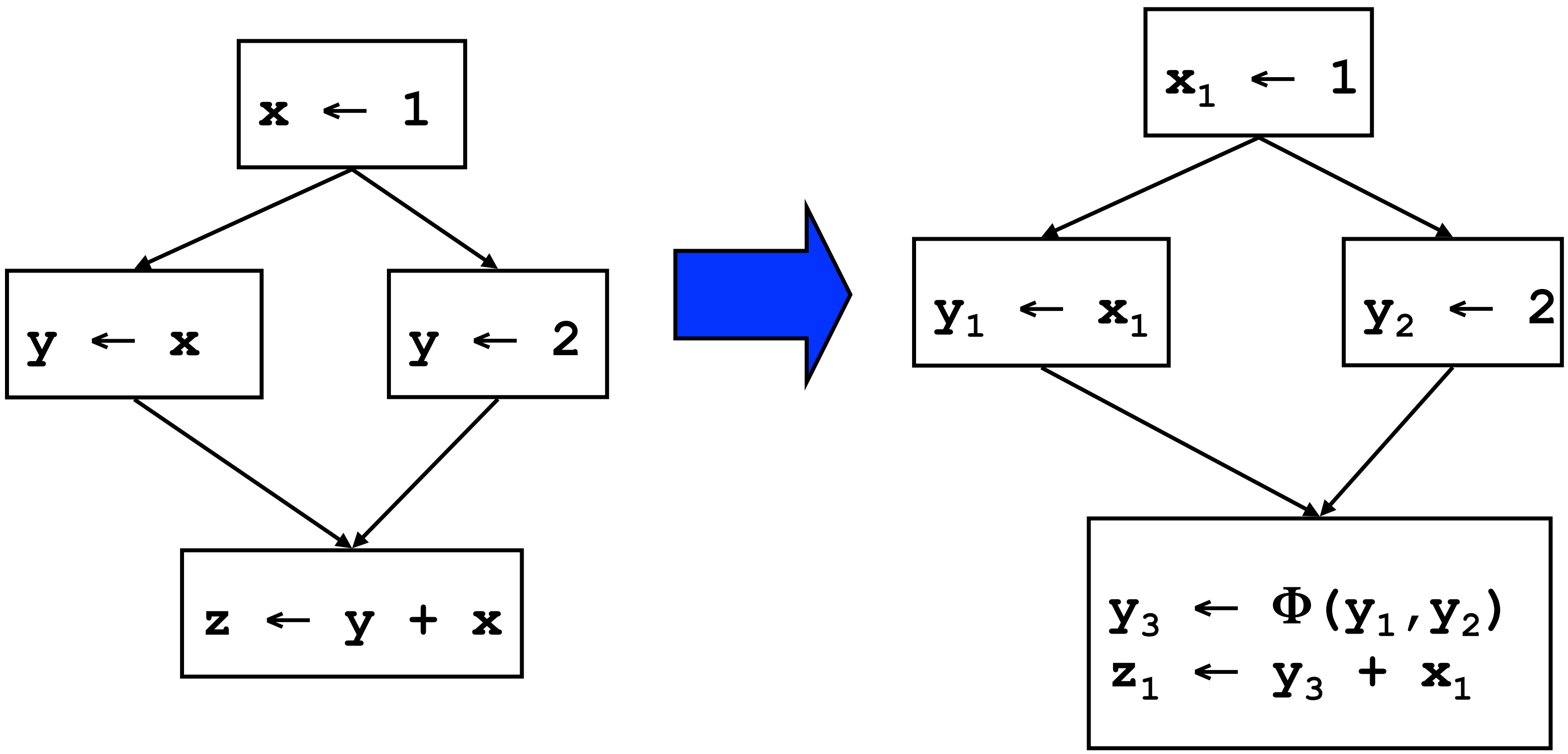
Lecture 14

SSA-Style Optimizations

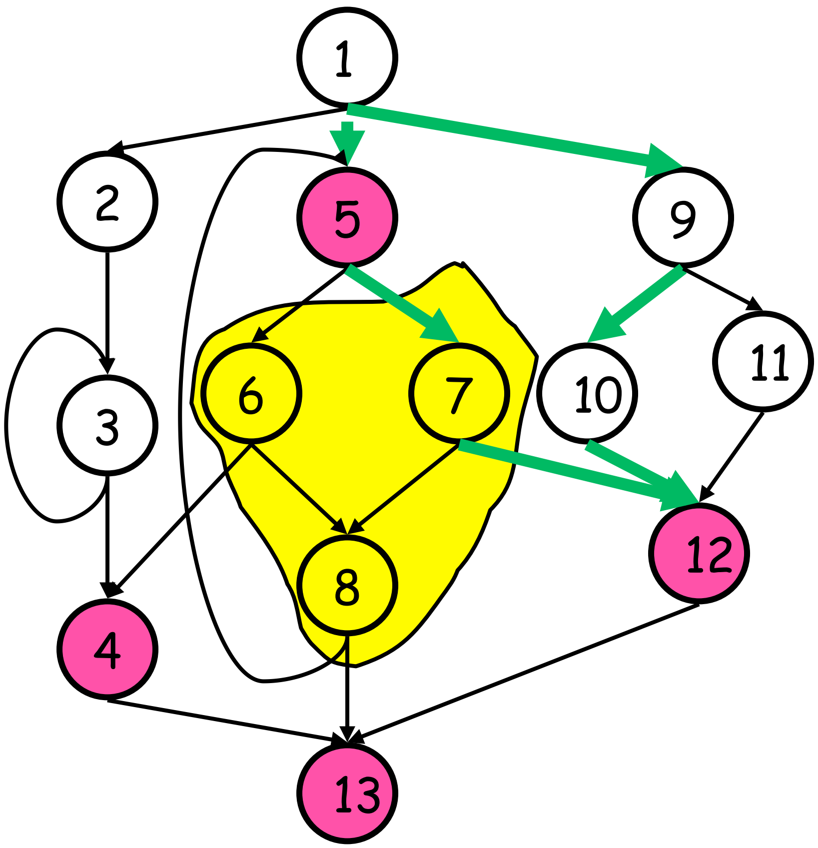
(Slides courtesy of Seth Goldstein.)

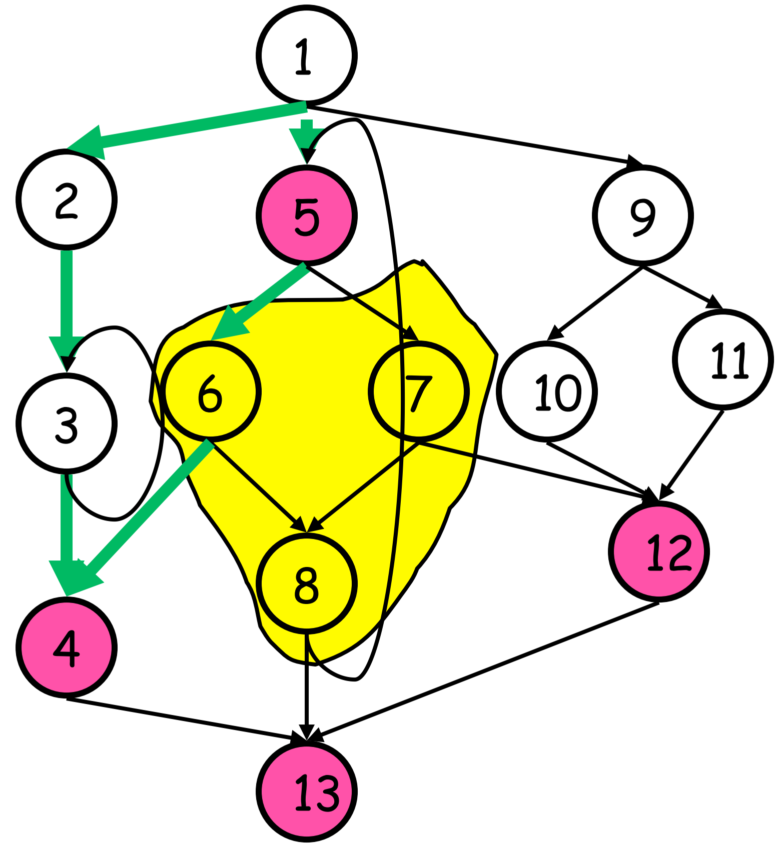
Review: Minimal SSA

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



Review: Dominance Frontier and Path Convergence





Constant Propagation

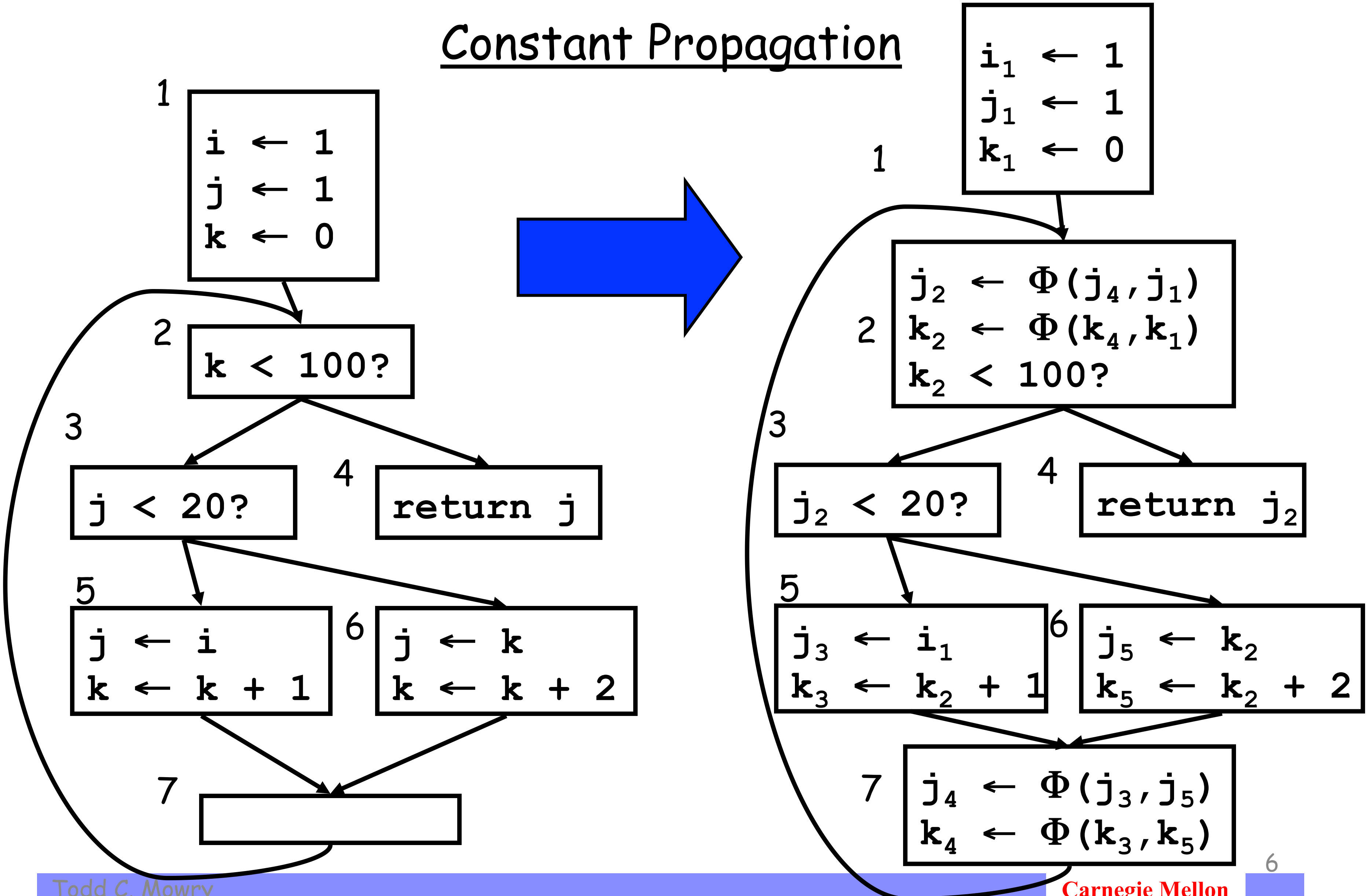
- If "$v \leftarrow c$", replace all uses of v with c
- If "$v \leftarrow \Phi(c,c,c)$", replace all uses of v with c

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

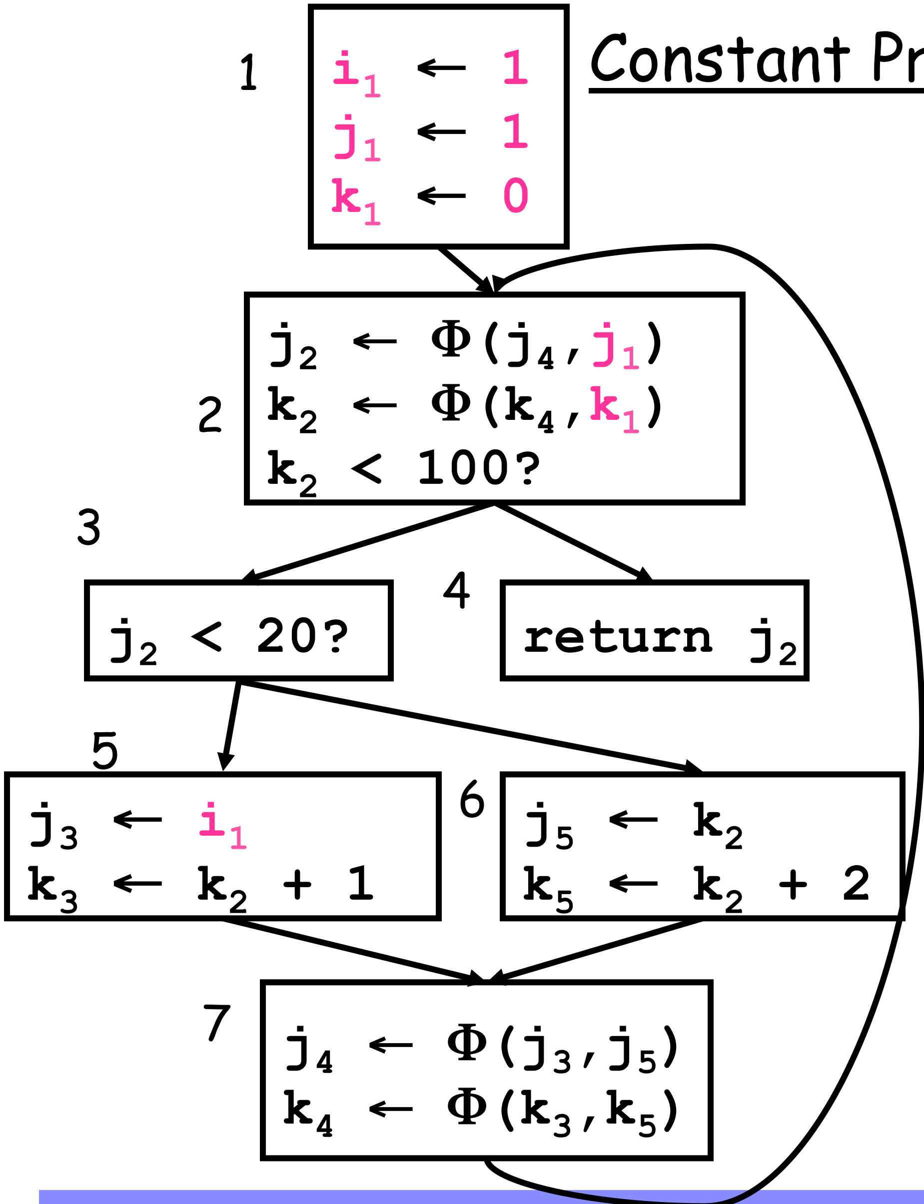
Other Optimizations with SSA

- 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!)

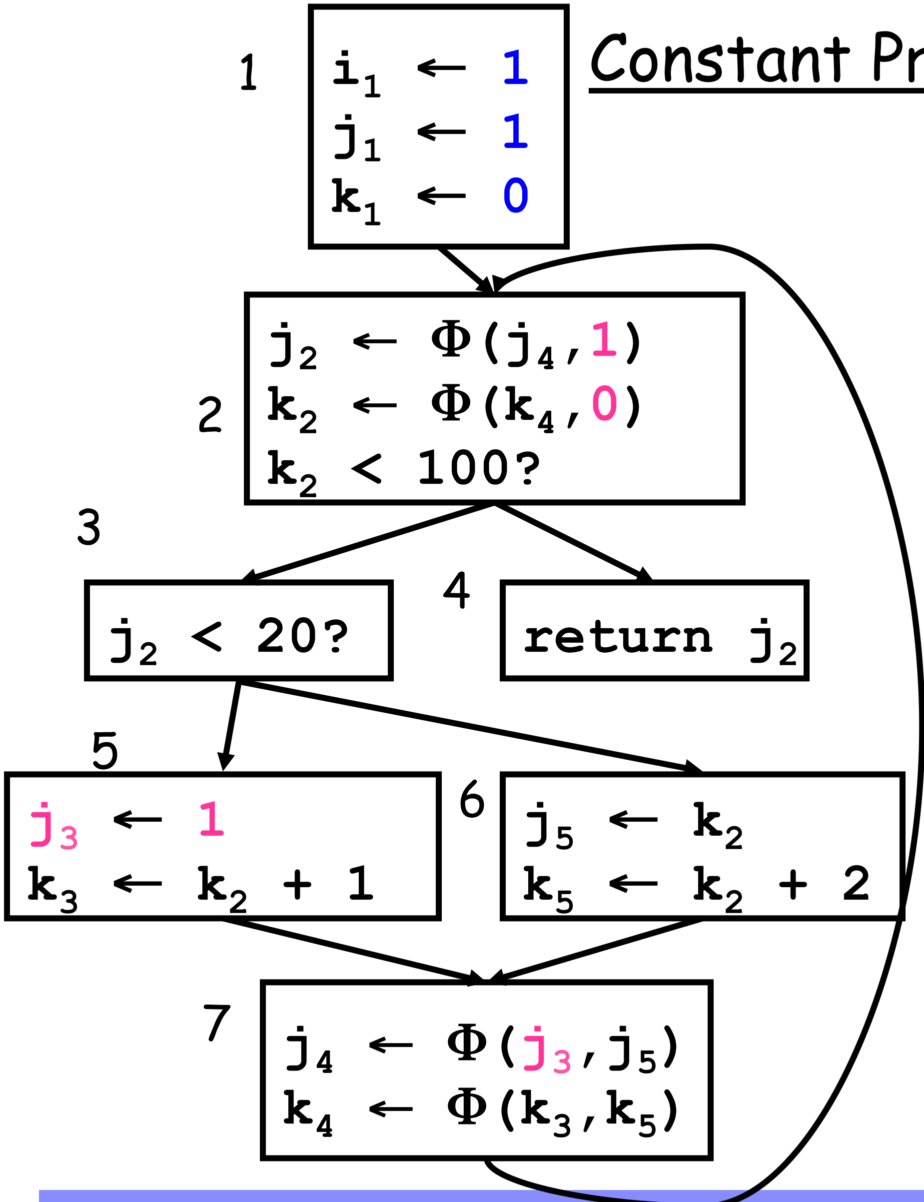
Constant Propagation



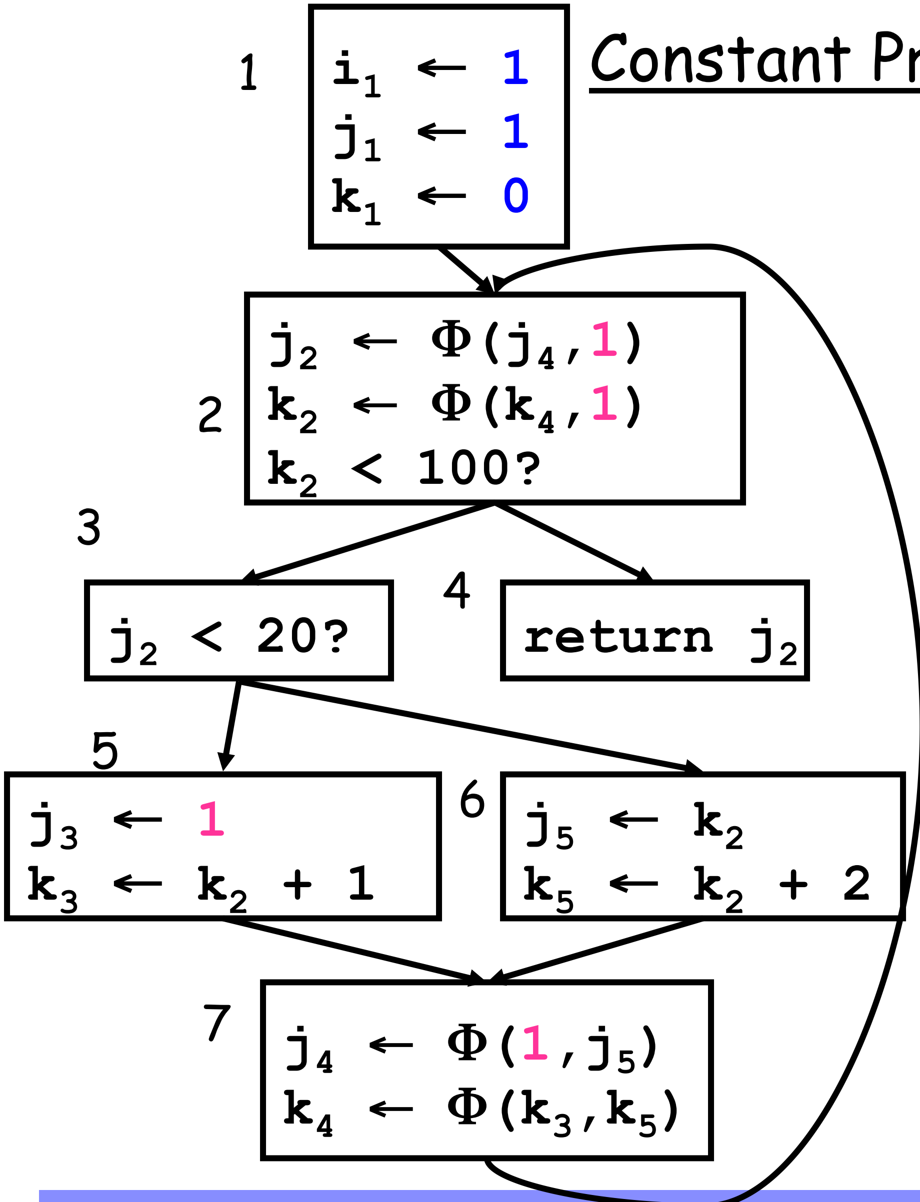
Constant Propagation



Constant Propagation

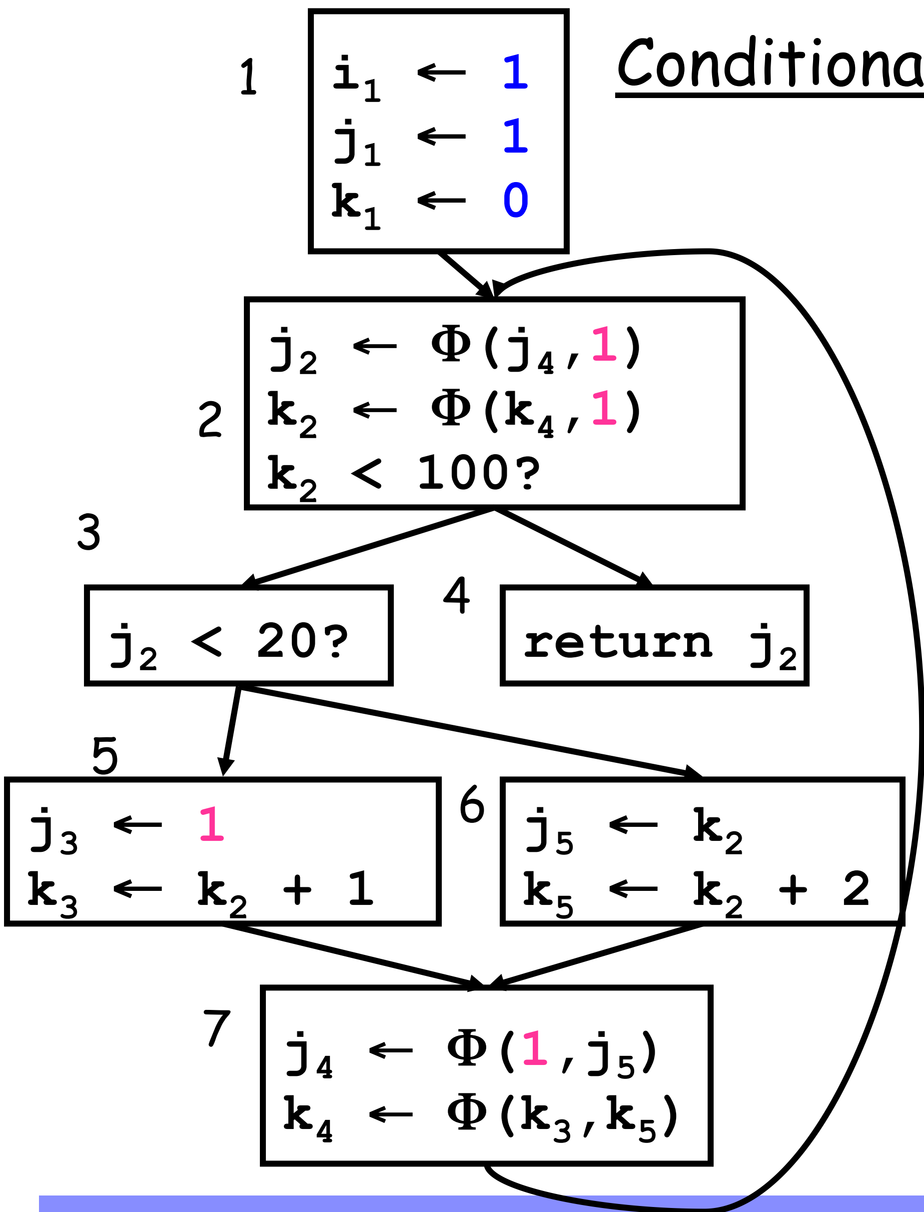


Constant Propagation



But, so what?

Conditional Constant Propagation



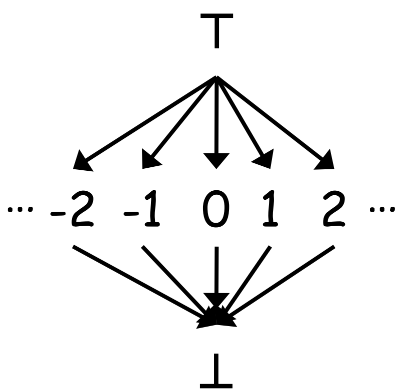
- Does block 6 ever execute?
- Simple CP can't tell
- Conditional CP can tell:
  - Assumes blocks don't execute until proven otherwise
  - Assumes values are constants until proven otherwise

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:

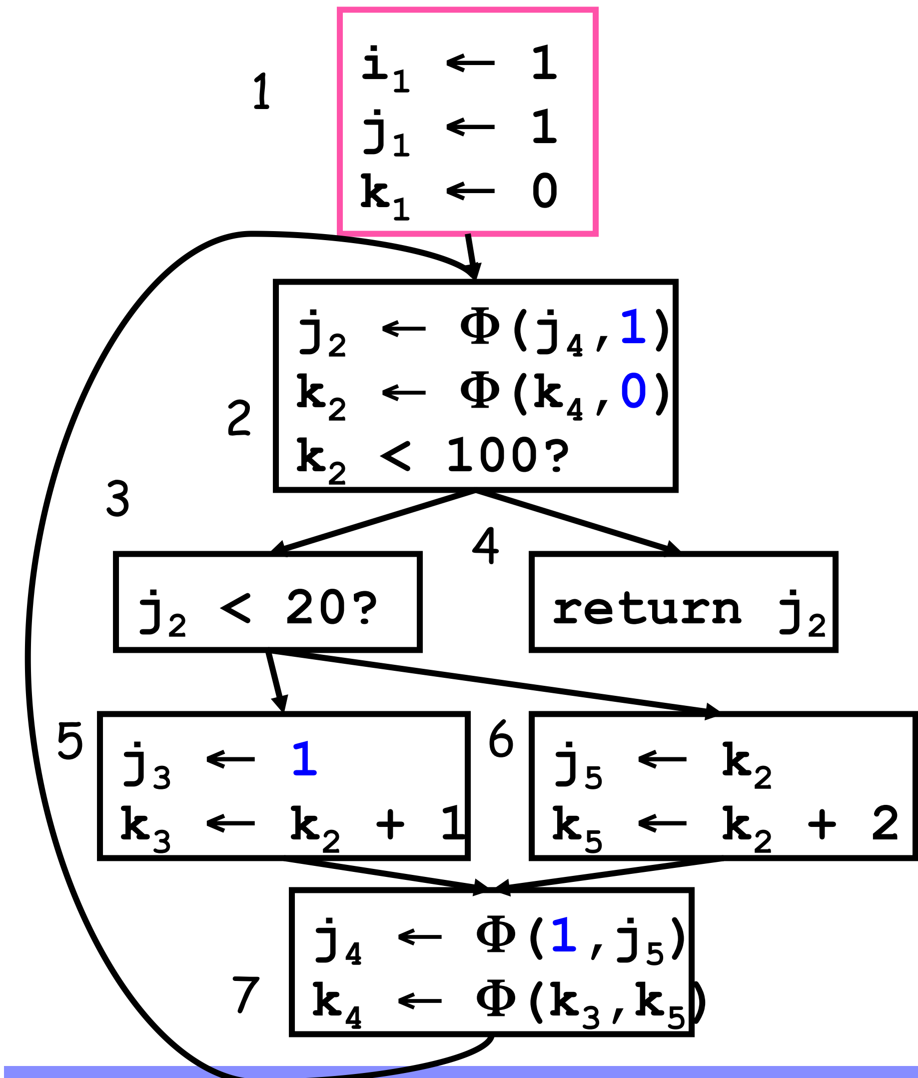


not executed

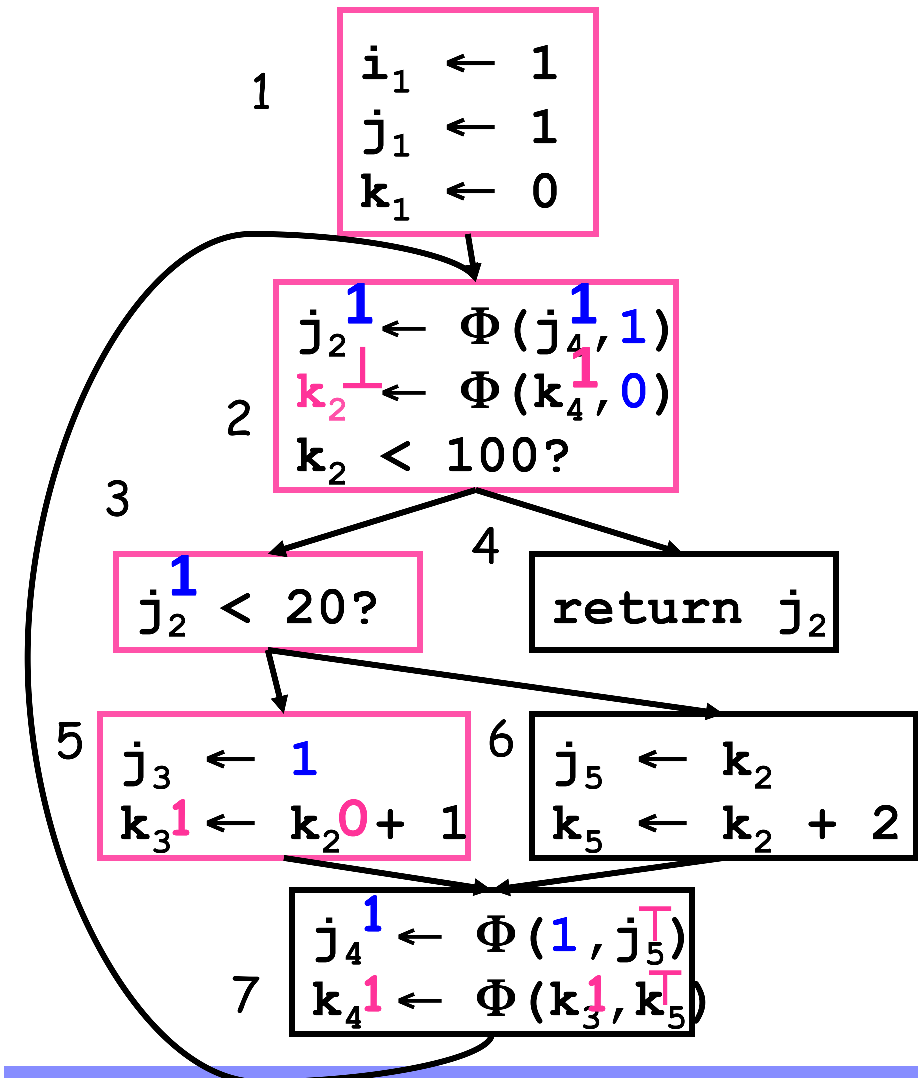
we have seen evidence that the variable has been assigned a constant with the value

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

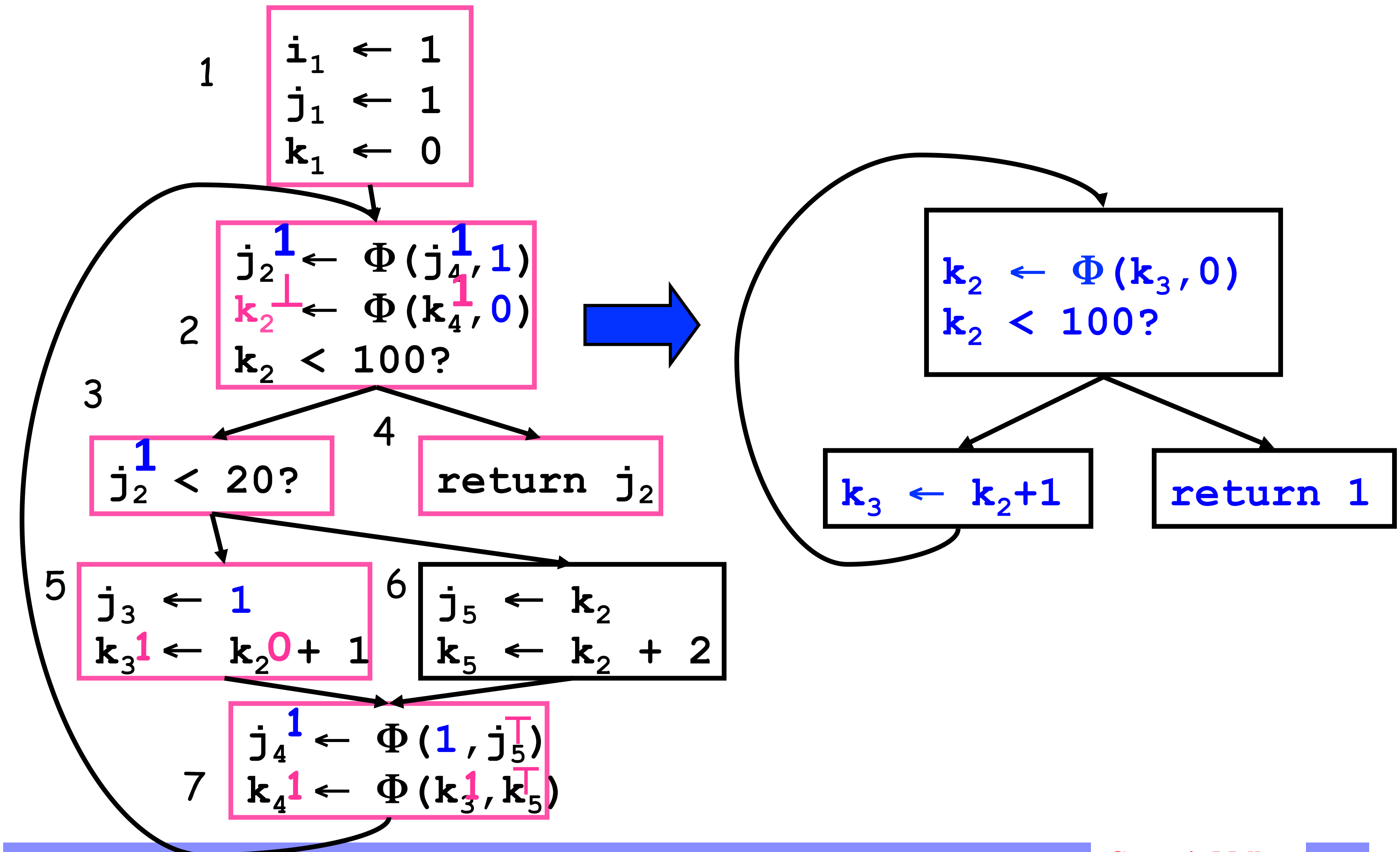
Conditional Constant Propagation



Conditional Constant Propagation



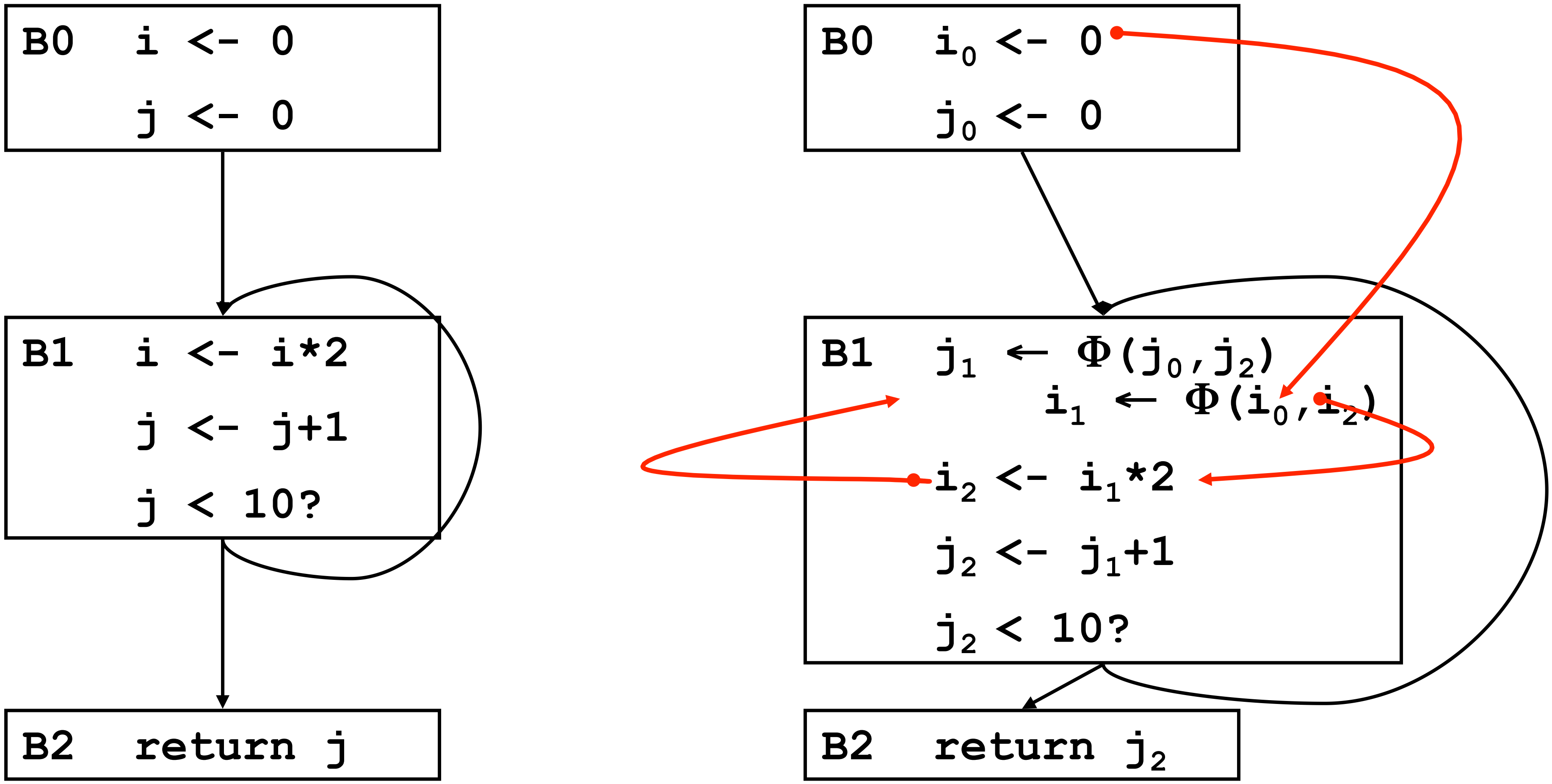
Conditional Constant Propagation



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.operands.definers {
          def.users <- def.users - {S}
          if |def.users| == 0 then
            W <- W UNION {def}
        }
        delete S
}
```

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.operands.definers into W

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

Example DCE

B0 $i_0 \leftarrow 0$
$j_0 \leftarrow 0$

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

B2 return j_2

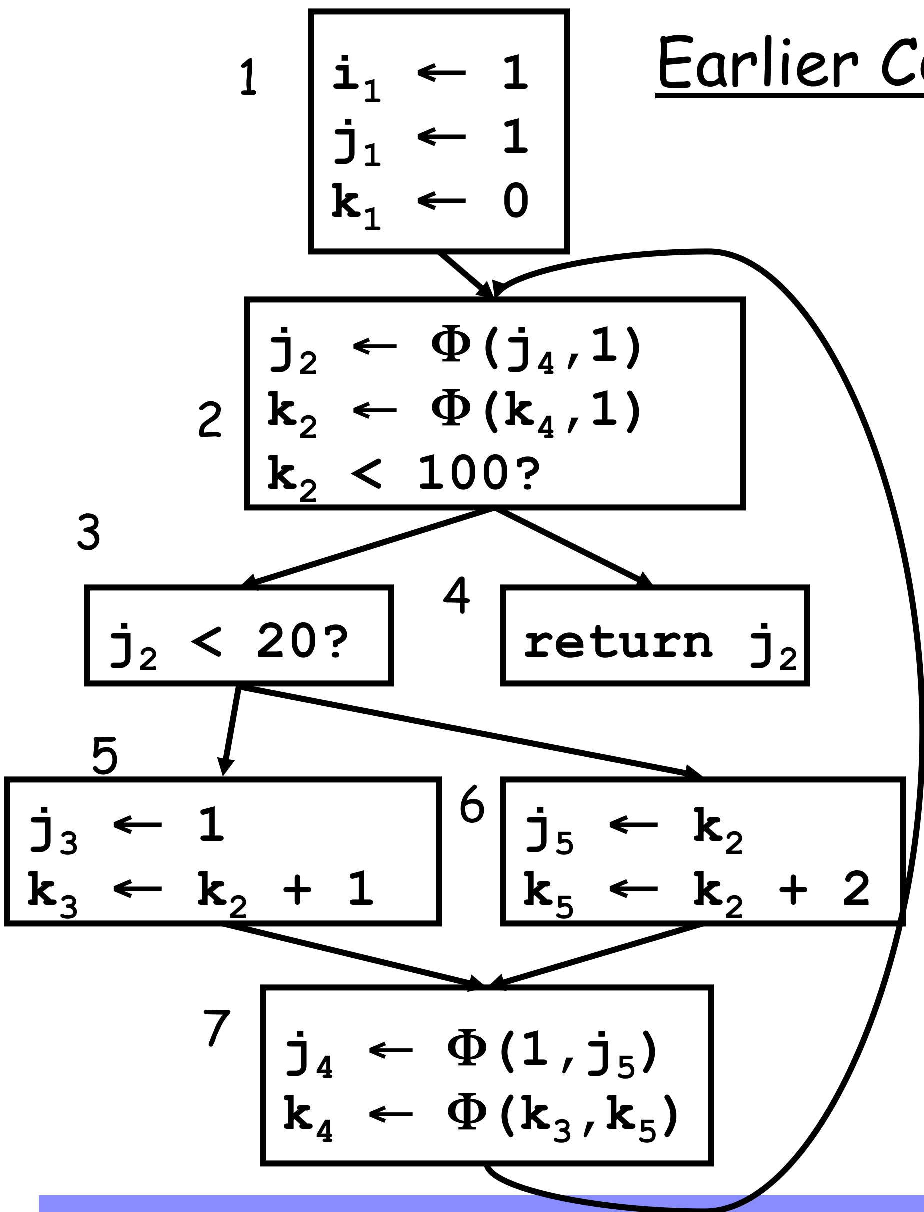
B0 $i_0 \leftarrow 0$
$j_0 \leftarrow 0$

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

B2 return j_2

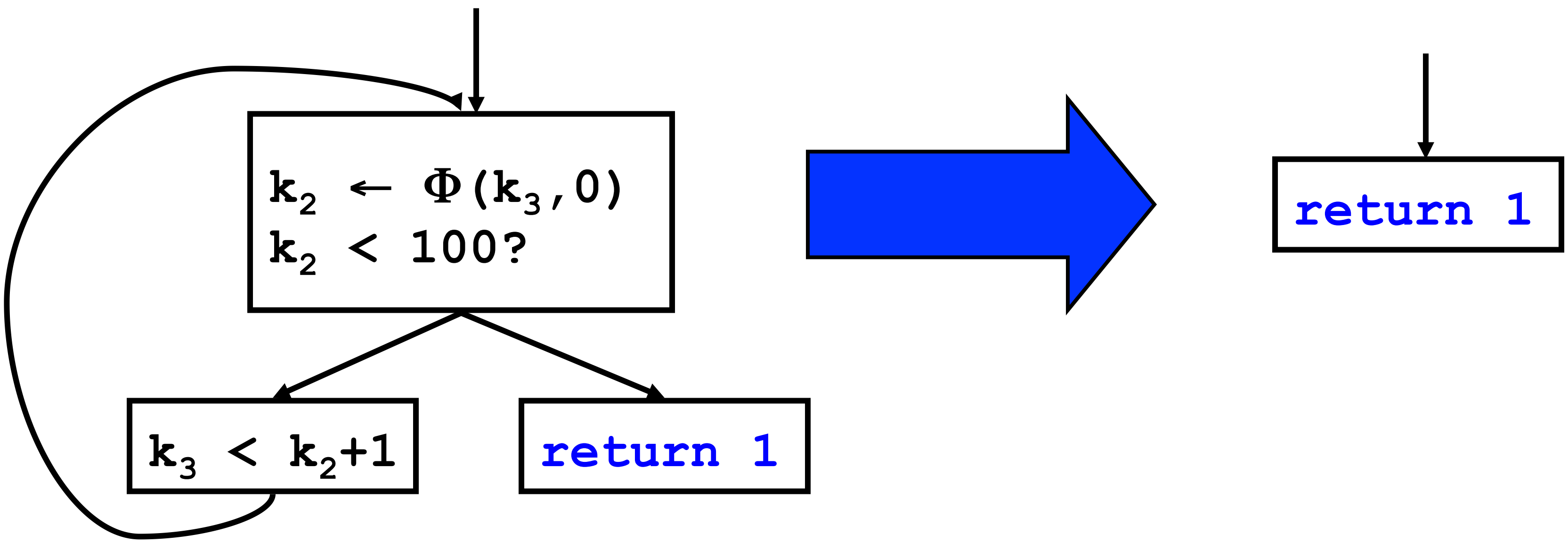
Problem!

Earlier CCP Example Revisited



Applying Dead Code Elimination to the Result of CCP

After CCP **After DCE**

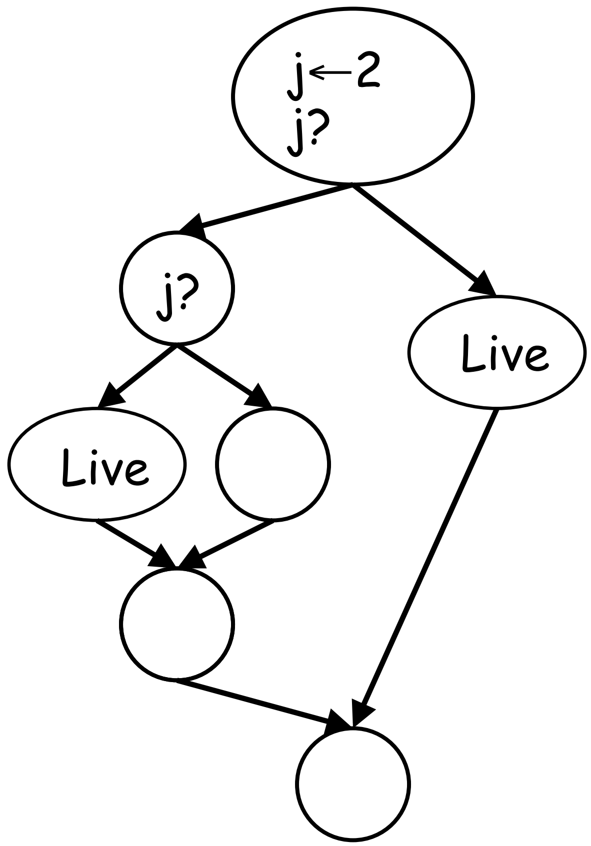


Small problem.

Fixing DCE

if S is live, then

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

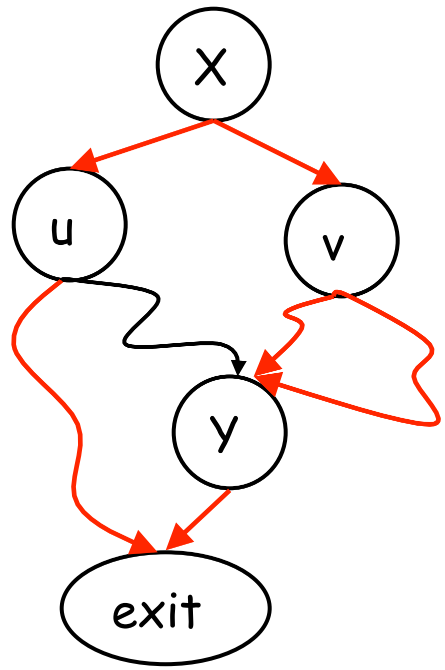


Control Dependence

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 (Fixed Version)

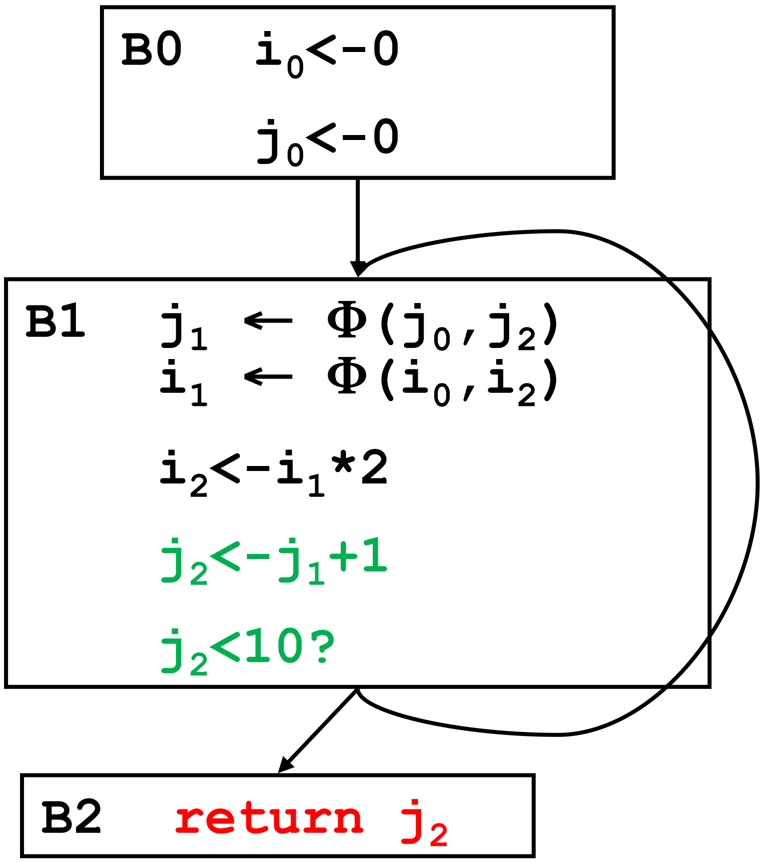
Assume a statement is dead until proven otherwise.

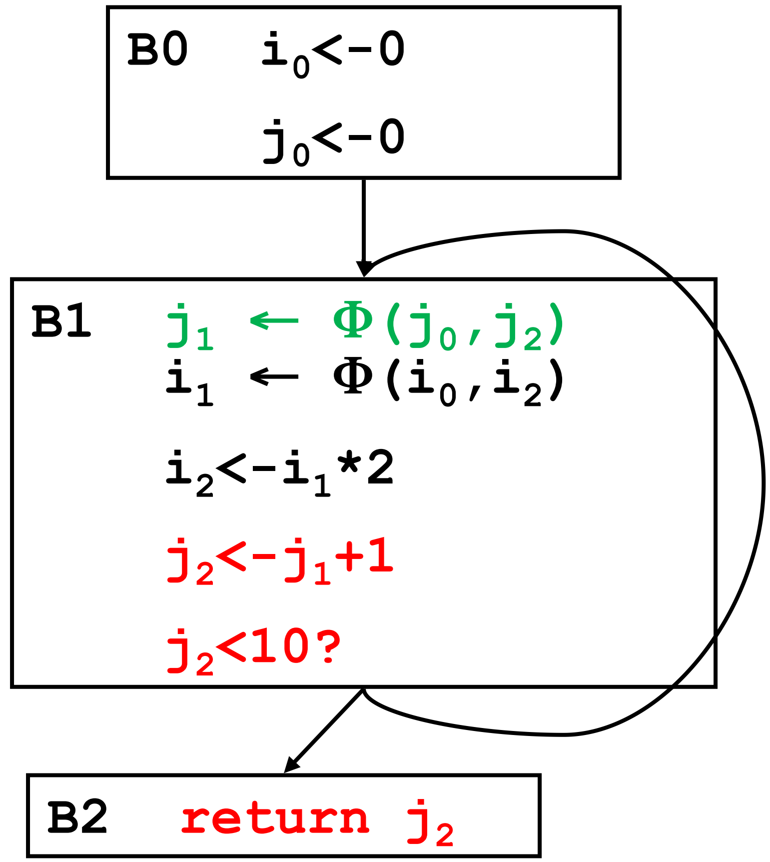
```
init:
   mark as live all stmts that have side-effects:
        - I/O
        - stores into memory
        - returns
        - calls a function that MIGHT have side-effects
   As we mark S live, insert:
        - S.operands.definers into W
        - S.CD-1 into W

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

Conditional tests for blocks upon which S are control-dependent are also inserted into work-list.

Example DCE


B0
i0<-0
j0<-0
B1
j1 ← Φ(j0,j2)
i1 ← Φ(i0,i2)
i2<-i1*2
j2<-j1+1
j2<10?
B2
return j2


B0
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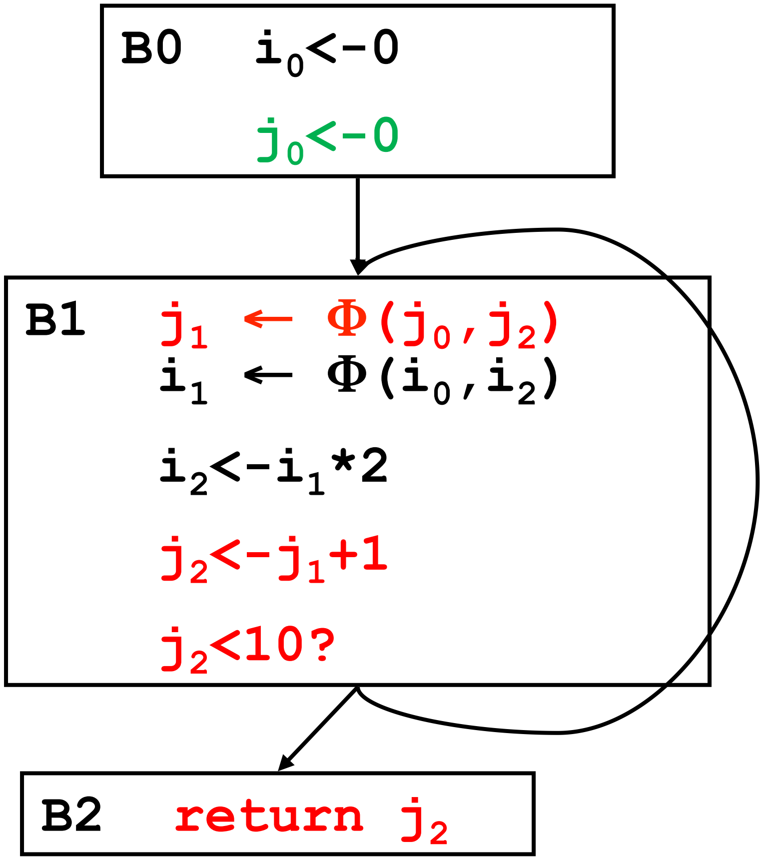
Example DCE


B0
i_0<-0
j_0<-0
B1
$j_1 \leftarrow \Phi(j_0, j_2)$
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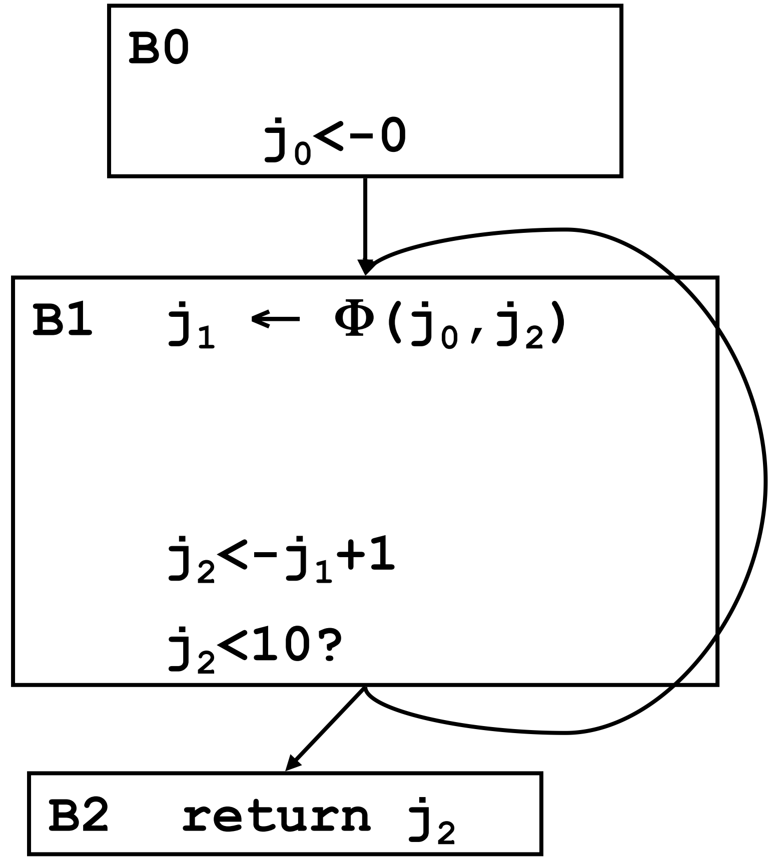
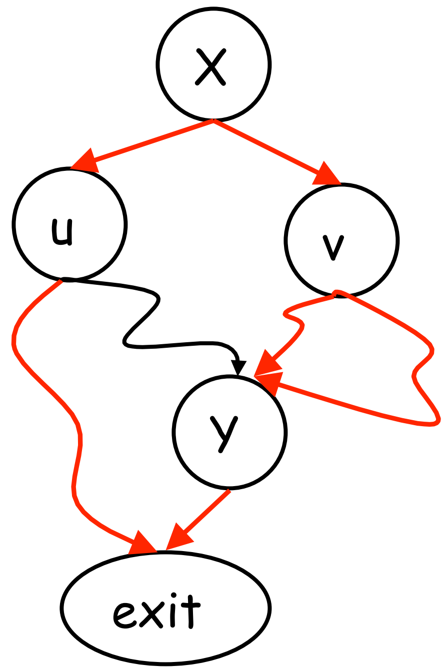
B2
return j_2


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

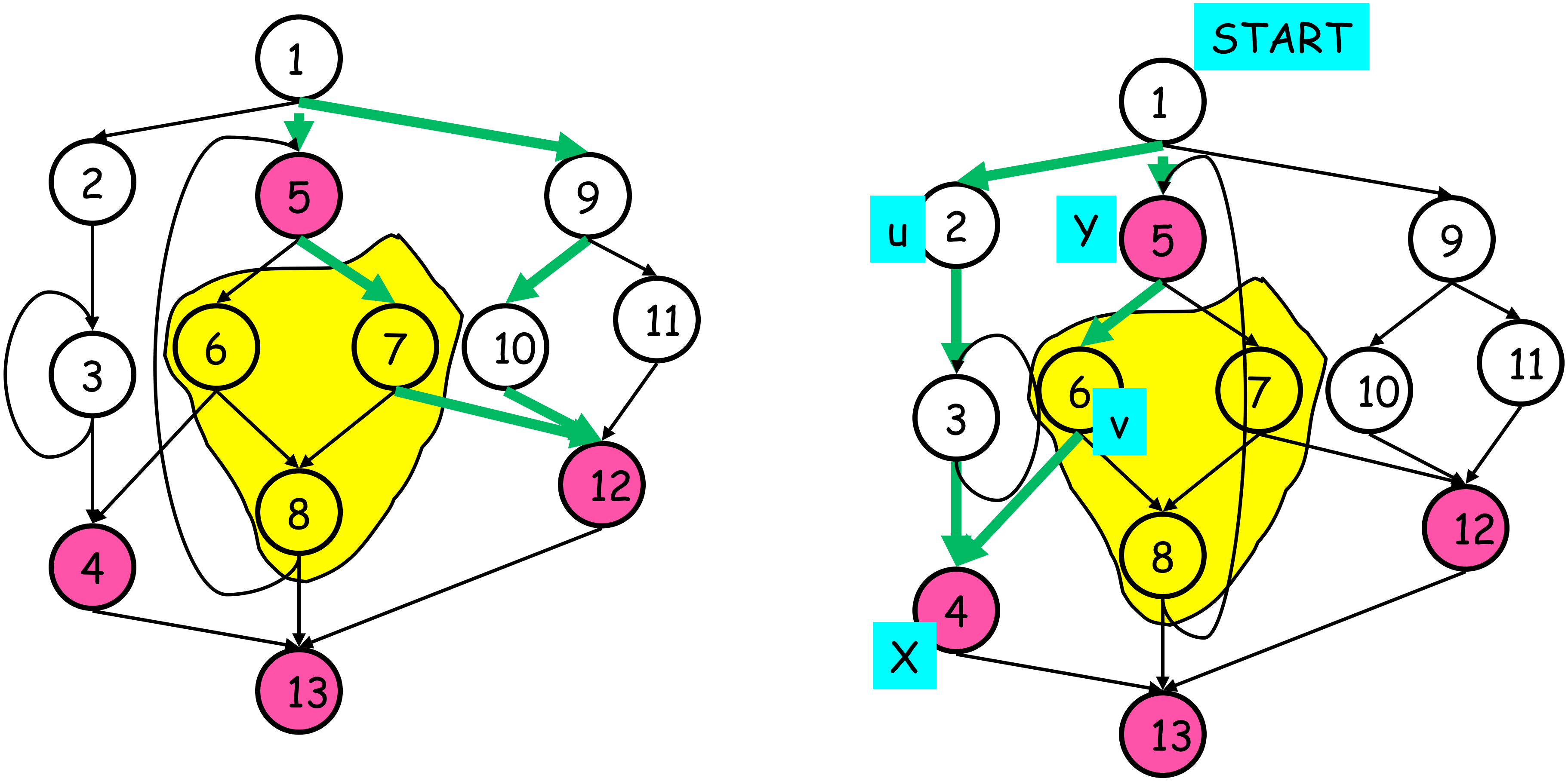
Finding the Control Dependence Graph

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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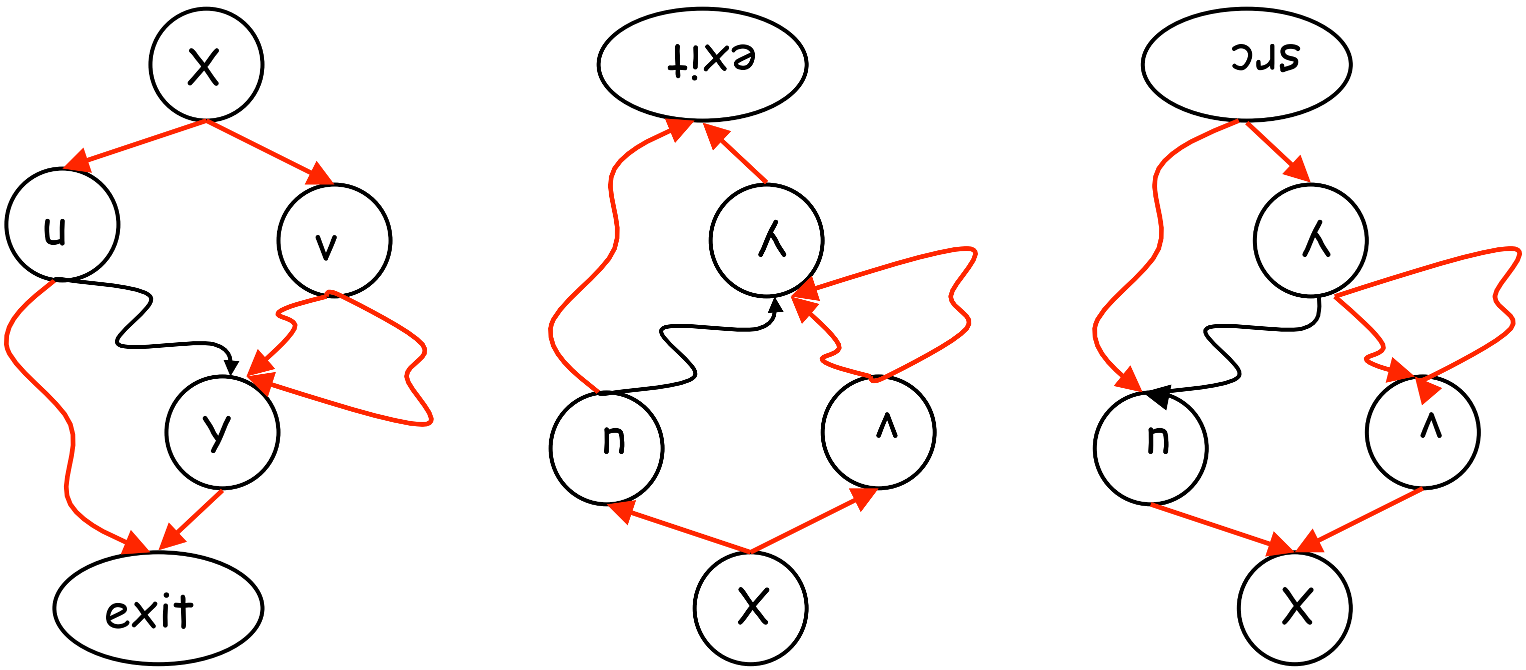
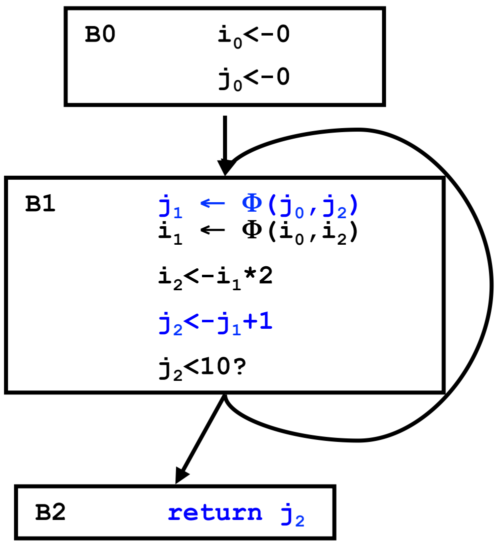
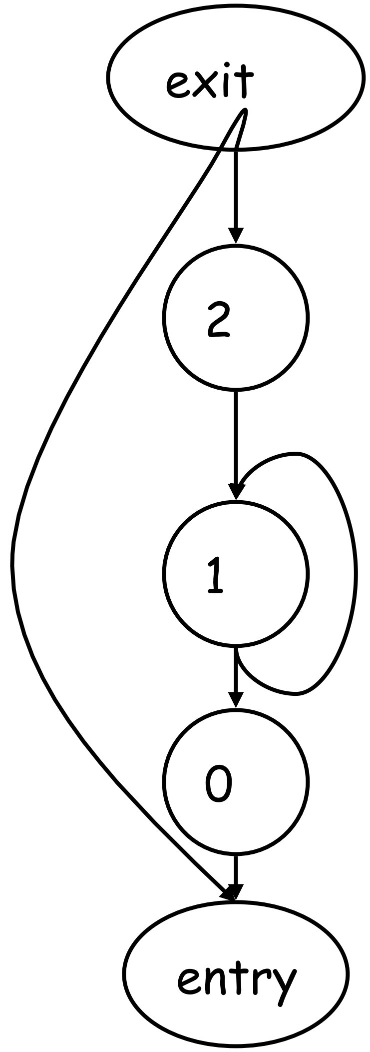


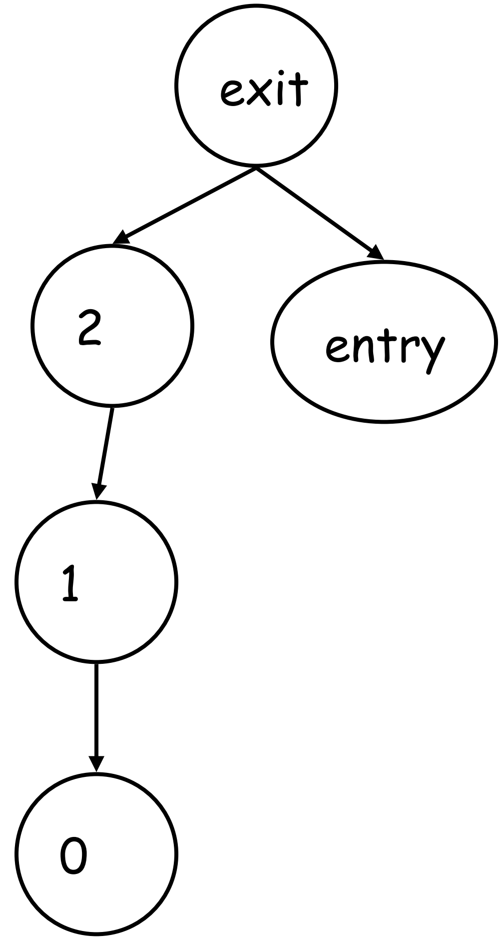
Finding the CDG

- 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 $x \in DF_{G'}(y)$

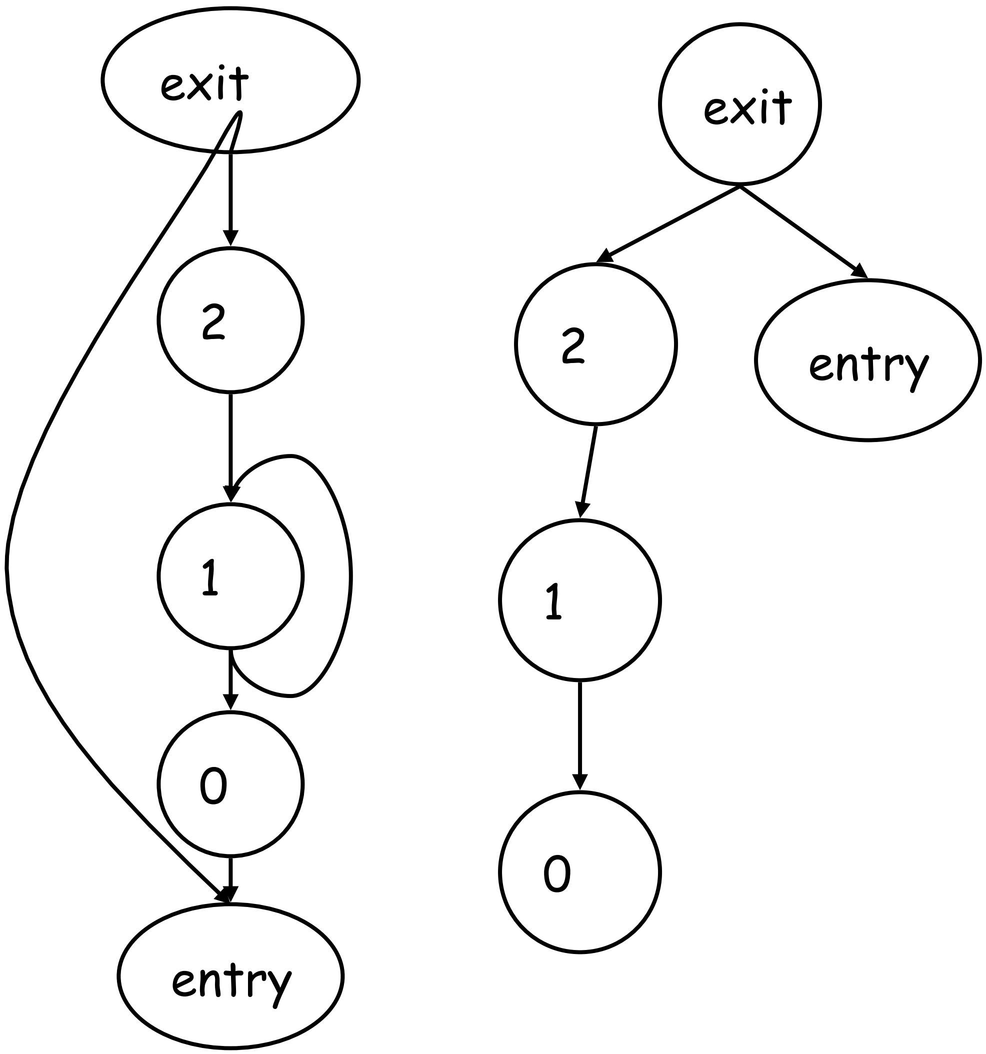
CDG of example







CDG of example



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