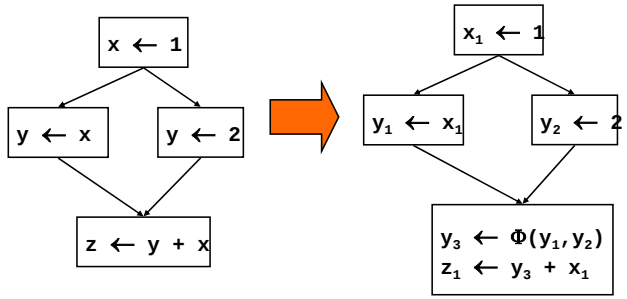
15-745

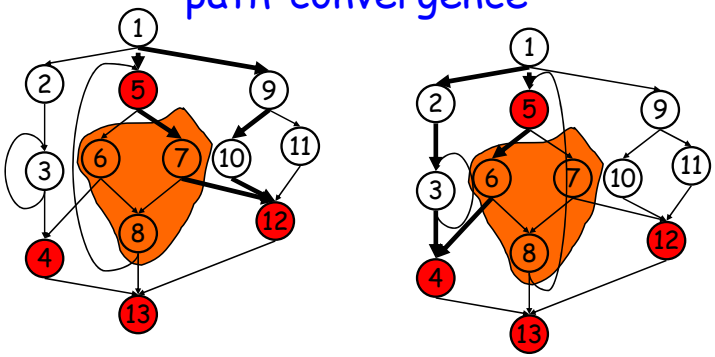
SSA & CCP & DCE & CDG

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 & path-convergence



Constant Propagation

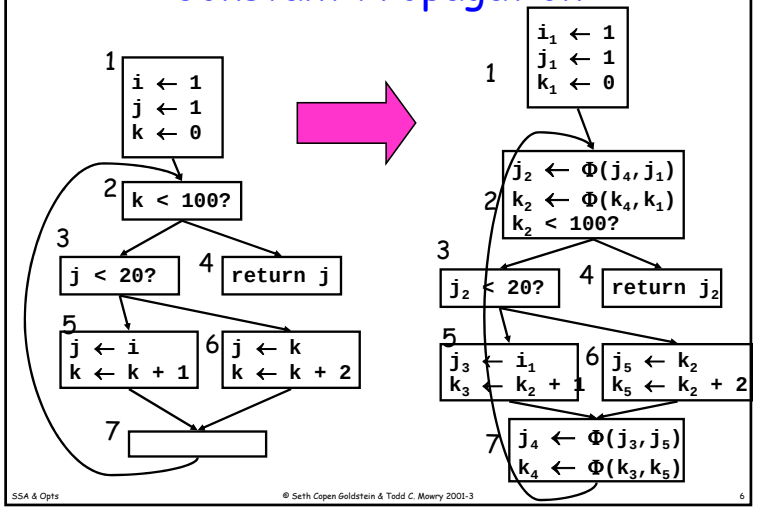
- If "v ← c", replace all uses of v with c
- If "v ← **Φ(c,c,c)**" replace all uses of v with c

```
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)
}
```

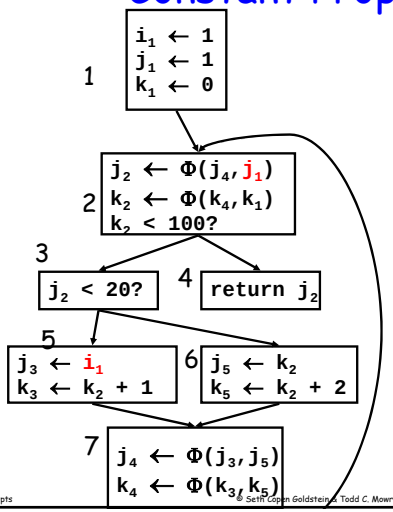
Other stuff we can do?

- Copy propogation
  - delete "x ← Φ(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

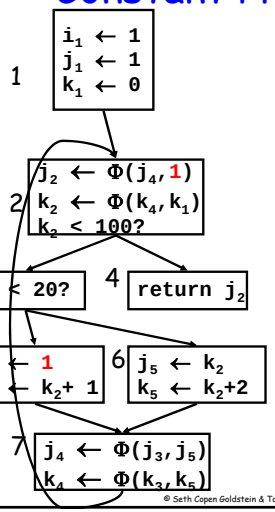
Constant Propagation



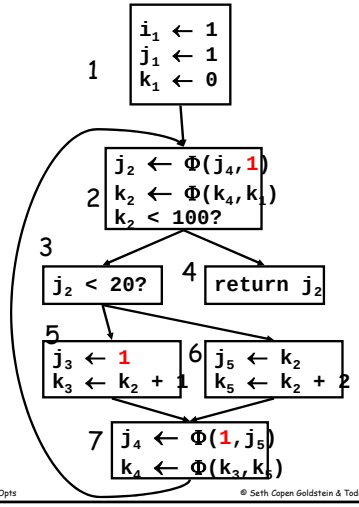
Constant Propagation



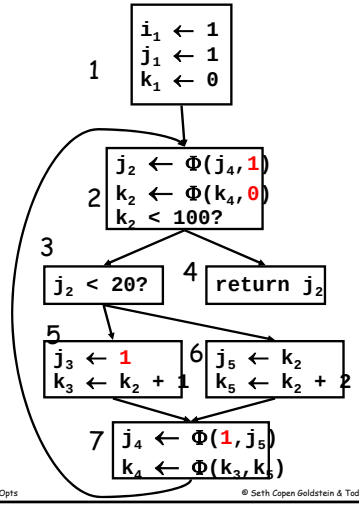
Constant Propagation



Constant Propagation

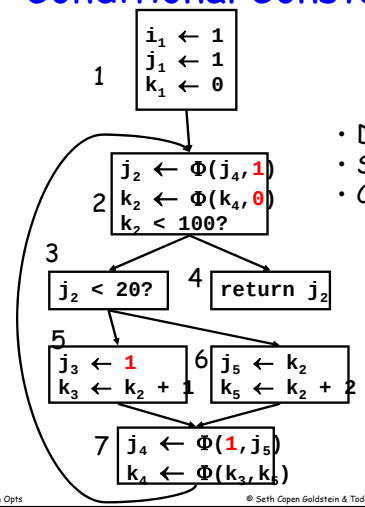


Constant Propagation



But, so what?

Conditional Constant Propagation



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

Tracks:

- 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)

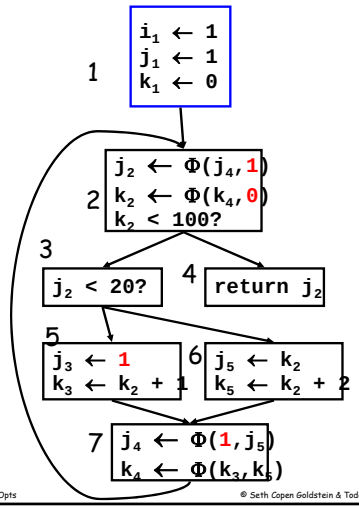
Use a lattice for variables:

TOP = not executed

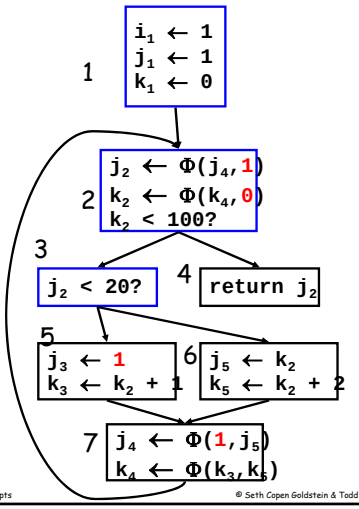
integers = we have seen evidence that the var has been assigned a constant with the value

BOT = we have evidence that variable can hold different values at different times

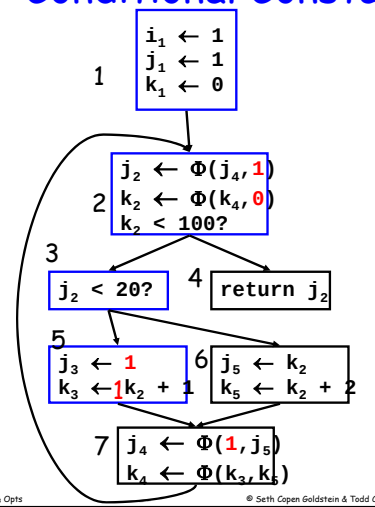
Conditional Constant Propagation



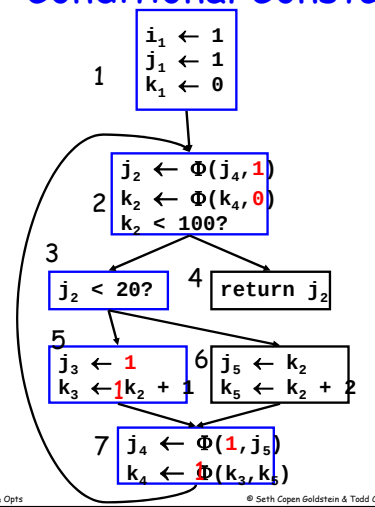
Conditional Constant Propagation



Conditional Constant Propagation



Conditional Constant Propagation



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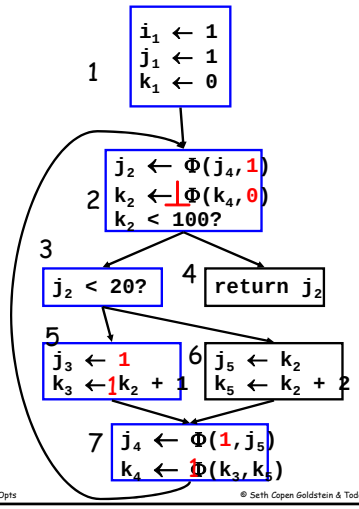
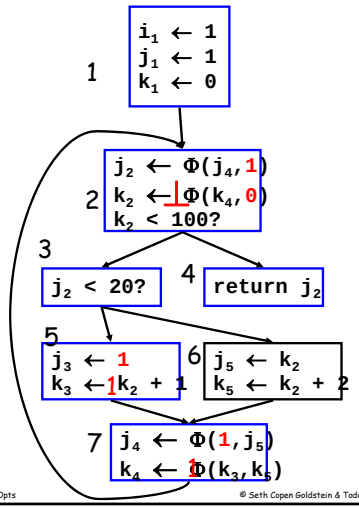
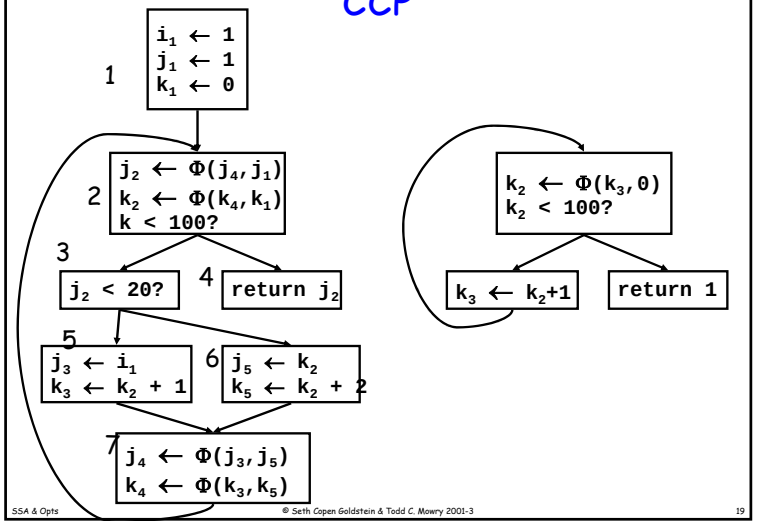


Conditional Constant Propagation



CCP

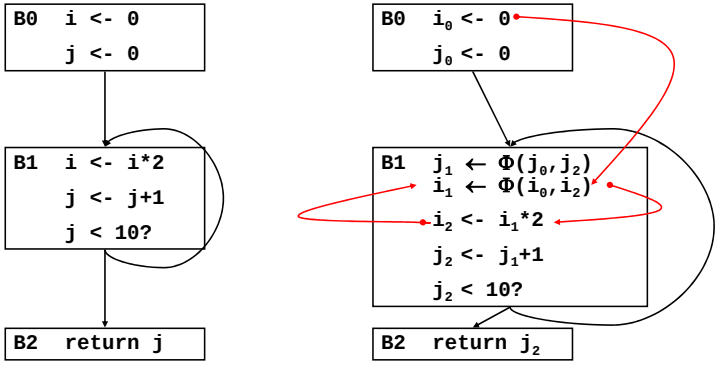


Dead Code Elimination

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

```
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
}
```

Example DCE



Standard DCE leaves Zombies!

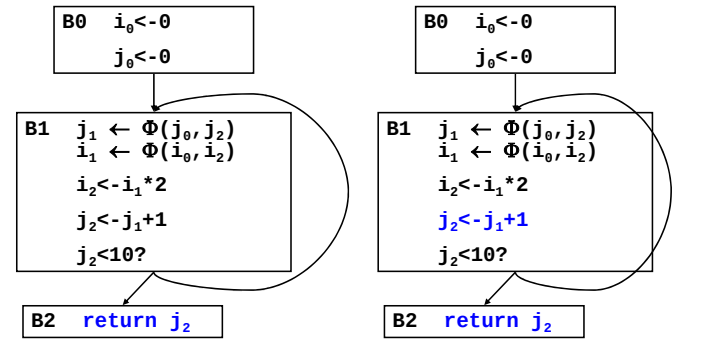
Aggressive Dead Code Elimination

Assume a stmt is dead until proven otherwise.

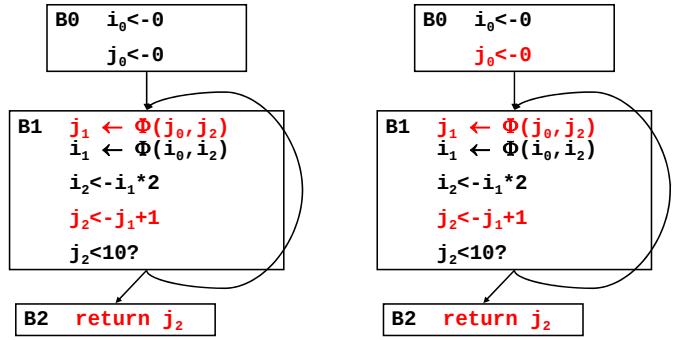
```
init:
   mark as live all stmts that have side-effects:
       - I/O
       - stores into memory
       - returns
       - calls a function that MIGHT have side-effects
   As we mark S live, insert S.defs into W

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


Example DCE



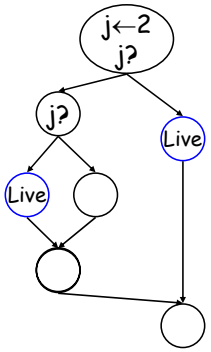
Example DCE



Problem!

Fixing DCE

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



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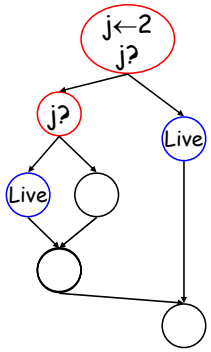
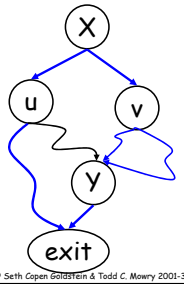


Control Dependence

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

IOW, X can determine whether or not Y is executed.

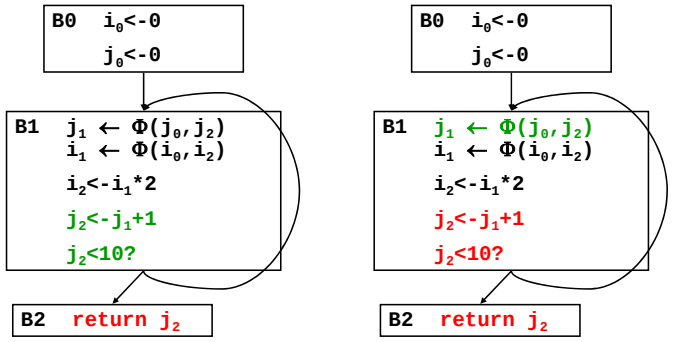


Aggressive Dead Code Elimination

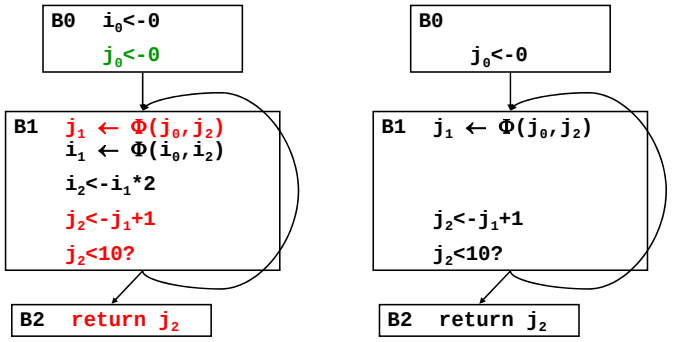
Assume a stmt is dead until proven otherwise.

```
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
}
```

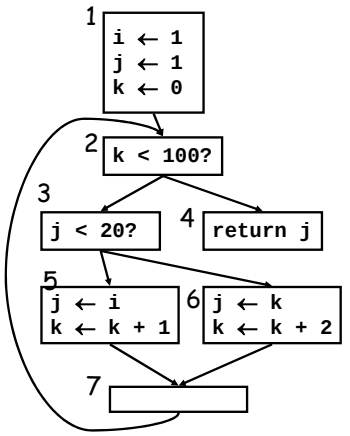
Example DCE



Example DCE



CCP Example



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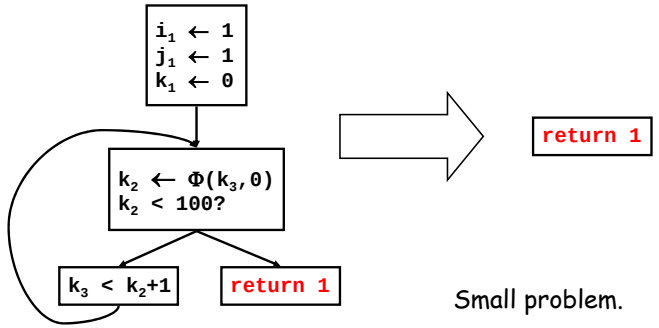
CCP -> DCE



Small problem.

Finding the CDG

Y is control-dependent on X if
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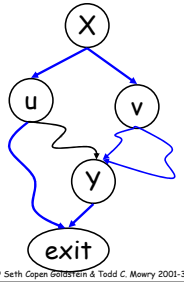
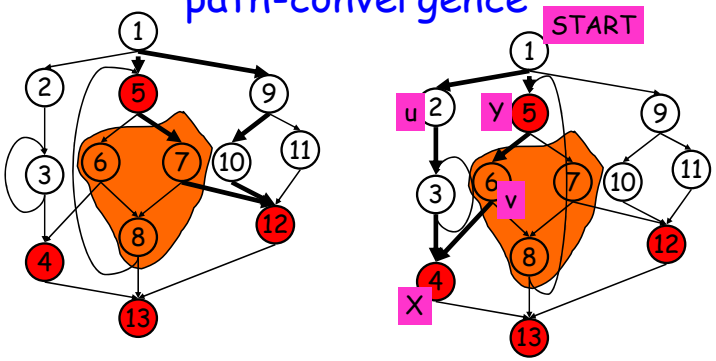
- ∀ paths v→exit go through Y

IOW, X can determine whether or not Y is executed.



Dominance Frontier & path-convergence



Any ideas?

Finding the CDG

Y is control-dependent on X if
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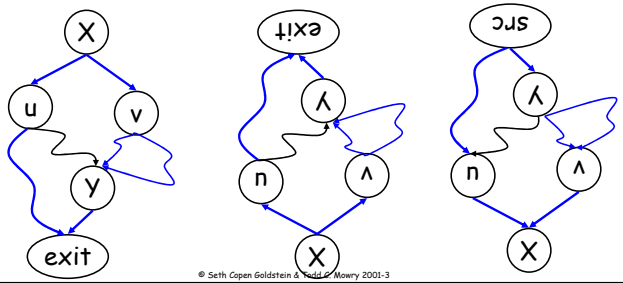
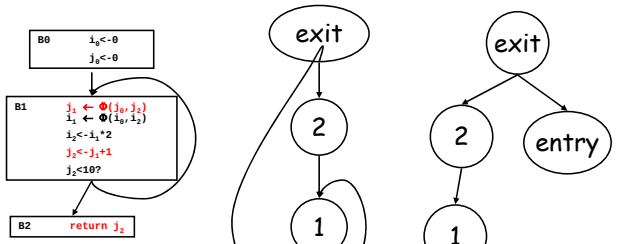


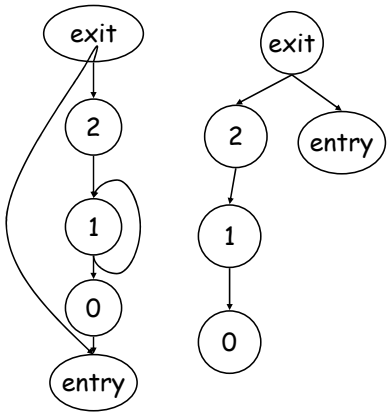
Finding the CDG

- 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: {}

