Basic Block Code Generation

\[
\begin{align*}
X &:= Y + Z \\
Z &:= Z \times 5 \\
T7 &:= Z + 1 \\
Y &:= Z - T7 \\
X &:= Z + Y
\end{align*}
\]

- Generate code one basic block at a time.
- We don’t know which path through the flow-graph has taken us to this basic block. ⇒ We can’t assume that any variables are in registers.
- We don’t know where we will go from this block. ⇒ Values kept in registers must be stored back into their memory locations before the block is exited.

Load variables into registers.
Compute....
Store register values back into their memory locations.

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Next-Use Information

\[
\begin{align*}
X &:= Y + Z \\
Z &:= Z \times 5 \\
T7 &:= Z + 1 \\
Y &:= Z - T7 \\
X &:= Z + Y
\end{align*}
\]

- We want to keep variables in registers for as long as possible, to avoid having to reload them whenever they are needed.
- When a variable isn’t needed any more we free the register to reuse it for other variables. ⇒ We must know if a particular value will be used later in the basic block.
- If, after computing a value \( X \), we will soon be using the value again, we should keep it in a register. If the value has no further use in the block we can reuse the register.

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Next-Use Information II

X is live at (5)

\[(5) \quad X := \cdots \]
\[(14) \quad \cdots := \cdots X \cdots \]

- \( X \) is live at (5) because the value computed at (5) is used later in the basic block.
- \( X \)’s next_use at (5) is (14).
- It is a good idea to keep \( X \) in a register between (5) and (14).

X is dead at (12)

\[(12) \quad \cdots := \cdots X \cdots \]
\[(25) \quad X := \cdots \]

- \( X \) is dead at (12) because its value has no further use in the block.
- Don’t keep \( X \) in a register after (12).

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Next-Use Algorithm

- A two-pass algorithm computes next-use & liveness information for a basic block.

- In the first pass we scan over the basic block to find the end. Also:
  1. For each variable \( X \) used in the block we create fields \( X\.live \) and \( X\.next_use \) in the symbol table. Set \( X\.live:=\text{FALSE}; X\.next_use:=\text{NONE} \).

Next-Use Algorithm II

1. Scan forwards over the basic block:

   - Initialize the symbol table entry for each used variable, and the tuple data for each tuple.

2. Scan backwards over the basic block.

   For every tuple \((i): x := y \text{ op } z\) do:

   (a) Copy the live/next_use-info from \( x, y, z \)'s symbol table entries into the tuple data for tuple \((i)\).

   (b) Update \( x, y, z \)'s symbol table entries:

      - \( x\.live := \text{FALSE}; \)
      - \( x\.next_use := \text{NONE}; \)
      - \( y\.live := \text{TRUE}; \)
      - \( z\.live := \text{TRUE}; \)
      - \( y\.next_use := i; \)
      - \( z\.next_use := i; \)
Register & Address Descriptors

- During code generation we need to keep track of what's in each register (a **Register Descriptor**). One register may hold the values of several variables (e.g. after x := y).
- We also need to know where the values of variables are currently stored (an **Address Descriptor**). A variable may be in one (or more) register, on the stack, in global memory; all at the same time.

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Id</td>
<td>Memory</td>
</tr>
<tr>
<td>x</td>
<td>fp(16)</td>
</tr>
<tr>
<td>y</td>
<td>fp(20)</td>
</tr>
<tr>
<td>z</td>
<td>0x2020</td>
</tr>
<tr>
<td>t1</td>
<td></td>
</tr>
</tbody>
</table>

A Simple Code Generator

We have:

A **flowgraph**: We generate code for each individual basic block.

An **Address Descriptor (AD)**: We store the location of each variable: in register, on the stack, in global memory.

A **Register Descriptor (RD)**: We store the contents of each register.

**Next-Use Information**: We know for each point in the code whether a particular variable will be referenced later on.

We need:

GenCode(i: x := y op z): Generate code for the i:th intermediate code instruction.

GetReg(i: x := y op z): Select a register to hold the result of the operation.

**Machine Model**

- We will generate code for the address-register machine described in the book. It is a CISC, not a RISC; it is similar to the x86 and MC68k.

  - The machine has n general purpose registers R0, R1, ..., Rn.

MOV M, R Load variable M into register R.

MOV R, M Store register R into variable M.

OP M, R Compute R := R OP M, where OP is one of ADD, SUB, MUL, DIV.

OP R2, R1 Compute R1 := R1 OP R2, where OP is one of ADD, SUB, MUL, DIV.
GenCode((i): X := Y OP Z)

- L is the location in which the result will be stored. Often a register.
- Y' is the most favorable location for Y.
  i.e. a register if Y is in a register, Y's memory location otherwise.
1. L := GetReg(i: X := Y op Z).
2. Y' := “best” location for Y. IF Y is not in Y' THEN gen(MOV Y', L).
3. Z' := “best” location for Z.
4. gen(OP Z', L)
5. Update the address descriptor: X is now in location L.
6. Update the register descriptor: X is now only in register L.
7. IF (i).Y.next_use=None THEN update the register descriptor: Y is not in any register. Same for Z.

GetReg(i: X := Y op Z)

- If we won’t be needing the value stored in Y after this instruction, we can reuse Y's register.
1. IF
   - Y is in register R and R holds only Y
   - (i).Y.next_use=None
   THEN RETURN R;
2. ELSIF there's an empty register R available THEN RETURN R;
3. ELSIF
   - X has a next use and there exists an occupied register R
   THEN Store R into its memory location and RETURN R;
4. OTHERWISE RETURN the memory location of X.

Code Generation Example

<table>
<thead>
<tr>
<th>Interim. Code</th>
<th>Machine</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) x := y + z</td>
<td>MOV y, r0</td>
</tr>
<tr>
<td></td>
<td>ADD z, r0</td>
</tr>
<tr>
<td>(2) z := x * 5</td>
<td>MUL 5, r0</td>
</tr>
<tr>
<td>(3) y := z - 7</td>
<td>MOV r0, r1</td>
</tr>
<tr>
<td></td>
<td>SUB 7, r1</td>
</tr>
<tr>
<td>(4) x := z + y</td>
<td>MOV r0, z</td>
</tr>
<tr>
<td></td>
<td>ADD r1, r0</td>
</tr>
<tr>
<td></td>
<td>MOV r1, y</td>
</tr>
<tr>
<td></td>
<td>MOV r0, x</td>
</tr>
</tbody>
</table>

- Note that x and y are kept in registers until the end of the basic block. At the end of the block, they are returned to their memory locations.
### Code Generation Example II

<table>
<thead>
<tr>
<th>Intermediate</th>
<th>Machine</th>
<th>AD</th>
<th>RD</th>
<th>Live</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x := y + z$</td>
<td>MOV $y, r_0$</td>
<td>$r_0 = x$</td>
<td>$x = r_0$</td>
<td>$x = r_0$</td>
</tr>
<tr>
<td>$z := x - 7$</td>
<td>ADD $z, r_0$</td>
<td>$r_0 = z$</td>
<td>$z = r_0$</td>
<td>$z = r_0$</td>
</tr>
<tr>
<td>$y := z$</td>
<td>MUL 5, $r_0$</td>
<td>$r_0 = z$</td>
<td>$z = r_0$</td>
<td>$z = r_0$</td>
</tr>
<tr>
<td>$x := z$</td>
<td>SUB $z, r_0$</td>
<td>$r_0 = y$</td>
<td>$y = r_0$</td>
<td>$y = r_0$</td>
</tr>
</tbody>
</table>

### Code Generation Example III

<table>
<thead>
<tr>
<th>Intermediate</th>
<th>Machine</th>
<th>AD</th>
<th>RD</th>
<th>Live</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x := z + y$</td>
<td>MOV $r_0, z$</td>
<td>$z = r_0$</td>
<td>$z = r_0$</td>
<td>$z = r_0$</td>
</tr>
<tr>
<td>$x := z + y$</td>
<td>MOV $r_1, r_0$</td>
<td>$r_0 = x$</td>
<td>$x = r_0$</td>
<td>$x = r_0$</td>
</tr>
<tr>
<td>$x := z + y$</td>
<td>MOV $r_1, r_0$</td>
<td>$r_1 = y$</td>
<td>$y = r_1$</td>
<td>$y = r_1$</td>
</tr>
</tbody>
</table>

### Readings and References

- Read Louden:
  - *Generation of Intermediate Code*
    - 407–442
  - *Machine Code Generation*
    - 453–467
- This lecture is taken from the Dragon book:
  - *Next-Use Information*
    - 534–535
  - *Simple Code Generation*
    - 535–541
  - *Address & Register Descriptors*
    - 537

### Summary

- Register allocation requires **next-use information**, i.e. for each reference to $x$ we need to know if $x$'s value will be used further on in the program.
- We also need to keep track of what's in each register. This is sometimes called **register tracking**.
- We need a register allocator, a routine that picks registers to hold the contents of intermediate computations.