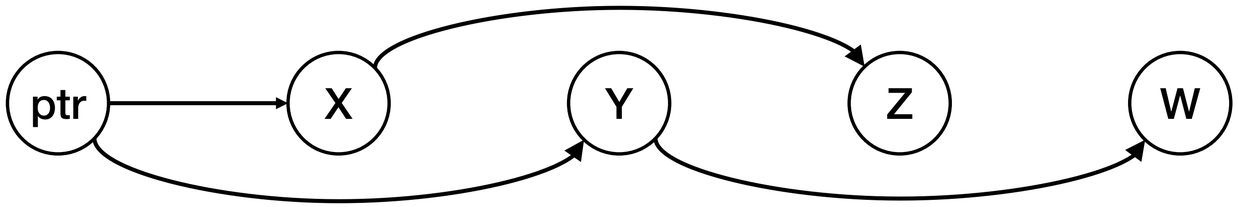
Flow-Sensitive Pointer Analysis

flow-sensitive analysis

- Basic data-flow analysis
- Track points-to graph at each point in the program
  - Graphs ordered according to subset inclusion on *edges* of the graph
- All that's left: what are the transfer functions?

notation: points-to sets

- Can think of a points-to graph as a set of **points-to sets**
  - $pt(x)$ = the set of nodes that x points to = the targets of edges that have x as a source



- $pt(\text{ptr}) = \{x, y\}$
- $pt(\text{x}) = \{z\}$

notation

- Suppose S and S' are set-valued variables: $S = \{x, y\}$ and $S' = \{x, z\}$
- $S' \leftarrow S$ **strong update**
  - S' has a new value of whatever is in S
  - $S' = \{x, y\}$
- $S' \cup\!\leftarrow S$ **weak update**
  - Add whatever is in S to S'
  - $S' = \{x, y, z\}$

dataflow equations

- Forward analysis (points-to information is about what has already happened)
- Use $\sqcup$ at merges (points-to information is *may* information)
- Transfer functions: G is graph before statement, G' is graph after

address of
x = & y

copy
x = y

load
x = * y

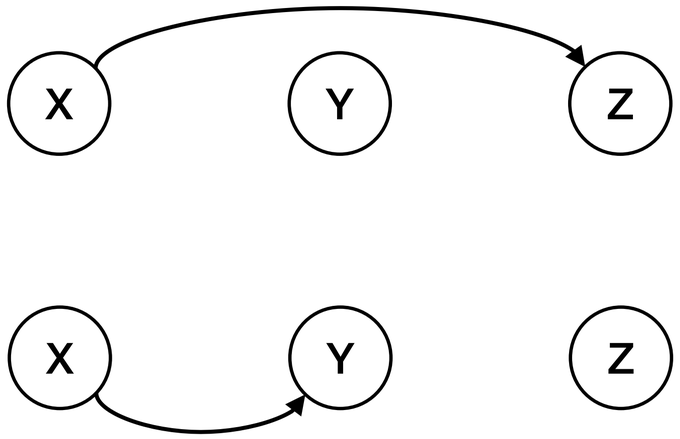
store
* x = y

dataflow equations

- Forward analysis (points-to information is about what has already happened)
- Use ⊔ at merges (points-to information is *may* information)
- Transfer functions: G is graph before statement, G' is graph after

address of
x = & y

$G' = G$ with $pt(\mathrm{x}) \leftarrow \{\mathrm{y}\}$



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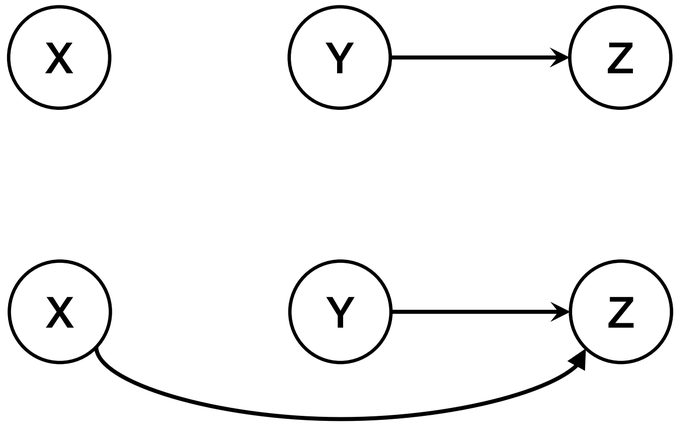

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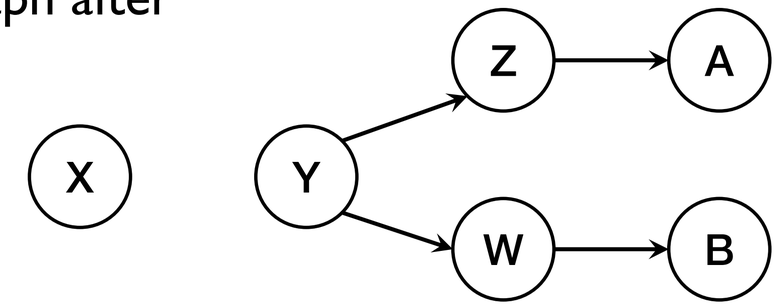
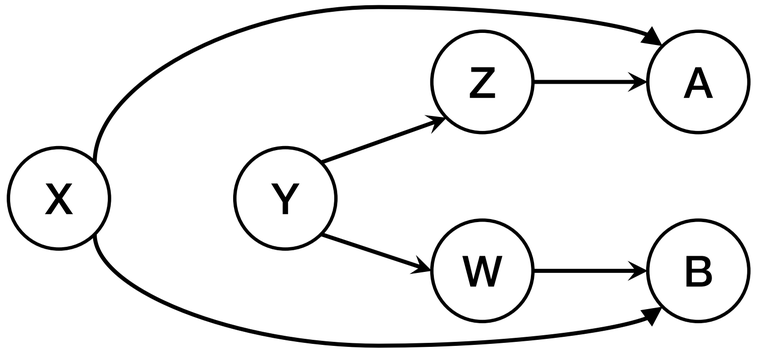


load
x = * y

$G' = G$ with $pt(\mathrm{x}) \leftarrow \bigcup_{\mathrm{a} \in pt(\mathrm{y})} pt(\mathrm{a})$



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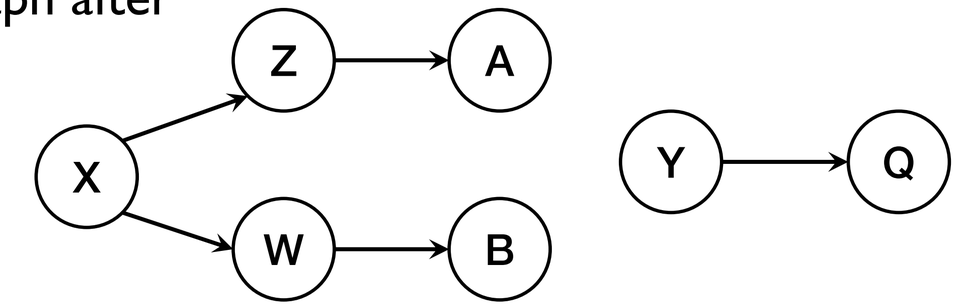
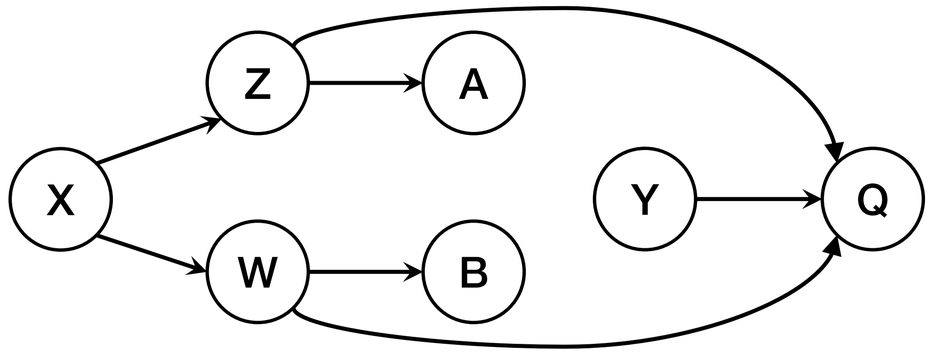
$G' = G$ with $\forall a \in pt(x).\, pt(a) \cup\leftarrow pt(y)$





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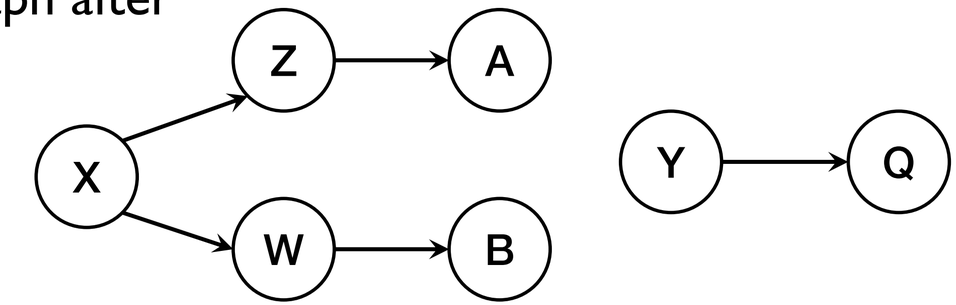
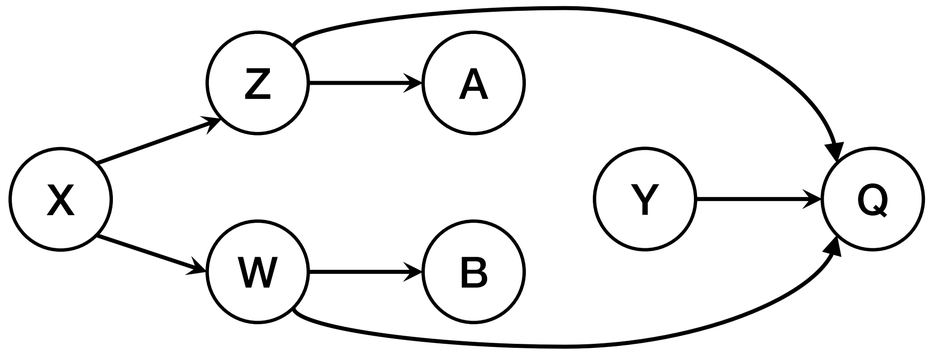
Weak update! why?





weak vs. strong updates

- Strong update
  - At an assignment, you know what variables are being written to
  - Can *remove* points-to information coming in to the statement
- Weak update
  - * x = … means “whatever x *points to* should be updated”
  - At runtime, only one variable is written to, but at analysis time, we don’t know which one
  - Each variable *may* be written to, but we cannot safely remove any information

loads and stores as paths

- One way to keep this straight is to think of loads and stores as multiple paths through the program, one path per thing the pointer points to

load
x = * y

```
//pts(y) = {a, b}
if (…)
   x = a
else
   x = b
```

store
* x = y

```
//pts(x) = {a, b}
if (…)
   a = y
else
   b = y
```

next: flow-insensitive pointer analysis