Compiler Optimisation
4-from-ssa – Conversion from SSA (addendum)

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Introduction

Things to watch out for when converting from SSA.

- Effect of optimisation
- Critical edges
- Lost copy problem
- Swap problem
Effect of Optimisation

Optimisations can prevent conversion by just merging variables

Example

\[ a = x + y \]
\[ b = x + y \]
\[ a = 17 \]
\[ c = x + y \]

Just a basic block
Effect of Optimisation

Optimisations can prevent conversion by just merging variables

Example

<table>
<thead>
<tr>
<th>Equation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( a_0 = x_0 + y_0 )</td>
<td>Convert to SSA. Note that ( b_0 ) and ( c_0 ) are copies of ( a_0 ).</td>
</tr>
<tr>
<td>( b_0 = x_0 + y_0 )</td>
<td></td>
</tr>
<tr>
<td>( a_1 = 17 )</td>
<td></td>
</tr>
<tr>
<td>( c_0 = x_0 + y_0 )</td>
<td></td>
</tr>
</tbody>
</table>
Effect of Optimisation

Optimisations can prevent conversion by just merging variables

<table>
<thead>
<tr>
<th>Example</th>
<th></th>
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<tbody>
<tr>
<td>$a_0 = x_0 + y_0$</td>
<td></td>
</tr>
<tr>
<td>$b_0 = a_0$</td>
<td></td>
</tr>
<tr>
<td>$a_1 = 17$</td>
<td>Optimise the redundant expressions. What will happen if we merge variables now?</td>
</tr>
<tr>
<td>$c_0 = a_0$</td>
<td></td>
</tr>
</tbody>
</table>
Effect of Optimisation

Optimisations can prevent conversion by just merging variables

Example

\[
\begin{align*}
  a &= x + y \\
  b &= a \\
  a &= 17 \\
  c &= a \ (x+y)
\end{align*}
\]

If we merge \(a_0\) and \(a_1\) back into \(a\), then \(c\) gets the wrong value

So, keep variables, use copies in predecessors of \(\phi\) nodes\(^1\)

---

\(^1\)As in lecture-3.
Critical Edges

Copies on predecessors difficult with *critical edges*.

**Critical Edge**

A CFG edge whose destination has multiple predecessors and whose source has multiple successors.

*Source has multiple successors*: a copy in the source means all of its successors get the copy. If the copy is live into them then potential semantics change.

*Destination has multiple predecessors*: If there was only one, we could put the copy in the destination and probably wouldn’t need the phi node anyway.
Lost copy problem

- Most SSA algorithms *split* critical edges
- Next example shows necessary splitting to prevent lost copy
Lost copy problem

Example

A simple loop

Convert to SSA
Lost copy problem

Example

\[ i_0 = 1 \]

\[ i_1 = \varphi(i_0, i_2) \]

\[ y_0 = i_1 \]

\[ i_2 = i_1 + 1 \]

\[ z_0 = y_0 + \ldots \]

Converted to SSA

\( y_0 \) now redundant

Optimisation: Replace uses with \( i_1 \) and remove definition
Lost copy problem

Example

\[ i_0 = 1 \]

\[ i_1 = \varphi(i_0, i_2) \]

\[ i_2 = i_1 + 1 \]

\[ z_0 = i_1 + \ldots \]

\[ y_0 \text{ removed} \]

Try to convert from SSA

Place copies without splitting
Lost copy problem

Example

\[ i_0 = 1 \]

\[ i_1 = i_0 \]

\[ i_1 = \varphi(i_0, i_2) \]

\[ i_2 = i_1 + 1 \]

\[ i_1 = i_2 \]

\[ z_0 = i_1 + \ldots \]

Copies placed

Now remove \( \phi \)
Lost copy problem

**Example**

\[ i_0 = 1 \]
\[ i_1 = i_0 \]
\[ i_2 = i_1 + 1 \]
\[ z_0 = i_1 + \ldots \]

Note: Back edge is critical and \( i_1 \) is live in to loop exit

Does \( z_0 \) use the same version of \( i_1 \) as before the copy?

*Instead, split loop’s back edge*
Lost copy problem

Example

\[
\begin{align*}
  i_0 &= 1 \\
  i_1 &= i_0 \\
  i_2 &= i_1 + 1 \\
  z_0 &= i_1 + \ldots \\
  i_1 &= i_2
\end{align*}
\]

Edge split keeps semantics

Extra jump can be expensive inside hot loops

Instead, use temporaries to remember correct values
Lost copy problem

Example

\[ i_0 = 1 \]
\[ i_1 = i_0 \]
\[ i_2 = i_1 + 1 \]
\[ t = i_1 \]
\[ i_1 = i_2 \]

Extra temporary in place

\[ z_0 = t + \ldots \]
Swap problem

- $\phi$ nodes execute simultaneously in parallel
  - i.e. All read their operands at once, before any assignments
- Copies do not
  - Naive conversion with copies can cause incorrect behaviour

Example

<table>
<thead>
<tr>
<th>Simultaneous phis, swap values</th>
<th>Naive copy, swap lost(^2)</th>
<th>Temporary inserted</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_1 = \phi(x_0, y_1)$</td>
<td>$x_1 = y_1$</td>
<td>$t = x_1$</td>
</tr>
<tr>
<td>$y_1 = \phi(y_0, x_1)$</td>
<td>$y_1 = x_1$</td>
<td>$y_1 = t$</td>
</tr>
</tbody>
</table>

\(^2\)Assume $x_1 = x_0, y_1 = y_0$ placed in another block.
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