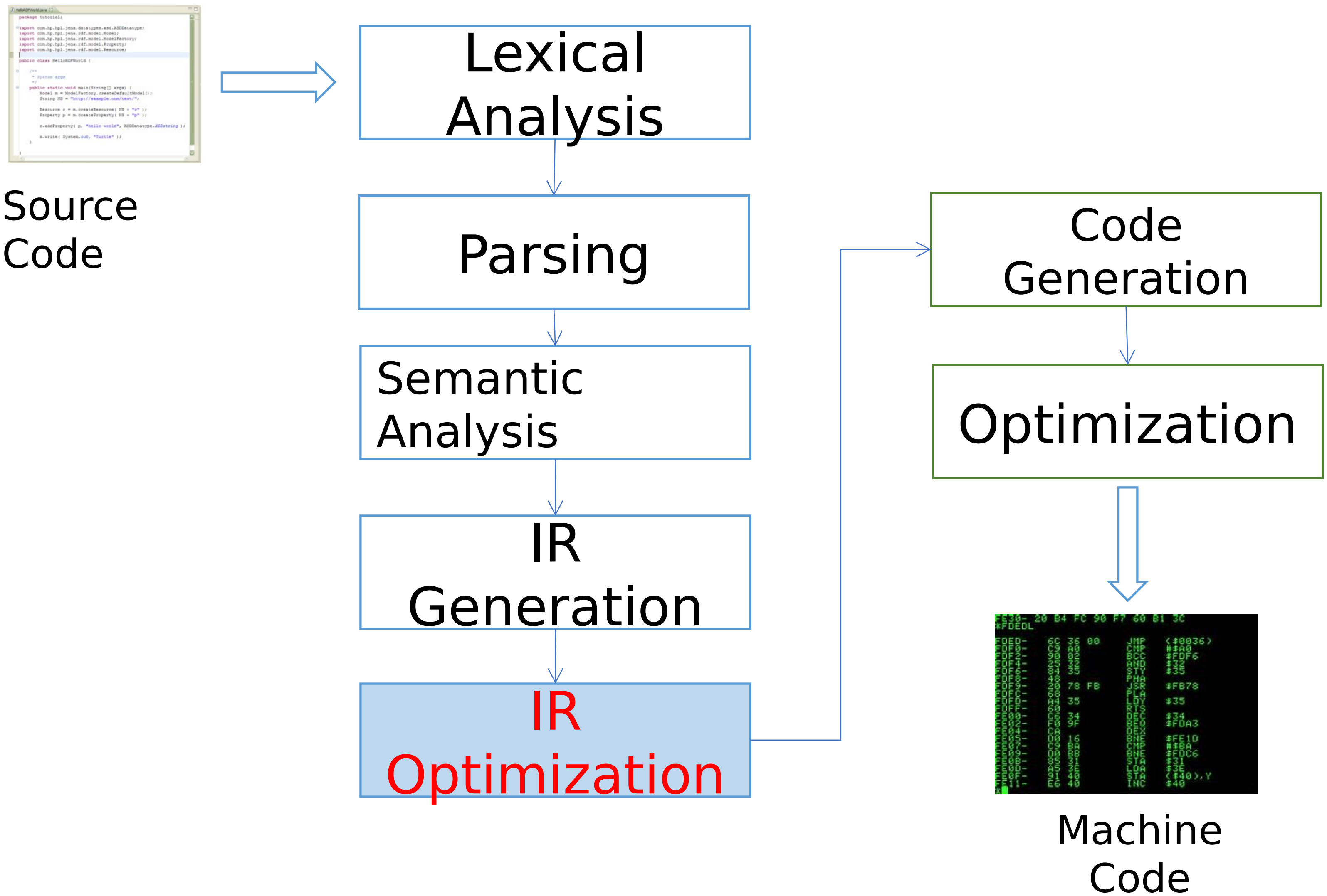
8 Basic Blocks and Traces

Where We Are



Source Code
Lexical Analysis
Parsing
Semantic Analysis
IR Generation
IR Optimization
Code Generation
Optimization
Machine Code

Introduction

- The Mismatches between Trees and machine-language programs
  - ✓ Tree language operators are chosen carefully to match the capabilities of most machines.
  - ✓ Some aspects do not correspond exactly with machine languages;
  - ✓ Some aspects of the Tree language interfere with compile-time optimization analyses.

Some of the Mismatches

- The CJUMP instruction can jump to either of two labels.
  - ✓ Real machines' conditional jump instructions fall through to the next instruction if the condition is false.

- ESEQ nodes within expressions are inconvenient.
  - ✓ Different orders of evaluating subtrees yield different results
- CALL nodes within expressions cause the same problem.

- CALL nodes within the argument-expressions of other CALL nodes will cause problems
  - ✓ When trying to put arguments into a fixed set of formal-parameter registers.

Three stages of the transformation

1. **A tree is rewritten into a list of canonical trees without SEQ or ESEQ nodes**

2. **This list is grouped into a set of basic blocks, which contain no internal jumps or labels**

3. **The basic blocks are ordered into a set of traces in which every CJUMP is immediately followed by its false label.**

The module *canon*

- **The tree-rearrangement functions:**

```
/* canon.h*/
Typedef struct C_stmListList_ *C_stmListList;
struct C_block { C_stmListList stmLists; Temp_label label;};
Struct C_stmListList_ { T_stmList head; C_stmListList tail;};

T_stmList C_linearize(T_stm stm);
Struct C_block C_basicBlocks(T_stmList stmList);
T_stmList C_traceSchedule(struct C_block b);
```

The module *canon*

- Linearize removes the ESEQs and moves the CALLs to top level.
- Basic Blocks groups statements into sequences of straight-line code.
- Trace Schedule orders the blocks so that every CJUMP is followed by its false label.

8.1 Canonical Trees

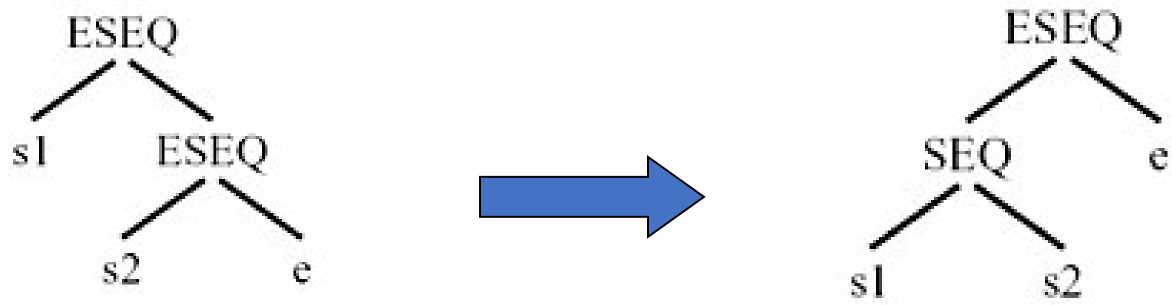
Definition of canonical tree

Canonical trees as having these properties:

1. No SEQ or ESEQ.
2. The parent of each CALL is either EXP(…) or MOVE(TEMP *t*, …).

Transformations on ESEQ

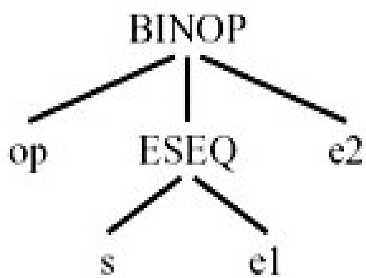
- The idea is to lift the ESEQ nodes higher and higher in the tree, until they can become SEQ nodes.



$\mathrm{ESEQ}(s_1, \mathrm{ESEQ}(s_2, e))$

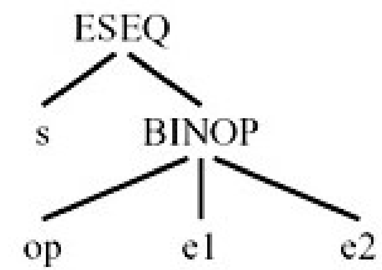
$\mathrm{ESEQ}(\mathrm{SEQ}(s_1, s_2), e)$

Transformations on ESEQ



$$\mathrm{BINOP}(op, \mathrm{ESEQ}(s, e_1), e_2)$$

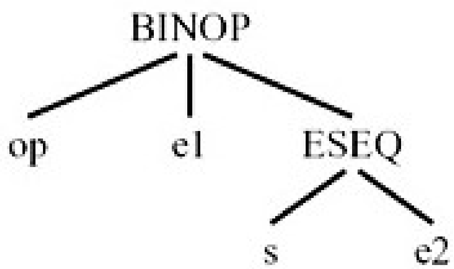
$$\mathrm{MEM}(\mathrm{ESEQ}(s, e_1))$$
$$\mathrm{JUMP}(\mathrm{ESEQ}(s, e_1))$$
$$\mathrm{CJUMP}(op, \mathrm{ESEQ}(s, e_1), e_2, l_1, l_2)$$

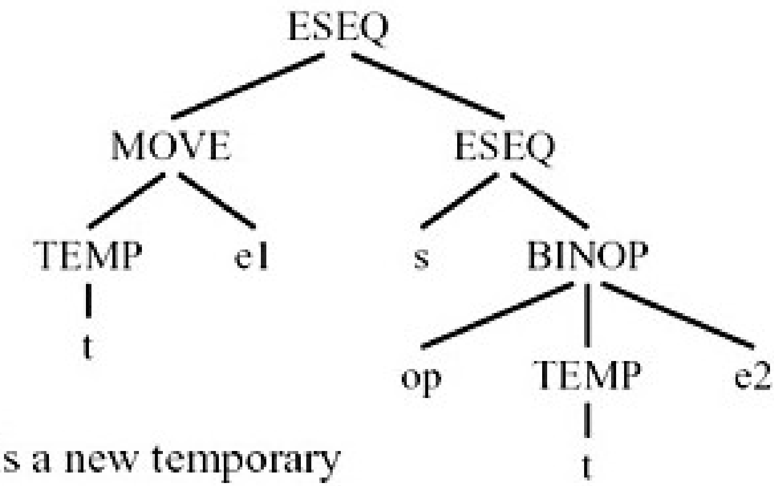


$$\mathrm{ESEQ}(s, \mathrm{BINOP}(op, e_1, e_2))$$

$$\mathrm{ESEQ}(s, \mathrm{MEM}(e_1))$$
$$\mathrm{SEQ}(s, \mathrm{JUMP}(e_1))$$
$$\mathrm{SEQ}(s, \mathrm{CJUMP}(op, e_1, e_2, l_1, l_2))$$

Transformations on ESEQ





t is a new temporary

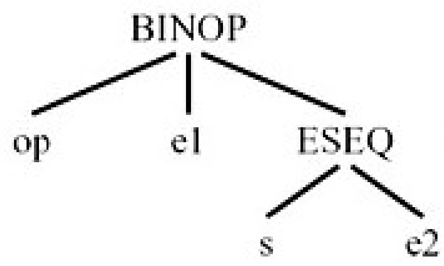
$\mathrm{BINOP}(op, e_1, \mathrm{ESEQ}(s, e_2))$

$\mathrm{ESEQ}(\mathrm{MOVE}(\mathrm{TEMP}\ t, e_1),$
$\quad \mathrm{ESEQ}(s, \mathrm{BINOP}(op, \mathrm{TEMP}\ t, e_2)))$

$\mathrm{CJUMP}(op, e_1, \mathrm{ESEQ}(s, e_2), l_1, l_2)$

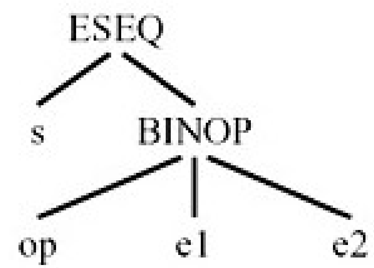
$\mathrm{SEQ}(\mathrm{MOVE}(\mathrm{TEMP}\ t, e_1),$
$\mathrm{SEQ}(s, \mathrm{CJUMP}(op, \mathrm{TEMP}\ t, e_2, l_1, l_2)))$

Transformations on ESEQ



if s, e_1 commute

$\Rightarrow$



if s, e_1 commute

$$\mathrm{BINOP}(op, e_1, \mathrm{ESEQ}(s, e_2)) \quad = \quad \mathrm{ESEQ}(s, \mathrm{BINOP}(op, e_1, e_2))$$

$$\mathrm{CJUMP}(op, e_1, \mathrm{ESEQ}(s, e_2), l_1, l_2) \quad = \quad \mathrm{SEQ}(s, \mathrm{CJUMP}(op, e_1, e_2, l_1, l_2))$$

Transformations on ESEQ

- The commute function estimates (very naively) whether a statement commutes with an expression:
  - ✓ A constant commutes with any statement .
  - ✓ The empty statement commutes with any expression.
  - ✓ Anything else is assumed not to commute.

General Rewriting Rules

- For each kind of Tree statement or expression, similar rules can be made to pull ESEQs out of the statement or expression.

[*e*1, *e*2, ESEQ(*s*, *e*3)]

s commute with e1, e2

(*s*; [*e*1, *e*2, *e*3])

*e*2 not commute with *s*

(SEQ(MOVE(t1, e1), SEQ(MOVE(t2, e2), s)); [TEMP(t1), TEMP(t2), e3])

*e*2 commutes with *s* but *e*1 does not

(SEQ(MOVE(t1, e1), s); [TEMP(t1), e2, e3])

Algorithm

- Step 1: Make a "subexpression-extraction" method for each kind.
- Step 2: make a “subexpression-insertion” method， given an ESEQ-clean version of each subexpression

```
typedef struct expRefList_ *expRefList
struct expRefList_ {T_exp *head; expRefList tail;};

struct stmExp {T_stm s; T_exp e;}

Static T_stm reorder(expRefList rlist);

Static T_stm do_stm(T_stm stm);
Static struct stmExp do_exp(T_exp exp);
```

Algorithm

- **Reoder: to pull out all the ESEQs out of a list of expression and combine the statement-parts of these ESEQ into one big T_stm**
- **Reoder(*l*) calls upon an auxiliary function do_exp on each expression in list *l***

```
static struct stmExp do_exp(T_exp exp){
Switch(exp->kind){
    case T_BINOP:
        return StmExp(reorder(ExpRefList(&exp->u.BINOP.left,
                      ExpRefList(&exp->u.BINOP.right,NULL))),exp);
    case T_MEM:
        return StmExp(reorder(ExpRefList(&exp->u.MEM, NULL)),exp);
    case T_ESEQ:{
       struct stmExp x=do_exp(exp->u.ESEQ.exp);
        return StmExp(seq(do_stm(exp->u.ESEQ.stm), x.s), x.e) ;
       }
     …
```

Algorithm

```
static T_stm do_stm(T_stm stm){
Switch(stm->kind){
    case T_SEQ:
        return seq(do_stm(stm->u.SEQ.left),
                          do_stm(stm->u.SEQ.right));
    case T_JUMP:
        return seq(reorder(ExpRefList(&stm-
>u.JUMP.exp, NULL)), stm);
     ...
```

- **With the assistance of do_exp and do_stm, the reorder function can pull the statement s*i* out the expression e*i* on its list of references ,going from right to left.**

Move CALLs to Top Level

BINOP(PLUS, CALL(…..), CALL(….))

- The Tree language permits CALL nodes to be used as subexpressions.
- Each function returns its result in the same dedicated return-value register TEMP(RV)
- The second call will overwrite the RV register before the PLUS can be executed.

Move CALLs to Top Level

- The idea is to assign each return value immediately into a fresh temporary register

  CALL(fun, args) $\rightarrow$

  ESEQ(MOVE(TEMP t, CALL(fun,args)), TEMP t)

A Linear List of Statements

- The linearize function repeatedly applies the rule

  SEQ(SEQ(a,b),c) = SEQ(a,seq(b,c))

- Just consider this to be a simple list of statements

  $s_1,s_2,s_3,s_4,\ldots\ldots\ldots s_{n-1},s_n$

  none of the s_i contain SEQ or ESEQ nodes

A Linear List of Statements

```
Static T_stmList linear(T_stm stm, T_stmList right)
{
   if (stm->kind == T_SEQ)
      return linear(stm->u.SEQ.left, linear(stm->u.SEQ.right,right));
  else return T_StmList(stm, right);
}

T_stmList C_linearize(T_stm stm){
     return linear(do_stm(stm), NULL);
```

The end of Chapter 8(1)