

# CS 367 Project 2 – Spring 2023:

## TinySF Software Floating-Point Library

### Due: Friday, March 3, 11:59pm

This is to be an individual effort. No partners. No Internet code/collaboration.  
Protect your code from anyone accessing it. Do not post code on public repositories.  
No late work allowed after 48 hours; each day late automatically uses one of your tokens.

Core Topics: Floating Point, Bitwise Operators, C Programming Design (Helper Functions)

## 1. Project Overview

The Zeus User Operations Notary (**ZUON**) Programming Language is a python-like interpreted programming language designed to run on an **embedded system** without any hardware floating-point support. Many such embedded systems typically do not have support for floats in hardware. You won't have to worry about any of this, of course, but it means that you won't be able to use any normal floats or doubles. **You may not use any C float or double types.**

**Your job is to implement TinySF, which is a custom 13-bit floating-point library.**

You will be implementing functions to create the **TinySF** 13-bit floating point library that ZUON will be using. You will be completing four functions in `src/tinysf.c` for the API; however, it is **highly** recommended that you write a large number of helper functions.

In addition to encoding and decoding TinySF values, you will also do some native arithmetic in this format, using the techniques covered in class, operating on `tinysf_s` values.

## 2. The ZUON Programming Language

The good news is that the ZUON programming language is already written; all you have to do is finish the API implementation for the four **TinySF** functions in `tinysf.c` that ZUON will use. This language is normally programmed interactively from the command line without any inputs, in which case it will let you type in your operations, one per line, for it to execute.

ZUON supports any variable that starts with a letter: (eg. `foo`, `B`, or `o_b_1`)  
ZUON has four different arithmetic operators:     `=`     `+`     `-`     `*`  
ZUON has a negation operator:     `-`  
          (eg. When you enter `-2`, we convert 2 first to TinySF, then we do the negation!)  
ZUON has two constants:     `inf` and `nan`  
ZUON has two functions:     `print()` and `display()`  
ZUON has two commands:     `help` and `quit` (exit also works)  
ZUON does single-line comments:     `#`     (eg. `# this is a comment`)

You may also use scripts, like how Python scripts are run. The ZUON scripts use the **.zuon** extension and run the commands that will ultimately call your functions.

Here is a summary of how ZUON calls your functions:

Any number entered will call your **toTinySF** function to convert it into a TinySF Value (tinysf\_s)

ZUON Functions:

<b>print()</b>	Calls your <b>toNumber</b> to convert a tinysf_s value to a Number
<b>display()</b>	Debug Function that will display any tinysf_s value in Binary

Arithmetic Operators:

<b>+</b>	Calls your <b>opTinySF</b> to add two tinysf_s values and return a tinysf_s result.
<b>-</b>	Calls your <b>opTinySF</b> to subtract two tinysf_s values and return a tinysf_s result.
<b>*</b>	Calls your <b>opTinySF</b> to multiply two tinysf_s values and return a tinysf_s result.

Negation Operator:

<b>-</b>	Calls your <b>negateTinySF</b> to negate a tinysf_s values and return a tinysf_s result.
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ZUON Commands:

<b>help</b>	Prints out Help Information
<b>quit</b>	Quits ZUON. ( <b>exit</b> also works)

### 3. ZUON Programming Language Output

ZUON outputs directly to the screen with the results of the operations that are given.

### ZUON Programming Language Scripts

If you run a script, the output will be given all at once.

Here is an example **ZUON** script in (scripts/sample.zuon) with one statement per line:

```
# Sample Script
first = -0.45
print(first)
second = 4.5
print(second)
sum = first + second
print(sum)
difference = first - second
print(difference)
product = first * second
print(product)
complex = 3 + second - 1.25 * -2
print(complex)
display(complex)
quit
```

This script inputs 14 commands into the ZUON Programming language.

Here is the output for the provided sample script.

```
kandrea@zeus-2:handout$ ./zuon < scripts/sample.zuon
Welcome to the Zeus User Operations Notary (ZUON) programmable calculator.
(ʘ°□°)ʘ┐ ┌───: $ # Sample Script
(ʘ°□°)ʘ┐ ┌───: $ first = -0.45
(ʘ°□°)ʘ┐ ┌───: $ print(first)
first = -0.4501953125
(ʘ°□°)ʘ┐ ┌───: $ second = 4.5
(ʘ°□°)ʘ┐ ┌───: $ print(second)
second = 4.5
(ʘ°□°)ʘ┐ ┌───: $ sum = first + second
(ʘ°□°)ʘ┐ ┌───: $ print(sum)
sum = 4.046875
(ʘ°□°)ʘ┐ ┌───: $ difference = first - second
(ʘ°□°)ʘ┐ ┌───: $ print(difference)
difference = -4.953125
(ʘ°□°)ʘ┐ ┌───: $ product = first * second
(ʘ°□°)ʘ┐ ┌───: $ print(product)
product = -2.0234375
(ʘ°□°)ʘ┐ ┌───: $ complex = 3 + second - 1.25 * -2
(ʘ°□°)ʘ┐ ┌───: $ print(complex)
complex = 10.0
(ʘ°□°)ʘ┐ ┌───: $ display(complex)
TinySF Value in Binary = : 0101001000000 (0xa40)
(ʘ°□°)ʘ┐ ┌───: $ quit
SIC PARVIS MAGNA
Have a nice day!
```

## ZUON Programming Language Interpreter

You can also run `./zuon` directly from the command line without a script, just like with a Python interpreter. You can type each of the same lines in by hand and you'll get the same output.

```
kandrea@zeus-1:handout$ ./zuon
Welcome to the Zeus User Operations Notary (ZUON) programmable calculator.
(ʘ°□°)ʘ┐ ┌───: $ foo = 0.25
(ʘ°□°)ʘ┐ ┌───: $ bar = -1.5
(ʘ°□°)ʘ┐ ┌───: $ print(foo * 2 + bar)
Value = -1.0
(ʘ°□°)ʘ┐ ┌───: $ print(-inf)
Value = -Infinity
(ʘ°□°)ʘ┐ ┌───: $ display(inf)
TinySF Value in Binary = : 0111100000000 (0xf00)
(ʘ°□°)ʘ┐ ┌───: $ print(0 * -inf)
Value = NaN
(ʘ°□°)ʘ┐ ┌───: $ quit
SIC PARVIS MAGNA
Have a nice day!
```

## 4. Specification for Project 2

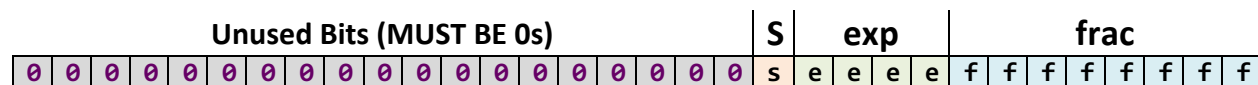
We've already written the ZUON Programming language for you and provided you with the stubs (empty functions) for the four functions you will be writing inside of `src/tinysf.c`

Complete this code, along with any number of helper functions that you would like to use, to implement these four functions. In this project, you will be working with our custom `tinysf_s` type variables. These custom types are **32-bit unsigned ints** in memory. Within these 32-bits, you will be encoding our custom 13-bits floating point value.

Since a `tinysf_s` type is just a standard **unsigned int**, you can do operations on it just like you normally would with an unsigned int. (eg. shifting, masking, and other bitwise ops). Ultimately, you will be getting the **S**, **exp**, and **frac** information and storing them within your `tinysf_s` value, just like we've been doing in class.

### TinySF Representation (`tinysf_s`) Values

The `tinysf_s` values are encoded using the following format within an unsigned 32-bit int:



This is the 13-bit Representation for `tinysf_s` values:

1 bit for sign (s), 4 bits for exponent (exp) and 8 bits for fraction (frac).

TinySF is a slightly simplified version of floating-point encoding. We can support **Normalized** and **Special** (NaN or  $\infty$ ) encodings and we support **Round-to-Nearest-Even**, as discussed in class. ZUON does not support Denormalized values but does have a **Zero Value** (all 0 bits for exp and frac) that is supported.

Rules describing the outcomes of arithmetic operations will be discussed later.

### Input Values to TinySF

Since this is a program for a computer that does not have formal floating-point support, you may notice that there are no **float** or **double** types anywhere in the code for this program. In fact, **you will not be allowed to use any float or double types in your solution either.**

Because of this, the inputs to the functions you will be writing will be **int** types inside of a struct. These values will give you all the information that you need to use to implement your custom floating-point type (`tinysf_s`) values.

**Number Struct Definition (inc/common\_structs.h):**

```
typedef struct number_struct {
    int is_negative;        // 1 if Negative, 0 if Positive
    int is_infinity;        // 1 if Infinity, 0 Otherwise
    int is_nan;             // 1 if NaN, 0 Otherwise
    unsigned int whole;      // 32-bit Whole Portion of Number in Binary
    // (eg. For 3.25, whole = 0x3)
    unsigned int fraction;   // 32-bit Fraction Portion in Binary
    // (eg. For 3.25, frac = 0x40000000, which represents .01000000000000...)
    Factoring_s conversion; // Used Internally by ZUON, Ignore this!
} Number_s;
```

Two of your functions (**toTinySF** and **toNumber**) will have this struct passed into them by reference. **Do NOT free those when you are done with them.** (They are controlled by ZUON).

**Example:** Let's say someone enters the value **3.0625** in ZUON.

ZUON will pass a **Number\_s** struct to your **toTinySF** function with the following members set:

- is\_negative = 0
- is\_infinity = 0
- is\_nan = 0
- whole = 3
- fraction = 0x10000000 *(in GDB, you can print in hex with **print/x** instead of **print**)*
  - 3.0625 is **11.0001** in Binary.
  - The fraction field is a 32-bit unsigned int that has the Binary value of the fraction.
  - So, **.0001** would be **.0001 0000 0000 0000 0000 0000 0000 0000** as 32-bit value.
  - fraction gives you the bits to the right of the binary point, as a 32-bit value.
    - 0x10000000 is **0001 0000 0000 0000 0000 0000 0000 0000** as 32-bits.
  - So, fraction gives you the fraction component AS a whole 32-bit value.

## Entering Negative Values

One note on negatives is that when you type in a negative value, ZUON will first convert the number itself using **toTinySF** and then will call your **negateTinySF** function to negate it.

This is because ZUON is a **real programming language**, so when you enter the following:

**-1.23**

ZUON parses it as this, converting 1.23 to a **tinysf\_s** first, and then doing the negation operator:

**-(1.23)**

Note that negative numbers can be part of other expressions that will call **toTinySF**, so pay special attention to the **is\_negative** flag and make sure to set your S bit accordingly.

## Function Descriptions

src/**tinysf.c** has been given to you as your starting file. This contains a stub for all of the four required functions. You are strongly encouraged to create helper functions, constants, etc. in your design. They too must all be kept within **tinysf.c** as this is the only file you will be submitting.

You are not allowed to use any **float** or **double** types in this project.

Write the code for these functions, **using bitwise operators** for encoding/decoding.

**TinySF Function:**      **tinysf\_s toTinySF(Number\_s \*number)**

When ZUON gets any number, (example: apple = 1.25) it will call this function.

**toTinySF** will take a Number Struct (with its **whole** and **fraction** parts) and encode the data into our custom 13-bit representation and return that value.

**tinysf\_s** is a typedef for an unsigned 32-bit **int** in C

Once you have encoded the value into this **tinysf\_s**, you will be returning it.

**Example:** The val **1.25** has Sign = 0, exp = 0111, frac = 01000000

The 13-bit encodings should be: 0 0111 01000000

The full tinysf\_s (32-bit) value will be: 0000 0000 0000 0000 0000 | 0111 | 0100 0000  
(Hex: 0x0740 )

### So, how do you get these fields from the value?

You are not allowed to use **float** or **double** when working within your function, but you can do the same operations we did in class. (Hint: Think of Binary Scientific Notation)

Think carefully in your design about how you want to shift the whole and fraction integers, and how you will need to move values between them, in order to get the right format for Binary Scientific Notation.

Remember also that you will need to have something to track your E component and that for each shift you do, you will need to adjust that E.

The key idea is to get your value into the right range while adjusting E. This will give you the ability to determine the S, E, and M components first.

**Example for 3.25:**

- number->whole is 0x3
    - This is 0000 0000 0000 0000 0000 0000 0000 0011 in Binary
  - number->fraction is 0x40000000 (*the bits on the right of the binary point*)
    - This is 0100 0000 0000 0000 0000 0000 0000 0000 in Binary
- Together, they represent 11.01 in Binary

To get this in Binary Scientific Notation for Normalized Encoding, you can shift!

- Be careful here because these are two 32-bit unsigned integers!
- Starting point:
  - number->whole is 3, which is 0x00000003
    - This is 0000 0000 0000 0000 0000 0000 0000 0011 in Binary
  - number->fraction is 0x40000000
    - This is 0100 0000 0000 0000 0000 0000 0000 0000 in Binary
  - These represent: 11.01
- Goal after shifting right once:
  - number->whole is 1, which is 0x00000001
    - This is 0000 0000 0000 0000 0000 0000 0000 0001 in Binary
  - number->fraction is 0xA0000000
    - This is 1010 0000 0000 0000 0000 0000 0000 0000
  - These represent: 1.101

**Rounding:**

Follow the Rounding Rules (next section).

**Return your tinysf\_s value.**

**Special Rules:**

- **For Underflows** (eg. exp would be  $\leq 0$  with  $1 \leq M < 2$  in the Normalized Range):
  - Encode the Zero Value (exp and frac bits all 0s) with the appropriate sign bit.
- **Negatives**
  - Note that you can get a negative value on input and it must be handled.
- **Special Values**
  - Note that you may get either Infinity (**is\_infinity**) or Nan (**is\_nan**) passed in.
    - These need to be handled according to the standard encoding.
  - If you get **both** of these flags, treat the number as NaN.
- **For Overflows** (eg. exp is too large for Normalized):
  - Encode the **tinysf\_s** variable as the special value  $\infty$  or  $-\infty$  as appropriate.
  - Specials are as we covered with the exp set to all 1s and frac set accordingly.

**TinySF Function:** `int toNumber(Number_s *num, tinysf_s value)`

When ZUON gets the **print** function, example: `print(foo)`, it will call this function.

**toNumber** will convert our 13-bit representation (value) into the S, M, and E and then put the resulting components into a `Number_s` struct that's passed in by reference.

**Do NOT free or malloc on num, this is managed by ZUON and is already allocated for you!**

Extract the **S**, **exp**, and **frac** portions of the `tinysf_s` type and then convert them back into normal number form (just the whole and fraction values without any multipliers) these fields of the `Number_s` struct. **num** is guaranteed that all values inside were initialized to 0s.

Fill in these Fields of **num**:

- **is\_negative**
  - Set this to 1 if the value is negative, or 0 if positive.
- **is\_infinity**
  - Set this to 1 if the value represents Infinity, or 0 otherwise.
- **is\_nan**
  - Set this to 1 if the value represents NaN, or 0 otherwise.
- **whole**
  - Set this to the whole number of your converted value.
- **fraction**
  - Set this to the binary representation of the bits that would be on the right of the binary point in the converted value.
- **conversion** –Do not Modify this Struct, it is used by ZUON. Leave As-Is

Example: If your value passed in was 0x1740

Unused Bits (MUST BE 0s)																S	exp				frac							
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	0	1	0	0	0	0	0	0

This `tinysf_s` value encodes the number  $-1^1 * 1.01 * 2^0$ , which has a value of -1.25 in Decimal.

Your `toNumber` function must take this `tinysf_s` value and convert it back to the original number format, so that you would set your `Number_s` struct with these values:

- **is\_negative = 1**
- **is\_infinity = 0**
- **is\_nan = 0**
- **whole = 1**
  - 1 is 0000 0000 0000 0000 0000 0000 0000 0001 in binary as an unsigned int.
- **fraction = 0x40000000**
  - 0x40000000 is 0100 0000 0000 0000 0000 0000 0000 0000 as an unsigned int.
  - This represents the bits on the RIGHT of the binary point.



You will not return `num`, since it's passed in by reference, so when you set the values and return, ZUON already has access to it.

**Return 0.**

**TinySF Function:** `tinysf_s opTinySF(char operator, tinysf_s val1, tinysf_s val2)`

This will perform a mathematical operation on two `tinysf_s` values, based on the following values of **operator**.

Operator Values:

'+'	Floating Point Addition	(eg. <code>val1 + val2</code> )
'-'	Floating Point Subtraction	(eg. <code>val1 - val2</code> )
'*'	Floating Point Multiplication	(eg. <code>val1 * val2</code> )

The overview for each of these three operations is in the section that follows. Each also has their own set of special arithmetic rules, which is in a subsequent section as well.

### Special Rules for the Results for any of the Operators:

- **Rounding:**
  - The result may not fit evenly into your format anymore! Make sure to round (**round-to-nearest-even**) to fit into the `frac` field.
- **For Underflows** (eg. `exp` would be  $\leq 0$  with  $1 \leq M < 2$  in the Normalized Range):
  - Encode the Zero Value (`exp` and `frac` bits all 0s) with the appropriate sign bit.
- **For Overflows** (eg. `exp` is too large for Normalized):
  - Encode the `tinysf_s` variable as the special value  $\infty$  or  $-\infty$  as needed.
  - Specials are as we covered with the `exp` set to all 1s and `frac` set accordingly.
- **Sign Considerations:**
  - Always follow the operation sign rules.
- **Special Values:**
  - Your result may be  $\infty$  or  $-\infty$  or NaN (see **Arithmetic Rules** in a coming section)

**Return the resulting value of the operation, or -1 if the operator is not valid.**

The following pages contain details for each of the three valid operators.

**Arithmetic Special Cases:** See the subsequent section on **Arithmetic Rules**

**Operator: ‘\*’      Multiplication of val1 \* val2**

This will multiply two `tinysf_s` values and then return the result as a formatted `tinysf_s`.

**Multiplication Examples in ZUON:**      `foo * bar`  
    `bar * -3.5`

Extract the **S**, **exp**, and **frac** portions of each one of the two value arguments, convert them into S, E, and M, then multiply them together using the technique covered in class:

val1:	S1, M1, E1	
val2:	S2, M2, E2	
product:	S, M, E	
		<b><math>S = S1 \wedge S2</math></b>
		<b><math>M = M1 * M2</math></b>
		<b><math>E = E1 + E2</math></b>

One trick you may use if you like, it may be helpful, since your M will be in terms of **whole** and **fraction** parts, would be to shift M to make each value only whole numbers first and then just multiply them as integers, at which point you can take the result and encode that back into a proper `tinysf_s` value. Just remember to properly manage your E components during shifting!

Once you have the S, M, and E of the product, then encode them back into the `tinysf_s` format and return that result.

#### **Special Rules for Multiplication:**

- **Rounding:**
  - The result may not fit evenly into your format anymore! Make sure to round (**round-to-nearest-even**) to fit into the frac field.
- **For Underflows** (eg. exp would be  $\leq 0$  with  $1 \leq M < 2$  in the Normalized Range):
  - Encode the Zero Value (exp and frac bits all 0s) with the appropriate sign bit.
- **For Overflows** (eg. exp is too large for Normalized):
  - Encode the `tinysf_s` variable as the special value  $\infty$  or  $-\infty$  as needed.
- **Sign Considerations:**
  - Always follow the multiplication sign rules.
- **Arithmetic Special Cases:** See the next section on **Arithmetic Rules**

**You are not allowed to use double or float data types at any point in these functions.**

**Operator: '+'**     Addition of val1 + val2

This will add two `tinysf_s` values and then return the result as a properly formatted `tinysf_s`.

<b>Addition Examples in ZUON:</b>	<b>foo + bar</b>
	<b>2.5 + 3.5</b>

Extract the **S**, **exp**, and **frac** portions of each one of the two value arguments, convert them into S, E, and M, then add them together using the technique covered in class:

```
value1:      S1, M1, E1
value2:      S2, M2, E2
result:      S, M, E
```

### Align the Mantissas:

You need both Es to be the same, so pick one of your values and adjust it. Once both E1 and E2 are equal, you can now add your Ms to get the resulting M of the sum. The E of the result will then be E1.

For the Sign, you will need to determine what it should be.

Example,  $5.0 + -3.0$  will be positive, while  $-5.0 + 3.0$  will be negative.

Once you have S, M, and E of result, encode them into **tinysf\_s** format and return the result.

One trick you may use if you like, it may be helpful, since your M will be in terms of **whole** and **fraction** parts, would be to shift M to make each value only whole numbers first and then just add them as integers, at which point you can take the result and encode that back into a proper **tinysf s** value. Just remember to properly manage your E components during shifting!

Once you have the S, M, and E of the sum, then encode them back into the **tinysf\_s** format and return that result.

### Special Rules:

- **Rounding:**
  - The result may not fit evenly into your format anymore! Make sure to round (**round-to-nearest-even**) to fit into the frac field.
- **For Underflows** (eg. exp would be  $\leq 0$  with  $1 \leq M < 2$  in the Normalized Range):
  - Encode the Zero Value (exp and frac bits all 0s) with the appropriate sign bit.
- **For Overflows** (eg. exp is too large for Normalized):
  - Encode the **tinysf\_s** variable as the special value  $\infty$  or  $-\infty$  as needed.
- **Arithmetic Special Cases:** See the next section on **Arithmetic Rules**

**You are not allowed to use double or float data types at any point in these functions.**

**Operator: '-' Subtraction of val1 - val2**

This will perform the following subtraction: **val1 – val2**

**Subtraction Examples in ZUON:**      **foo - bar**  
   **2.5 - 3.5**

Extract the **S**, **exp**, and **frac** portions of each one of the two value arguments, convert them into S, E, and M, then add them together using the technique covered in class:

value1:      S1, M1, E1  
value2:      S2, M2, E2  
result:      S, M, E

**Align the Mantissas:**

You need both Es to be the same, so pick one of your values and adjust it.  
Once both E1 and E2 are equal, you can now subtract for  $M1 - M2$  to get the resulting M of the difference. The E of the result will then be equal to E1 and E2.

For the Sign, you will need to determine what it should be.

Example,  $5.0 + -3.0$  will be positive, while  $-5.0 + 3.0$  will be negative.

Once you have S, M, and E of result, encode them into **tinysf\_s** format and return the result.

One trick you may use if you like, it may be helpful to shift M to be whole numbers first and then subtract them as integers, at which point you can take the result and encode that back into a tinysf\_s value. Just remember to properly manage your E components!

Once you have the S, M, and E of the sum, then encode them back into the **tinysf\_s** format and return that result.

**Special Rules:**

- **Rounding:**
  - The result may not fit evenly into your format anymore! Make sure to round (**round-to-nearest-even**) to fit into the frac field.
- **For Underflows** (eg. exp would be  $\leq 0$  with  $1 \leq M < 2$  in the Normalized Range):
  - Encode the Zero Value (exp and frac bits all 0s) with the appropriate sign bit.
- **For Overflows** (eg. exp is too large for Normalized):
  - Encode the **tinysf\_s** variable as the special value  $\infty$  or  $-\infty$  as needed.
- **Arithmetic Special Cases:** See the next section on **Arithmetic Rules**

**You are not allowed to use double or float data types at any point in these functions.**

**TinySF Function:** `tinysf_s negateTinySF(tinysf_s value)`

This will negate a `tinysf_s` value.

**Negation Examples in ZUON:**                      **-bar**  
    **-3.5**

Change the sign of the input value and then output that result in **tinysf\_s** format.

Return the **tinysf\_s** result.

**You are not allowed to use double or float data types at any point in these functions.**

The remaining ZUON Commands are already written for you.

**ZUON Function:**                      **display(variable)**

**display Example in ZUON:**                      **display(bar)**

This command shows the binary representation of your **tinysf\_s** values.  
 It's great for debugging! It's also written for you, so no work is needed.

**Example:**

```
(j°□°)j ( ————: $ bar = 1.25
(j°□°)j ( ————: $ display(bar)
TinySF Value in Binary = : 0011101000000 (0x740)
```

This represents a `tinysf_s` value with these bits:

**0 0111 01000000**

S = 0, exp = 0111, frac = 01000000

This shows the bits of the variable you set with your earlier functions, as well as a quick representation in hex (0x068) to help you compare with the `ref_all_values` program:

**E= 0 exp=(b0111)**

...

**M = 1.250000 (b1.01000000), val=1.25000 [0x0740]**

**ZUON Function:**                      **print(variable)**

**print Example in ZUON:**                      **print(bar)**

This command shows you the value of a variable or an expression. This will call your **toNumber** function whenever it's called.

**Example:**

```
(j°□°)j (┌───┐: $ bar = 1.25
(j°□°)j (┌───┐: $ print(bar)
bar = 1.25
(j°□°)j (┌───┐: $ print(3.0 - 1.5)
Value = 1.5
```

**ZUON Operator:**      **quit**

**exit Examples in ZUON:**      **quit**  
    **exit**

You can use either **exit** or **quit** to quit the program. Easier than leaving Python!

**ZUON Operator:**      **help**

**help Examples in ZUON:**      **help**

This simply prints out some helpful command references with examples.

## 5. Rounding Rules

Note that frac is big (8-bits), however it's not big enough to store all possible values, so we will need to do rounding using **round-to-nearest-even**, which means we round to the number we're closest to, unless it's halfway between the two closest values. If it is halfway, we round to the number that has a 0 for its LSB.

As an example, **tinysf** can represent **128.0** and **128.5**, but nothing in between. When **128.24** is entered into ZUON, it will round down (to nearest) down to 128.0. When **128.26** is entered into ZUON, it will round up (to nearest) up to 128.5. When **128.25** is entered, this is exactly halfway between **128.0** and **128.5**, so it will round to even.

We can determine what things **should** round to by looking at the output of a provided helper program, **ref\_all\_values**. This program prints out every possible value that can be represented in tinysf, along with the Mantissa and binary representation.

```
...
M = 1.000000 (b1.00000000), val=128.000000000000000000000000000000 [0x0e00]
M = 1.003906 (b1.00000001), val=128.500000000000000000000000000000 [0x0e01]
...
```

So, we can see that **128.0** and **128.5** are both representable, but **128.25** is not. So, since we're rounding to even here, we'll round down to 128, since in binary, it is 1.00000000

## 6. Notes on ZUON

ZUON is a programming language, just like Python is, and as such, it does process your expressions like a programming language would.

As an example, ZUON can do this:

```
Welcome to the Zeus User Operations Notary (ZUON) programming language.
(⌋ ° □ °) ⌋ ⌋: $ foo = 3.5
(⌋ ° □ °) ⌋ ⌋: $ print(foo + 5.6 + bar = 2.5)
Value = 11.59375
(⌋ ° □ °) ⌋ ⌋: $ print(bar)
bar = 2.5
(⌋ ° □ °) ⌋ ⌋: $ print(-1)
Value = -1.0
```

Every expression will return the value, so you can combine operations like you would with Python, for instance. Each operation is performed in order of precedence and will result in a TinySF value.

Since every expression results in a TinySF value, by typing in 3.5 ZUON will convert it using **toTinySF** while processing that statement.

The last command in the above example is an interesting one. `print(-1)`

```
(⌋ ° □ °) ⌋ ⌋: $ print(-1)
```

This is interesting because ZUON first takes the 1 as a number and calls your **toTinySF()** function on the value 1.0. The result of that that you return will then be operated on by the – (negation) operator. In this case, putting a – in front of a number will make it negative by first having the number converted to a TinySF value with **toTinySF()**, and THEN will call **negateTinySF()** on the result!

You also have two special values you can use in ZUON:

- **inf**                      Infinity
- **nan**                     NaN

Make sure your **toTinySF** can handle inputs of infinity (number->is\_infinity == 1) and NaN (number->is\_nan == 1) on inputs.

**In the unexpected case of both being set, treat the number as NaN.**

**Example of using inf and nan in ZUON:**

Welcome to the Zeus User Operations Notary (ZUON) programming language.

$$(\mu \circ \square^{\circ})_{\cap} \text{---}\text{---}\text{---}: \$ a = \inf$$

$(\cup \square) \cap \frac{1}{-} \frac{1}{-}$ : \$ print(a)

a = Infinity

$(\cup \square) \cup \text{---} \cup \text{---}$ : \$ a = nan

$(\cup \square) \cap \frac{\perp}{\text{---}} \perp$ : \$ print(a)

a = NaN

$(\cup \circ \square \circ \cup) \frown \text{---} \text{---} \text{---}$ : \$ a = -\inf

$(\text{ }^\circ \square ^\circ)_{\cap} \frac{\perp}{\perp}: \$ \text{ print(a)}$

a = -Infinity

## 7. Special Arithmetic Rules

Use these rules for special cases when doing arithmetic:

(X represents any Real number that is not 0, NaN, or  $\infty$ )

**1. Addition Special Rules** (*Arguments can be in any order of mathematical equivalence*)

- $\infty + \infty = \infty$
- $\infty - \infty = NaN$
- $-\infty - \infty = -\infty$
- $NaN \pm Anything = NaN$
- $X - X = 0$
- $\infty \pm X = \infty$
- $-\infty \pm X = -\infty$
- $0 + 0 = 0$
- $0 - 0 = 0$
- $-0 - 0 = -0$
- $-0 + 0 = 0$
- $0 \pm \infty = \pm\infty$  (*sign appropriate*)
- $0 \pm X = \pm X$  (*same Value sign*)
- $-0 \pm X = \pm X$  (*same Value sign*)

## 2. Multiplication Special Rules *(Args can be in any order of mathematical equivalence)*

Follow multiplication rules for Signs (e.g.  $-\infty * -\infty = \infty$  or  $-0 * 4 = -0$ )

- $\infty * \infty = \infty$
- $NaN * Anything = NaN$
- $\infty * X = \infty$
- $\infty * 0 = NaN$
- $0 * X = 0$

**Remember the sign rules for any Multiplication!**

(Multiplying by  $\infty$ ,  $-\infty$ , 0 or  $-0$  is handled using normal multiplication sign rules)



## 8. Project Constraints

You may Not `#include <math.h>` or use any `math.h` functions, including `pow()`

You may Not use any `double` or `float` types anywhere in your code.

There are Two Special Number Types: Infinity and NaN.

- These will be implemented using the standard special number pattern in your `tinysf_s` floating-point representation. (Remember  $\infty$  and  $-\infty$ )
- There is only one NaN, regardless of sign, it's not a number.
  - Any pattern which matches a NaN is considered equivalent.
  - **Your `tinysf_s` inputs should be able to recognize any value bit representation of NaN.**
  - Your functions may use any valid NaN representation.

Rounding is to the Nearest Even (ie. what we covered in class)

- If your frac is too big for the field, look at the first bit to the right of the rounding point.
  - If it's a 0, we're less than halfway between, so round down.
  - If it's a 1, look to the right at the remaining bits.
    - If at least one other bit is a 1, it's over half, so round up.
    - If all 0s on the right, it's halfway, so round to even.

Negative Numbers must be handled.

- All values (including  $\infty$ ) will be handled properly with negatives.
- All functions should support -0 values being passed in as arguments.

## 9. Getting Started

First, get the starting code (`project2_handout.tar`) from the same place you got this document. Once you un-tar the handout on zeus (using `tar xvf project2_handout.tar`), you will have the following key folders and key files:

- **Makefile** – Run **make** to build the assignment (and **make clean** to clean up).
- **src/**
  - **tinysf.c** – **This is the only file you will be modifying (and submitting).** There are stubs in this file for the functions that will be called by the rest of the framework. Feel free to define more functions if you like but put all of your code in this file!
- **inc/**
  - **tinysf.h** – **Do Not Modify.** This has some nice constants that you may wish to use if you like.
  - **common\_structs.h** – **Do Not Modify.** This has the struct definitions for the project.
  - **zuon\_settings.h:** You may modify this. This defines what the prompt looks like and whether or not you want to see the colors. Feel free to change as you like.

- **scripts/**
  - **sample.zuon** – This is the provided sample ZUON script. You can write your own for testing!
- **ref\_all\_values** – This is a program we wrote to make debugging easier for us. It prints out all legal values in our representation. This will help you determine what values you should be seeing.

## ref\_all\_values Program

For each E (the E is given and the exp equivalent is given in binary), **ref\_all\_values** lists all possible values that can be represented (vals). For each val, you get the M in decimal and in binary for convenience.

For example, let's say we assign **4.45** to **foo**. This number is not a valid **val** in the output for this program, as shown in the snippet from the **all\_values** output below.

Mantissa (Mantissa in Binary)	Value in Decimal	[tinysf_s in Hex]
...		
M = 1.109375 (b1.00011100), val=4.43750000000000000000000000000000 [0x091c]		
M = 1.113281 (b1.00011101), val=4.45312500000000000000000000000000 [0x091d]		
...		

The closest values to **4.45** are **4.375** and **4.453125**. Since we're rounding using round-to-nearest-even, we have to see which is closer. 4.45 is much closer to 4.453125, so this will round up to the closest value, which is **4.453125** as seen in the following output.

```
(j°□°)j (└───┘): $ foo = 4.45
(j°□°)j (└───┘): $ display(foo)
TinySF Value in Binary = : 0100100011101 (0x91d)
(j°□°)j (└───┘): $ print(foo)
foo = 4.375
```

Displaying the value also shows us the Hex code (0x91d) that we were expecting from the **ref\_all\_values** output [0x091d] for 4.453125.

Of course, doing this in decimal is very hard. It's a lot easier once you're working in the code to do the rounding from the binary directly to keep the bits that fit in frac.

## 10. Implementation Notes

- **ZUON (.zuon) Script Files** – The accepted syntax is very simplistic and it should be easy to write your own scripts to test your code (which we strongly encourage).
  - **ZUON** only uses standard variable names (any that start with a letter).
  - **ZUON** command reference:
 

▪ <b>print(x)</b>	Prints the Number.	<b>toNumber()</b>
▪ <b>display(x)</b>	where x is a variable to display the bit representation	
▪ <b>x = value</b>	Performs assignment.	<b>toTinySF()</b>
▪ <b>y + z</b>	Performs addition.	<b>opTinySF()</b>
▪ <b>y - z</b>	Performs subtraction.	<b>opTinySF()</b>
▪ <b>y * z</b>	Performs multiplication.	<b>opTinySF()</b>
▪ <b>-x</b>	Performs negation.	<b>negateTinySF()</b>
▪ <b>quit</b>	Exits the program. (exit also works)	
▪ <b>help</b>	Prints out help information.	
▪ <b>#</b>	Single-Line Comment.	

Note that you can chain operators just like in Python too:

```
(J°□°)J_ ———: $ foo = 4.45
(J°□°)J_ ———: $ display(foo)
TinySF Value in Binary = : 0100100011101 (0x91d)
(J°□°)J_ ———: $ print(foo)
foo = 4.453125
(J°□°)J_ ———: $ foo = 1.0
(J°□°)J_ ———: $ bar = -0.25
(J°□°)J_ ———: $ result = foo + foo * -bar + 3.5 * -foo
(J°□°)J_ ———: $ print(result)
result = -2.25
```

- As a programming language, we also have operator precedence, but fortunately this is pretty much as expected.
  - Parentheses are highest precedence.
  - Negation is next highest.
  - Multiplication is next highest.
  - Addition and Subtraction are next.
  - The Assignment (=) is the lowest.

```
(J°□°)J_ ———: $ a = -(3+2)
(J°□°)J_ ———: $ print(a)
a = -5.0
(J°□°)J_ ———: $ a = -3+2
(J°□°)J_ ———: $ print(a)
a = -1.0
```

- If you run **ZUON** from the command line without inputting a script file, you must end the session with either **quit** or **exit**.
- To run **ZUON** with a script file, you can pass it in with redirects:
 

```
./ZUON < scripts/sample.zuon
```

## Note on Types:

Remember that in C, all integer types are just collections of bits. So, an **unsigned int** is just 32-bits. We can interpret this as an Integer, of course, but we can also just use it as a container and work with those individual bits.

The **tinysf\_s** type is an unsigned int internally, but you can think of it as a 32-bit container. Remember if you do any shifting, C will perform right-shifts on the signed/unsigned type rules.

## 11. Testing your Code

### Testing with Zuon

First, you can run your code in **zuon**, which will let you enter expressions and see the outputs in the full program that your TinySF is designed for. The best way to test in here is to enter a value using variable assignment and then to use the **display** function on it. The **display** function is pre-written and will tell you exactly what the value was converted to by your **toTinySF** function, making it easy to compare with the values from **ref\_all\_values**, without needing to have **toNumber** written at all.

Once you have that working, you can then pass values into the **print** function to print them out to the screen. All values passed into **print** will have been converted by your **toTinySF** function earlier, but now **print** will call your **toNumber** function to print them out as full values again. So, you can use **print** to test your **toNumber**, once you know your **toTinySF** function is working.

After that, you can test the remaining functions using the above.

### Testing with a Unit Tester

We also included a simple unit testing program with the handout you can build with **make tester** and then run with **./tester** in the handout folder. The file `src/tester.c` has a main function that calls an example function a sample of what you could put in here. That function calls **negateTinySF** with a known encoded value (0x700) and then prints out what it returns.

In this case, 0x0700 represents the following encoded value:

Unused Bits (MUST BE 0s)																S	exp			frac							
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0

And the expected result of negation should be 0x1700

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	0	0	0	0	0	0	0
---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

So, this tester is looking to see if the result was indeed 0x1700. You can modify/use this tester in any way that you find helpful. It is **much** easier to run **GDB** using the tester than **zuon**.

## 12. Submitting & Grading

Submit this assignment electronically on Blackboard. Note that the only file that gets submitted is `tinysf.c`. Make sure to put your name and G# as a commented line in the beginning of your source file.

You can make multiple submissions; but we will test and grade **ONLY** the latest version that you submit (with the corresponding late penalty, if applicable).

**Important:** Make sure to submit the correct version of your file on Blackboard! Submitting the correct version late will incur a late penalty; and submitting the correct version 48 hours after the due date will not bring any credit.

Questions about the specification should be directed to the CS 367 Piazza forum.

**A full Rubric is available on Blackboard for the Project as well with more details.**

Your grade will be determined as follows:

- **20 points** - code & comments. Be sure to document your design clearly in your code comments. This score will be based on reading your source code.
- **80 points** – correctness. We will be building your code using the `tinysf.c` code you submit along with our code.
  - If your program does not compile, **we cannot grade it**.
  - If your program compiles but does not run, **we cannot grade it**.
  - We will give partial credit for incomplete programs that build and run.
  - You will not get credit for a particular part of the assignment (multiplication for example), if you do not use the required techniques, even if your program performs correctly on the test cases for this part.

### Valgrind Notes:

This program leaks more than if the Titanic crashed into the Poseidon in an Aquaman movie.

**No Valgrind will be Run and No Leak Checks will be Made.**

## Changelog

**v1.0: February 15<sup>th</sup> – Initial Release**

**v1.01: February 16<sup>th</sup> – Corrected two Examples that showed 011 instead of 0111 for exp**  
**eg.  $1.25 = 0\ 0111\ 01000000$  (0x740)**  
**S = 0**  
**exp = 0111**  
**frac = 01000000**