Xtreme EDA

Basic C++ for SystemC

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- Founded 2003
  - Broad Background (Hardware/Software/Methodology/Systems)
  - Active in SystemC Standardization working groups
  - Authors of book SystemC: From the Ground Up
  - Merged with XtremeEDA Corporation as a US subsidiary July 2008
- Services
  - ESL Adoption Planning
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Objectives - C++ for SystemC

- Provide a quick C++ review
  - Assumes a knowledge of C
- Make it easier to learn SystemC
  - Focus on elements used by SystemC
- NOT a ground up tutorial
  - See references for that
  - Use as a guideline on what to learn

Fasten your seatbelts!

Agenda - C++ for SystemC

- Nature of C++
- Strings
- Streaming I/O
- Namespaces
- Functions
  - Defining & using
  - Pass by value & reference
  - Const arguments
  - Overloading
  - Operators as functions
- Templates
  - Defining
  - Using
- Classes (OO)
  - Data & Methods
  - Constructors
  - Destructors
  - Inheritance
  - Polymorphism
  - Constant members
  - Static members
  - Guidelines
- STD Library tidbits
In 1980, Bjarne Stroustrup, from Bell labs, began the development of the C++ language, that would receive formally this name at the end of 1983, when its first manual was going to be published. In October 1985, the first commercial release of the language appeared as well as the first edition of the book "The C++ Programming Language" by Bjarne Stroustrup.

During the 80s the C++ language was being refined until it became a language with its own personality. All that with very few losses of compatibility with the code with C, and without resigning to its most important characteristics. In fact, the ANSI standard for the C language published in 1989 took good part of the contributions of C++ to structured programming.

From 1990 on, ANSI committee X3J16 began the development of a specific standard for C++. In the period elapsed until the publication of the standard in 1998, C++ lived a great expansion in its use and today is the preferred language to develop professional applications on all platforms.

**Multi-paradigm language**

- Procedural programming - C
  - Simple data, Conditionals, Loops & Functions
- Modular programming
  - Namespaces, Exception handling
- Data abstraction
  - Structures, User defined types (enums & simple classes)
  - Concrete types & abstract types
- Object Oriented
  - Class hierarchies, inheritance, overriding, polymorphism
- Generic Programming
  - Templates, Containers, Algorithms
**C-style “strings”**

```c
char* msg = "Hello there";
char mesg2[80];
```

- Really just pointer to unchecked array
  - Danger, Will Robinson! Danger!

```c
typedef char* cstr;
cstr name = "K&R"; // Array of 4 chars
#include <cstring>
strcpy(cstr, cstr), strcat(cstr, cstr),
strcmp(cstr, cstr), strlen(cstr), strchr(cstr, c)
#include <ctype.h>
isalpha(c), isupper(c), isdigit(c), isspace(c),
isalnum(c), toupper(c), tolower(c)
```

**std::string**

```c
#include <string>
std::string msg3(“Hello”);
std::string msg4;
```

- Much better/safer than C-strings
  - Assign operator= and Concatenate operator+
  - Dynamically resizes
  - s.length() < string::npos, s.size(), s.capacity(), s.resize(N), s[pos]
  - Compare with operators ==, !=, >, <, <=, >=
  - Methods .insert(), .find(), .replace(), .substr(), swap()
**C-style I/O**

```cpp
printf(char* fmt, var1, var2, ...);
```

- Terse format limited to predefined types
  - "%d %s %f %x %c"
- Not type checked at compile-time
- Guidelines
  - Discouraged in C++ (see next slides)

**Streaming I/O**

```cpp
#include <iostream>
```

- Streaming I/O makes it more natural
  ```cpp
  cout << "Heading: " << obj << endl;
  ```
- Objects "output themselves in an appropriate format."
  - No need to remember the correct %d %f %s
  - All output is consistent
Streaming I/O guidelines

• Define for every datatype
  - ostream& operator<<(const ostream& os, const Data& d)
    - { os << "Data field: " << d.data ... ; } // no endl please

• Also
  - ofstream& operator<<(const ofstream&, const Data&);

• Use boost::format to aid

C Scope

1. float joe(3.14159);
2.
3. ofstream float joe;
4. void func() {
5.   signed joe;
6.   for (long joe = 0; joe!=3; ++joe)
7.     cout << joe << ' ' << ::joe << endl;
8. }
9. int main() {
10.   char joe = 'c';
11.   { BLOK:
12.     double joe = 6.28318; // Hides main joe
13.     cout << joe << ' ' << ::joe << endl;
14.     func();
15.   }
16. }
### Namespaces - powerful

```cpp
float joe(3.14159); // global
namespace gi { complex joe(2007,1984); }
namespace your { string joe("your"); }
namespace my { namespace gi { short joe(42); }}

#include "some.h" // externs to above
using your;
namespace my {
  string joe("along");
  void moe() {
    long joe = 96;
    { NESTED:
      char joe = 'c'; // Hides long joe
      cout << ::joe << ' ' << joe << ' ' << gi::joe << ' ' << gi::joe << ' ' << my::joe << endl;
    }
  }
}
int main() { my::moe(); }
```

### Namespaces - anonymous

- Good for hiding
- Preferred alternative to file `static`

```cpp
namespace {
  int magic = 42;
}
void use_magic() {
  cout << magic << endl;
}
```
Namespace - Guidelines

- Some EDA vendors have restrictions
  - Cadence disallows `sc_module` inside `namespace`
- Use, but don’t abuse
  - Good for modular programming
  - Keeps nests < 2 deep
  - XtremeEDA uses top-level `::XEDA` for library
- Use anonymous instead of `static`
  - For file scoped variables
- Use `::global` for clarity
  - Identifies globals & discourages their use
- Convenience of using
  - Do `using ::SPACE::MEMBER;` as needed
  - Don’t `using namespace SPACE;` in headers

Agenda - Functions

- C++ supports procedural programming
- Functions are the basis for procedures
- The following topics will be covered:
  - Declaring, defining and using functions
  - Passing arguments by value
  - Pass arguments by reference
  - Const arguments
  - Overloading function names
  - Operators as functions
Declaring functions

- Simple indicates the syntax for usage and makes it available for use
- Often included in header (.h) files
- May be repeated without causing errors

```c++
int main(int argc, char* argv[]);
void display(string message);
float sum(vector v);
void status(void);
```

Defining functions

- Defines behavior
- May only be done once

```c++
void display(string message) {
    cout << message << endl;
};
typedef vector<int>::iterator vi_t;
int sum(vector<int> v) {
    int total = 0;
    for (vi_t e=v.beg(); e!=v.end(); ++e) {
        total+=*e;
    }
    return total;
};
```
Using functions

- Straight forward

```cpp
display("Hello there");
int y = sum(v) + 3;
status();
```

- It is possible to pass address or function
  - Use in lookup tables
  - As a parameter to a generic algorithm

Passing arguments by value

- Copy supplied arguments into variables
  - Only way in C

- Example

```cpp
void f(int a) {
  a = a+1;
  cout << "a=
  };
int main() {
  int x = 42;
  f(x);
  f(5);
  cout << "x=
  return 0;
}
```

a=43
a=10
x=42
Passing arguments by reference

• Make variables point to original argument
  – Had to use messy pointers in C

Example

```cpp
void f(int & a) {
    a = a + 1;
    cout << "a=" << a << endl;
}

int main() {
    int x = 42;
    f(x);
    // f(5); ILLEGAL - Cannot modify "5"
    cout << "x=" << x << endl;
    return 0;
}
```

New C++ syntax

Const arguments

```cpp
int sum(const std::vector<int> & v);
```

• Compiler enforces “read-only” use
• Similar to task input in Verilog
• Good for passing large values by reference
• Documents intent

New C++ syntax
Overloading function names

• Use **same name** for several different functions
  – Distinguished by number of arguments -or-
  – Distinguished by types of arguments
  – This is illegal in C
    ```
    int add(const std::vector<int>& v);
    float add(const std::vector<float>& v);
    int add(int* a, int size);
    int add(int a, int b);
    int add(complex a, int b);
    int add(int b, complex a);
    void add(float a, complex a, complex& result);
    ```
• Return type not considered as part of signature

Operators as functions

• **a+b** is another way of saying **add(a,b)**
• C++ allows you to overload operators
  – May only use existing operators
  – May not change # arguments or precedence
  – May not redefine existing combinations
  • E.g. may not redefine **int + int** (this is goodness)
  – Some operators require reference or const
• Example
  ```
  complex operator+(complex lhs, complex rhs);
  ```
• Use only where it makes intuitive sense
  – What does **car + car = mean?**
Topics - Templates

- C++ supports generic programming
- The following topics will be covered:
  - Using
  - Defining
  - Guidelines

Why generic programming?

- Suppose you want to create a struct/class that can hold several data types and perform operations on them cleanly.
  - Could use union, but code has to store information about which data type is currently active, and code has to be duplicated to do different tasks.
Templates (generic programming)

- Using templates is fairly easy & powerful
  - Standard template library (STL) is based on (drum roll) . . . Templates!
  - SystemC uses templates a lot
- Defining templates is a bit messy
  - Guideline: Design a class without templates before you add the details of templatization
- Functions and classes may be templated
  - Most folks familiar with class templates

Ex: using templates

- From STL
  - `list<pixel>` image_list;
  - `map<string, bool>` used;
- From SystemC
  - `sc_int<12>` reg;
  - `sc_fifo<int>` int_fifo;
  - `sc_fifo<packet>` pkt_fifo;
  - `sc_fixed<8, 4>` scale;
Defining templates

- To define a template class use the `template` reserved word and include argument specifications in angle brackets (`<>`) as shown here

```cpp
template<class T, int N>
struct fifo {
    T buff[N];
    void push(T v);
    T pop();
};

int main() {
    fifo<string,5> s_fifo;
    fifo<int,32> i_fifo;
    s_fifo.push("hello");
    i_fifo.push(50);
}
```

Templates are powerful

- Plate tectonics are powerful too!
- Several types of templates
  - Template classes
    ```cpp
template<typename T> CLASSNAME {...};
```
  - Template functions
    ```cpp
template<typename T> RETURN FUNC(ARG) {...};
```
- Get basic class working before templating
- Can have several arguments
  - Both typename's and integral values
  - Latter arguments may have defaults
Defining templates can hurt

- An entire book devoted to the subject!
- Must consider disambiguation
  - C++ rules can be challenging
  - Will two classes/functions suffice?
- Quite a few idiosyncrasies
  - Best to use `template<typename T>`
  - `#include "CLASSNAME.cpp"
  - Use `this->` for members
- Partial & complete specialization

Agenda - Object-Oriented C++

- C++ supports the Object-Oriented (OO) paradigm
- The following topics will be covered:
  - Defining a class
  - Methods
  - Access types
  - Constructors & initialization
  - Destructors
  - Inheritance
  - Initializing base classes
  - Adding members
  - Overriding methods
  - Multiple inheritance
  - Protection & friends
  - Virtual methods
  - Pure virtual
  - Abstract classes
  - Interface classes
  - Virtual inheritance
  - Constant members
  - Static Members
Properties of objects

• Objects are data types
  – Examples: integer; processor; complex number; creature; shape; window
• Objects have state
  – Examples: integer value; processor register contents; real & imaginary portion of complex; size & orientation of a shape; window name, type & color
• Objects have behavior
  – Examples: integer can be added, subtracted, multiplied; processor can execute instructions; complex can be added, multiplied (scalar & cross); shape can be drawn, inquired of size; window can be moved, resized, drawn, closed

What is a class?

• Classes are custom data types
  – Effectively extend a programming language
• Classes define object types
  – Define data such as properties, and state
  – Define behaviors and capabilities
• Classes have:
  – State (member data)
  – Methods (member functions)
**Member Data & Member Functions**

- In C++, **all** data types are classes
- Instances of a data type are called objects
  - `int a; // creating an object instance`
- Objects have functions they can perform
  - `a = 5; // store`
  - `a = a + 5; // retrieve, add & store`
- C++ uses keywords `struct` or `class`
  - Functions are allowed as members

---

**What is a class in C++?**

- In C++, a class is simply a `struct` that has at least one member function (aka method).
  ```cpp
  struct NAME {
    void METHOD(); // makes NAME a class
  };
  ```
- By default, all members of a `struct` or public (i.e. accessible directly from the outside using the “dot” operator.)
- The keyword `class` was introduced to help document intent and almost synonymous to `struct` except for a minor detail of access that will be discussed later.
  ```cpp
  class NAME2 { // also a class
    void METHOD(); // makes NAME a class
  };
  ```
Class suggestions

• Comments in the implementation (cpp) should be limited to internal how or why things are done (i.e. implementation notes)

• Separate data from functions
  – Strict OO programming dictates all access to an object should be through member functions.
  – Considered taboo to modify member data of a class

• C++ convention
  – Prefix member data variables with m_.

• Put plenty of usage comments in the header
  – The header is the file that users will see

Creating a class

• Separate specification (declaration) from implementation (definition)
  – Use header file (.h) to specify
  – Use implementation file (.cpp) to define

• Use struct or class
  – OO purists prefer class
  – SystemC historically used struct, but changed its tune during the standardization process
Ex: tail_light.h (specify a class)

```c++
#ifndef TAIL_LIGHT_H
#define TAIL_LIGHT_H

class tail_light {
    public: // Member functions - behavior
        bool is_on();
        void set_on();
        void set_off();
        void set_rate(float duty_cycle); // 0.0 to 1.0
        void set_rate(bool light[10]);
        float get_rate();
    // Member data - internal state
        bool m_on;
        bool m_light[10]; // 1/10th of duty cycle status
    }
#endif
```

Using a class

- Treat a class as a new data type (like int)
  - Happens to be user-defined
  - Has unique behaviors
    - CLASSNAME IDENTIFIER();
- Use of the member functions follows the same syntax we use with member data in a struct
  - Uses the dot operator
    - OBJECT_FUNCTION(ARG...)
Ex: main.cpp (use a class)

```cpp
#include "headlight.h"
#include "tail_light.h"

int main() {
    // create objects (instantiate)
    headlight left_front, right_front;
tail_light left_rear, right_rear;
    // call member functions
    left.set_rate(0.5);
    left.set_on();
    right.set_off();
    if (left_rear.is_on()) {
        cout << "Left tail light is on" << endl;
    }
}
```

Implementing a class

- Implementation means defining the behaviors of member functions (methods)
- Place implementation in separate .cpp file
- Include the header file
- Use of a namescope operator (::) to identify methods (member functions)
  - Indicates function belongs to the class
  - `TYPE CLASSNAME::METHODNAME(ARGS) {BODY}`
Ex: tail_light.cpp (1 of 3)

```cpp
#include "tail_light.h"

// Define methods in tail_light
bool tail_light::is_on() {
    return m_on;
}

void tail_light::set_on() {
    m_on = true;
}

void tail_light::set_off() {
    m_on = false;
}
```

Ex: tail_light.cpp (2 of 3)

```cpp
void tail_light::set_rate(float duty) {
    if (duty < 0.0 || 1.0 < duty) {
        cout << "ERROR: Illegal rate " << duty << endl;
    } else {
        for (int i=0; i!=10; ++i) {
            m_light[i] = (i >= 10*duty);
        } // endfor
    } // endif
}
```
Ex: tail_light.cpp (3 of 3)

```cpp
float tail_light::get_rate() {
  float rate = 0;
  for (int i=0; i!=10; ++i) {
    if (m_light[i]) {
      rate += 0.1;
    } // endif
  } // endfor
  return rate;
}
```

---

The “has a” relationship

- Data members of a class are objects
  - Hierarchies of class instantiations are a powerful way of creating complex classes
  - This is known as **composition**
  - This establishes a “has a” relationship
  - For instance:
    ```
    struct T1 { int k; };
    struct T2 { T1 o2; };
    struct T3 { T2 o3a; T1 o3b};
    ```
    - Class T1 has a **int**
    - Class T2 has a T1
    - Class T3 has a T1 and has a T2
**Inline methods**

- In the preceding, class declaration (header) was kept separate from class implementation (cpp)
- It is possible to do both in one step
  ```cpp
  struct A {
      int m_v;
      void print() { cout << "v="<<v<<endl; }
  };
  ```
- The method `print` is created **inline** with the code where it is invoke (if possible).
  - Creates very fast code - good
  - Larger executable - ok
  - Exposes implementation to end user
- Use only for extremely simple methods
  - `get` & `set` methods are good examples

```
#ifndef TAIL_LIGHT_H
#define TAIL_LIGHT_H

struct tail_light {
    // Member functions - behavior
    bool is_on() { return m_on; }
    void set_on() { m_on = true; }
    void set_off() { m_on = false; }
    void set_rate(float duty_cycle); // 0.0 to 1.0
    void set_rate(bool light[10]);
    float get_rate();
    // Member data - internal state
    bool m_on;
    bool m_light[10]; // 1/10th of duty cycle status
};
#endif /* TAIL_LIGHT_H */
```

Ex: inline
Class Accessibility

• By default all members of a `struct` are public
• It is desirable to hide parts of class from users (e.g. member data or private functions)
• Three keyword labels control access to members of a class:
  - `public`: // anyone can access
  - `private`: // only for members of this class
  - `protected`: // available to family members
    • More on this later
• By default
  - `struct` is public
  - `class` is private

Adding access to a struct

• `struct` default is public
• Public members on right
  - `func()`, `help()`, `m_y`
• Private member on right
  - `sub() m_x, m`
• T2 is not very useful
  - Cannot acces m!

```cpp
struct T1 {
  int func(float rate);
  void help();
  private:
    int sub(char c);
    int m_x;
  public:
    int m_y;
};
struct T2 {
  private:
    int m;
};
```
Adding access to a class

- **class** default is public
- Public members on right
  - `display()`, `m_y`, `m_x`
- Private member on right
  - `task()`, `help()`, `sub() m_x`
- T4 acts like a **struct**

```cpp
class T3 {
    void task(int& w);
    void help();
private:
    int sub(char c);
    int m_x;
public:
    void display();
    int m_y;
};
class T4 {
    public:
    int m;
};
```

Ex: Public & Private

```cpp
#ifndef TAIL_LIGHT_H
#define TAIL_LIGHT_H
class tail_light {
public: // Member functions - behavior
    bool is_on() { return m_on; }  
    void set_on() { m_on = true; }  
    void set_off() { m_on = false; }  
    void set_rate(float duty_cycle); // 0.0 to 1.0
    void set_rate(bool light[10]);
    float get_rate();
private: // Member data - internal state
    bool m_on;
    bool m_light[10]; // 1/10th of duty cycle status
};
#endif /* TAIL_LIGHT_H */
```
Notes on Using Public and Private

• Always precede members of a class with access designations (i.e. public, private)
• When defining classes, prefer the keyword class
• Place public stuff first, private last
  – It’s what the user wants to know
• Minimize private stuff

Constructors

• Our tail_light class is missing something
  – Initial values of the member data are unknown
  – Need initialize
• Functional programming suggests adding a member method called reset or initialize
  – Problematic
    • Requires user call every time object is created
    • Experience shows the user will eventually forget
    • Failure to initialize variables difficult to debug
Initialization - the wrong way

• Perhaps we can just initialize?

```cpp
struct tail_light {
    bool m_on(true);
    bool m_light[10] = {false, /*etc*/, false};
};
```

• Problematic
  – C++ doesn’t allow this syntax
  – `m_on(true)` syntactically looks like a function defn

Solution: Use a constructor

• C++ has a special syntax for initialization
  – Special method called a `constructor`

• A constructor is a member function that has the same name as the class name, and returns no value:

```cpp
struct CLASSNAME {
    CLASSNAME(ARGS...);
};
```

• Constructor with no args is “default constructor”
Ex: Default Constructor

```c++
struct tail_light {
    ...
    // default constructor
    tail_light(void);
};
```

```
void tail_light::tail_light(void) {
    m_on = true;
    // Default 50% duty cycle
    for (int i=0;i!=10;++i) {
        m_light[i] = (i<5);
    }
}
```

Constructors with arguments

- Possible to have a constructor take an argument
  - Useful to establish a tail_light with a different initial duty cycle

- Because constructors are simply functions
  - Can overload them the same way as any function
  - Might have both a default constructor (50% duty cycle), and the constructor that takes an argument. A constructor is always invoked when objects are instantiated.
Ex: Constructor (non-default)

```cpp
struct tail_light {
    ...
    // constructor with args
    tail_light(int percent);
};
```

```cpp
tail_light::tail_light(int pct) {
    m_on = true;
    int div = int(10*pct/100+0.5);
    for (int i=0; i!=10; ++i) {
        m_light[i] = (i<div);
    } // endfor
}
```

Default constructors

- If you do not provide a constructor, then the “default constructor” is provided for you.
  - Default constructor simply allocates space for the data members (i.e. no initial values).
- If you specify a constructor with one or more arguments, then the “default constructor” will not be provided unless you provide it (i.e. overload).
- If you do not specify a constructor when instantiating, then the “default constructor” is invoked for you.
- If you do not specify a constructor when instantiating and there is no default constructor, then it is an error.
Choosing the constructor

- There is still a potential problem with our approach to initialization
- Consider a class that instantiates a class

```c++
struct Complex {
    double re; double im;
    // No default constructor
    Complex(double r, double i);
};
struct Amplifier {
    Complex x;
};
```

_INITIALIZER lists

- A syntactical construct was added to C++ to allow choosing the constructor for data members

```c++
CLASSNAME::CLASSNAME(ARGS…) : ELT(ARGS),… // initializer list
{  // BODY
    
};
```
Initializer notes

- Occurs before the body of the constructor is executed
- Using empty parentheses invokes the default constructor for a class
  - For `int`, this means set to zero
- Proceeds in the order data members are declared
  - HINT: List them in the same order as declared
  - If order dependences exist, document them
- Initialization arguments may be an expression
  - valid at construction time

```cpp
class T1 {
    float m_k;
    T1(float k): m_k(k) { m_k++; }
};
```

```cpp
class T2 {
    int m_n;
    T1 m_a1;
    T2() : m_n(), T1(1) {};
};
```

```cpp
class T3 {
    int x, y, z;
    T3(): y(1), x(y+1), z(y) {};
};
```

Ex: Initializer list

```cpp
tail_light::tail_light(int pct)
    : m_on(true)
{  
    int div = int(10*pct/100+0.5);
    for (int i=0; i!=10; ++i) {
        m_light[i] = (i<div);
    } // endfor
}
```
What is a destructor?

- Objects/data are destroyed when
  - Code leaves a scope
  - `delete` is explicitly called
  - Program terminates
- It is desirable to do cleanup
  - Free storage
  - Output statistics
  - Delete embedded linked list (avoid leaks)
- For this C++ provides a destructor

Defining the destructor

- C++ destructor is a method named after the class with a preceding tilde (~) that takes no arguments (ever) and returns no value (where would it go)

```cpp
CLASSNAME::~CLASSNAME() {
    BODY
}
```

- If you don’t provide a destructor, the compiler will provide a default that simply frees member data memory.
Ex: Destructor

- Declaration

```cpp
struct tail_light {
    ~tail_light();
};
```

- Implementation

```cpp
tail_light::~tail_light() {
    cout<<"destroyed tail_light"<<endl;
}
```

Destructor notes

- Called for every object as it is destroyed
- There is only **one** destructor per class
- If you rely on the default destructor, put a comment to that effect in the header.
Inheritance motivation

• Some classes share common attributes
  – Sedan & hatchback automobiles could be modeled as classes
    • Both have 4 wheels, engine, steering, etc.
  – Managers & engineers could be classes
    • Both have names, ages, etc.
  – Circles & squares
    • Both have sizes, positions & orientations
• Desirable to only write code once for common features
• Ability of one class to "inherit" from another
  – Sedan & hatchback inherit from car class
  – Manager & engineer inherit from employee class
  – Circle & square inherit from shape class

How to inherit

• Design the base (parent) class carefully
• Specify the class to inherit with the syntax
  
  ```cpp
  class DERIVED_CLASS
    : PARENT_CLASS_LIST {
    ...
  }
  ```

  • Parent class list
    – Comma separated
    – Name of class
    – Optional access specifier
    – Syntax
      
      ```cpp
      public|private|protected CLASSNAME, ...
      ```
Ex: Parent class - light.h

```cpp
#ifndef LIGHT_H
#define LIGHT_H
#include <string>
class light {
public:
    enum Color {WHITE, RED, YELLOW, GREEN};
    light(Color c); // constructor
    light(std::string k, Color c); // constructor
    bool is_on() {return m_on;}
    void set_on() {m_on = true;}
    void set_off() {m_on = false;}
private:
    Color m_color;
    bool m_on;
    std::string m_kind;
};
#endif
```

Ex: Inheritance

```cpp
#ifndef TAIL_LIGHT_H
#define TAIL_LIGHT_H
#include "light.h"
class tail_light : public light {
public: // Member functions - behavior
    tail_light(); // default constructor
tail_light(int percent_on); // constructor
    ~tail_light(); // destructor
    void set_rate(float duty_cycle); // 0.0 to 1.0
    void set_rate(bool light[10]);
    float get_rate();
private: // Member data - internal state
    bool m_light[10]; // 1/10th of duty cycle status
};
#endif
```
The “is a” relationship

- A parent class (base) & a child class (derived) use the “is a” relationship
  - The child class “is a” parent class
  - The converse is not true
- TG1 is a TG0
- TG2 & TG3 are a TG1

Initialization of inherited classes

- When constructing a class that instantiates another class within it
  - Base (parent) classes are constructed first
- What if you need to specify arguments to base class constructor
  - e.g. parent class has no default constructor
- Use the initializer list!
Ex: Initializer list

tail_light::tail_light(int pct)
 : light(Red)
{
    int div = int(10*pct/100+0.5);
    for (int i=0;i!=10;++i) {
        m_light[i] = (i<div);
    } //endfor
} //endfor

Adding Members

• Inheriting class (child or derived class) may define new behaviors and data
  – Sports car has spoiler
  – Manager has ability to approve raises
  – Square has sides
• Simply add new member functions/data
Overriding Inherited traits

- Derived classes may have different data/behaviors for given function
  - Sports car has 2 doors instead of 4
  - Manager attends more meetings
  - Circle draws differently
- Defining the same method again in the derived class effectively hides the parent method

Ex: Overriding methods

```cpp
class tail_light : public light {
public:
    bool is_on(); // override
    ...}

bool tail_light::is_on() {
    // on if m_on is true and current
    // light cycle is true
    ...}
```
**Accessing parent methods**

- A derived class can access all the public/protected members of the base class
  - Even if it overrides the parent
    ```cpp
    BASECLASS::METHOD(ARGS...)
    ```
- This allows modification of base behavior
  ```cpp
  DERIVEDCLASS::METHOD(ARGS) {
    // pre modifications
    BASECLASS::METHOD(ARGS);
    // post modifications
    return RESULT;
  }
  ```

**Multiple inheritance**

- C++ allows inheritance from more than one parent class
  - Known as multiple inheritance
  - Used judiciously, it is powerful and useful
- What happens if two base classes have the same common method signatures?
  - Simply override and specify which one rules...
- What if two base classes share a common ancestor (famous diamond problem)?
**Protected members**

- **private** access specification means private to the class where used
  - Children may not access parent’s private info
- What about “family” secrets?
  - Use the designation **protected**
  - Protected information is available to class where declared and any derived class
- When designing a class must think ahead

---

**Ex: Protected**

```cpp
class light {
public:
    enum Color {WHITE, RED, YELLOW, GREEN};
    light(Color c); // constructor
    bool is_on() {return m_on; }  
    void set_on() {m_on = true; }  
    void set_off() {m_on = false; }
    protected:
        bool m_on;
private:
    Color m_color;
};
```

---

Restricted Material
Friends

• What if we would like to extend access to another function or class that is not a part of the family?
  – Specify the function or class as a friend
  – WARNING: Friends can access everything
    ```cpp
    class B;
    class A {
      friend B;
    };
    – Use sparingly
    ```

What is polymorphism?

• The ability to have a function or method that takes derived objects as base class arguments and behaves correctly with respect to overridden behaviors.
Consider a class of shapes
– A shape might have an inherent ability to draw itself; however...
– A circle has a unique draw method
  • i.e. overrides base shape::draw
– A square has a different draw method
  • i.e. overrides base shape::draw
– It would be nice to be able to have a list of shapes and then just
draw each one

Consider a base printer class
– Both laser and inkjets have the ability to print
– Print works differently in the laser and inkjet printers
– A test function might take a generic printer as a parameter and
attempt to print regardless of the sub-class of printer

**Why polymorphism?**

Ex: Without polymorphism

```cpp
class printer {
public:
    void print(string s) {
        cerr << "Base:Oops!" << endl;
    }
};
class laser : public printer {
public:
    void print(string s) {
        cout << "Laser:" << s << endl;
    }
};
class inkjet : public printer {
public:
    void print(string s) {
        cout << "Inkjet:" << s << endl;
    }
};

void f(printer p) {
    p.print("hello");
}

int main() {
    printer generic;
    laser lj5550;
    inkjet dj2800;
    f(generic);
    f(lj5550);
    f(dj2800);
}
```

Base:Oops!
Base:Oops!
Base:Oops!
Virtual methods

- To enable polymorphism C++ designates the shared methods as virtual
  - virtual RTN_TYPE METHOD(ARGS);
- This causes C++ to create a lookup table in the class, which allows a derived class to specify an overridden function.

Ex: With polymorphism

```cpp
class printer {
public:
    virtual void print(string s) {
        cerr<<"Base:Oops!"<<endl;
    }
};
class laser : public printer {
public:
    void print(string s) {
        cout<<"Laser:"<<s<<endl;
    }
};
class inkjet : public printer {
public:
    void print(string s) {
        cout<<"Inkjet:"<<s<<endl;
    }
};

void f(printer p) {
    p.print("hello");
}

int main() {
    printer generic;
    laser lj5550;
    inkjet dj2800;
    f(generic);
    f(lj5550);
    f(dj2800);
}
```
Pure virtual methods

- It would be nice if we could ensure that all printers had a print function at compile-time instead of a run-time error.
- Declaring a method to be pure enables this:
  - `virtual RTN_TYPE METHOD(ARGS)=0;`
- Think of `=0` as meaning “This function has no implementation.”

Abstract & Interface classes

- A class containing a pure virtual method is called an **abstract class**.
- An abstract class cannot be instantiated because there is no definition for the pure virtual method.
- A class containing **only** pure virtual methods (no data either), is call an **interface class**.
- An interface class is effectively an API (Application Programming Interface) for a class.
**Ex: With pure virtual**

```cpp
class printer {
public:
    virtual void print(string s) = 0;
};
class laser : public printer {
public:
    void print(string s) {
        cout << "Laser:" << s << endl;
    }
};
class inkjet : public printer {
public:
    void print(string s) {
        cout << "Inkjet:" << s << endl;
    }
};

void f(printer p) {
    p.print("hello");
}

int main() {
    //printer generic; ILLEGAL
    laser lj5550;
    inkjet dj2800;
    f(lj5550);
    f(dj2800);
}
```

**The dreaded diamond**

- When inheriting from multiple classes that inherit from a base class, it is possible that duplication of data occurs.
- TG1 & TG2 each have a copy of TG0::m
- TG3 has two copies
  - TG1::TG0::m
  - TG2::TG0::m

```cpp
class TG0 {T m;}
class TG1:TG0 {}
class TG2:TG0 {}
class TG3:TG1,TG2 {}
```
Virtual inheritance (Avoiding the dreaded diamond)

- To prevent this, declare the inherited class as `virtual`.
- NOTE: This is a completely different concept from virtual methods.

```cpp
class TG0 { T m };
class TG1 : virtual TG0 {...}
class TG2 : virtual TG0 {...}
class TG3: TG1, TG2 {...}
```

Constant members

- Adding the keyword `const` to a method restricts the method from modifying any member data

```cpp
class T1 {
    public:
    int get() const { return m; }
    void get(int & v) const { v = m; }
    void set(int v);
    private:
    int m;
};
```

- May not call non-const methods inside a `const`
- Use `const` whenever possible
  - Good for get methods
Ex: const members - light.h

```cpp
#ifdef LIGHT_H
#define LIGHT_H
#include <string>
class light {
public:
    enum Color {WHITE, RED, YELLOW, GREEN};
    light(Color c); // constructor
    light(std::string k, Color c); // constructor
    bool is_on() const { return m_on; }
    void set_on() { m_on = true; }
    void set_off() { m_on = false; }
private:
    Color m_color;
    bool m_on;
    std::string m_kind;
};
#endif
```

Static members

- Inside ordinary functions, static is used to create variables that have infinite lifetimes. The same is true for classes.
- Static member functions may not alter non-static member data nor call non-static methods.
- Must initialize static member data externally
- Use static to gather statistics for all the objects of an entire class

```cpp
class T1 {
    T1():m(0) {++cnt;}
    ~T1() {--cnt;}
    void set(int v) {m=v;}
    static void count(){
        cout<<k<<endl;
        int m;
    }
    static int cnt;
};
static int T1::cnt(0);
```
Disabling default methods

- Use `private` or `protected` to disable
  - Sometimes you want to prevent copying or construction (e.g. interfaces)
  - Use comment to clarify intent

```cpp
class no_copy {
    protected: // Disable the following
    no_copy(); // Constructor

    private: // Disable the following for everyone
    no_copy& operator=(const no_copy& rhs) {}
    no_copy(const no_copy& old) {} }
```

Take control of the class

- Always define and comment constructor(s)
  ```cpp
  CLASSNAME(ARG,...); // Constructor
  ```
- Avoid implicit conversions by using `explicit`
  ```cpp
  explicit CLASSNAME(ARG);
  ```
- Always define or disable the copy constructor & `operator=`
  - At minimum provide a comment // Default copy
    ```cpp
    CLASSNAME(const CLASSNAME&);
    CLASSNAME& operator=(const CLASSNAME);
    ```
- Interface classes define API
  - Pure virtual methods have no implementation
    ```cpp
    virtual RETURN METHOD(ARGS) = 0;
    ```
- Destructors are your friend - destroy data leaks
  - Allows correct polymorphism
    ```cpp
    virtual ~CLASSNAME();
    ```
Exceptions

- C++ provides a mechanism to handle exceptions
  - Divide by zero
  - System call errors (e.g. read error)
  - User-defined exceptions ("FIFO underflow")
- SystemC does not currently use exceptions
  - Proposed extensions for modeling do use exceptions
  - Modeling situations may use exceptions

Exceptions in 3 parts

- **Easy syntax/concept**
  - class to hold information on the exception

```cpp
class my_exception {
    string msg; my_exception(string m):msg(m){}
};

void some_func(): my_exception {
    if (badSituation) throw my_exception("Oops");
}
```

```cpp
try {
    some_func();
} catch (my_exception& problem) {
    REPORT_ERROR(problem.msg);
    if (unrecoverable) throw; //upward again
} catch (other_exception& problem) { ... 
```

- **Function might throw the exception**
- **Throw it**
- **Catch it**
Exceptions - Caveats

- Always catch by reference
- May confuse threading, so use with care
  - Always catch if thrown unless desire abort
  - Don’t expect kernel to understand
  - `SC_REPORT_ERROR` or `SC_REPORT_FATAL` may be better for many instances
- Can lead to spaghetti code
  - How much preventative coding do you do?
  - Clean design of classes is important
- Can lead to memory leaks
  - Watch those automatic variables

Safe Code Techniques

- Pass by Value or Reference when possible
  - Less error prone to use by reference than pointers

```cpp
void Func1(long *v_ptr) {
  *v_ptr = 55;
}
long v;
Func2(&v);

void Func2(long &v) {
  v = 55;
}
long v;
Func2(v);
```

- Use `const` where possible
  - Avoids possibility of side effects catching you unaware

```cpp
char const * const RCSID = "$Id$";
class myclass {
  double const m_maxval;
  myclass(const double maxval) :m_maxval(maxval) {};
  bool legal(const double ref&) const;
};
```
Hiding data in a class

- Data hiding provides implementation freedom
- Good for IP (eslx library)

```cpp
class my_private; // no need to #include header!
class my {
    my(); // Constructor
    virtual ~my(); // Destructor
    private:
        my_private* m;
};
```

```cpp
struct my_private { // no need for private
    int hidden_int;
    my_private() {…} // Constructor
    void hidden_func() {…}
};
```

```cpp
my::my(): m(new my_private) {…}
// use m->hidden_int or m->hidden_func()
```

To hide or not to hide

- Hiding speeds up compilation
  - No need to parse headers
- May hide too much
  - If need to debug (waveforms), should expose specific data or provide methods to do so.
- SYSTEMC GUIDELINES
  - Ports are public
  - Signals that may need tracing are public
NIH - Use it!

- Standard Template & BOOST Libraries
  - Free, reviewed, debugged
- Quick Overview
  - History
  - `cstring` vs `std::strings`
  - Streaming I/O + `boost::format`
  - `vector<T>::at()`, `list<T>`
  - `map<T1,T2>`, `set<T>`
  - `boost::regex`
  - `boost_shared_ptr`

STL General Background (Wikipedia)

- `<http://wwwsgi.com/tech/stl/>`
- The C++ Standard Library is based on the STL published by SGI. Both include some features not found in the other. SGI's STL rigidly specifies a set of headers, while ISO C++ does not specify header content.
- The architecture of STL is largely the creation of one person, Alexander Stepanov. In 1979 he began working out his initial ideas of generic programming and exploring their potential for revolutionizing software development. Although Dave Musser had developed and advocated some aspects of generic programming as early as 1971, it was limited to a rather specialized area of software development (computer algebra).
- Stepanov recognized the full potential for generic programming and persuaded his then-colleagues at General Electric Research and Development (including, primarily, Dave Musser and Deepak Kapur) that generic programming should be pursued as a comprehensive basis for software development.
Boost General Background

- [http://www.boost.org](http://www.boost.org)
- Free peer-reviewed portable C++ source libraries.
- Emphasizes libraries that work well with the C++ Standard Library and intended to be widely useful, and usable across a broad spectrum of applications.
- Boost license encourages both commercial & non-commercial use. Not GNU.
- 10 Boost libraries are already included in the C++ Standards Committee's Library Technical Report (TR1) as a step toward becoming part of a future C++ Standard. More Boost libraries are proposed for TR2.
- Why "boost"? Beman Dawes stated "Boost began with Robert Klarer and I fantasizing about a new library effort over dinner at a C++ committee meeting in Sofia Antipolis, France, in 1998. Robert mentioned that Herb Sutter was working on a spoof proposal for a new language named Booze, which was supposed to be better than Java. Somehow that kicked off the idea of "Boost" as a name. We'd probably had a couple of glasses of good French wine at that point. It was just a working name, but no one ever came up with a replacement.”

Boost List of Functionality - sampler

- **any** - Safe, generic container for single values of different value types, from Kevlin Henney.
- **array** - STL compliant container wrapper for arrays of constant size, from Nicolai Josuttis.
- **assign** - Filling containers with constant or generated data has never been easier, from Thorsten Ottosen.
- **format** - Type-safe 'printf-like' format operations, from Samuel Krempp.
- **math** - Several contributions in the domain of mathematics, includes atanh, sinc, and sinh
- **numeric/conversion** - Optimized Policy-based Numeric Conversions, from Fernando Cacciola.
- **interval** - Extends the usual arithmetic functions to mathematical intervals
- **multi_array** - Multidimensional containers and adaptors for arrays of contiguous data, from Ron Garcia.
Boost List of Functionality - sampler

- random - A complete system for random number generation, from Jens Maurer.
- rational - A rational number class, from Paul Moore.
- regex - Regular expression library, from John Maddock
- uBLAS - Basic linear algebra for dense, packed and sparse matrices, from Joerg Walter and Mathias Koch.
- smart_ptr - Five smart pointer class templates, from Greg Colvin, Beman Dawes, Peter Dimov, and Darin Adler.
- There are many others...

STL Containers

- Vectors, the better array
  ```cpp
  #include <vector>
  std::vector<float> fv(50, 0.0);
  for(int I=0; I!=fv.size(); ++I) { cin >> fv[I]; }
  ```
- Linked lists
  ```cpp
  #include <list>
  std::list<smart_int> sample();
  sample.push_back(value);
  typedef std::list<smart_int>::iterator ilist;
  for(ilist I=sample.begin(); I!=sample.end(); ++I) {
    I->randomize();
  }
  sample.sort();
  ```
STL Containers continued

• Maps - associative container, sparse

```cpp
#include <map>

std::map<packet, int> pstat;

packet pkt;

typedef std::map<packet, int>::iterator imap;

for (imap i=pstat.begin(); i!=pstat.end(); ++i) {
    cout << i->first.type << " occurred " << pstat.second << endl;
}
```

• Sets

```cpp
#include <set>

enum BusState {Idle,Rst,SRd,SWr,MRd,MWr};

std::set<BusState> bs; bs.clear();

bs.insert(Idle);

if (bs.count(MWr) == 1) bs.erase(Idle);
```

boost::array Intro

• An ordinary array with STL extensions like vector
  – Doesn't carry the overhead of resizing that vector does
  – Complete array assignment
  – Range checks optional

• USAGE:

```cpp
#include "boost/array.hpp"
boost::array<T,SIZE> VAR;
```

• EXAMPLE

```cpp
using boost::array;

array<int,4> a = { (1, 2, 3, 4) };

typedef array<int,4>::iterator iterator_t;

for (iterator_t i=a.begin(); i!=a.end(); ++i) {
    *i=f(*i) + a[2]; // silly equation using *i
}
```
Range checked Array

- `vector<T>` and `array<T,N>` classes both have range checking in the form of `.at()` method
  - Not quite as natural as using operator[]
- Easy to remedy with a derived class
  ```cpp
template<typename T, int N>
class Array : public boost::array<T,N> {
public:
  Array(): array<T,N>() {}  
  T& operator[](int i) { return at(i); }
  const T& operator[](int i) const {
    return at(i);
  }
};
```

boost::format Intro

- `printf` with argument checks & more...
- EXAMPLE
  ```cpp
  #include "boost/format.hpp"
  cout << boost::format(

      "Hi %s! x=%4.1f :%d-th step\n"

    ) % "Toto" % 20.19 % 50 ;
  ```
  Hi Toto! x=20.2 :50-th step

Restricted Material
**boost::format continued**

- `cout << boost::format("%1% %3% %2% %1\n") % "aa" % 'b' % 'c';`
  
  //OUTPUT: “aa c b aa”

- `boost::format fmt("%|2$3x|:>%|1$=20|<%|30Tx|")`;
  
  `string s = str(fmt % "The title" % 17);`

- `cout<<fmt.size()<<endl<<fmt.str()<<endl;`

```cpp
boost::regex Intro
```

- Regular expressions for C++
  - grep, sed, perl, vim, emacs searching
  - Several varieties of expressions including perl
  - Allows for both search and replace

- More general than just character strings
  - Can search arrays of data for data patterns

- Lots of methods/syntax
  - We’ll limit ourselves to simple string example

```cpp
#include "boost/regex.hpp"
```

- Link with `-lboost_regex`
boost::regex methods

- **boost::regex_match** determines if an expression matches an entire text
- **boost::regex_search** finds expression within a text
  - Most likely what you want to use
  - Allows identifying sub-matches
- **boost::regex_replace** makes replacements
  - Allows for sub-matches in replacement

boost::regex Example

```cpp
#include "boost/regex.hpp"
string text("This is some text to search")
string::const_iterator text_beg = text.begin();
string::const_iterator text_end = text.end();
boost::regex expr("some text");
boost::match_results<string::const_iterator> rslt;
bool found = boost::regex_search
    (text_beg, text_end, rslt, expr);
if (found)
    cout << "Matched "
    << string(rslt[0].first, rslt[0].second)
    << " @ posn " << (rslt[0].first - text_beg)
    << " length " << (rslt[0].second - rslt[0].first)
    << endl;
```

What to search

Regular expression

The search

Where found

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Boost Shared Pointers Intro

- Pointers are dangerous because it is easy to lose track of and create memory leaks.
- Smart pointers solve this by providing garbage collection.
- Six types:
  
<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>scoped_ptr</td>
<td>Simple sole ownership of single objects. Noncopyable.</td>
</tr>
<tr>
<td>scoped_array</td>
<td>Simple sole ownership of arrays. Noncopyable.</td>
</tr>
<tr>
<td>shared_ptr</td>
<td>Object ownership shared among multiple pointers</td>
</tr>
<tr>
<td>shared_array</td>
<td>Array ownership shared among multiple pointers</td>
</tr>
<tr>
<td>weak_ptr</td>
<td>Non-owning observers of an object owned by shared_ptr.</td>
</tr>
<tr>
<td>intrusive_ptr</td>
<td>Shared ownership of objects with an embedded reference count.</td>
</tr>
</tbody>
</table>

Normal pointers would create memory leaks

boost::shared Intro

- Shared pointers allow copying without worrying about dangling pointers. When reference count drops to zero, the object is destroyed.
  - Caveat: Dangerous if circularly linked (RARE)
- USAGE:
  - #include "boost/shared_ptr.hpp"
  - boost::shared_ptr&lt;T&gt; v1_ptr(new T);
  - boost::shared_ptr&lt;T&gt; v2_ptr;
  - v2_ptr.reset(new T);
  - v1_ptr = v2_ptr;
  - *v2_ptr = value;
  - std::cout &lt;&lt; *v1_ptr &lt;&lt; std::endl;
  - {boost::shared_ptr&lt;TYPE&gt; v3_ptr(new T);}
Questions