CS 5130 Homework II

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1. Answer the following questions related to reaching definitions analysis for the CFG (a) Give the GEN and PRSV sets for each basic block

 $U = \{r1@1, r10@2, r2@3, r11@4, r3@5, r15@6, r4@7, r13@8, r5@9, r14@10, r6@12, r14@13, r4@15, r14@16, r14@16,$ $r1@17, r7@18, r15@19, r4@21, r11@22, r5@23, r15@24, r6@26, r10@27, r8@28, r11@29\}$

BB	GEN	PRSV
В0	r1@1,r10@2,r2@3,r11@4,r3@5	r15@6,r4@7,r13@8,r5@9,r14@10,r6@12,r14@13,r4@15,r14@16,
		r7@18, r15@19, r4@21, r5@23, r15@24, r6@26, r10@27, r8@28
B1	r15@6,r4@7,r13@8,r5@9,r14@10	r1@1,r10@2,r2@3,r11@4,r3@5,r6@12,
	113@0,14@1,113@0,13@9,114@10	r1@17,r7@18,r11@22,r6@26,r10@27,r8@28,r11@29
B2	r6@12,r14@13	$r1@1,r10@2,r2@3,r11@4,r3@5,r15@6,r4@7,r13@8,r5@9,\ r4@15$
DZ	10@12,114@13	r1@17,r7@18,r15@19,r4@21,r11@22,r5@23,r15@24,r10@27,r8@28,r11@29
ВЗ	r4@15,r14@16,r1@17,r7@18,r15@19	r10@2,r2@3,r3@5,r13@8,r5@9,r14@10,
Б3	14@15,114@10,11@17,17@16,115@15	r6@12,r14@13r5@23,r6@26,r10@27,r8@28
B4	r4@21,r11@22,r5@23,r15@24	r1@1,r10@2,r2@3,r3@5,r13@8,r14@10,r6@12,r14@13, r14@16,
D4	r4@21,r11@22,r3@23,r13@24	r1@17,r7@18,r6@26,r10@27,r8@28
B5	r6@26,r10@27,r8@28,r11@29	r1@1, r2@3, r3@5, r15@6, r4@7, r13@8, r5@9, r14@10, r14@13,
D0		r4@15,r14@16,r1@17,r7@18, r15@19,r4@21,r5@23,r15@24

(b)

Init.(iter.0)

 $IN(b) = \emptyset$, $OUT(b) = Gen(b) \cup (IN(b) \cap PRSV(b)) = Gen(b)$

BB	IN	OUT
В0	Ø	r1@1,r10@2,r2@3,r11@4,r3@5
B1	Ø	r15@6,r4@7,r13@8,r5@9,r14@10
B2	Ø	r6@12,r14@13
В3	Ø	r4@15,r14@16,r1@17,r7@18,r15@19
B4	Ø	r4@21,r11@22,r5@23,r15@24
B5	Ø	r6@26,r10@27,r8@28,r11@29

iter.1

$$\begin{split} & \text{IN(b)} = \bigcup_{p \in pred(b)} OUT(p) \\ & \text{OUT(b)} = \text{Gen(b)} \, \cup \, \left(\text{IN(b)} \cap \text{PRSV(b)} \right) = \text{Gen(b)} \end{split}$$

BB	IN	OUT
В0	Ø	r1@1,r10@2,r2@3,r11@4,r3@5
B1	r1@1, r10@2, r2@3, r11@4, r3@5, r4@21, r11@22, r5@23, r15@24	r1@1, r10@2, r2@3, r11@4, r3@5, r15@6, r4@7, r13@8, r5@9, r14@10, r11@22
B2	r1@1, r10@2, r2@3, r11@4, r3@5, r15@6, r4@7, r13@8, r5@9,	r1@1, r10@2, r2@3, r11@4, r3@5, r15@6, r4@7, r13@8, r5@9,
D2	r14@10, r4@15, r14@16, r1@17, r7@18, r15@19, r11@22	r6@12,r14@13,r11@22
ВЗ	r1@1, r10@2, r2@3, r11@4, r3@5, r15@6, r4@7, r13@8, r5@9,	r10@2,r2@3,r3@5,r13@8,r5@9,r6@12,
Бэ	r6@12,r14@13,r11@22	r14@13,r4@15,r14@16,r1@17,r7@18,r15@19
В4	r1@1, r10@2, r2@3, r11@4, r3@5, r15@6, r4@7, r13@8,	r1@1,r2@3,r3@5,r13@8,r14@10,
104	r5@9,r14@10,r6@12,r14@13,r11@22	r6@12,r14@13,r4@21,r11@22,r5@23,r15@24
B5	r1@1, r2@3, r3@5, r13@8, r14@10,	r1@1,r2@3,r3@5,r13@8,r14@10,r14@13,
р э	r6@12, r14@13, r4@21, r11@22, r5@23, r15@24	r4@21,r11@22,r5@23,r15@24,r6@26,r10@27,r8@28,r11@29

iter.2

$$\begin{split} & \text{IN(b)} = \bigcup_{p \in pred(b)} OUT(p) \\ & \text{OUT(b)} \text{=} \text{Gen(b)} \, \cup \, (\text{IN(b)} \cap \text{PRSV(b)}) = \text{Gen(b)} \end{split}$$

BB	IN	OUT
В0	Ø	r1@1,r10@2,r2@3,r11@4,r3@5
B1	r1@1, r10@2, r2@3, r11@4, r3@5, r13@8,	r1@1,r10@2,r2@3,r11@4,r3@5,r15@6,r4@7,r13@8,r5@9,
D1	r14@10, r6@12, r14@13, r4@21, r11@22, r5@23, r15@24	r14@10,r6@12,r11@22
B2	r1@1, r10@2, r2@3, r11@4, r3@5, r15@6, r4@7, r13@8, r5@9,	r1@1,r10@2,r2@3,r11@4,r3@5,r15@6,r4@7,r13@8,r5@9,
102	r14@10,r6@12,r14@13,r4@15,r14@16,r1@17,r7@18,r15@19,r11@22	r6@12,r14@13,r4@15,r1@17,r7@18,r15@19,r11@22
ВЗ	r1@1, r10@2, r2@3, r11@4, r3@5, r15@6, r4@7, r13@8, r5@9,	r10@2,r2@3,r3@5,r13@8,r5@9,r6@12,
Б3	${\tt r6@12,r14@13,r4@15,r1@17,r7@18,r15@19,r11@22}$	r14@13,r4@15,r14@16,r1@17,r7@18,r15@19
B4	$r1@1, r10@2, r2@3, r11@4, r3@5, r15@6, r4@7, r13@8, \ r5@9,$	r1@1,r10@2,r2@3,r3@5,r13@8,r14@10
D4	r14@10, r6@12, r14@13, r4@15, r1@17, r7@18, r15@19, r11@22	r6@12,r14@13,r1@17,r4@21,r11@22,r5@23,r15@24
B5	r1@1, r10@2, r2@3, r3@5, r13@8, r14@10	r1@1,r2@3,r3@5,r13@8,r4@10,r14@13,r1@17
БЭ	r6@12,r14@13,r1@17,r4@21,r11@22,r5@23,r15@24	r4@21,r5@23,r15@24,r6@26,r10@27,r8@28,r11@29

iter.3

$$\begin{split} & \text{IN(b)} = \bigcup_{p \in pred(b)} OUT(p) \\ & \text{OUT(b)} \text{=} \text{Gen(b)} \, \cup \, (\text{IN(b)} \cap \text{PRSV(b)}) = \text{Gen(b)} \end{split}$$

BB	IN	OUT
B0	\emptyset	r1@1,r10@2,r2@3,r11@4,r3@5
B1	r1@1, r10@2, r2@3, r11@4, r3@5, r13@8, r14@10,	$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$
D1	$r6@12,r14@13,r1@17\ r4@21,r11@22,r5@23,r15@24$	r14@10,r6@12,r1@17,r11@22
$_{\mathrm{B2}}$	r1@1, r10@2, r2@3, r11@4, r3@5, r15@6, r4@7, r13@8, r5@9,	
102	r14@10,r6@12,r14@13,r4@15,r14@16,r1@17,r7@18,r15@19,r11@22	r6@12,r14@13,r4@15,r1@17,r7@18,r15@19,r11@22
ВЗ	r1@1, r10@2, r2@3, r11@4, r3@5, r15@6, r4@7, r13@8, r5@9,	r10@2,r2@3,r3@5,r13@8,r5@9,r6@12,
D.5	r6@12,r14@13,r4@15,r1@17,r7@18,r15@19,r11@22	r14@13,r4@15,r14@16,r1@17,r7@18,r15@19
B4	r1@1, r10@2, r2@3, r11@4, r3@5, r15@6, r4@7, r13@8,	r1@1,r10@2,r2@3,r3@5,r13@8,
D4	r5@9,r6@12,r1@17,r11@22	r6@12,r1@17,r4@21,r11@22,r5@23,r15@24
B5	r1@1, r10@2, r2@3, r3@5, r13@8,	r1@1,r2@3,r3@5,r13@8,r1@17
Гр9	r6@12,r1@17,r4@21,r11@22,r5@23,r15@24	r4@21,r5@23,r15@24,r6@26,r10@27,r8@28,r11@29

iter.4

$$\begin{split} & \text{IN(b)} = \bigcup_{p \in pred(b)} OUT(p) \\ & \text{OUT(b)} \text{-}\text{Gen(b)} \, \cup \, (\text{IN(b)} \cap \text{PRSV(b)}) = \text{Gen(b)} \end{split}$$

BB	IN	OUT
В0	\emptyset	r1@1,r10@2,r2@3,r11@4,r3@5
B1	r1@1, r10@2, r2@3, r11@4, r3@5, r13@8,	r1@1, r10@2, r2@3, r11@4, r3@5, r15@6, r4@7, r13@8, r5@9,
D1	${\rm r} 6@12, {\rm r} 1@17 \ {\rm r} 4@21, {\rm r} 11@22, {\rm r} 5@23, {\rm r} 15@24$	r14@10,r6@12,r1@17,r11@22
B2	r1@1, r10@2, r2@3, r11@4, r3@5, r15@6, r4@7, r13@8, r5@9,	
152	r14@10,r6@12,r14@13,r4@15,r14@16,r1@17,r7@18,r15@19,r11@22	${\tt r6@12,r14@13,r4@15,r1@17,r7@18,r15@19,r11@22}$
ВЗ	r1@1, r10@2, r2@3, r11@4, r3@5, r15@6, r4@7, r13@8, r5@9,	r10@2, r2@3, r3@5, r13@8, r5@9, r6@12,
Бо	${\tt r6@12,r14@13,r4@15,r1@17,r7@18,r15@19,r11@22}$	r14@13,r4@15,r14@16,r1@17,r7@18,r15@19
B4	r1@1, r10@2, r2@3, r11@4, r3@5, r15@6, r4@7, r13@8,	r1@1,r10@2,r2@3,r3@5,r13@8,
104	r5@9,r6@12,r1@17,r11@22	r6@12,r1@17,r4@21,r11@22,r5@23,r15@24
B5	r1@1, r10@2, r2@3, r3@5, r13@8,	r1@1,r2@3,r3@5,r13@8,r1@17
Б9	r6@12, r1@17, r4@21, r11@22, r5@23, r15@24	r4@21,r5@23,r15@24,r6@26,r10@27,r8@28,r11@29

iter.5

No change

(c)

B0 $r1 \Rightarrow r1@1, r2 \Rightarrow r2@2$

 $B1 \ r3 \Rightarrow r3@5, r10 \Rightarrow r10@2, r11 \Rightarrow r11@4 or r11@22, r4 \Rightarrow r4@7, r13 \Rightarrow r13@8, r10 \Rightarrow r10@2, r5 \Rightarrow r5@9, r14 \Rightarrow r14@10 \Rightarrow r10@2, r4 \Rightarrow r4@7, r13 \Rightarrow r13@8, r10 \Rightarrow r10@2, r5 \Rightarrow r5@9, r14 \Rightarrow r14@10 \Rightarrow r10@2, r4 \Rightarrow r4@7, r13 \Rightarrow r13@8, r10 \Rightarrow r10@2, r5 \Rightarrow r5@9, r14 \Rightarrow r14@10 \Rightarrow r10@2, r4 \Rightarrow r4@7, r13 \Rightarrow r13@8, r10 \Rightarrow r10@2, r5 \Rightarrow r5@9, r14 \Rightarrow r14@10 \Rightarrow r10@2, r4 \Rightarrow r4@7, r13 \Rightarrow r13@8, r10 \Rightarrow r10@2, r5 \Rightarrow r5@9, r14 \Rightarrow r14@10 \Rightarrow r10@2, r4 \Rightarrow r4@7, r13 \Rightarrow r13@8, r10 \Rightarrow r10@2, r5 \Rightarrow r5@9, r14 \Rightarrow r14@10 \Rightarrow r10@2, r4 \Rightarrow r4@7, r13 \Rightarrow r13@8, r10 \Rightarrow r10@2, r5 \Rightarrow r5@9, r14 \Rightarrow r14@10 \Rightarrow r10@2, r4 \Rightarrow r4@7, r13 \Rightarrow r13@8, r10 \Rightarrow r10@2, r5 \Rightarrow r5@9, r14 \Rightarrow r14@10 \Rightarrow r10@2, r4 \Rightarrow r4@7, r13 \Rightarrow r13@8, r10 \Rightarrow r10@2, r5 \Rightarrow r5@9, r14 \Rightarrow r14@10 \Rightarrow r10@2, r4 \Rightarrow r4@7, r13 \Rightarrow r13@8, r10 \Rightarrow r10@2, r5 \Rightarrow r5@9, r14 \Rightarrow r14@10 \Rightarrow r10@2, r4 \Rightarrow r4@7, r13 \Rightarrow r13@8, r10 \Rightarrow r10@2, r10 \Rightarrow r10\%2, r10\%2, r10 \Rightarrow r10\%2, r1$ $\text{B2 } r11 \Rightarrow r11@4 or r11@22, r14 \Rightarrow r14@13, r6 \Rightarrow r6@12, r14 \Rightarrow r14@13 \text{ B3 } r10 \Rightarrow r10@2, r11 \Rightarrow r11@22 or r11@4, r4 \Rightarrow r4@15, r15 \Rightarrow r11@22 or r11@4, r4 \Rightarrow r4@15, r15 \Rightarrow r11@20 or r11@4, r4 \Rightarrow r4@15, r15 \Rightarrow r11@4, r15 \Rightarrow r15 \Rightarrow r11@4, r15 \Rightarrow r15 \Rightarrow$ $r5@23, r15 \Rightarrow r15@24 \text{ B5 } r11 \Rightarrow r11@22, r14 \Rightarrow r14@13, r6 \Rightarrow r6@26, r10 \Rightarrow r10@27, r14 \Rightarrow r14@13, r8 \Rightarrow r8@28 \Rightarrow r15@24 \Rightarrow r14@13, r8 \Rightarrow r8@28 \Rightarrow r15@24 \Rightarrow r14@13, r8 \Rightarrow r8@28 \Rightarrow r15@24 \Rightarrow r14@13, r8 \Rightarrow r8@28 \Rightarrow r8@28$

2. Answer the following questions related to liveness analysis analysis for the CFG (a) Give the GEN and PRSV sets for each basic block

 $U = \{r1, r2, r3, r4, r5, r6, r7, r8, r10, r11, r13, r14, r15\}$

BB	GEN	PRSV
B5	r11,r14	r1,r2,r3,r4,r5,r7,r13,r14,r15
	/	
B4	r10,r11,r13	r1,r2,r3,r6,r7,r8,r10,r13,r14
B3	r10,r11,r15	r2,r3,r5,r6,r8,r10,r13,r14
B2	r11,r14	r1,r2,r3,r4,r5,r7,r8,r10,r11,r13,r15
B1	r3,r10,r11	r1,r2,r3,r6,r7,r8,r10,r11,r15
В0	Ø	r4,r5,r6,r7,r8,r13,r14,r15

(b) Liveness is a backwards problem, That is because to verify a node is liveness or not we, so we need to take postOrder to analysis it.

(c) Init.(iter.0) $OUT(b) = \emptyset$, $IN(b) = Gen(b) \cup (OUT(b) \cap PRSV(b)) = Gen(b)$

BB	OUT	IN
В5	Ø	r11,r14
B4	Ø	r10,r11,r13
В3	Ø	r10,r11,r15
B2	Ø	r11,r14
B1	Ø	r3,r19,r11
В0	Ø	Ø

iter.1

 $\begin{aligned} & \text{OUT(b)} = \bigcup_{s \in succs(b)} IN(s) \\ & \text{IN(b)} \\ & = \text{Gen(b)} \cup (\text{OUT(b)} \cap \text{PRSV(b)}) = \text{Gen(b)} \end{aligned}$

BB	OUT	IN
B5	Ø	r11,r14
B4	r3,r11,r14,r19	r3,r10,r11,r13,r14
В3	r11,r14	r10,r11,r14,r15
B2	r3,r10,r11,r13,r14,r15	r3,r10,r11,r13,r14,r15
B1	r3,r10,r11,r13,r14,r15	r3,r10,r11,r15
В0	r3,r10,r11,r15	r15

iter.2

 $\begin{array}{l} \text{OUT(b)} = \bigcup_{s \in succs(b)} IN(s) \\ \text{IN(b)} = \text{Gen(b)} \cup \left(\text{OUT(b)} \cap \text{PRSV(b)} \right) = \text{Gen(b)} \end{array}$

BB	OUT	IN
B5	Ø	r11,r14
B4	r3,r10,r11,r14,r15	r3,r10,r11,r14
В3	r3,r10,r11,r13,r14,r15	r3,r10,r11,r13,r14,r15
B2	r3,r10,r11,r13,r14,r15	r3,r10,r11,r13,r14,r15
B1	r3,r10,r11,r13,r14,r15	r3,r10,r11,r15
В0	r3,r10,r11,r15	r15

iter.4

 $\begin{aligned} & \text{OUT(b)} = \bigcup_{s \in succs(b)} IN(s) \\ & \text{IN(b)} \\ & = \text{Gen(b)} \cup (\text{OUT(b)} \cap \text{PRSV(b)}) = \text{Gen(b)} \end{aligned}$

BB	OUT	IN
B5	Ø	r11,r14
B4	r3,r10,r11,r14,r15	r3,r10,r11,r14
В3	r3,r10,r11,r13,r14,r15	r3,r10,r11,r13,r14,r15
B2	r3,r10,r11,r13,r14,r15	r3,r10,r11,r13,r14,r15
B1	r3,r10,r11,r13,r14,r15	r3,r10,r11,r15
В0	r3,r10,r11,r15	r15