

Andrew ID: _____

1. [Available Expressions]. Perform available expressions dataflow analysis to this program:

Answer:

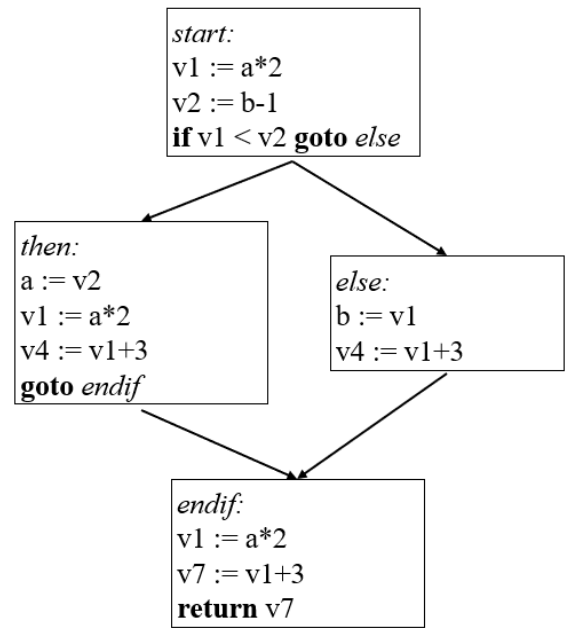
$Out_{start} = \{a^*2, b-1\}$

$Out_{then} = \{a^*2, b-1, a^*2+3\}$

- $a := v2$ kills a^*2 since it is an assignment to a variable (namely a) used in the computation of a^*2
- $v1 := a * 2$ gens a^*2
- $v4 := v1 + 3$ gens a^*2+3
- $In_{then} = Out_{start} = \{a^*2, b-1\}$
- $Kill_{then} = \{a^*2\}$
- $Gen_{then} = \{a^*2, a^*2+3\}$

$Out_{else} = \{a^*2, a^*2+3\}$

- $b := v1$ kills $b-1$ since it is an assignment to a variable (namely b) used in the computation of $b-1$
- $v4 := v1 + 3$ gens a^*2+3
- $In_{else} = Out_{start} = \{a^*2, b-1\}$
- $Kill_{else} = \{b-1\}$
- $Gen_{else} = \{a^*2+3\}$



For the final *endif* block, we have $In_{endif} = Out_{then} \cap Out_{else} = \{a^*2, a^*2+3\}$. Since both a^*2 and $a^*2+3 = v1+3$ are available entering the block, we do not need to recompute them. Hence, as an optimization, we can eliminate both instructions in *endif* before the return and return $v4$ instead (we record where each available expression is – in $v4$ in this case).

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// "start", "then", and "else" are the same
endif:
return v4
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2. [Live Variables]. Perform live variable analysis on this program, and eliminate dead code:

Answer: Work backwards--read each block from the bottom up, and process the blocks from the return back to the start of the procedure:

$$\text{Out}_{\text{endif}} = \{ v7 \}$$

$$\begin{aligned} \text{In}_{\text{endif}} &= \text{Gen}_{\text{endif}} \cup (\text{Out}_{\text{endif}} \setminus \text{Kill}_{\text{endif}}) \\ &= \{ a \} \cup (\{ v7 \} \setminus \{ v7, v6 \}) \\ &= \{ a \} \end{aligned}$$

$$\text{Out}_{\text{then}} = \text{In}_{\text{endif}} = \{ a \}$$

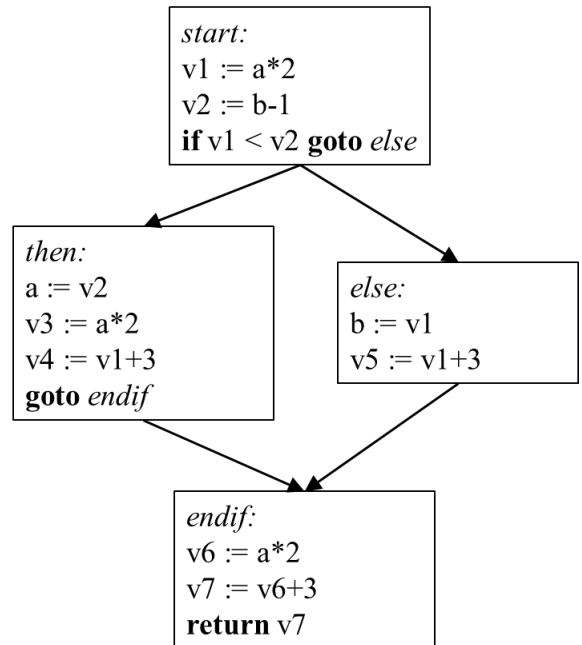
$$\begin{aligned} \text{In}_{\text{then}} &= \text{Gen}_{\text{then}} \cup (\text{Out}_{\text{then}} \setminus \text{Kill}_{\text{then}}) \\ &= \{ v1, v2 \} \cup (\{ a \} \setminus \{ a, v3, v4 \}) \\ &= \{ v1, v2 \} \end{aligned}$$

$$\text{Out}_{\text{else}} = \text{In}_{\text{endif}} = \{ a \}$$

$$\begin{aligned} \text{In}_{\text{else}} &= \text{Gen}_{\text{else}} \cup (\text{Out}_{\text{else}} \setminus \text{Kill}_{\text{else}}) \\ &= \{ v1 \} \cup (\{ a \} \setminus \{ b, v5 \}) \\ &= \{ a, v1 \} \end{aligned}$$

$$\text{Out}_{\text{start}} = \text{In}_{\text{then}} \cup \text{In}_{\text{else}} = \{ a, v1, v2 \}$$

$$\begin{aligned} \text{In}_{\text{start}} &= \text{Gen}_{\text{start}} \cup (\text{Out}_{\text{start}} \setminus \text{Kill}_{\text{start}}) \\ &= \{ a, b \} \cup (\{ a, v1, v2 \} \setminus \{ v1, v2 \}) \\ &= \{ a, b \} \end{aligned}$$



Based on this live variable information, we can remove the statements:

- $v4 := v1+3$
- $v3 := a*2$
- $v5 := v1+3$
- $b := v1$ (note: if b is a variable visible outside the procedure, we can't eliminate it)