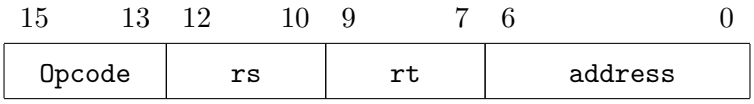
Question 1 (20 points):

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 branch instruction in *TinyProc* is as shown below:



Where `rs` and `rt` specify the source and target registers for the branch instruction, respectively. The address of the target of a branch instruction is computed using the same mechanism used in the MIPS processor, but the increment of the PC and the shift left have to be adjusted for a 16-bit address machine: first the Program Counter (PC) is incremented by **two**, then the bitfield `address` of the branch instruction is shifted left **by one**, sign-extended to sixteen bits, and added to the incremented PC. Based on this information, answer the following questions:

1. (**5 points**) What is the binary representation of the `address` field of a branch instruction that results in the largest jump backward and on the largest jump forward in *TinyProc*?

   `address` of branch for largest jump backward: 100 0000

   `address` of branch for largest jump forward: 011 1111

2. (**5 points**) The *range* of a branch instruction is the address distance between the target of a branch instruction and the branch instruction itself. For example if a branch instruction is at the address 0x0010 and the target is at address is at 0x0020, then the range of this branch instruction is $0x0010 = 16_{10}$. What is the maximum range of a branch instruction, expressed as a decimal number in *TinyProc*?

$$
\begin{aligned}
range &= |PC - FartestTarget| \\
FartestTargetBack &= PC + 2 + 0xFF80 \\
rangeBack &= |PC - (PC + 0xFF82)| \\
rangeBack &= 0xFF82 = 1111\ 1111\ 1000\ 0010 \\
rangeBack &= 0000\ 0000\ 0111\ 1110 = 2^7 - 2^1 = 128 - 2 = 126 \\
FartestTargetForward &= PC + 2 + 0x007E \\
rangeForward &= |PC - (PC + 0x0080)| = 0x0080 = 2^7 = 128\ instructions
\end{aligned}
$$

   Therefore the maximum range for a branch instruction is **128 instructions**.

3. (**5 points**) How many registers does *TinyProc* have? Each register field has three bits, therefore there are eight possible combinations for this field: 000, 001, 010, 011, 100, 101, 110 and 111. Thus *TinyProc* has **8** registers.

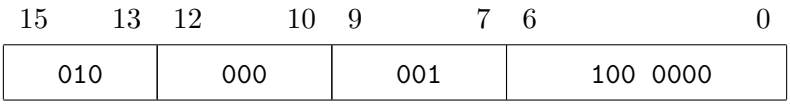
4. (**5 points**) The instruction "`beq $0, $1, SKIP`" branches to the instruction at the label `SKIP` if the value in register `$0` and in register `$1` are the same. In *TinyProc* the `Opcode` for a `beq` instruction is `010`. Assume that this instruction is at address `0xFC00` and that the label `SKIP` is at address `0xFB82`. What is the binary representation of this instruction expressed in hexadecimal?

$$\begin{aligned} (PC+2) + dist &= target \\ dist &= target - (PC+2) \\ dist &= target + (-(PC+2)) \end{aligned}$$

(PC+2): 0xFC02 =	1111	1100	0000	0010
/(PC+2) =	0000	0011	1111	1101
-(PC+2) =	0000	0011	1111	1110
target: 0xFB82 =	1111	1011	1000	0010
dist = target + (-(PC+2)) =	1111	1111	1000	0000
dist >> 1 =	1111	1111	1100	0000

Therefore the `address` field for the instruction is `100 0000`

The rest of the instruction format is:



010 000 001 100 0000 = 0100 0000 1100 0000 = **0x40C0**