CS738: Advanced Compiler Optimizations

SSA Continued

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Agenda

- Properties of SSA
- SSA to Executable
- SSA for Optimizations

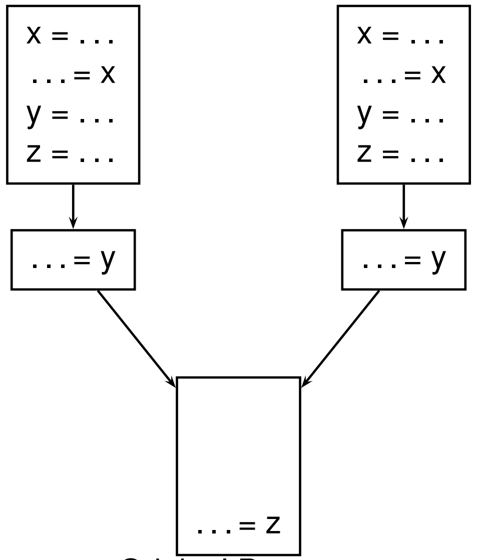
Complexity of Construction

- $R = \max(N, E, A, M)$
- N: nodes, E: edges in flow graph
- A: number of assignments
- M: number of uses of variables
- Computation of DF: $O(R^2)$
- Computation of SSA: $O(R^3)$
- In practice, worst case is rare.
- Practical complexity: $O(R)$

Linear Time Algorithm for ϕ-functions

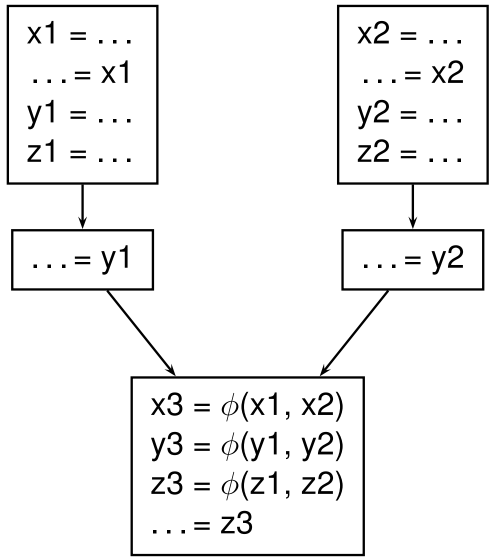
- By Sreedhar and Gao, in POPL'95
- Uses a new data structure called DJ-graph
- Linear time is achieved by careful ordering of nodes in the DJ-graph
- DF for a node is computed only once an reused later if required.

Variants of SSA Form: Simple Example



Original Program

Variants of SSA Form: Simple Example



Minimal SSA form

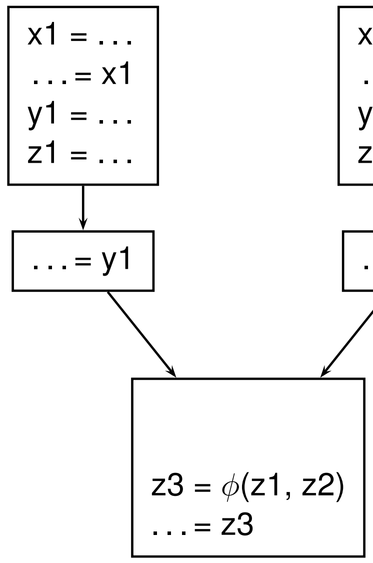
Variants of SSA Form

- Minimal SSA still contains extraneous ϕ-functions
  - Inserts some ϕ-functions where they are dead
  - Would like to avoid inserting them
- Pruned SSA
- Semi-Pruned SSA

Pruned SSA

- Only insert ϕ-functions where their value is live
- Inserts fewer ϕ-functions
- Costs more to do
- Requires global Live variable analysis

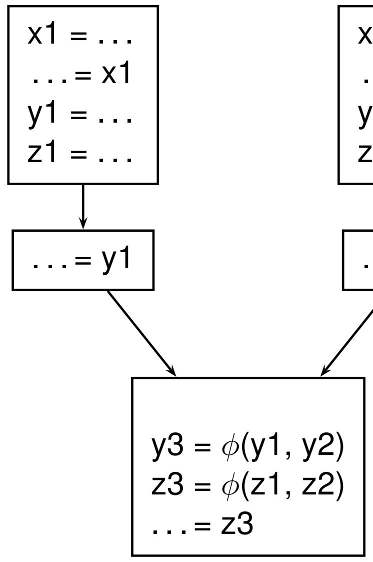
Variants of SSA Form: Pruned SSA Example



Semi-Pruned SSA Form

- Discard names used in only one block
- Total number of ϕ-functions between minimal and pruned SSA
- Needs only local Live information
- Non-locals can be computed without iteration or elimination

Variants of SSA Form: Semi-pruned SSA Example



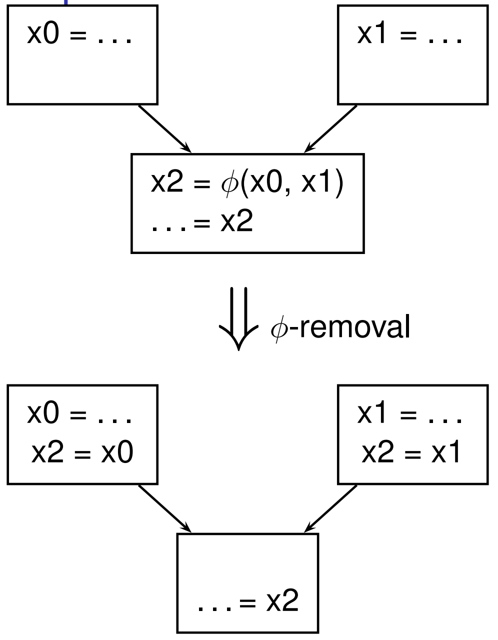
Computing Non-locals

```
foreach block B {
   defined = {}
   foreach instruction $v = x \text{ op } y$ {
      if $x$ not in defined
          non-locals = non-locals ∪ $\{x\}$
      if $y$ not in defined
          non-locals = non-locals ∪ $\{y\}$
      defined = defined ∪ $\{v\}$
   }
}
```

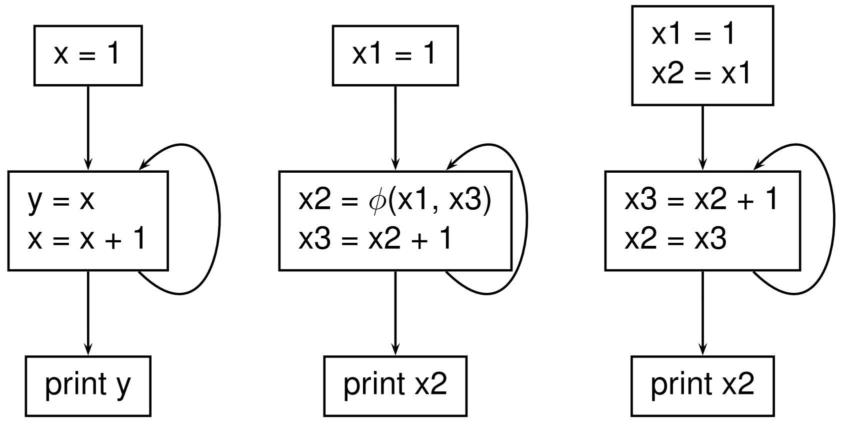
SSA to Executable

- At some point, we need executable code
  - Need to fix up the ϕ-function
- Basic idea
  - Insert copies in predecessors to mimic ϕ-function
  - Simple algorithm
    - Works in most cases, but not always
  - Adds lots of copies
    - Many of them will be optimized by later passes

ϕ-removal: Example



Lost Copy Problem

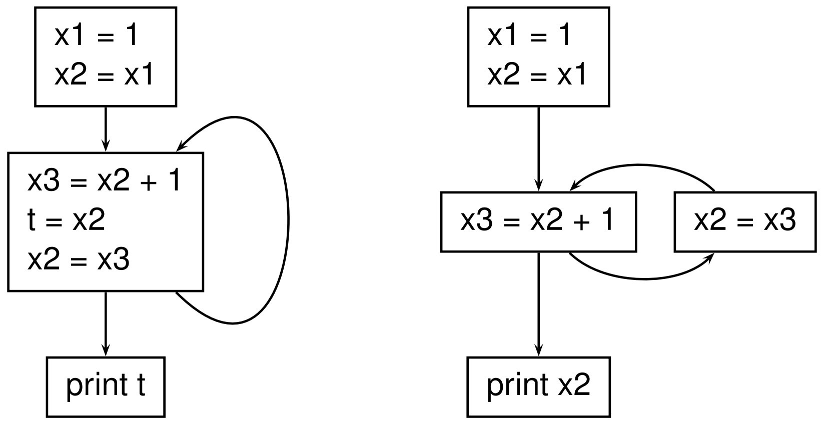


Program

SSA from with copy propagation

After ϕ-removal

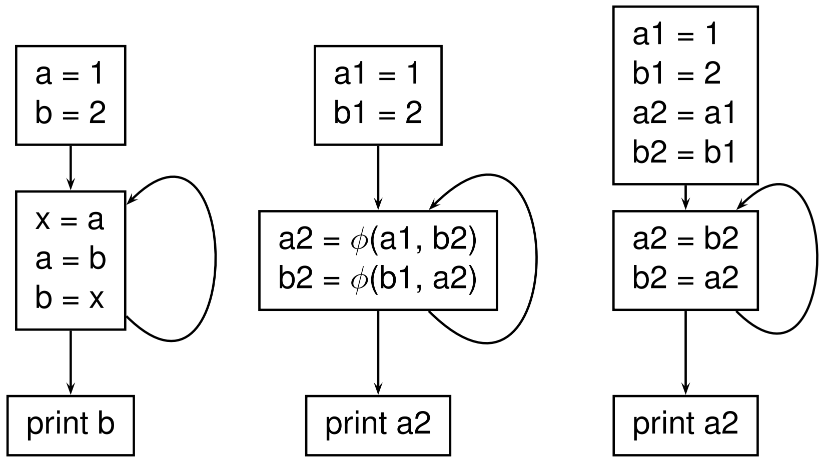
Lost Copy Problem: Solutions



1. Use of Temporary

2. Critical Edge Split

Swap Problem



Program

SSA form with copy propagation

After ϕ-removal

Swap Problem: Solution

- Fix requires compiler to detect and break dependency from output of one ϕ-function to input of another ϕ-function.
- May require temporary if cyclic dependency exists.

SSA Form for Optimizations

- SSA form can improve and/or speed up many analyses and optimizations
  - (Conditional) Constant propagation
  - Dead code elimination
  - Value numbering
  - PRE
  - Loop Invariant Code Motion
  - Strength Reduction