Bitvector Analyses

How to implement?

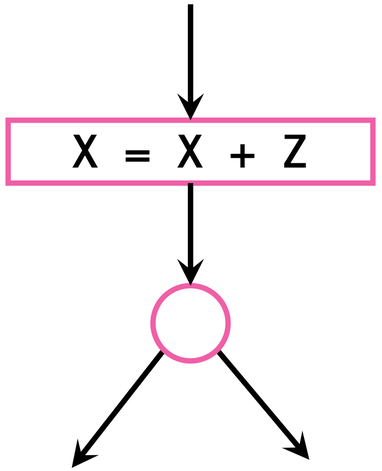
- Dataflow analyses like live-variable analysis are *bit-vector* analyses: are even more structured than regular dataflow analysis
  - Consistent lattice: powerset
  - Consistent transfer functions
- Many sources only talk about bitvector dataflow

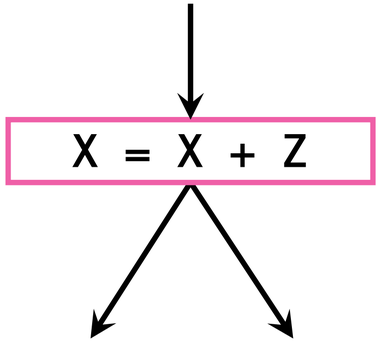
Bit-vector lattices

- Consider a single element, V, of the powerset(S) lattice
- Each item in S either appears in V or does not: can represent using a single bit
  - Can represent V as a *bit vector*
    - {a, b, c} = <1, 1, 1>
    - { } = <0, 0, 0>
    - {b, c} = <0, 1, 1>
- ⊔ and ⊓ (which are just ∪ and ∩) are simply bitwise ∨ and ∧, respectively

Eliminating merge nodes

- Many dataflow presentations do not use explicit merge nodes in CFG
- How do we handle this?
- Problem: now a node may be a statement *and* a merge point
- Solution: compose confluence operator and transfer functions
- Note: non-merge nodes have just one successor; this equation works for all nodes!

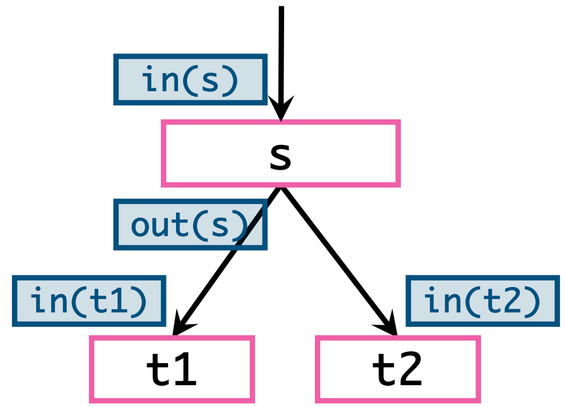




$$T(s) = \mathbf{use}(s) \cup ((\bigcup_{X \in succ(s)} X) - \mathbf{def}(s))$$

Simplifying matters

$$T(s) = \mathbf{use}(s) \cup ((\bigcup_{X \in succ(s)} X) - \mathbf{def}(s))$$



- Let's split this up into two different sets
  - OUT(s): the set of variables that are live *immediately after* a statement is executed
  - IN(s): the set of variables that are live *immediately before* a statement is executed

$$\begin{aligned} IN(s) &= \mathbf{use}(s) \cup (OUT(s) - \mathbf{def}(s)) \\ OUT(s) &= \bigcup_{t \in succ(s)} IN(t) \end{aligned}$$

Generalizing

- USE(s) are the variables that become live due to a statement—they are *generated* by this statement

- DEF(s) are the variables that stop being live due to a statement—they are *killed* by this statement

$$
\begin{aligned}
IN(s) &= \mathbf{gen}(s) \cup (OUT(s) - \mathbf{kill}(s)) \\
OUT(s) &= \bigcup_{t \in succ(s)} IN(t)
\end{aligned}
$$

Bit-vector analyses

- A bit-vector analysis is any analysis that
  - Operates over the powerset lattice, ordered by $\subseteq$ and with $\cup$ and $\cap$ as its meet and join
  - Has transfer functions that can be written in the form:

$$\begin{aligned} IN(s) &= \mathbf{gen}(s) \cup (OUT(s) - \mathbf{kill}(s)) \\ OUT(s) &= \bigcup_{t \in succ(s)} IN(t) \end{aligned}$$

  - Are these transfer functions monotonic? (Hint: if *f* and *g* are monotonic, is $f \circ g$ monotonic?)
  - gen and kill are dependent on the statement, but not on IN or OUT
- Things are a little different for forward analyses, and some analyses use $\cap$ instead of $\cup$

next: more analyses