Phases of a compiler

Figure 1.6, page 5 of text
Basic Blocks
&
Flow Graphs
Basic blocks and flow graphs

- To help us analyze the intermediate code we will group instructions from our program into "basic blocks".
A basic block is a "maximal sequence of consecutive three-address instructions with the properties that, 

a) the flow of control can only enter the basic block through the first instruction in the block [...]

b) control will leave the block without halting or branching, except possibly at the last instruction in the block"

[p. 526]
"The basic blocks become the nodes of a flow graph, whose edges indicate which blocks can follow which other blocks."

[p 526]
"Algorithm 8.5 [p. 526]
INPUT: a sequence $B$ of three-address instructions.
OUTPUT: a list of basic blocks for $B$, in which each instruction is assigned to exactly one basic block
METHOD: First, find leaders (see below). For each leader, its basic block consists of itself and all instructions up to but not including the next leader, or the end of the intermediate program." [lightly edited from original]

"The rules for finding leaders are:
1) The first three address instruction (3AI) in the intermediate code is a leader.
2) Any instruction that is the target of a (conditional or unconditional) jump is a leader.
3) Any instruction that immediately follows a (conditional or unconditional) jump is a leader." [lightly edited from original]
This code initializes a 10x10 real matrix to the identity matrix (1's along the main diagonal).

Assumptions:
matrix is of size 10x10 containing reals
a real occupies 8 bytes
matrix is stored in row-major form (see p. 382)
A possible three-address code translation of the high-level program.
Identifying leaders

L 1) \( i = 1 \)
2) \( j = 1 \)
3) \( t1 = 10 \times i \)
4) \( t2 = t1 + j \)
5) \( t3 = 8 \times t2 \)
6) \( t4 = t3 - 88 \)
7) \( a[t4] = 0.0 \)
8) \( j = j + 1 \)
9) if \( j \leq 10 \) goto (3)
10) \( i = i + 1 \)
11) if \( i \leq 10 \) goto (2)
12) \( i = 1 \)
13) \( t5 = i - 1 \)
14) \( t6 = 88 \times t5 \)
15) \( a[t6] = 1.0 \)
16) \( i = i + 1 \)
17) if \( i \leq 10 \) goto (13)

Leaders are:
1. first instruction
Identifying leaders

1) \( i = 1 \)
2) \( j = 1 \)
3) \( t_1 = 10 \times i \)
4) \( t_2 = t_1 + j \)
5) \( t_3 = 8 \times t_2 \)
6) \( t_4 = t_3 - 88 \)
7) \( a[t_4] = 0.0 \)
8) \( j = j + 1 \)
9) if \( j \leq 10 \) goto (3)
10) \( i = i + 1 \)
11) if \( i \leq 10 \) goto (2)
12) \( i = 1 \)
13) \( t_5 = i - 1 \)
14) \( t_6 = 88 \times t_5 \)
15) \( a[t_6] = 1.0 \)
16) \( i = i + 1 \)
17) if \( i \leq 10 \) goto (13)

Leaders are:
1. first instruction
2. the target of any jump

L
Identifying leaders

1. \( i = 1 \)
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14. \( t_6 = 88 \times t_5 \)
15. \( a[t_6] = 1.0 \)
16. \( i = i + 1 \)
17. if \( i \leq 10 \) goto (13)

Leaders are:
1. first instruction
2. the target of any jump
3. the instruction immediately after any jump
8.4.3 Flow Graphs

Each basic block is a node in the flow graph.

There is an edge between blocks B and C of the flow graph if:

1. there is a (conditional or unconditional) jump from the end of B to the start of C, or
2. C immediately follows B and B does not end with an unconditional jump.
Terminology

- B is a predecessor of C
- C is a successor of B
Flow Graph

Figure 8.9 [p. 530]

Entry and exit nodes added.

Jump targets replaced by block names.
8.4.2 Liveness and next-use

"Knowing when the value of a variable will be used next is essential for generating good code. If the value of a variable that is currently in a register will never be referenced subsequently, then that register can be assigned to another variable."
8.4.2 Liveness and next-use

i: \[ x = \ldots \] assuming there are no assignments to \( x \) between \( i \) and \( j \)

j: \[ \ldots = x \text{ op } \ldots \]

If statement \( j \) uses \( x \), then \( x \) is live at \( i \). Since we need the value of \( x \) we should try to keep it in a register.
8.4.2 Liveness and next-use

\[ i: \quad \ldots x \ldots \]
\[ \quad \text{assuming there} \]
\[ \quad \text{is no use of } x \]
\[ \quad \text{between } i \text{ and } j \]

\[ j: \quad x = \ldots \]

Statement \( j \) overwrites old value of \( x \); we say \( x \) is dead at \( i \). This means we need not preserve that value in a register.
Algorithm 8.7 [p. 528]
Determining the liveness and next-use information for each statement in a basic block.

**INPUT:** A basic block B of three address instructions. Assume the symbol table initially shows all non-temporary variables in B as being live on exit.

**OUTPUT:** At each statement i: \( x = y + z \) in B, we attach to i the liveness and next-use information for x, y, and z.

**METHOD:** We start at the last statement in B and scan backwards to the beginning of B. At each statement i: \( x = y + z \) in B do the following:

1) attach to statement i the information currently found in the symbol table regarding the next-use and liveness of x, y, and z.
2) In the symbol table, set x to "not live" and "no next use".
3) In the symbol table, set y and z to "live" and the next uses of y and z to instruction i.

Not this instruction specifically, but instructions of the form \( x = y \) op \( z \), \( x = \) op \( y \), or \( x = y \).
Code Transformations on basic blocks

- Local optimizations can be performed on code inside basic blocks.
- Represent code inside a basic block as a DAG.
- The basic blocks will themselves be connected to form a flow graph.
1. For each variable in the block, create a node representing the variable's initial value.

2. For each statement $s$ in the block, create a node $N$.

"The children of $N$ are those nodes corresponding to statements that are the last definitions, prior to $s$, of the operands used by $s."
Constructing DAG for basic blocks

3. For each node representing a statement, label it with the operator applied.

4. For each node representing a statement, attach a list of the variables for which it is the last definition within the block.
Constructing DAG for basic blocks

5. For each node representing a statement, its children are the nodes that are the last definitions of the operands used in the statement.

6. Identify as output nodes those whose variables are live on exit from the block ("their values may be used later, in another block of the flow graph")
Example 8.10 [p. 534]

1) $a = b + c$
2) $b = a - d$
3) $c = b + c$
4) $d = a - d$
Example 8.10 [p. 534]

1. For each variable in the block, create a node representing the variable’s initial value.

Apply the "value-number" method from section 6.1.1.

1) \( a = b + c \)
2) \( b = a - d \)
3) \( c = b + c \)
4) \( d = a - d \)
Example 8.10 [p. 534]

Apply the "value-number" method from section 6.1.1

2. For each statement \(s\) in the block, create a node \(N\).

3. For each node representing a statement, label it with the operator applied.

4. For each node representing a statement, attach a list of the variables for which it is the last definition within the block.

\[
\begin{align*}
1) & \quad a = b + c \\
2) & \quad b = a - d \\
3) & \quad c = b + c \\
4) & \quad d = a - d
\end{align*}
\]
Example 8.10 [p. 534]

1) \(a = b + c\)

2) \(b = a - d\)

3) \(c = b + c\)

4) \(d = a - d\)

Apply the "value-number" method from section 6.1.1
Example 8.10 [p. 534]

Apply the "value-number" method from section 6.1.1

1) \( a = b + c \)
2) \( b = a - d \)
3) \( c = b + c \)
4) \( d = a - d \)
Example 8.10 [p. 534]

Apply the "value-number" method from section 6.1.1

1) \[a = b + c\]
2) \[b = a - d\]
3) \[c = b + c\]
4) \[d = a - d\]
Example 8.10 [p. 534]

If $b$ is live on exit:

1) $a = b + c$
2) $b = a - d$
3) $c = b + c$
4) $d = b$

Diagram:

```
+  +
|  |
|  |
|  |
a  d
```

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+  -
|  |
|  |
|  |
b  c
```

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+  -
|  |
|  |
|  |
b  c
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+  -
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|  |
b  c
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+  -
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b  c
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+  -
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b  c
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b  c
```

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+  -
|  |
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|  |
b  c
```
Example 8.10 [p. 534]

If b is not live on exit:

1) \( a = b + c \)
2) \( d = a - d \)
3) \( c = d + c \)
Next time

- Introduce a simple algorithm to generate assembly language code.

- The algorithm is presented in terms of a generic assembly language.

- In project 4 you must adapt this and other algorithms covered to our target assembly language.