Exercise 1

针对第十二讲代码优化（2）P55 上流图，计算活跃变量数据流方程。

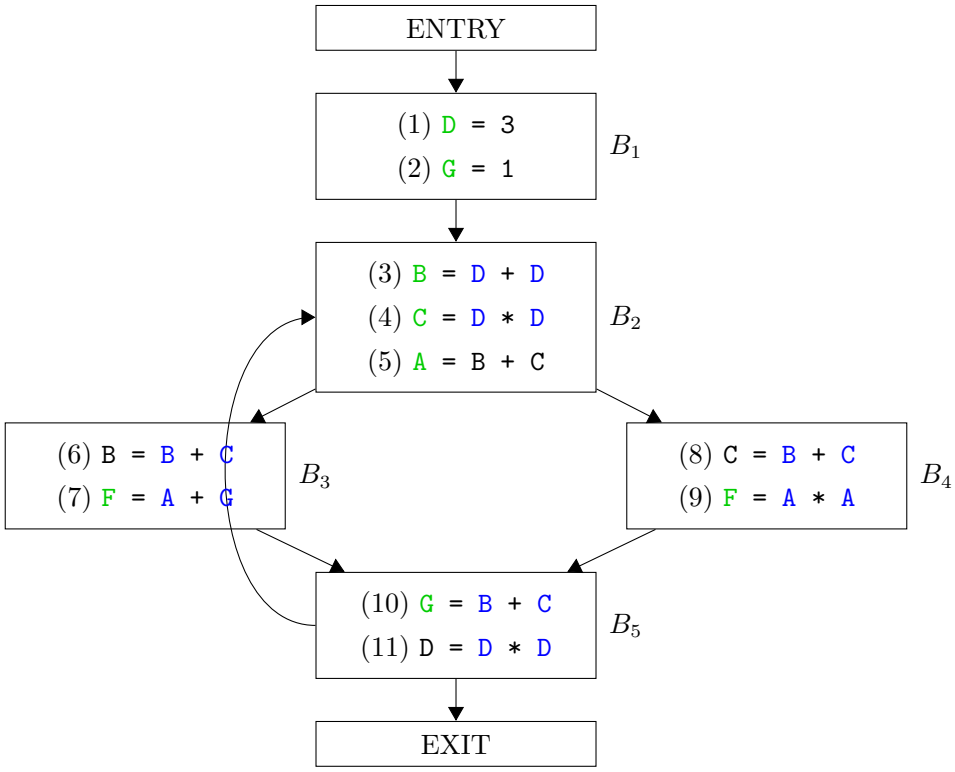

图 1: 第十二讲代码优化（2）P55 上流图

解 首先给出每个基本块的 *use* 和 *def* 集合

基本块	*use*	*def*
B_1	$use_1 = \{\}$	$def_1 = \{\texttt{D}, \texttt{G}\}$
B_2	$use_2 = \{\texttt{D}\}$	$def_2 = \{\texttt{A}, \texttt{B}, \texttt{C}\}$
B_3	$use_3 = \{\texttt{A}, \texttt{B}, \texttt{C}, \texttt{G}\}$	$def_3 = \{\texttt{F}\}$
B_4	$use_4 = \{\texttt{A}, \texttt{B}, \texttt{C}\}$	$def_4 = \{\texttt{F}\}$
B_5	$use_5 = \{\texttt{B}, \texttt{C}, \texttt{D}\}$	$def_5 = \{\texttt{G}\}$

初始值

$$\mathrm{IN}[B_1] = \mathrm{IN}[B_2] = \mathrm{IN}[B_3] = \mathrm{IN}[B_4] = \mathrm{IN}[B_5] = \varnothing$$
$$\mathrm{OUT}[B_5] = \varnothing$$

第一次迭代

$$\begin{aligned}
\mathrm{OUT}[B_5] &= \mathrm{OUT}[B_5] \cup \mathrm{IN}[B_2] && = \{\} \cup \{\} && = \{\} \\
\mathrm{IN}[B_5] &= use_5 \cup (\mathrm{OUT}[B_5] - def_5) && = \{\mathtt{B},\mathtt{C},\mathtt{D}\} \cup (\{\} - \{\mathtt{G}\}) && = \{\mathtt{B},\mathtt{C},\mathtt{D}\} \\
\mathrm{OUT}[B_4] &= \mathrm{OUT}[B_4] \cup \mathrm{IN}[B_5] && = \{\} \cup \{\mathtt{B},\mathtt{C},\mathtt{D}\} && = \{\mathtt{B},\mathtt{C},\mathtt{D}\} \\
\mathrm{IN}[B_4] &= use_4 \cup (\mathrm{OUT}[B_4] - def_4) && = \{\mathtt{A},\mathtt{B},\mathtt{C}\} \cup (\{\mathtt{B},\mathtt{C},\mathtt{D}\} - \{\mathtt{F}\}) && = \{\mathtt{A},\mathtt{B},\mathtt{C},\mathtt{D}\} \\
\mathrm{OUT}[B_3] &= \mathrm{OUT}[B_3] \cup \mathrm{IN}[B_5] && = \{\} \cup \{\mathtt{B},\mathtt{C},\mathtt{D}\} && = \{\mathtt{B},\mathtt{C},\mathtt{D}\} \\
\mathrm{IN}[B_3] &= use_3 \cup (\mathrm{OUT}[B_3] - def_3) && = \{\mathtt{A},\mathtt{B},\mathtt{C},\mathtt{G}\} \cup (\{\mathtt{B},\mathtt{C},\mathtt{D}\} - \{\mathtt{F}\}) && = \{\mathtt{A},\mathtt{B},\mathtt{C},\mathtt{D},\mathtt{G}\} \\
\mathrm{OUT}[B_2] &= \mathrm{OUT}[B_2] \cup \mathrm{IN}[B_3] \cup \mathrm{IN}[B_4] && = \{\} \cup \{\mathtt{A},\mathtt{B},\mathtt{C},\mathtt{D},\mathtt{G}\} \cup \{\mathtt{A},\mathtt{B},\mathtt{C},\mathtt{D}\} && = \{\mathtt{A},\mathtt{B},\mathtt{C},\mathtt{D},\mathtt{G}\} \\
\mathrm{IN}[B_2] &= use_2 \cup (\mathrm{OUT}[B_2] - def_2) && = \{\mathtt{D}\} \cup (\{\mathtt{A},\mathtt{B},\mathtt{C},\mathtt{D},\mathtt{G}\} - \{\mathtt{A},\mathtt{B},\mathtt{C}\}) && = \{\mathtt{D},\mathtt{G}\} \\
\mathrm{OUT}[B_1] &= \mathrm{OUT}[B_1] \cup \mathrm{IN}[B_2] && = \{\} \cup \{\mathtt{A},\mathtt{D},\mathtt{G}\} && = \{\mathtt{D},\mathtt{G}\} \\
\mathrm{IN}[B_1] &= use_1 \cup (\mathrm{OUT}[B_1] - def_1) && = \{\} \cup (\{\mathtt{D},\mathtt{G}\} - \{\mathtt{D},\mathtt{G}\}) && = \{\}
\end{aligned}$$

第二次迭代

$$\begin{aligned}
\mathrm{OUT}[B_5] &= \mathrm{OUT}[B_5] \cup \mathrm{IN}[B_2] && = \{\} \cup \{\mathtt{D},\mathtt{G}\} && = \{\mathtt{D},\mathtt{G}\} \\
\mathrm{IN}[B_5] &= use_5 \cup (\mathrm{OUT}[B_5] - def_5) && = \{\mathtt{B},\mathtt{C},\mathtt{D}\} \cup (\{\mathtt{D},\mathtt{G}\} - \{\mathtt{G}\}) && = \{\mathtt{B},\mathtt{C},\mathtt{D}\} \\
\mathrm{OUT}[B_4] &= \mathrm{OUT}[B_4] \cup \mathrm{IN}[B_5] && = \{\mathtt{B},\mathtt{C},\mathtt{D}\} \cup \{\mathtt{B},\mathtt{C},\mathtt{D}\} && = \{\mathtt{B},\mathtt{C},\mathtt{D}\} \\
\mathrm{IN}[B_4] &= use_4 \cup (\mathrm{OUT}[B_4] - def_4) && = \{\mathtt{A},\mathtt{B},\mathtt{C}\} \cup (\{\mathtt{B},\mathtt{C},\mathtt{D}\} - \{\mathtt{F}\}) && = \{\mathtt{A},\mathtt{B},\mathtt{C},\mathtt{D}\} \\
\mathrm{OUT}[B_3] &= \mathrm{OUT}[B_3] \cup \mathrm{IN}[B_5] && = \{\mathtt{B},\mathtt{C},\mathtt{D}\} \cup \{\mathtt{B},\mathtt{C},\mathtt{D}\} && = \{\mathtt{B},\mathtt{C},\mathtt{D}\} \\
\mathrm{IN}[B_3] &= use_3 \cup (\mathrm{OUT}[B_3] - def_3) && = \{\mathtt{A},\mathtt{B},\mathtt{C},\mathtt{G}\} \cup (\{\mathtt{B},\mathtt{C},\mathtt{D}\} - \{\mathtt{F}\}) && = \{\mathtt{A},\mathtt{B},\mathtt{C},\mathtt{D},\mathtt{G}\} \\
\mathrm{OUT}[B_2] &= \mathrm{OUT}[B_2] \cup \mathrm{IN}[B_3] \cup \mathrm{IN}[B_4] && = \{\mathtt{A},\mathtt{B},\mathtt{C},\mathtt{D},\mathtt{G}\} \cup \{\mathtt{A},\mathtt{B},\mathtt{C},\mathtt{D},\mathtt{G}\} \cup \{\mathtt{A},\mathtt{B},\mathtt{C},\mathtt{D}\} && = \{\mathtt{A},\mathtt{B},\mathtt{C},\mathtt{D},\mathtt{G}\} \\
\mathrm{IN}[B_2] &= use_2 \cup (\mathrm{OUT}[B_2] - def_2) && = \{\mathtt{D}\} \cup (\{\mathtt{A},\mathtt{B},\mathtt{C},\mathtt{D},\mathtt{G}\} - \{\mathtt{A},\mathtt{B},\mathtt{C}\}) && = \{\mathtt{D},\mathtt{G}\} \\
\mathrm{OUT}[B_1] &= \mathrm{OUT}[B_1] \cup \mathrm{IN}[B_2] && = \{\mathtt{D},\mathtt{G}\} \cup \{\mathtt{D},\mathtt{G}\} && = \{\mathtt{D},\mathtt{G}\} \\
\mathrm{IN}[B_1] &= use_1 \cup (\mathrm{OUT}[B_1] - def_1) && = \{\} \cup (\{\mathtt{D},\mathtt{G}\} - \{\mathtt{D},\mathtt{G}\}) && = \{\}
\end{aligned}$$

第三次迭代

$$
\begin{aligned}
\mathrm{OUT}[B_5] &= \mathrm{OUT}[B_5] \cup \mathrm{IN}[B_2] && = \{\mathtt{D},\mathtt{G}\} \cup \{\mathtt{D},\mathtt{G}\} && = \{\mathtt{D},\mathtt{G}\} \\
\mathrm{IN}[B_5] &= use_5 \cup (\mathrm{OUT}[B_5] - def_5) && = \{\mathtt{B},\mathtt{C},\mathtt{D}\} \cup (\{\mathtt{D},\mathtt{G}\} - \{\mathtt{G}\}) && = \{\mathtt{B},\mathtt{C},\mathtt{D}\} \\
\mathrm{OUT}[B_4] &= \mathrm{OUT}[B_4] \cup \mathrm{IN}[B_5] && = \{\mathtt{B},\mathtt{C},\mathtt{D}\} \cup \{\mathtt{B},\mathtt{C},\mathtt{D}\} && = \{\mathtt{B},\mathtt{C},\mathtt{D}\} \\
\mathrm{IN}[B_4] &= use_4 \cup (\mathrm{OUT}[B_4] - def_4) && = \{\mathtt{A},\mathtt{B},\mathtt{C}\} \cup (\{\mathtt{B},\mathtt{C},\mathtt{D}\} - \{\mathtt{F}\}) && = \{\mathtt{A},\mathtt{B},\mathtt{C},\mathtt{D}\} \\
\mathrm{OUT}[B_3] &= \mathrm{OUT}[B_3] \cup \mathrm{IN}[B_5] && = \{\mathtt{B},\mathtt{C},\mathtt{D}\} \cup \{\mathtt{B},\mathtt{C},\mathtt{D}\} && = \{\mathtt{B},\mathtt{C},\mathtt{D}\} \\
\mathrm{IN}[B_3] &= use_3 \cup (\mathrm{OUT}[B_3] - def_3) && = \{\mathtt{A},\mathtt{B},\mathtt{C},\mathtt{G}\} \cup (\{\mathtt{B},\mathtt{C},\mathtt{D}\} - \{\mathtt{F}\}) && = \{\mathtt{A},\mathtt{B},\mathtt{C},\mathtt{D},\mathtt{G}\} \\
\mathrm{OUT}[B_2] &= \mathrm{OUT}[B_2] \cup \mathrm{IN}[B_3] \cup \mathrm{IN}[B_4] && = \{\mathtt{A},\mathtt{B},\mathtt{C},\mathtt{D},\mathtt{G}\} \cup \{\mathtt{A},\mathtt{B},\mathtt{C},\mathtt{D},\mathtt{G}\} \cup \{\mathtt{A},\mathtt{B},\mathtt{C},\mathtt{D}\} && = \{\mathtt{A},\mathtt{B},\mathtt{C},\mathtt{D},\mathtt{G}\} \\
\mathrm{IN}[B_2] &= use_2 \cup (\mathrm{OUT}[B_2] - def_2) && = \{\mathtt{D}\} \cup (\{\mathtt{A},\mathtt{B},\mathtt{C},\mathtt{D},\mathtt{G}\} - \{\mathtt{A},\mathtt{B},\mathtt{C}\}) && = \{\mathtt{D},\mathtt{G}\} \\
\mathrm{OUT}[B_1] &= \mathrm{OUT}[B_1] \cup \mathrm{IN}[B_2] && = \{\mathtt{D},\mathtt{G}\} \cup \{\mathtt{D},\mathtt{G}\} && = \{\mathtt{D},\mathtt{G}\} \\
\mathrm{IN}[B_1] &= use_1 \cup (\mathrm{OUT}[B_1] - def_1) && = \{\} \cup (\{\mathtt{D},\mathtt{G}\} - \{\mathtt{D},\mathtt{G}\}) && = \{\}
\end{aligned}
$$

不再有 IN 值发生改变，迭代终止。

$$
\begin{aligned}
\mathrm{IN}[\mathrm{EXIT}] &= \varnothing \\
\mathrm{OUT}[B] &= \bigcup_{S\text{是}B\text{的一个后继}} \mathrm{IN}[S] \\
\mathrm{IN}[B] &= use_B \cup (\mathrm{OUT}[B] - def_B)
\end{aligned}
$$

```
1  IN[EXIT] = ∅
2  for 基本块B ≠ EXIT
3      IN[B] = ∅
4  while 某个 IN 值发生了改变
5      for 基本块B ≠ EXIT
6          OUT[B] = ⋃_{S是B的一个后继} IN[S]
7          IN[B] = use_B ∪ (OUT[B] − def_B)
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