Lecture 14

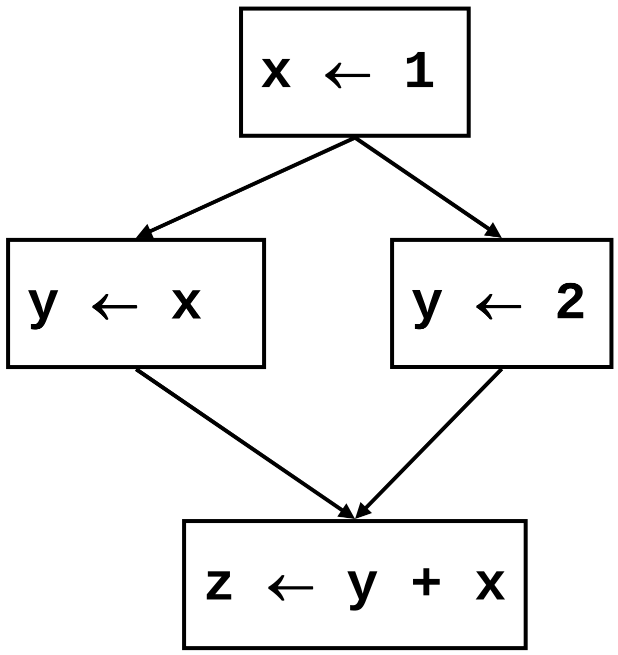
SSA-Style Optimizations

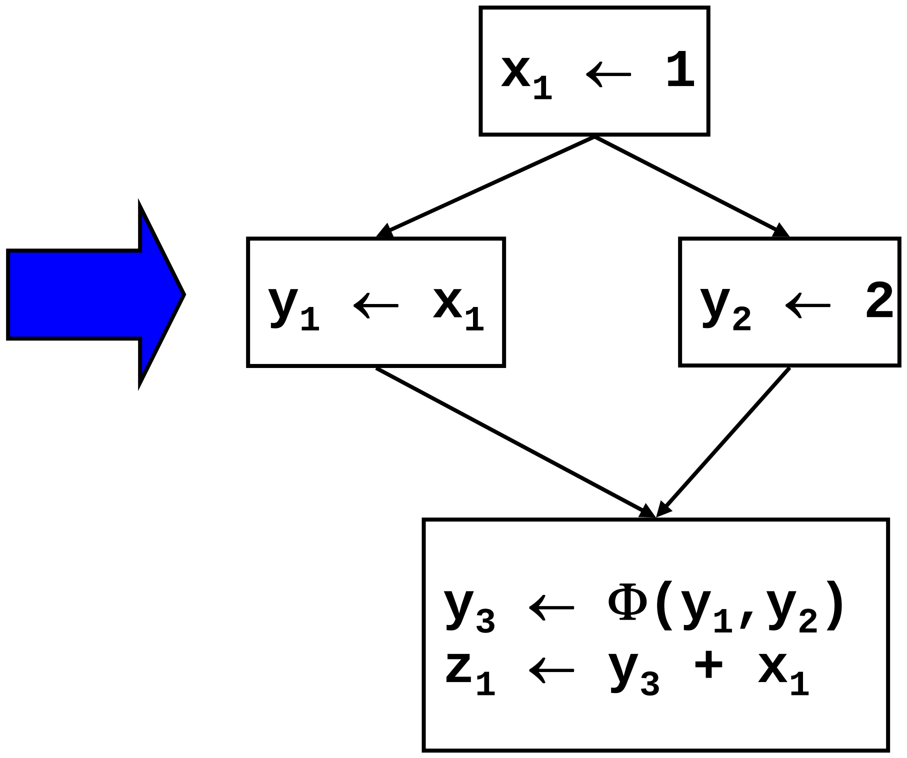
(Slides courtesy of Seth Goldstein.)

Carnegie Mellon

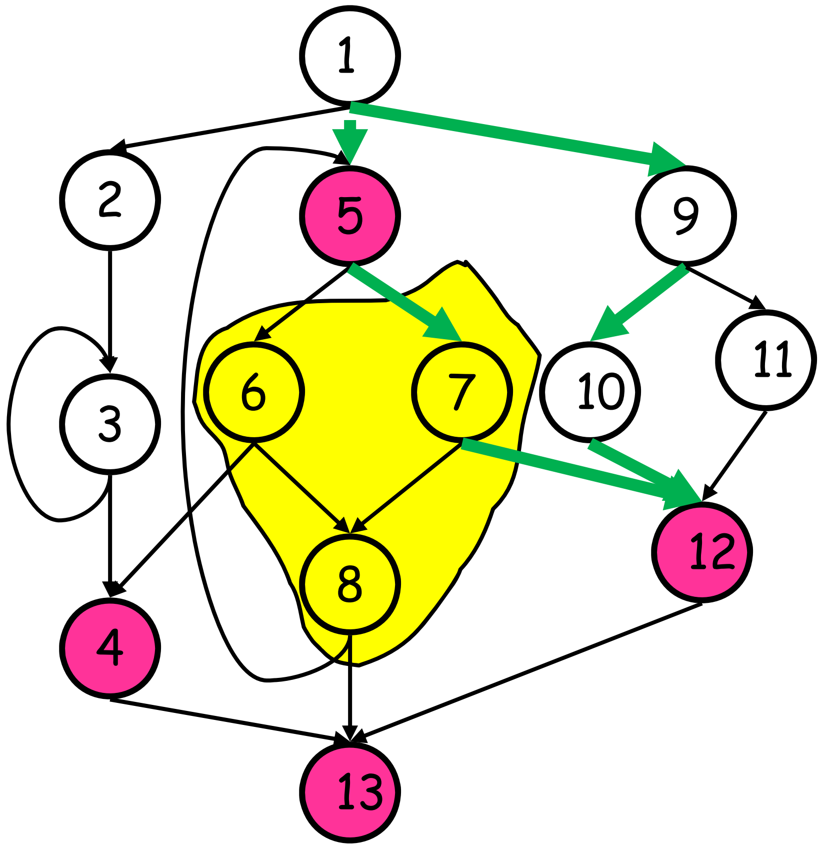
Review: Minimal SSA

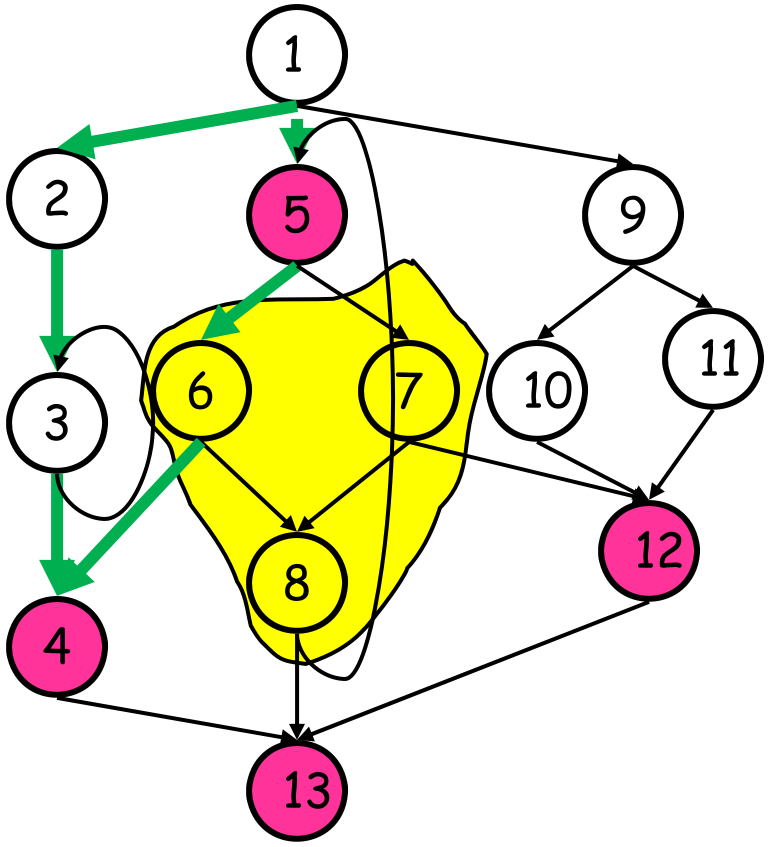
- Each assignment generates a fresh variable.
- At each join point insert Φ functions for all variables with multiple outstanding defs.





Review: Dominance Frontier and Path Convergence





Constant Propagation

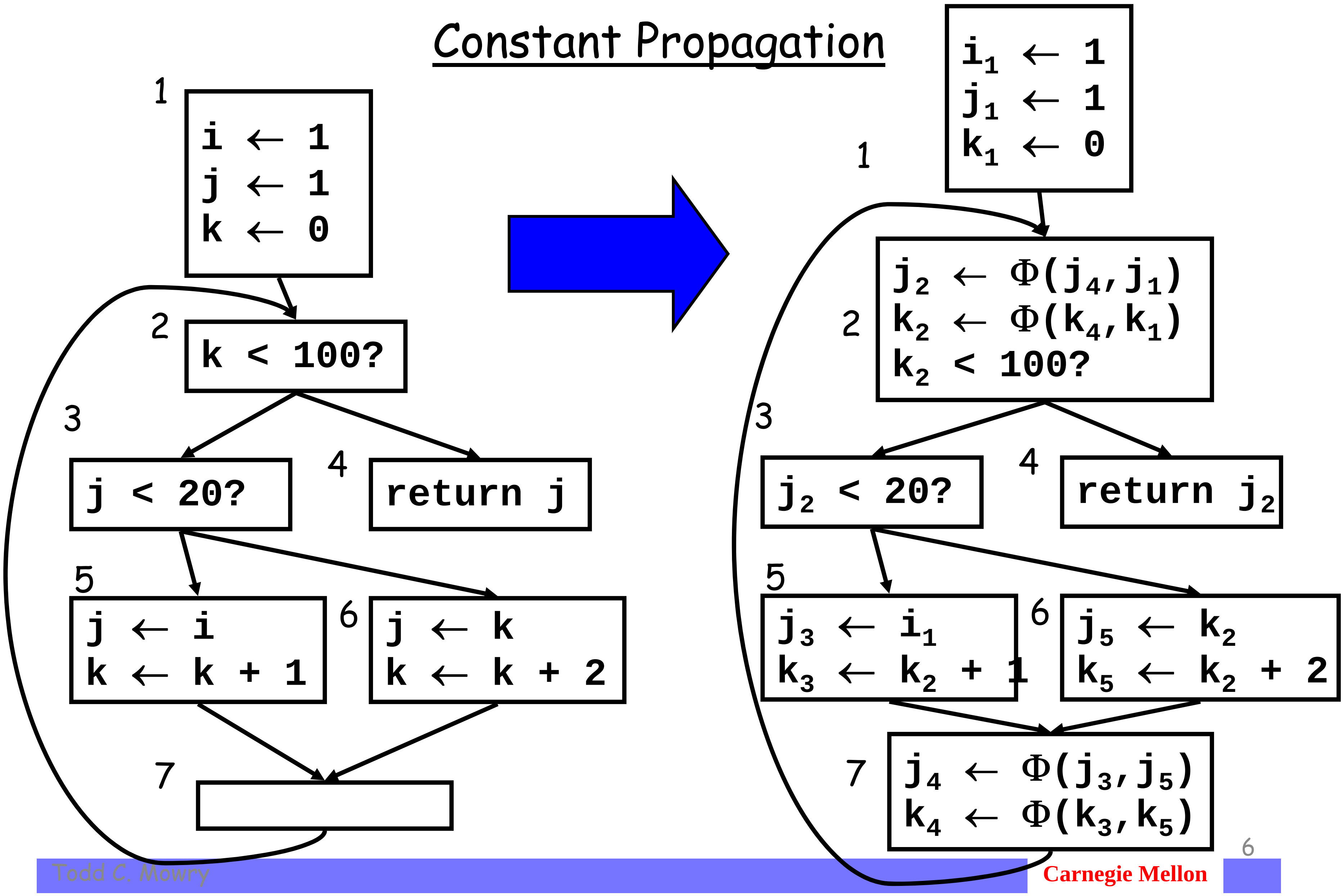
- If "v ← c", replace all uses of v with c
- If "v ← Φ(c,c,c)", replace all uses of v with c

```
W <- list of all defs
while !W.isEmpty {
        Stmt S <- W.removeOne
         if S has form "v <- Φ(c,…,c)"
           replace S with V <- c
        if S has form "v <- c" then
           delete S
           foreach stmt U that uses v,
             replace v with c in U
             W.add(U)
}
```

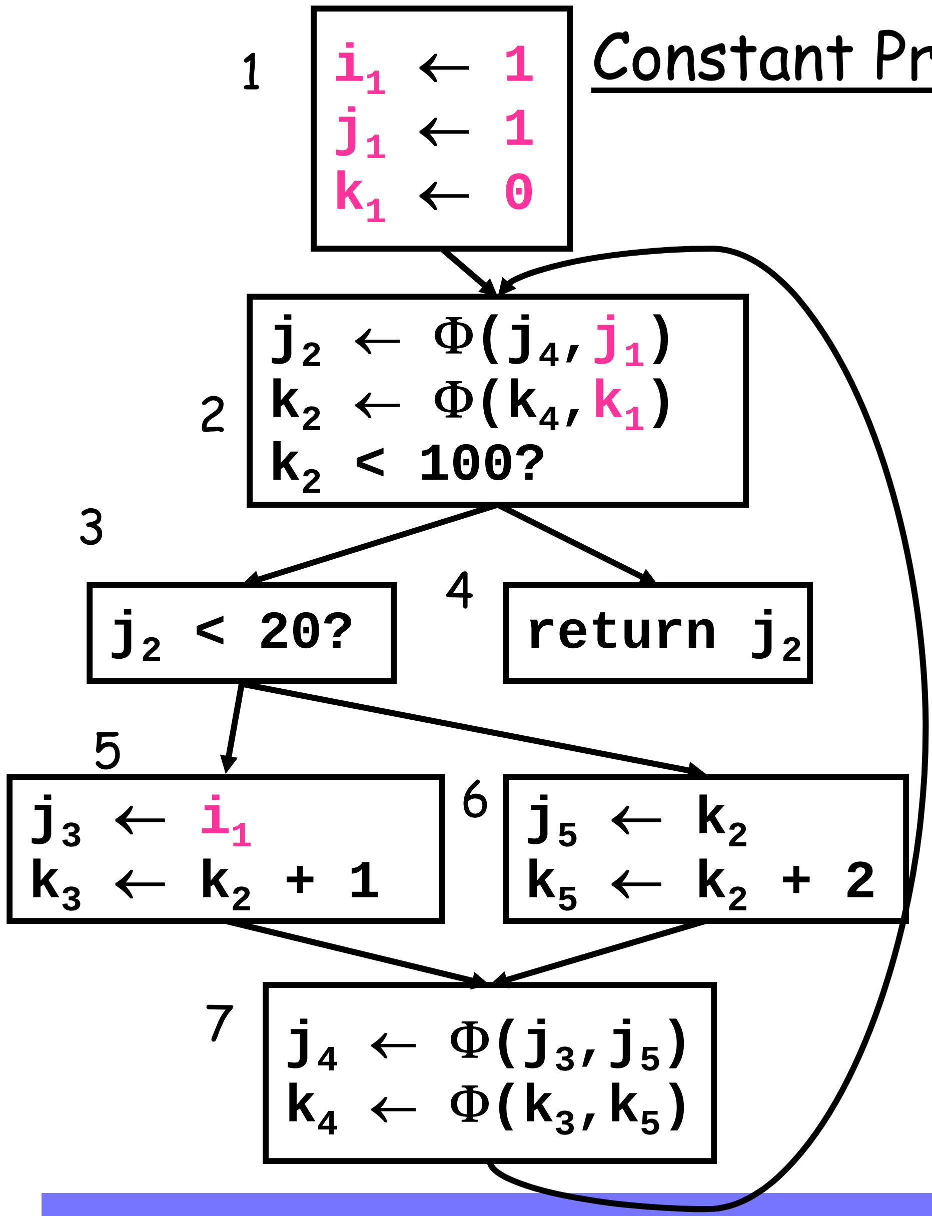
Other Optimizations with SSA

- Copy propogation
  - delete "$x \leftarrow \Phi(y,y,y)$" and replace all x with y
  - delete "$x \leftarrow y$" and replace all x with y
- Constant Folding
  - (Also, constant conditions too!)
- Unreachable Code
  - Remember to delete all edges from unreachable block

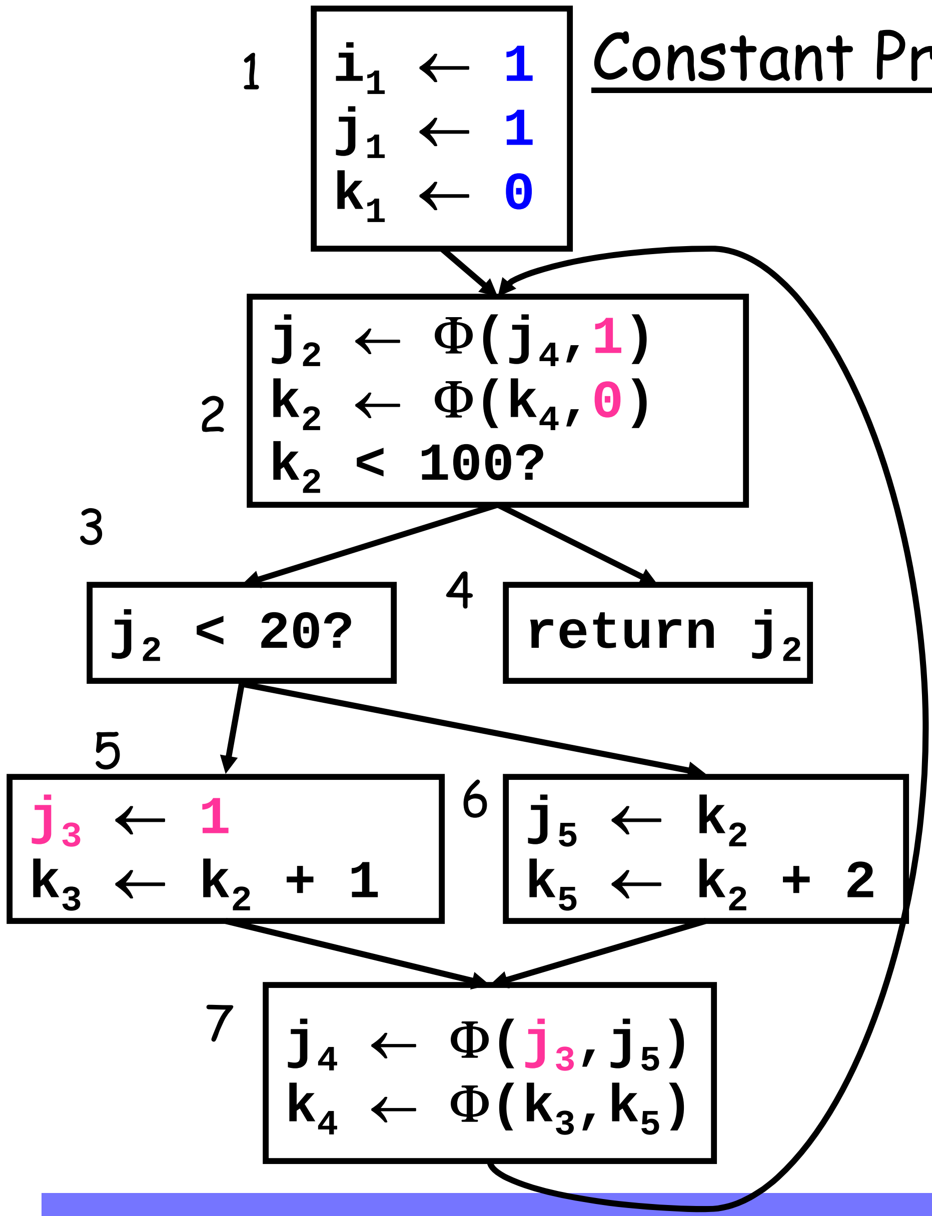
Constant Propagation



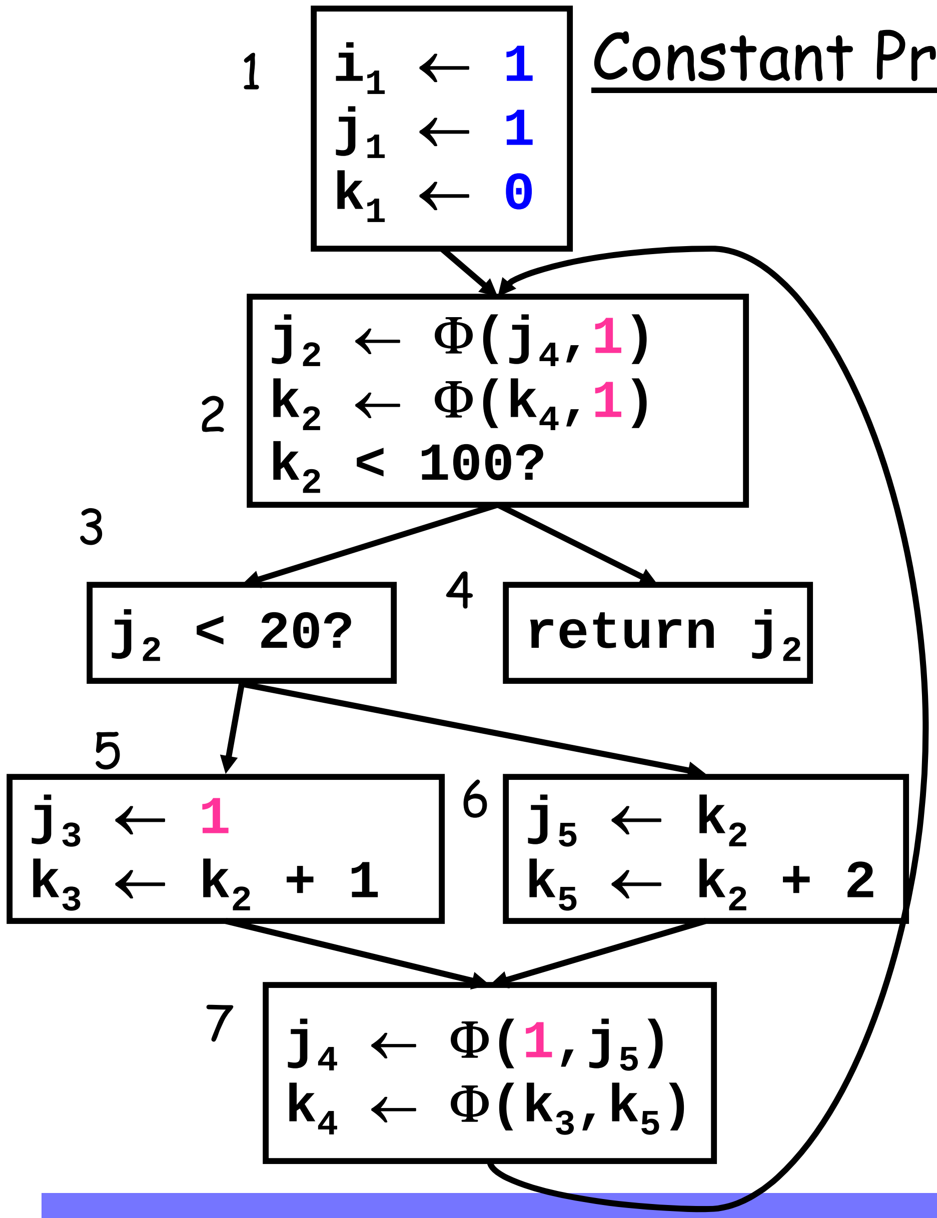
Constant Propagation



Constant Propagation

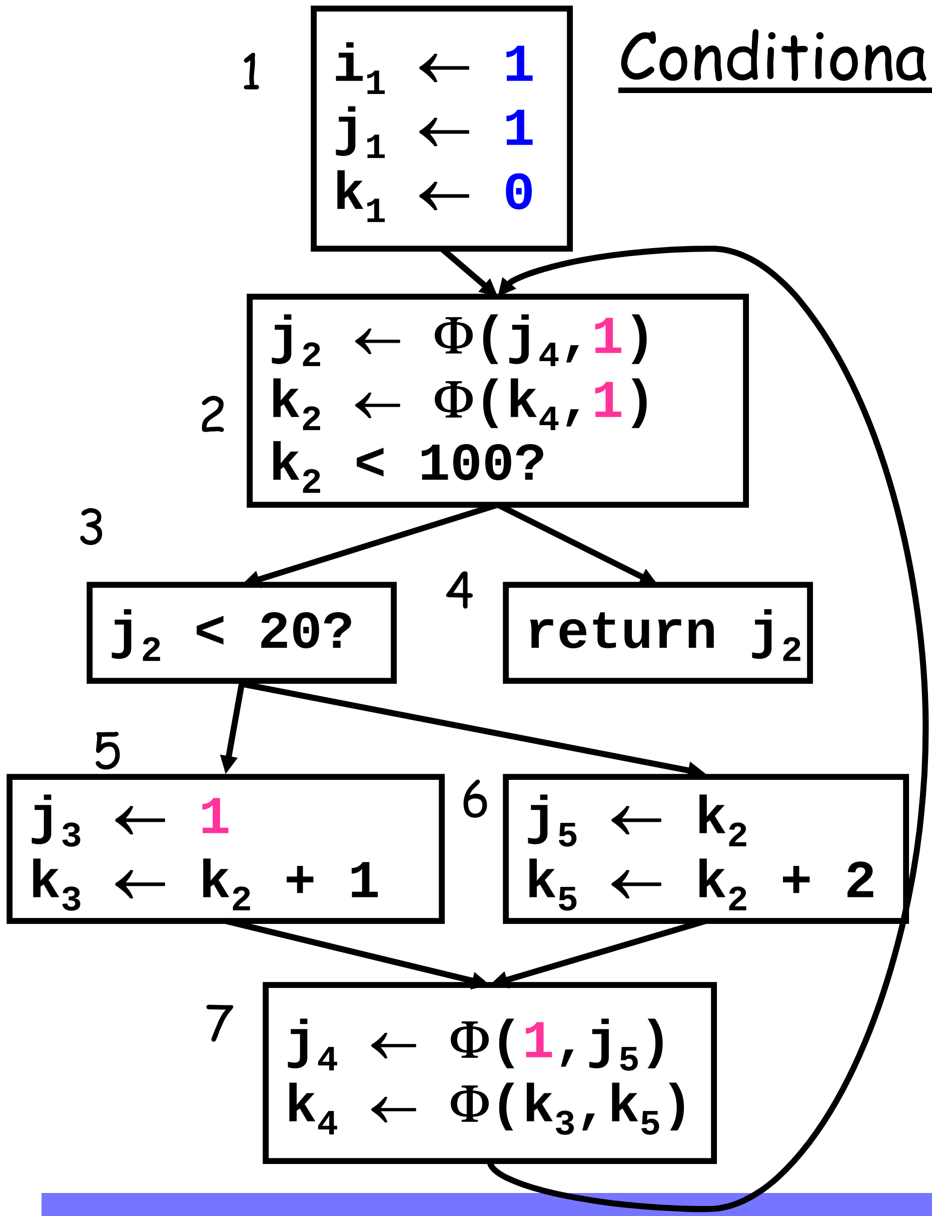


Constant Propagation



But, so what?

Conditional Constant Propagation



- Does block 6 ever execute?
- Simple CP can't tell
- Conditional CP can tell:
  - Assumes blocks don't execute until proven otherwise
  - Assumes values are constants until proven otherwise

Conditional Constant Propagation Algorithm

Keeps track of:

- Blocks
  - assume unexecuted until proven otherwise
- Variables
  - assume not executed (only with proof of assignments of a non-constant value do we assume not constant)

Lattice for representing variables:

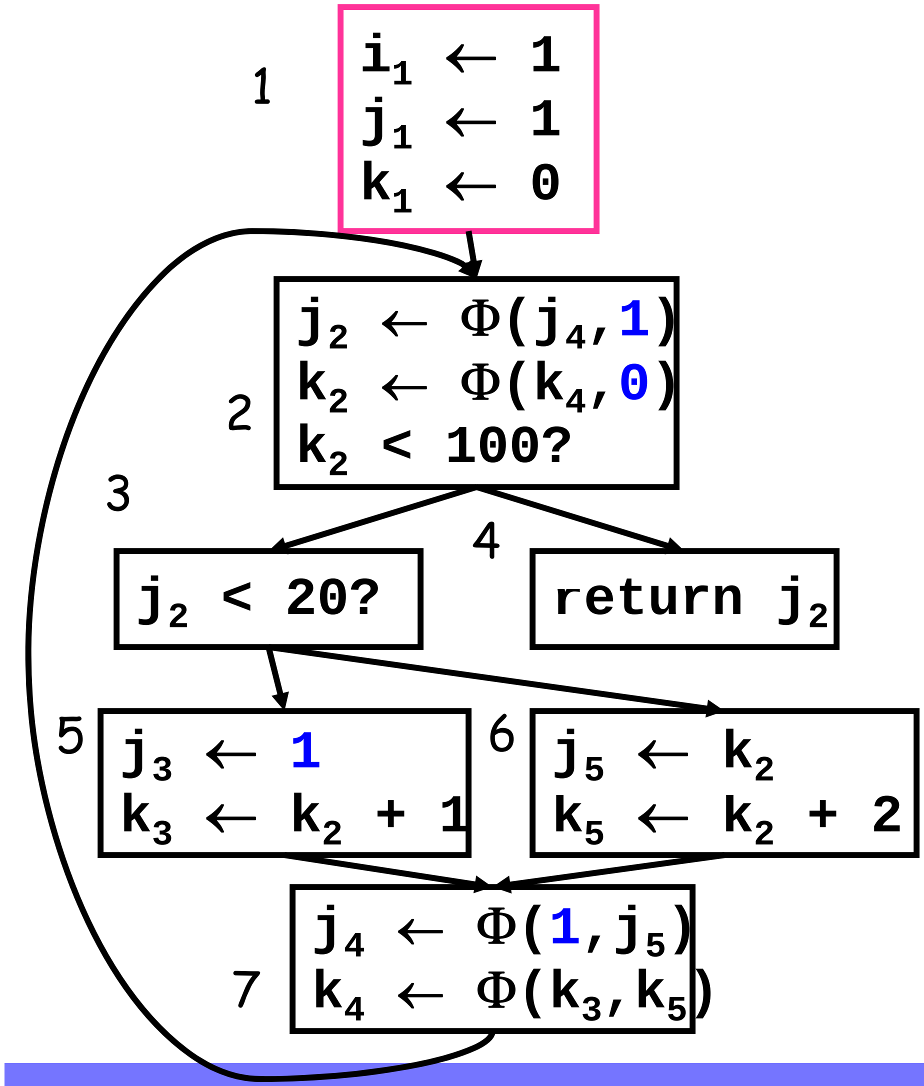
$$\begin{tikzcd}
 & & \top \arrow[dll] \arrow[dl] \arrow[d] \arrow[dr] \arrow[drr] & & \\
\cdots\ -2 \arrow[drr] & -1 \arrow[dr] & 0 \arrow[d] & 1 \arrow[dl] & 2\ \cdots \arrow[dll] \\
 & & \perp & &
\end{tikzcd}$$

not executed

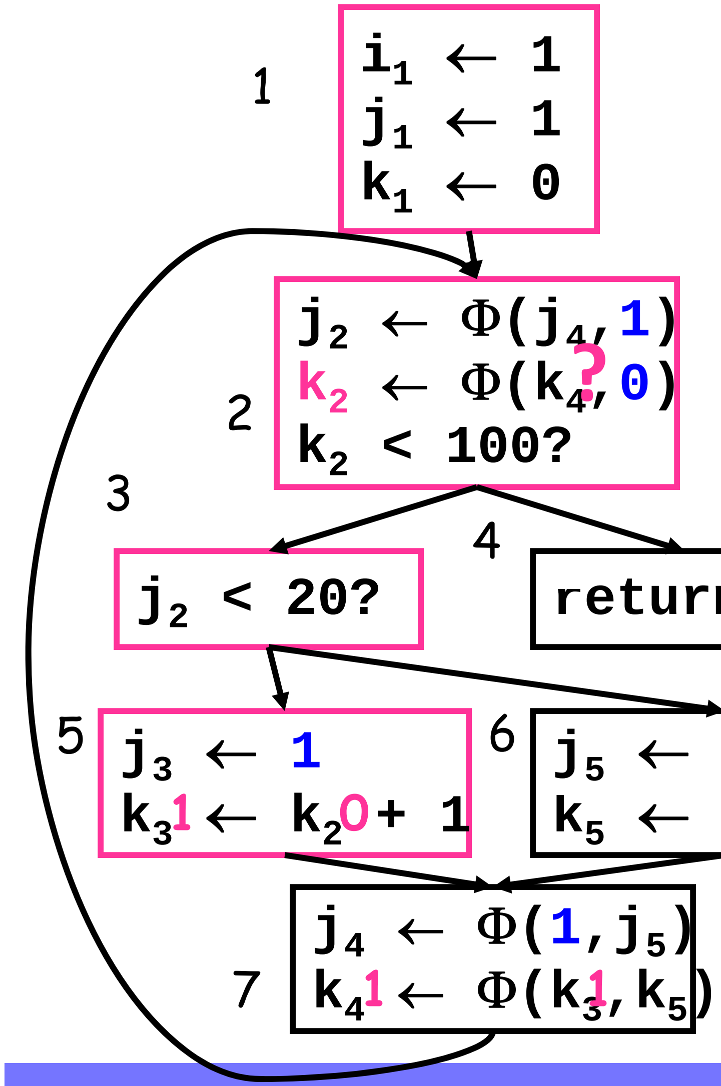
we have seen evidence that the variable has been assigned a constant with the value

we have seen evidence that the variable can hold different values at different times

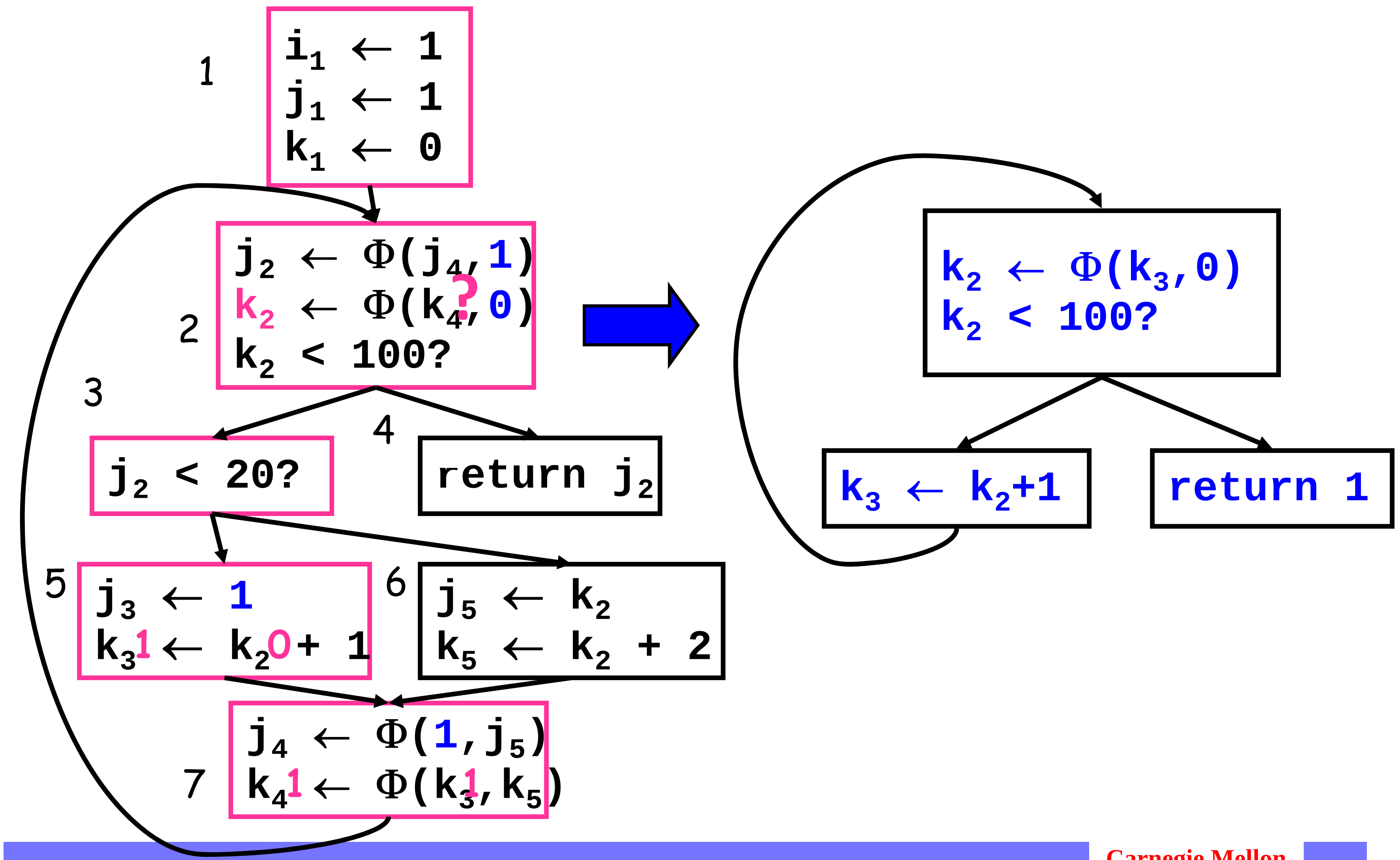
Conditional Constant Propagation



Conditional Constant Propagation


1
$i_1 \leftarrow 1$
$j_1 \leftarrow 1$
$k_1 \leftarrow 0$
2
$j_2 \leftarrow \Phi(j_4, 1)$
$k_2 \leftarrow \Phi(k_4, 0)$
?
$k_2 < 100?$
3
$j_2 < 20?$
4
return j_2
5
$j_3 \leftarrow 1$
k_3 1 $\leftarrow k_2$ 0 $+ 1$
6
$j_5 \leftarrow k_2$
$k_5 \leftarrow k_2 + 2$
7
$j_4 \leftarrow \Phi(1, j_5)$
k_4 1 $\leftarrow \Phi(k_3$ 1 $, k_5)$

Conditional Constant Propagation

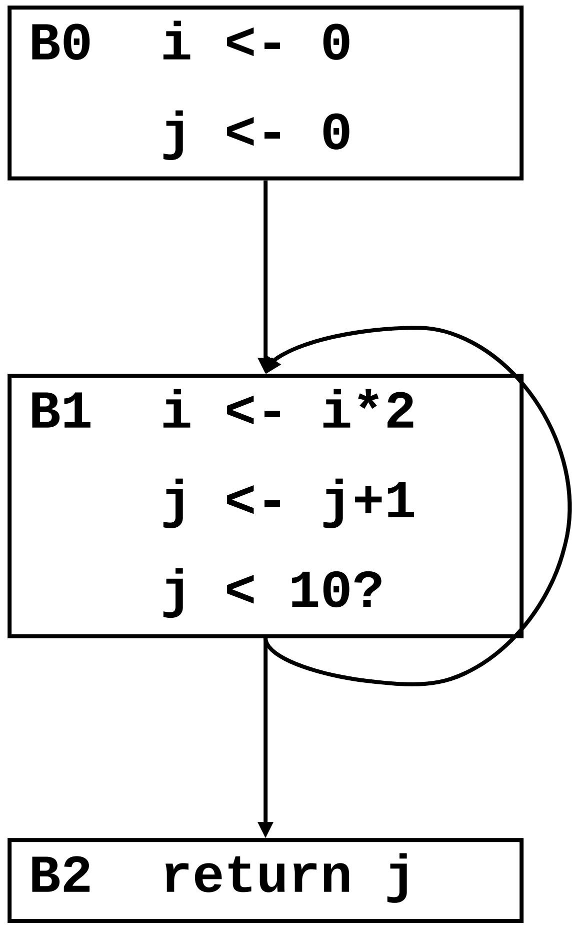


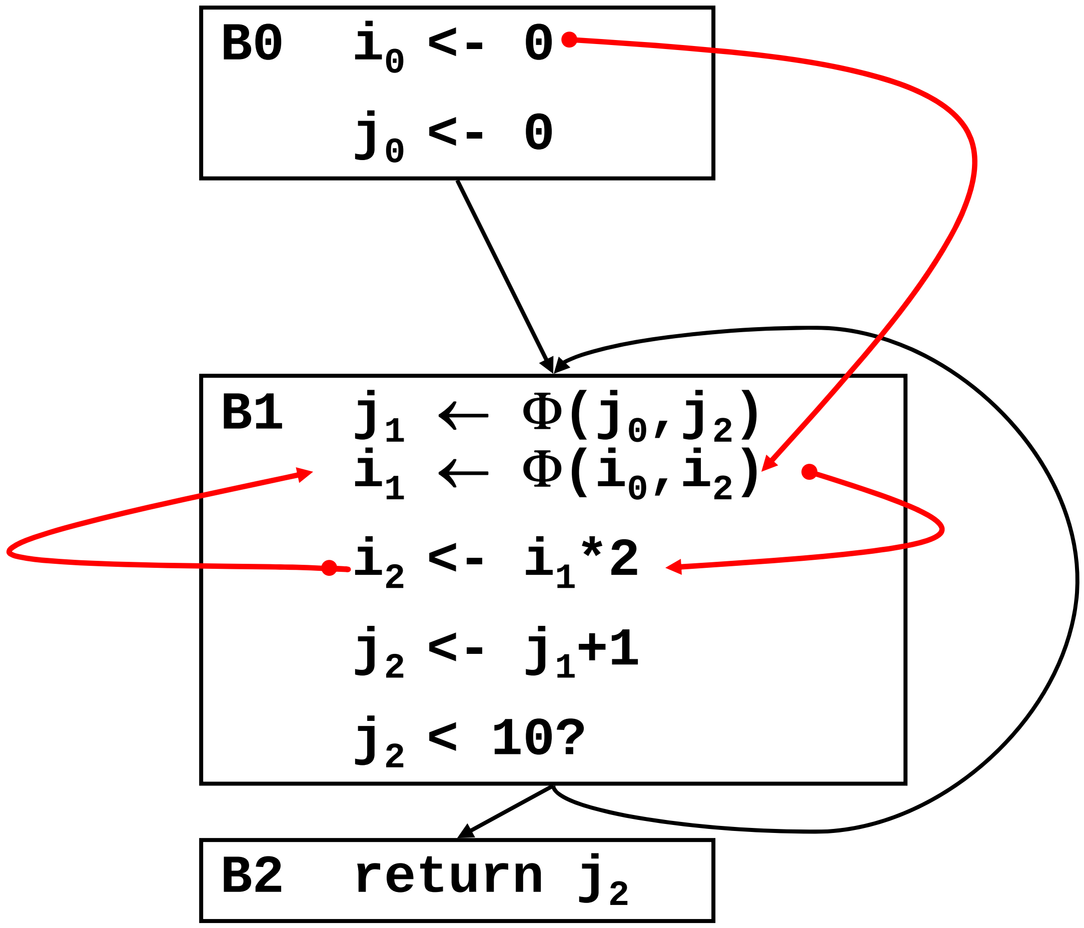
Dead Code Elimination

```
W <- list of all defs
while !W.isEmpty {
        Stmt S <- W.removeOne
        if |S.users| != 0 then continue
        if S.hasSideEffects() then continue
        foreach def in S.definers {
            def.users <- def.users - {S}
            if |def.users| == 0 then
                W <- W UNION {def}
        }
        delete S
}
```

Since we are using SSA, this is just a list of all variable assignments.

Example DCE





Standard DCE leaves Zombies!

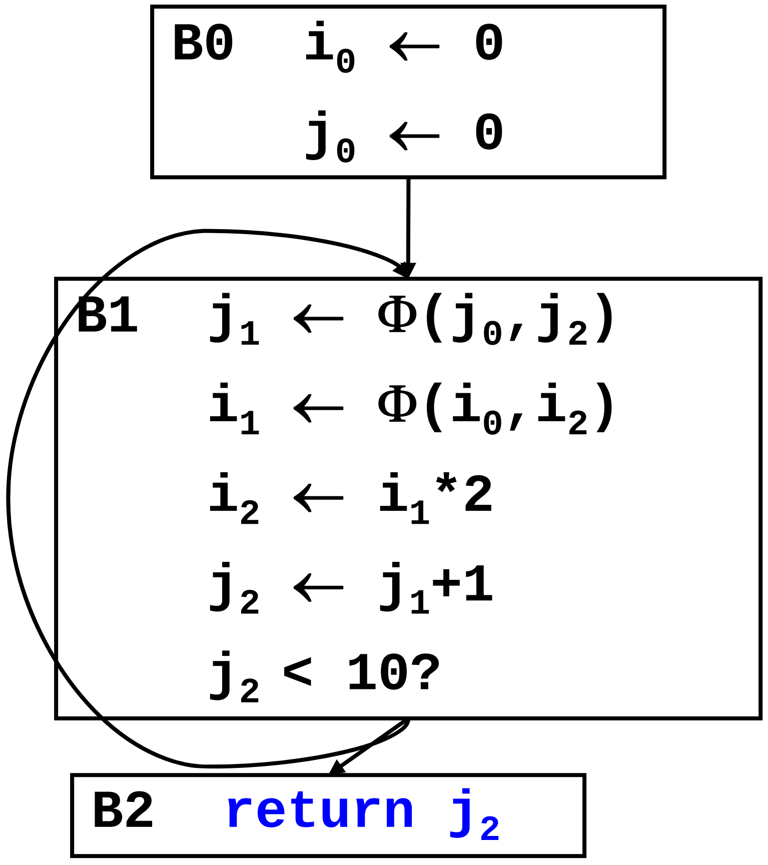
Aggressive Dead Code Elimination

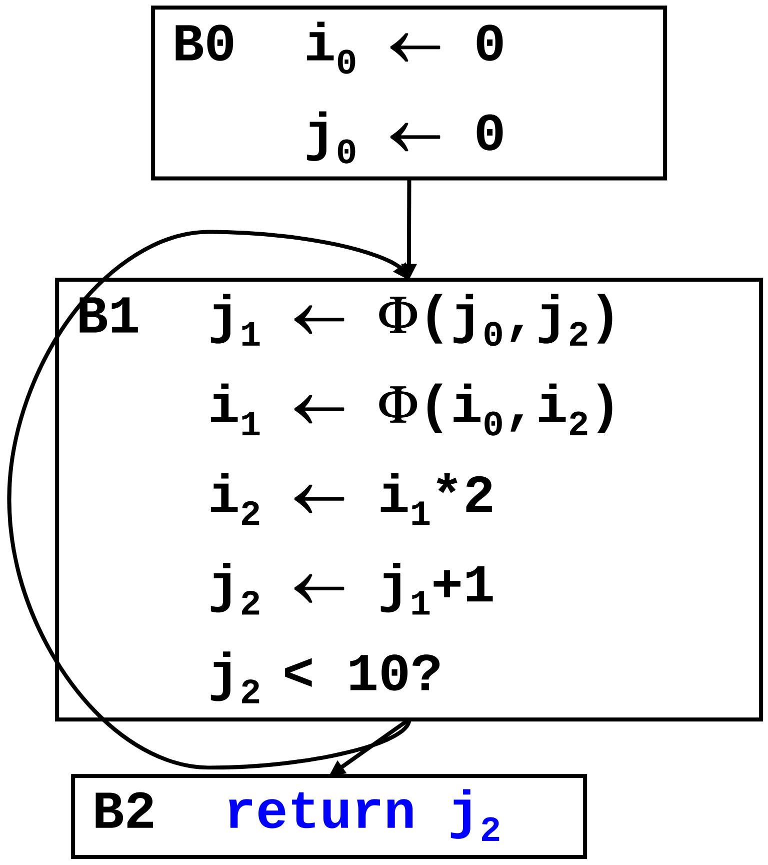
Assume a statement is dead until proven otherwise.

```
init:
   mark as live all stmts that have side-effects:
       - I/O
       - stores into memory
       - returns
       - calls a function that MIGHT have side-effects
   As we mark S live, insert S.defs into W

while (|W| > 0) {
   S <- W.removeOne()
   if (S is live) continue;
   mark S live, insert S.defs into W
}
```

Example DCE



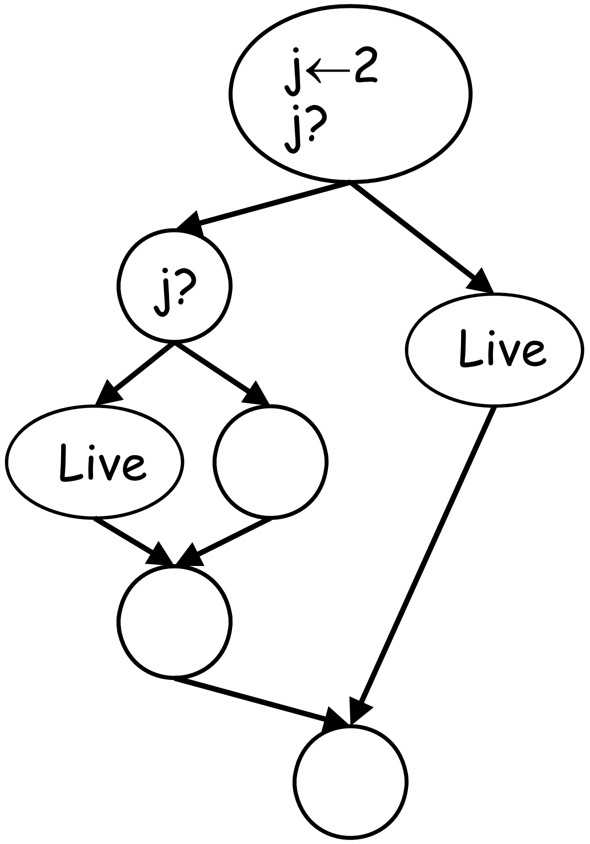


Problem!

Fixing DCE

if S is live, then

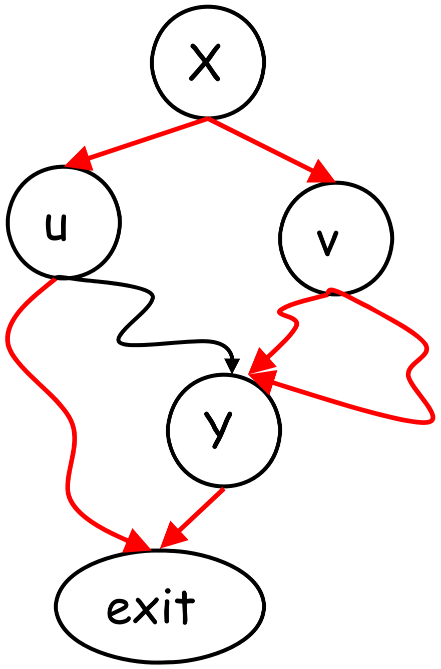
  if T determines if S can execute, T should be live



Control Dependence

Y is control-dependent on X if
- X branches to u and v
- ∃ a path u→exit which does not go through Y
- ∀ paths v→exit go through Y

i.e. X can determine whether or not Y is executed.

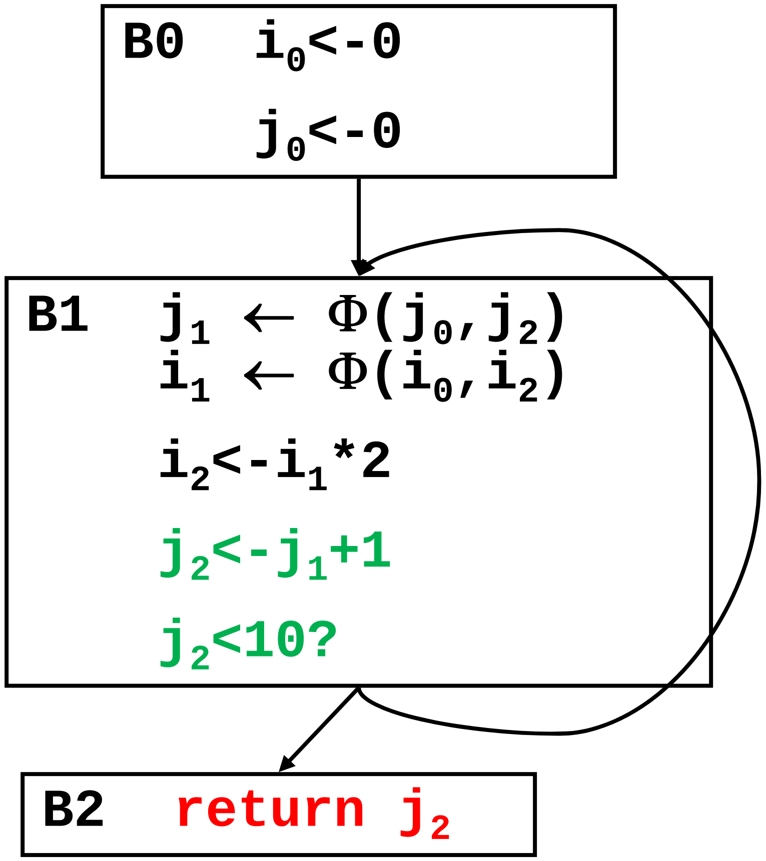


Aggressive Dead Code Elimination

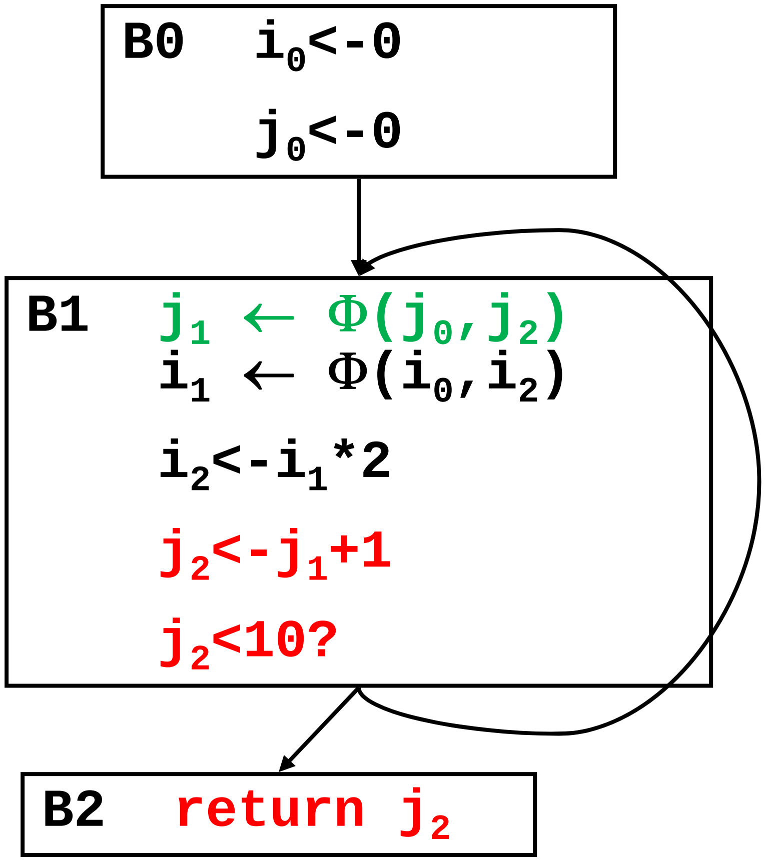
Assume a statement is dead until proven otherwise.

```
while (|W| > 0) {
   S <- W.removeOne()
   if (S is live) continue;
   mark S live, insert:
       - forall operands, S.operand.definers into W
       - S.CD-1 into W
}
```

Example DCE



B0 i_0<-0
j_0<-0
B1 $j_1 \leftarrow \Phi(j_0,j_2)$
$i_1 \leftarrow \Phi(i_0,i_2)$
i_2<-i_1*2
j_2<-j_1+1
j_2<10?
B2 return j_2



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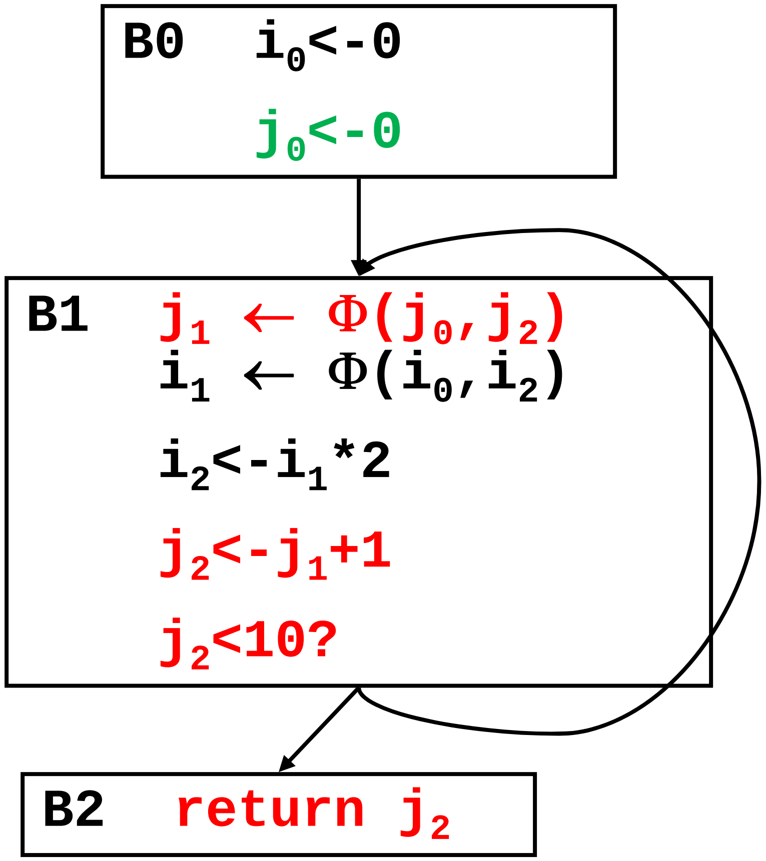
Example DCE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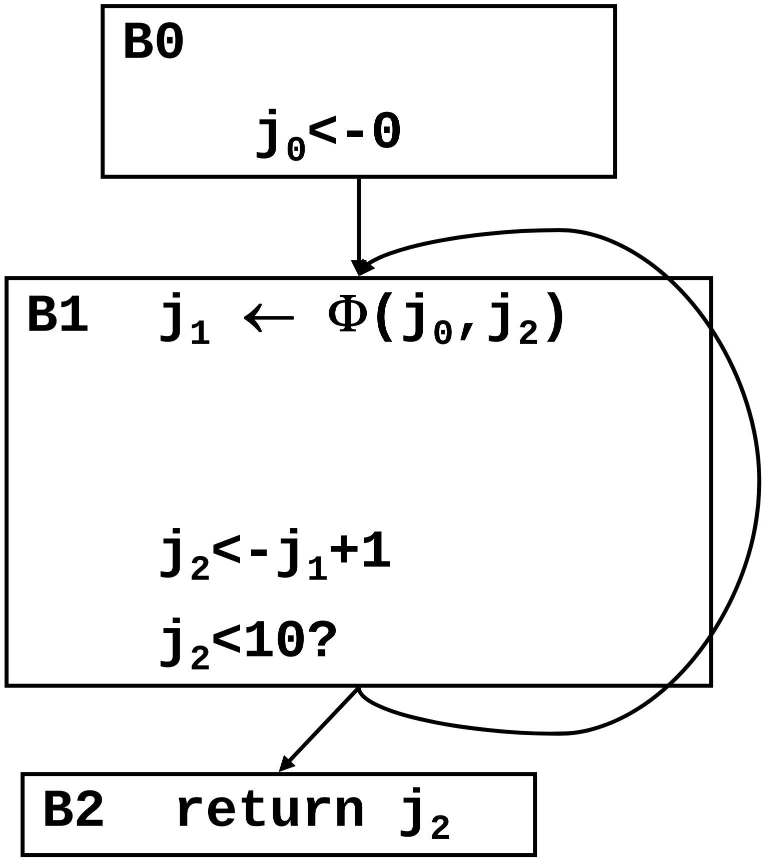
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j_0<-0
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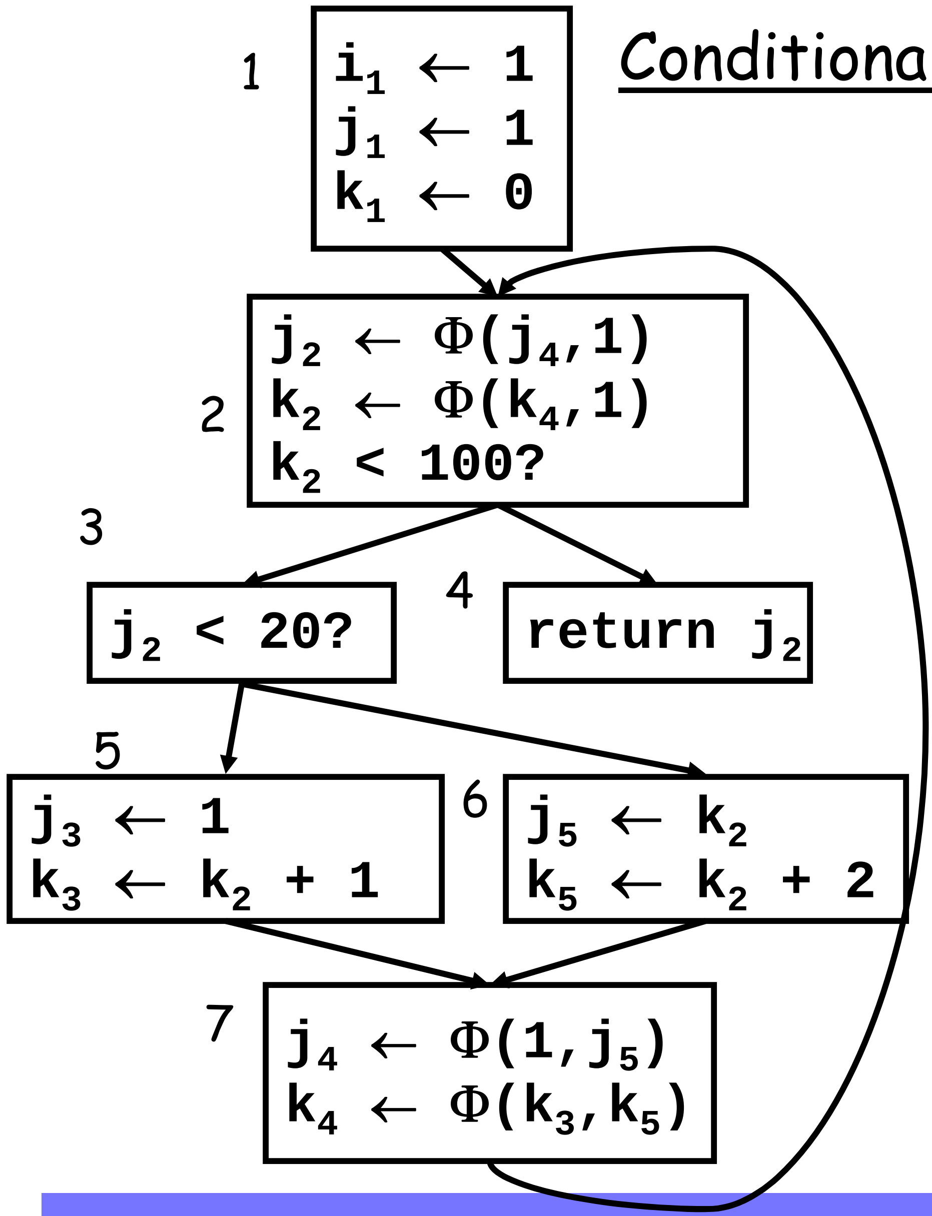
Conditional Constant Propagation



(Recall from earlier.)

- Does block 6 ever execute?
- Simple CP can't tell
- Conditional CP can tell:
  - Assumes blocks don't execute until proven otherwise
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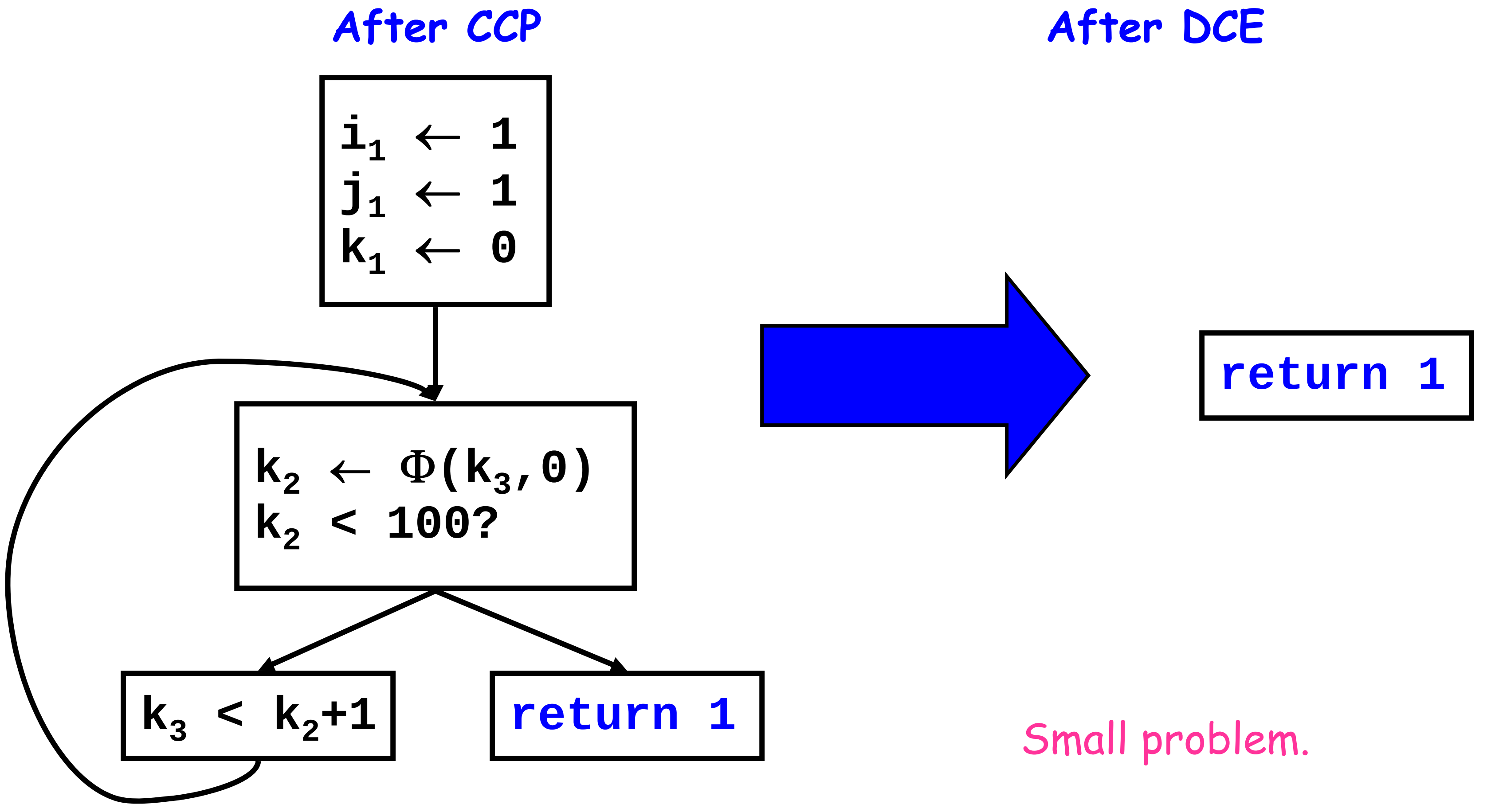
Applying Dead Code Elimination to the Result of CCP



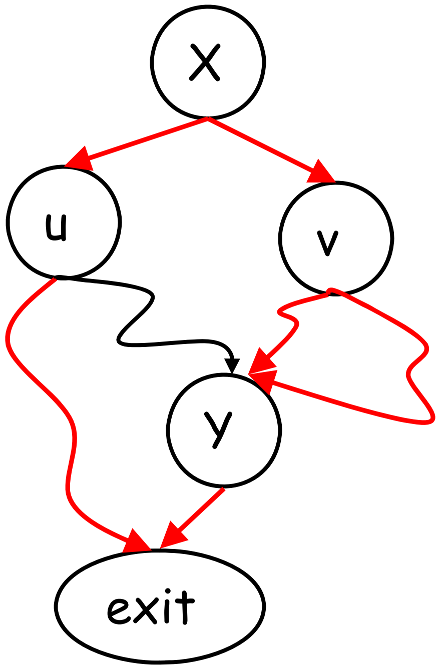
Small problem.

Finding the Control Dependence Graph

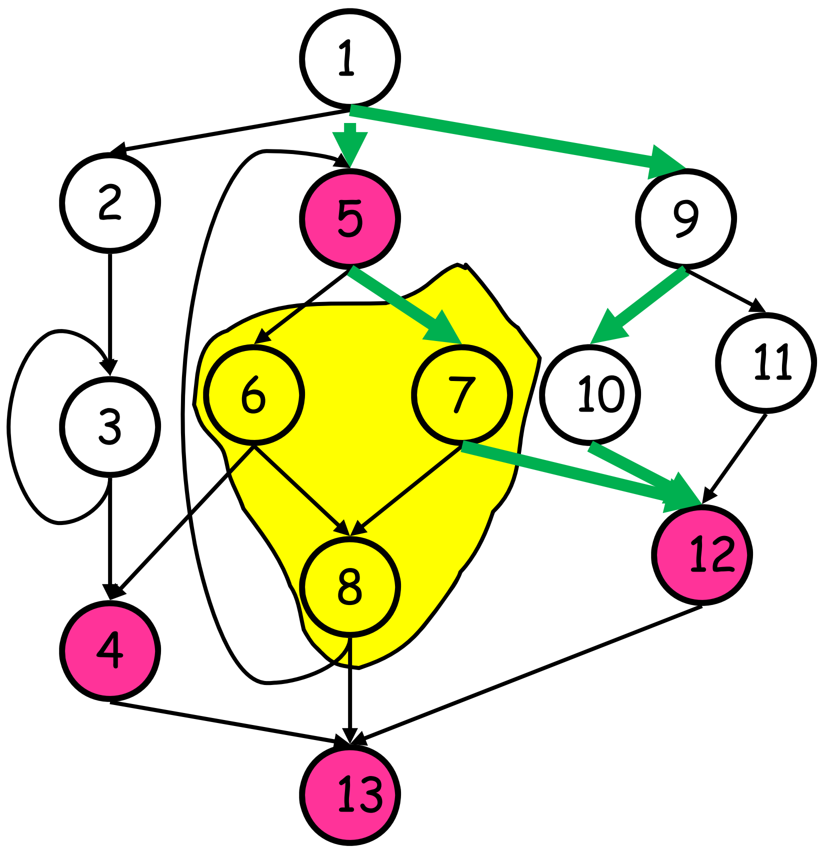
Y is control-dependent on X if

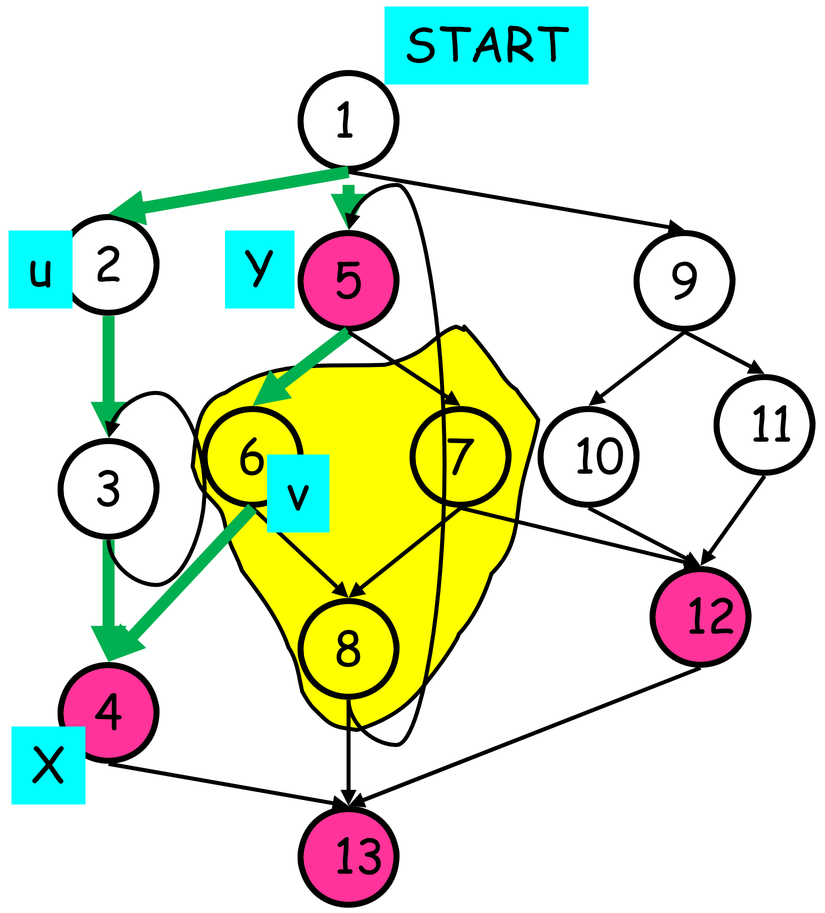
- X branches to u and v
- ∃ a path u→exit which does not go through Y
- ∀ paths v→exit go through Y

i.e. X can determine whether or not Y is executed.



Dominance Frontier and Path Convergence





Any ideas?

Finding the Control Dependence Graph

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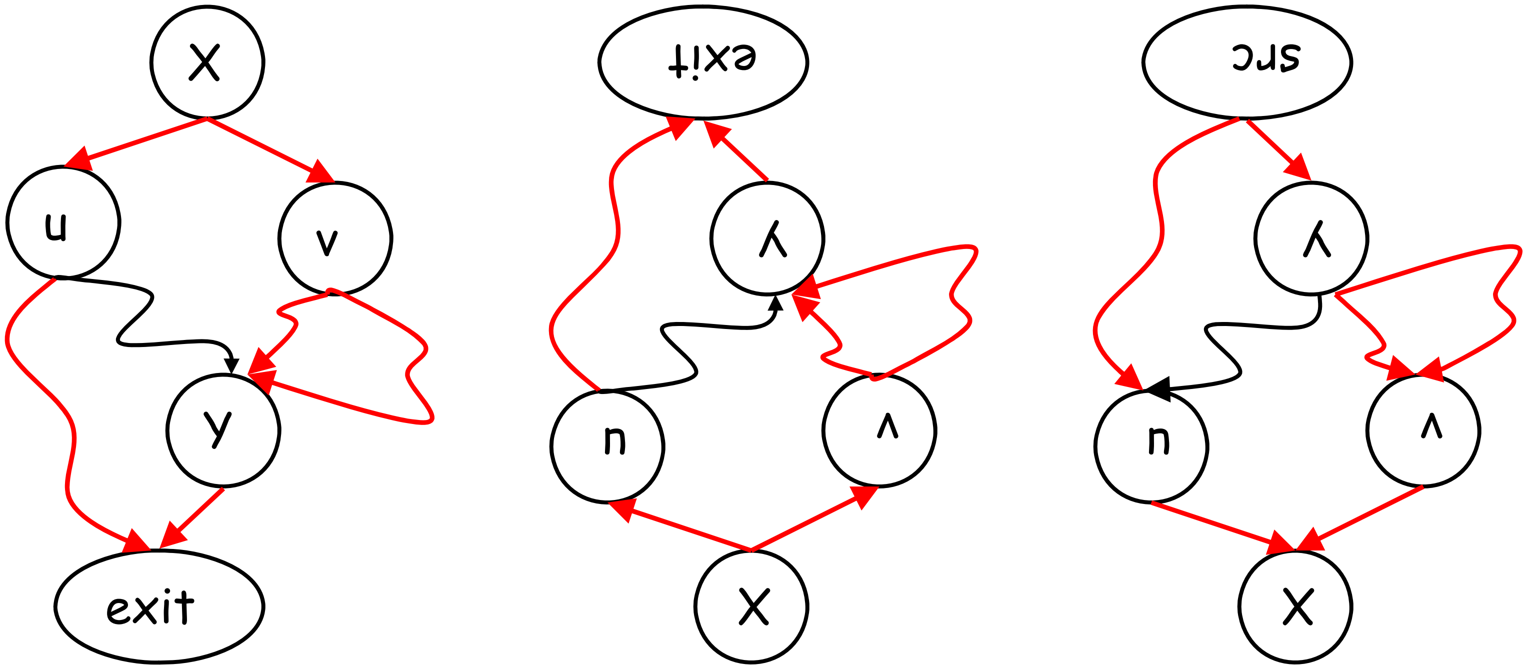
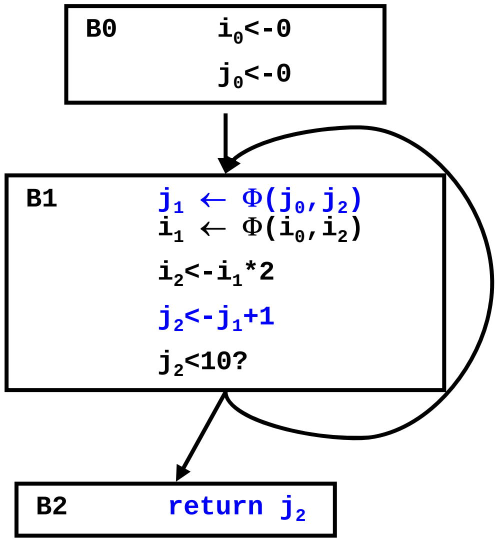
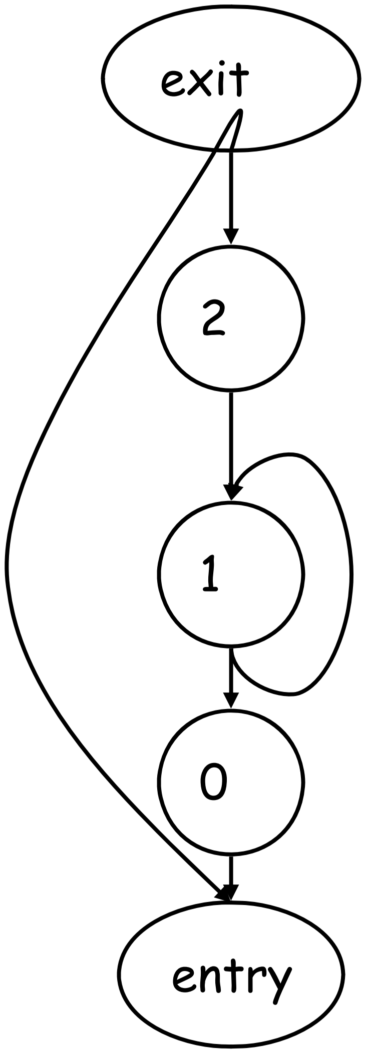


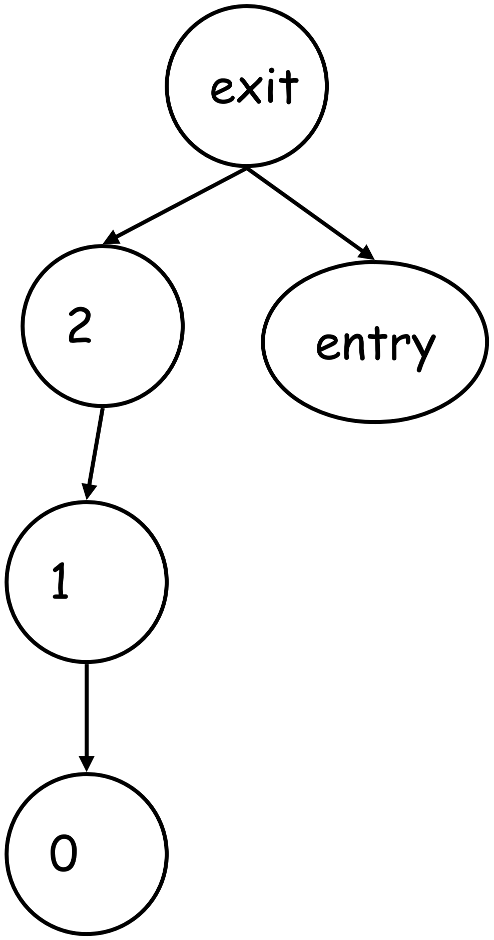
Finding the CDG

- Construct CFG
- Add entry node and exit node
- Add (entry,exit)
- Create G', the reverse CFG
- Compute D-tree in G' (post-dominators of G)
- Compute $DF_{G'}(y)$ for all $y \in G'$ (post-DF of G)
- Add $(x,y) \in G$ to CDG if $x \in DF_{G'}(y)$

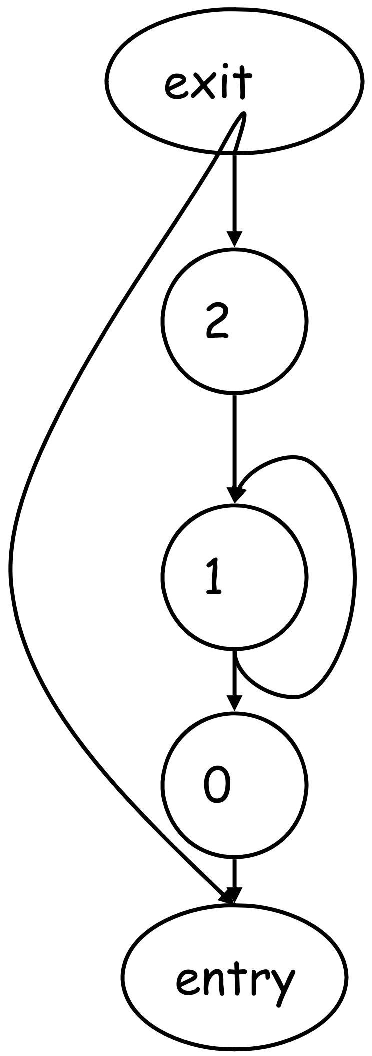
CDG of example

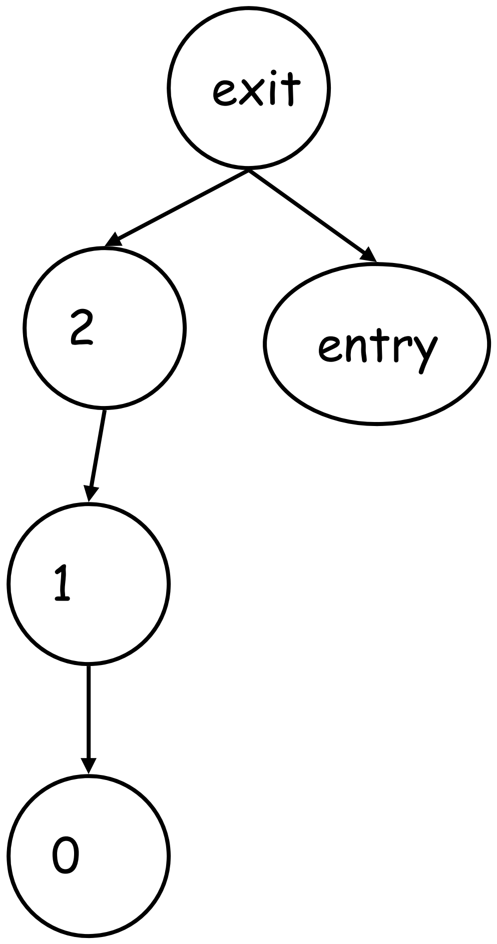






CDG of example





exit:	{}
2:	{entry}
1:	{1,entry}
0:	{entry}
entry:	{}