Chapter 6. Code Optimization

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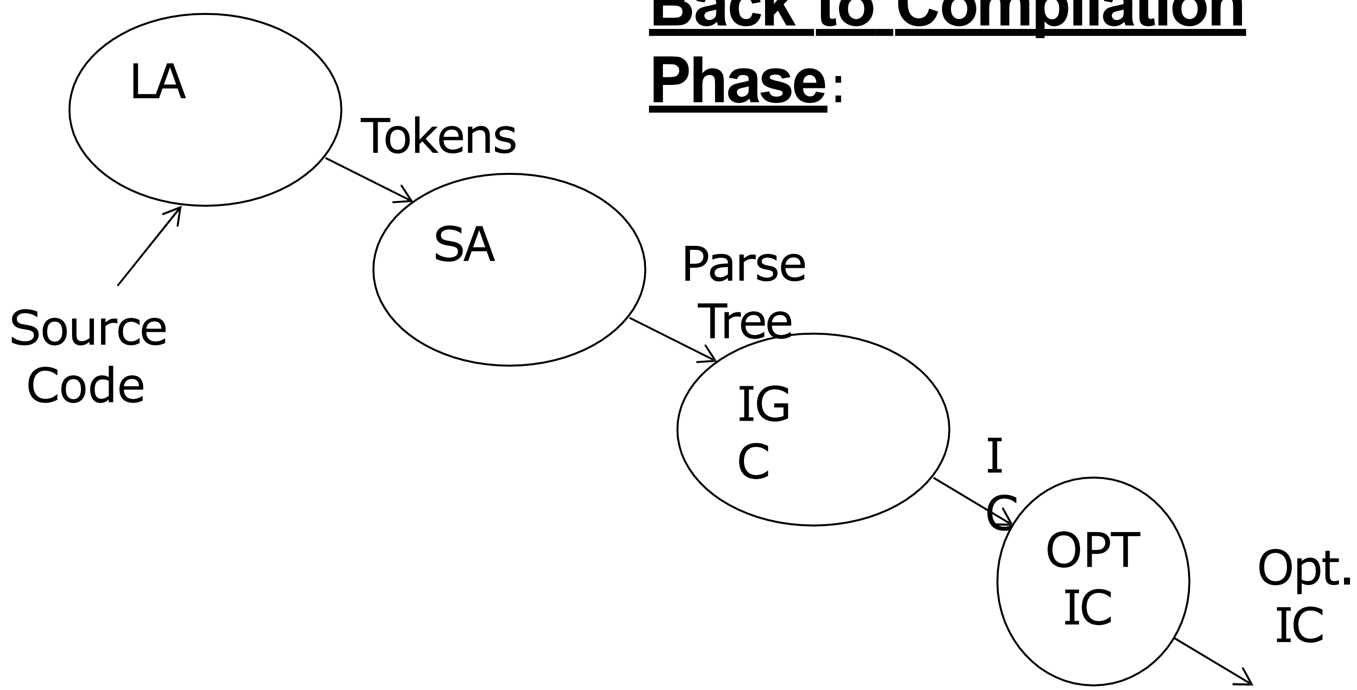
Back to Compilation Phase:



6.1 Introduction

Optimization is an attempt to simplify and to remove as many unnecessary and redundant 3AC/Assembly instructions

two types of optimization

- machine independent (optimization on IC)
- machine dependent (optimization on assembly)

E.g. machine independent Opt.

t = a +b
x = t

=> x = a+b (Simplify)

t1 = a*b
c = t1 + 1
t2 = a*b
d = t2 + 2

(t2 = a * b is not necessary)

=> d = t1 + 2

6.2 Machine independent optimizations

6.2.1 Basic Optimizations

a) constant folding: Pre-computation of the results at the compilation time

e.g.,

x = 2*3 => x = 6

b) constant propagation: replace all constant values during compilation time

e.g.,

tax_rate = 8.25 /* constant and tax_rate does not change */

=> change all tax_rate to 8.25 during compilation time

c) Reduction in strength: replace an expensive operator with a "cheaper" operator

e.g.,

$a = x^2$

=> $= x * x$

why?

$a = x^2$

=> in 3 AC

t1 = ln (x)

t2 = 2 * t1

a = exp (t2)

Expensive !

d) dead code elimination: eliminates code that is never executed or does nothing useful

e.g.,

```
if ( 5 < 3) .....                    /* never can be executed */
```

or

```
X =5;  /* assigned but never used */
…
X =7;  /* reassignment without the using previous assignment */
```

6.2.2. Loop Optimization

a) Loop invariant expressions:
take out the invariant expressions from the loop

e.g.,

```
for k = 1 to 100 do
    c[k] = 2 * (p-q*x) * (n-k+1)
```

=>

```
t1 = p-q*x
c[k] = t1 * (n-k+1)
```

b) loop unrolling: unroll nested loops to simple loops

e.g.,

```
for i = 1 to
    200 do  for j = 1
        to 2 do  write
            (x[i,j])
```

=>

```
for i = 1 to 200 do
write (x[i, 1], x[i,
    2])
```


which saves loop

6.2.3 Removing redundant 3 ACs

E.g.,
Source: x = (a+b) * (a+b)

3AC:
t1 = a+b
t2 = a+b
t3 = t1 * t2
x = t2
=>
t1 = a+b
x = t1 * t1
(from 4 instructions to 2 instructions)

How?

<u>3 steps</u>

Step 1:Generate modified DAG (Directed Acyclic Graph) of the

3AC Step 2: Sort the nodes in DAG Topologically

Step 3: Traverse the soft list backwards and generate 3 ACs

e.g.,

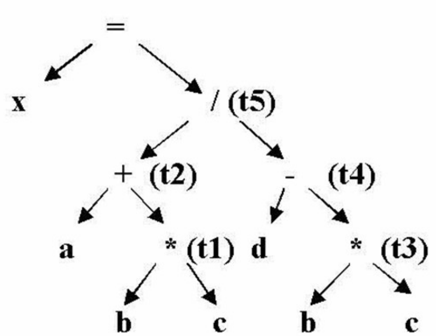
source: x = (a+ b*c) / (d - b*c)

3ACs:

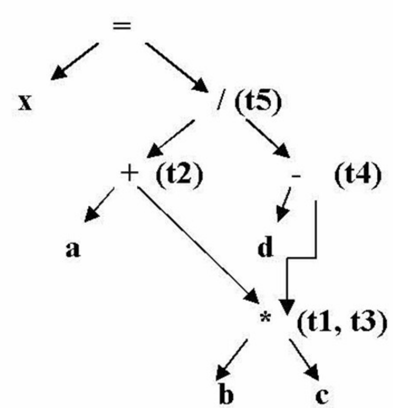
1. t1 = b*c
2. t2 = a + t1
3. t3 = b*c (not necessary)
4. t4 = d -t3
5. t5 = t2 / t4 (not necessary)
6. x = t5 (x = t4/t2)

Step 1: Create modified DAG of the 3 ACs
Directed Acyclic Graph: AST but one sub-tree per expression

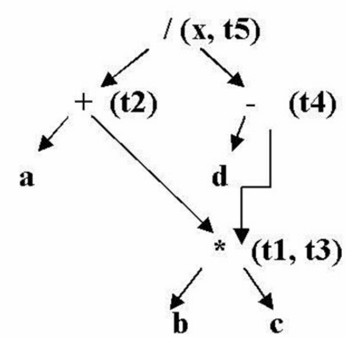
a) AST



b) DAG
Eliminate same expressions



c) modified DAG

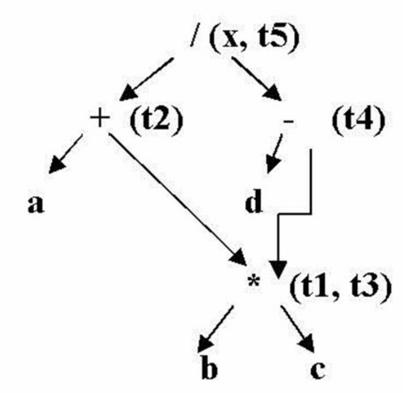


Step 2: Topological Sort

Set n =1
repeat

- select any source favoring left child & assign the number n
-

=>
n = 1 x, t5
n = 2 t2
n = 3 a
n = 4 t4
n = 5 d
n = 6 t1, t3
n = 7 b
n = 8 c



Step 3: Traverse the nodes (n) backwards and generate 3 ACs

```
1. t1 = b * c
2. t4 = d - t1
3. t2 = a + t1
4. x =  t2 / t4
```

Result: two instructions are eliminated

6.3 Machine Dependent Optimization

Peep-hole optimization

Look at the generated assembly code thru a small moving window (peep-hole) over few instructions at a time and do small scale optimization within that window

1. Redundant load/store elimination

a = b+c **a = b+c & d = a+e**

LOAD R0 = b
ADD R0 = c
STORE a, R0

2. Flow of control optimization: Avoid jumps on jumps

2. Jump-Over-Jump

Source:
repeat
...
until i = limit

```
loop-start
......

L       Rx, i
CMP     Rx, limit
je      loop-exit
jump    loop-start

loop-exit
```

=>

```
loop-start
......

L       Rx, i
CMP     Rx, limit
jne     loop-start

loop-exit
```

6.4 6.4 Data Flow Analysis (DFA)

We know how to optimize within a "basic block". (Ex. Removing a redundant 3Acs)
If we want optimize between blocks, we need to do DFA.

- Basic Block: A basic block is a sequence of 3 AC instructions that are executed sequentially, from the beginning till the end, i.e., no Branches

Ex. in terms of source code

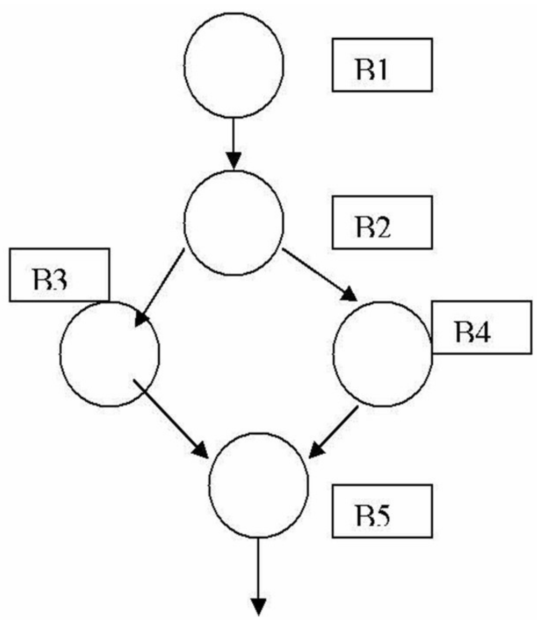
X1 B1
X2
If (a > b) then
B2
Begin B3
A1
A2
End
Else
b3

B4
Y1
B5

2. Definitions

We can express the blocks in terms of Flow Graph (FG)

FG is a directed graph in which each node is a basic block and the edges show the transfer off controls.



Predecessor of a node Bj: Bi is predecessor if Bj, if there is an edge from I to j

Also, then Bj is a successor of Bi.

Ex. B2 is a successor of B1 and B2 is a predecessor of B3 /B4

3. **<u>Forms of DFA</u>**

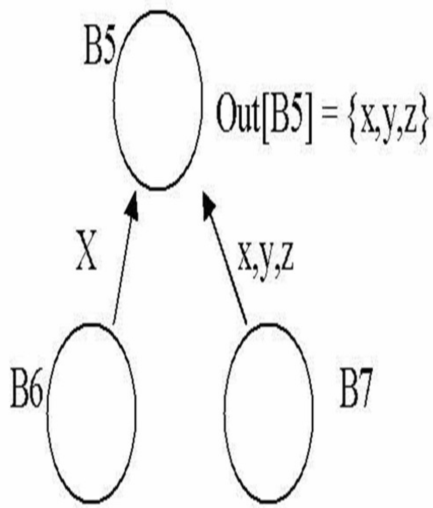
Forward Analysis : Examines Blocks from the First to the Last
Backward Analysis: Examines Block from the Last to First

In Each Flow Analysis: All Path and Any Path Analysis

⇒Total 4 different: Forward (Any and All Paths)
and Backward (Any and All Paths) Analysis.

•Each Analysis gives 3 unique equations

Example: Backward and Any Path Analysis



EQ1: OUT [Bj] = U IN [Bi]

Bi succ Bj

Ex.. IN[B6] = {x} IN[B7] = {x,y,z} => OUT [B5] = {x,y,z}

EQ2: IN[Bj] = USED[Bj] U (OUT[Bj] – Kill [Bj])

Kill: Expression is killed if operands is changed (ex. New assignment)

EQ3: OUT[Bn] = { }

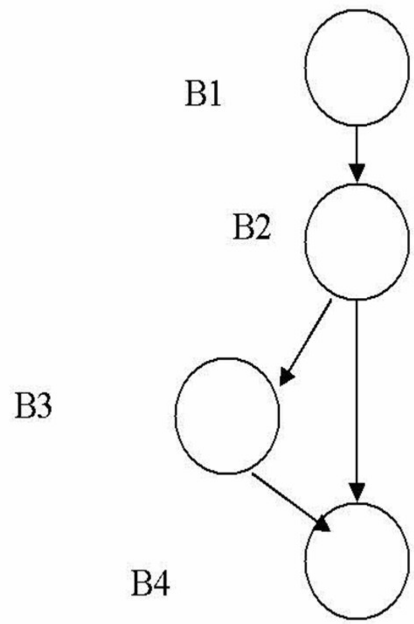
What is wrong with this code?

```
Procedure DFA
 Int a, b;

{
    get(a);
    if (a = 3)
        b = a;
    put (a, b);
    }
```

Use of the Backward-Any Path Analysis
(Find Initialized Variable)

Procedure DFA
Int a, b;

```
{
    get(a);          B1
    if (a = 3)
        b = a;       B2
    put (a, b);
}                    B3

                     B4
```



OUT[B4] = { }
IN [B4] = {a,b}

OUT[B3] = {a,b}
IN [B3] = {a} U ({a,b} – {b}) = {a}

OUT[B2] = {a} U {a,b} = {a,b}
IN [B2] = {a} U ({a,b} – { }) = {a,b}

OUT[B1] = {a,b}
IN [B1] = { } U ({a,b} – {a}) = {b}

⇨ IN[B1] = {b}
⇨ B is NOT defined prior to B1
⇨ Error

EQ1: OUT [Bj] = U IN [Bi]
Bi succ Bj

EQ2: IN[Bj] = USED[Bj] U (OUT[Bj] – Kill [Bj])
Kill: Expression is killed if operands is changed (ex. New assignment)

EQ3: OUT[Bn] = { }

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