Compiler Construction

Chapter 5 – Code Generation (1)

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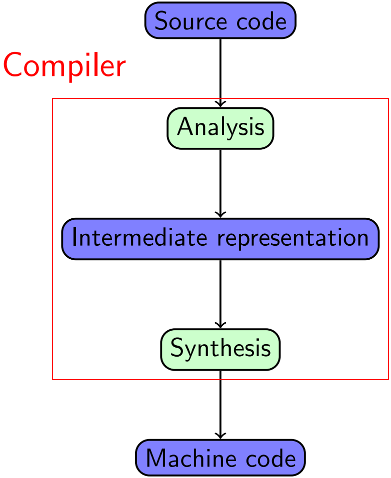
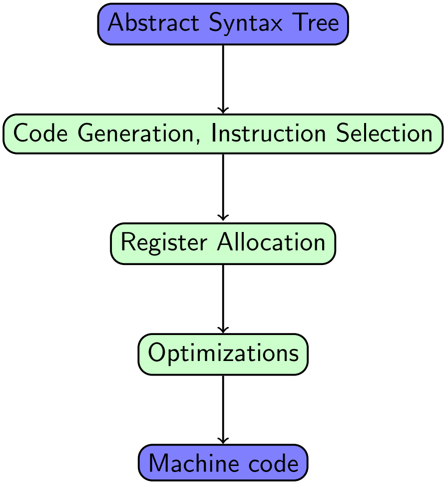
Compiler Overview



Synthesis Phase



Agenda

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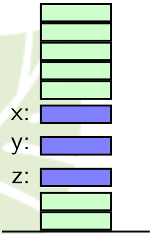
Code generation for

1. Expressions
2. (Sequence of) Statements
3. Conditionals
4. Loops
5. Arrays
6. Records
7. Pointer
8. Functions
9. Whole programs

Variables are stored in stack S at a certain address



- Associating variables with addresses happens during symbol table creation
- Addresses are stored in declaration nodes in the AST
- Every usage of a variable has a pointer to the variable's declaration node
- In the following, we assume an address environment ρ, which yields the (relative) address of each variable

L-Value and R-Value

- Variables are used in two different ways
- In an assignment `x = y + 1`, we are interested in the content of `y` and in the address of `x`
- l-value of `x`: address
- r-value of `x`: content

$\text{code}_R\ e\ \rho$	generates code to compute the r-value of e in address environment ρ
$\text{code}_L\ e\ \rho$	analogous for l-value

$\text{code}_R\ e_1 + e_2\ \rho$	$=$	$\text{code}_R\ e_1\ \rho$ $\text{code}_R\ e_2\ \rho$ `add` analogous for `mul`, ...
$\text{code}_R\ (-e)\ \rho$	$=$	$\text{code}_R\ e_1\ \rho$ `neg` analogous for `not`, ...
$\text{code}_R\ q\ \rho$	$=$	`loadc q`
$\text{code}_L\ x\ \rho$	$=$	`loadc` $\rho(x)$
$\text{code}_R\ x\ \rho$	$=$	$\text{code}_L\ x\ \rho$ `load`
$\text{code}_R\ x = e\ \rho$	$=$	$\text{code}_R\ e\ \rho$ $\text{code}_L\ x\ \rho$ `store`

- If e is an expression, then e; is a statement
- Statements do not return a value, hence the stack pointer is the same before and after
- code $e;\ \rho$ generates such code
- Note below: *stm* is a statement *stms* is a sequence of statements

code $e;\ \rho$	$=$	$\text{code}_R\ e\ \rho$ pop
code $stm\ stms\ \rho$	$=$	code $stm\ \rho$ code $stms\ \rho$

Code Generation for If

- Let s be the statement `if` (c) *stms*
- Generate code to evaluate c and to execute *stms*
- In between jump on zero to behind the code generated for `stms`

$$
\begin{array}{lcl}
\text{code } s\ \rho & = & \text{code}_R\ c\ \rho \\
 & & \texttt{jumpz A} \\
 & & \text{code } stms\ \rho \\
 & \text{A:} & \ldots
\end{array}
$$

Code Generation for If-Else

- Let s be the statement `if (c)` tt `else` ee
- Use similar strategy

$$
\boxed{
\begin{array}{lll}
\text{code } s\ \rho & = & \text{code}_R\ c\ \rho \\
 & & \texttt{jumpz A} \\
 & & \text{code } tt\ \rho \\
 & & \texttt{jump B} \\
 & \text{A:} & \text{code } ee\ \rho \\
 & \text{B:} & \ldots
\end{array}
}
$$

Example

Let $\rho = \{x \mapsto 4, y \mapsto 7\}$ and generate code s ρ for s being

$\texttt{if } (x > y) \qquad x = x - y; \qquad \texttt{else } y = y - x;$

- Let s be the statement `while` (e) s'
- We generate code as follows:

$$
\begin{array}{lll}
\text{code } s\ \rho & = & \\
 & \text{A:} & \text{code}_R\ e\ \rho \\
 & & \texttt{jumpz B} \\
 & & \text{code } s'\ \rho \\
 & & \texttt{jump A} \\
 & \text{B:} & \ldots
\end{array}
$$

Code Generation for For

- Let s be the statement `for` $(e_1; e_2; e_3)\ s'$
- Equivalent to $e_1;$ `while` $(e_2)\ \{s'\ e_3;\}$
- Therefore ...

code $s\ \rho$	$=$	$\text{code}_R\ e_1\ \rho$
		`pop`
	A:	$\text{code}_R\ e_2\ \rho$
		`jumpz B`
		code $s'\ \rho$
		$\text{code}_R\ e_3\ \rho$
		`pop`
		`jump A`
	B:	...

Example

Let $\rho = \{a \mapsto 7, b \mapsto 8\; c \mapsto 9\}$ and generate code $s\ \rho$ for s being

$$\texttt{while}\ (a > 0)\ \{c = c + 1;\ \ a = a - b;\}$$

Arrays

- Consider `int[11] a;`
- Array `a` contains 11 elements hence it occupies 11 cells
- $\rho(a)$ is the address of element `a[0]`

Size of Types

- We need to define the size $|\cdot|$ of a type (as in `sizeof`)

$$|t| = \begin{cases} 1 & \text{for base types } t \\ k \cdot |t'| & \text{if } t \equiv t'[k] \end{cases}$$

- For declarations $d \equiv t_1\ x_1; \ldots t_k\ x_k;$

$$\begin{array}{rcll} \rho(x_1) & = & 0 & \\ \rho(x_i) & = & \rho(x_{i-1}) + |t_{i-1}| & \quad \text{for } i > 1 \end{array}$$

- ρ and $|\cdot|$ are computed at compile time

- In C, an array is a pointer. A declared array a is a pointer constant with r-value the start address of a
- Hence for array e: $\text{code}_R\ e\ \rho = \text{code}_L\ e\ \rho$
- Let `t[c] a;` be an array declaration

$$\boxed{\begin{array}{lcl} \text{code}_L\ e_1[e_2]\ \rho & = & \text{code}_R\ e_1\ \rho \\ & & \text{code}_R\ e_2\ \rho \\ & & \texttt{loadc}\ |t| \\ & & \texttt{mul} \\ & & \texttt{add} \end{array}}$$

- Let `struct { int a; int b;} x;` be part of a declaration list
- `x` gets the first free cell of the record's space as relative address
- The components get addresses relative to the beginning of the record
  - $\rightarrow$ Here $\{a \mapsto 0, b \mapsto 1\}$
- Size and addresses of record t with component types t_i

$$|t| = \Sigma_{i=1}^{k} |t_i| \qquad \rho(c_1) = 0 \qquad \rho(c_i) = \rho(c_{i-1}) + |t_{i-1}|$$

$$\boxed{\begin{array}{lcl} \text{code}_L\ e.c\ \rho & = & \text{code}_L\ e\ \rho \\ & & \texttt{loadc}\ \rho(c) \\ & & \texttt{add} \end{array}}$$