Advanced C++ Programming

Classes and Interfaces

Preliminaries

Overview & Goals

- As we established in the first lecture, all of you have used Java before
  - As such, I will not explain the concepts of object-oriented programming
  - However, I don't believe that all of you are good at basic interface design
- We will focus on the **specifics of C++**, but also general programming **design rules** which apply to other languages as well
- *Note*: "Interfaces" in the title doesn't just mean a special type of (base) class, it is concerned with how to design your functions and classes in general

Types of Interfaces

There are four main types of interfaces you can offer in C++:

- **Functions**
  - Which operate on some inputs and produce an output
- **Classes**
  - Which group operations and the data they operate on
- **Function Templates** and **Class Templates**, which will be the topic of later lectures

Function Interface Design

Basics of good Interface Design in C++

- Interfaces should be
  - **Explicit**: avoid non-local or implicit state
  - **Precisely Typed**: more specific types at the interface level allow
    - Better *error-checking* at compile time
    - Better *optimization*
    - And they are more *self-documenting*
- Let’s examine “02_01_basic_interfaces.cpp”

Function Size and Number of Parameters

- Individual functions should only perform **a single task**
- They should also be small
  - A good general rule of thumb: *if your function is larger than one screen, it is too large*
- Too many parameters, especially of the same type, usually indicate a design issue
- Some examples are shown in “02_02_function_size.cpp”

Typing of Parameters

- As illustrated in the sample, explicit types are preferable
- The core guidelines offer more options to improve clarity of interfaces in a widely-understood way
  - See F.22 to F.25

Parameter Passing and Return Values

- For multiple return values, use tuples or structs
  - I prefer structs, due to field names serving as documentation
- Selecting whether to use basic values, references, pointers or something else for parameters is important
  - There are some good basic guidelines
- We'll study these points in "02_03_parameters_and_retvals.cpp"

<table>
<tr><th></th><th>Cheap or impossible to copy (e.g., int, unique_ptr)</th><th>Cheap to move (e.g., vector<T>, string) or Moderate cost to move (e.g., array<vector>, BigPOD) or Don’t know (e.g., unfamiliar type, template)</th><th>Expensive to move (e.g., BigPOD[], array<BigPOD>)</th></tr>
<tr><td>Out</td><td colspan="2">X f()</td><td></td></tr>
<tr><td>In/Out</td><td colspan="3">f(X&)</td></tr>
<tr><td>In</td><td rowspan="2">f(X)</td><td colspan="2">f(const X&)</td></tr>
<tr><td>In & retain copy</td><td>f(const X&) + f(X&&) & move **</td><td></td></tr>
<tr><td>In & move from</td><td colspan="3">f(X&&) **</td></tr>
</table>

** or return unique_ptr<X>/make_shared_<X> at the cost of a dynamic allocation*

*** special cases can also use perfect forwarding (e.g., multiple in+copy params, conversions)*

From the C++ Core Guidelines

Don’t Return References to Local Variables

- It’s the same as returning a pointer to a local – it will go out of scope *
- Instead:
  1. Prefer simply returning values (copy elision should work in most cases)
  2. In situations where that is not an option, use `unique_ptr` or `shared_ptr`

- Let’s look at “02_04_return_smart_pointers.cpp”

* Exception: Function local statics, will be discussed in the next chapter

Smart Pointers

- Defined in the standard library `<memory>`
  - http://en.cppreference.com/w/cpp/header/memory
- 2 main types:
  - **`unique_ptr`** – single owner, ownership can be transferred
  - **`shared_ptr`** – potentially shared ownership
- Should ***only*** be used to model **ownership**
  - If you don't need to transfer ownership, use references or plain pointers

Class Design and Class Hierarchies

“`class`” vs “`struct`”

- Functionally the same, except that “struct” members are public by default
- Useful convention:
  - Use `class` if the class has an invariant
  - Use `struct` if the data members can vary independently
- In the examples not related to class design
  I mostly use structs, but that is only for brevity of the demonstration
- Note that “class” and “struct” can result in different mangled identifiers in the object code, so you need to ensure that you use them consistently!

A condition on the state of the class which needs to be established in order for the public member functions to execute correctly

Class Hierarchies

- We’ll investigate the example in “02_05_class_hierarchies.cpp”
- Of note: `virtual`, `const` and pure virtual (`= 0`) qualifiers
- Implementation inheritance is possible
- Use the `override` keyword!

Destructors in Class Hierarchies

- Base class destructors should be either
  - **Public and virtual**; *or*
  - **Protected and non-virtual**

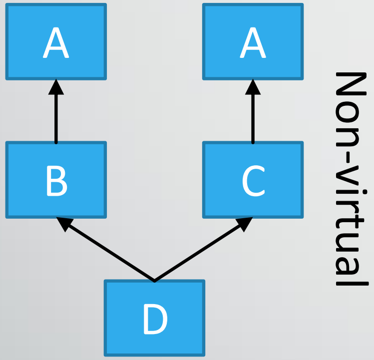
*If the destructor is public and non-virtual, **undefined behaviour** will occur when an object of a derived type is destroyed through a pointer to its base type.*

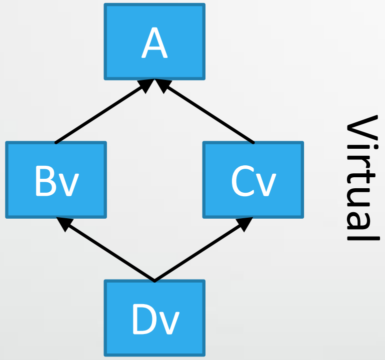
Multiple Inheritance

- Let’s start by looking at “02_06_multiple_inheritance”
- C++ allows **multiple implementation inheritance**
  - Note that this doesn’t mean you should use it all the time
    → In many cases composition is a better choice
  - But it can be very useful for mixins, and reducing the amount of boilerplate code

Diamond Inheritance Issue & Virtual Inheritance

- Consider "02_07_virtual_inheritance.cpp"





- No duplication of data
- No ambiguity in upcasts
- Some overhead for virtual dispatch

- Often, linearizing your class hierarchy is a better choice
- But sometimes virtual inheritance allows for the cleanest solution

Private Inheritance & Visibility in General

- Private inheritance is rarely useful –
  primarily if you want to provide *only part of an interface*
  - See “02_08_private_inheritance.cpp”
- General visibility:
  - Use “public” for the interface, and “private” for implementation details
  - Don’t use “protected” data
  - Non-const data members should be either *all public* or *all private*

Operator Overloading

- Operator overloading is demonstrated in “02_09_operator_overloading.cpp”
- Points to keep in mind:
  - Primarily use operator overloading to implement **conventional / expected usage**
  - Operators should be defined in the same namespace as the classes they operate on
    - *Note: namespaces and argument-dependent lookup*

When to use Member Functions

1. If the function requires access to the internal state of a class
2. If it is a *virtual* function
3. If it is an operator that is required to be a member (“`=`”, “`()`”, “`[]`”, “`->`”)

In all other cases, a free-standing function should be preferred.

Friends

- Friend declarations allow other functions/classes to access private data
- Let’s look at an example in “02_10_friends.cpp”
- Friend declarations should **only** be used in exceptional situations
  - They introduce *tight coupling*, which you generally want to avoid
- Might be indicative of a design flaw
- “Long-distance” friendships are worse

https://en.wikipedia.org/wiki/Coupling_(computer_programming)

“Hidden Friends”

- Hidden Friends are a useful technique for defining friend functions without polluting the overload set

Conclusion

Additional Resources

- Cpp Core Guidelines:
  - I: Interfaces
  - F: Functions
  - C: Classes and class hierarchies
- You *really* should read these, and refer to them when making design decisions in the future

Summary

- Interface design is an essential programming skill
- Functions:
  - Keep them tightly **focused**, **explicit**, and **precisely typed**
  - Know how to pass values in and out of functions in different circumstances
- Classes:
  - Use “`class`” and “`struct`” as per common convention
  - You have access to virtual dispatch, multiple inheritance, virtual inheritance, operator overloading and friend declarations

  → *But this doesn’t mean that you always have to use all of them!*