Reading Assignment


“On the Fly” Local Register Allocation

Allocate registers as needed during code generation.
Partition registers into 3 classes.

- Allocatable
  Explicitly allocated and freed; used to hold a variable, literal or temporary.
  On SPARC: Local registers & unused In registers.

- Reserved
  Reserved for specific purposes by OS or software conventions.
  On SPARC: %fp, %sp, return address register, argument registers, return value register.

• Work
  Volatile—used in short code sequences that need to use a register.
  On SPARC: %g1 to %g4, unused out registers.

Register Tracking

Improve upon standard getReg/freeReg allocator by tracking (remembering) register contents.

Remember the value(s) currently held within a register; store information in a Register Association List.

Mark each value as Saved (in memory) or Unsaved (in memory).

Each value in a register has a Cost. This is the cost (in instructions) to restore the value to a register.

Register Targeting

Allow “end user” of a value to state a register preference in AST or IR.

or

Use Peephole Optimization to eliminate unnecessary register moves.

or

Use preferencing in a graph coloring register allocator.
The cost of allocating a register is the sum of the costs of the values it holds.

\[ \text{Cost(register)} = \sum \text{cost(values)} \]

When we allocate a register, we will choose the cheapest one.

If 2 registers have the same cost, we choose that register whose values have the most distant next use. (Why most distant?)

**Costs for the SPARC**

<table>
<thead>
<tr>
<th>Cost</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Dead Value</td>
</tr>
<tr>
<td>1</td>
<td>Saved Local Variable</td>
</tr>
<tr>
<td>1</td>
<td>Small Literal Value (13 bits)</td>
</tr>
<tr>
<td>2</td>
<td>Saved Global Variable</td>
</tr>
<tr>
<td>2</td>
<td>Large Literal Value (32 bits)</td>
</tr>
<tr>
<td>2</td>
<td>Unsaved Local Variable</td>
</tr>
<tr>
<td>4</td>
<td>Unsaved Global Variable</td>
</tr>
</tbody>
</table>

### Register Tracking Allocator

```java
def getReg() {  
    if (\(∃ r ∈ \text{regSet and cost(r)} == 0\))   
        choose(r)  
    else {  
        c = 1;  
        while(true) {  
            if (\(∃ r ∈ \text{regSet and cost(r)} == c\)) {  
                choose r with cost(r) == c and most distant next use of associated values;  
                break;  
            }  
            c++;  
        }  
        \(\text{Save contents of r as necessary;}\)  
    }  
    return r;  
}
```

- Once a value becomes dead, it may be purged from the register association list without any saves.
- Values no longer used, but unsaved, can be purged (and saved) at zero cost.
- Assignments of a register to a simple variable may be delayed—just add the variable to the Register's Association List entry as unsaved.

The assignment may be done later or made unnecessary (by a later assignment to the variable)

- At the end of a basic block all unsaved values are stored into memory.
**Example**

```c
int a, b, c, d; // Globals
a = 5;
b = a + d;
c = b - 7;
b = 10;
```

**Naive Code**

```assembly
mov 5, %l0
st %l0, [a]
ld [d], %l1
add %l0, %l1, %l0
st %l0, [b]
ld %l1, %l0
sub %l0, 7, %l0
st %l0, [c]
mov 10, %l1
st %l0, [a]
st %l1, [b]
```

18 instructions are needed (memory references take 2 instructions)

**With Register Tracking**

```assembly
Instruction Generated %10 %11
mov 5, %l0
! Defer assignment to a
ld [d], %l1
!d unused after next inst
add %l0, %l1, %l1
!b is dead after next inst
sub %l1, 7, %l1
! %l1 has lower cost
st %l1, [c]
mov 10, %l1
! save unsaved values
st %l0, [a]
st %l1, [b]
```

12 instructions (rather than 18)

**Pointers, Arrays and Reference Parameters**

When an array, reference parameter or pointed-to variable is read, all unsaved register values that might be aliased must be stored.

When an array, reference parameter or pointed-to variable is written, all unsaved register values that might be aliased must be stored, then cleared from the register association list.

Thus if `a[3]` is in a register and `a[i]` is assigned to, `a[3]` must be stored (if unsaved) and removed from the association list.

**Optimal Expression Tree Translation— Sethi-Ullman Algorithm**


Goal: Translate an expression tree using the fewest possible registers.

Approach: Mark each tree node, N, with an Estimate of the minimum number of registers needed to translate the tree rooted by N.

Let RN(N) denote the Register Needs of node N.
In a Load/Store architecture (ignoring immediate operands):

\[
\text{RN(leaf)} = 1
\]

\[
\text{RN(Op)} = \\
\quad \text{If } \text{RN(Left)} = \text{RN(Right)} \\
\quad \quad \text{Then } \text{RN(Left)} + 1 \\
\quad \quad \text{Else Max(RN(Left), RN(Right))}
\]

Example:

\[
\begin{array}{c}
+3 \\
\downarrow \\
2 \\
\uparrow \\
A^1 \\
\downarrow \\
+3 \\
\downarrow \\
\text{Simple Expression Tree}
\end{array}
\]

**Key Insight of SU Algorithm**

Translate subtree that needs more registers first.

Why?

After translating one subtree, we'll need a register to hold its value. If we translate the more complex subtree first, we'll still have enough registers to translate the less complex expression (without spilling register values into memory).

**Specification of SU Algorithm**

TreeCG(tree *T, regList RL);

Operation:

- Translate expression tree T using only registers in RL.
- RL must contain at least 2 registers.
- Result of T will be computed into head(RL).

**Summary of SU Algorithm**

if T is a node (variable or literal)

load T into R1 = head(RL)

else (T is a binary operator)

Let R1 = head(RL)
Let R2 = second(RL)
if RN(T.left) >= Size(RL) and RN(T.right) >= Size(RL)
(A spill is unavoidable)
TreeCG(T.left, RL)
Store RL into a memory temp
TreeCG(T.right, RL)
Load memory temp into R2
Generate (OP R2,R1,R1)
elseif RN(T.left) >= RN(T.right)
TreeCG(T.left, RL)
TreeCG(T.right, tail(RL))
Generate (OP R1,R2,R1)
else
TreeCG(T.right, RL)
TreeCG(T.left, tail(RL))
Generate (OP R2,R1,R1)
Example (with Spilling)

Assume only 2 Registers;
RL = [%l0, %l1]

We Translate the left subtree first (using 2 registers), store its result into memory, translate the right subtree, reload the left subtree's value, then do the final operation.

Larger Example

Assume 3 Registers;
RL = [%l0, %l1, %l2]

Since right subtree is more complex, it is translated first.

ld [A], %l0
ld [B], %l1
sub %l0, %l1, %l0
st %l0, [temp]
ld [C], %l0
ld [D], %l1
add %l0, %l1, %l0
ld [temp], %l1
add %l1, %l0, %l0

ld [C], %l0
ld [D], %l1
add %l0, %l1, %l0
ld [E], %l1
ld [F], %l2
mul %l1, %l2, %l1
add %l0, %l1, %l0
ld [A], %l1
ld [B], %l2
sub %l1, %l2, %l1
add %l1, %l0, %l0
Refinements & Improvements

- Register needs rules can be modified to model various architectural features.

For example, Immediate operands, that need not be loaded into registers, can be modeled by the following rule:

\[ \text{RN(literal)} = 0 \text{ if literal may be used as an immediate operand} \]

- Commutativity & Associativity of operands may be exploited:

\[
\begin{align*}
\text{A}^1 & \text{ B}^1 \Rightarrow \text{C}^1 \\
\text{A}^1 & \text{ B}^1 \text{ C}^1 \text{ D}^1 \\
\text{A}^1 & \text{ B}^1 & \text{ C}^1 & \text{ D}^1
\end{align*}
\]

Is Minimizing Register Use Always Wise?

SU minimizes the number of registers used but at the cost of reduced ILP.

\[
\begin{align*}
\text{A}^1 & \text{ B}^1 \Rightarrow \text{C}^1 \\
\text{A}^1 & \text{ B}^1 \text{ C}^1 \text{ D}^1
\end{align*}
\]

Since only 2 registers are used, there is little possibility of parallel evaluation.

When more registers are used, there is often more potential for parallel evaluation:

\[
\begin{align*}
\text{A} & \text{ B} \Rightarrow \text{C} \\
\text{A} & \text{ B} & \text{ C} & \text{ D}
\end{align*}
\]

Here as many as four registers may be used to increase parallelism.