Data Dependence

Definition

- Data dependences are constraints on the order in which statements may be executed

We say statement s_2 depends on s_1

- **Flow (true) dependence**: s_1 writes memory that s_2 later reads (RAW)
- **Anti-dependence**: s_1 reads memory that s_2 later writes (WAR)
- **Output dependences**: s_1 writes memory that s_2 later writes (WAW)
- **Input dependences**: s_1 reads memory that s_2 later reads (RAR)

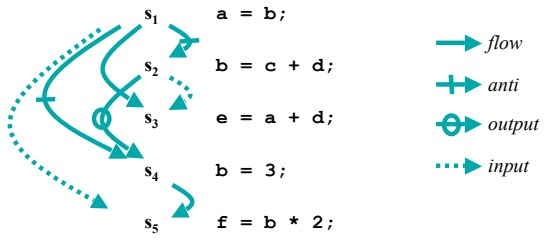
True dependences

- Flow dependences represent actual flow of data

False dependences

- Anti- and output dependences reflect reuse of memory, not actual data flow; can often be eliminated

Example



Representing Data Dependences

Implicitly

- Using variable defs and uses
- Pros: simple
- Cons: hides data dependence (analyses must find this info)

Def-use chains (du chains)

- Link each def to its uses
- Pros: explicit; therefore fast
- Cons: must be computed and updated, space consuming

Alternate representations

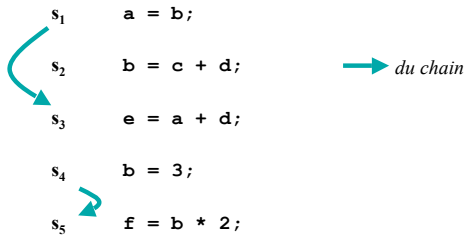
- *e.g.,* Static single assignment form (SSA), dependence flow graphs (DFG), value dependence graphs (VDG)

DU Chains

Definition

- du chains link each def to its uses

Example

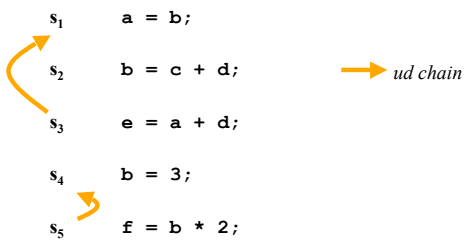


UD Chains

Definition

– ud chains link each use to its defs

Example



Role of Alternate Program Representations

Advantage

– Allow analyses and transformations to be simpler & more efficient/effective

Disadvantage

– May not be "executable" (requires extra translations to and from)

– May be expensive (in terms of time or space)

Process

Static Single Assignment (SSA) Form

Idea

– Each variable has only one static definition

– Makes it easier to reason about values instead of variables

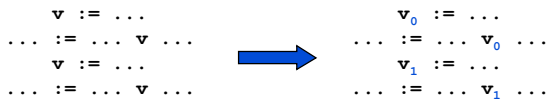
– Similar to the notion of functional programming

Transformation to SSA

– Rename each definition

– Rename all uses reached by that assignment

Example

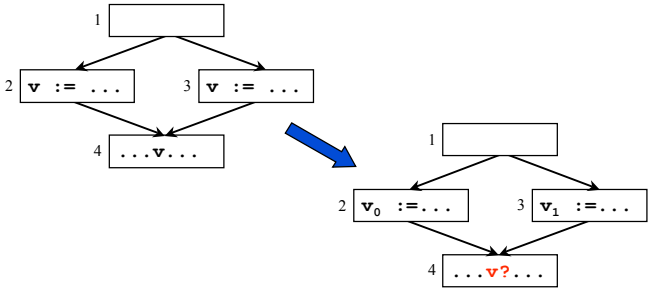


What do we do when there's control flow?

SSA and Control Flow

Problem

– A use may be reached by several definitions

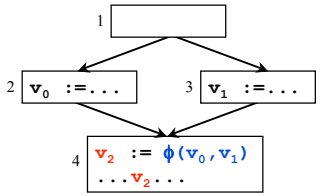


SSA and Control Flow (cont)

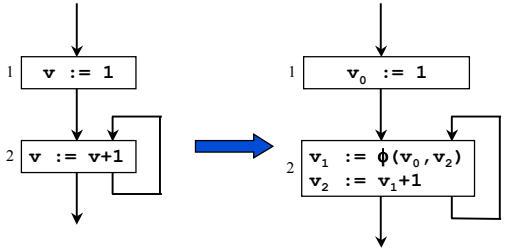
Merging Definitions

– ϕ-functions merge multiple reaching definitions

Example



Another Example



SSA vs. ud/du Chains

SSA form is more constrained

Advantages of SSA

– More compact
– Some analyses become simpler when each use has only one def
– Value merging is explicit
– Easier to update and manipulate?

Furthermore

– Eliminates false dependences (simplifying context)

```
for (i=0; i<n; i++)
     A[i] = i;
for (i=0; i<n; i++)
     print(foo(i));
```

Unrelated uses of `i` are given different variable names

SSA vs. ud/du Chains (cont)

Worst case du-chains?

```
switch (c1) {
case 1:      x = 1; break;
case 2:      x = 2; break;
case 3:      x = 3; break;
}
x4 = ϕ(x1, x2, x3)
switch (c2) {
case 1:      y1 = x; break;
case 2:      y2 = x; break;
case 3:      y3 = x; break;
case 4:      y4 = x; break;
}
```

m defs and n uses leads to m×n du chains

Transformation to SSA Form

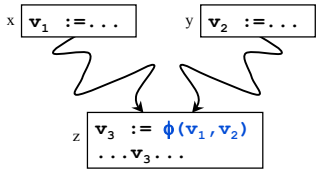
Two steps

- 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

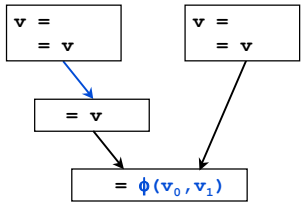
- Same as minimal, except v must be live across some edge of the CFG

Pruned

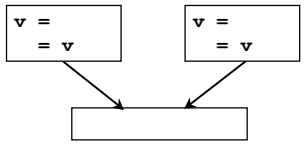
- Same as minimal, except dead ϕ-functions are not inserted

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?

Concepts

Data dependences
- Three kinds of data dependences
- du-chains

Alternate representations

SSA form

Conversion to SSA form
- ϕ-function placement

Next Time

Assignments
- HW1 due

Lecture
- SSA continued