CS 201, Winter- Assignment 3

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Problem 3: Consider the following control flow graph (CFG) and answer the following questions.

1. Find all the EBBs in the CFG; (1 point)
2. Find the dominator set for each basic block; (1 point)
3. Build the dominance tree for the CFG; (1 point)
4. Apply superlocal value numbering (SVN) to the CFG; (2 points)
5. Apply dominator-based value numbering (DVN) to the CFG. (2 points)

For SVN and DVN, it is required to show the final status of the CFG after value numbering, the entries in the hash tables, and discuss the redundancies identified. No need to remove the redundancies. (total: 7 points)

Note that students are allowed to discuss the general concepts and techniques, but are NOT allowed to discuss this specific problem with each other (i.e., the problem should be solved independently).
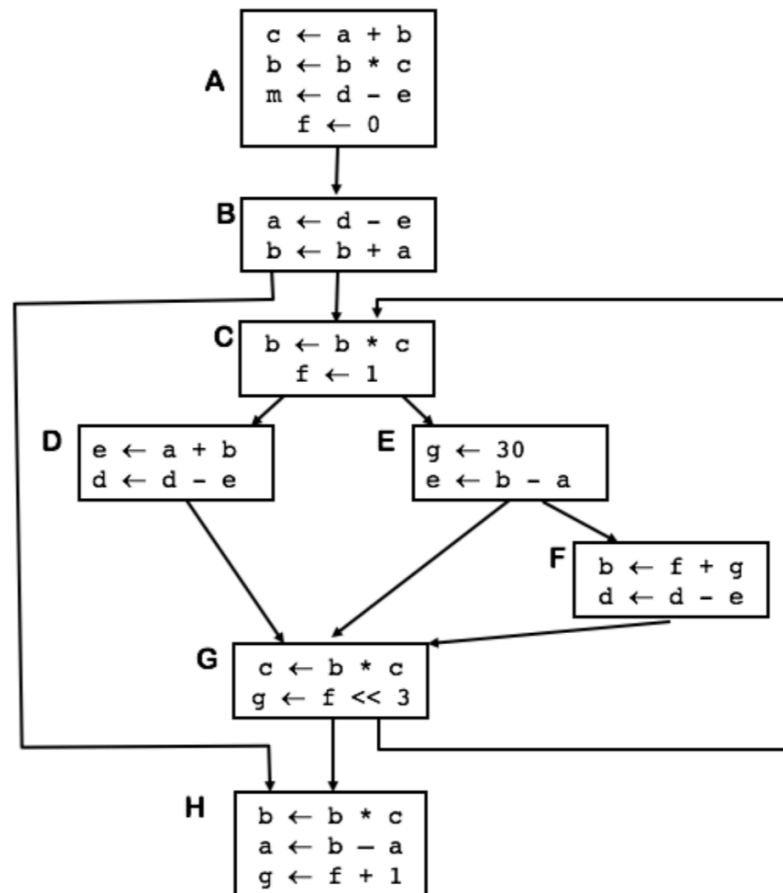
8 Considering the Control Flow Graph, answer the following questions:

1 Find all the 2BBs in the CFG. (1 point)

Ans Extended Basic Block or EBB is defined as the maximum set of blocks $B_1, B_2 \ldots, B_n$ where B_i $(2 \leq i \leq n)$ has a unique predecessor, which is in the EBB.

According to the control flow graph, the EBBs are:-
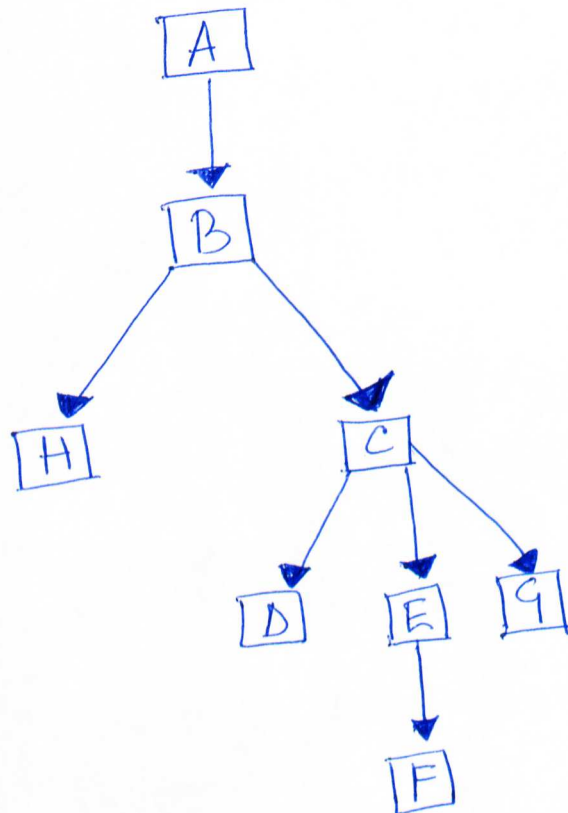
$$\{A, B\}, \{C, D, E, F\}, \{G\}, \{H\}$$

2 Find the dominator set for each basic block. (1 point)

Ans

BLOCK	DOMINATOR	IMMEDIATE DOMINATOR
A	A	—
B	A, B	A
C	A, B, C	B
D	A, B, C, D	C
E	A, B, C, E	C
F	A, B, C, E, F	E
G	A, B, C, G	C
H	A, B, H	B

3 Build the dominance tree for the CfG (1 point).

Ans

```
         ┌───┐
         │ A │
         └───┘
           │
           ▼
         ┌───┐
         │ B │
         └───┘
          ╱   ╲
         ▼      ▼
      ┌───┐   ┌───┐
      │ H │   │ C │
      └───┘   └───┘
              ╱ │ ╲
             ▼  ▼  ▼
         ┌───┐┌───┐┌───┐
         │ D ││ E ││ G │
         └───┘└───┘└───┘
                 │
                 ▼
              ┌───┐
              │ F │
              └───┘
```

4 Apply superlocal value numbering (SVN) to the CFG.
(2 points.

Ans

Value Numbering for all the blocks with Hash tables.

For Block A

$$c_0^3 \leftarrow a_0^1 + b_0^2$$

$$b_1^4 \leftarrow b_0^2 * c_0^3$$

$$m_0^7 \leftarrow d_0^5 - e_0^6$$

$$f_0^8 \leftarrow o^8$$

$\langle a, 1 \rangle$
$\langle b_0, 2 \rangle$
$\langle 1+2, 3 \rangle$
$\langle c, 3 \rangle$
$\langle 2+3, 4 \rangle$
$\langle b_1, 4 \rangle$
$\langle d_0, 5 \rangle$
$\langle e_0, 6 \rangle$
$\langle 5-6, 7 \rangle$
$\langle m_0, 7 \rangle$
$\langle 0, 8 \rangle$
$\langle f, 8 \rangle$

For Block B

$$a_1{}^7 \leftarrow d_0{}^5 - e_0{}^6$$

$$b_2{}^8 \leftarrow b_1{}^4 \leftarrow a_1{}^7$$

$$\langle a_1, 7 \rangle$$
$$\langle 4+7, 8 \rangle$$
$$\langle b_2, 8 \rangle$$

FOR BLOCK C

$$b_3{}^9 \leftarrow b_2{}^8 * c_0{}^3$$

$$f_1{}^{10} \leftarrow 1^{10}$$

$$\langle 3*3, 9 \rangle$$
$$\langle b_3, 9 \rangle$$
$$\langle 1, 10 \rangle$$
$$\langle f_1, 10 \rangle$$

FOR BLOCK D

$$e_1{}^{11} \leftarrow a_1{}^7 + b_3{}^9$$

$$d_1{}^{12} \leftarrow d_0{}^5 - e_1{}^{11}$$

$$\langle 7+9, 11 \rangle$$
$$\langle e_1, 11 \rangle$$
$$\langle 5-11, 12 \rangle$$
$$\langle d_1, 12 \rangle$$

FOR BLOCK E

$$g_0{}^{13} \leftarrow 30^{13}$$

$$e_2{}^{14} \leftarrow b_3{}^9 - a_1{}^7$$

$$\langle 30, 13 \rangle$$
$$\langle g_0, 13 \rangle$$
$$\langle 9-7, 14 \rangle$$
$$\langle e_2, 14 \rangle$$

FOR BLOCK F

$$b_4{}^{15} \leftarrow f_1{}^{10} + g_0{}^{13}$$

$$d_2{}^{16} \leftarrow d_1{}^{12} - e_2{}^{14}$$

$$\langle 10+13, 15 \rangle$$
$$\langle b_4, 15 \rangle$$
$$\langle 12-14, 16 \rangle$$
$$\langle d_2, 16 \rangle$$

FOR BLOCK G

$$c_1^{17} \leftarrow b_4^{15} * c_0^{3}$$

$$g_1^{19} \leftarrow f_1^{10} << 3^{18}$$

$\langle 5*3, 17 \rangle$
$\langle c_1, 17 \rangle$
$\langle 3, 18 \rangle$
$\langle 10 << 18, 19 \rangle$
$\langle g_1, 19 \rangle$

FOR BLOCK H

$$b_5^{20} \leftarrow b_4^{15} * c_1^{17}$$

$$a_2^{21} \leftarrow b_5^{20} - a_1^{7}$$

$$g_2^{22} \leftarrow f_1^{10} + 1^{10}$$

$\langle 5*17, 20 \rangle$
$\langle b_5, 20 \rangle$
$\langle 20-7, 21 \rangle$
$\langle a_2, 21 \rangle$
$\langle 10+10, 22 \rangle$
$\langle g_2, 22 \rangle$

Considering the EBBs
$\{AB\}$, $\{C, D, E, F\}$, $\{G\}$, $\{H\}$ we
find the redundancies using Super Local Value
Numbering.

BLOCK B

$$a_1 \leftarrow d_0 - e_0$$
$$b_2 \leftarrow b_1 + a_1$$

$\}$ redundant by SVN

BLOCK F

$$b_4 \leftarrow f_1 + g_0$$
$$d_2 \leftarrow d_1 - e_2 \longrightarrow \text{redundant SVN.}$$

5 Apply dominator - based value numbering (DVN) to the CFG. (2 points)

Ans

FOR BLOCK A

$$c_0 \leftarrow a_0 + b_0$$
$$b_1 \leftarrow b_0 * c_0$$
$$m_0 \leftarrow d_0 - e_0$$
$$f_0 \leftarrow 0$$

NOTE: To find the redundancies using DVN, we consider the Dominance tree.

BLOCK B

$$a_1 \leftarrow d_0 - e_0 \qquad \longleftrightarrow \text{redundant by SVN}$$
$$b_2 \leftarrow b_1 + a_0 \qquad \longleftrightarrow \text{redundant by SVN}$$

BLOCK C

$$b_3 \leftarrow \phi(b_2, b_6)$$
$$f_1 \leftarrow \phi(f_0, f_3)$$
$$c_2 \leftarrow \phi(c_0, c_1)$$
$$b_4 \leftarrow b_3 + c_2$$
$$f_2 \leftarrow 1$$

BLOCK D

$$e_1 \leftarrow a_1 + b_4 \qquad \longleftrightarrow \text{redundant by DVN}$$
$$d_1 \leftarrow d_0 - e_1 \qquad \longleftrightarrow \text{redundant by DVN}$$

BLOCK E

$$g_0 \leftarrow 30$$
$$e_2 \leftarrow b_4 - a_1$$

BLOCK F

$$b_5 \leftarrow f_2 + g_0$$
$$d_2 \leftarrow d_1 - e_2 \longleftrightarrow \text{redundant by SVN}$$

BLOCK G

$$b_6 \leftarrow \phi(b_4, b_5)$$
$$f_3 \leftarrow \phi(f_1, f_2)$$
$$c_1 \leftarrow b_6 * c_2 \longleftrightarrow \text{redundant by DVN}$$
$$g_1 \leftarrow f_3 << 3$$

BLOCK H

$$b_7 \leftarrow \phi(b_6, b_0)$$
$$c_3 \leftarrow \phi(c_1, c_0)$$
$$f_4 \leftarrow \phi(f_3, f_0)$$
$$b_8 \leftarrow b_7 * c_2 \longleftrightarrow \text{redundant by DVN}$$
$$a_2 \leftarrow b_8 - a_1$$
$$g_2 \leftarrow f_4 + 1$$

References:

- I would like to thank Professor Zhijia Zao and TA Junqiao Qiu for their help in clarifying the doubts.

- https://courses.cs.washington.edu/courses/csep501/14sp/video/archive/html5/video.l