Single Static Assignment

CSE 401 Section 10/10

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Adapted from Laura Vonesson's Wi17 Slides

The Final Stretch

 You are here

SUN	MON	TUE	WED	THU	FRI	SAT
				 Compiler Additions		Report M501 Additions
M501 Report Evals!!			Review Session (4:30 EEB 045)	**Final Exam** (8:30)	**Eternal Mastery of Compilers** →	

Problem 1

(review of dataflow)

Single Static Assignment

- An intermediate representation where each variable has only one definition:

Original		**SSA Form**
a := x + y		a_1 := x + y
b := a – 1	⇨	b_1 := a_1 – 1
a := y + b		a_2 := y + b_1
b := x * 4		b_2 := x * 4
a := a + b		a_3 := a_2 + b_2

SSA: Why We Love It

- Without SSA, all definitions and uses of a variable get mixed together
  - Computing information about the definitions of a variable is an expensive but necessary part of many dataflow analyses

- Doing the work of converting to SSA once makes many analyses + optimizations more efficient
  - SSA can be thought of as an implicit representation of Definition/Use chains

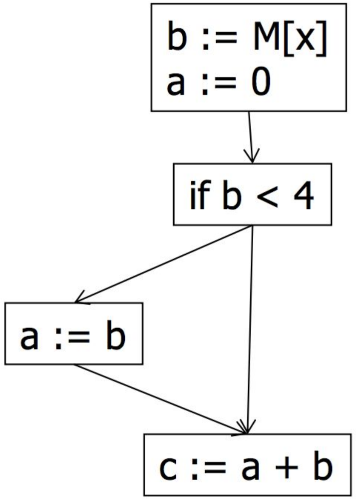
SSA: Why We Love It

- Ex: Dead Store Elimination
  - Without SSA: Compute live variables at every point, which requires working backwards and using the dataflow sets to check for *any path* that does not kill the variable, and eliminate any stores that are not to a live variable.
  - With SSA: Eliminate any store where the variable being assigned has 0 uses.

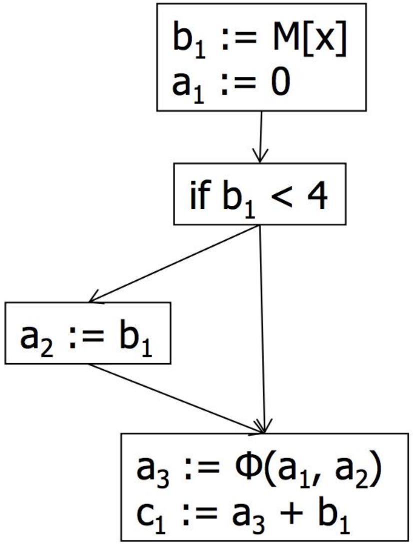
Phi-Functions

- A method of representing an uncertain value for a certain definition
  - Not a “real” instruction -- only a formality needed for SSA

Original



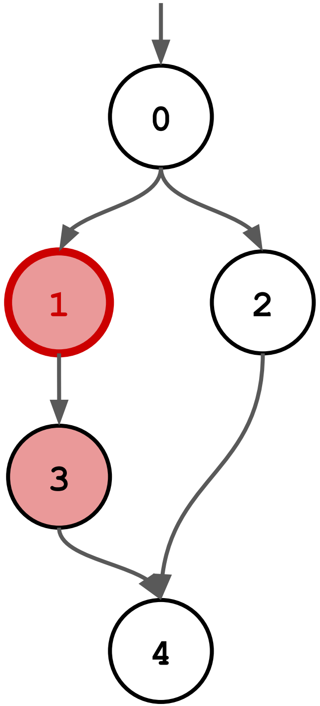
SSA Form



Dominators

- A node **X** ***dominates*** a node **Y** iff every path from the entry point of the control flow graph to **Y** includes **X**

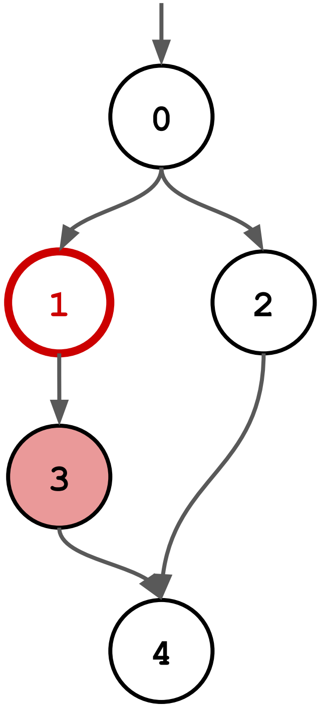
Node 1 dominates nodes 1 and 3.
It does not dominate 4 because there is another path that reaches it.



Strict Dominance

- A node **`X`** ***strictly dominates*** a node **`Y`** if **`X`** dominates **`Y`** and **`X`** ≠ **`Y`**.

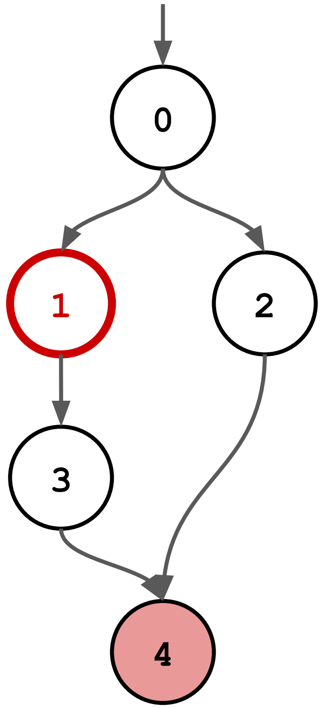
Node 1 only strictly dominates node 3 because it is the only dominated node that is not equal to 1.



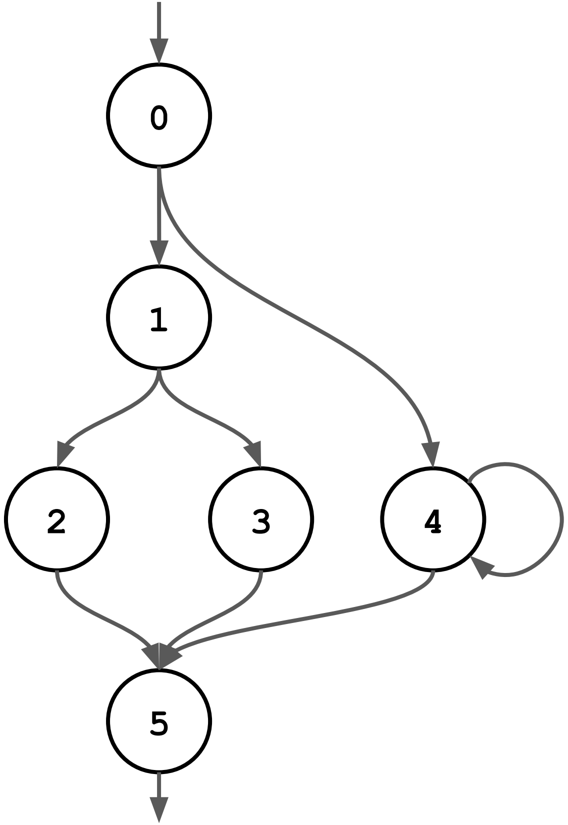
Dominance Frontiers

- A node **`Y`** is in the ***dominance frontier*** of node **`X`** if **`X`** dominates an immediate predecessor of **`Y`** but **`X`** does not strictly dominate **`Y`**.
- Essentially, the border between dominated and non-dominated nodes
    - Note: a node can be in its own dominance frontier
- This is where phi function merging is necessary

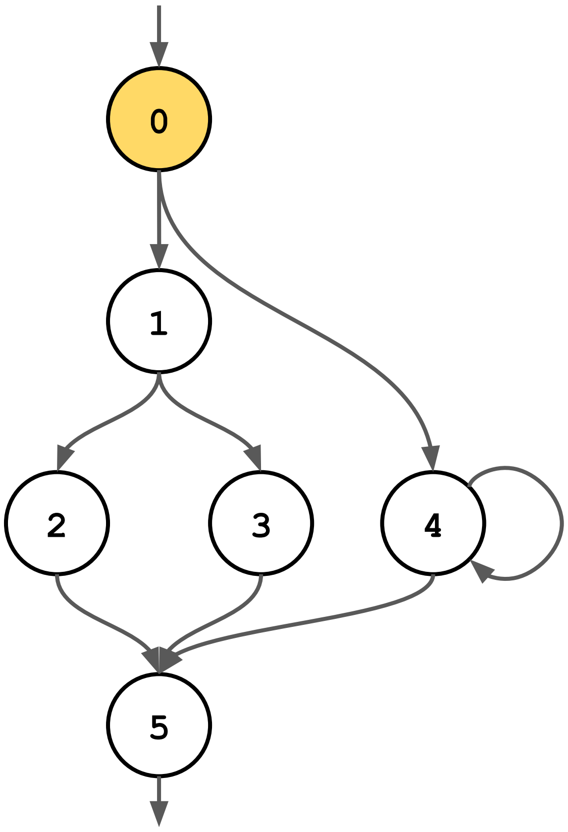
Node 4 is in the dominance frontier of node 1 because an immediate predecessor (node 3) is dominated by 1.



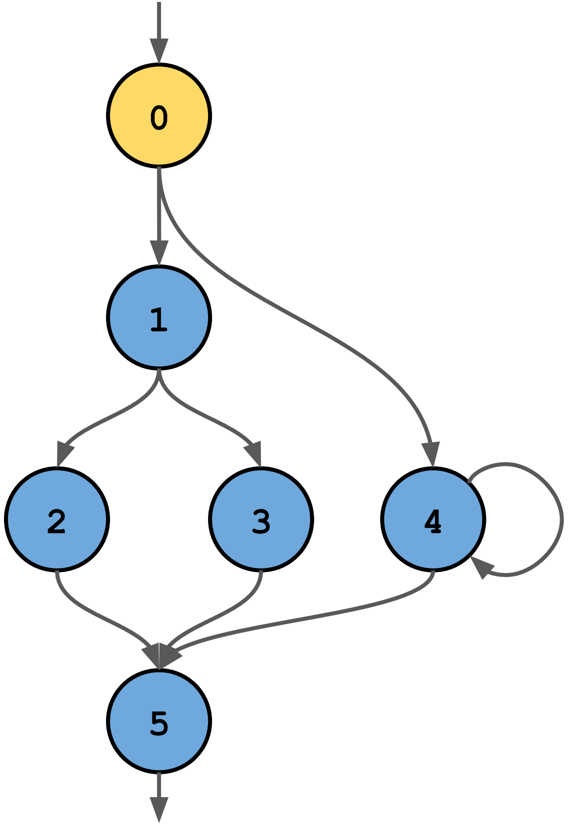
Problem 2



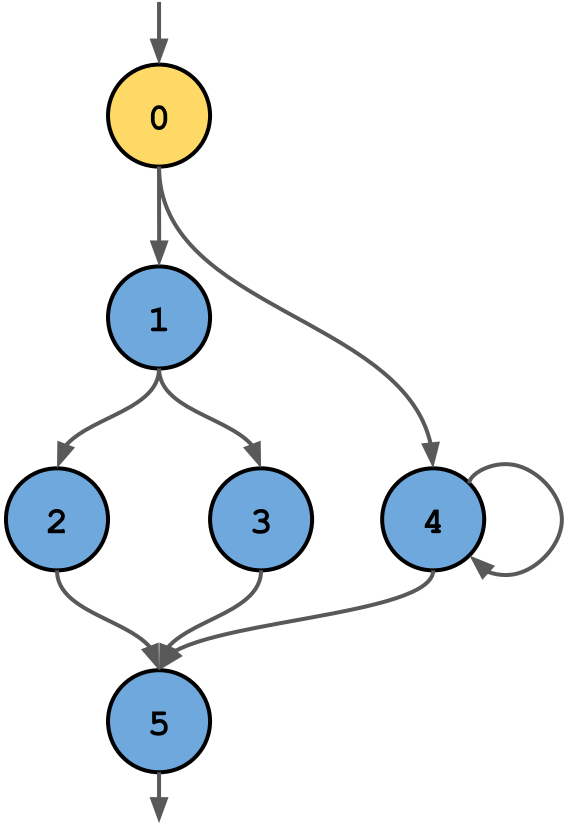
NODE	STRICTLY DOMINATES	DOMINANCE FRONTIER
0		
1		
2		
3		
4		
5		



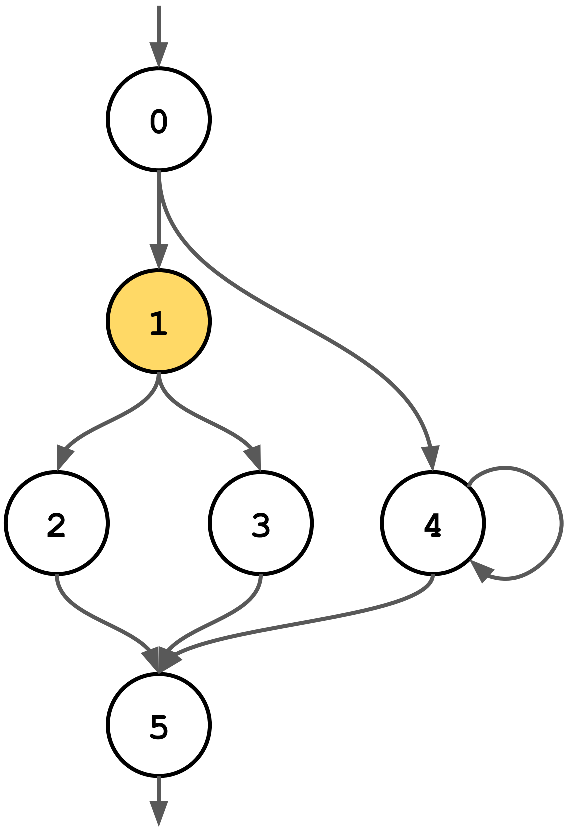
NODE	STRICTLY DOMINATES	DOMINANCE FRONTIER
0		
1		
2		
3		
4		
5		



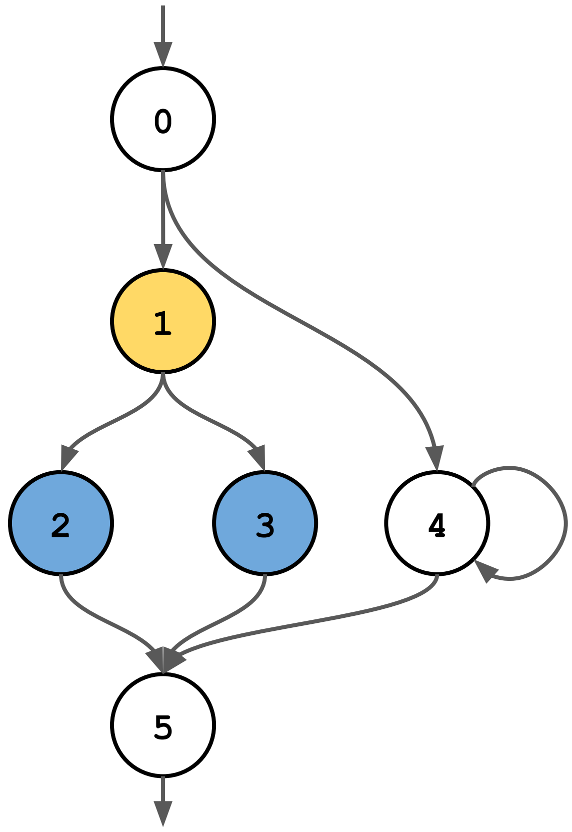
NODE	STRICTLY DOMINATES	DOMINANCE FRONTIER
0	1, 2, 3, 4, 5	
1		
2		
3		
4		
5		



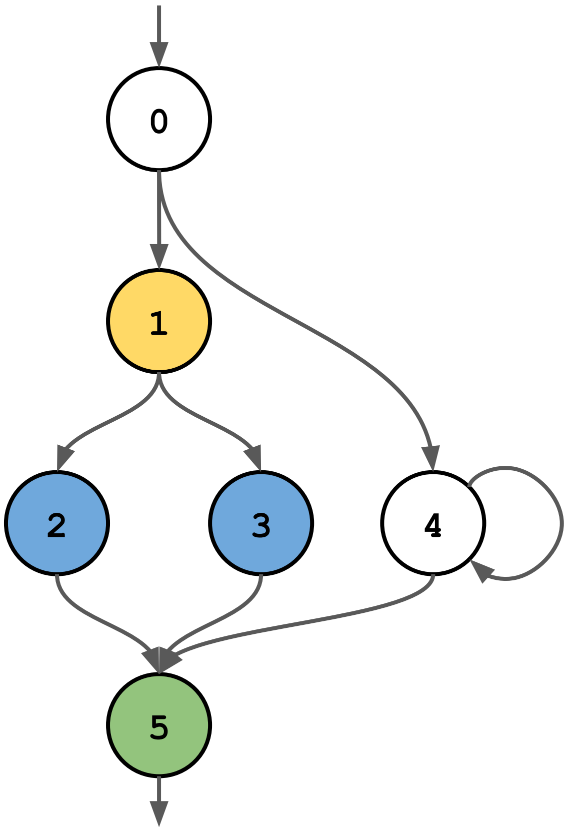
NODE	STRICTLY DOMINATES	DOMINANCE FRONTIER
0	1, 2, 3, 4, 5	∅
1		
2		
3		
4		
5		



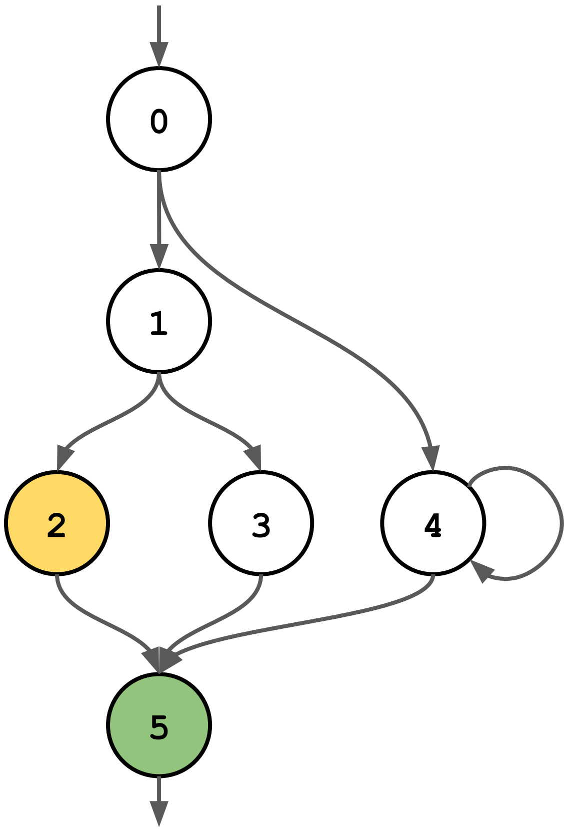
NODE	STRICTLY DOMINATES	DOMINANCE FRONTIER
0	1, 2, 3, 4, 5	∅
1		
2		
3		
4		
5		



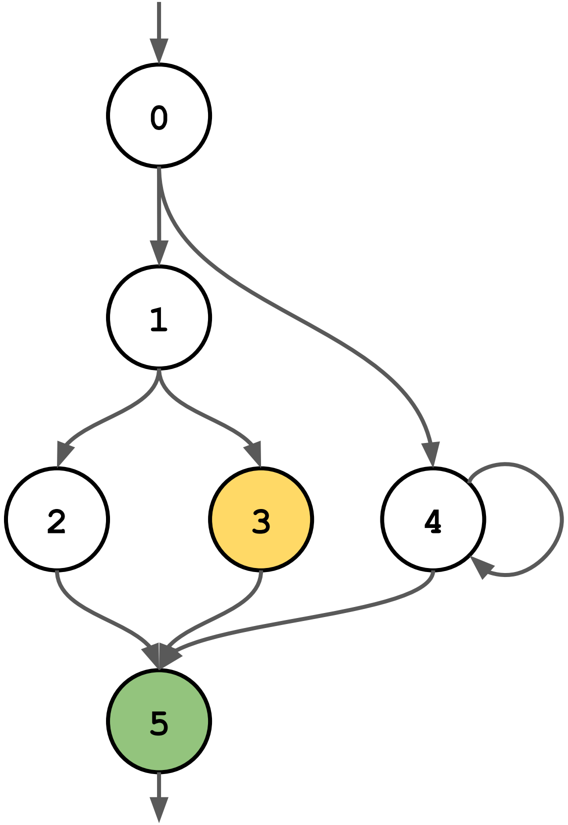
NODE	STRICTLY DOMINATES	DOMINANCE FRONTIER
0	1, 2, 3, 4, 5	∅
1	2, 3	
2		
3		
4		
5		



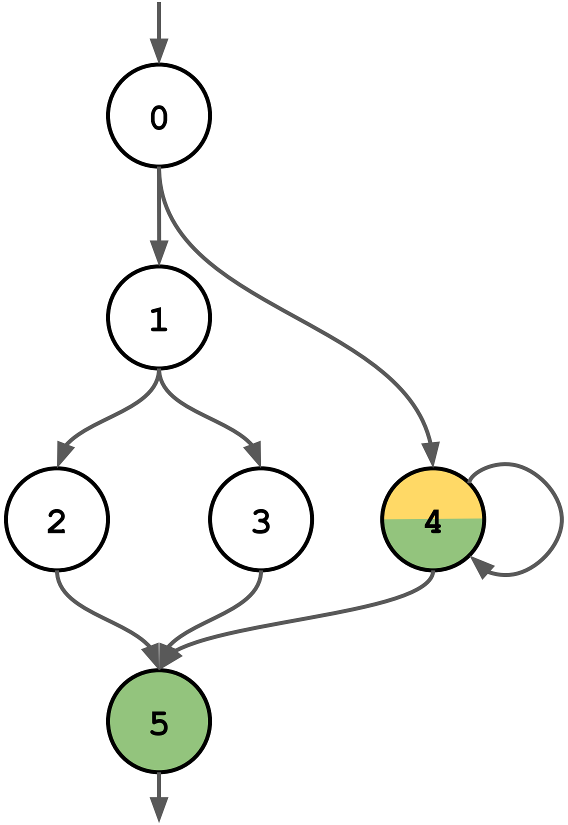
NODE	STRICTLY DOMINATES	DOMINANCE FRONTIER
0	1, 2, 3, 4, 5	∅
1	2, 3	5
2		
3		
4		
5		



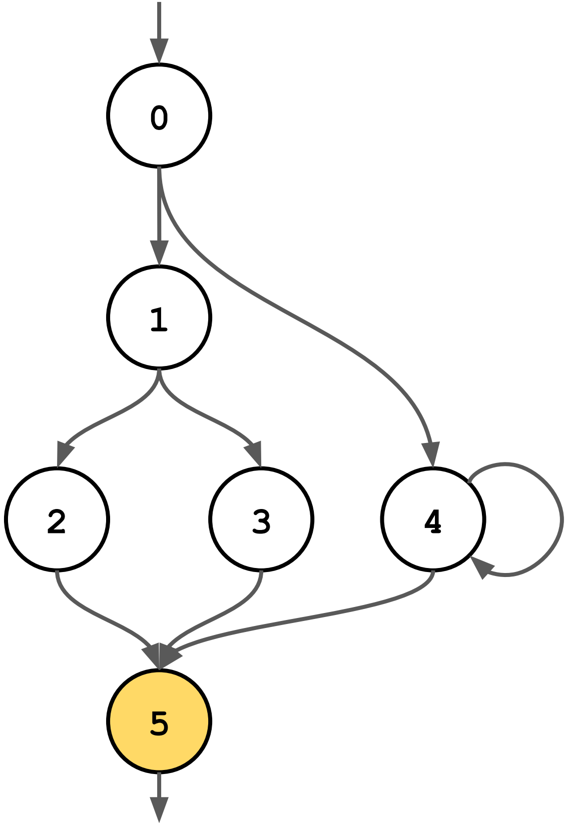
NODE	STRICTLY DOMINATES	DOMINANCE FRONTIER
0	1, 2, 3, 4, 5	∅
1	2, 3	5
2	∅	5
3		
4		
5		



NODE	STRICTLY DOMINATES	DOMINANCE FRONTIER
0	1, 2, 3, 4, 5	∅
1	2, 3	5
2	∅	5
3	∅	5
4		
5		

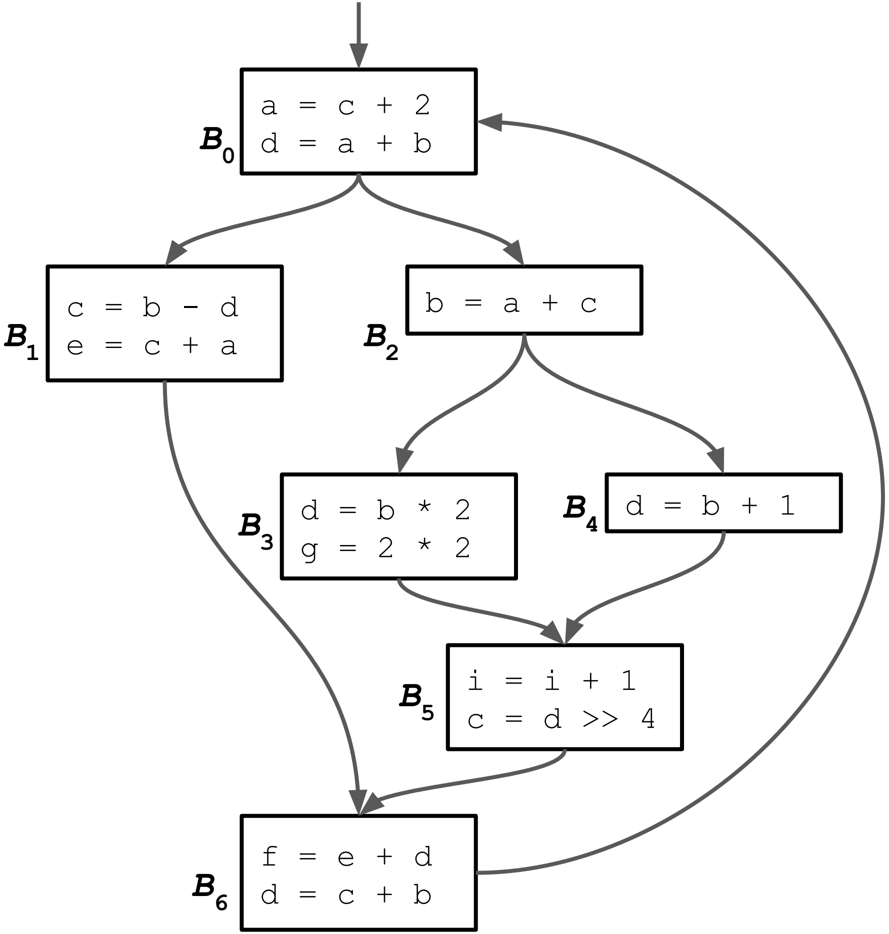


NODE	STRICTLY DOMINATES	DOMINANCE FRONTIER
0	1, 2, 3, 4, 5	∅
1	2, 3	5
2	∅	5
3	∅	5
4	∅	4, 5
5		

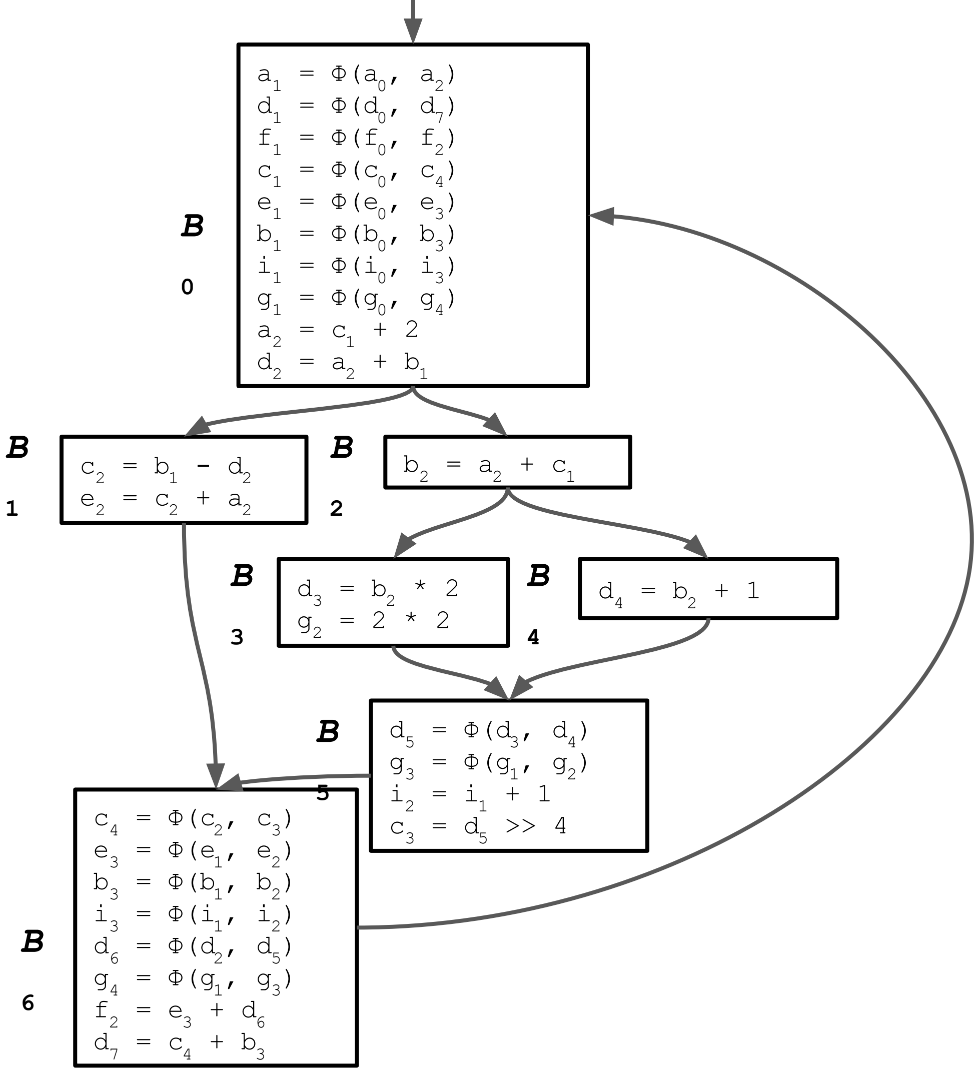


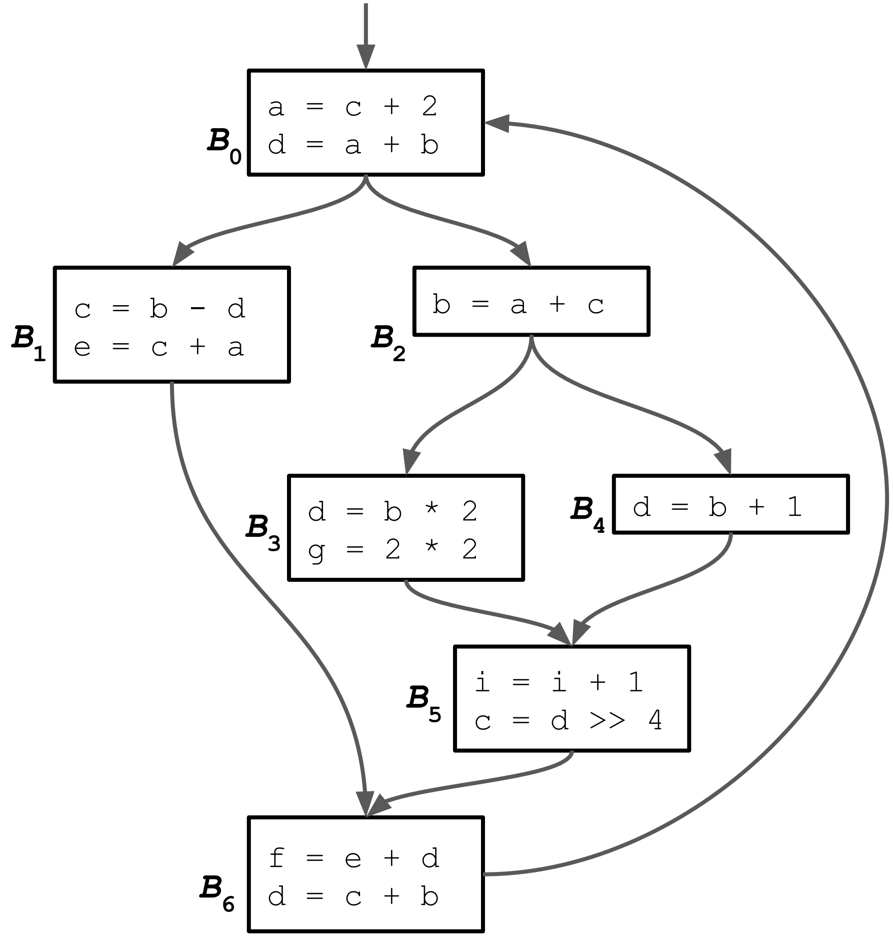
NODE	STRICTLY DOMINATES	DOMINANCE FRONTIER
0	1, 2, 3, 4, 5	∅
1	2, 3	5
2	∅	5
3	∅	5
4	∅	4, 5
5	∅	∅

Problem 3


B0
a = c + 2
d = a + b
B1
c = b - d
e = c + a
B2
b = a + c
B3
d = b * 2
g = 2 * 2
B4
d = b + 1
B5
i = i + 1
c = d >> 4
B6
f = e + d
d = c + b

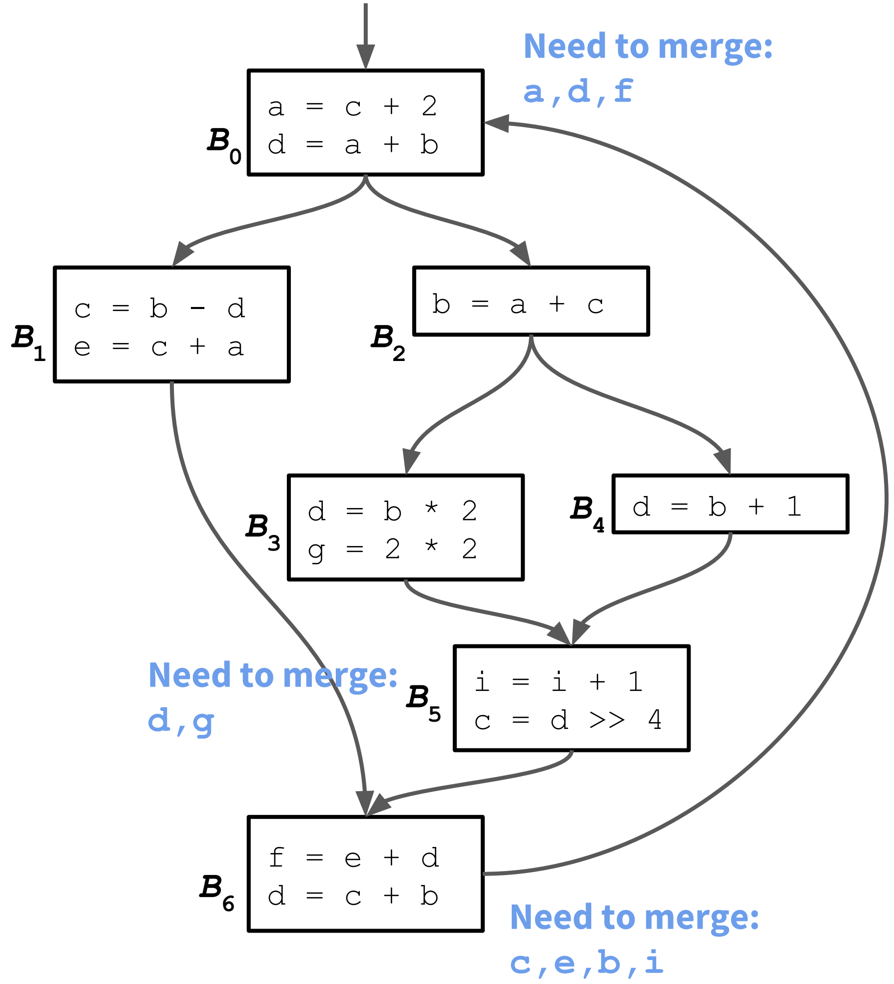
Solution


B
0
a1 = Φ(a0, a2)
d1 = Φ(d0, d7)
f1 = Φ(f0, f2)
c1 = Φ(c0, c4)
e1 = Φ(e0, e3)
b1 = Φ(b0, b3)
i1 = Φ(i0, i3)
g1 = Φ(g0, g4)
a2 = c1 + 2
d2 = a2 + b1
B
1
c2 = b1 - d2
e2 = c2 + a2
B
2
b2 = a2 + c1
B
3
d3 = b2 * 2
g2 = 2 * 2
B
4
d4 = b2 + 1
B
5
d5 = Φ(d3, d4)
g3 = Φ(g1, g2)
i2 = i1 + 1
c3 = d5 >> 4
B
6
c4 = Φ(c2, c3)
e3 = Φ(e1, e2)
b3 = Φ(b1, b2)
i3 = Φ(i1, i2)
d6 = Φ(d2, d5)
g4 = Φ(g1, g3)
f2 = e3 + d6
d7 = c4 + b3



Step 1: Compute Dominance Frontiers

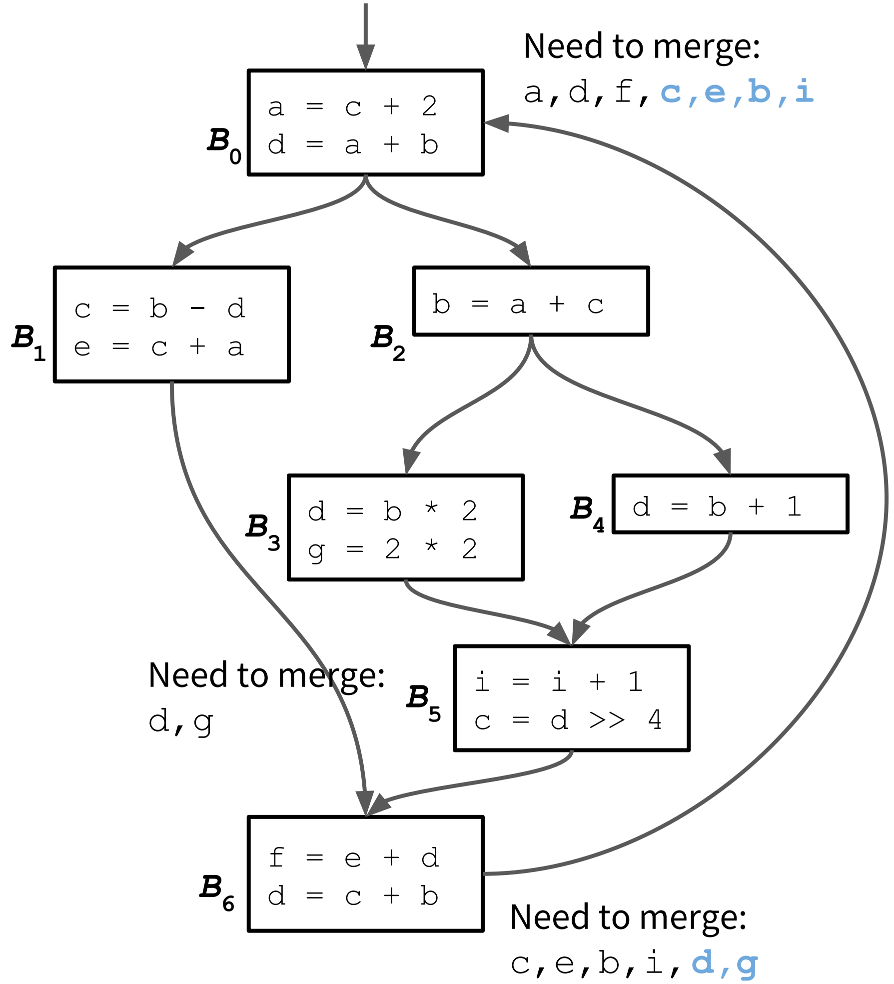
NODE	STRICTLY DOMINATES	DOMINANCE FRONTIER
0	1, 2, 3, 4, 5, 6	0
1	∅	6
2	3, 4, 5	6
3	∅	5
4	∅	5
5	∅	6
6	∅	0



Step 2: Determine Necessary Merges

Each node in the dominance frontier of node X will merge definitions created in node X

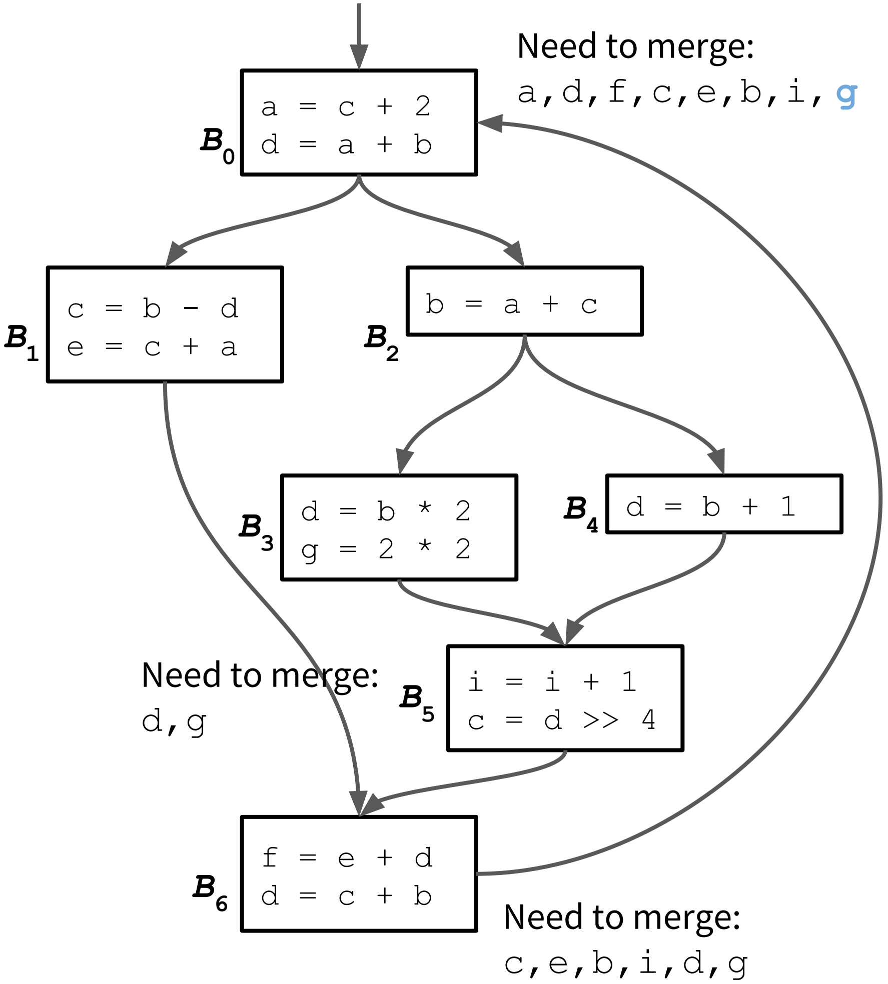
NODE	STRICTLY DOMINATES	DOMINANCE FRONTIER
0	1, 2, 3, 4, 5, 6	0
1	∅	6
2	3, 4, 5	6
3	∅	5
4	∅	5
5	∅	6
6	∅	0



Step 3: Continue Computing Merges

Each merge will create a new definition, and that definition may need to be merged again -- continue until there are no changes

NODE	STRICTLY DOMINATES	DOMINANCE FRONTIER
0	1, 2, 3, 4, 5, 6	0
1	∅	6
2	3, 4, 5	6
3	∅	5
4	∅	5
5	∅	6
6	∅	0



Step 3: Continue Computing Merges

Each merge will create a new definition, and that definition may need to be merged again -- continue until there are no changes

NODE	STRICTLY DOMINATES	DOMINANCE FRONTIER
0	1, 2, 3, 4, 5, 6	0
1	∅	6
2	3, 4, 5	6
3	∅	5
4	∅	5
5	∅	6
6	∅	0

Step 4: Write SSA Definitions

Merges go first, and each successive definition of a variable should increment its index by 1.

B_0

```
a = c + 2
d = a + b
```

Need to merge:

a,d,f,c,e,b,i,g

⇒

B_0

$a_1 = \Phi(a_0, a_2)$
$d_1 = \Phi(d_0, d_7)$
$f_1 = \Phi(f_0, f_2)$
$c_1 = \Phi(c_0, c_4)$
$e_1 = \Phi(e_0, e_3)$
$b_1 = \Phi(b_0, b_3)$
$i_1 = \Phi(i_0, i_3)$
$g_1 = \Phi(g_0, g_4)$
$a_2 = c_1 + 2$
$d_2 = a_2 + b_1$

Step 4: Write SSA Definitions

Merges go first, and each successive definition of a variable should increment its index by 1.

B_1

```
c = b - d
e = c + a
```

Nothing to merge

B_1

$c_2 = b_1 - d_2$

$e_2 = c_2 + a_2$

Step 4: Write SSA Definitions

Merges go first, and each successive definition of a variable should increment its index by 1.

B_2: `b = a + c`

⇒

B_2: $b_2 = a_2 + c_1$

Nothing to merge

Step 4: Write SSA Definitions

Merges go first, and each successive definition of a variable should increment its index by 1.

B_3

```
d = b * 2
g = 2 * 2
```

Nothing to merge

⇒

B_3

$d_3 = b_2 * 2$

$g_2 = 2 * 2$

Step 4: Write SSA Definitions

Merges go first, and each successive definition of a variable should increment its index by 1.

B_4	`d = b + 1`	⇒	B_4: $d_4 = b_2 + 1$

Nothing to merge

Step 4: Write SSA Definitions

Merges go first, and each successive definition of a variable should increment its index by 1.

B_5

```
i = i + 1
c = d >> 4
```

Need to merge:

d, g

⇒

B_5

$$
\begin{aligned}
d_5 &= \Phi(d_3,\ d_4) \\
g_3 &= \Phi(g_1,\ g_2) \\
i_2 &= i_1 + 1 \\
c_3 &= d_5 \gg 4
\end{aligned}
$$

Step 4: Write SSA Definitions

Merges go first, and each successive definition of a variable should increment its index by 1.

B_6

```
f = e + d
d = c + b
```

Need to merge:

c,e,b,i,d,g

⇒

B_6

$$
\begin{aligned}
c_4 &= \Phi(c_2,\ c_3)\\
e_3 &= \Phi(e_1,\ e_2)\\
b_3 &= \Phi(b_1,\ b_2)\\
i_3 &= \Phi(i_1,\ i_2)\\
d_6 &= \Phi(d_2,\ d_5)\\
g_4 &= \Phi(g_1,\ g_3)\\
f_2 &= e_3 + d_6\\
d_7 &= c_4 + b_3
\end{aligned}
$$

Thanks for a Great Quarter!

- **The 401 18sp Staff :)**