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Composition of Classes

Composition: an organized collection of components interacting to achieve a coherent, common behavior.

Why compose classes?

Permits a "lego block" approach to design and implementation:
- Each object captures one reusable concept.
- Composition conveys design intent clearly.

Improves readability of code.

Promotes reuse of existing implementation components.

Simplifies propagation of change throughout a design or an implementation.

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Composition by Association

Association (acquaintance)

Example: a database object may be associated with a file stream object.
The database object is "acquainted" with the file stream and may use its public interface to accomplish certain tasks.

Acquaintance may be one-way or two-way.

Association is managed by having a "handle" on the other object.

Associated objects have independent existence (as opposed to one being a sub-part of the other).

Association is generally established dynamically (at run-time), although the design of one of the classes must make a provision for creating and maintaining the association.

Sometimes referred to as the "knows-a" relationship.

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A Simple Association


```
class DisplayableNumber {
private:
   int      Count;
   ostream* Out;
public:
   DisplayableNumber(int InitCount = 0, ostream& Where = cout);
   void ShowIn(ostream& setOut);
   void Show() const;
   void Reset(int newValue);
   int Value() const;
};
```

```
void DisplayableNumber::ShowIn(ostream& setOut) {
   Out = &setOut;
}

void DisplayableNumber::Show() const {
   *Out << Count << endl;
}
```

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Composition by Aggregation

Aggregation (containment)

Example: a LinkList object contains a Head pointer to the first element of a linked list of Node objects, which are only created and used within the context of a LinkList object.

The objects do not have independent existence; one object is a component or sub-part of the other object.

Aggregation is generally established within the class definition. However, the connection may be established by pointers whose values are not determined until run-time.

Sometimes referred to as the "has-a" relationship.

A Simple Aggregation


```
class Array {        // static-sized array encapsulation
private:
   int   Capacity;   // maximum number of elements list can hold
   int   Usage;      // number of elements list currently holds
   Item* List;       // the list

   void ShiftTailUp(int Start);
   void ShiftTailDown(int Start);
   void Swap(Item& First, Item& Second);

public:
   Array();                              // empty list of size zero
   Array(int initCapacity);              // empty list of size initCapacity
   Array(int initCapacity, Item Value);  // list of size initCapacity,
                                         //    each cell stores Value
   Array(const Array& oldArray);         // copy constructor

   int  getCapacity() const;               // retrieve Capacity
   int  getUsage() const;                  //          Usage
   bool isFull() const;                    // ask if List is full
   bool isEmpty() const;                   //             or empty
// . . . continues . . .
```


A Simple Aggregation

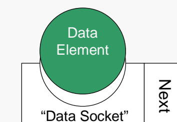

```
// . . . continued
   bool InsertAtTail(Item newValue);      // insert newValue at tail of list
   bool InsertAtIndex(Item newValue, int Idx);// insert newValue at specified
                                          //    position in List

   bool DeleteAtIndex(int Idx);       // delete element at given index
   bool DeleteValue(Item Value);      // delete all copies of Value in list

   Item Retrieve(int Idx) const;      // retrieve value at given index
   int  FindValue(Item Value) const;  // find index of first occurrence of
                                      //    given value

   void Clear();                      // clear list to be empty, size zero
   void Reverse();                    // reverse order of list elements

   ~Array();                          // destroy list (deallocate memory)
};
```


Composition for Flexibility

The use of composition not only promotes the reuse of existing implementations, but also provides for more flexible implementations and improved encapsulation:

Here we have a design for a list node object that:

- separates the structural components (list pointers) from the data values
- allows the list node to store ANY type of data element



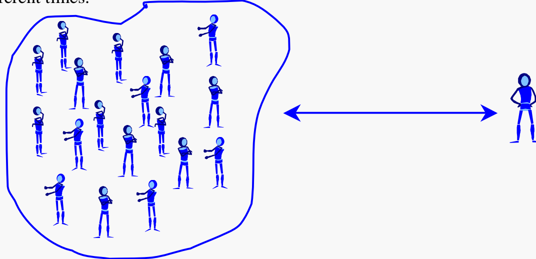

```
class LinkNode {
private:
   ItemType Data;      // data "capsule"
   LinkNode* Next;     // pointer to next node

public:
   LinkNode();
   LinkNode(ItemType newData);
   void setData(ItemType newData);
   void setNext(LinkNode* newNext);
   ItemType getData() const;
   LinkNode* getNext() const;
};
```

Communicating Objects

Think of the "Borg"on Star Trek.

Borg crew member = 1 object
Borg Collective = composition of objects

To achieve the purpose of the Collective, each Borg must continually communicate with other Borg. A Borg can be a "sender" or a "receiver", and may play both roles at different times.



Similarly, objects can be senders or receivers.

Communication: inter-Object Communication

By name: sender "knows the name" of the receiver and uses the name to access the public interface of the receiver.

```
DisplayableNumber D(42, cout);

D.Show();   // D accesses cout by its pointer member
```

```
void DisplayableNumber::Show() const {

   *Out << Count << endl;
}
```


Communication: Passing an Object

An object may be passed as a function parameter:

```
DisplayableNumber D(42, cout);
ofstream oFile("output.text");

D.ShowIn(oFile);   // D receives oFile as a parameter
```

```
void DisplayableNumber::ShowIn(ostream& setOut) {

   Out = &setOut;   // store address of setOut
}
```

As is always the case in C++, by default an object parameter is passed by value to the called function.

Communication: Returning an Object

An object may be the return value from a function:

```
typedef DisplayableNumber Item;    // define an alias
const int Digits = 10;
Array LCD(Digits, Item(0, cout));    // array of DNs

. . .

DisplayableNumber Digit4 = LCD.Retrieve(4);  // shallow copy

. . .
```

```
Item ArrayClass::Retrieve(Item Idx) const {

   if (Idx >= Usage)
      return -1;
   else
      return List[Idx];
}
```

Using an object as the return value provides a mechanism for encapsulating a body of related heterogeneous data (as does using a struct).

Composition Example: Simple Array of Objects


```
#include <iostream>
using namespace std;
#include "DisplayableNumber.h"
const int Digits = 5;

void main() {
   DisplayableNumber* LCD = new DisplayableNumber[Digits];

   for (int Idx = 0; Idx < Digits; Idx++) {
       LCD[Idx].Show();
   }
   delete [] LCD;
}
```

If the constructors and destructors are instrumented, this program produces the output:

```
Constructing: DisplayableNumber
Constructing: DisplayableNumber
Constructing: DisplayableNumber
Constructing: DisplayableNumber
Constructing: DisplayableNumber
0
0
0
0
0
Destructing: DisplayableNumber
Destructing: DisplayableNumber
Destructing: DisplayableNumber
Destructing: DisplayableNumber
Destructing: DisplayableNumber
```


Aggregation Example: Fancy Array of Objects


```
#include <iostream>
using namespace std;

#include "Array.h"
const int Digits = 5;

void main() {
   Array LCD(Digits, Item(0, cout));

   for (int Idx = 0; Idx < Digits; Idx++) {
      LCD.Retrieve(Idx).Show();
   }
}
```

Note use of a nameless, or “anonymous” object.

Note use of member function of the returned `DisplayableNumber` object.

`Array.h` #includes `Item.h`, which contains:

```
#include "DisplayableNumber.h"
typedef DisplayableNumber Item;
```


Aggregation Example: Fancy Array of Objects


```
#include <iostream>
using namespace std;

#include "Array.h"
const int Digits = 5;

void main() {
   Array LCD(Digits, Item(0, cout));

   for (int Idx = 0; Idx < Digits; Idx++) {
      LCD.Retrieve(Idx).Show();
   }
}
```

If the constructors and destructors are instrumented, this program produces the output shown.

There are a few subtleties illustrated here…

```
Constructing: DisplayableNumber
Constructing: Array
Constructing: DisplayableNumber
Constructing: DisplayableNumber
Constructing: DisplayableNumber
Constructing: DisplayableNumber
Constructing: DisplayableNumber
Destructing: DisplayableNumber
Destructing: DisplayableNumber
0
Destructing: DisplayableNumber
0
Destructing: DisplayableNumber
0
Destructing: DisplayableNumber
0
Destructing: DisplayableNumber
0
Destructing: DisplayableNumber
Destructing: Array
Destructing: DisplayableNumber
Destructing: DisplayableNumber
Destructing: DisplayableNumber
Destructing: DisplayableNumber
Destructing: DisplayableNumber
```


Aggregation and Constructor Sequencing


```
const int Digits = 5;
. . .
Array LCD(Digits, Item(0, cout));
```

```
Constructing: DisplayableNumber
Constructing: Array
Constructing: DisplayableNumber
Constructing: DisplayableNumber
Constructing: DisplayableNumber
Constructing: DisplayableNumber
Constructing: DisplayableNumber
```

Here, the sub-objects are constructed AFTER the `Array` object is constructed. The reason is fairly clear if the `Array` constructor is examined:

```
Array::Array(int initCapacity, Item Value) {

   Capacity = initCapacity;
   Usage    =  Current = 0;
   List     = new Item[initCapacity];

   for (int Idx = 0; Idx < Capacity; Idx++)
      List[Idx] = Value;

   Usage = Capacity;
}
```

Here, the array elements don’t exist until the `Array` constructor creates the array dynamically.

Aggregation and Destructor Sequencing


```
#include <iostream>
using namespace std;

#include "Array.h"
const int Digits = 5;

void main() {
   Array LCD(Digits, Item(0, cout));

   . . .
}
```

```
. . .
Destructing: DisplayableNumber
Destructing: DisplayableNumber

. . .

Destructing: Array
Destructing: DisplayableNumber
Destructing: DisplayableNumber
Destructing: DisplayableNumber
Destructing: DisplayableNumber
Destructing: DisplayableNumber
```

The anonymous `DisplayableNumber` object constructed in the `Array` constructor call is destructed when the call completes. Also, since it is passed by value, a copy is made within the constructor, and the copy is also destructed when the call completes.

When `main()` terminates, the `Array` object is destructed. The `Array` destructor `deletes` its array, and that causes the destruction of each array element.

Anonymous Objects and Returned Objects


```
. . .
for (int Idx = 0; Idx < Digits; Idx++) {
   LCD.Retrieve(Idx).Show();
}
. . .
```

```
. . .
0
Destructing: DisplayableNumber
0
Destructing: DisplayableNumber
0
Destructing: DisplayableNumber
0
Destructing: DisplayableNumber
0
Destructing: DisplayableNumber
. . .
```

On each pass through the `for` loop, an anonymous object is created and then destructed (when it goes out of scope at the end of the loop).

But, why are no constructor calls shown?

```
Item Array::Retrieve(int Idx) const {

   if (Idx >= Usage)
      return Item();
   else
      return List[Idx];
}
```

Because the return value is created by a copy constructor (not instrumented).

One Last Aggregation Puzzler


```
class Foo {
private:
   DisplayableNumber DN;
public:
   Foo();
   Foo(DisplayableNumber DN);
   ~Foo();
};
```

```
Foo::Foo() {
   cout << "Constructing: Foo" << endl;
   DN = DisplayableNumber(0, cout);
}

Foo::Foo(DisplayableNumber DN) {
   cout << "Constructing: Foo" << endl;
   this->DN = DN;
}

Foo::~Foo() {
   cout << "Destructing: Foo" << endl;
}
```

Now, the `DisplayableNumber` is a data member; it is created when a `Foo` object is created.

(TRUE aggregation)

```
DisplayableNumber myDN(17, cout);

Foo urFoo(myDN);
```

```
Constructing: DisplayableNumber
. . .
Constructing: DisplayableNumber
Constructing: Foo
Destructing: DisplayableNumber
. . .
Destructing: Foo
Destructing: DisplayableNumber
Destructing: DisplayableNumber
```


Typical Aggregation Sequencing

In a typical aggregation, where the sub-objects are data members (not allocated dynamically), the following rules hold for constructor and destructor sequencing:

Construction: the default constructor is invoked for each sub-object, then the constructor for the containing object is invoked.

So, aggregates are constructed from the inside-out.

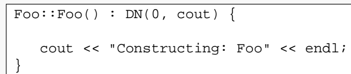
Destruction: the destructor is invoked for the containing object first, and then the destructor for each sub-object is invoked.

So, aggregates are destructed from the outside-in.

It's also possible to invoke a non-default constructor for a sub-object. . .

Controlling Aggregation Sequencing

Constructors for sub-objects may be explicitly invoked BEFORE the body of the containing object's constructor:



```
Foo::Foo() : DN(0, cout) {

   cout << "Constructing: Foo" << endl;
}
```

Here, a `DisplayableNumber` constructor is invoked and passed two parameters (which could have been parameters to the `Foo` constructor if that had been appropriate).

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Different Ways to Communicate

Is object communicated by:

- copying
- reference
- pointer

Can the receiver modify the object?

If the receiver does modify the object, does the sender see the changes?

What language syntax is used in receiver to access (`.` or `->`)?

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Characteristics of Communicated Objects

Technique	Copied	Changeable	Visible	C++ Syntax
by copy	yes	yes	no	.
by reference	no	yes	yes	.
by pointer	no	yes	yes	->
by const reference	no	no	no	.
by const pointer	no	no	no	->

By Copy:

- ✔ Sender is "isolated" from changes by receiver
- ✘ No good if sender/receiver want to share object
- ✘ Bad if object is large (why?)

By Identity (pointer or reference):

- ✘ No isolation
- ✔ Permits sharing of objects
- ✔ Improves memory cost for large objects

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