OBJECT-ORIENTED PROGRAMMING LANGUAGES -- C++ --

C++	Classes	const	Inheritance
Using C++	Automatic typedef		inline Derived
Classes			
Types	Function Overload		Reference types
Composition			
Scope Resolution		Type-safe link	new, delete
Binding			
Protection	Constructors	Containers	Virtual Functions
friend Functions		Destructors	Header Files
Operator Overloading			

THE C++ LANGUAGE

3 Developed by *Bjarne Stroustrup* starting in the early 1980's

3 Based on merging features of *C* and *Simula-67* (developed in Scandinavia in 1967)

3 Originally called *C with Classes* since it involved adding Simula-67's *class* concept to C

3 *C with Classes* was later expanded by simply adding improvements to C (*not* to implement object orientation necessarily), so the concept of *the next step after C*, or *C++* (the C increment operator is ++), evolved

OBJECT ORIENTATION

3 *Simula-67* supports the creation of *simulations*, and simulations of systems usually involve many discrete, independently operating entities

3 The authors of *Simula-67* called these entities *objects*

3 Rather than perform actions on objects in a simulation, *Simula-67* evolved the concept of *sending messages to objects*, and that's what *object-oriented programming (OOP)* entails

3 *OOP* later proved to be an easy way to think about many other types of problems, so a number of other *object-oriented programming languages (OOPLs)* were developed, most notably *Smalltalk*

3 These *OOPLs* provided many benefits, but the steep learning curve and significant period of limited productivity were drawbacks

AN OBJECT-ORIENTED C C++

3 Developed to take advantage of the ease of programming provided by an OOPL

3 Developed to provide an easy learning path for C programmers

3 Developed to fix defects in C which allow certain kinds of bugs to slip through the compiler -- bugs which may go unnoticed until runtime

C++ allows the programmer to focus on *concepts* rather than forcing him to concentrate on the code which implements those concepts

THE ANSI C++ STANDARD

3 ANSI committee *X3J16* was created to produce an international standard for C++, which is still in development

3 Most of today's C++ compilers deviate from the standard in one way or another, so portability of code between different C++ compilers on different platforms tends to suffer today

3 *GNU C++* is becoming a standard in its own right due to the fact that it is free and it runs on many platforms, including 386 PCs and workstations, but *GNU C++* does not conform to the C++ standard exactly

THREE WAYS OF USING C++

3 *Like C or C with extensions* -- many C programs may be compiled with a C++ compiler with little or no modifications (mainly in the area of function prototypes)

3 *Like C with enhanced data abstration capabilities* -- more sophisticated data structures may be manipulated with greater ease in C++

3 *Like an OOPL* -- all the benefits of contemporary *object-oriented programming* may be achieved through C++

TYPES = STRUCTS + FUNCTIONS

A *type* is a C *struct* with *functions*

```
    struct complex {        /* The C struct */
     float real_part;
     float imag_part;
    };


    struct complex {        9/29/22 The C++ struct
     float real_part;
     float imag_part;
     complex();            9/29/22 a constructor (discussed
later)
     void add (complex, complex);  9/29/22 operates on
object
    };
```

typedef FOR C++ STRUCTS IS AUTOMATIC

```
    struct complex a, b;  /* C form is supported
*/
    complex x, y;  9/29/22 "struct" is not
required

    x.real_part = 2.2;
    x.imag_part = 3.3;
    y.real_part = 4.2;
    y.imag_part = 4.3;
    y.add(x, y);   9/29/22 y = x + y
```

SCOPE RESOLUTION OPERATOR 07:21:41 PM

3 *Member functions* associated with a struct are *declared* as *function prototypes* in the struct

3 When *member functions* are *defined*, their associated struct is specified using the *scope resolution operator* (07:21:41 PM)

void struct_name07:21:41 PM member_function_name() { /* body */ };

as in

void complex07:21:41 PMadd (complex left, complex right)

{ /* body */ };

SCOPE RESOLUTION OPERATOR, Continued

3 The *scope resolution operator* may be used whenever the compiler would not normally choose the desired name

```
    int x;
    void main() {
     int x;
     x = 2;    9/29/22 local X is
assigned
     07:21:41 PMx = 4;  9/29/22 global
X is assigned
    };
```

MEMBER FUNCTION SCOPE

3 A member function may access any other member in the same struct, including both data and other member functions

```
    void complex07:21:41 PMadd(complex left, complex
right) {
     real_part = left.real_part + right.real_part;
       9/29/22 note that the real_part left of the
       9/29/22 equal size refers to the real_part
       9/29/22 of the target object
     imag_part = left.imag_part + right.imag_part;
    };
```

DATA PROTECTION

Access to data and functions within a struct is controlled by the three *access specifiers* :

- **3 *private* -- prevents access except by other members**
- **3 *protected* -- like *private*, except inherited classes also have access (inheritance is discussed later)**
- **3 *public* -- permits everyone, including end users, to access the members**

Access to *private* and *protected* members can be granted to non-member functions by using the <u>*friend*</u> keyword when declaring the non-member function inside a struct

public AND private WITH friend

```
#define SIZE 10
struct int_array {
 private:
   int a[SIZE];
 public:
   void init();  9/29/22 a member function
   friend void print (int_array);  9/29/22 a friend function
};
void print (int_array x) {  9/29/22 not a member function
 for (int i=0; i<SIZE; i++) cout << x.a[i] << "  ";
 cout << "\n";
}
```

CLASSES

class

is the preferred keyword for defining new types in C++

3 *struct* defaults to *public* for the access of its members

3 *class* defaults to *private* for the access of its members

```
     class typename {        struct typename {
      9/29/22 private members      9/29/22 public
members
     public:                 private:
      9/29/22 public members   9/29/22 private
members
     };                           };
```

AUTOMATIC typedef DECLARATIONS

The *tag names* of these entities are designated as reserved words within their scope automatically (similar to doing a *typedef* in C), and the form of their declarations and definitions are similar:

- 3 ***class***
- 3 ***struct***
- 3 ***union***
- 3 ***enum***

FUNCTION OVERLOADING

3 *Function Overloading* allows more than one function to be given the same name *as long as all these functions have distinct argument lists*

3 *Function Overloading* prevents name clashes when *multiple libraries* come into use

3 Function overloading works through *name mangling*, where the compiler-generated name for the function includes information on the types of its arguments

3 Examples of overloaded functions:

```
void print(int);
void print(int, char);
void print(double);
```

DEFAULT FUNCTION ARGUMENTS

3 ***Default arguments*** **are used in a function's argument list when common values are to be automatically generated by the compiler rather than always forcing the programmer to specify them**

3 ***Default arguments*** **may be given only once, in the** ***function declaration***

3 **Only** ***trailing arguments*** **may be given default values, and once default values are assigned, they must be assigned to the rest of the remaining arguments as well**

TYPE-SAFE LINKAGE

C++ was designed in part to eliminate problems found in C

3 C++ requires full *function prototyping* -- C does not

3 C++ performs *strong type checking (type-safe linkage)*, so if the arguments to a function when it is called are not the same types as when it was declared, the compiler will flag this error at compile time -- C does not

3 C++ does not always hold you to *type-safe linkage* because there are times when you may want to link in code generated by a C compiler; C++ lets you do this through an *alternate linkage specification*, which looks like this:

```
extern "C" {type
function_name(arg_types); }
```

CONSTRUCTORS

3 A *constructor* is used to initialize a variable based on a class *when the variable is created*

3 A *constructor* is a *member function* of the class that has the same name as the class

3 *Constructor* calls occur automatically at the point the variable is created, and the programmer cannot access the variable before the *constructor* is called

3 *Constructor functions* may be *overloaded* like other member functions so that various kinds of initialization may be done

3 *Default arguments* may also be used with *constructor functions* so long as ambiguities are not created

3 *Constructor functions* are not required by C++, but they are often very convenient

DESTRUCTORS

3 ***Destructor functions*** **are used to ensure proper cleanup when a variable is destroyed**

3 **A *destructor function* is a member function with the same name as the class preceded by a tilde**

3 **Calls to *destructor functions* are automatic, occurring when a variable goes out of scope**

3 ***Destructor functions*** **may not have any arguments**

3 ***Destructor functions*** **are optional, like *constructor functions***

3 **Unlike *constructor functions*, only one *destructor function* may be declared**

const AVOIDING THE PREPROCESSOR

3 *const* replaces part of the function of the *#define* preprocessor directive

3 *const* performs value substitution, adding type checking and normal expression evaluation

3 *const* is placed in front of any variable definition, indicating that --

1. the value cannot be changed
2. the compiler should try not to allocate storage, keeping the information in the symbol table instead

const float pi = 3.14159;

const IN ANSI C AND C++

3 *const* behaves differently in ANSI C and C++

3 Linkage --

u In C, *const* defaults to *external* linkage (global)

u In C++, *const* defaults to *internal* linkage (local)

3 Memory allocation --

u In C, *const* always allocates storage for the value

u In C++, *const* tries to store values in the symbol table

3 Constant expressions (like array definitions) --

u In C, *const* variables cannot be used in constant expressions (e.g., cannot be used in header files)

u In C++, *const* variables can be used in constant expressions if symbol table storage is possible (i.e., elaborate structures are not involved)

inline FUNCTIONS

- 3 In C++, the user can create *inline* functions, where, when they are called, their code itself is placed at the point of the call rather than a subroutine call instruction
- 3 *inline* functions were created to replace the *macro* functions required in C to perform such code optimization
- 3 Functions defined within a class declaration are automatically *inline*
- 3 Global functions must use the *inline* keyword to become *inline*
- 3 Full C++ type checking is performed on *inline* functions, like any other functions
- 3 The prototype and function body of an *inline* function are stored in the *symbol table*

DEFINING OBJECTS

3 In C++, *objects* (variables) may be defined anywhere

Some variables cannot be initialized until code has been executed, so C++ allows a variable to be defined at any point in a scope; the *life* of such a variable extends from that point to the end of the scope

3 In C++, *aggregate initialization* is supported extensively

3 Storage is reserved at the beginning of a scope

Local storage usually comes off the stack, so C++ scans forward when a scope is entered

3 Initialization of an object takes place at the point of definition, even though the space has already been allocated

3 An *object* is not available until the point of definition

If the scope is left before the *constructor* is called, the *destructor* is not called

Goto's which skip variable initialization are

REFERENCES

3 As we have already seen, C++ supports pointers like C

3 C++ also supports the *reference* (or *reference type*), which is like a pointer except that the compiler automatically takes the address and dereferences it for you (allowing dot notation instead of arrow notation)

```
int& fct(float&);
...
int *ip;
float *fp;
ip = fct(*fp);
```

REFERENCES, Continued

3 ***References*** **are almost exclusively used as function arguments and return values**

3 **Inside a *member function*, the address of the current object is accessed with the keyword**

this

3 **Example of *this* :**

```
class xint {
 int a, b;
 void init();
public:
 xint() { this->init(); }
};
```

REFERENCES, Continued

3 *References* can be independent, acting like a normal variable except that they modify storage used by other variables

```
int i = 100;
int &ip = i;
ip++;  9/29/22 changes the value of i to 101
```

STATIC CLASS MEMBERS IN C++

3 Class members (data or functions) that work with the class as a whole rather than individual objects are declared with the keyword *static*

3 *Static* members may be accessed by all members of a class, but the name of the static member is *hidden* within the scope of the class, so nothing outside the class may access it

3 *Static data members* only have one instance for all objects of a class

3 Defining and initializing static data is performed by a global definition that reserves storage and initializes the data

3 *Static member functions* also work with the entire class

3 The address of an object, referred to with the keyword *this*, is not passed into a static member function, so static member functions can only access static data members or call other static member functions

3 *Static member functions* may only be called with an object or by specifying the *class* and the *scope resolution operator*

DYNAMIC OBJECT CREATION

- **Dynamic object creation is built into the C++ language, through the keywords *new* and *delete* rather than being implemented only in library function calls such as *malloc()* and *free()***
- **Dynamic object creation lets the type and lifetime of an object be chosen at run time**

malloc() AND new

3 *malloc()* allocates space for an object given its size

3 *new* allocates space for an object given its type

3 *malloc()* does not initialize the space

3 *new* calls the associated *constructor* function to initialize the object

```
int *ip;
ip = (int
*)malloc(sizeof(int));
 /* done in C */
ip = new int;
 9/29/22 done in C++
```

free() AND delete

3 *free()* deallocates space provided by malloc()

3 *delete* deallocates space provided by new

3 *free()* does no cleanup other than freeing the space

3 *delete* calls a destructor for the object

With the advent of *new* and *delete* in C++, there is no reasonable need for *malloc()* and *free()* except for compatibility with C

CONTAINER CLASSES

3 *Container classes*, also called *collections*, are classes which hold objects created at run time

3 *Container classes* often hold groups of objects from other classess, making them a form of composite class

HEADER FILES

3 In C++, a *header file* contains *declarations* only, not *definitions*

3 A *header file* includes:

- u class declarations
- u function declarations
- u *const* values
- u anything else that is a part of the *public interface* to a class or library

3 A *header file* must be *insulated* so the compiler sees its contents only once when compiling a file; preprocessor statements, like those used before for STORABLE.H, should be used to perform this insulation

3 In essence, these preprocessor statements direct the header file to be skipped if it has already been included

INHERITANCE

3 ***Inheritance*:**

- u **allows new classes to be built from existing classes**
- u **supports code reuse without the need to rewrite**
- u **does not entail modification to the code on which the new classes are based**
- u **requires access to only the *header files* of the classes on which the new classes are based**

3 **When a new class inherits from a base class:**

- u **all of the public members of the base class can be public in the new class**
- u **none of the public members of the base class can be public in the new class**
- u **any combination of the above**
- u **members of the same name as in the base may now have different meanings**

INHERITANCE SYNTAX

single colon

```
   class derived : [public] base { /* details
*/ };
```

name of base class

if public, public members in base class are automatically public members in the derived class

name of new, derived class

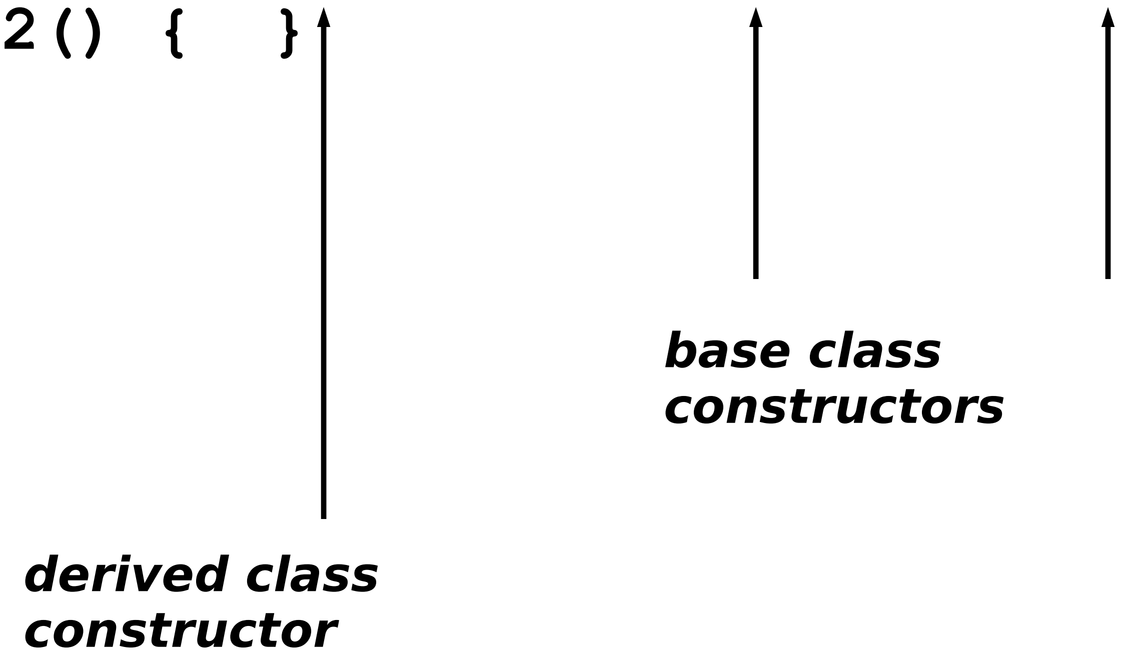
INHERITANCE

- **3 *Inheritance* requires a lot of design-oriented thought in order to be applied correctly**
- **3 Use *inheritance* only when it makes sense -- *is the derived class really an offspring of the base class, and does it make sense that the derived class should inherit capabilities from the base class?***
- **3 Breaking a problem into classes has the effect of *partitioning* the problem**

BASE CLASS CONSTRUCTORS AND DESTRUCTORS

3 *Base class constructors* are called in the *constructor initializer list,* which was shown in MULTINH.CPP:

```
derived07:21:41 PMderived() : base1(),
base2() {  }
```



DERIVED CLASSES

3 The way C++ calls *base class constructors* ensures that all *derived class constructors* can depend on the base class being properly initialized

3 Up to one *destructor* may be defined for each class

3 *Destructors* are called automatically, and all destructors are called for an object, which includes the destructors for its base classes, their base classes, and so on

3 There is no *destructor* equivalent for the *constructor initializer list*

3 *Destructors* are called from the *top down* (the opposite to the order of *constructor* calls)

CREATING CLASSES WITH COMPOSITION

3 *Inheritance* is not the only way to create new classes from existing classes in C++; *inheritance* is sometimes said to represent an *is-a* relationship

3 *Composition* is a method of building classes that *contain* objects of other classes; composition is sometimes said to represent a *has-a* relationship

A *car* is a type of *vehicle* inheritance

A *car* has an *engine* and four *wheels* composition

CREATING CLASSES WITH COMPOSITION

3 *Composition* involves creating instances of a class inside another class

3 If the objects have constructors which require arguments, those objects must be explicitly initialized in the *constructor initializer list*

3 The order of calls in a *constructor initializer list* is not necessarily the order in which they appear; instead, the base class constructor is called first, and so on, and the member object constructors are called in the order in which the objects are declared in the class

3 The *constructor initializer list* only determines the arguments given to the constructors, not the order of constructor calls

const AND enum INSIDE CLASSES

3 A *const* inside a class behaves differently from a *const* outside a class

3 A *const* in C++ must always be initialized when it is created

3 A C++ class declaration is not a definition (it does not reserve storage), so a const in a class must be given an initial value when the constructor is called

```
class X {
 const i;  9/29/22 const i = 1; not
allowed
public:
 X (int I) : i(I) {}
};
```

i is initialized to I

const AND enum, Continued

3 Because *const* allocates storage, it can not be used in a constant expression, so the following is invalid:

```
class int_array {
 const sz;
 int array[sz];  9/29/22 not a constant
expression
 9/29/22 ...
};
```

3 A solution to this problem is to employ an *untagged enumeration* value as a const:

```
class int_array {
 enum { sz = 100 };
 int array[sz];
 9/29/22 ...
};
```

EARLY AND LATE BINDING

3 ***Binding*** **-- a linkage between a function call and a function definition**

3 ***Compile-time, static, or early, binding*** **-- those linkages resolved during the run of the compiler and linker**

3 ***Run-time, dynamic, or late, binding*** **-- linkages are resolved through a table of addresses of possible routines to call; this table is provided, and a particular table entry is selected during execution of the code**

3 **The *virtual function* is the particular C++ feature which supports late binding**

VIRTUAL FUNCTIONS

virtual return_type function_name(type arg);

- **3 The *virtual* keyword in C++ implements late binding**
- **3 The *virtual* keyword causes a hidden pointer, called *VPTR*, to be created**
- **3 The *VPTR* is assigned by the constructor to the address of the *VTABLE*, which in turn contains the addresses of all virtual functions**
- **3 A *virtual* function call consists of code that indexes into the VTABLE through the VPTR**

CREATING EXTENSIBLE PROGRAMS

3 **The goal of *object-oriented design* is to identify the essential concepts and activities performed by the system (or program) and to translate them into types**

- u **Humans organize the world as types**
- u **C++ allows a programmer to organize a program as types**
- u **Types in C++ provide models for the real-world types**
- u **The program becomes an image, or model, of the problem being solved**

3 **A program has a single essential purpose or job it is trying to do**

EXTENDING AN OBJECT-ORIENTED DESIGN

3 *Base classes* generally represent the primary concepts of an object-oriented program

3 Most base classes are *abstract*, representing concepts rather than specific things, so it does not make sense to create objects of an *abstract base class*

3 C++ allows an abstract base class to contain pure *virtual* functions by assigning the function body to zero:

```
virtual void f() = 0;
```

3 No objects can be created of such a class; objects may be created only from classes derived from this *abstract base class*

3 These derived classes contain definitions for the *pure virtual functions* in the *base class*

EXTENDING A PROGRAM

1. **Derive a new class from the *abstract base class***

   The desired extensions are embodied by redefining the *virtual functions* in the *abstract base class*

2. **Add new data structures and functions as necessary, including new constructor functions which invoke the base constructors as needed in the *constructor definition list***

   The derived class is now taking on *attributes* and *behaviors* which distinguish it from the abstract base class

3. **Add code at the point where new objects are created so the constructor for the new derived class is called**

   The new objects are created and properly initialized

OPERATOR OVERLOADING

3 In C++, the meaning of almost any operator may be changed when that operator is used with variables of particular types

3 The meaning of an operator changes only when an operator is used with the indicated types

3 This permits the operators to be used as *infix* functions:

```
a + b;
```

3 In the above example, the function "+" is applied to the target object "a" with the argument "b", just like set() below is applied to the target object "A" with the argument "B":

```
A.set(B);
```

3 The syntax used for declaring the operator function for the "+" operator is:

```
return_type  operator+  (type arg);
```