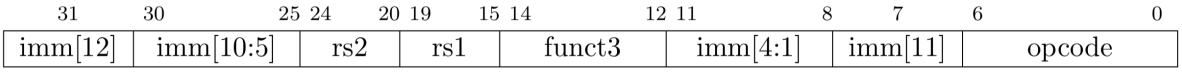
►Solution◄

Question 1: (0 points)
Bank of Questions

Binary Representation of `jal` and Branches (V05)

For the RISC-V code given in Figure 1, notice the `bne` and `jal` instructions at the addresses `0x0040 0010` and `0x0040 0020` respectively. What are the hexadecimal representations of these instructions? To solve this problem, you need to recall that registers `t3` and `zero` are mapped to register number 28 and 0, respectively. Also, you need to recall the formats and effects of branch and jump instructions. They are shown below.

Question 2: (10 points)
Branch Instruction




```
bne rs, rt, imm <==> if(rs != rt)   PC <-- PC + {imm,1b'0}
                     else           PC <-- PC + 4
```

The opcode of `bne` instruction is `1100011` and the func3 is `001`.

Solution: When the processor is executing the `bne` instruction, the PC is at `0x0040 0010`. The target of the branch, i.e., `L2`, is 8 bytes away from this instruction. Therefore, the immediate value that needs to be added to the PC is 8. Remember that the instruction binary representation does not contain a value for the least-significant (bit zero) of the immediate

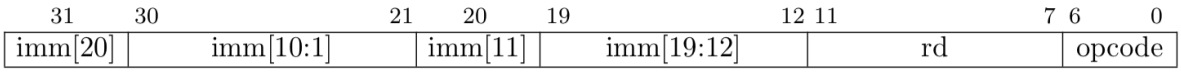
Thus, for the `bne` instruction, we have the values of each field as follows:

$$\texttt{opcode} = \texttt{1100011}$$
$$\texttt{func3} = \texttt{001}$$
$$\texttt{rs1} = \texttt{11100}$$
$$\texttt{rs2} = \texttt{00000}$$
$$\texttt{imm[12:1]} = \texttt{000000000100} = \texttt{0 0 000000 0100}$$

Therefore, the binary representation of the `bne` in the given RISC-V program is: `0000 0000 0000 1110 0001 0100 0110 0011`.

The hexadecimal representation is: `0x 000E 1463`.

Question 3: (10 points)
Jump and Link Instruction




```
jal rd, imm <==> rd <-- PC + 4
                 PC <-- PC + {imm,1b'0}
```

The opcode of `jal` instruction is `1101111`.

Solution: When the processor is executing the `jal` instruction, the PC is at `0x0040 0020`. The target of the jump, i.e., `L1`, is -24 bytes away from this instruction. While computing the target address of a jump, the processor internally left-shifts the immediate specified in the jump instruction by one bit. Therefore, the immediate that we must specify in the `jal` instruction should be $-24/2 = -12$.

Thus, for the `jal` instruction above, we have values of each field as follows:

$$\texttt{opcode} = \texttt{1101111}$$
$$\texttt{rd} = \texttt{00000}$$
$$\texttt{imm[20:1]} = \texttt{11111111111111110100}$$

Therefore, the binary representation of the `jal` instruction in the above RISC-V program is: `1111 1110 1001 1111 1111 0000 0110 1111`.

The hexadecimal representation is: `0x FE9F F06F`.

```
1   0x0040 0000    mysteryProc:  addi  t1, zero, 32
2   0x0040 0004                  sll   s0, s0, t1
3   0x0040 0008             L1:  add   t2, a0, zero
4   0x0040 000C                  lbu   t3, 0(t2)
5   0x0040 0010                  bne   t3, zero, L2
6   0x0040 0014                  jal   zero, L3
7   0x0040 0018             L2:  addi  a0, a0, 1
8   0x0040 001C                  addi  s0, s0, 1
9   0x0040 0020                  jal   zero, L1
10  0x0040 0024             L3:  add   a0, zero, s0
11  0x0040 0028                  jalr  zero, ra, 0
```

Figure 1: Mystery code procedure