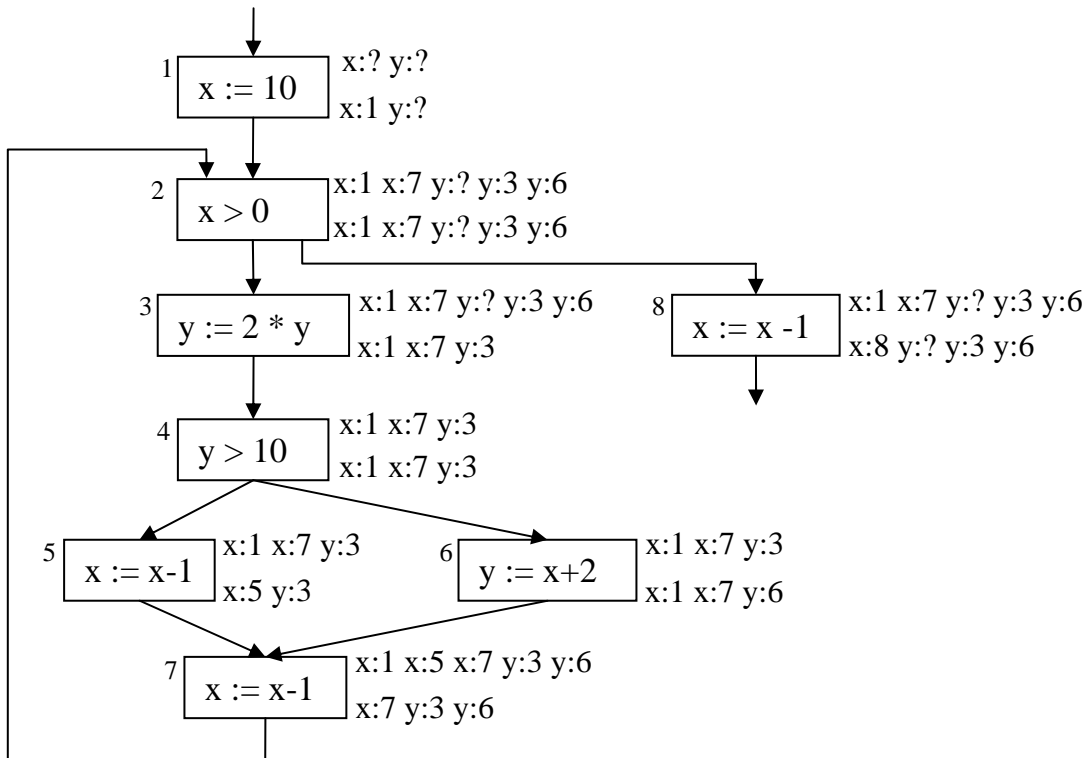


Software Verification

Exercise Solution: Data Flow Analysis

1 Reaching definitions analysis

(a) and (b)



(c)

Block	x	y
1	∅	∅
2	1,7	∅
3	∅	?,3,6
4	∅	3
5	1,7	∅
6	1,7	∅
7	1,5,7	∅
8	1,7	∅

2 Live variables analysis

(a)

```

[x := y]1
[x := x - 1]2
[x := 4]3
while [y < x]4 do
    [y := y + x]5
end
[y := 0]6

```

(b)

$$\begin{aligned}
 LV_{\text{entry}}(1) &= LV_{\text{exit}}(1) \setminus \{x\} \cup \{y\} \\
 LV_{\text{entry}}(2) &= LV_{\text{exit}}(2) \setminus \{x\} \cup \{x\} \\
 LV_{\text{entry}}(3) &= LV_{\text{exit}}(3) \setminus \{x\} \\
 LV_{\text{entry}}(4) &= LV_{\text{exit}}(4) \cup \{x, y\} \\
 LV_{\text{entry}}(5) &= LV_{\text{exit}}(5) \setminus \{y\} \cup \{x, y\} \\
 LV_{\text{entry}}(6) &= LV_{\text{exit}}(6) \setminus \{y\}
 \end{aligned}$$

$$\begin{aligned}
 LV_{\text{exit}}(1) &= LV_{\text{entry}}(2) \\
 LV_{\text{exit}}(2) &= LV_{\text{entry}}(3) \\
 LV_{\text{exit}}(3) &= LV_{\text{entry}}(4) \\
 LV_{\text{exit}}(4) &= LV_{\text{entry}}(5) \cup LV_{\text{entry}}(6) \\
 LV_{\text{exit}}(5) &= LV_{\text{entry}}(4) \\
 LV_{\text{exit}}(6) &= \emptyset
 \end{aligned}$$

(c)

l	$LV_{\text{entry}}(l)$	$LV_{\text{exit}}(l)$
1	y	x,y
2	x,y	y
3	y	x,y
4	x,y	x,y
5	x,y	x,y
6	\emptyset	\emptyset

(d) We eliminate block 1 of the form $x := \dots$ if x is not an element of $LV_{\text{exit}}(l)$.

```
[x := y]1
[x := 4]3
while [y < x]4 do
    [y := y + x]5
end
```

(e)

No, variable x in block 1 is still dead.

Modified equation:

$$LV_{\text{entry}}(l) = \begin{cases} \text{if } kill_{LV}(l) \subseteq LV_{\text{exit}}(l) \text{ then} \\ \quad LV_{\text{exit}}(l) \setminus kill_{LV}(l) \cup gen_{LV}(l) \\ \text{else} \\ \quad LV_{\text{exit}}(l) \end{cases}$$

Rationale behind this equation: if a block assigns a variable that is not live afterwards, then it must be eliminated, and should not influence the analysis by adding the variables it reads to the live variable set.

Modified analysis:

l	$LV_{\text{entry}}(l)$	$LV_{\text{exit}}(l)$
1	y	y
2	y	y
3	y	x,y
4	x,y	x,y
5	x,y	x,y
6	\emptyset	\emptyset

Modified code elimination:

```
[x := 4]3
while [y < x]4 do
    [y := y + x]5
end
```