

- **Basic OOP Concepts**

- **Introduction**

- **Goal of OOP: Reduce complexity of software development by keeping details, and especially changes to details, from spreading throughout the entire program.**

- **This presentation assumes "Basic Class Design" presentation.**

- **Definitions**

- *Client Code* - the code that uses the classes under discussion.
- *Coupling* - code in one module depends on code in another module
 - Change in one forces rewrite (horrible!), or recompile (annoying), of code in the other.

- **Four key concepts of OOP**

- *Abstraction - responsibilities (interface) is different from implementation*
 - Distinguish between interface and its behavior vs. the implementation and its details
 - A class provides some services, takes on some responsibilities, that are defined by the public interface. How it works inside doesn't matter.
 - Client should be able to use just the public interface, and not care about the implementation.
- *Encapsulation - guarantee responsibilities by protecting implementation from interference*
 - Developer of a class can guarantee behavior of a class only if the internals are protected from outside interference. Specifying private access for the internals puts a wall around the internals, making a clear distinction between which code the class developer is responsible for, and what the client developers are responsible for.
- *Inheritance - share interface and/or implementation in related classes*
 - Express commonalities between classes of objects by arranging them into an inheritance hierarchy. Allows functionality shared between classes to be written/debugged/maintained in one place, the base class, and then reused in descendant classes (shared implementation).
 - More importantly, allows client code to interact with classes in the hierarchy through an interface specified in the base class of the hierarchy (shared interface).
- *Polymorphism - decouple client from exact class structure*
 - Allows client code to use classes in a class hierarchy in a way that depends only on the public interface of the base class. Derived classes will implement this interface differently, but in ways compatible with the shared public interface.

- **Guidelines for Designing Individual and Concrete Classes**

- **"Concrete" classes - no inheritance or polymorphism involved.**

- *Objects interact with each other, contain each other, refer to each other.*
- *Main program causes initial objects to be created, delegates work to objects as needed.*

- **Two kinds of classes:**

- *Objects that are in the problem domain.*
 - Accounts, Customers, Banks, Rooms, Meetings, Persons, Ships, Islands, Resources.
- *Objects that support the other objects.*
 - E.g. String, Ordered_list, map<>, priority_queue<>

- **Design a class by choosing a clear set of responsibilities.**

- *If class responsibilities can't be made clear, then OOP might not be a good solution*
 - Lots of problems work better in procedural programming than in OOP, so there is no need to force everything into the OO paradigm.

- Making this distinction is critical to understanding the difference between traditional procedural programming and OOP.
- *Beware of classes that do nothing more than a C struct.*
 - Is it really a "Plain Old Data" object, like C struct, or did you overlook something?
 - If it is a simple bundle of data, define it as a simple struct.
 - If there are functions that operate on the data, maybe they should be member functions, and maybe these objects really are responsible for something.
- *Symptoms of a lazy class - not being responsible for its own data and computations.*
 - Other code (e.g. main module) has to tell the object what to do and when to do it, or what its variable values should be, when it has the knowledge to do the work itself.
 - E.g. instead of the class updating its own member variables when it does something, other code tells it to do the update.
 - All (or almost all) member variables have both getter and setter functions, which suggests that the client code is doing the work, and the class is just a passive holder of data.
- *Symptoms of misallocated responsibilities - redundant or misplaced computations.*
 - The class makes decisions or does computations that other code also does.
 - E.g. client makes decisions, then class also makes similar decisions internally.
 - Why doesn't just one of them do it?
 - The class has to figure out what work it is supposed to do when the client code could be more specific.
 - E.g. look at a member function parameter and branch to different code depending on it.
 - Why not separate member functions and the client decides which to call instead of passing a code?
 - The client code is responsible for passing information between objects that don't communicate directly.
 - Might be a "god" module.
- **Principle: Avoid heavy-weight, bloated, or "god" classes - prefer clear limited responsibilities.**
 - *If a class does everything, it is probably a bad design. You may have misunderstood the problem domain. You have probably combined things that should be delegated to derived classes or peer classes, or even to separate objects from a simpler class.*
 - *Symptoms of a heavy-weight or bloated class:*
 - A large number of unrelated member functions or variables that don't correspond to any simple concept of the classes responsibility.
 - An inability to summarize the class's responsibility in a short English description.
 - Only one of them gets created, because it does multiple things that would be separate objects if the class was simpler.
 - When a member function is called, you have to include an additional parameter that signals the object what kind of thing to do.
 - If the object is a container of data of some sort, it includes several functions that are so specialized that it couldn't possibly be used in another project that needs that same general kind of functionality.
 - *Symptoms of a "god" class:*
 - Doing things to or for other classes that they could be doing for themselves.
 - Common example: Stuffing another object with its data instead of letting it initialize itself from the data source.
 - Everybody's friend: "god" class has to mess around inside everybody else, so they declare it to be a friend.

- Complete accessors to private members provided for benefit of the "god" class to allow it to see and control everything.
 - Control should stem from the interaction of objects with clear responsibilities, not one object in charge of everything.
- **Make all member variables private in each class.**
 - *Concept: Programmer of a class has to be able to guarantee that class will fulfill its responsibilities - do what he/she says it will do.*
 - encapsulation - making member data private- is the basic step that makes this guarantee possible - prevents other code from tampering with the data.
 - *No public and no protected member variables.*
 - *Beware of get_ functions that return a non-const pointer or reference to a private member variable - breaks the encapsulation!*
- **Put in the public interface only the functions that clients can meaningfully use.**
 - *Reserve the rest for protected interface or private helpers.*
 - *Resist the temptation to provide getters/setters for everything.*
 - Leads to lazy classes, or "god" classes.
- **Friend classes and functions are part of the public interface, and belong with the class.**
 - *Friend class or function is part of the same module or component.*
 - *Most clear if declaration and implementation is in the same .h and .cpp files.*
 - *A class developer should declare a class or functions to be a friends only if he/she/they are also responsible for, and have control over, that class or function.*
- **Make member functions const if they do not modify the logical state of the object.**
 - *Use mutable for those occasions where a strictly internal implementation state needs to be changed.*
- **Guidelines for Class Hierarchies**
 - **The base class must represent a meaningful abstraction in the domain.**
 - *At least the interface must be shared by the derived class objects.*
 - *Vehicles - move from place to place, need fuel, etc.*
 - **Make base classes abstract - corresponding to the abstraction in the application domain.**
 - *Clearly defines their roles as the root of a class hierarchy (or subhierarchy)*
 - *Clearly shows that the class corresponds to an abstraction in the problem domain.*
 - *Avoids some inheritance oddities from saying is-a with things that aren't really is-a.*
 - E.g. If you can instantiate an animal, that means it has the same status as a cat - which can't be true.
 - *Can approximate making a base class abstract by making its constructors protected instead of public.*
 - Derived class constructors can still invoke the base class constructors, but client code can't.
 - **Most-derived ("leaf") classes should represent concrete objects in the domain.**
 - *Car, airplane (fighter plane, cargo plane, etc), ship (warship, cargo ship), submarine*
 - **Intermediate classes should also represent meaningful abstractions in the domain.**
 - *Have at least interface in common*
 - *Land vehicles, flying vehicles, floating vehicles, etc.*
 - *Make abstract if possible (e.g. with protected constructors if no pure virtual functions).*
 - **Inherit publicly only to represent the "is-a" (substitutability) relationship.**

- *A derived class can be used in the same way as the base class, because the derived object "is a" base object.*
- **Distinguish between the public and protected interface.**
 - *Public is for client code*
 - Functions provide services for client code
 - *Protected is for derived classes.*
 - Functions provide services for derived classes
- **Put common functionality as high up in the class hierarchy as it is meaningful to do so.**
 - *If same code and members appears in two classes, they probably should be in a class they both inherit from.*
 - Common error: Taking the same member variables alone as indicating common functionality to be placed in a base class.
 - Member variables by themselves do not contribute to "common functionality."
 - Note that each object has its own copy of all (non-static) member variables, including those in the base classes. So there is no "savings" in memory footprint from having member variables in a base class than in derived classes.
 - Symptom of the problem: Strong temptation to make the base class member variables protected, or to provide protected write accessors for them.
 - Solution: Focus on the work done by the member functions - place functions (and their related member variables) as high up in the class hierarchy as it is meaningful to do so. If necessary, refactor to support this.
- **Let each class in a hierarchy be responsible for itself.**
 - *Initializes and de-initializes itself.*
 - Base or Derived classes, or client, is not responsible for setting up an object if its own constructor can do it.
 - Supported by constructor/destructor call sequence performed by the compiler
 - Enforced by making the member variables in each class private.
 - *Does all computations related to its own member variables.*
 - Protected or public member functions make them happen, supply outside data.
 - Enforced by making the member variables in each class private.
 - Derived classes can call functions in Base classes to do relevant work.
 - Overriding can allow each derived class to put its own variation on the base class operations,
- **To re-use code that is in a class, prefer using a member variable of that type (aggregation, has-a relationship) instead of private inheritance (implemented-with relationship).**
 - *Usually produces fewer conceptual and programming problems.*
- **If the class might be used as a base class, declare a virtual destructor.**
 - *Otherwise, might not be able to use derived class objects polymorphically and have them properly destroyed.*

- **The fundamental OOP technique: A polymorphic class hierarchy.**
 - **Fundamental: Use virtual functions instead of "switch on type" logic!**
 - *"Switch on type" logic in C++ is usually a design failure!*
 - *Occasionally it is unavoidable, but almost always is a result of bad design.*
 - Somebody else screwed it up, now you have to deal with it.
 - *Virtual functions should be doing the work as much as possible!*
 - **Use inheritance and polymorphism to hide details and changes.**
 - *Basic concept: Hide present and future differences under a base class, and use polymorphism to get the different behavior controlled by the same client code.*
 - Slogan: Figure out what will vary and hide it from the client!
 - Base class declares virtual functions
 - Base class is usually abstract - only leaf classes should be instantiatable as objects.
 - Each Base virtual function is either pure virtual or provides a "default" definition that Derived classes can use if they wish.
 - Client code refers to all objects with a Base * pointer, calls virtual functions through the Base * pointer to get polymorphic behavior of the objects.
 - Benefits
 - By overriding virtual functions as desired, each Derived class can have a different behavior, in any desired pattern.
 - Client code does not need to know what Derived class the objects belong too - the virtual function calls automagically route the call to the correct version of the virtual function defined by the Class that the object belongs to.
 - Using virtual functions, the client code can use objects whose exact type it doesn't know.
 - Client code needs to know only the Base class declaration - this provides the interface for all of the classes in the hierarchy.
 - Client just #includes Base.h - needs nothing else.
 - Means that Derived classes can be added, removed, modified, without changing the client code that class the interface.
 - If done properly, client code does not even need to be recompiled.
 - **If some functions are defined only in derived classes, choose a way to access them.**
 - *"The fat interface problem" - no single good label for the problem.*
 - If the classes in an inheritance hierarchy are not uniform in what functions it makes sense for them to have, you can't choose a set of base class virtual functions that are equally applicable to all derived classes.
 - Example: A ship simulation: Have various kinds of ships, etc.
 - All can be told to move on certain course and speed, all have some fuel capacity, maximum speed, etc. Good choices of base class members.
 - Different kinds of warships might respond differently to command to "attack", different kinds of cargo ships to command to load and deliver cargo. But:
 - Should warships be told to load and deliver cargo?
 - Should cargo ships be told to attack?
 - Worst: A submarine is a kind of ship, but has submerge capability. Should there be a "submerge" function in the base class of Ship?
 - Makes no sense for all other kinds of Ships?
 - So if some functions are meaningful for only some derived classes, how do we enable the Client to access them?

- *Four solutions:*

- **1. "Fat interface"**

- For a virtual function call to reach a function defined in a Derived class, all possible virtual functions must be declared in the base class.
 - What if you have a function declared and defined only in one Derived class? How can you call it given only a Base * pointer?
 - Base declares vf1, vf2 as virtual
 - Derived declares vf1 (for example)
 - DerivedDerived declares vfx
 - using Base * Bp, can call p->vf1(); p->vf2();
 - how can we call vfx? vfx is not known as a member of Base, so call through Bp will fail.
 - Example: Navy simulation
 - Ship class - has navigation functions
 - Warships - have weapons, etc
 - Submarine - can submerge
 - Go ahead and declare vfx virtual in Base and supply a "default" definition there (e.g. does nothing). Base class now has an interface to everything all of the derived classes are able to do - a "fat" interface.
 - No other classes declare vfx. Now Bp->vfx(); works to call DerivedDerived vfx if Bp points to a DerivedDerived object, does "default" if not.
 - E.g. Ship has virtual void submerge() {} function.
 - Pros: simple, easy, uses fast and general virtual function mechanism throughout. Compiler and linker guarantee correct behavior of call.
 - Cons: clutters base with conceptually odd declarations - vfx might not be meaningful for the concept represented by Base. Isn't attempting to do vfx on the wrong kind of object a fundamental error?
 - Seems strange to have the code saying that it is meaningful to tell all Ships to submerge!
 - But the default action could be to signal that we were trying to call vfx on the wrong kind of object.

- **2. Use separate containers to keep track of objects by their types.**

- If the structure of the program permits it, keep separate track of the pointers to Derived objects in such a way that they are known to be valid.
- A list of Base * for all of the objects. A separate list of pointers to Derived objects. Arrange code so that if vfx needs to be done, only the pointers to Derived objects are considered.
- E.g. Ship example. Use list of Ship * pointers to operate on all ships. Have a separate list of pointers for Submarines. If want to tell a Ship to submerge, look for its pointer in the Submarine list, and then use it to call submerge() function.
 - The Submarine list can contain either Submarine * or Ship * with a static cast to Submarine done for the call.
- Pro - clean design, uncluttered Base interface, no potentially slow or difficult to maintain RTTI usage. Can naturally flow from the design if kept in mind initially.
- Con - tends to weaken value of Polymorphic Hierarchy - have to keep separate containers of pointers, client code contaminated by the class hierarchy structure. Can be messy, difficult, or impractical.

- **3. Downcast safely.**

- Determine whether it is valid to downcast the Base * pointer to Derived *, and if so, do the cast and the call.

- Use RTTI, especially `dynamic_cast` for this - its what it is for - avoid do-it-yourself type identification.
 - ```
if(Derived * Dp = dynamic_cast< Derived *>(Bp))
 DDp->vfx();
else
 // do something else
```
  - ```
/* here if command is "submerge" */
if(Submarine * subp = dynamic_cast<Submarine * >(Ship_ptr) )
    subp->submerge();
else
    throw Error("This ship cannot submerge!");
```
- Using `static_cast` for this purpose is dangerous - can cause undefined behavior if pointed-to object is not really a Derived object.
 - but if you use `dynamic_cast`, you have to test the result to get any benefit!
 - If the `dynamic_cast` fails, it signals that we were trying to do vfx on an improper object - we can either do nothing, or treat it as an error of some sort.
- Pros:
 - Keeps base class interface uncluttered, avoid conceptual difficulties
- Cons
 - If done more than a little, tends to lead to switch-on-type logic, with its poor performance and difficulties for extension and maintenance. Some performance overhead, since `dynamic_cast` is a run-time operation that is generally slower than a virtual function call because it is actually very general and powerful (e.g. it knows how to navigate a multiple-inheritance class structure).
- How much `dynamic_cast` is OK?
 - If a failed `dynamic_cast` is an error condition of some sort, then using it is not a problem.
 - We're supposed to be able to do this, but let's check to be sure, and its an error if we can't.
 - If a failed `dynamic_cast` means to try a different `dynamic_cast`, and continue until the code finds the "right" cast, then you have switch on type logic.
 - Are you an X? No? Well, are you a Y? No, OK, how about a Z? - yuch!
 - Sometimes switch-on-type can't be avoided, or actually represents the best approach, but this is rare - don't start with it, start with virtual functions instead!
- **4. Use "Capability" base classes and "capability queries."**
 - An elaboration of the downcast safely approach.
 - Instead of asking "Are you an object from class X?" we ask "Can we talk to you with the X interface?" - Maybe more than one class supports the X interface!
 - Define a class that represents the special interface - a pure interface class, typically
 - - e.g. a Submersible class that declares pure virtual functions for submerge, surface, etc.

```
class Submersible { virtual void submerge() = 0; }
class Transportable {virtual void load() = 0; virtual void unload() = 0;}
```
 - The Submarine class (and potentially other classes - e.g. James Bond's car) inherit from this Submersible interface class as well as the Ship class.


```
class Submarine : public Ship, public Submersible { ... };
```
- To access a function in the special class, do a `dynamic_cast` to the interface class pointer type, and test for success.
 - E.g. attempt to `dynamic_cast` the Ship * pointer to a Submersible * pointer; if successful, then the object in question has the Submersible capabilities.

```

    if (Submersible * p = dynamic_cast<Submersible *>(ship_ptr))
        p->submerge();
    else
        throw Error("You can't talk to this ship that way!");

```

- Difference from "downcast safely" is that we are not asking "what specific leaf class type are you?" but "can I talk to you using this interface?"
- More general, less likely to turn into switch-on-type, but still has that potential problem.
 - Key is whether there are fewer interfaces than types of object.
 - If there is, then you can cover many kinds of objects with few capability classes
 - If not, the technique degenerates into switch-on-type maintenance problems.
- *Best solution depends on details of the situation.*
 - Separate containers is either very clean, or extremely awkward. If there are only a few Derived functions that aren't declared virtual in Base, downcasting safely or using a capability class is often good. If the concept is not seriously damaged by the fat interface, it is by far the simplest, clearest, and the best performing.
 - Make the decision by considering how much future extension is going to be needed and what effects it will have.
 - Will use of dynamic_cast or capabilities queries risk slipping down the slope into switch-on-typerty? Will fat interface get grossly obese?
 - Distinguish between whether our attempt to call a special function is due to input data or our programming.
 - E.g. if a Navy simulation user accidentally tells a battleship to submerge, it is a simple user error which the "default" implementation can signal by throwing an exception - no big deal.
 - E.g. Stroustrup points out that containers actually don't have that many meaningful operations in common, so fat interface would have a large number of "default" cases that imply a programming error which would have to be detected and caught in some way e.g. an assert. The overall result is ugly. The programmer has chosen the container and should be in a position to say exactly how it is used.

• Additional Techniques for OOP

• Decouple client from object creation details with a virtual constructor or factory.

- *What if client code is responsible for creating all of the Derived objects?*
 - To create an object of a class, it is necessary to know its class declaration.
 - Now client has to #include Derived.h for each leaf Derived class.
 - Result: if another Derived class is added to the hierarchy, client code must be modified, a new header possibly included.
 - Another problem: If there is a change in a Derived class declaration (e.g. a new member variable), the client code has to be recompiled.
 - Symptom of client and classes being coupled - interferes with easy development - change propagates through the system, forces other changes.
 - Better to have client code decoupled from the classes.
- *Concept: Insulate the client code from the creation process with a creation function that returns a Base * in response to some form of specification.*
 - "Virtual constructor", "Factory" idiom/pattern - more later.
 - Define a function that returns a Base *, and accepts arguments that specify in some way or another the kind of object desired.
 - e.g. maybe the specifications are in a file
 - e.g. maybe a particular pattern of argument values determine the kind of object desired.

- e.g. the specification could be a string identifying the desired object class and initial values.
- The function creates the desired kind of object with new and returns the pointer to it.
 - in Factory.h - minimal declarations and includes:

```
class Base;

Base * factory(int i);
```

- Note how well-decoupled this is - include the factory creator function with **nothing else** coming along!
- in Factory.cpp - include class declarations


```
#include "Factory.h"
#include "Derived1.h"
#include "Derived2.h"
#include "Derived3.h"
```

```
Base * factory(int i)
{
    switch(i) {
        case 1: return new Derived1;
        case 2: return new Derived2;
        case 3: return new Derived3;
        // etc
    }
}
```

- Define this function in the .cpp file, in a different module from the client code. Client #includes Base and creator prototype only.
 - #include "Base.h"
 - #include "Factory.h"
- If a new class is added, or a class is changed, only Factory.cpp will need modification or recompilation; client will need modification only to the extent that it has to supply a new specification.
 - e.g. if Factory uses a pattern of variable values, or a file, to get the specifications, client code may not need modification at all!
- One place the Factory function could be declared is as a static member of the Base class.
 - Keeps the Factory associated with the class hierarchy, but couples the .cpp file to rest of hierarchy.
 - But can be elsewhere - e.g. all by itself, helping decouple the base class code from the rest of the class hierarchy code.
- **Consider making the base class an interface class.**
 - *Pure interface class defines only pure virtual functions, has no member variables - strictly an interface to derived types.*
 - Very lightweight; often just needs a .h file, no .cpp
 - No commitments to any implementation details of derived types.
 - *But often useful to have some member variables or functions in the base class for common behavior - while not pure, it still serves a clear role.*
- **Let Derived class supply additional specialized work to the work done by the Base class.**
 - *Technique: a virtual function can have a definition at each level of the hierarchy; the derived version can call its base version before or after doing its own work.*

- Example: Each class has a print() member function that outputs information about that classes member variables. Each class is responsible for outputting its own information.
 - Derived::print() calls Base::print() to output the Base member variables, then Derived::print() adds the information about its own member variables.
 - Repeat at each level of the hierarchy.
 - Contrast to the most Derived::print() accessing the data members of each Base class and printing it out. Code is highly repetitious, difficult to maintain. E.g. suppose we add another variable to the Base class
- **A non-virtual member function can call a virtual member function.**
 - *Use to provide a class-specific piece of functionality in the context of an ordinary member function.*
 - Example: non-virtual of(), virtual vf():
 - Base::of()
 - {
 - vf(); // does virtual call if Class1 has Derived classes
 - }
 - Why this works: if a member function calls a member function, the call is through the this pointer:
 - this->vf();
 - if this object's class is a base class, the this has type base *, so a virtual call will be made.
- **Use dynamic_cast appropriately.**
 - *Flakey switch-on-type thinking - avoid if at all possible: What kind of object is it? Try dynamic_casts until one works - yuch!*
 - // use item_ptr to decide what to do with an item in a Dungeons & Dragons game:


```
if (dynamic_cast<Apple *> (item_ptr)) {...}
else if(dynamic_cast<Golden_potion *> (item_ptr)){...}
else if(dynamic_cast<Iron_armor *> (item_ptr)) {...}
else if ....
```
 - *OK: We are supposed to be able to tell the object to do this, but an error might have been made, so check the object type to be sure, and signal an error if it is the wrong type.*
 - perfectly OK to use in situations where if it fails it is due to a programming error, bug, or user input error
 - Dest_type * p = dynamic_cast<Dest_type *>(theBaseptr);


```
if(!p)
    throw Error("Illegal command - try again!");
```
- **Be on the lookout for applications of design patterns**
 - *Many common design problems have been solved before.*
 - *Don't reinvent the wheel - apply previous patterns instead where appropriate and helpful.*
 - *Usually, multiple patterns, each with some customization, are used in a complex program.*