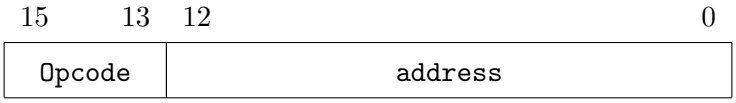
Question 3 (20 points):

You are participating in the Computing Science Industrial Internship Program and your placement is with *Tiny Inc.*, a company that produces *TinyProc* — a new processor developed for the automobile industry. All instructions in *TinyProc* have 16 bits. *TinyProc* also works with 16-bit addresses. The format of a jump instruction in *TinyProc* is as shown below:



where the address of the target of a jump instruction is computed using the same mechanism used in the MIPS processor with the adjustments necessary for it to work with a 16-bit address: first the Program Counter (PC) is incremented by **two**, then the **two** most-significant bits of the PC are concatenated with the thirteen bits of the address field from the instruction shifted to the left by **one**. The OpCode for a jump instruction in *TinyProc* is `100`. Based on this information, answer the following questions:

1. (**5 points**) Assume that a *TinyProc* instruction is at memory address `0xFF00` and that its target is at address `0xC0A8`, What is the binary representation, expressed in hexadecimal of this instruction?

Target PC: 0xC0A8 =	1100	0000	1010	1000
14 least-significant bits of target =	00	0000	1010	1000
shifted right by one =	0	0000	0101	0100
Concatenated with jump opcode =	1000	0000	0101	0100
Expressed in Hexadecimal =		**0x8054**		

2. (**5 points**) Assume that a *TinyProc* jump instruction is at address 0xBFFE. What is the farthest jump forward and the farthest jump backward that this instruction could execute? In other words, what is the lowest address to which this instruction could jump and what is the highest address to which this instruction could jump — express the lowest and highest target addresses in hexadecimal?

PC: 0xBFFE =	1011	1111	1111	1110
PC + 2 =	1100	0000	0000	0000
lowest target =	1100	0000	0000	0000
lowest target =		**0xC000**		
highest target =	1111	1111	1111	1110
highest target =		**0xFFFE**		

3. (**5 points**) For the jump instruction in question 1.b above, what is the binary format, expressed in hexadecimal for the jump instructions that will jump to the lowest and to the highest targets?

lowest target =	1100	0000	0000	0000
14 least-significant bits of lowest target =	00	0000	0000	0000
shifted right by one =	0	0000	0000	0000
with Opcode =	1000	0000	0000	0000
highest target jump binary format =		**0x8000**		
highest target =	1111	1111	1111	1110
14 least-significant bits of highest target =	11	1111	1111	1110
shifted right by one =	1	1111	1111	1111
with Opcode =	1001	1111	1111	1111
highest target jump binary format =		**0x9FFF**		

4. (**5 points**) The *range* of a jump instruction is the address distance between the target of the jump instruction and the jump instruction itself. For example if a jump instruction is at the address 0x0010 and the target is at address 0x0030, then the range of this branch instruction is $0x0020 = 32_{10}$. Assume that a jump instruction is at address `0xBF00`. What is the maximum range for this jump instruction, expressed as a decimal number, in *TinyProc*?

PC: 0xBF00 =	1011	1111	0000	0000
lowest target =	1000	0000	0000	0000
lowest target range =	|lowest target - PC|			
lowest target range =	0011	1111	0000	0000
lowest target range =	$2^{14} - 2^8 = 16 \times 1024 - 256$			
lowest target range =	**16128 instructions**			
highest target =	1011	1111	1111	1110
highest target range =	0000	0000	1111	1110
highest target range =	$2^8 - 2^1 = 256 - 2$			
highest target range =	**254 instructions**			

Therefore the maximum range for this *TinyProc* jump instruction is **16128 instructions**.