Question 1.

(a)

Identities: VN3 = VN2 × VN4
VN5 = VN1 + VN3
VN7 = VN6 + VN3
VN10 = VN8 × VN9
VN12 = VN2 + VN11

Changed/added entries underlined in red

Defs shown in magenta

Value numbers to constants mapping in orange

localaddr vr6, $160
VN1 → {vr6→VN1}, {}

muli vr7, vr0, $8
VN3 → {vr6→VN1, vr0→VN2, vr7→VN3}, {VN4→8}

addi vr8, vr6, vr7
VN5 → {vr6→VN1, vr0→VN2, vr7→VN3, vr8→VN5}, {VN4→8}

localaddr vr9, $0
VN6 → {vr6→VN1, vr0→VN2, vr7→VN3, vr8→VN5, vr9→VN6}, {VN4→8}

muli vr10, vr0, $8
VN3 → {vr6→VN1, vr0→VN2, vr7→VN3, vr8→VN5, vr9→VN6, vr10→VN3}, {VN4→8}

addi vr11, vr9, vr10
VN7 → {vr6→VN1, vr0→VN2, vr7→VN3, vr8→VN5, vr9→VN6, vr10→VN3, vr11→VN7}, {VN4→8}

ldci vr12, $10
VN8 → {vr6→VN1, vr0→VN2, vr7→VN3, vr8→VN5, vr9→VN6, vr10→VN3, vr11→VN7, vr12→VN8}, {VN4→8, VN8→10}

ldi vr13, (vr11)
VN9 → {vr6→VN1, vr0→VN2, vr7→VN3, vr8→VN5, vr9→VN6, vr10→VN3, vr11→VN7, vr12→VN8, vr13→VN9}, {VN4→8, VN8→10}

muli vr14, vr13, vr12
VN10 → {vr6→VN1, vr0→VN2, vr7→VN3, vr8→VN5, vr9→VN6, vr10→VN3, vr11→VN7, vr12→VN8, vr13→VN9, vr14→VN10}, {VN4→8, VN8→10}

sti (vr8), vr14
→ [unchanged]

ldci vr2, $1
VN11 → {vr6→VN1, vr0→VN2, vr7→VN3, vr8→VN5, vr9→VN6, vr10→VN3, vr11→VN7, vr12→VN8, vr13→VN9, vr14→VN10, vr2→VN11}, {VN4→8, VN8→10, VN11→1}

addi vr3, vr0, vr2
VN12 → {vr6→VN1, vr0→VN2, vr7→VN3, vr8→VN5, vr9→VN6, vr10→VN3, vr11→VN7, vr12→VN8, vr13→VN9, vr14→VN10, vr2→VN11, vr3→VN12}, {VN4→8, VN8→10, VN11→1}

mov vr0, vr3
VN12 → {vr6→VN1, vr0→VN12, vr7→VN3, vr8→VN5, vr9→VN6, vr10→VN3, vr11→VN7, vr12→VN8, vr13→VN9, vr14→VN10, vr2→VN11, vr3→VN12}, {VN4→8, VN8→10, VN11→1}

(b) The instruction $\boxed{\texttt{muli vr10, vr0, \$8}}$ can be replaced with $\boxed{\texttt{mov vr10, vr7}}$. This substitution is possible because `vr7` contains VN3, which is the product of VN2 (the value in `vr0`) and VN4 (the constant value 8.)

Question 2.

spills/restores in orange

underlined in magenta: vr will not be used again, MR can be reclaimed

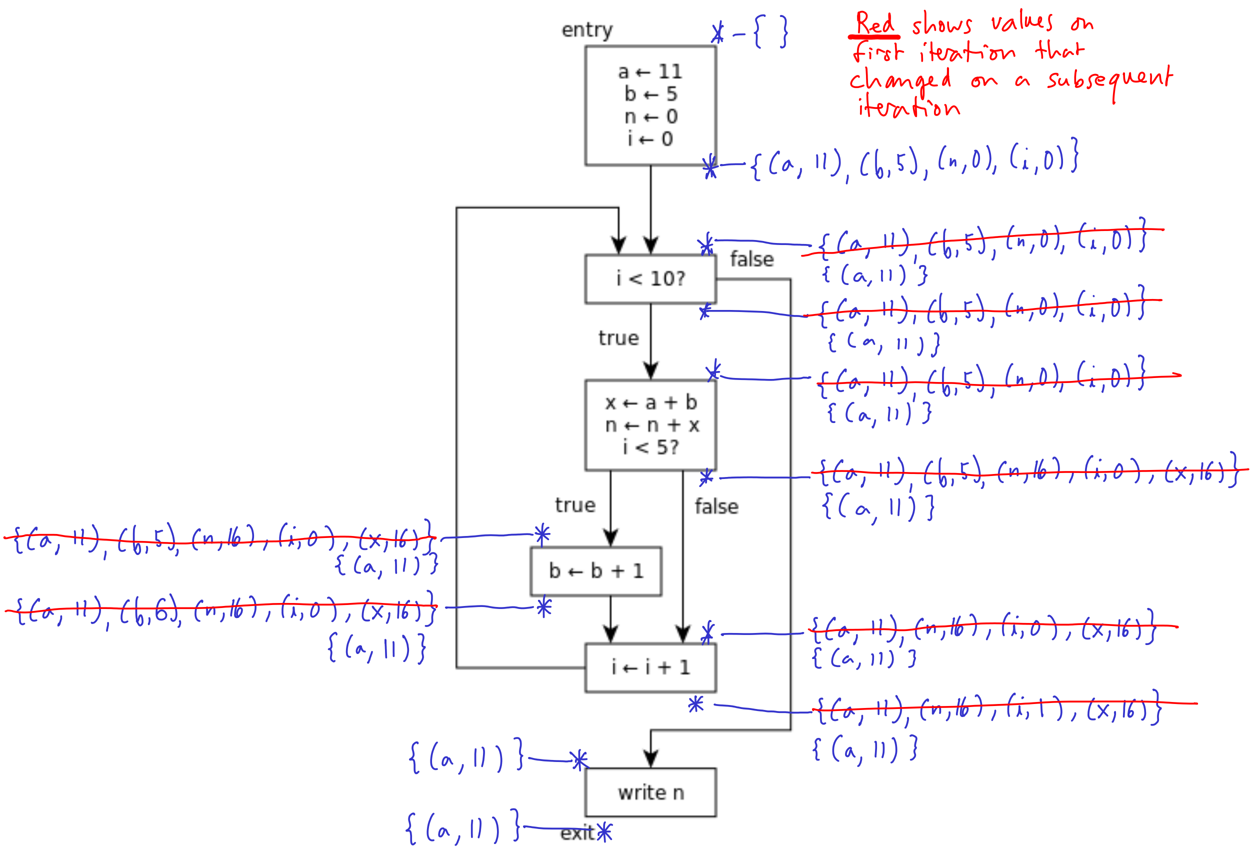
localaddr vr19, $4000000	vr19 → MR0
muli vr20, vr0, $4000	vr19 → MR0, vr20 → MR1
addi vr21, vr19, vr20	vr19 → MR0, vr20 → MR1, vr21 → MR2
muli vr22, vr1, $8	vr21 → MR2, vr22 → MR0
addi vr23, vr21, vr22	vr21 → MR2, vr22 → MR0, vr23 → MR1
ldi vr4, (vr23)	vr23 → MR1, vr4 → MR0
localaddr vr24, $2000000	vr4 → MR0, vr24 → MR1
muli vr25, vr2, $4000	vr4 → MR0, vr24 → MR1, vr25 → MR2
* spill vr4/MR0, loc 1	
addi vr26, vr24, vr25	vr24 → MR1, vr25 → MR2, vr26 → MR0
muli vr27, vr1, $8	vr26 → MR0, vr27 → MR1
addi vr28, vr26, vr27	vr26 → MR0, vr27 → MR1, vr28 → MR2
ldi vr29, (vr28)	vr28 → MR2, vr29 → MR0
muli vr30, vr3, vr29	vr29 → MR0, vr30 → MR1
* restore vr4, MR0, loc 1	
addi vr31, vr4, vr30	vr30 → MR1, vr4 → MR0, vr31 → MR2
mov vr4, vr31	vr31 → MR2, vr4 → MR0
localaddr vr32, $4000000	vr4 → MR0, vr32 → MR1
muli vr33, vr0, $4000	vr4 → MR0, vr32 → MR1, vr33 → MR2
* spill vr4/MR0, loc 1	
addi vr34, vr32, vr33	vr32 → MR1, vr33 → MR2, vr34 → MR0
muli vr35, vr1, $8	vr34 → MR0, vr35 → MR1
addi vr36, vr34, vr35	vr34 → MR0, vr35 → MR1, vr36 → MR2
* restore vr4, MR0, loc 1	
sti (vr36), vr4	vr36 → MR2, vr4 → MR0
ldci vr5, $1	vr5 → MR0
addi vr6, vr1, vr5	vr5 → MR0, vr6 → MR1
mov vr1, vr6	vr6 → MR1

Question 3.

(a.1) Combining $\boxed{\{(p, 2), (q, 3), (r, 5)\}}$ and $\boxed{\{(p, 2), (q, 4)\}}$ yields $\boxed{\{(p, 2)\}}$. I.e., only "p" has a specific known constant value. The variable "q" could be either 3 or 4, and "r" could be either 5 or some unknown value.

(a.2) The only members retained in the result set are the ones where the same variable is mapped to the same constant value. All other members are discarded. So, this is a *must* analysis.

(b)



Due to the loop, the values of variables "b", "n", and "i" change, while the value of "b" remains constant.

Question 4 (628 only).

When dataflow values are combined, variables which have different values can be downgraded to special "positive" and "negative" values, if the original values were both positive or both negative.

For example, the dataflow values $\boxed{\{(a, 1), (b, 2), (c, -3), (d, 4)\}}$ and $\boxed{\{(a, 1), (b, 5), (c, -6), (d, -7)\}}$ could be combined to produce the value $\boxed{\{(a, 1), (b, \text{positive}), (c, \text{negative})\}}$.

When modeling the effect of instructions in a basic block, the analysis must make conservative assumptions. For example, if the instruction $\boxed{n \leftarrow n + 1}$ is modeled, and the variable "n" currently has the value "positive", the analysis should remove the entry for "n", because integer overflow might cause "n" to become negative.