Composition: Cooperating 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.

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.

A Simple Association

```cpp
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;
};
```

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

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

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**A Simple Aggregation**

### Class Array

```cpp
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 . . .

    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

```cpp
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;
    ~LinkNode(); // destroy list (deallocate memory)
};
```
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

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

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
...

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

```cpp
#include <iostream>
#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

```cpp
#include <iostream>
#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.

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

```
0
```

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

Aggregation and Constructor Sequencing

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

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.
The anonymous \textit{DisplayableNumber} object constructed in the \textit{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 \texttt{main()} terminates, the \textit{Array} object is destructed. The \textit{Array} destructor deletes its array, and that causes the destruction of each array element.

On each pass through the \texttt{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?

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

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

\begin{itemize}
  \item Construction: the default constructor is invoked for each sub-object, then the constructor for the containing object is invoked.
  \item Destruction: the destructor is invoked for the containing object first, and then the destructor for each sub-object is invoked.
\end{itemize}

It's also possible to invoke a non-default constructor for a sub-object...
Constructors for sub-objects may be explicitly invoked BEFORE the body of the containing object’s constructor:

```c++
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).

**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 ->)?

**Characteristics of Communicated Objects**

<table>
<thead>
<tr>
<th>Technique</th>
<th>Copied</th>
<th>Changeable</th>
<th>Visible</th>
<th>C++ Syntax</th>
</tr>
</thead>
<tbody>
<tr>
<td>by copy</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>-</td>
</tr>
<tr>
<td>by reference</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>-</td>
</tr>
<tr>
<td>by pointer</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
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</tr>
<tr>
<td>by const reference</td>
<td>no</td>
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</tr>
</tbody>
</table>

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