DAG-Based Optimization
of IR Code in a Basic Block

Directed Acyclic Graph (DAG)

Look at one Basic Block at a time
\(<x, v, w> := f(x, b, z)\)

Construct a DAG from the IR.
Generate code from the DAG.
Generate IR Code
Generate Target Code

Leaves
Represent initial values on entry to the block
• Variables
• Constants

Interior Nodes
Labelled by operators
Also:
Each interior node may have an attached list of variable names
Example

Source Code:
```
repeat
    prod := prod + A[i] * B[i];
    i := i + 1;
until i > 20;
```

IR:
```
t1 := 4 * i
r2 := A[t1]
t3 := 4 * i
t4 := B[t4]
t5 := t2 * t4
t6 := prod + t5
prod := t6
t7 := i + 1
i := t7
```

Assume each array element is 4 bytes

- Go through IR instructions.
- For each operation construct a new node.
- Label each node.
- Re-use existing nodes, when possible.

Mappings

Functions:
- Domain
- Range

Supply an element from the domain...
The function returns an element from the range.
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Supply an element from the domain...
The function returns an element from the range.

Definition: A “Mapping”
A data structure that implements a function.
Can be updated.

Examples:
- A mapping from Strings to Integers. (e.g., a phone book)
- A mapping from Variables to VarDecls (e.g., a symbol table)
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Examples:
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A mapping from Variables to VarDecls (e.g., a symbol table)

Basic Operations:
- Lookup (key) → value
- AddEntry (key, value)
- DeleteEntry (key)
- etc...

Visual Representations

<table>
<thead>
<tr>
<th>key</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Porter&quot;</td>
<td>725-4039</td>
</tr>
<tr>
<td>&quot;Brown&quot;</td>
<td>725-1234</td>
</tr>
<tr>
<td>&quot;Tolmach&quot;</td>
<td>725-3434</td>
</tr>
<tr>
<td>&quot;Fant&quot;</td>
<td>725-7654</td>
</tr>
<tr>
<td>&quot;Antoy&quot;</td>
<td>725-4050</td>
</tr>
<tr>
<td>&quot;Mocas&quot;</td>
<td>725-8899</td>
</tr>
</tbody>
</table>
Visual Representations

key          value

- "Porter"   725-4039
- "Brown"    725-1234
- "Tolmach"  725-3434
- "Antoy"    725-4050
- "Mocas"    725-8899

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Implementation

A Mapping from small Integers to ...
Use an Array

If the key is something more complex...
Can still use an array.
**Implementation**

A Mapping from small Integers to ...

Use an Array

If the key is something more complex...
Can still use an array.

More complex implementation ideas:

- Objects, Pointers
- Linked Lists
- Arrays
- Binary Trees
- Hash Tables

Basic Operations:

- Lookup (key) → value
- AddEntry (key, value)
- DeleteEntry (key)
- ...etc...

**Building the DAG**

Need a mapping

Call it “CurrentNode”

FROM: Variable Names
TO: Nodes in the DAG

CurrentNode (x) points to the node currently labelled with “x”.

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Building the DAG

Need a mapping
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Algorithm to Construct the DAG

Go through the Basic Block (in order)
For each IR in the block...
Add to the growing DAG...
Assume we have a binary IR instruction, such as
x := y ⊕ z
If CurrentNode(y) is undefined...
Create a leaf named “y₀”.
Set CurrentNode(y) to point to it.
If CurrentNode(z) is undefined...
<same>
Look for a node labelled “⊕”
with left child = CurrentNode(y)
and right child = CurrentNode(z)
(If none found, then create one.)
Call this node N.
Delete x from the list of ID’s attached
to CurrentNode(x).
Add x to the list of ID’s attached to N.
Set CurrentNode(x) to point to N.
Algorithm to Construct the DAG

If we have a unary operation, such as
\[ x := -y \]

If `CurrentNode(y)` is undefined...
    Create a leaf named “\( y_0 \)”.  
    Set `CurrentNode(y)` to point to it.  
Look for a node labelled “-”  
    with child = `CurrentNode(y)`  
    (If none found, then create one.)  
Call this node \( N \).  
Delete \( x \) from the list of ID’s attached to `CurrentNode(x)`.  
Add \( x \) to the list of ID’s attached to \( N \).  
Set `CurrentNode(x)` to point to \( N \).

Algorithm to Construct the DAG

If we have a copy operation
\[ x := y \]

If `CurrentNode(y)` is undefined...
    Create a leaf named “\( y_0 \)”.  
    Set `CurrentNode(y)` to point to it.  
Let \( N = CurrentNode(y) \).
Delete \( x \) from the list of ID’s attached to `CurrentNode(x)`.  
Add \( x \) to the list of ID’s attached to \( N \).  
Set `CurrentNode(x)` to point to \( N \).
Example

IR Code:
\[ x := x \times 3 \]
\[ y := y + x \]
\[ x := y - z \]
\[ y := x \]

IR Code:
\[ \ldots \]

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**Example**

**IR Code:**

\[
\begin{align*}
x & := x \times 3 \\
y & := y + x \\
x & := y - z \\
y & := x
\end{align*}
\]

**IR Code:**

```
+ y
y_0
- z
x_0

* x
0 3

x

+ y
y_0

* x
0 3

x
```

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Example

**IR Code:**

\[
\begin{align*}
x & := x \times 3 \\
y & := y + x \\
x & := y - z \\
y & := x
\end{align*}
\]

Topological Sort

An ordering of the nodes of the DAG. Each node must be listed after all its children.

**Idea:**
Find a topological order of nodes. Evaluate a node after all its children have been evaluated. ...and before it is needed by its parents!

**Summary:**
- Build DAG
- Find topological order
- Regenerate IR instructions.
To Regenerate the IR Code
Look at each node, in topological order...

Some of the labels have been removed from the list.

Of the remaining labels
see which are LIVE at the end of the Basic Block.

Ignore the DEAD variables; select a live variable.
(If no LIVE variables, create a temp variable.)
To Regenerate the IR Code
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Look at each node, in topological order...

Some of the labels have been removed from the list.

Of the remaining labels
see which are LIVE at the end of the Basic Block.

Ignore the DEAD variables; select a live variable.
(If no LIVE variables, create a temp variable.)

Generate an IR instruction for the operation.
Generate copies for any additional LIVE variables.

Example

Before:
\[
\begin{align*}
t_1 & := 4 \times i \\
t_2 & := A[t_1] \\
t_3 & := 4 \times i \\
t_4 & := B[t_4] \\
t_5 & := t_2 \times t_4 \\
t_6 & := \text{prod} + t_5 \\
\text{prod} & := t_6 \\
t_7 & := i + 1 \\
i & := t_7 \\
\text{if } i \leq 20 & \text{ goto BB9}
\end{align*}
\]

Now:
\[
\begin{align*}
t_1 & := 4 \times i \\
t_2 & := A[t_1] \\
t_4 & := B[t_4] \\
t_5 & := t_2 \times t_4 \\
\text{prod} & := \text{prod} + t_5 \\
i & := i + 1 \\
\text{if } i \leq 20 & \text{ goto BB9}
\end{align*}
\]

Assume all “i” variables Are DEAD after this BB
Assignments to Arrays

- \( x := A[i] \)
- \( A[j] := 43 \)
- \( z := A[i] \)

Problems

Will “\( x \)” and “\( z \)” be set to the same value?
Possibly not!!!
Assignments to Arrays

\[ x := A[i] \]
\[ A[j] := 43 \]
\[ z := A[i] \]

The Optimized Code:

\[ x := A[i] \]
\[ z := x \]
\[ A[j] := 43 \]

Indirect Assignments (through pointers)

\[ x := *p \]
\[ *q := z \]
\[ z := *p \]

Will “x” and “z” be set to the same value? Possibly not!!!

“Equivalenced” Names

\[ x := y + i \]
\[ w := 43 \]
\[ z := y + i \]

What of “w” is another Name for “y”??
Solution #1
Put things like
A[..] := ...
*p := ...
call ...
into their own blocks.

Solution #2
When building the DAG...
We try to re-use nodes
Look for a node labelled “+” with operands “x” and “y”...
If found, use that node.
Else, create a new node.

Array Accesses -- always do the fetch from the array
Pointer Indirection -- always do the fetch from memory
Also, we need to impose some order constraints.

Order Restrictions
x := A[i]
A[j] := y
z := A[i]
Order Restrictions

\[
x := A[i]
\]
\[
A[j] := y
\]
\[
z := A[i]
\]
Order Restrictions

\[ x := A[i] \]
\[ A[j] := y \]
\[ z := A[i] \]

Must follow

Add special edges the DAG to show the order restrictions.
Order Restrictions

...[...] := ...

... := ...[...]

*<p> := ...

... x ...

call ...

... x ...

call ...

... := ...

...[...] := ...

... := ...[...]

*<p> := ...

... x ...

call ...

... x ...

call ...