CS61C Spring 2025 — Precheck: Floating Point, RISC-V — Discussion 3

1 Discussion Pre-Check

1.1 The idea of floating point is to use the ability to move the radix (decimal) point wherever to represent a large range of real numbers as exact as possible.

True. Floating point:
- Provides support for a wide range of values. (Both very small and very large)
- Helps programmers deal with errors in real arithmetic because floating point can represent `+∞`, `-∞`, `NaN` (Not a Number)
- Keeps high precision. Recall that precision is a count of the number of bits in a computer word used to represent a value. IEEE 754 allocates a majority of bits for the significand, allowing for the use of a combination of negative powers of two to represent fractions.

1.2 Floating Point and Two's Complement can represent the same total amount of numbers (any reals, integer, etc.) given the same number of bits.

False. Floating Point can represent infinities as well as NaNs, so the total amount of representable numbers is lower than Two's Complement, where every bit combination maps to a unique integer value.

1.3 The distance between floating point numbers increases as the absolute value of the numbers increase.

True. The uneven spacing is due to the exponent representation of floating point numbers. There are a fixed number of bits in the significand. In IEEE 32-bit storage there are 23 bits for the significand, which means the LSB represents `2^{-23}` times 2 to the exponent. For example, if the exponent is zero (after allowing for the offset) the difference between two neighboring floats will be `2^{-23}`. If the exponent is 8, the difference between two neighboring floats will be `2^{-15}` because the mantissa is multiplied by `2^{8}`. Limited precision makes binary floating-point numbers discontinuous; there are gaps between them.

1.4 Floating Point addition is associative.

False. Because of rounding errors, you can find Big and Small numbers such that:
`(Small + Big) + Big != Small + (Big + Big)`

FP approximates results because it only has 23 bits for the significand.

1.5 Let `a0` point to the start of an array `x`. `lw s0, 4(a0)` will always load `x[1]` into `s0`.

False. This only holds for data types that are four bytes wide, like `int` or `float`. For data-types like `char` that are only one byte wide, `4(a0)` is too large of an offset to return the element at index 1, and will instead return a `char` further down the array (or some other data beyond the array, depending on the array length).

1.6 Assuming no compiler or operating system protections, it is possible to have the code jump to data stored at `0(a0)` (offset 0 from the value in register `a0`) and execute instructions from there.

True. If your compiler/OS allows it (some do not, for security reasons), it is possible for your code to jump to and execute instructions passed into the program via an array. Conversely, it's also possible for your code to treat itself as normal data (search up self-modifying code if you want to see more details).

1.7 `jalr` is a shorthand expression for a `jal` that jumps to the specified label and does not store a return address anywhere.

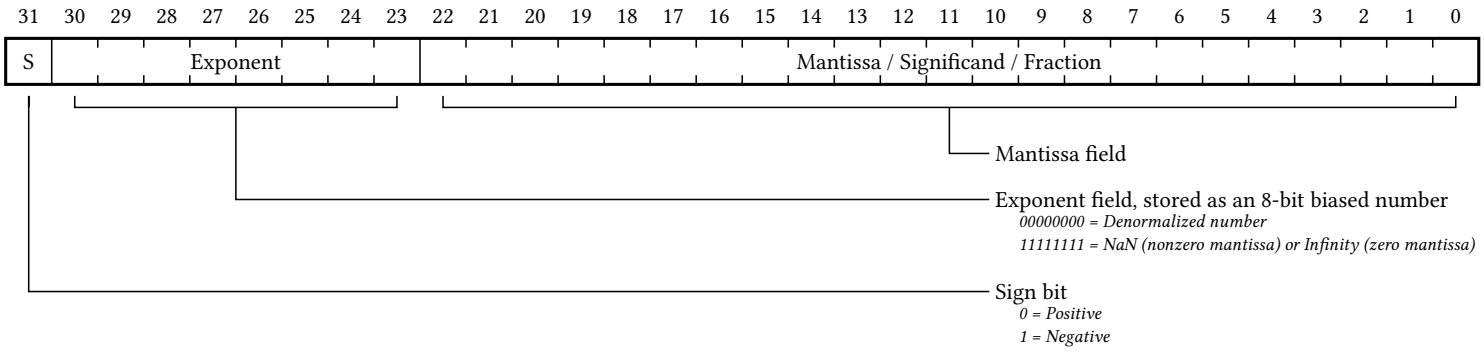
False. `jalr` is used to return to the memory address specified in the second argument. Keep in mind that `jal` jumps to a label (which is translated into an immediate by the assembler), whereas `jalr` jumps to an address stored in a register, which is set at runtime. Related, `j label` is a pseudo-instruction for `jal x0, label` (they do the same thing).

2 Floating Point

The IEEE 754 standard defines a binary representation for floating point values using three fields.

- The *sign* determines the sign of the number (0 for positive, 1 for negative).
- The *exponent* is in **biased notation**. For instance, the bias is −127, which comes from $-(2^{\{8-1\}}-1)$ for single-precision floating point numbers.
- The *significand* (or *mantissa*) is akin to unsigned integers but used to store a fraction instead of an integer and refers to the bits to the right of the leading "`1`" when normalized. For example, the significand of `1.010011` is `010011`.

The table below shows the bit breakdown for the single-precision (32-bit) representation. The leftmost bit is the MSB, and the rightmost bit is the LSB.



For normalized floats:

$$\textbf{Value} = (-1)^{\text{Sign}} \times 2^{\text{Exp+Bias}} \times 1.\text{Significand}_2)$$

For denormalized floats:

$$\textbf{Value} = (-1)^{\text{Sign}} \times 2^{\text{Exp+Bias+1}} \times 0.\text{Significand}_2)$$

Exponent (Pre-bias)	Significand	Meaning
0	Anything	Denorm
1-254	Anything	Normal
255	0	± Infinity
255	Nonzero	NaN

Note that in the above table, our exponent has values from `0` to `255`. When translating between binary and decimal floating point values, we must remember that there is a bias for the exponent.

3 RISC-V Instructions

RISC-V is an assembly language composed of simple instructions that each perform a single task such as addition of two numbers or storing data to memory. Below is a comparison between RISC-V code and its equivalent C code:

```
// x in s0, &y in s1
addi s0, x0, 5          int x = 5;
sw s0, 0(s1)            y[0] = x;
mul t0, s0, s0
sw t0, 4(s1)            y[1] = x * x;
```

For your reference, here are some of the basic instructions for arithmetic/bitwise operations and memory access, which can also be found on the 61C Reference Card.

The below are abbreviations that will be used in the table:

- `rs1`: Argument register 1
- `rs2`: Argument register 2
- `rd`: Destination register
- `imm`: Immediate value (integer literal constant)
- `R[register]`: Value contained in `register`
- `inst`: One of the instructions in the table

Register-to-register operations (R-type): `inst rd rs1 rs2`	
`add`	Adds `R[rs1]` and `R[rs2]` and stores the result in `rd`
`xor`	Exclusive ORs `R[rs1]` and `R[rs2]` and stores the result in `rd`
`mul`	Multiplies `R[rs1]` by `R[rs2]` and stores the result in `rd`

Register-to-register operations (R-type): `inst rd rs1 rs2`	
`sll`	Logical left shifts `R[rs1]` by `R[rs2]` and stores the result in `rd`
`srl`	Logical right shifts `R[rs1]` by `R[rs2]` and stores the result in `rd`
`sra`	Arithmetic right shifts `R[rs1]` by `R[rs2]` and stores the result in `rd`
`slt(u)`	If `R[rs1] < R[rs2]`, puts 1 in `rd`, else puts 0 (`u` compares unsigned)

Memory operations	
`sw rs2 rs1(imm)`	Stores `R[rs2]` *to* the address `R[rs1] + imm` in memory
`lw rd rs1(imm)`	Loads address `R[rs1] + imm` *from* memory into `rs2`

Branch operations (B-type): `inst rs1 rs2 label`	
`bne`	If `rs1 != rs2`, jump to `label`
`beq`	If `rs1 == rs2`, jump to `label`

Jump operations (J-type): `inst rd label`	
`jal`	Stores the next instruction's address into `rd` and jumps to `label`

A RISC-V "immediate" is any numeric constant. For example, `addi t0, t0, 20`, `sw a4, -8(sp)`, and `lw a1, 0x44(t2)` have immediates `20`, `-8`, and `0x44` respectively. Note that the size (maximum number of bits) of an immediate in any given instruction depends on what type of instruction it is (more on this soon!).

You may also see that there is an "i" at the end of certain instructions, such as `addi`, `slli`, etc. This means that `rs2` becomes an "immediate" or an integer instead of using a register. There are immediates in instructions which use an offset such as `sw` and `lw`. When coding in RISC-V, use the 61C reference card for the details of each instruction (the reference card is your friend)!