Programming Languages and Compiler Design

Intermediate-Code Generation

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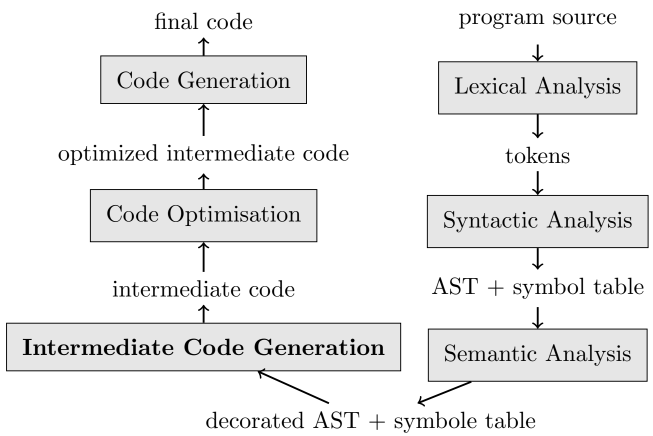
Intermediate Code Generation

Where are we in the compiler steps?



Intermediate Code Generation

We are interested in the **While** programming language with an abstract grammar that describes abstract syntax trees.

We consider the following problem:

Intermediate-Code Generation Problem

"Given an abstract syntax tree, how to generate 3*-address code?"*

About 3-address code

- General-purpose intermediate representation of programs.
- Many analysis can be performed on it.
- Easy to translate to assembly code.

Abstract Syntax

Syntactic Categories

Metavariables	Categories	Comments
a	AExp	arithmetical expressions
b	BExp	Boolean expressions
S	Inst	statements

Statements

$$\begin{array}{lcl} S & \rightarrow & name := a \mid \texttt{skip} \mid S;S \mid \texttt{If}\ b\ \texttt{then}\ S\ \texttt{else}\ S \\ & & \mid \texttt{while}\ b\ \texttt{do}\ S\ \texttt{od} \\ name & \rightarrow & x \mid tab[i] \mid tab[i,j] \end{array}$$

Arithmetical expressions

$$a \rightarrow n \mid x \mid a + a \mid tab[i] \mid tab[i,j]$$

Boolean expressions

$$b \rightarrow \texttt{True} \mid \texttt{False} \mid \neg b \mid b \wedge b \mid a = a \mid a < a$$

3-address code

We first define the *syntax* of 3-address code.

We use the following functions:

- Let `Name` be the space of names that can either:
  - appear in the program, or
  - are created by function `newTemp` : $\rightarrow$ `Name`.
- Let $\mathbb{N}$ be the set of natural numbers.
  There is a partial function

$$\texttt{val} : \textbf{Aexp} \rightarrow (\texttt{Name} \cup \mathbb{N}).$$

- Let $\mathcal{L}abel$ be the set of labels. They are created by function `newLabel` : $\rightarrow \mathcal{L}abel$

Meta-variables: $\mathrm{x} \in$ `Name` and $\mathrm{y}, \mathrm{z} \in (\texttt{Name} \cup \mathbb{N})$, $\mathrm{l} \in \mathcal{L}abel$.

Syntactic Categories and Grammar

Syntactic categories

Metavariables	Categories	Comments
C	Code	3-address code
op	Op$=\{+,-,*\}$	
oprel	Oprel$=\{<,>,=,\leq,\geq\}$	

Grammar

$$\begin{array}{lcl} \mathrm{C} & \rightarrow & \mathrm{x} := \mathrm{y}\ \mathrm{op}\ \mathrm{z} \mid \mathrm{x} := \mathrm{y} \\ & & \mid \texttt{if}\ \mathrm{y}\ \mathrm{oprel}\ \mathrm{x}\ \texttt{goto}\ \mathrm{l} \mid \texttt{goto}\ \mathrm{l} \\ & & \mid \mathrm{x} := \mathrm{y}[\mathrm{z}] \\ & & \mid \mathrm{y}[\mathrm{z}] := \mathrm{x} \end{array}$$

Principles of Code Generation

Our objective is to define 3-address code:

Code Generation Functions

$$\begin{array}{lcl} \texttt{GCodeAExp} & : & \mathrm{AExp} \rightarrow \mathrm{Code}^* \times (\texttt{Name} \cup \mathbb{N}) \\ \texttt{GCodeBExp} & : & \mathrm{BExp} \times \mathcal{L}abel \times \mathcal{L}abel \rightarrow \mathrm{Code}^* \\ \texttt{GCodeStm} & : & \mathrm{Inst} \rightarrow \mathrm{Code}^* \end{array}$$

where:

- Code* is the set of 3-address code sequences,
- the sequence delimiter is $\|$.

Code Generation for Arithmetical Expressions

We consider:

- 1-dimensional arrays with N elements ranging from 0 to $N-1$, and
- 2-dimensional arrays with $N \times M$ elements,
  where
  - N is the number of lines,
  - M is the number of columns.

The size of an element is T.

Access to an element

Consider a 2-dimensional array:

- if the array is sorted by columns:

$$Tab[i,j] \quad \text{is at} \quad N * T * j + i * T$$

- if the array is sorted by lines:

$$Tab[i,j] \quad \text{is at} \quad M * T * i + j * T$$

Code Generation for Arithmetical Expressions

GCodeAExp(x)	=		(ε,x)
GCodeAExp(n)	=		(ε,n)
GCodeAExp(tab[i])	=	Let	
			t1=newTemp, t2=newTemp
		in	(t_1 := T*i ||
			t_2 := tab[t_1],t_2)
GCodeAExp(tab[i,j])	=	Let	
			t1=newTemp(), t2=newTemp()
			t3=newTemp(), t4=newTemp()
			t5=newTemp()
		in	(t_1 := T*i ||
			t_2 := N$\times$ T||
			t_3 := $t_2 \times$ j ||
			t_4 := t_1+t_3 ||
			t_5 := tab[t_4],t_5)
GCodeAExp(a_1 + a_2)	=	Let	(C_1,t_1)=GCodeAExp(a_1),
			(C_2,t_2)=GCodeAExp(a_2),
			t=newTemp
		in	(C_1||C_2|| t := t_1+t_2,t)

Code Generation for Boolean Expressions

GCodeBExp($a_1 < a_2$, ltrue, lfalse)	=	Let	(C_1,t_1)=GCodeAExp(a_1),
			(C_2,t_2)=GCodeAExp(a_2),
		in	C_1||C_2||
			if $t_1 < t_2$
			goto ltrue ||
			goto lfalse
GCodeBExp($b_1 \wedge b_2$, ltrue, lfalse)	=	Let	l=newLabel()
		in	GCodeBExp(b_1, l, lfalse)||
			l:||
			GCodeBExp(b_2, ltrue, lfalse)
GCodeBExp($\neg$ b, ltrue, lfalse)	=		GCodeBExp(b, lfalse, ltrue)

Code Generation for Statements

Assignment and sequential composition

To each node of the abstract syntax tree, we associate code.

GCodeStm (x := a)	=	Let	(C,t)=GCodeAExp(a)
		in	C|| x := t
GCodeStm(tab[i] := a)	=	Let	t1=newTemp,
			(C,t)=GCodeAExp(a)
		in	(t_1 := T*i ||
			C || tab[t_1] :=t)
GCodeStm (S_1 ; S_2)	=	Let	C_1 = GCodeStm(S_1),
			C_2 = GCodeStm(S_2)
		in	C_1 || C_2

Code Generation for Statements

Iterative statement

GCodeStm (while b do S od)	=	Let	lbegin=newLabel(),
			ltrue=newLabel(),
			lfalse=newLabel()
		in	lbegin:||
			GCodeBExp(b, ltrue, lfalse)||
			ltrue:||
			GCodeStm(S)||
			goto lbegin||
			lfalse:

Code Generation for Statements

Conditional statement

GCodeStm (if b then S_1 else S_2)	=	Let	lnext=newLabel(),
			ltrue=newLabel(),
			lfalse=newLabel()
		in	GCodeBExp(b,ltrue,lfalse)||
			ltrue:
			GCodeStm(S_1)||
			goto lnext ||
			lfalse:||
			GCodeStm(S_2)||
			lnext:

Summary - Intermediate-Code Generation

Intermediate-Code Generation

- From `While` to 3-address code.
- 3-address code = general-purpose representation of code:
  - easy to generate,
  - suitable for optimization,
  - easy to generate to assembly code.
- Ready for optimization!