OOP Assignment (inf_int Class)

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Introduction

Our team’s project is mainly about “making a class that can maintain an infinite length of number, having basic operators of addition, subtraction, and multiplication.” As a basic ‘Integer class’ given by C++ can only maintain at most approximately 2 billion, we should create a customized integer class, named as ‘inf_int.’ In this report, we will explain how we made a brief concept, specification, and implementation of this customized ‘inf_int’ class.

Concept of the ‘inf_int’

As we explained above, a basic integer class (a.k.a ‘int’) can only maintain at most 2 billion, which means that assigning above 2 billion to the ‘int’ will make an overflow of the program, leading to the fatal error to the program. To prevent this, we decided to use ‘string’ instead. A string type can maintain an infinite length of the string (actual length is 4.2billion, which is still close to infinite, 10^(4.2billion)). A brief abstraction of the class ‘inf_int’ looks like this:

```
class inf_int
{
private :
    char* digits;
    unsigned int length;
    bool thesign;

public :
    inf_int();
    inf_int(int);
    inf_int(const char* );
    inf_int(const inf_int&);
    ~inf_int();

    inf_int& operator=(const inf_int&);

    friend bool operator==(const inf_int& , const inf_int&);
    friend bool operator!=(const inf_int& , const inf_int&);
    friend bool operator>(const inf_int& , const inf_int&);
    friend bool operator<(const inf_int& , const inf_int&);

    friend inf_int operator+(const inf_int& , const inf_int&);
    friend inf_int operator-(const inf_int& , const inf_int&);
    friend inf_int operator*(const inf_int& , const inf_int&);
    friend ostream& operator<<(ostream& , const inf_int&);
};
```

Functionality

A customized class ‘inf_int’ has a responsibility not only to operate basic arithmetic functions properly, but also to perform comparison operator and I/O functions. Thus, we overloaded the basic operators to get our ‘inf_int” class as the parameters, declaring them as ‘friend’ functions to give them permission to access the internal data (digits, length, thesign). By doing this, operators will access the char-type digits and perform the functions by reading each digit. Now we need to specify the implementations.

Clarifying the functions with a chart, it will look like this:

Classification	Symbol	Description
Constructor	(*construct or symbol*)	Initializing internal members when creating object
Compare	>, < , ==, !=	Comparing inf_int classes’s values
Arithmetic operator	+, -, *, /, %	Performing arithmetic operator (We will perform this by implementing ‘Add’, ‘Sub’ method)
Assign	=	Assigning values to the inf_int object
I/O Function	<<	Output function of the inf_int class

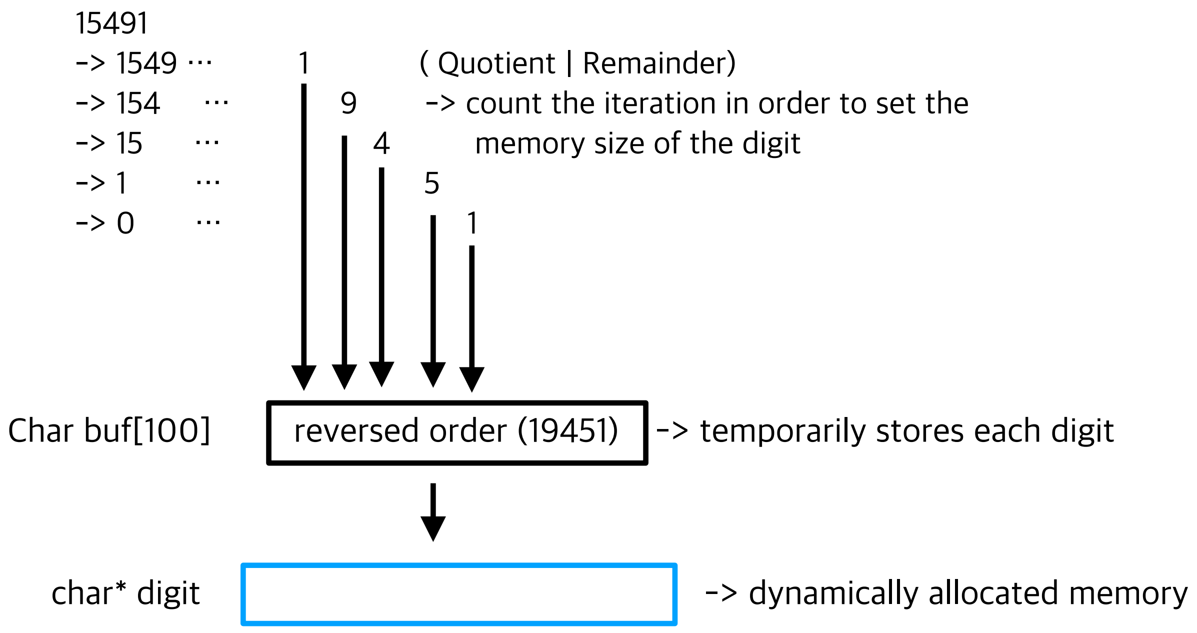
Implementations

Constructors

Before explaining the implementation of the function, we first need to specify the structure of the internal data (digits, length, thesign). As explained above, we should store digits in char type. However, since we cannot figure out the exact length of the number before declaring it, we should not use the static array. Instead, we should use **‘dynamic allocation.’** This concept will be used in the constructor of the ‘inf_int’ class, as the internal members are initialized when the constructor is called.

Four types of constructors are declared in the ‘inf_int’ class : One that gets an integer as a parameter, one that gets a string, another as a copy constructor, and the other with none parameter.

Starting with the first constructor (integer), we should beware that the structure of a string type, and the integer type is different. As we assumed that the length of the digits is infinite, we cannot simply cast the integer to the string type. If doing so, it won’t properly perform the arithmetic functions with another ‘inf_int’ object having infinite length of digits. Considering this case, we should divide the integer with 10 to get each digit, which will be saved in reversed order for the reason that is explained by the diagram below.


15491
-> 1549 ··· 1
-> 154 ··· 9
-> 15 ··· 4
-> 1 ··· 5
-> 0 ··· 1
(Quotient | Remainder)
-> count the iteration in order to set the memory size of the digit
Char buf[100]
reversed order (19451)
-> temporarily stores each digit
char* digit
-> dynamically allocated memory

Dividing 10 repeatedly and extracting each remainder will produce a single digit of the target integer, which will be stored in the temporary char array (buf) but in reversed order. After that, the data of the temporary char array will be moved to the digit, which is initialized with dynamic memory allocation method. What makes such process possible is the loop of the division. Counting the loop iteration that performs division until the quotient becomes zero, will allow the program to get the length of the target integer, and by using the length, we can dynamically allocate the memory with such size and initialize the internal member, “length.” The sign will be equal to the target integer.

The code will be like this:

```
inf_int::inf_int(int n)

{
    char buf[100];
    if (n < 0)
    {
        this->thesign = false;
        n = -n;
    }
    else
    {
        this->thesign = true;
    }
    int i = 0;
    while (n > 0)
    {
        buf[i] = n % 10 + '0';
        n /= 10;
        i++;
    }

    if (i == 0)
    {
        new (this) inf_int();
    }
    else
    {
        buf[i] = '\0';
        this->digits = new char[i + 1];
        this->length = i;
        strcpy(this->digits, buf);
    }
}
```

Once the constructor with integer parameter is created, the other types of constructor is not that complicated, as the data type is same as the internal member, 'digit.' The one with string parameter just needs some process to read each character and copy into the 'char* digit,' getting the length of the target string which will be same as the value of the member 'unsigned int length,' and deciding the sign by reading the first character. The only thing we have to beware is that, the digits should be stored in reverse value in order to perform other functions. Thus, we also have to copy each letter of the target string and store reversely.

Copy constructor only needs a process to read the target 'inf_int' object's internal member and literally copy each data into the internal members. Since the digits are already stored in reversed order in all 'inf_int' objects, we could just simply copy its string and paste it to the digits.

A default constructor (that doesn't need any parameter) will have a simple process to initialize the internal members. In this project, we will initialize the digit as zero, additionally putting the null at the end of the digit array to indicate the end of the string, and set the length as 1 and bool sign as true.

Code will look like this :

```
inf_int::inf_int()
{
   this->digits = new char[2];
   this->digits[0] = '0';
   this->digits[1] = '\0';
   this->length = 1;
   this->thesign = true;
}

inf_int::inf_int(const char *str)
{
   unsigned int i;
   if (str[0] == '-')
   {
      this->thesign = false;
      this->length = strlen(str) - 1;
      this->digits = new char[length + 1];
      for (i = length - 1; i >= 0; i--)
      {
         digits[i] = str[length - i];
      }
   }
   else
   {
      this->thesign = true;
      this->length = strlen(str);
      this->digits = new char[length + 1];
      for (i = length - 1; i >= 0; i--)
      {
         digits[i] = str[length - i - 1];
      }
   }
}
inf_int::inf_int(const inf_int &a)
{
   this->digits = new char[a.length + 1]
   strcpy(this->digits, a.digits);
   this->length = a.length;
   this->thesign = a.thesign;
}
inf_int::~inf_int()
{
   delete digits;
}
```

Additionally, since we allocated memory dynamically for storing digits, we should free it if the object is to be destructed. Thus, we should declare the destructor so as the digits to be freed by the destructor.

Comparator

The next step is specifying the comparators. According to the abstraction class we made before, our class should handle four comparators (>, <, ==, !=). Simply using the basic operators without overloading will make an unexpected result, as our 'inf_int' class has an infinite length of digits. To make it possible, we should compare in a different way.

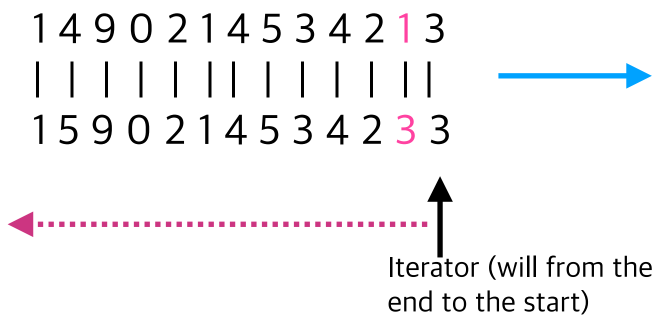
Assume that there are two numbers of different length, or different sign, and we are using the relational operators(>, <). If the length of the two numbers we are to compare is different, simply just picking up the longer one will get the proper result. Or, if the sign of the two numbers are different, picking up the positive one will be right. Moreover, assume that we are using the equality operators. We could just compare if the length, and the sign of two numbers are same. The problem occurs when the two numbers **have the same length, and the same sign.** In this case, we should compare each digit one by one.

```
1 4 9 0 2 1 4 5 3 4 2 1 3
| | | | | | || | | | | | ||
1 5 9 0 2 1 4 5 3 4 2 3 3
<——————————————————————>
Least Significant                 Most Significant
Digit                             Digit
```

Reminding the principle of storing digits, we stored digits in reversed way in order to perform functions with infinite length of number, which means that for example, if we intended to save '15032' in inf_int object, the digits will be saved in order of '23051.'

This is the point we should make it clear, that the most significant digit (or the biggest value) is stored at the end of the digit array, whereas the least significant digit is stored at the start point of the array. Thus, we should prioritize the most significant digit while performing the comparator.

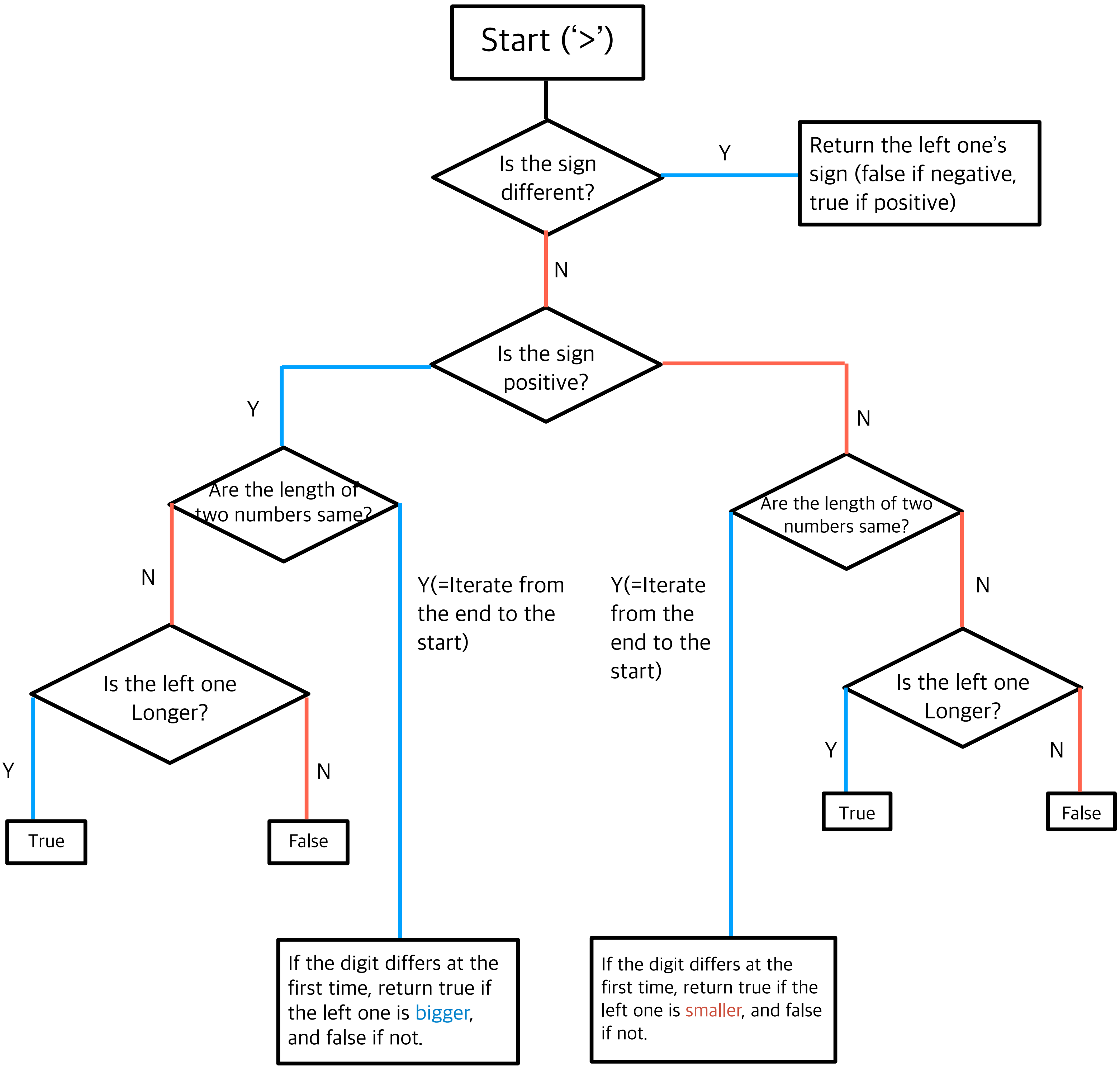
According to the example above, the digit of the number at the right side is bigger than of the number above. Therefore, the comparator will make a result by looking up the pink-highlighted digit.



If the numbers are positive :
-> 1 < 3 => the below is bigger

If the numbers are negative :
-> -1 > -3 => the above is bigger

Representing these cases by diagram will be like this (in this case, '>') :
(Shown in next page)


Start ('>')
Is the sign different?
Y
Return the left one's sign (false if negative, true if positive)
N
Is the sign positive?
Y
N
Are the length of two numbers same?
N
Y(=Iterate from the end to the start)
Is the left one Longer?
Y
N
True
False
If the digit differs at the first time, return true if the left one is bigger, and false if not.
Are the length of two numbers same?
Y(=Iterate from the end to the start)
N
Is the left one Longer?
Y
N
True
False
If the digit differs at the first time, return true if the left one is smaller, and false if not.

The other relational operator (<), and the equality operators(==, !=) will follow this principle similarly. The relational operator will perform the principle above in reversed manner. The equality operators will only have to consider if the digits of two numbers are different when the two number's length and sign are same.

Looking up some glimpse of this comparator's code, it will look like this :

```
bool operator>(const inf_int &a, const inf_int &b)
{
    if (a.thesign != b.thesign)
        return a.thesign;

    if (a.thesign) // a가 양수일 때
    {
        if (a.length > b.length) // 길이가 길면 무조건 큼
            return true;
        else if (a.length < b.length) // 길이가 작으면 무조건 작음
            return false;
        else
        {
            for (int i = a.length - 1; i >= 0; i--) // 길이가 같다면 하나하나 비교 시작 (12345면 배열엔 543210이 담겨있는 상태)
            {
                if (a.digits[i] > b.digits[i])
                    return true;
                else if (a.digits[i] < b.digits[i])
                    return false;
                else
                    continue; // 같은 자릿수에 숫자까지 동일하다면 패스
            }
        }
    }
    else // a가 음수일 때
    {
             /…/
    }
}
```

We can know that the structure of the comparator's code is just same as the structure of the diagram above, comparing the sign first, then the length second, and iterating if the sign and the length is same. Closely looking up the iterating part, the 'for loop' starts from the end of the digit array. If the different digit is found for the first time, the program breaks the loop and returns the result, depending on the sign of the target numbers.

Before we move onto the next part (arithmetic operators), we should make one thing clear. Why did we use references in the parameter of the operator? Reminding what we learned in the past lecture, we learned that there are two types of copying. One is a 'shallow copy,' and the other is 'deep copy.' Shallow copy is a type of copy that only copies its reference, not the whole object, which won't make another object in the program, while deep copy is a type of copy that copies the object itself and creates another identical object, which will consume additional memory. What we are copying is a 'inf_int' class, which has an infinite length of digit. Hence, creating another object would create enormous amount of memory which is not efficient at all.

To avoid this, we use 'pass by reference' to perform shallow copy, just to copy its references without creating another 'big-size' object. Not only we can save memory, but also we can ensure that the digits are not changed, because the function literally points the target object so the values will be exactly passed into the function.

Arithmetic operator

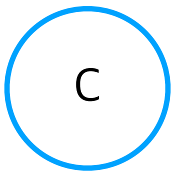
The main feature of our project is arithmetic operators. These are harder than the functions explained above, since there are more things we should consider when performing arithmetic operators. For example, there exists a 'carry' when doing addition, and there needs another process to convert the 'char' into to the 'integer' to perform calculation.

Simply just overloading operators won't make a proper result. First, if a carry occurs, the length of the result becomes longer than those of the operands, which means that there should be an additional memory space to maintain the lengthened digits, and what makes even worser is we should classify the cases that which cases makes the length of the result become longer. This should be considered when doing subtraction, multiplication, and division, which will make the length of the result more variably. Hence, we need to use dynamic memory allocation.

Before overloading operators, we should implement a basic arithmetic functions (add, sub), as arithmetic operators do not always perform its original operations. For example, -1234 + 5321 is considered as subtraction. Thus, we added two methods, 'Add' and 'Sub' that operates only by one digit. We will calculate the numbers by repeatedly using them in loop.

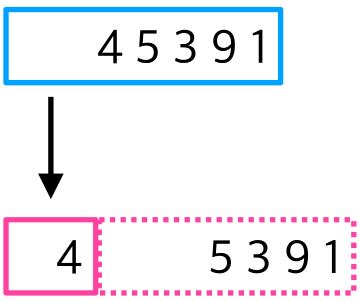
Start with Add (not an operator '+', as 'positive number + negative number' should be considered as subtraction). An additional thing we have to consider is 'carry.' Whether the carry occurs or not will determine the needs of additional dynamic memory allocation.

Brief Idea of Addition, and Subtraction (e.g. 19354+82912):
- Create an empty 'inf_int' object, c.



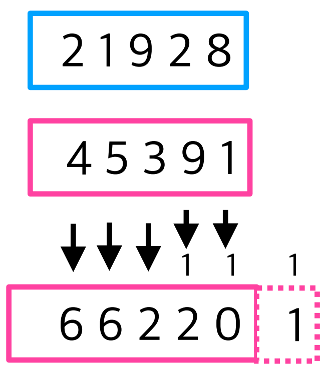
=> Initialized with 0

- Add a to c, but by a single digit. Memory spaces will be allocated to c in a single unit with loop.



Assuming that the inf_int has a infinite length, we cannot allocate memory at once, so we should allocate memory one by one. Digits will be stored in reversed order.

- Add b to c. ‘a’ is stored in c in advance, so the actual addition occurs at this process.



If there’s another carry at the end of the digit, additional memory allocation will be performed to store carry.

If carry occurs while performing addition, it will be stored in the next index of the array in advance, and in next iteration, addition will be performed with the carry

Digits of the operands will be converted into the integers, and will be added one by one (with loop).

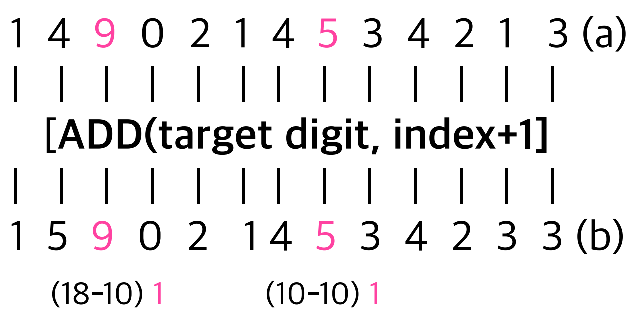
The process of subtraction is similar as the addition, but somewhat different in other parts. If the result is smaller than zero, carry occurs and ‘1’ will be stored in the next index.

In conclusion, we allocate memory as we cannot know the exact length of the result before the calculation is finished. If the carry occurs, we store it in the next index so in the next iteration, calculation will be done with the carry.

The next step is overriding the operators. Start with ‘+’, we should classify the cases of which operations will be performed. Since the operand could be negative, it won’t alway s perform addition. Thus, before operating, we should check the sign to decide what operation should be performed. If the sign of two numbers are same, ‘Add’ will be performed and the sign of result will follow the sign of the operands. But before implementing the operators, we should set the parameter of ‘Add’, and ‘Sub.’

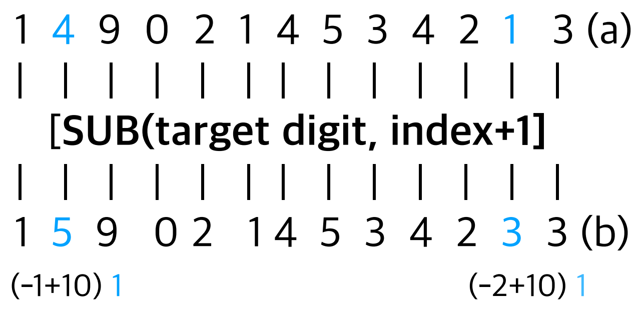
Previously, we mentioned that the method ‘Add’ will be performed in a single digit range. Thus, in order to make ‘Add’ possible to be performed in the loop, we should pass the information of the current iteration, and the digit.

for Loop with iterator I



1 4 9 0 2 1 4 5 3 4 2 1 3 (a)
[ADD(target digit, index+1]
1 5 9 0 2 1 4 5 3 4 2 3 3 (b)
(18-10) 1
(10-10) 1

=> ADD(a.digit[I], index+1) => in order to reallocate memory, pass the index and compare with the current length. When carry occurs, the addition result of each digits will be subtracted with 10, storing 1 in next index



1 4 9 0 2 1 4 5 3 4 2 1 3 (a)
[SUB(target digit, index+1]
1 5 9 0 2 1 4 5 3 4 2 3 3 (b)
(-1+10) 1
(-2+10) 1

=> SUB(a.digit[I], index+1) => in order to reallocate memory, pass the index and compare with the current length. When carry occurs, the subtraction result of each Digits will be added with 10, storing 1 in next index

The next operator is ‘-‘. Since we made ‘Sub’ method in advance, all we need to do is to sort every cases when performing operator.

Case Chart (a - b) :

Pos - Pos	|a| >= |b|	Initialize minuend with a, then subtract b. Make the sign positive.
	|a| < |b|	Initialize minuend with b, then subtract a. Make the sign negative.
Pos - Neg	|a| >= |b|	Add a and b and make sign positive
	|a| < |b|	
Neg - Pos	|a| >= |b|	Add a and b and make sign negative
	|a| < |b|	
Neg - Neg	|a| >= |b|	Initialize minuend with a, then subtract b. Make the sign negative
	|a| < |b|	Initialize minuend with a, then subtract b. Make the sign positive

Using this chart, we can make some conditional statements to determine which one to perform, and use same principle as the operator ‘+’ did.

The remaining operators are multiplication (‘*’), and division (‘/‘). Doing this operations will require the basic principle of multiplication, and division. When we multiply the numbers having somewhat long length, we multiply one by one but also shifting by 10 simultaneously. Division shares the similar principle, which subtracts the divisor from dividend but in shifted way to match the ciphers. This is why we made our method ‘ADD’, and ‘SUB’ get an additional parameter, index. Passing the index will make ‘ADD’, or ‘SUB’ start operation from given index, which is same as shifting the divisor or multiplier by 10 in basic multiplication or division.

```
4 3 6 9 8 4 3 6 5 7 2 9 (multiplicand)
8 2 9 4 2 3 1 5 3 2 1 7  (multiplier)
________________________-

32 (shift 0)
 8 (shift 1)
  36 (shift 2)
   16 (shift 3)
    8 (shift 4)…         +
________________________
```

Thanks to the Add’s parameter, we can easily shift the result of multiplying digits of multiplicand and multiplier. Starting with the first digit of multiplicand, this will be multiplied with multiplier’s digit and will be shifted when iterating.

Implementing multiplication as a code will be like this :

```
inf_int operator*(const inf_int& a, const inf_int& b)
{
    inf_int c;
    for (unsigned int i = 0; i < a.length; ++i)
    {
        for (unsigned int j = 0; j < b.length; ++j)
        {
            c.Add((a.digits[i] - '0') * (b.digits[j] - '0'), j + i + 1);
        }
    }
    a.thesign == b.thesign ? c.thesign = true : c.thesign = false;
    return c;
}
```

First, we set ‘a’ as a multiplicand, and b as a multiplier. And by ‘for’ loop, we traverse multiplicand’s digit each and while traversing, we set an additional loop and traverse multiplier’s each digit. And as a result, the loop of multiplying the multiplicand’s digit and multiplier’s digit while iterating the multiplier will be formed, performing the basic principle of multiplication. We already implemented the ‘Add’ method that supports the addition of carry, and shifting, so we simply used c.Add with the parameter of the multiplication result, and the index of shifted cipher. The sign will be negative if the sign of two numbers are different, positive if same.

Division is more complicated compared to the multiplication. The main reason is that the result of the multiplication is in exact form, but for division, the remainder exists, which means that the result of the division is not as clear as the multiplication is. Using the basic principle of the division, we should continuously subtract divisor from the dividend until we cannot subtract anymore. In the subtraction process, we should match the cipher, and thus we have to shift them by the gap of the dividend, divisor’s cipher.

Ex.) 456789 / 1111

```
9 8 7 6 5 4  => initialize the temporary inf_int q with 456789 (reversed order)
    1 1 1 1 [sub => q : 345689 > 111100 (operand * 10 ^2 (shifted by 2)) ]
    1 1 1 1 [sub => q : 234589 > 111100 (operand * 10 ^2 (shifted by 2)) ]
    1 1 1 1 [sub => q : 123489 > 111100 (operand * 10 ^2 (shifted by 2))]
    1 1 1 1 [sub => q : 12389 < 111100 (operand * 10 ^2 (shifted by 2))] => quot 1 : 4
  1 1 1 1   [sub => q : 1279 < 11110 (operand * 10 (shifted by 1))]  => quot 2 : 1
1 1 1 1     [sub => q : 168 < 1111 (operand)] => becomes remainder  => quot 3 : 1
──────────────────────────────────────────────────────────────────────
8 6 1            Quotient = quot1*(10^2) + quot2*(10^1) + quot3*(10^0) = 411
                 Remainder = 168
```

This mechanism will be used in our division. We first create an inf_int object q, using copy constructor to initialize with the value of dividend. Then, we match the ciphers of dividend and divisor in order to continuously subtract q, and also count the subtraction to get the first cipher part of the quotient. If no more subtraction is allowed (if q-operand < 0), we shift down the operand to match a cipher and continue to subtract. Repeating this process will allow us to get each cipher of the quotient, combining them to get the real quotient of the dvision, and the result of repeated subtraction will produce the remainder. Finally we set the sign of the quotient either positive or negative, positive if the signs are same, negative if the signs are different.

The example above is the case that the length of two numbers are same, but what if the length of the two numbers are different? In this case, the quotient always becomes has a cipher of 1, so simply subtracting until it's possible will get the quotient and the remainder. The two cases have the same principle : If at least one of the number is negative, convert them all into positive and do the division. At the last process, set the quotient positive if same, negative if different. The sign of the remainder will be automatically determined from the continuous subtraction. A short glimpse of the important part of the division looks like this :

```
inf_int dividend(a);
dividend.thesign = true;
char buf[100000];
int resultLength = 0;
for (int i = a.length - b.length + 1; i >= 1; i--) {
    inf_int divisor = b * inf_int(10).pow(i - 1);
    divisor.thesign = true;
    int subQ = 0;
    while (dividend > divisor || dividend == divisor) {
        dividend = dividend - divisor;
        subQ++;
    }
    if (subQ == 0 && resultLength == 0)
        continue;
    buf[resultLength++] = subQ + '0';
}
buf[resultLength] = '\0';
c = inf_int(buf);
c.length = resultLength;
c.thesign = (a.thesign == b.thesign ? true : false);
return c;
```

The shifting part corresponds to the line 3. Powering by the gap of the two numbers' length will allow the divisor to be shifted to the proper cipher. We continuously subtract the divisor from the dividend, adding the subQ, which corresponds to the 'Quotient.' Temporary array buf, will get the result in real time. The part of the conditional statement 'if (subQ == 0)' is that, if shifting the divisor makes the subtraction impossible, skip the process and go on to the next iteration, which is same as shifting down the divisor. We also added additional logic to recognize the zero as a value if the ‘0’ is not in the first digit. By doing this, we can prevent the error that the program doesn’t recognize ‘0’ as a value.

Execution Results :

Additional Information about Execution

Environment

- OS : Ubuntu 20.04.1 Server
- Architecture : amd64
- Compiler : g++ 9.4.0

Project Structure

- Directory src : Runnable CPP File Included
- Directory include : Header Files for CPP

Execution

- Run "make" command on shell

Command Example

- ubuntu@ubuntu-server: PROJECT_DIR/Assignment2$ make
- ubuntu@ubuntu-server: PROJECT_DIR/Assignment2$ ./out/inf_int

Conclusion & Importance of OOP

During the development of our program, we used the concept of the object-oriented programming. Instead of calculating every input in real time, we created the object derived from the ‘inf_int’ class, and pretended it as a form of a number. However, we protected the internal data by making them as private members, preventing the other objects from accessing or modifying data. The usage of the concept of the object-oriented programming can be found from the functions’ parameters. They get the objects as parameters, which means that the function recognizes the numbers as a form of independent objects, just like a living thing. Instead of processing every string one by one, they simply pass the objects and use the information they need.

We felt the importance of ‘oop,’ since the calculation of the infinite length of numbers is complicated. If we didn’t use the ‘oop,’ our code will be incomparably complicated, leading to the intensely increased cost of the program. But by using objects, our code become simpler, more recognizable, and more stable.

The advantages of the oop became more significant when we have to debug our program. We had to face the numerous errors and exceptions, some of which are so hard to be fixed, and thus we needed to modify the code. However, thanks to the concept of the oop, we easily found the source of error, and because the methods of the calculation were independently separated from the others, we did not have to worry about the influences of the modification. In other words, because we struggled to decrease the coupling of the functions in the development process, it required less effort to modify the errors, leading to the successful development of our program.