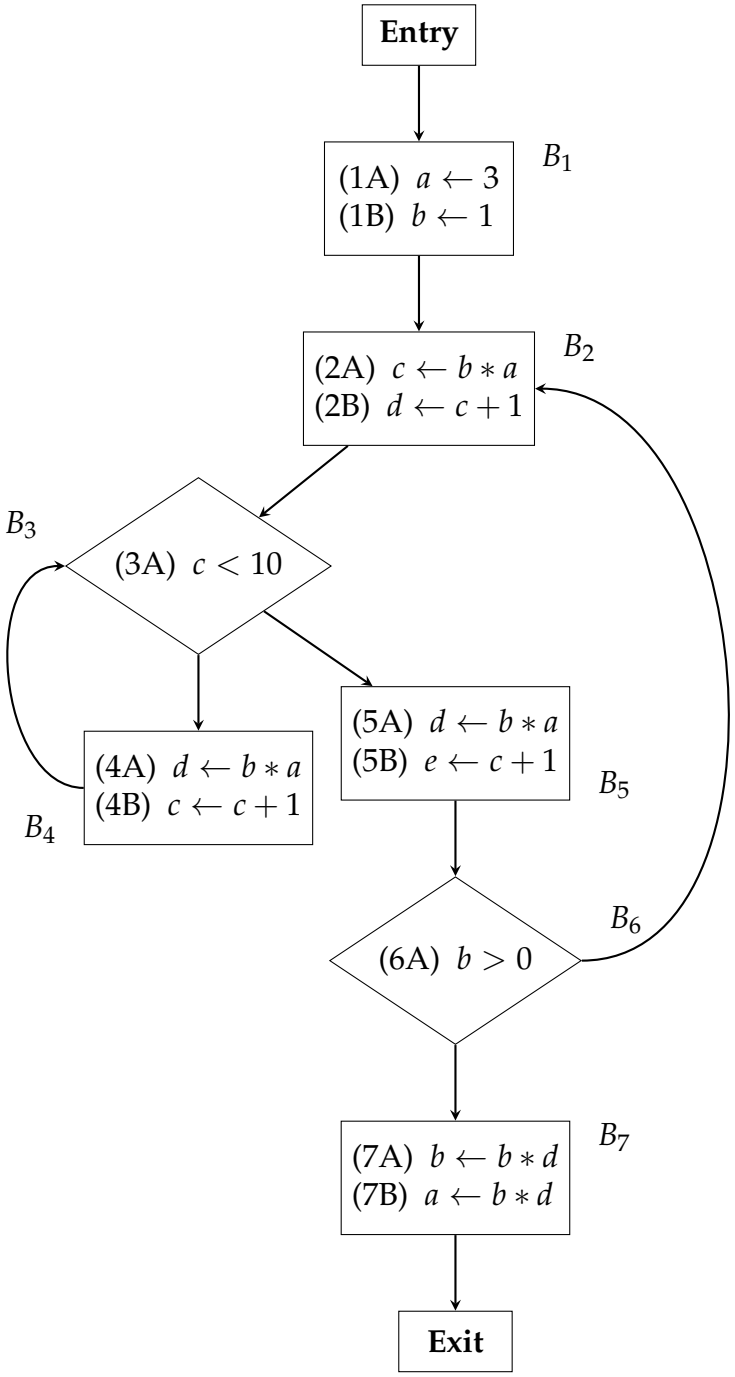
1 Program Analysis

This miniquiz will cover performing each of the three dataflow analyses discussed in lecture. Consider the following control graph for a single procedure.



1.1 Reaching Definitions

In this problem, you will perform a reaching definition analysis. Recall that a definition $x \leftarrow y \oplus z$ *reaches* a use U of x if U could read x as defined by $x \leftarrow y \oplus z$.

For each basic block B, the worklist algorithm updates its IN and OUT sets using these equations:

$$\mathsf{IN}[B] = \forall B_i \in \mathsf{pred}[B] \,.\, \bigcup \mathsf{OUT}[B_i].$$
$$\mathsf{OUT}[B] = (\mathsf{IN}[B] \setminus \mathsf{KILL}[B]) \cup \mathsf{GEN}[B].$$

Fill in the following table with the IN, OUT, KILL, and GEN sets for each basic block. As a starting point, the first row was filled in.

Basic Block B	GEN[B]	KILL[B]	IN[B]	OUT[B]
B_1	{1A, 1B}	{7A,7B}	$\emptyset$	{1A,1B}
B_2				
B_3				
B_4				
B_5				
B_6				
B_7				

Answer.

GEN is produced by including all the definitions inside the basic block. KILL is produced by finding all the other definitions of variables in other basic blocks. Then, the dataflow equations given above must be applied. Note, that it must be continually applied until you reach a fixed point.

Basic Block B	GEN[B]	KILL[B]	IN[B]	OUT[B]
B_1	{1A, 1B}	{7A,7B}	$\emptyset$	{1A,1B}
B_2	{2A, 2B}	{4A, 4B, 5A}	{1A, 1B, 2A, 4B, 5A, 5B}	{1A, 1B, 2A, 2B, 5B}
B_3	$\emptyset$	$\emptyset$	{1A, 1B, 2A, 2B, 4A, 4B, 5B}	{1A, 1B, 2A, 2B, 4A, 4B, 5B}
B_4	{4A, 4B}	{2A, 2B, 5A}	{1A, 1B, 2A, 2B, 4A, 4B, 5B}	{1A, 1B, 4A, 4B, 5B}
B_5	{5A, 5B}	{2B, 4A}	{1A, 1B, 2A, 2B, 4A, 4B, 5B}	{1A, 1B, 2A, 4B, 5A, 5B}
B_6	$\emptyset$	$\emptyset$	{1A, 1B, 2A, 4B, 5A, 5B}	{1A, 1B, 2A, 4B, 5A, 5B}
B_7	{7A, 7B}	{1A, 1B}	{1A, 1B, 2A, 4B, 5A, 5B}	{2A, 4B, 5A, 5B, 7A, 7B}

1.2 Available Expressions

In this problem, you will perform an available expression analysis. Recall that an expression $x \oplus y$ is *available* at program point P if:

- All paths from the entry block to P evaluate $x \oplus y$ before reaching P.
- There are no re-definitions for x or y after the evaluation $x \oplus y$, but before P.

For each basic block B, the worklist algorithm updates its IN and OUT sets using these equations:

$$\mathsf{IN}[B] = \forall B_i \in \mathsf{pred}[B] \,.\, \bigcap \mathsf{OUT}[B_i].$$
$$\mathsf{OUT}[B] = (\mathsf{IN}[B] \setminus \mathsf{KILL}[B]) \cup \mathsf{GEN}[B].$$

Fill in the following table with the IN, OUT, KILL, and GEN sets for each basic block. As a starting point, the first row was filled in for you. Consider only the following expressions, numbered in the order provided below:

1. $b * a$
2. $c + 1$
3. $b * d$

Basic Block B	GEN[B]	KILL[B]	IN[B]	OUT[B]
B_1	$\emptyset$	{1,3}	$\emptyset$	$\emptyset$
B_2				
B_3				
B_4				
B_5				
B_6				
B_7				

Answer.

GEN is produced by including all the expressions computed inside the block. KILL is produced by finding all the expressions that involve variables that are assigned values inside the block.

Basic Block B	GEN[B]	KILL[B]	IN[B]	OUT[B]
B_1	$\emptyset$	{1,3}	$\emptyset$	$\emptyset$
B_2	$\{1,2\}$	$\{3\}$	$\{1,2\}$	$\{1,2\}$
B_3	$\emptyset$	$\emptyset$	$\{1,2\}$	$\{1,2\}$
B_4	$\{1\}$	$\{2,3\}$	$\{1,2\}$	$\{1\}$
B_5	$\{1,2\}$	$\{3\}$	$\{1,2\}$	$\{1,2\}$
B_6	$\emptyset$	$\emptyset$	$\{1,2\}$	$\{1,2\}$
B_7	$\{3\}$	$\{1\}$	$\{1,2\}$	$\{2,3\}$

1.3 Live Variables

In this problem, you will perform a liveness analysis. Recall that a variable x is said to be *live* at program point P if:

- Some path from P to the exit block contains a use U of x.
- There are no re-definitions for x along that path until U.

For each basic block B, the worklist algorithm updates its IN and OUT sets using these equations:

$$\mathsf{IN}[B] = \mathsf{USE}[B] \cup (\mathsf{OUT}[B] \setminus \mathsf{DEF}[B])\,.$$
$$\mathsf{OUT}[B] = \forall B_i \in \mathsf{succ}[B] \,.\, \bigcup \mathsf{IN}[B_i].$$

Fill in the following table with the IN, OUT, USE, and DEF sets for each basic block. As a start, the last row was filled in for you. Assume all variables are local, that is no variables are live upon exiting the procedure.

Basic Block B	USE[B]	DEF[B]	IN[B]	OUT[B]
B_1				
B_2				
B_3				
B_4				
B_5				
B_6				
B_7	$\{b, d\}$	$\{a, b\}$	$\{b, d\}$	$\emptyset$

Answer.

USE is every variable that is used inside an expression in the basic block. DEF is every variable that is assigned to in the basic block.

Basic Block B	GEN[B]	KILL[B]	IN[B]	OUT[B]
B_1	$\emptyset$	{a,b}	$\emptyset$	$\{a,b\}$
B_2	$\{a,b\}$	$\{c,d\}$	$\{a,b\}$	$\{a,b,c\}$
B_3	$\{c\}$	$\emptyset$	$\{a,b,c\}$	$\{a,b,c\}$
B_4	$\{a,b,c\}$	$\{c,d\}$	$\{a,b,c\}$	$\{a,b,c\}$
B_5	$\{a,b,c\}$	$\{d,e\}$	$\{a,b,c\}$	$\{a,b,d\}$
B_6	$\{b\}$	$\emptyset$	$\{a,b,d\}$	$\{a,b,d\}$
B_7	$\{b,d\}$	$\{a,b\}$	$\{b,d\}$	$\emptyset$