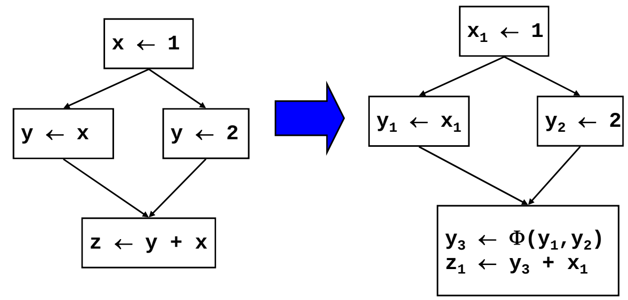
Lecture 13

SSA-Style Optimizations

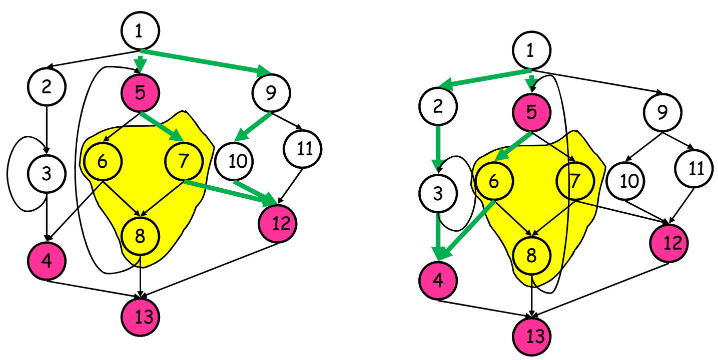
(Slides courtesy of Seth Goldstein.)

Review: Minimal SSA

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



Review: Dominance Frontier and Path Convergence



Constant Propagation

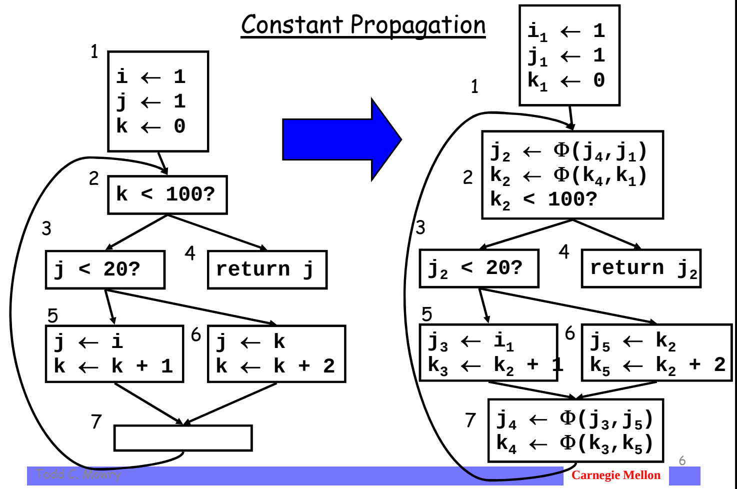
- If "v ← c", replace all uses of v with c
- If "v ← Φ(c,c,c)", replace all uses of v with c

```
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)
}
```

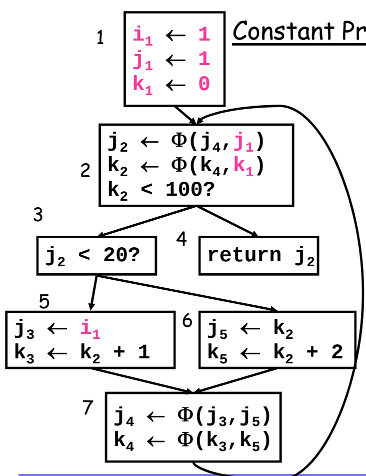
Other Optimizations with SSA

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

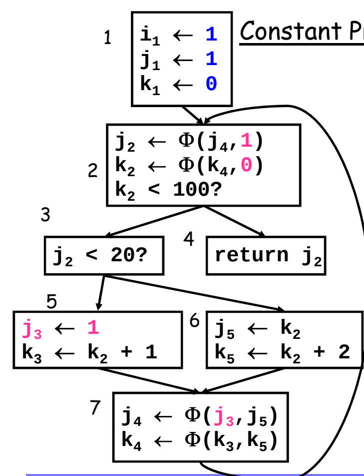
Constant Propagation



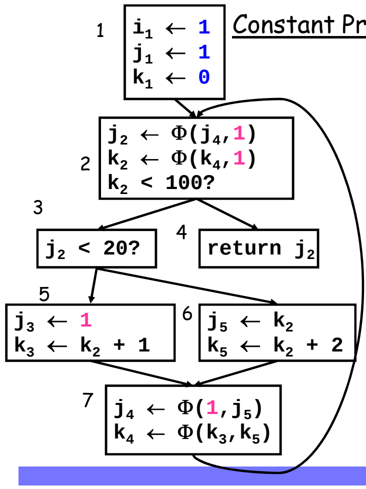
Constant Propagation



Constant Propagation

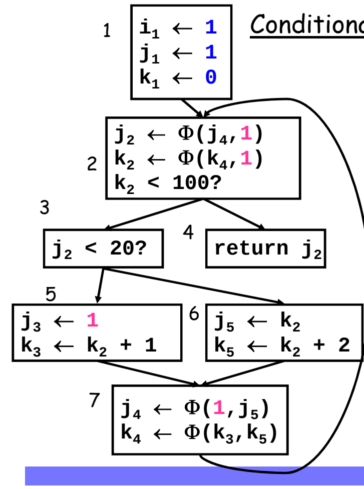


Constant Propagation



But, so what?

Conditional Constant Propagation



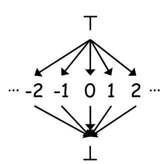
- Does block 6 ever execute?
- Simple CP can't tell
- Conditional CP can tell:
  - Assumes blocks don't execute until proven otherwise
  - Assumes values are constants until proven otherwise

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:

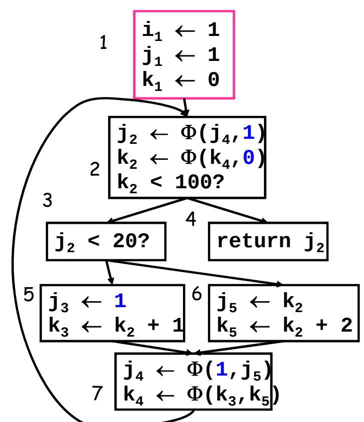


not executed

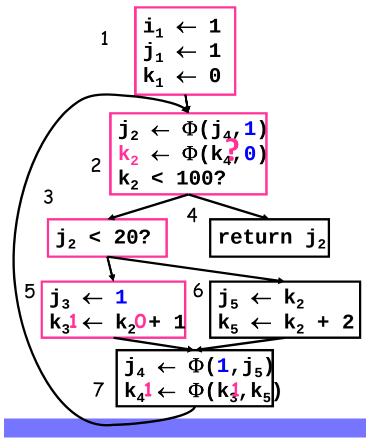
we have seen evidence that the variable has been assigned a constant with the value

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

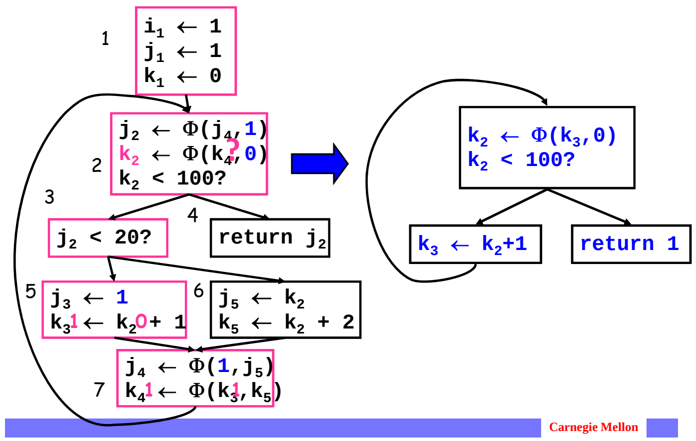
Conditional Constant Propagation



Conditional Constant Propagation



Conditional Constant Propagation

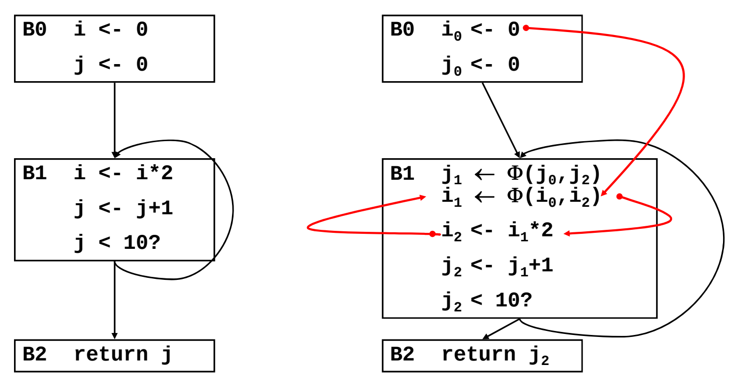


Dead Code Elimination

```
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.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!

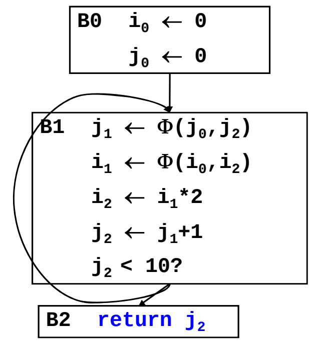
Aggressive Dead Code Elimination

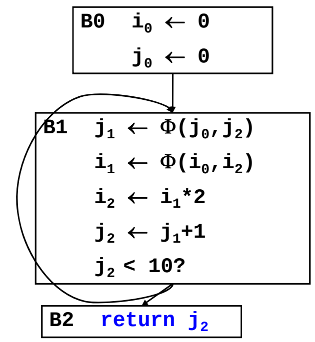
Assume a statement is dead until proven otherwise.

```
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

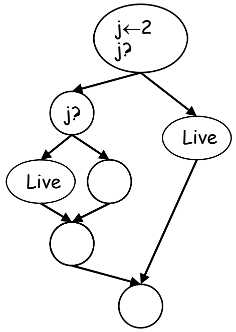




Problem!

Fixing DCE

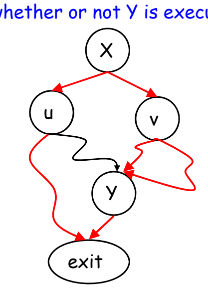
if S is live, then
    if T determines if S can execute, T should be live



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.

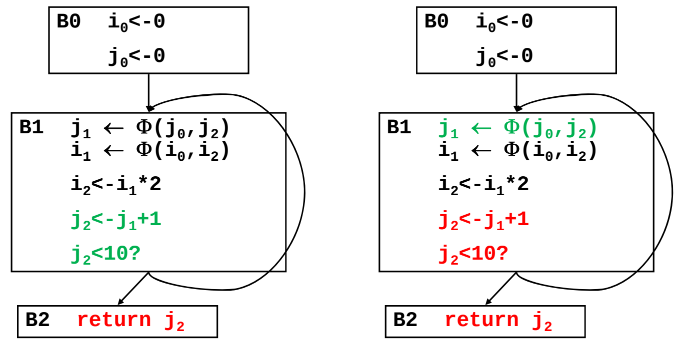


Aggressive Dead Code Elimination

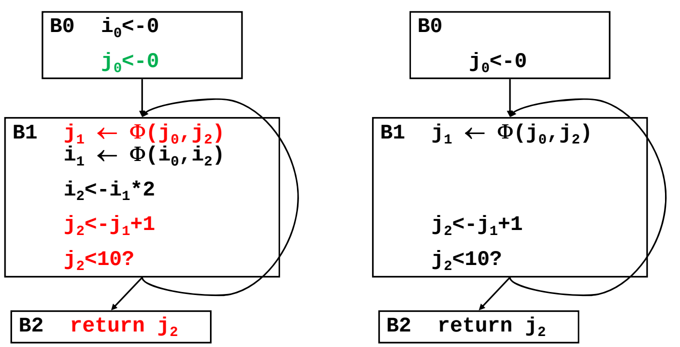
Assume a statement is dead until proven otherwise.

```
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
}
```

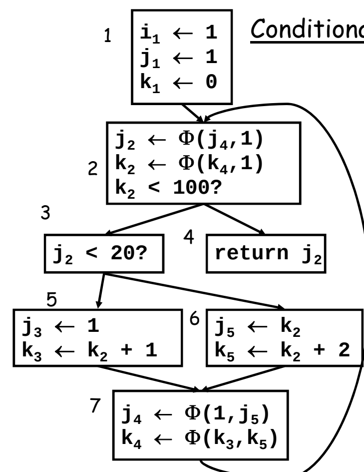

Example DCE



Example DCE



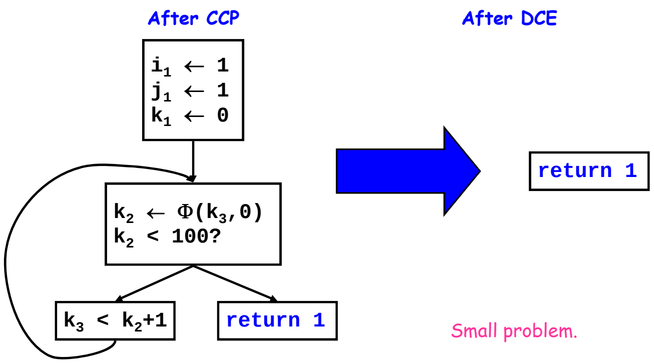
Conditional Constant Propagation



(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
  - Assumes values are constants until proven otherwise

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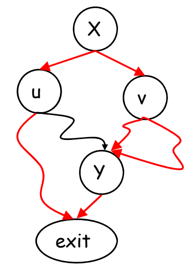
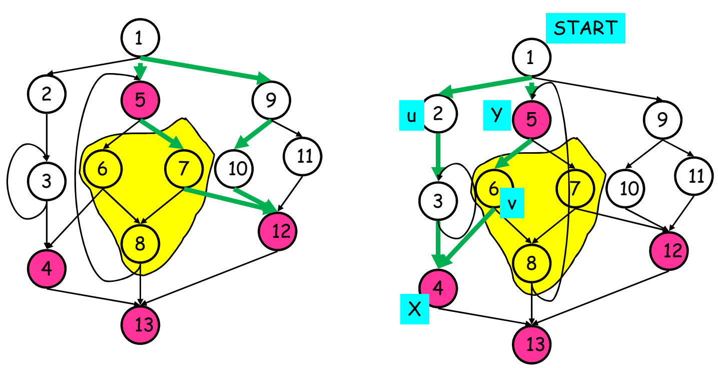
i.e. X can determine whether or not Y is executed.



Dominance Frontier and Path Convergence



Any ideas?

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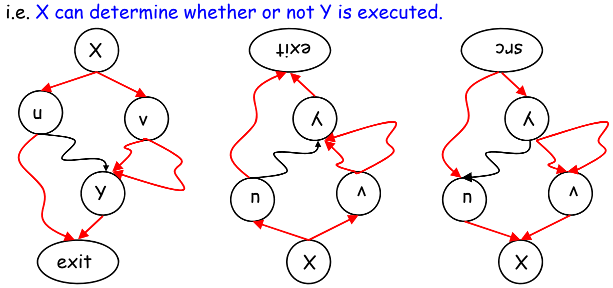
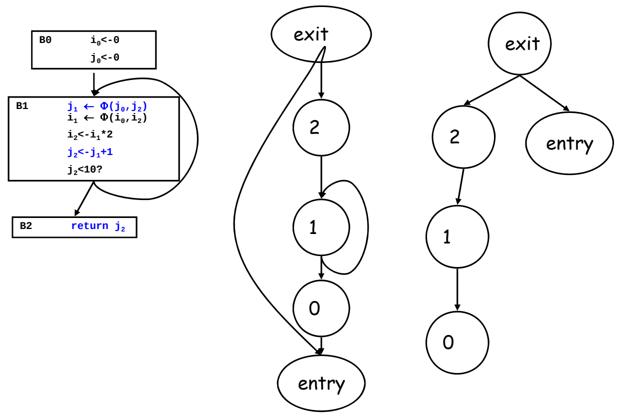
i.e. X can determine whether or not Y is executed.



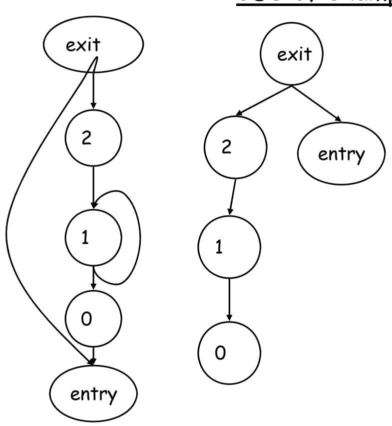
Finding the CDG

- 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:	{}