SSA Form 2

Static Single Assignment Form

CMPT 379: Compilers

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SSA Form

- Conversion from a Control Flow Graph (created from TAC) into SSA Form is not trivial
- SSA creation algorithms:
  - Original algorithm by Cytron et al. 1986
  - Lengauer-Tarjan algorithm (see the Tiger book by Andrew W. Appel for more details)
  - Harel algorithm

Conversion to SSA Form

- Simple idea: add a ϕ function for every variable at a join point
- A join point is any node in the control-flow graph with more than one predecessor
- But: this is wasteful and unnecessary.

Conversion to SSA

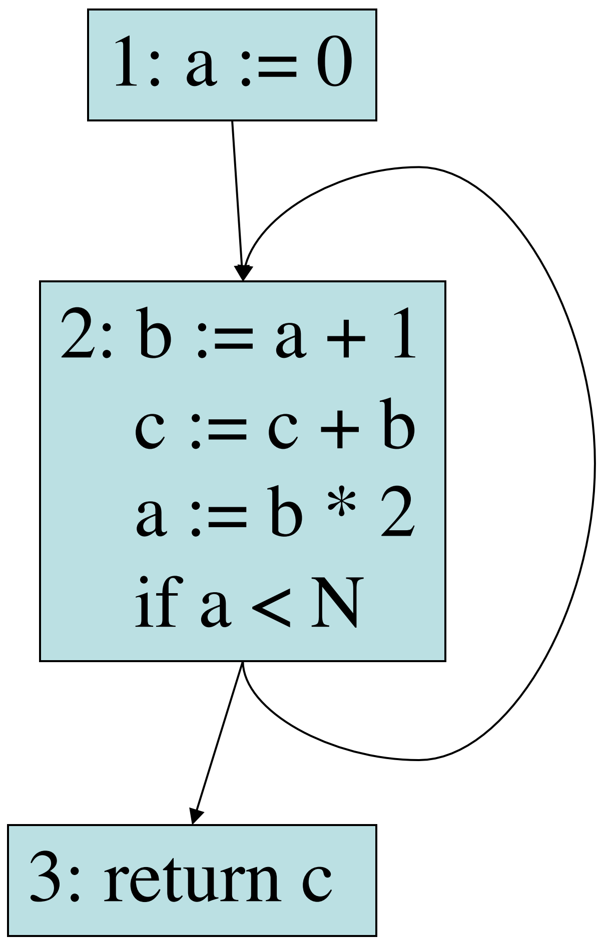
b1 is never used, stmt can be deleted

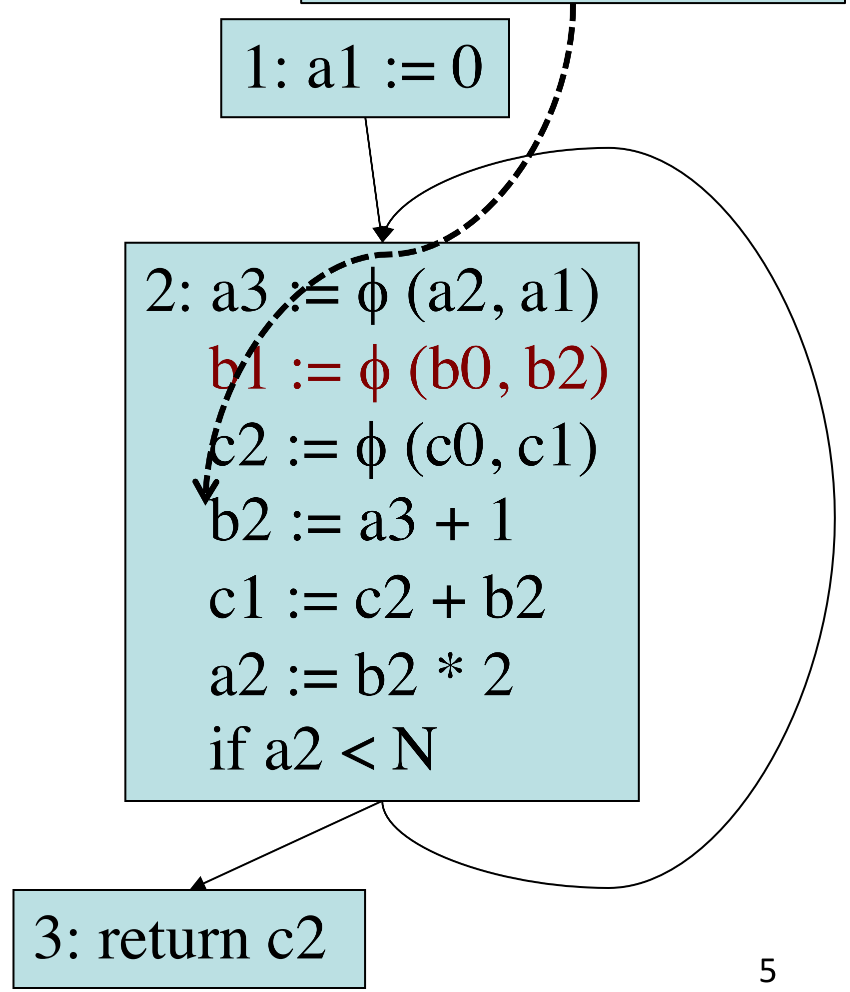
```
1: a := 0

2: b := a + 1
   c := c + b
   a := b * 2
   if a < N

3: return c
```

```
1: a1 := 0

2: a3 := ϕ (a2, a1)
   b1 := ϕ (b0, b2)
   c2 := ϕ (c0, c1)
   b2 := a3 + 1
   c1 := c2 + b2
   a2 := b2 * 2
   if a2 < N

3: return c2
```

Conversion to SSA

b2 changes in each loop. SSA is **not** functional programming!



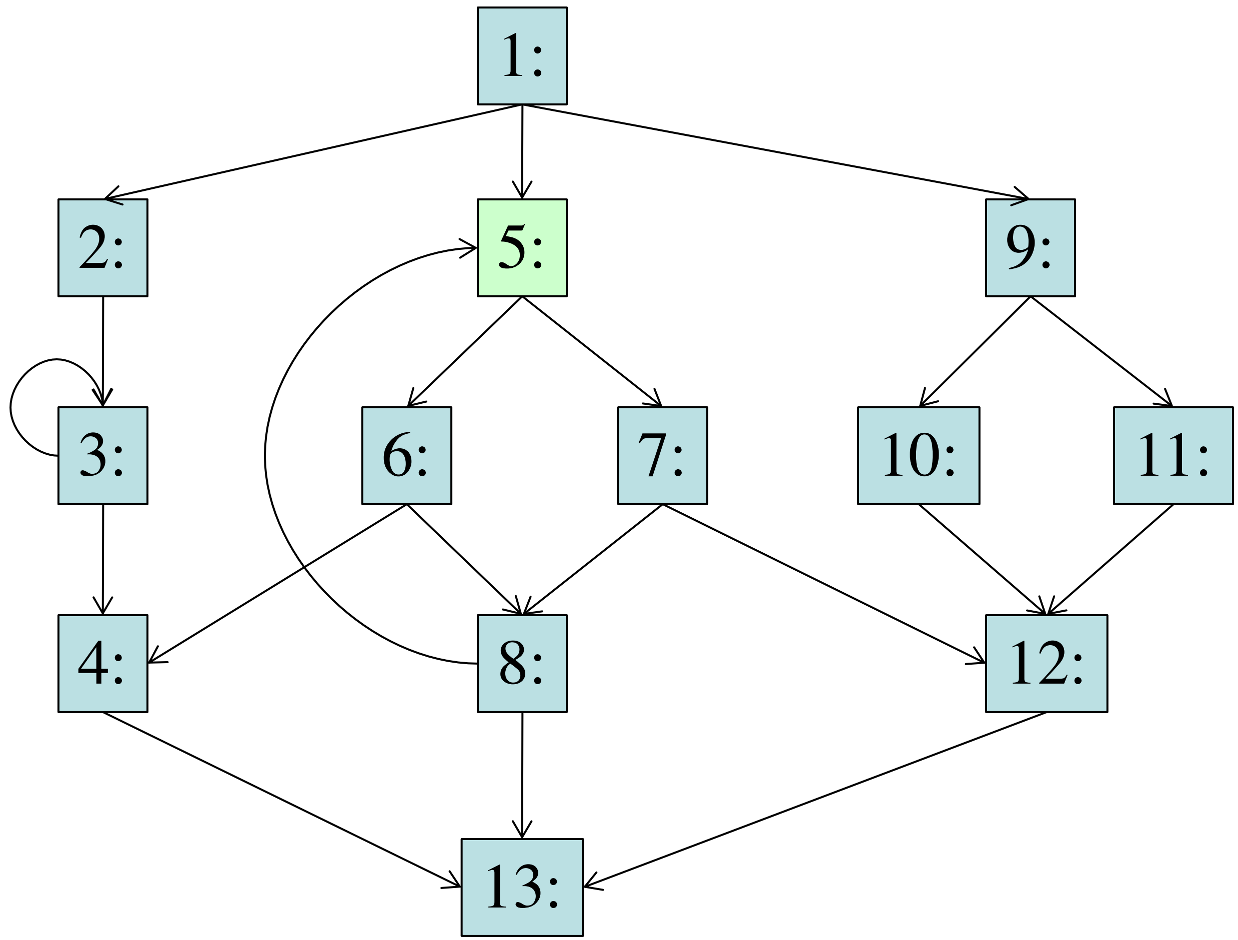


Dominance Relation

- X *dominates* Y if every path from the start node to Y goes through X
- D(X) is the set of nodes that X dominates
- X *strictly dominates* Y if X dominates Y and $X \neq Y$

Dominance Relation

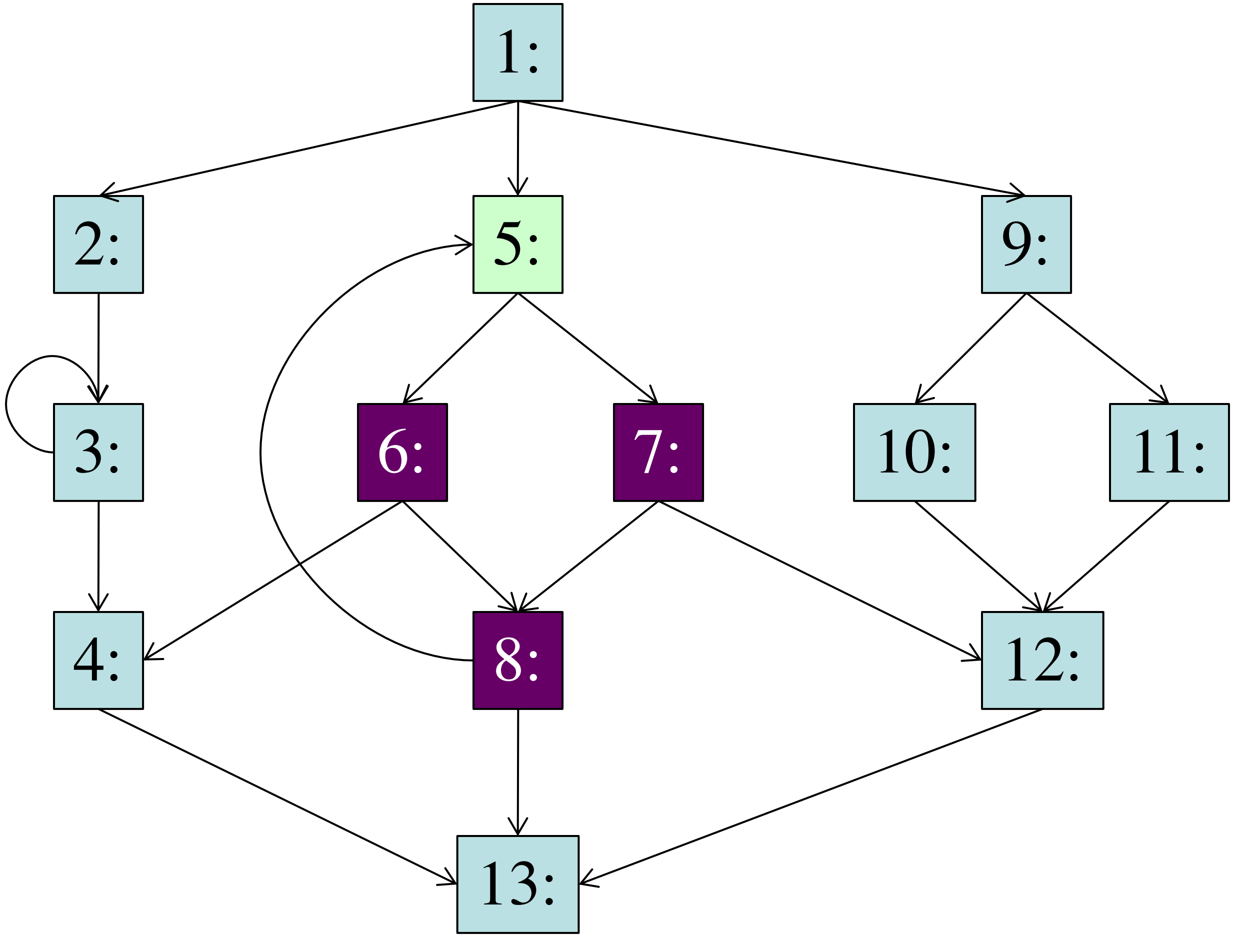
D(5)={6,7,8}



5 strictly dominates 6, 7, 8

Dominance Relation

D(5)={6,7,8}

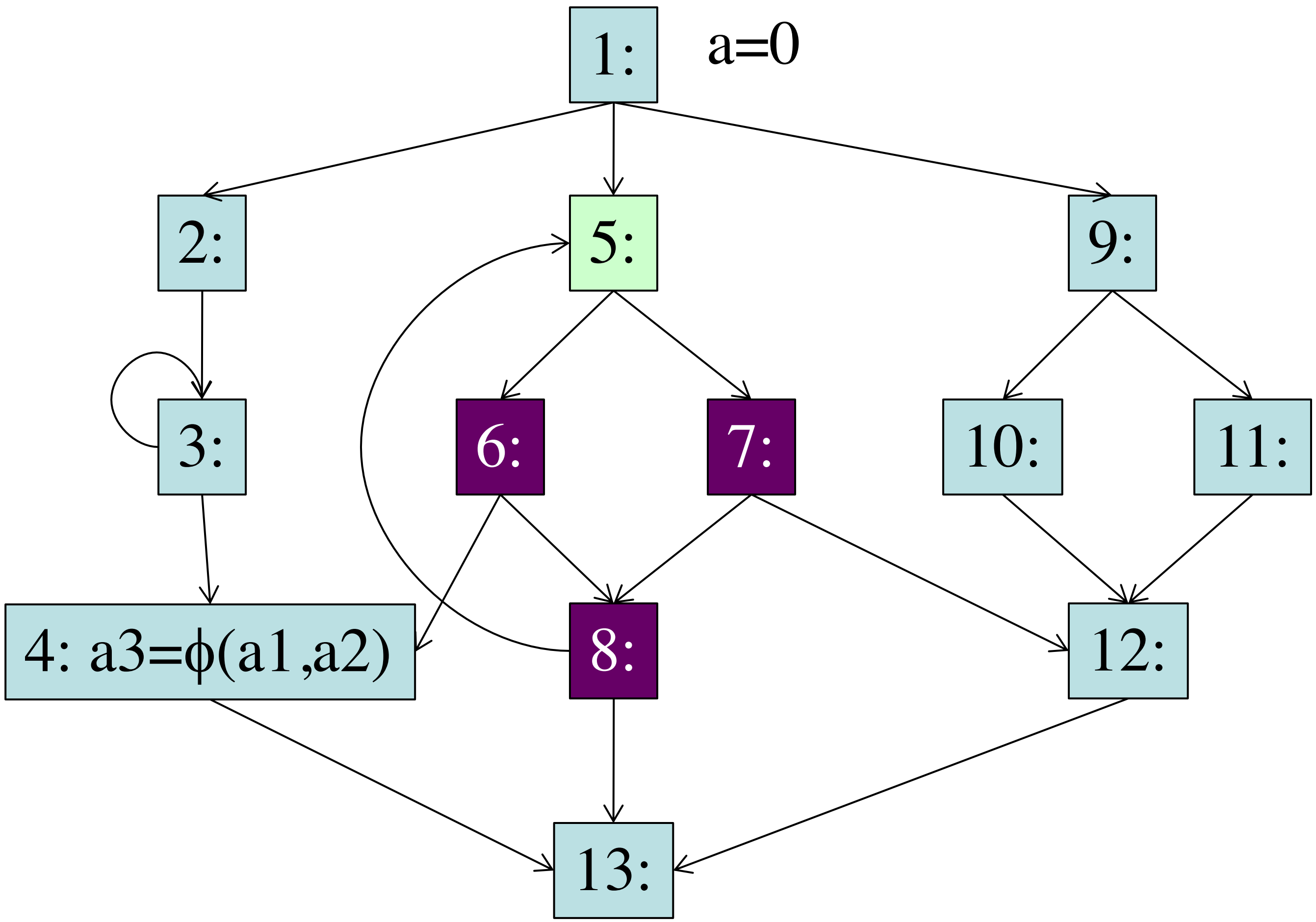


5 strictly dominates 6, 7, 8

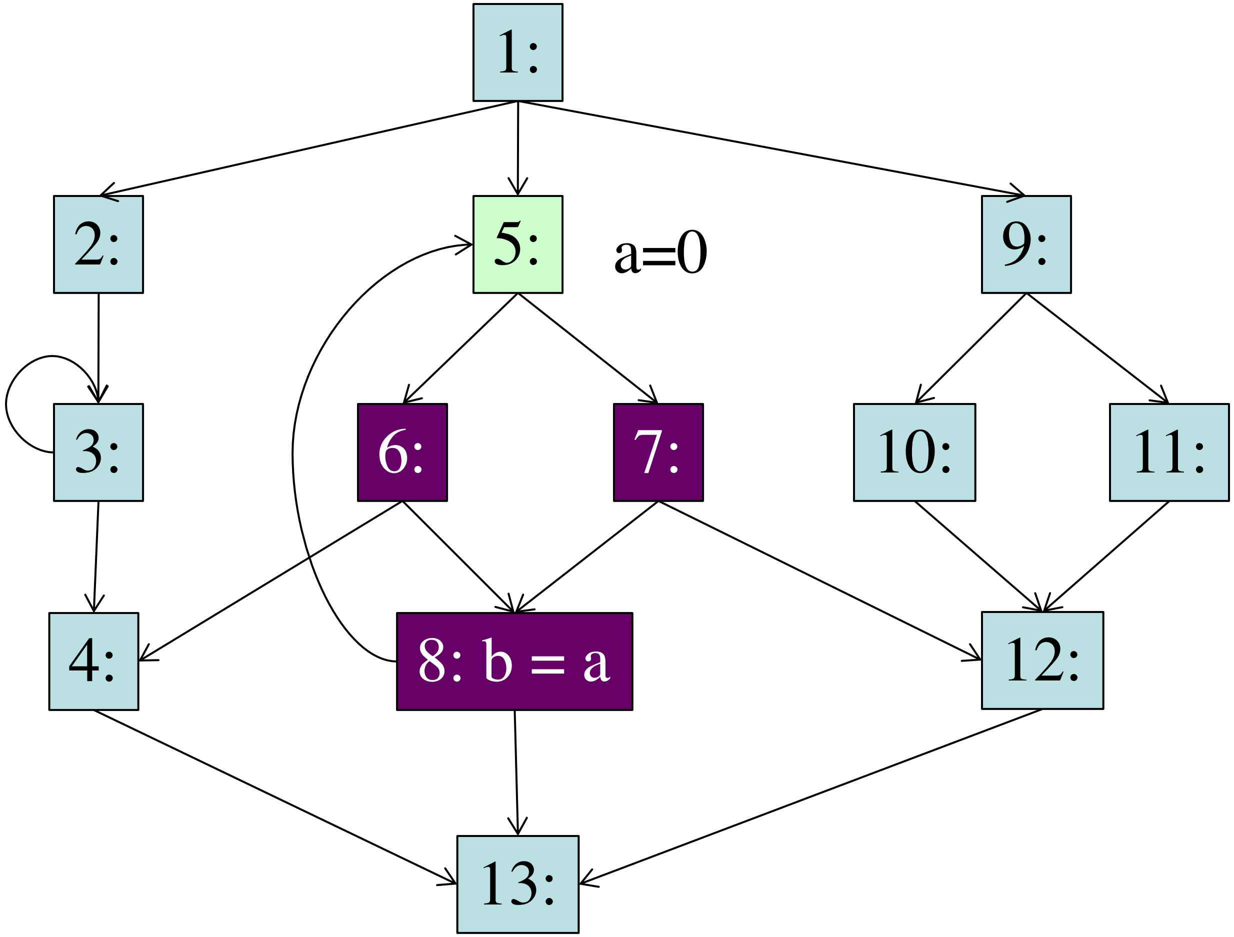
Dominance Property of SSA

- Essential property of SSA form is the definition of a variable must *dominate* use of the variable:
  - If variable *a* is used in a ϕ function in block X, then definition of *a* dominates every predecessor of X
  - If *a* is used in a non-ϕ statement in block X, then the definition of *a* dominates X.

Dominance Relation



Dominance Relation



Dominance Frontier

- X *strictly dominates* Y if X dominates Y and X ≠ Y
- *Dominance Frontier* (DF) of node X is the set of all nodes Y such that:
  - X dominates a predecessor of Y, AND
  - X does not strictly dominate Y

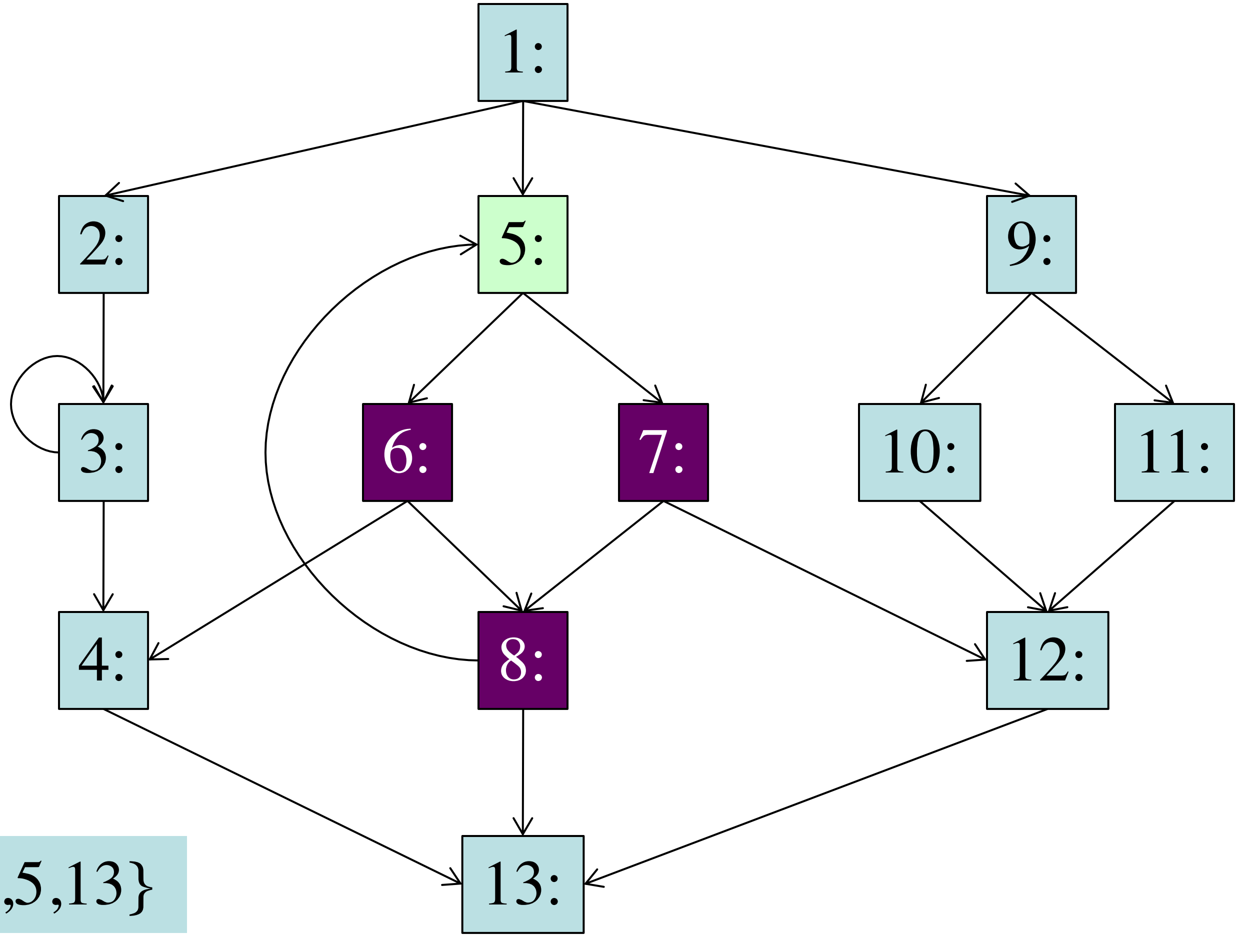
Dominance Frontier

D(5)={6,7,8}

S(6)={4,8}

S(7)={8,12}

S(8)={5,13}



DF(5) = {4,12,5,13}

Dominance Frontier

- Algorithm to compute DF(X):
  - Local(X) := set of successors of X that X does not immediately dominate
  - Up(X) := if X dominates K, Up(X) is the set of nodes in DF(K) that are not dominated by X.
  - DF(X) := Union of Local(X) and (Union of Up(K) for all K that are children of X)

Dominance Frontier

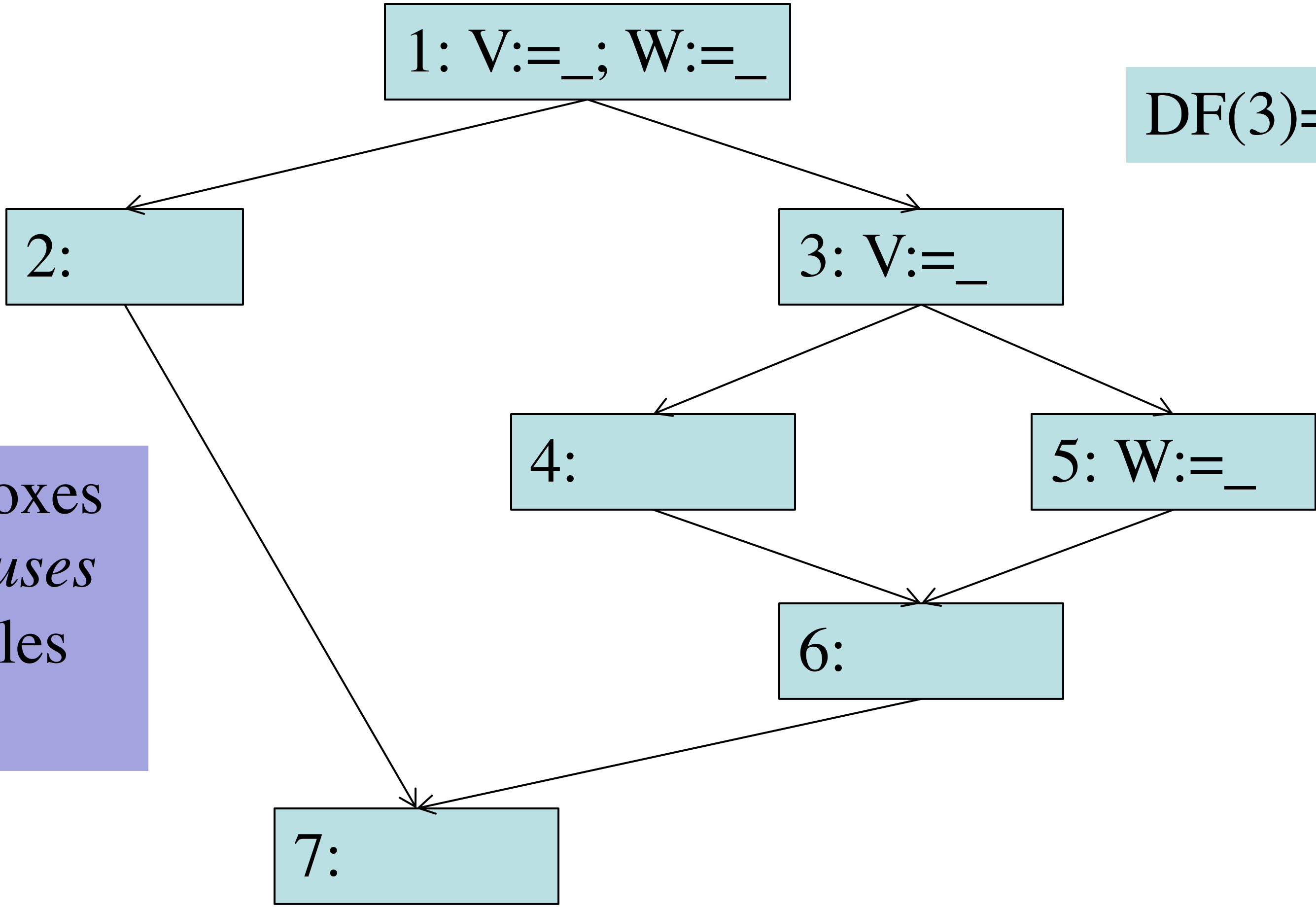
- ComputeDF(X):

```
S := {} // empty set
For each node Y in Successor(X):
   If X does not immediately dominate Y:
      S := S ∪ {Y} // this is Local(X), ∪ means union
For each child K of X in D(X): // X dominates K
   For each element Y in ComputeDF(K):
      If X does not dominate Y,
               S := S ∪ {Y} // this is Up(X)
DF(X) = S; return S
```

Dominance Frontier

- Dominance Frontier Criterion
  - If node X contains definition of some variable *a*, then any node Y in the DF(X) needs a ϕ function for *a*.
- Iterated Dominance Frontier
  - Since a ϕ function is itself a definition of a new variable, we must iterate the DF criterion until no nodes in the CFG need a ϕ function.

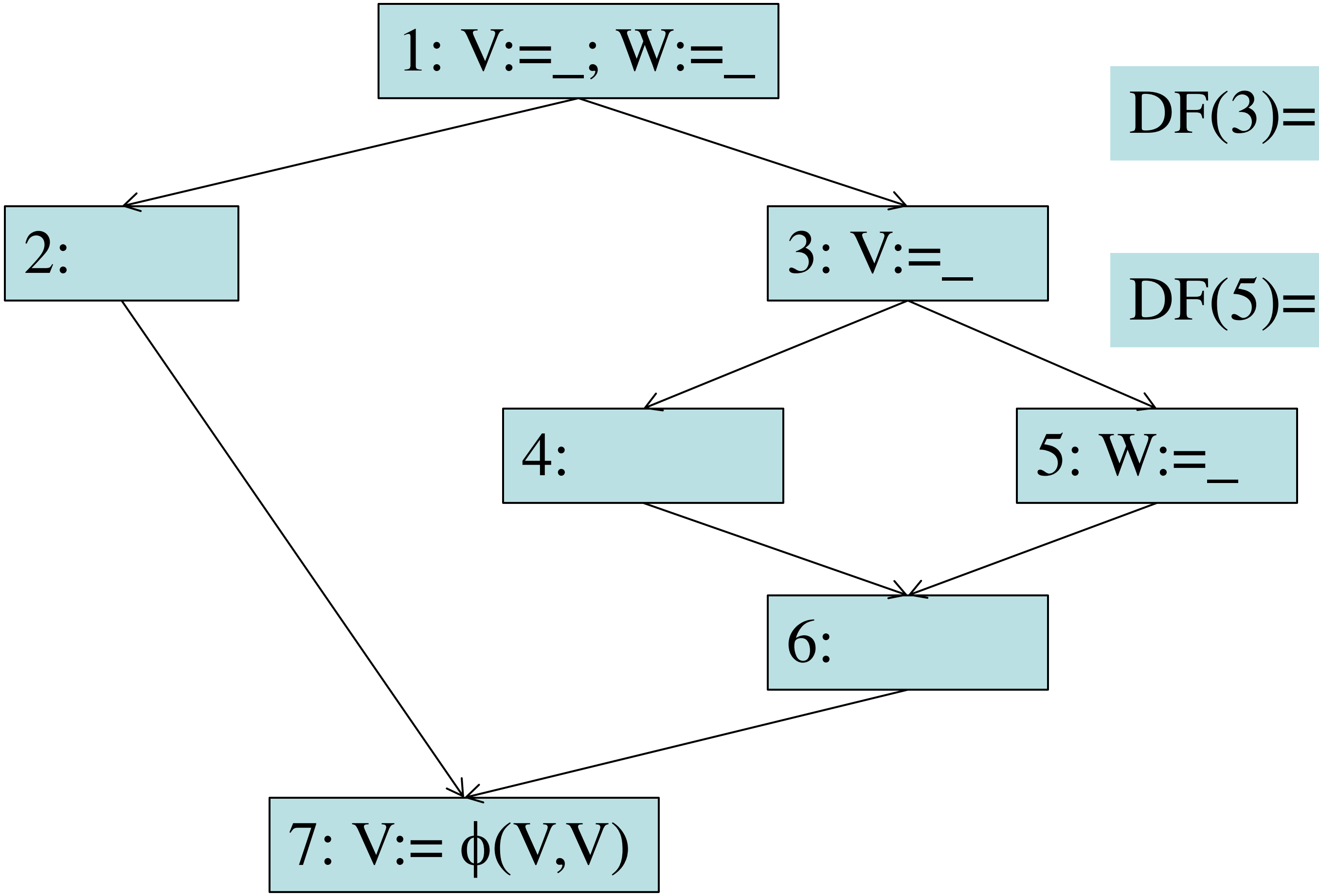
Placing ϕ Functions



DF(3)={7}

Empty boxes indicate *uses* of variables V, W

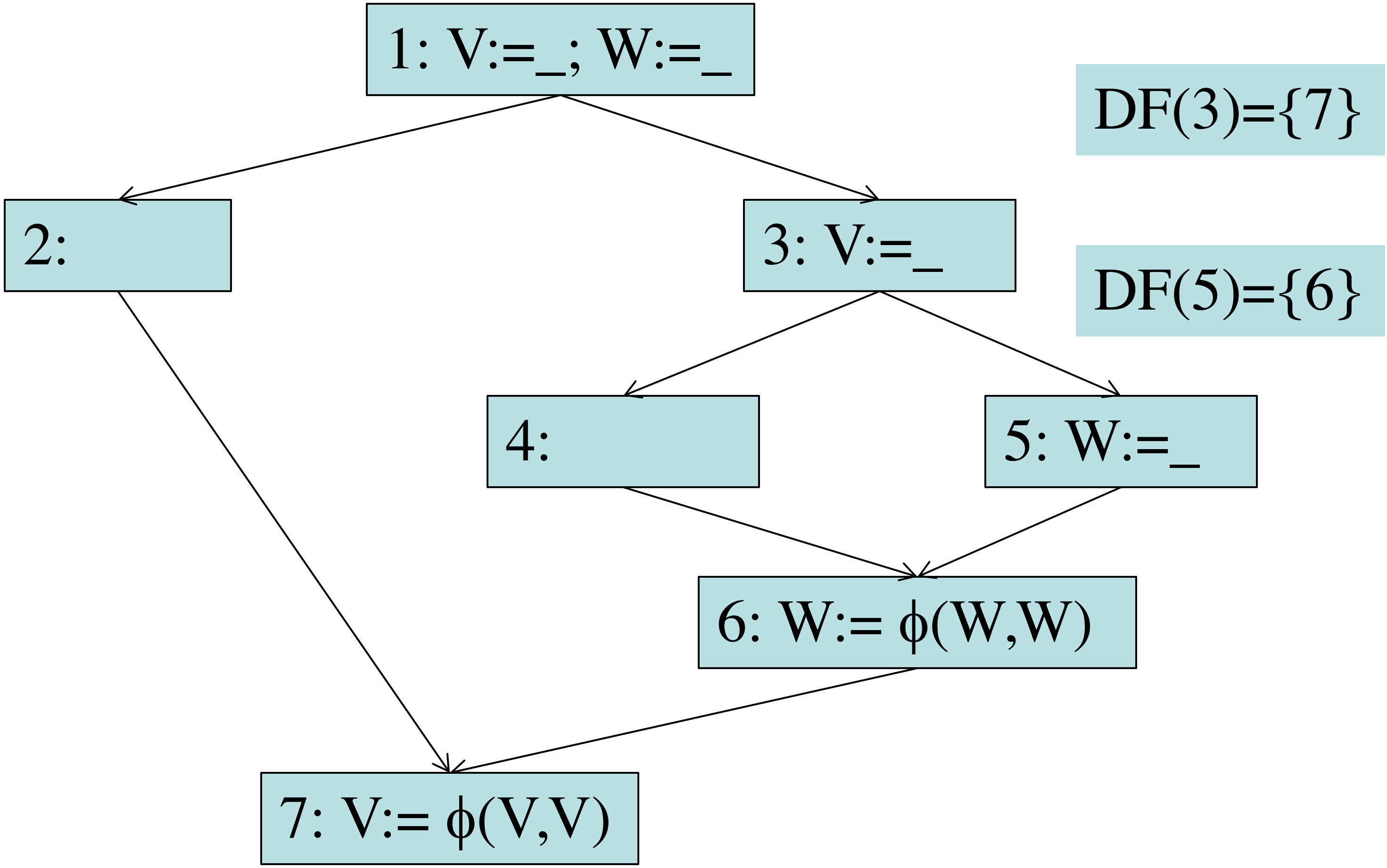
Placing ϕ Functions



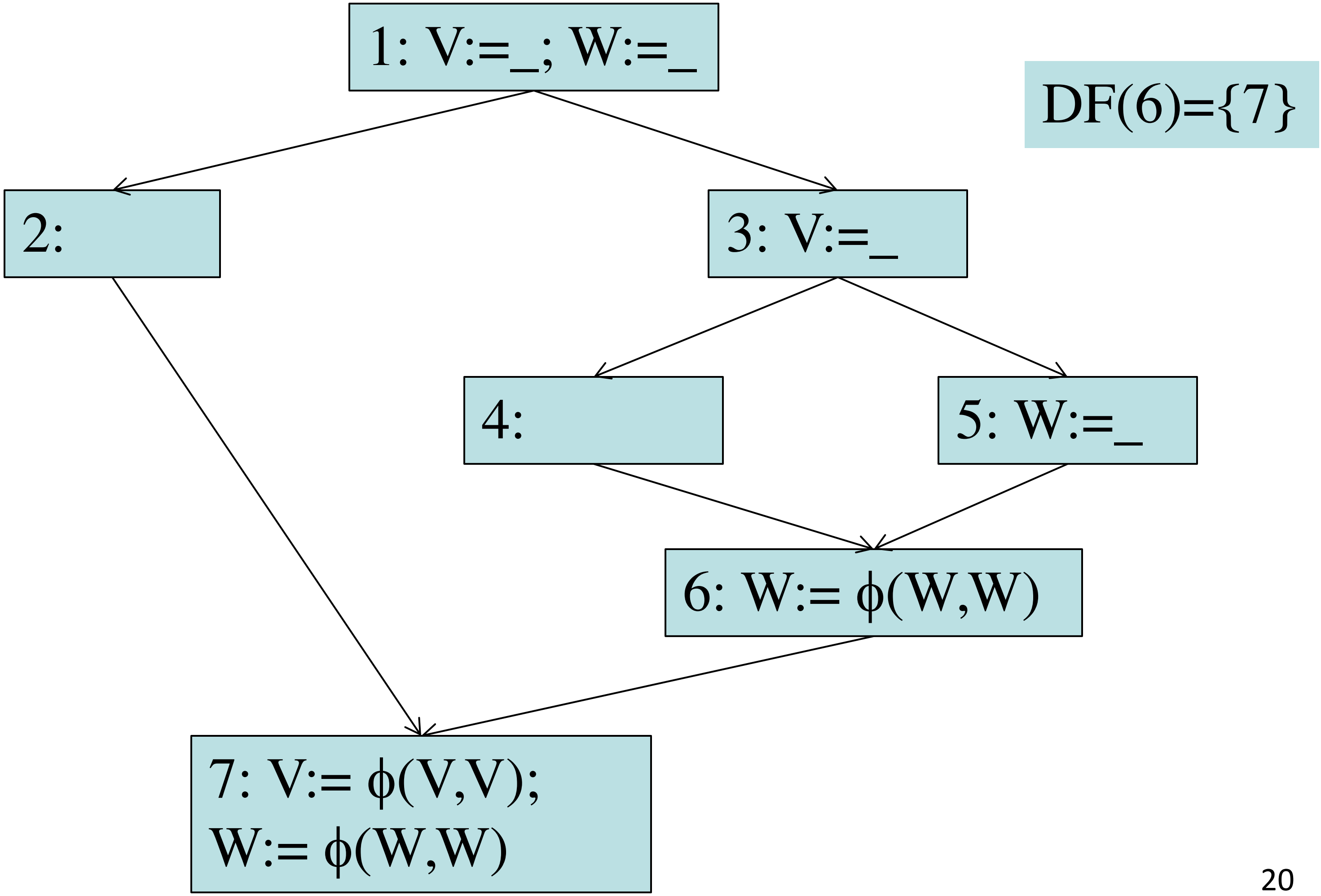
DF(3)={7}

DF(5)={6}

Placing ϕ Functions



Placing ϕ Functions



Rename Variables