Composition of Classes

**Aggregation**

**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 Aggregation

**Aggregation (containment)**

Example: an Employee object contains an Address object which encapsulates related information within a useful package.

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

Neither object has “meaning” without the other.

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

Sometimes referred to as the “has-a” relationship.

Advantages of Aggregation

**Aggregation**

Simplicity – client can deal directly with the containing object (the aggregating object or aggregation) instead of dealing with the individual pieces.

Safety – sub-objects are encapsulated.

Specialized interface – general objects may be used together with an interface that is specialized to the problem at hand.

Structure indicates the designer's intention and system abstraction.

Can substitute implementations.

Static vs Dynamic Aggregation

**Static** – the number of sub-objects does not vary.
- a person has a name and an address
- a rectangle has a NW corner and a height and a width

**Dynamic** – the number of sub-objects may vary.
- a catalog may have many items, and they may be added/deleted
- a host list has a changing list of entries
Aggregation in Class Diagrams

This is similar to the representation of an association relationship except that the arrow is rooted in a diamond instead of a circle.

Cardinality is indicated in the same manner. For a dynamic aggregation, the cardinality for the aggregated type (Name here) would be either a range, such as 0..n or an asterisk.

Simple Aggregations

An Address object physically contains a number of constituent objects:

```cpp
class Address {
private:
    string Street1,
    Street2;
    string City;
    string State;
public:
    Address(); // irrelevant for now
    ~Address();
};
```

For instance, the object City is created when an Address object is created and destroyed when that object is destroyed. For our purpose, the City object has no meaning aside from its contribution to the Address object.

A More Interesting Aggregation

A Person object physically contains an Address object and a Name object:

```cpp
enum Gender {MALE, FEMALE, GENDERUNKNOWN};
class Person {
private:
    Name Nom;      // sub-object
    Address Addr;  // sub-object
    Person* Spouse; // association link
    Gender Gen;    // simple data member
public:
    Person();
    // mostly irrelevant for now
    ~Person();
};
```

There is also a provision in the Person object for an association with another Person object.

Typical Aggregation Construction/Destruction

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.

There is no default initialization for simple data members. Those should be handled explicitly in the constructor for the "enclosing" object.
The Person constructors must manage sensible initialization of the simple data members:

```cpp
Person::Person() {
    Spouse = NULL;
    Gen = GENDERUNKNOWN;
}

Person::Person(Name N, Address A, Gender G) {
    Nom = N;
    Addr = A;
    Spouse = NULL;
    Gen = G;
}
```

It is not necessary for the default constructor to manage initializing the sub-objects Nom and Addr since the default constructors for their types will be invoked automatically.

Consider the trivial program below:

```cpp
int main() {
    Person P;
}
```

The constructors and destructors were instrumented so that we can see when they are invoked.

Obviously, this is consistent with the stated rules for aggregate construction and destruction.

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

The use of composition promotes the reuse of existing implementations, and 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...
- without needing any knowledge of that type

```cpp
class LinkNode {
private:
    Item Data; // data "capsule"
    LinkNode* Next; // pointer to next node
public:
    LinkNode();
    LinkNode(Item newData);
    void setData(Item newData);
    Item getData() const;
    LinkNode* getNext() const;
};
```
Aggregation via Containers

One of the most common scenarios for aggregation is the use of some sort of container object to organize a collection of objects of some type.

The following slides present the interface for a simple array class that can be used with any type of data element.

To achieve that, we assume that the name of the type to be stored has been mapped to a dummy type name, which is then used in the class implementation.

For example,

```cpp
typedef Person Item;
```

A Simple Container Class

```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);

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 . . .

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

A Simple Container Class

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

global void main() {
    ofstream Out("LCD.out");
    Array LCD(Digits, Item(0, &Out));
    for (int Idx = 0; Idx < Digits; Idx++) {
        LCD.Retrieve(Idx).Show();
    }
}
```

Aggregation Example: Fancy Array of Objects

```cpp
#include <iostream>
using namespace std;
#include "Array.h"

const int Digits = 5;

void main() {
    ofstream Out("LCD.out");
    Array LCD(Digits, Item(0, &Out));
    for (int Idx = 0; Idx < Digits; Idx++) {
        LCD.Retrieve(Idx).Show();
    }
}
```

As shown in the previous slide, the array class in this example contains methods to manipulate and access the list of items. For instance, the `Retrieve` method retrieves an item at a specified index, and the `DeleteAtIndex` method deletes an item at a given index.

In the example code, the `Array` object is declared and initialized with a certain number of digits. Then, for each digit, the content is printed to an output file named `LCD.out`. This demonstrates how the array class can be used to organize and manipulate objects of a specific type.
### 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. There are a few subtleties illustrated here...

### Aggregation and Constructor Sequencing

```cpp
Aggregation Example: Fancy Array of Objects
```

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

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

```cpp
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.

### Anonymous Objects and Returned Objects

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

On each pass through the `for` loop, an anonymous object is created and then destructed (when its lifetime ends at the end of the loop body).

But, why are no constructor calls shown?

```cpp
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

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

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

(physical aggregation)

```cpp
DisplayableNumber myDN(17, &cout);
Foo urFoo(myDN);
```

Constructing: DisplayableNumber...

Constructing: DisplayableNumber...

Constructing: Foo...

Destructing: DisplayableNumber...

Destructing: Foo...

Destructing: DisplayableNumber...

Extended Example

Consider a system for keeping track of passengers in a bus system, keeping a counter for bus passengers using each of several payment methods:

```cpp
class Passenger {
private:
    int Cnt;
public:
    Passenger();
    Passenger(int iCnt);
    void incUniv();
    void incMonthly();
    void incCash();
    void increment();
    int getCount();
    ~Passenger();
};
```

We will employ a Counter class:

```cpp
class Counter {
private:
    int Cnt;
public:
    Counter();
    Counter(const Counter& C);
    void increment();
    int getCount();
    ~Counter();
};
```

The integer data member is initialized using the initializer list.

The second constructor is a copy constructor.
We will employ a PassengerCounter class:

```cpp
class PassengerCounter {
private:
    Counter UnivID, Monthly, Cash;
public:
    PassengerCounter();
    PassengerCounter(const PassengerCounter& P);
    void incUnivID();
    void incMonthly();
    void incCash();
    int getUnivIDCount() const;
    int getMonthlyCount() const;
    int getCashCount() const;
    void Summarize(ostream& Out) const;
    ~PassengerCounter();
};
```

Constructors:
```cpp
PassengerCounter::PassengerCounter() :
    UnivID(), Monthly(), Cash() {}
PassengerCounter::PassengerCounter(const PassengerCounter& P) :
    UnivID(P.UnivID), Monthly(P.Monthly),
    Cash(P.Cash) {}
```

Mutators:
```cpp
void PassengerCounter::incUnivID() {
    UnivID.Increment();
}
void PassengerCounter::incMonthly() {
    Monthly.Increment();
}
void PassengerCounter::incCash() {
    Cash.Increment();
}
```

Accessors:
```cpp
int PassengerCounter::getUnivIDCount() const {
    return UnivID.getCount();
}
int PassengerCounter::getMonthlyCount() const {
    return Monthly.getCount();
}
int PassengerCounter::getCashCount() const {
    return Cash.getCount();
}
```

Display function:
```cpp
void PassengerCounter::Summarize(ostream& Out) const {
    Out << "Payment summary:" << endl << endl;
    Out << "University ID  |" << setw(5) << getUnivIDCount() << endl;
    Out << "Monthly pass   |" << setw(5) << getMonthlyCount() << endl;
    Out << "Cash           |" << setw(5) << getCashCount() << endl;
}
```

Driver to test the PassengerCounter class:
```cpp
int main() {
    PassengerCounter RiderStats;
    srand( (unsigned)time( NULL ) );
    for (int i = 0; i < 100; i++) {
        int payType = rand() % 3;
        switch (payType) {
            case 0: RiderStats.incUnivID(); break;
            case 1: RiderStats.incMonthly(); break;
            case 2: RiderStats.incCash(); break;
            default: break;
        }
    }
    RiderStats.Summarize(cout);
    return 0;
}
```
Aside: Equality

The design of an equality operation poses some questions which require careful consideration. The same applies to any of the relational operators.

When are two Counter objects equal
   - When are same object?
   - When have same value?

Which is more appropriate depends on class and how it is used.

Whichever is appropriate, you can provide an overloaded equality operator for the class.

The point is that the meaning of equality requires a formal definition, and it may well not mean that the objects have identical content.

Equality: Implementations

If equality means the objects are the same object, compare the addresses of the objects:

```cpp
bool Counter::operator==(const Counter& Other) {
    return (this == &Other);
}
```

This would be silly unless you are using pointers to Counter objects.

If equality means the objects store the same counter value, compare the Cnt members of the objects:

```cpp
bool Counter::operator==(const Counter& Other) {
    return (Cnt == Other.Cnt);
}
```

Relational Operators in General

If objects of a class will routinely be stored in a container, the class should provide overloading for at least some of the relational operators.

In order to perform searches and sorts, the container object must be able to compare the stored objects. There are several approaches:

- use accessor members of the stored objects and compare data members directly
- use comparison member functions of the stored objects, as opposed to operators, to compare the data members
- use overloaded relational operators provided by the stored objects

The first requires the container to know something about the types of the data members being compared.

The second requires the stored objects to provide member functions with constrained interfaces.

The third allows natural, independent design on both sides.

< (less than): Implementation

There is no particular uncertainty about the correct definition of a less-than operator for the Counter class:

```cpp
bool Counter::operator<(const Counter& Other) {
    return (Cnt < Other.Cnt);
}
```

Other relational operators can be overloaded as easily.

It is insignificantly more expensive to overload all six relational operators than to overload only one or two.