This slide set covers pointers and arrays in C++. You should read Chapters 9 and 10 from your Deitel & Deitel book.
IntArray class

- Let’s implement an IntArray class to represent an array of integers

- This class will have the following features:
  - The array knows its size
  - Array items do not have garbage values
  - It always handles allocation and deallocation (such that as a user, you do not need to worry about explicitly using the new and delete operators)
  - It always deep copies the array items when an array’s copy is needed or the assignment operator is applied on the array
  - The subscript operator has array bound checking for accessing the array items
  - It uses cin >> and cout << for directly inputting and outputting the array items
IntArray definition

class IntArray {

public:
    // If a class has dynamically allocated data members, it is highly recommended to 
    // re-implement the destructor and copy constructor, and overload the assignment 
    // operator (instead of using the ones provided by the compiler)
    IntArray( const int = 0 ); // constructor with a default argument
    IntArray( const IntArray& ); // copy constructor
    ~IntArray(); // destructor
    IntArray& operator=( const IntArray& ); // overloaded assignment operator
    int& operator[]( const int ); // overloaded subscript operator

private:
    int size; // number of array items
    int* data; // dynamically allocated array

    // IntArray class declares the following two functions as its friend such that they
    // can access its private data members and call its private member functions
    friend istream& operator>>( istream&, IntArray& );
    friend ostream& operator<<( ostream&, const IntArray& );
};
IntArray implementation (constructor)

- Constructors are called implicitly by the compiler when an object is constructed (either by declaration or using the `new` operator)
  - The storage class of an object determines when it is constructed

- It is possible to implement multiple constructors as long as their signatures are different
  - The compiler selects which one to use based on its argument(s)
  - If an object is initialized with another object of the same type at its construction, the compiler calls the copy constructor

```cpp
// Constructor with a single integer parameter (this parameter has a default value set in the class definition such that it also serves as a default constructor)
IntArray::IntArray( const int aSize ) {
    if ( aSize <= 0 ) {
        size = 0;
        data = NULL;
    }
    else {
        size = aSize;
        data = new int[ size ];
        for ( int i = 0; i < size; i++ )
            data[ i ] = 0;
    }
}
```
**IntArray implementation (copy constructor)**

- **Copy constructor is called when**
  - An object is initialized with another of the same type at its declaration (construction)
    ```
    IntArray prev;
    IntArray current( prev );
    IntArray next = current;
    ```
  - An object is passed by value as an argument to a function (pass-by-value)
  - An object is returned by value from a function (however, C++ Standard allows compilers to optimize this)

- **If not provided explicitly, the compiler provides a default copy constructor performing memberwise shallow copy**
  - It does not deep copy the data members
    ```
    // This copy constructor deep copies the array items as opposed to default copy constructor provided by the compiler
    IntArray::IntArray( const IntArray& arr )
    : size( arr.size ) {
        if ( size > 0 ) {
            data = new int[ size ];
            for ( int i = 0; i < size; i++ )
                data[ i ] = arr.data[ i ];
        }
        else
            data = NULL;
    }
    ```

  *It must receive its argument by reference (not by value). Otherwise, it results in infinite recursion.*
  *Its argument should also be `const` to allow a constant object to be copied.*
Destructor is a special member function that is called implicitly by the compiler when an object is destructed (either when its lifetime ends or when the \texttt{delete} operator is used)

- Destructor calls are usually made in the reverse order of their corresponding constructor calls
- However, the storage class of objects may alter this order

Each class should have only one destructor (no overloading is allowed)

If not provided explicitly, the compiler creates an “empty” destructor

```cpp
IntArray::~IntArray() {
    if (data)
        delete[] data;
}
```

```cpp
// Constructor call for a single dynamically created object
IntArray* a1 = new IntArray(400);

// Default constructor call for every object in the array
IntArray* a2 = new IntArray[5];

// Destructor call for the single object
delete a1; //

// Every object in the array receives a destructor call. If "delete a2;" is used, only the first object receives a destructor call
delete[] a2;
```
Operator overloading

- For every class, the following operators are provided by the compiler:
  - Assignment operator (\texttt{=}) → performs memberwise assignment between two objects
  - Address operator (\texttt{&}) → returns the address of an object
  - Comma operator (\texttt{,}) → first evaluates its first (left) operand, then evaluates its second (right) operand and returns its value

- Although they are provided by the compiler, these operators can also be overloaded by the programmer.

- Other operators can also be overloaded except . :: ?: sizeof

- Operator overloading should be done for a class individually:
  - By defining a member function (in that class) for this operator
  - Where the name of this function should be \texttt{operator <operator-to-be-overloaded>
IntArray implementation *(assignment operator)*

- It is called when the left operand is an object
- If not provided explicitly, the compiler provides a default assignment operator that assigns each data member of the right object to the same data member of the left object
- However, this default assignment operator performs **shallow copy** for the memberwise assignments

```cpp
IntArray& IntArray::operator=( const IntArray& right ) {
    if ( &right != this ) { // to avoid self-assignment
        if ( size != right.size ) {
            if ( size > 0 )
                delete [] data;
            size = right.size;
            if ( size > 0 )
                data = new int[ size ];
            else
                data = NULL;
        }
        data = NULL;
    }
    for ( int i = 0; i < size; i++ )
        data[ i ] = right.data[ i ];
    return *this; // to allow cascading
}
```

One can also define additional assignment operators where the right operand is of another data type
**this pointer**

- Every object has access to its own address through a pointer called **this**
  - The **this** pointer is not a part of the object
  - The compiler passes it as an implicit argument to a non-static member function call of this object

- An object uses its this pointer
  - Implicitly when accessing its members directly
  - Explicitly when using the **this** keyword

- The type of the **this** pointer depends on the object’s type and whether the executing member function is declared as **const**

**static member functions**

- A member function can be declared as **static** if it does not access any non-static data member or call any non-static member function of its class
- **static** data members of a class exist in memory and its **static** member functions can be called even when there exist no object of this class in memory
- A **static** member function does not have the this pointer
IntArray implementation *(subscript operator)*

- Other operators can also be overloaded
- This subscript operator facilitates array bound checking for accessing the array items

```cpp
int& IntArray::operator[](const int ind) {
    if (ind < 0 || ind >= size) {
        throw out_of_range("Invalid index");
    } else {
        return data[ind];
    }
}
```

The return type of this function should be of a reference type since its returned value can be used both as an lvalue and as an rvalue

IntArray arr(5);
cout << arr[3]; // used as an rvalue
arr[3] = 10; // used as an lvalue

// You can throw and catch exceptions also in C++, as in the following example
#include <exception>
int main() {
    IntArray arr(100);
    try {
        arr[130] = 20;
    }
    catch (const exception& e) {
        cout << e.what() << endl;
    }
    return 0;
}
IntArray implementation (cin >> and cout <<)

- These are overloaded global functions since their left operand is not an IntArray object.
- They are implemented for directly inputting and outputting the array items.

```cpp
istream& operator>>( istream& in, IntArray& arr ) {
    cout << "Enter " << arr.size << " integers: ";
    for ( int i = 0; i < arr.size; i++ )
        cin >> arr.data[ i ];
    return in;
}

ostream& operator<<( ostream& out, const IntArray& arr ) {
    for ( int i = 0; i < arr.size; i++ )
        cout << arr.data[ i ] << " \t";
    cout << endl;
    return out;
}
```

A class may declare other classes or functions as its friend such that they can access its private data members and member functions.

```cpp
class IntArray {
    // ...
    friend istream& operator>>( istream& , IntArray& );
    friend ostream& operator<<( ostream& , const IntArray& );
};
```
Example: Given the following Test class, what are the outputs of the following programs?

These examples are for you to better understand when the constructor, copy constructor, destructor, and assignment operator are called.
**Example:** Given the `Test` class above, what are the outputs of this program?

Do not forget that the constructor, copy constructor, destructor, and assignment operator are called only **for an object**. For example, they are not called for an object pointer or a class data member.

```cpp
Test t1( 10 );
Test t2( 20 );

void foo( bool flag ){
    Test t3( 30 );
    static Test t4( 40 );

    if ( flag ){
        Test t5( 50 );
        Test t6( 60 );
    }
    Test t7( 70 );
}

int main() {
    cout << "checkpoint 1---" << endl;
    Test t8( 80 );

    cout << "checkpoint 2---" << endl;
    foo( false );

    cout << "checkpoint 3---" << endl;
    foo( true );

    cout << "checkpoint 4---" << endl;
    return 0;
}
```
Example: Given the Test class above, what are the outputs of this program?

Do not forget that the constructor, copy constructor, destructor, and assignment operator are called only for an object. For example, they are not called for an object pointer or a class data member.

```cpp
int main() {
    cout << "checkpoint 1---" << endl;
    Test *b1;
    
    cout << "checkpoint 2---" << endl;
    b1 = new Test ( 100 );
    delete b1;
    
    cout << "checkpoint 3---" << endl;
    b1 = new Test [2];
    b1[0].id = 200;
    b1[1].id = 300;
    delete []b1;
    
    cout << "checkpoint 4---" << endl;
    b1 = new Test [2];
    b1[0].id = 400;
    b1[1].id = 500;
    delete b1;
    
    cout << "checkpoint 5---" << endl;
    return 0;
}
```
Example: Given the Test class above, what are the outputs of this program?

Do not forget that the constructor, copy constructor, destructor, and assignment operator are called only for an object. For example, they are not called for an object pointer or a class data member.