SSA Technicalities

Last Time

- Introduced SSA

Today

- Aliasing in SSA
- Building SSA
- Backward data-flow analyses
- Transforming SSA back to code

Next Time

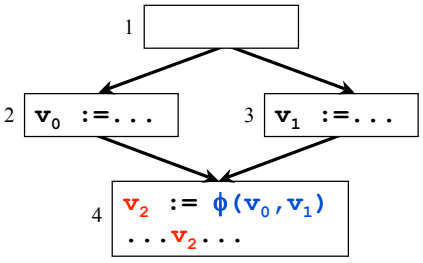
- Using SSA

SSA

Merging Definitions

- ϕ-functions merge multiple reaching definitions

Example



Technicalities

How can we handle aliasing in SSA?

How do we generate SSA?

What about backward data-flow analysis problems?

How do we generate code from SSA?

SSA and Aliasing

Simple solution

- treat all of memory as one variable
- MayDef and MayUse semantics degrade analysis accuracy

Add more functions into SSA to represent semantics

- MayUse and MayDef can be added before the computation of SSA
- Optimizations on SSA must handle the semantics of MayUse and MayDef

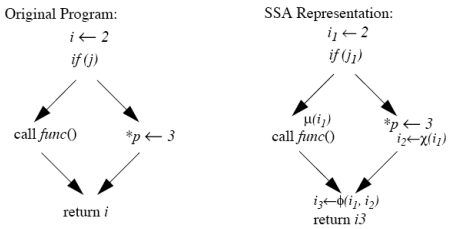


Fig. 1. Example of μ, χ and φ

[Chow et al. 96]

Transformation to SSA Form

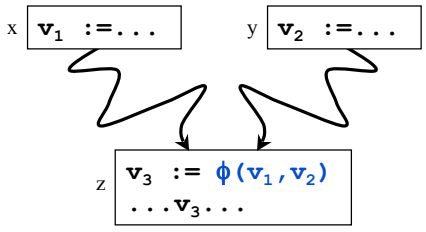
Two steps

- Insert ϕ-functions
- Rename variables

Where Do We Place ϕ-Functions?

Basic Rule

- If two distinct (non-null) paths x→z and y→z converge at node z, and nodes x and y contain definitions of variable v, then a ϕ-function for v is inserted at z



Approaches to Placing ϕ-Functions

Minimal

- As few as possible subject to the basic rule

Briggs-Minimal

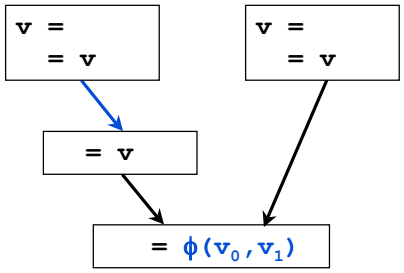
- Same as minimal, except v must be live across some edge of the CFG

Pruned

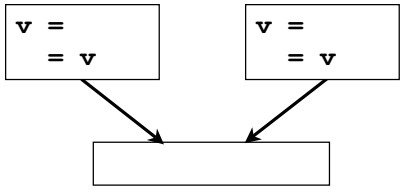
- Same as minimal, except dead ϕ-functions are not inserted

What's the difference between Briggs Minimal and Pruned SSA?

Briggs Minimal vs. Pruned



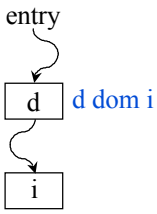
Briggs Minimal will add a ϕ function because v is live across the blue edge, but Pruned SSA will not because the ϕ function is dead



Neither Briggs Minimal nor Pruned SSA will place a ϕ function in this case because v is not live across any CFG edge

Why would we ever use Briggs Minimal instead of Pruned SSA?

Machinery for Placing ϕ-Functions



Recall Dominators

- d **dom** i if all paths from entry to node i include d
- d **sdom** i if d dom i and d≠i

Dominance Frontiers

- The **dominance frontier** of a node d is the set of nodes that are "just barely" not dominated by d; i.e., the set of nodes n, such that
  - d dominates a predecessor p of n, and
  - d does **not** strictly dominate n
- DF(d) = {n | ∃p∈pred(n), d dom p and d !sdom n}

Notational Convenience

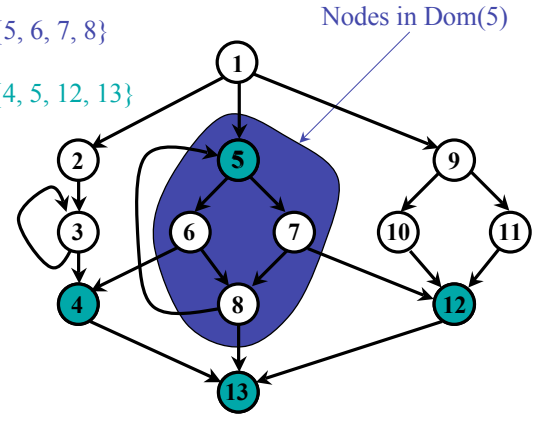
- $DF(S) = \bigcup_{s \in S} DF(s)$

Dominance Frontier Example

DF(d) = {n | ∃p∈pred(n), d dom p and d !sdom n}

Dom(5) = {5, 6, 7, 8}

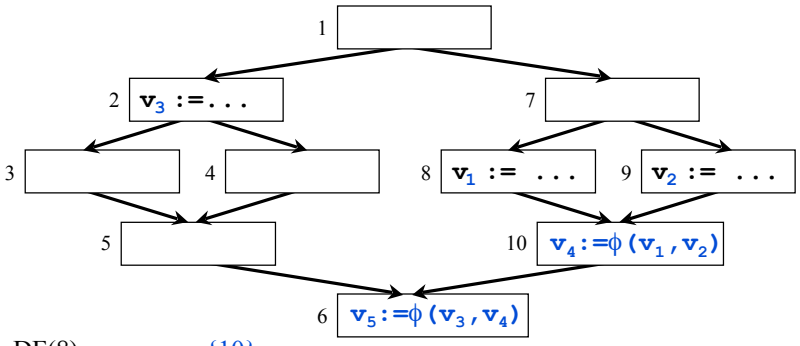
DF(5) = {4, 5, 12, 13}



What's significant about the Dominance Frontier?

In SSA form, definitions must dominate uses

SSA Exercise



DF(8) = {10}
DF(9) = {10}
DF(2) = {6}
DF({8,9}) = {10}
DF(10) = {6}
DF({2,8,9,10}) = {6,10}

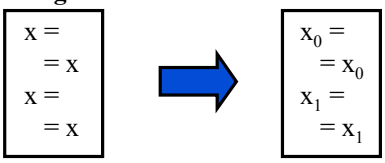
DF(d) = {n | ∃p∈pred(n), d dom p and d !sdom n}

Variable Renaming

Basic idea

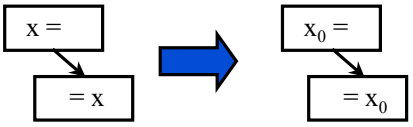
- When we see a variable on the LHS, create a new name for it
- When we see a variable on the RHS, use appropriate subscript

Easy for straightline code



Use a stack when there's control flow

- For each use of x, find the definition of x that dominates it

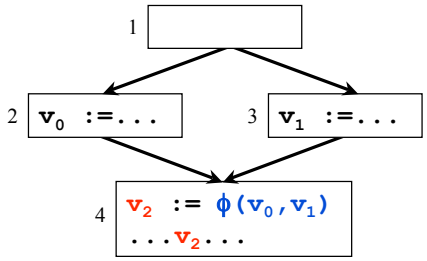


Traverse the dominance tree

Backward Analyses vs. Forward Analyses

For forward data-flow analysis, at phi node apply meet function

For backward data-flow analysis?



Static Single Information Form (SSI)

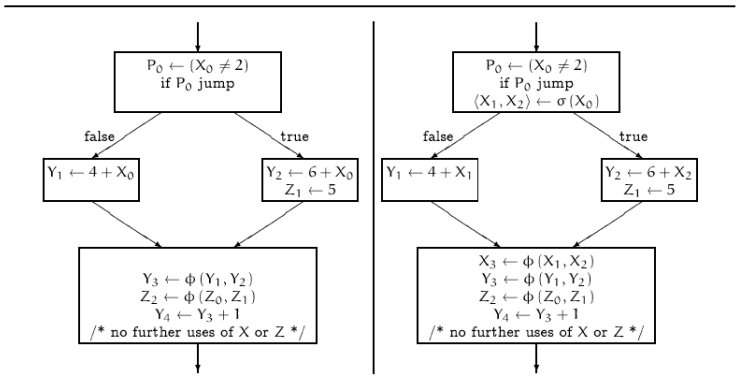


Figure 5.1: A comparison of SSA (left) and SSI (right) forms.

Ananian's Masters Thesis, 1997 MIT

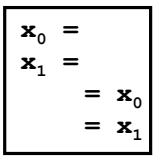
Transformation from SSA Form

Proposal

- Restore original variable names (*i.e.*, drop subscripts)
- Delete all ϕ-functions

Complications

- What if versions get out of order? (simultaneously live ranges)



Alternative

- Perform dead code elimination (to prune ϕ-functions)
- Replace ϕ-functions with copies in predecessors
- Rely on register allocation coalescing to remove unnecessary copies

Concepts

SSA and aliasing

- Simple involves may uses and defs to a single memory variable
- Other methods insert more functions into SSA
- For both optimization codes must handle semantics

SSA construction

- Place phi nodes
- Variable renaming

Backward data-flow analyses can use SSI modification to SSA

Transformation from SSA to executable code depends on the optimizations dead-code elimination and copy propagation

Next Time

Assignments

- Schedule for project 2 due Wednesday
- HW1 is due Friday

Lecture

- Using SSA