SSA Form 2

Static Single Assignment Form

CMPT 379: Compilers

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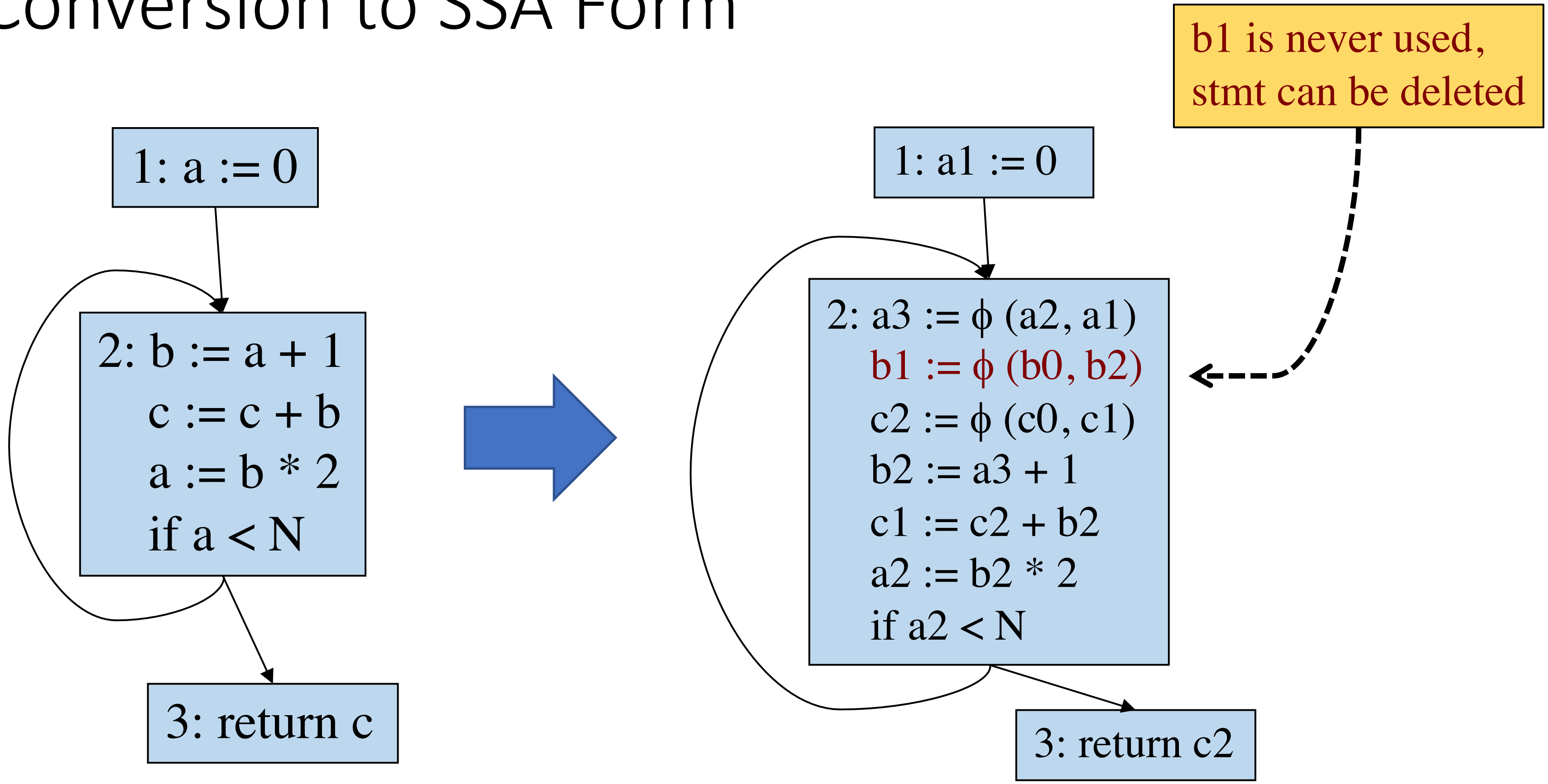
SSA Form

- Conversion from a Control Flow Graph (created from 3-address code) 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

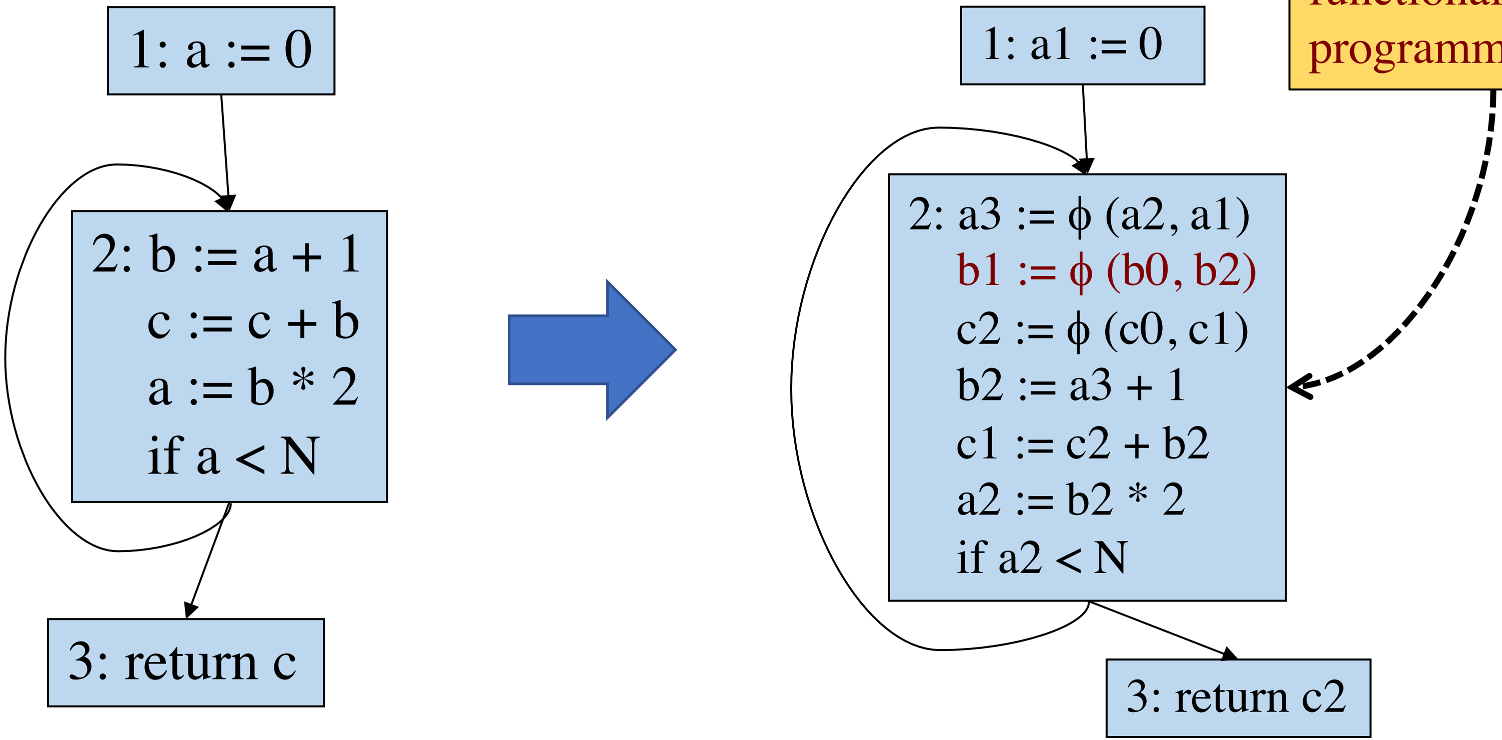
- Simple idea: add a ϕ function for every variable at a join point
- A join point is any node in the control-flow graph with more than one predecessor
- But: this is wasteful and unnecessary.

Conversion to SSA Form



Conversion to SSA Form

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



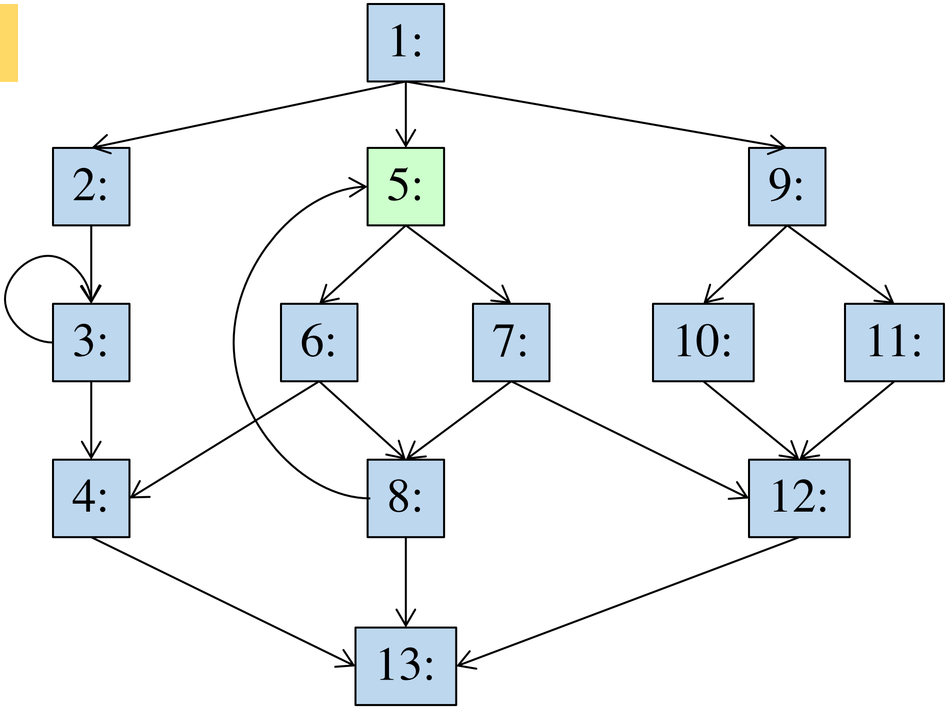
Conversion to SSA Form (with minimal ϕ functions)

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

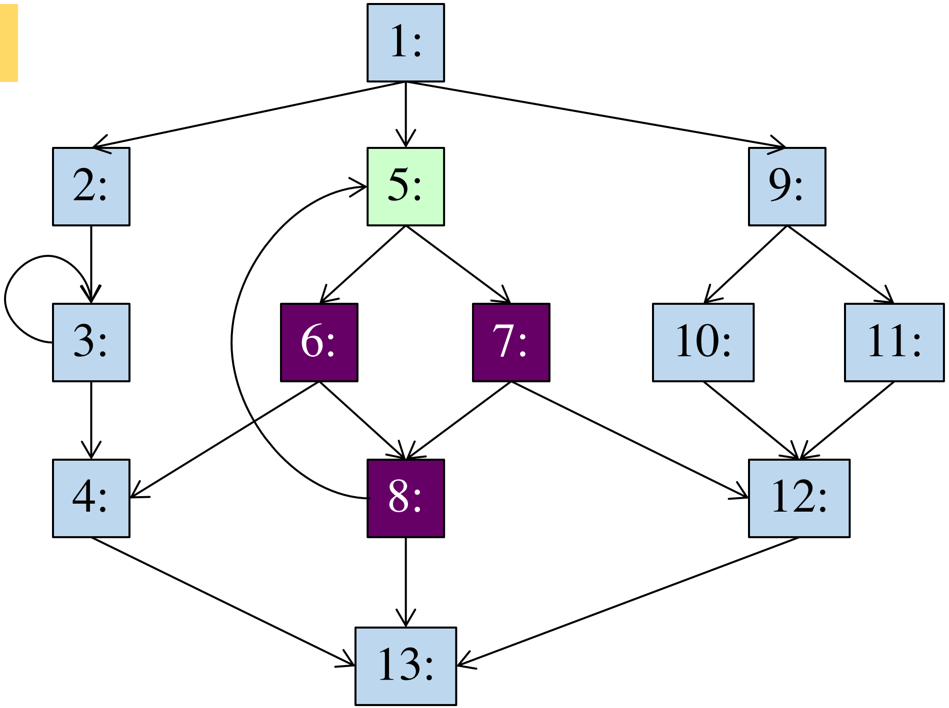
D(5)={6,7,8}



5 strictly dominates 6, 7, 8

Dominance Relation

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

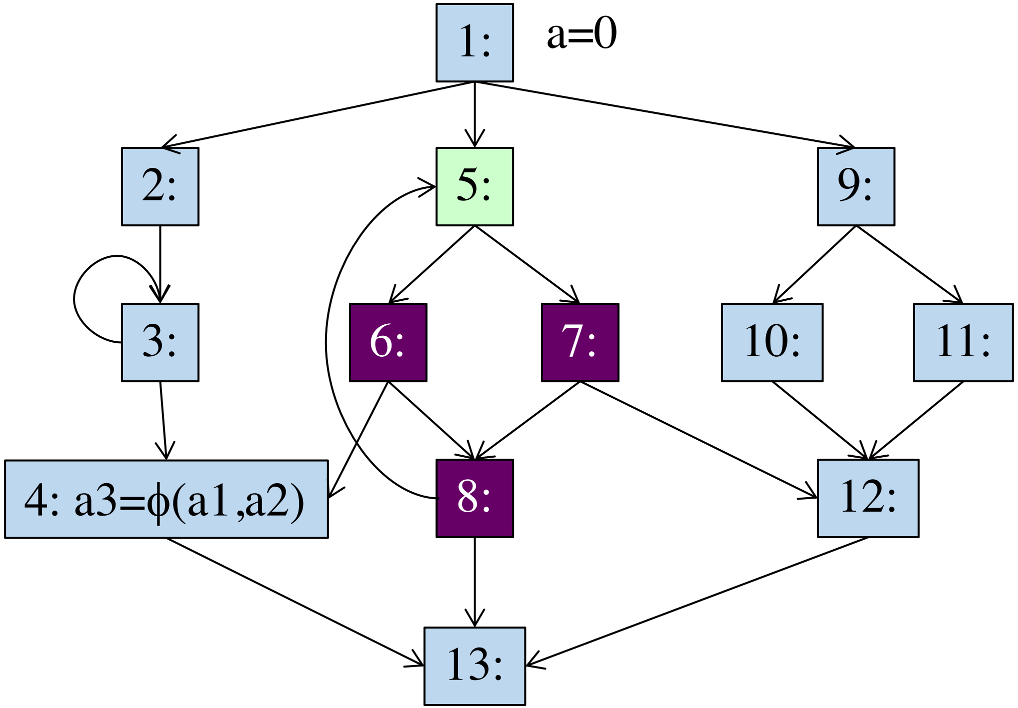


5 strictly dominates 6, 7, 8

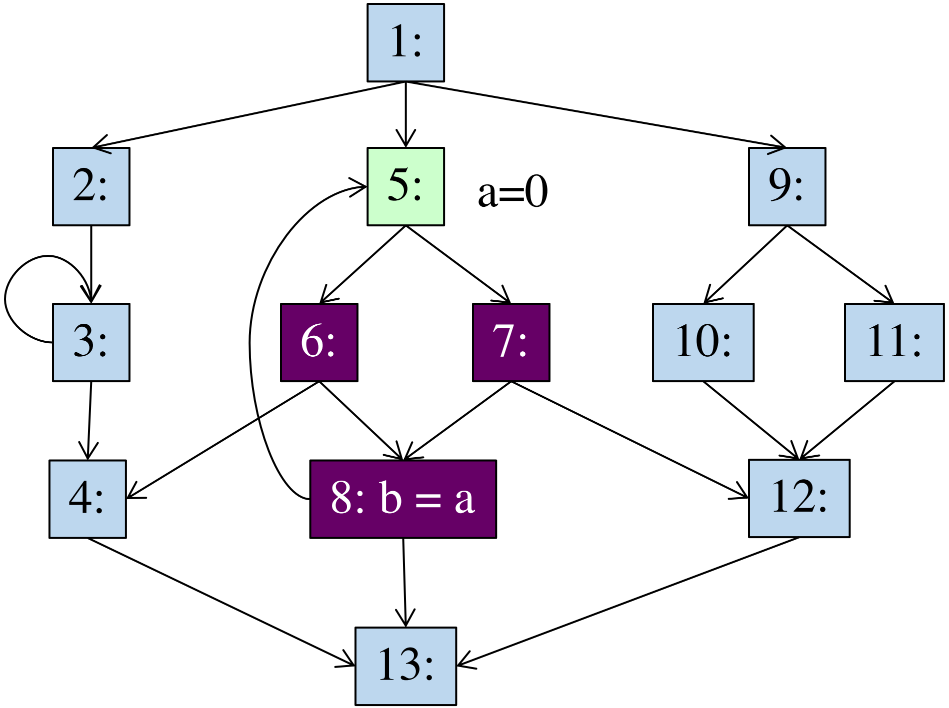
Dominance Property of SSA

- 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

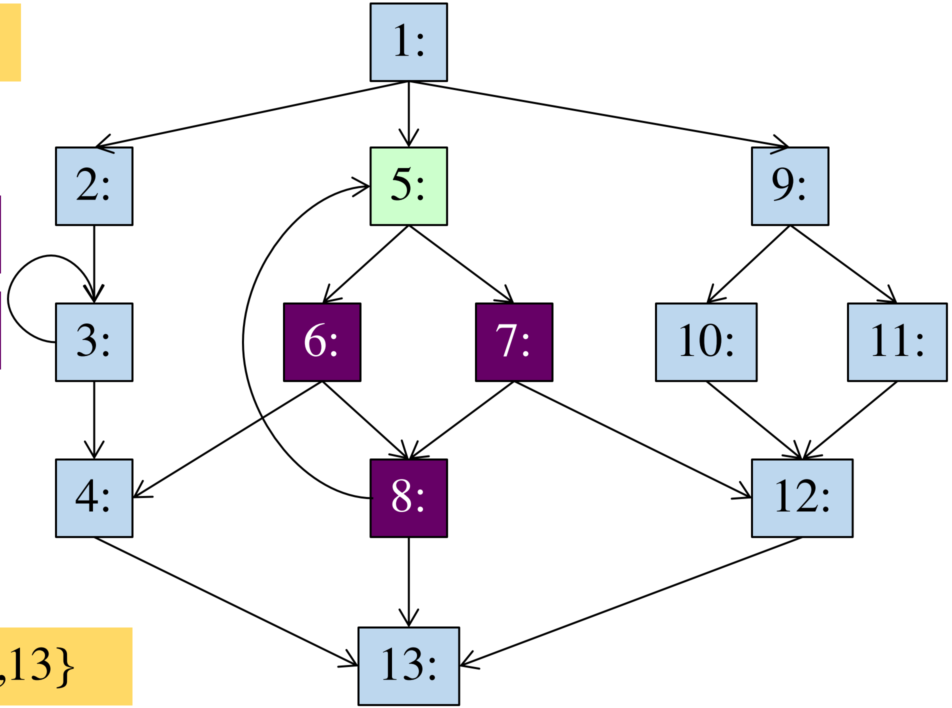
Dominance Frontier

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

S(6)={4,8}

S(7)={8,12}

S(8)={5,13}



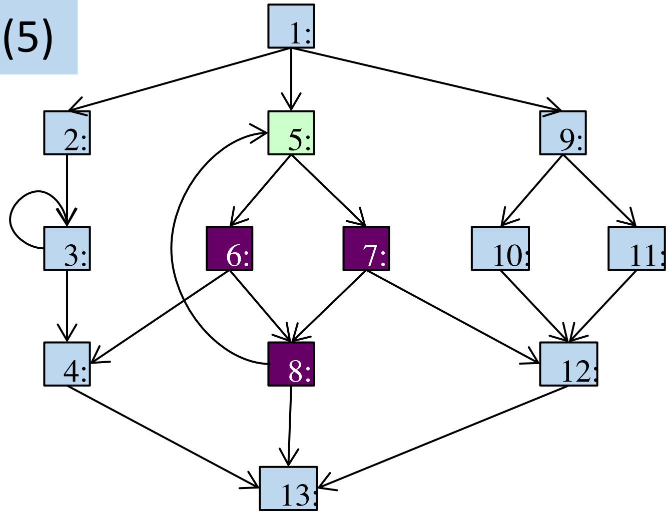
DF(5) = {4,12,5,13}

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)

ComputeDF(5)

Dominance Frontier



- ComputeDF(X):

  S := {} // empty set

  For each node Y in Successor(X):

  If X does not strictly 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

{6,7}

{}

{6,7,8}

{4, ⌫

⌫ ,12}

{5,13}

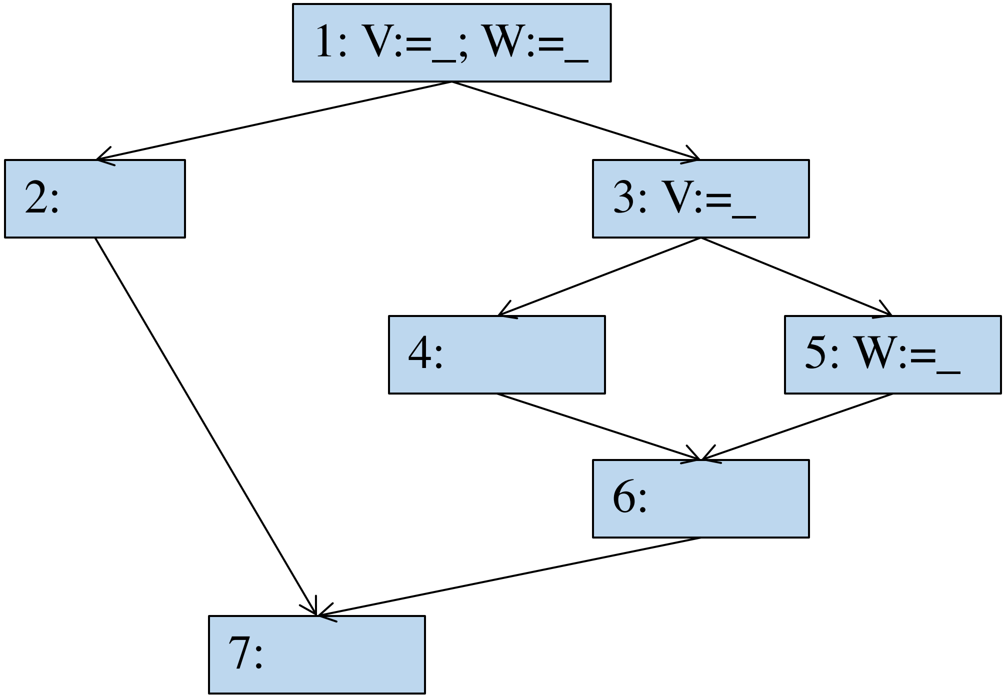
{4,12,5,13}

Dominance Frontier

- Dominance Frontier Criterion
  - If node X contains definition of some variable *a*, then any node Y that uses *a* in the set 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}

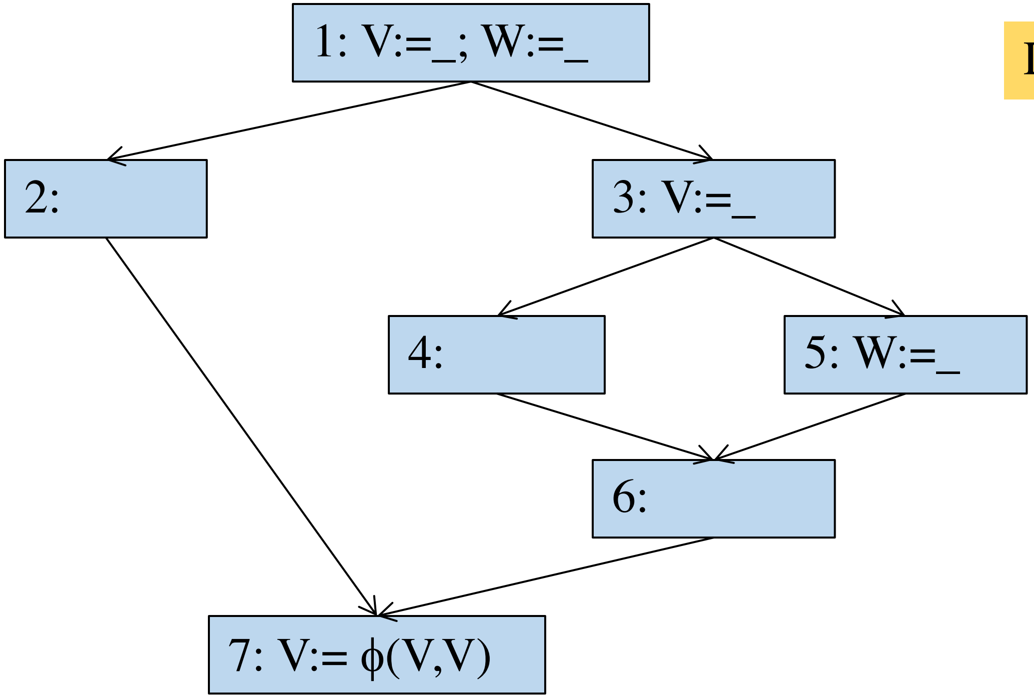


Empty boxes indicate *uses* of variables V, W

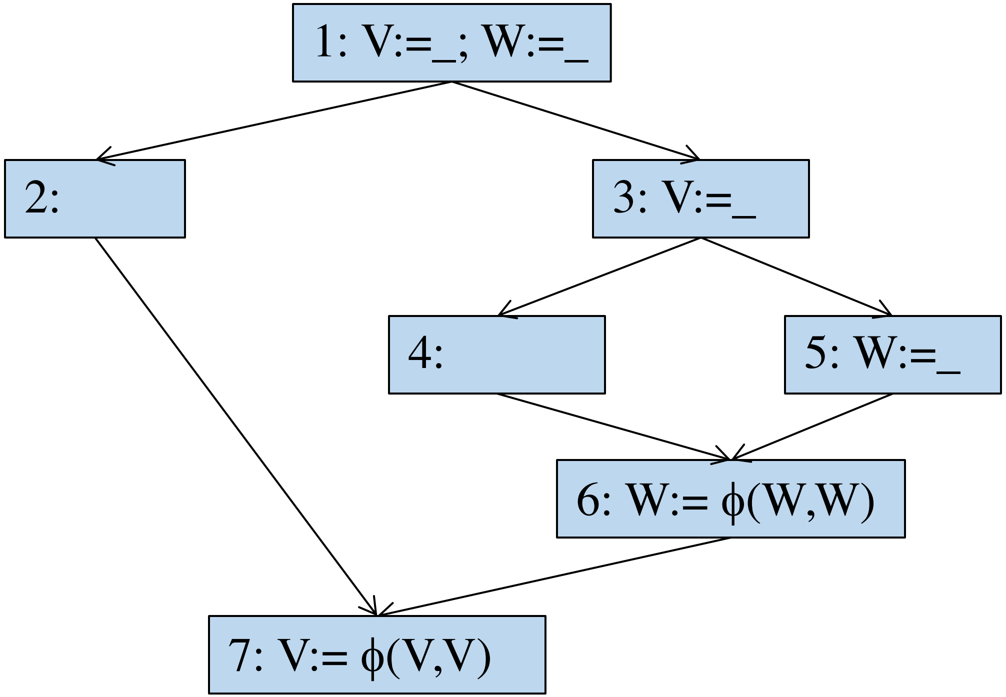
Placing ϕ Functions

DF(3)={7}

DF(5)={6}



Placing ϕ Functions

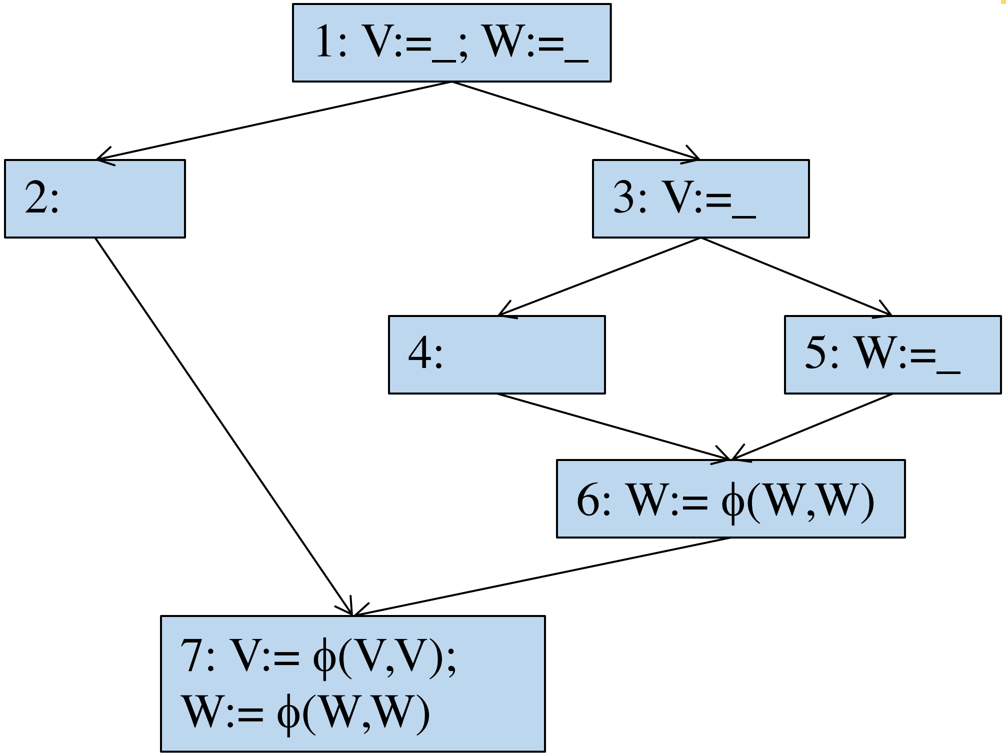


DF(3)={7}

DF(5)={6}

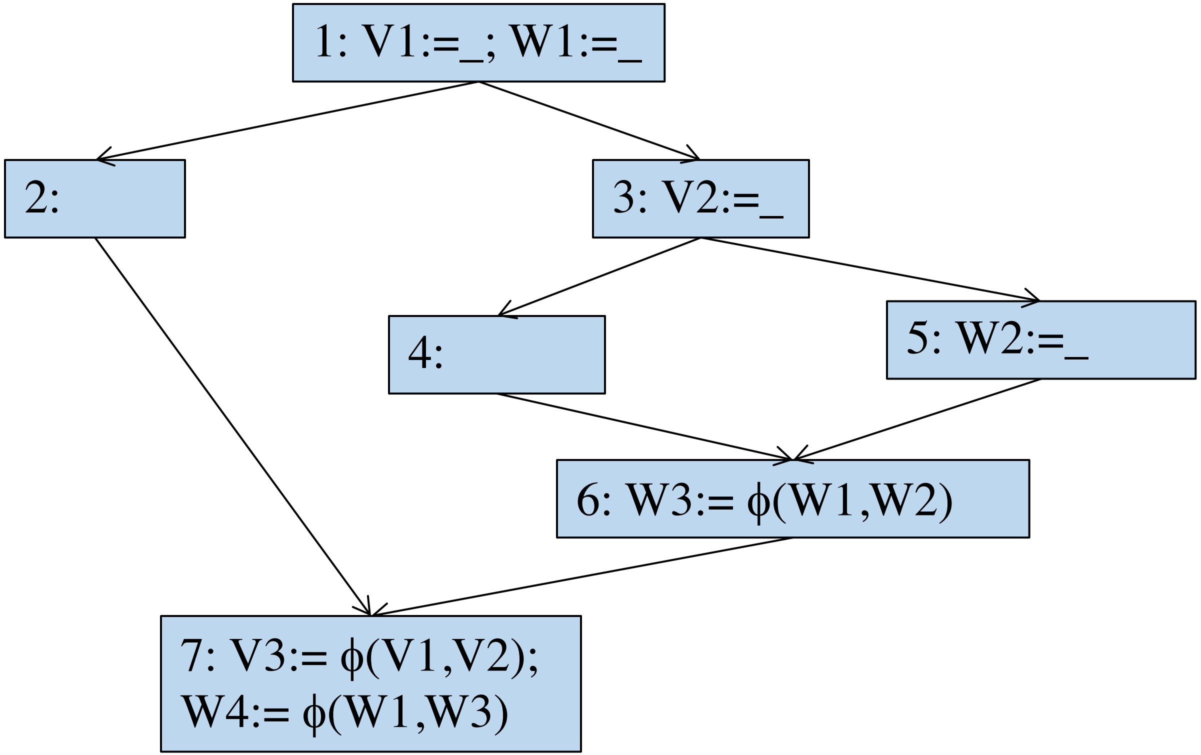
Placing ϕ Functions

DF(6)={7}



Rename Variables

DF(6)={7}



Summary

- Compute the dominance frontier for each node in the flowgraph
- For each node X place a ϕ function in each node that is in the dominance frontier for X
- Iterate the dominance frontier algorithm above for each new variable assignment in each ϕ function added in the previous step
- The end result: 3-address code converted into Static Single Assignment (SSA) form