C++ Programming for Scientists

Lecture # 3

A simple program involving integers

```
int main()
{
    int a = 17;
    int b = 33;
    int c = a + b + 50;

    printf("%d\n", c);

    return 0;
}
```

Big, *really* big integers

"496982034007341215862794536196784621078462756513297"

Goal: write a library to deal with large numbers.

Concerns

- require dynamic memory management.
- need functions creating, destroying, reading, printing, assigning, and basic arithmetic.
- avoid naming conflicts, e.g. `Create_BigInt()`, `Print_BigInt()`.
- programmers will need to know these names and the rules for calling them.
- programmers will need to explicitly initialize and destroy big numbers.
- will need to be careful when combining big numbers with other data types, like `int`.
- will have to "clean-up" unused memory by local big numbers when exiting functions.

A simple program involving `BigInts`

```
#include "bigint.h"

int main()
{
    BigInt a, b, c;
    BigInt t;

    Create_BigInt( &a, "29587365452419232");
    Create_BigInt( &b, "6948672303927125");

    Assign_BigInt( &c, Add_BigInt(a, b));
    Convert_Int_to_BigInt(&t, 50);
    Assign_BigInt( &c, Add_BigInt(c, t));

    Print_BigInt(c);

    Destroy_BigInt(&a);
    Destroy_BigInt(&b);
    Destroy_BigInt(&c);
    Destroy_BigInt(&t);

    return 0;
}
```

A simpler C++ program involving `BigInts`

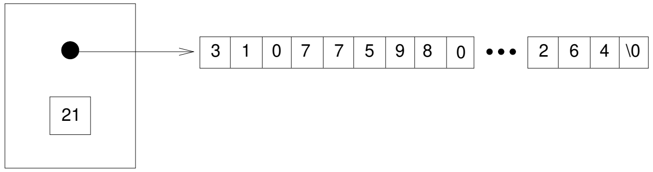
```
int main()
{
    BigInt a = "29587365452419232";
    BigInt b = "6948672303927125";
    BigInt c = a + b + 50;

    c.print();

    return 0;
}
```


The C++ compiler needed to know how to..

- *create* new instances of `BigInt`.
- *convert* character strings and integers to `BigInts`.
- *initialize* the value of one `BigInt` with another.
- *add* two `BigInts` together.
- *print* `BigInts`.
- *destroy* `BigInts` when no longer needed.

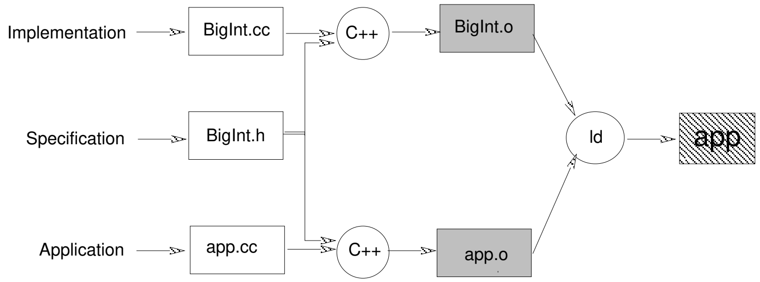
Where did this information come from?

The BigInt C++ Class declaration




```
class BigInt                          // "class" is a new C++ keyword
{
  private:                            // "private" variables are not
                                      //    accessible from the outside
    char *nd;
    int  ndigits;

  public:                             // "public" variables and functions
                                      //    can be accessed from the outside

    BigInt(const char *s);            // these are "constructors"; they
    BigInt(int);                      //    define ways of initializing BigInts.
                                      //    The first one builds BigInts from
                                      //    strings, the second one from ints.


    BigInt operator+(const BigInt &A);      // this is how we add BigInts

    BigInt& operator=(const BigInt &A);     // this is how we assign BigInts

    void print();                     // this is how we print BigInts

    ~BigInt();                        // this is how we destroy local BigInts
                                      //    when exiting functions
}
```


Integrating a BigInt library



Some common objects

- complex numbers
- vectors & matrices
- strings
- sets
- lists
- algebraic groups, rings, fields
- and, yes, even *stacks*...

C++ stack objects

C++ classes are essentially C `struct`'s bundled together with the corresponding *functions* that modify that data structure.

For example, here is the declaration for the stack example we used before, but now reformulated as a C++ class. This would typically be contained in its header file, e.g. "dstack.h":

```
// dstack.h -- Dynamic stack (DStack) declaration and function prototypes.
//
// Functions:
//
//      S.init(int N)          initialized stack of size N
//      S.push(val)             push new value on top of stack
//      S.pop()                  returns (and removes) top value of stack
//      S.num_items()            returns number of items currently on stack
//      S.size()                 returns max number of items stack can hold
//      S.full()                 returns 1 if stack is full, 0 otherwise
//      S.empty()                returns 1 if stack is empty, 0 otherwise
//      S.print()               print stack contents

class DStack
{
  private:
    float *bottom_;
    float *top_;
    int size_;

  public:
    DStack(int size=20);
    void push(float val);
    int num_items() const;
    float pop();
    int full() const;
    int empty() const;
    void print() const;
    ~DStack();
};
```

Things to note...

- A C++ `class` is basically a C `struct` that also allows functions as elements.
- Note that functions and variables are bundled together in *one* package.
- The `private` and `public` keywords clearly denote what items can and can't be modified by external programs.
- A common convention (although completely optional) is to suffix the private variable names with an underscore ("_") to help identify them.
- Member functions are accessed just like a `struct`'s element:

```
A.push(1.3);                    // used to be:  push(&A, 1.3);
x = A.pop();                    // used to be:  x = pop(&A);
if (!A.full()) A.push(2.9);     // used to be:  if (full(&A)) push(&A, 2.9);
```

- Also note that the "}" closing off the `class` declaration *must* be followed by a ";".

C++ classes: how they're used in programs

```
#include<iostream.h>
#include "dstack.h"

int main()
{
    DStack S(4);

    S.print();
    cout << "\n";

    S.push( 2.31);
    S.push(1.19);
    S.push(6.78);
    S.push(0.54);

    S.print(); cout <<  "\n";

    if (!S.full()) S.push(6.7);         // this should do nothing, as
                                        // stack is already full.
    S.print(); cout <<  "\n";

    cout << "Popped value is: " << S.pop() << "\n";
    S.print(); cout <<  "\n";

    S.push(S.pop() + S.pop());
    cout << "Replace top two items with their sum: \n";
    S.print(); cout <<  "\n";

    S.pop();
    S.pop();

    S.print(); cout << "\n";
    if (!S.empty()) S.pop();    // this should also do nothing,
                                // as stack is already empty.
    if (S.num_items() != 0)
    {
        cout << "Error: Stack is corrupt!\n";
    }

    return 0;                   // destructor for S automatically called
}
```

Program Output

```
Stack currently holds 0 items:

Stack currently holds 4 items:   2.31  1.19  6.78  0.54

Stack currently holds 4 items:   2.31  1.19  6.78  0.54

Popped value is: 0.54
Stack currently holds 3 items:   2.31  1.19  6.78

Replace top two items with their sum:
Stack currently holds 2 items:   2.31  7.97

Stack currently holds 0 items:
```


Things to note...

- Notice we've separated the *interface* of a `DStack` from its implementation.
- All `DStack`s are automatically initialized. There is no way to accidentally access an uninitialized stack!
- Notice also that any dynamic memory used by stacks is automatically freed by calling the destructor `~DStack()`.
- A `DStack` can still be treated like any basic data structure, e.g. being passed to and returned from functions.

C++ class implementation

What does the `DStack` *implementation* look like?

```
#include<iostream.h>
#include "dstack.h"

DStack::DStack(int N)              // how to initialize a stack with
{                                  //   N items.
   bottom_ = new float[N];
   top_ = bottom_;
   size_ = N;
}

DStack::~DStack()                  // how to reclaim memory from local
{                                  //   stacks when exiting functions
   delete [] bottom_;
}

int DStack::num_items() const      // number of items currently in stack
{
    return (top_ - bottom_ );
}

void DStack::push(float val)       // push a new value
{
    *top_ = val;
    top_++;
}

float DStack::pop()                // pop value from top
{
    top_--;
    return *top_;
}


int DStack::full() const           // 1 if full, 0 otherwise
{
    return (num_items() >= size_);
}
```



```
int DStack::empty() const          // 1 if empty, 0 otherwise
{
    return (num_items() <= 0);
}


void DStack::print() const
{
      cout << "Stack currently holds " << num_items() << " items: " ;
      for (float *element=bottom_; element<top_; element++)
      {
          cout << "  " << *element;
      }
      cout << "\n";

}
```

How we'd like to use complex numbers

```
#include <iostream.h>
#include "complex.h"

int main()
{
    Complex u(1.1, 3.9);
    Complex v(8.8, 5.4);
    Complex w, z;              // default to (0.0, 0.0)

    w = u + v;

    cout << "Default value: " << z << ".\n";

    cout << "Sum of " << u << " and " << v << " is " << w << ".\n";

}
```

Will produce

```
Sum of (1.1 + 3.9i) and (8.8 + 5.4i) is (9.9 + 9.3i).
```


Implementation of complex numbers

Declaration in "complex.h":

```
class Complex
{
    private:
        double real_;
        double img_;

    public:
        Complex();
        Complex(double real, double img);

        double real() const {return real_;}
        double img() const {return img_;}
        Complex conjugate() const;
        double  norm() const;
        Complex operator+(const Complex& x) const;
        Complex& operator=(const Complex& x);

        ~Complex();
};
```

- describing body of function in declaration (e.g. as in `real()` means that that function is declared *inline*.
- functions defined `const` (e.g. `norm()`, `operator+`) mean that calling them does not modify the object.
- the destructor `~Complex()` in this case, need not do anything, since the private data members do not utilize dynamic memory.

Complex number class: implementation

```
#include <math.h>
#include <iostream.h>
#include "complex.h"

Complex::Complex(double real, double img)
{
    real_ = real;
    img_ = img;
}

Complex::Complex()
{
    real_ = 0.0;
    img_ = 0.0;
}

Complex Complex::conjugate() const
{
    Complex t(real_, -img_);

    return t;
}

double Complex::norm() const
{
    return ( sqrt(real_*real_ + img_ * img_) );
}
```


Complex number class (cont'd)

```
Complex Complex::operator+(const Complex &b) const
{
    return Complex( real_ + b.real_ ,  img_  + b.img_);
}


Complex& Complex::operator=(const Complex &u)
{
    real_ = u.real_;
    img_ =  u.img_;
    return *this;
}

ostream & operator<<(ostream &s, const Complex &u)
{
    s << "(" << u.real() << " + " << u.img() << "i)";
    return s;
}

Complex::~Complex()
{
}
```

- why isn't `real_` and `img_` declared public and accessed directly. That is, why write `c.img()` rather than `c.img_` ?
- functions that were declared `const` in header, must also be declared const where implemented.

Programming Tips

- always define a default constructor and default destructor, even if you're not using dynamic memory! (You may later at some point...)
- use **#ifndef HEADER_FILENAME** macros to avoid including the same include file more than once.

```
#ifndef STACK_H_
#define STACK_H_

// declarations of DStack goes here

#endif
```

- use a naming convention to help identify private variables within class codes (e.g. appending an underscore to their name.)

Homework #3

1. Complete the C++ class for the complex numbers.

   Provide the following:

   - constructors (default plus at least one other), and destructor
   - operator definitions as discussed in class (+,−,∗,=)
   - some basic functionality (real(), imag(), conj(), norm(), etc.)
   - a print function
   - a short testing program demonstrating class usage

2. Recode your last stack example (Homework #2) as a C++ object. Implement the declaration in `dstack.h`, the implementation in `dstack.cc`, and a simple test driver in `tester.cc`. Use the code examples in this lecture as a guide.