Assignment 2

Members:

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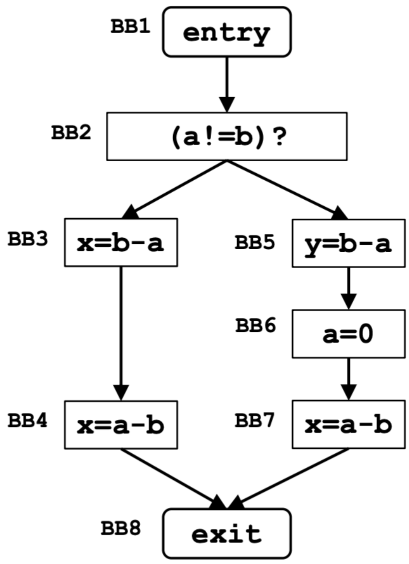
Very Busy Expressions

An expression is considered **very busy** at a point p if, regardless of the path taken from p, the expression is used before one of its operands is defined.

An expression $a + b$ is considered **very busy** at a point p if $a + b$ is evaluated on all paths from p to exit and there is no definition of a or b along those paths.

We are interested in the set of available expressions at the beginning of block B.

This set depends on the paths that start at point p before B.



Dataflow analysis framework

	Dominator analysis
Domain	Set of expressions
Direction	Backward $in[B] = f_B(out[B])$ $out[B] = \wedge in[succ(B)]$
Transfer function	$f_B(x) = Gen(B) \cup (x - Kill(B))$
Meet operator ($\wedge$)	$\cap$

	Dominator analysis
Boundary condition	$in[exit] = \emptyset$
Initial interior points	$in[B] = \mathbb{U}$

Since $\wedge = \cap$ we need to use an initial interior points $in[B] = \mathbb{U}$.

CFG iterations

	Iteration 1		Iteration 2	
	IN[BB]	OUT[BB]	IN[BB]	OUT[BB]
BB1	$Gen(BB1) \cup (out[BB1] - kill) = \emptyset \cup \{b-a, a-b\} - \emptyset = \{a-b, b-a\}$	$in[BB2] = \{b-a, a-b\}$	$Gen(BB1) \cup (out[BB1] - kill) = \emptyset \cup \{b-a, a-b\} - \emptyset = \{a-b, b-a\}$	$in[BB2] = \{b-a, a-b\}$
BB2	$Gen(BB2) \cup (out[BB2] - kill) = \emptyset \cup \{b-a, a-b\} - \emptyset = \{b-a, a-b\}$	$in[BB3] \cap in[BB5] = \{a-b, b-a\} \cap \{b-a, a-b\} = \{a-b, b-a\}$	$Gen(BB2) \cup (out[BB2] - kill) = \emptyset \cup \{b-a, a-b\} - \emptyset = \{b-a, a-b\}$	$in[BB3] \cap in[BB5] = \{a-b, b-a\} \cap \{b-a, a-b\} = \{a-b, b-a\}$
BB3	$Gen(BB3) \cup (out[BB3] - kill) = \{b-a\} \cup (\{a-b\} - \emptyset) = \{a-b, b-a\}$	$in[BB4] = \{a-b\}$	$Gen(BB3) \cup (out[BB3] - kill) = \{b-a\} \cup (\{a-b\} - \emptyset) = \{a-b, b-a\}$	$in[BB4] = \{a-b\}$
BB4	$Gen(BB4) \cup (out[BB4] - kill) = \{a-b\} \cup (\emptyset - \emptyset) = \{a-b\}$	$in[BB8] = \emptyset$	$Gen(BB4) \cup (out[BB4] - kill) = \{a-b\} \cup (\emptyset - \emptyset) = \{a-b\}$	$in[BB8] = \emptyset$
BB5	$Gen(BB5) \cup (out[BB5] - kill) = \{b-a\} \cup (\{a-b\} - \emptyset) = \{b-a, a-b\}$	$in[BB6] = \{a-b\}$	$Gen(BB5) \cup (out[BB5] - kill) = \{b-a\} \cup (\{a-b\} - \emptyset) = \{b-a, a-b\}$	$in[BB6] = \{a-b\}$
BB6	$Gen(BB6) \cup (out[bb6] - kill) = \emptyset \cup \{a-b\} - \{b-a\} = \{a-b\}$	$in[BB7] = \{a-b\}$	$Gen(BB6) \cup (out[bb6] - kill) = \emptyset \cup \{a-b\} - \{b-a\} = \{a-b\}$	$in[BB7] = \{a-b\}$
BB7	$Gen(BB7) \cup (OUT[BB7] - kill) = \{a-b\} \cup (\emptyset - \emptyset) = \{a-b\}$	$in[BB8] = \emptyset$	$Gen(BB7) \cup (OUT[BB7] - kill) = \{a-b\} \cup (\emptyset - \emptyset) = \{a-b\}$	$in[BB8] = \emptyset$
BB8	$\emptyset$		$\emptyset$	

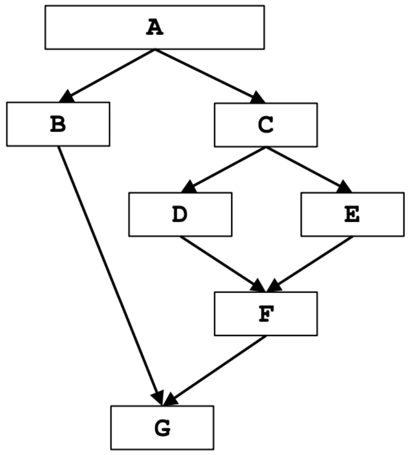
Since there are no changes between the $out[]$ of the first and second iterations, we can stop because convergence has been reached.

Dominator Analysis

Within a CFG, a basic block (BB) x dominates another BB y if node x appears in every path of the graph that leads from the entry block to block y.

Each BB has a set $DOM[B_i]$ where $B_i \in DOM[B_j]$ only if B_i dominates B_j.

A node dominates itself: $B_i \in DOM[B_i]$.



Dataflow analysis framework

	Dominator analysis
Domain	Set of BB
Direction	Forward $out[B] = f_B(in[B])$ $in[B] = \wedge out[pred(B)]$
Transfer function	$f_b(x) = Gen[B] \cup in[B]$
Meet operator $(\wedge)$	$\cap$
Boundary condition	$out[entry] = \{entry\}$
Initial interior points	$out[B] = \mathbb{U}$

The choice of boundary condition $out[entry] = \{entry\}$ is due to the fact that the reflexive property of the dominator analysis is specified.

In the execution of the iterations, A is considered the $entry$ block and G is considered the $exit$ block.

Iterazioni CFG

	Iteration 1		Iteration 2	
	IN[BB]	OUT[BB]	IN[BB]	OUT[BB]
A	$\emptyset$ (0000000)	{A} (1000000)	$\emptyset$ (0000000)	{A} (1000000)
B	{A} (1000000)	{A, B} (1100000)	{A} (1000000)	{A, B} (1100000)
C	{A} (1000000)	{A, C} (1010000)	{A} (1000000)	{A, C} (1010000)
D	{A, C} (1010000)	{A, C, D} (1011000)	{A, C} (1010000)	{A, C, D} (1011000)
E	{A, C} (1010000)	{A, C, E} (1010100)	{A, C} (1010000)	{A, C, E} (1010100)
F	{A, C} (1010000)	{A, C, F} (1010010)	{A, C} (1010000)	{A, C, F} (1010010)
G	{A} (1000000)	{A, G} (1000001)	{A} (1000000)	{A, G} (1000001)

Since there are no changes between the $out[]$ of the first and second iterations, we can stop because convergence has been reached.

Constant Propagation

The goal of constant propagation is to determine at which points in the program the variables have a constant value.

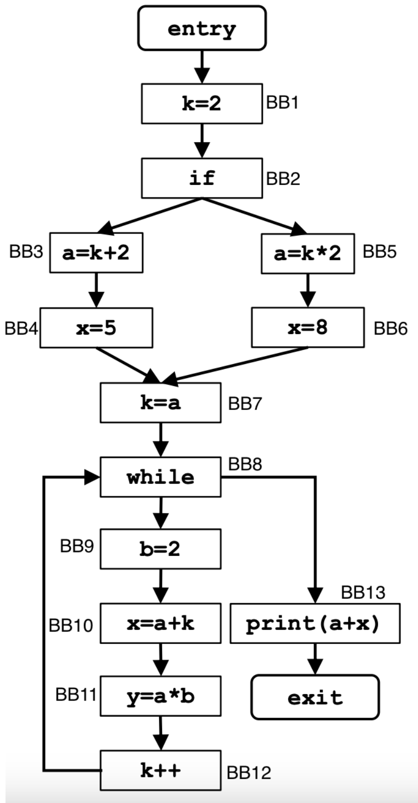
The information to be calculated for each node of the CFG is a set of pairs of the type <variable, constant value>.

If we have the pair $< x, c >$ at node n, it means that x is guaranteed to have the value c whenever n is reached during program execution.

NOTE: CP analysis can determine the constant value of binary expressions where one or both operands are variables whose constant value is known:

$$w = 5$$
$$x = 12$$
$$y = x – 2 \rightarrow y = 10$$
$$z = w + x \rightarrow z = 17$$

Take this into account when determining the equations.



Dataflow analysis framework

	Dominator analysis
Domain	Set of definitions

	Dominator analysis
Direction	Forward $out[B] = f_B(in[B])$ $in[B] = \wedge out[pred(B)]$
Transfer function	$f_B(x) = Gen(B) \cup (x - Kill(B))$
Meet operator $(\wedge)$	$\cap$
Boundary condition	$out[entry] = \emptyset$
Initial interior points	$out[B] = \mathbb{U}$

Iterazioni CFG

	Iteration 1		Iteration 2		Iteration 3	
	IN[BB]	OUT[BB]	IN[BB]	OUT[BB]	IN[BB]	OUT[BB]
BB1	$\emptyset$	$\{<k,2>\}$	$\emptyset$	$\{<k,2>\}$	$\emptyset$	$\{<k,2>\}$
BB2	$\{<k,2>\}$	$\{<k,2>\}$	$\{<k,2>\}$	$\{<k,2>\}$	$\{<k,2>\}$	$\{<k,2>\}$
BB3	$\{<k,2>\}$	$\{<a,4><k,2>\}$	$\{<k,2>\}$	$\{<a,4><k,2>\}$	$\{<k,2>\}$	$\{<a,4><k,2>\}$
BB4	$\{<a,4><k,2>\}$	$\{<a,4><k,2><x,5>\}$	$\{<a,4><k,2>\}$	$\{<a,4><k,2><x,5>\}$	$\{<a,4><k,2>\}$	$\{<a,4><k,2><x,5>\}$
BB5	$\{<k,2>\}$	$\{<a,4><k,2>\}$	$\{<k,2>\}$	$\{<a,4><k,2>\}$	$\{<k,2>\}$	$\{<a,4><k,2>\}$
BB6	$\{<a,4><k,2>\}$	$\{<a,4><k,2><x,8>\}$	$\{<a,4><k,2>\}$	$\{<a,4><k,2><x,8>\}$	$\{<a,4><k,2>\}$	$\{<a,4><k,2><x,8>\}$
BB7	$out[BB4] \cap out[BB6] = \{<a,4><k,2><z,5>\} \cap \{<a,4><k,2><x,8>\} = \{<a,4><k,2>\}$	$<k,4> +(\{<a,4>, <k,2>\} - <k,2>)$ = $\{<k,4>, <a,4>\}$	$out[BB4] \cap out[BB6] = \{<a,4><k,2><z,5>\} \cap \{<a,4><k,2><x,8>\} = \{<a,4><k,2>\}$	$<k,4> +(\{<a,4>, <k,2>\} - <k,2>)$ = $\{<k,4>, <a,4>\}$	$out[BB4] \cap out[BB6] = \{<a,4><k,2><z,5>\} \cap \{<a,4><k,2><x,8>\} = \{<a,4><k,2>\}$	$<k,4> +(\{<a,4>, <k,2>\} - <k,2>)$ = $\{<k,4>, <a,4>\}$
BB8	$\{<k,4>, <a,4>\}$	$\{<k,4>, <a,4>\}$	$out[BB12] \cap out[BB7] = \{<k,5>, <a,4>, <b,2>, <x,8>, <y,8>\} \cap \{<k,4><a,4>\} = \{<a,4>\}$	$\{<a,4>\}$	$out[BB12] \cap out[BB7] = \{<a,4>\} \cap \{<a,4>, <k,2>\} = \{<a,4>\}$	$\{<a,4>\}$
BB9	$\{<k,4>, <a,4>\}$	$\{<k,4>, <a,4>, <b,2>\}$	$\{<a,4>\}$	$\{<a,4>, <b,2>\}$	$\{<a,4>\}$	$\{<a,4>, <b,2>\}$

	Iteration 1		Iteration 2		Iteration 3	
BB10	$\{<k,4>,<a,4>,<b,2>\}$	$\{<k,4>,<a,4>,<b,2>,<x,8>\}$	$\{<a,4>,<b,2>\}$	$\{<a,4>,<b,2>\}$	$\{<a,4>,<b,2>\}$	$\{<a,4>,<b,2>\}$
BB11	$\{<k,4>,<a,4>,<b,2>,<x,8>\}$	$\{<k,4>,<a,4>,<b,2>,<x,8>,<y,8>\}$	$\{<a,4>,<b,2>\}$	$\{<a,4>,<b,2>,<y,8>\}$	$\{<a,4>,<b,2>\}$	$\{<a,4>,<b,2>,<y,8>\}$
BB12	$\{<k,4>,<a,4>,<b,2>,<x,8>,<y,8>\}$	$\{<k,5>,<a,4>,<b,2>,<x,8>,<y,8>\}$	$\{<a,4>,<b,2>,<y,8>\}$	$\{<a,4>,<b,2>,<y,8>\}$	$\{<a,4>,<b,2>,<y,8>\}$	$\{<a,4>,<b,2>,<y,8>\}$
BB13	$\{<k,4>,<a,4>\}$	$\{<k,4>,<a,4>\}$	$\{<a,4>\}$	$\{<a,4>\}$	$\{<a,4>\}$	$\{<a,4>\}$

Since there are no changes between the $out[]$ of the second and third iterations, we can stop because convergence has been reached.