12. A bit of C++

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Roadmap

- C++ vs C
- C++ vs Java
- References vs pointers
- C++ classes: Orthodox Canonical Form
- A quick look at STL — The Standard Template Library

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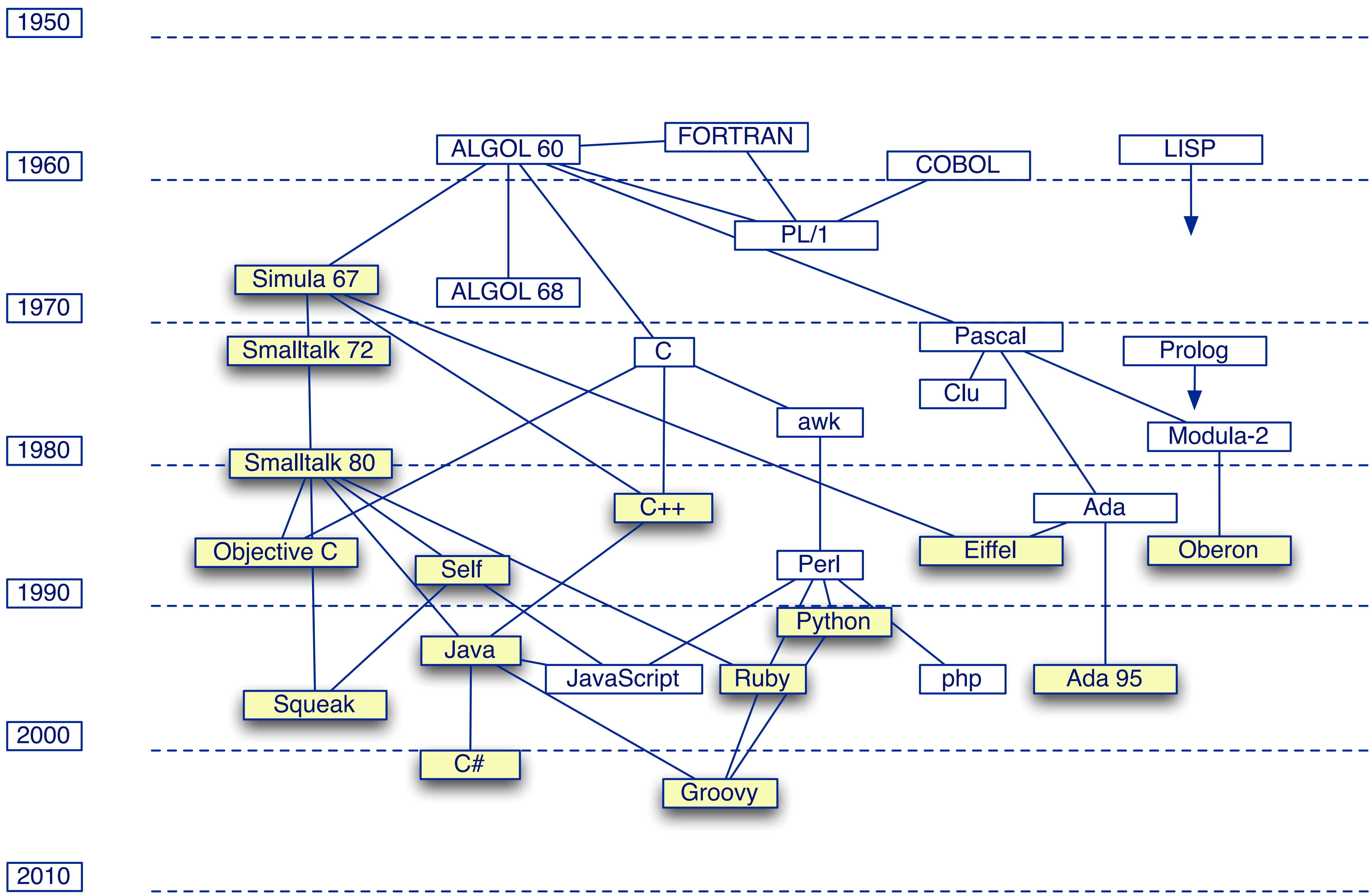
Essential C++ Texts

> Bjarne Stroustrup, *The C++ Programming Language* (Special Edition), Addison Wesley, 2000.
> Stanley B. Lippman and Josee LaJoie, *C++ Primer*, Third Edition, Addison-Wesley, 1998.
> Scott Meyers, *Effective C++,* 2d ed., Addison-Wesley, 1998.
> James O. Coplien, *Advanced C++: Programming Styles and Idioms*, Addison-Wesley, 1992.
> David R. Musser, Gilmer J. Derge and Atul Saini, *STL Tutorial and Reference Guide*, 2d ed., Addison-Wesley, 2000.
> Erich Gamma, Richard Helm, Ralph Johnson and John Vlissides, *Design Patterns*, Addison Wesley, Reading, MA, 1995.

Object-oriented language genealogy



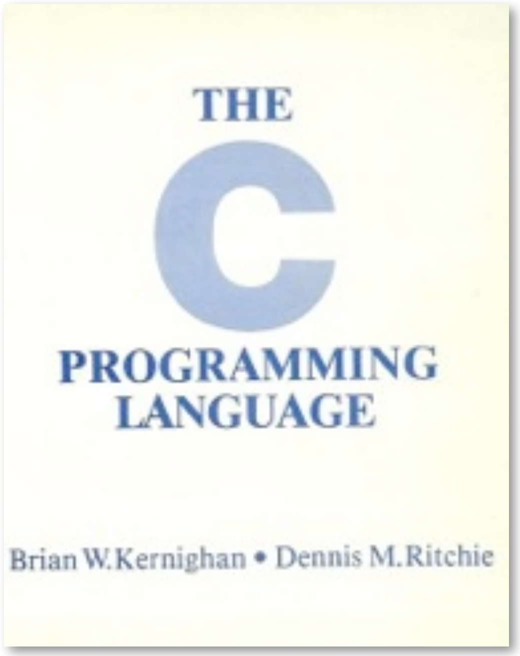
What is C?

> C is a general purpose, procedural, imperative language developed in 1972 by Dennis Ritchie at Bell Labs for the Unix Operating System.

— Low-level access to memory

— Language constructs close to machine instructions

— Used as a *"machine-independent assembler"*



My first C Program

```
#include <stdio.h>

int main(void)
{
    printf("hello, world\n");
    return 0;
}
```

My first C Program

A preprocessor directive

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int main(void)
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My first C Program

Include standard io declarations

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Write to standard output

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Write to standard output

char array

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A preprocessor directive

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#include <stdio.h>

int main(void)
{
    printf("hello, world\n");
    return 0;
}
```

Write to standard output

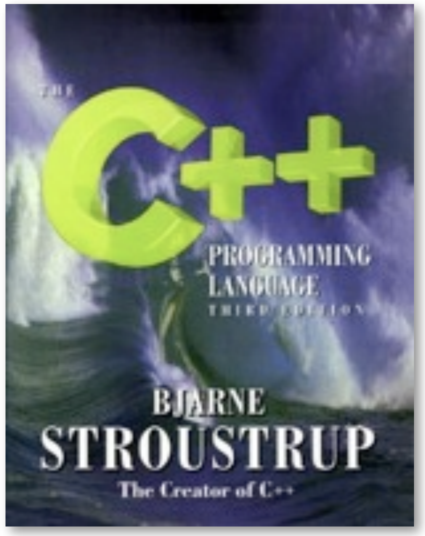
char array

Indicate correct termination

What is C++?

A *"better C"* (http://www.research.att.com/~bs/C++.html) that supports:

- Systems programming
- Object-oriented programming (*classes* & *inheritance*)
- Programming-in-the-large (*namespaces*, *exceptions*)
- Generic programming (*templates*)
- Reuse (large class & template libraries)



C++ vs C

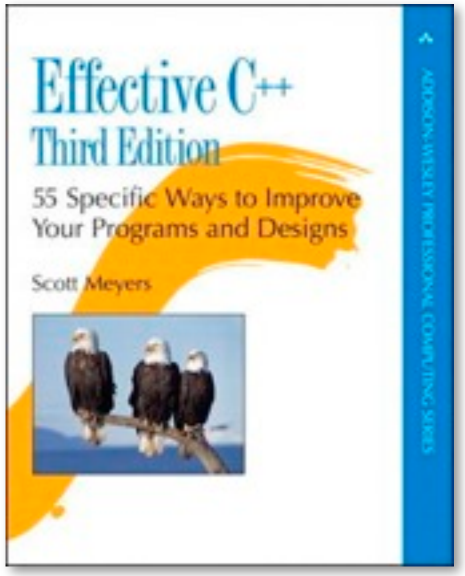
Most C programs are also C++ programs.

Nevertheless, good C++ programs usually do not resemble C:

- avoid macros (use `inline`)
- avoid pointers (use references)
- avoid `malloc` and `free` (use `new` and `delete`)
- avoid arrays and `char*` (use `vector`s and `string`s) ...
- avoid `struct`s (use classes)

C++ encourages a different style of programming:

- avoid procedural programming
  — *model your domain* with classes and templates



Roadmap

> C++ vs C
> **C++ vs Java**
> References vs pointers
> C++ classes: Orthodox Canonical Form
> A quick look at STL — The Standard Template Library

Hello World in Java

```
package p2;
// My first Java program!
public class HelloMain {
    public static void main(String[] args) {
        System.out.println("hello world!");
        return 0;
    }
}
```

“Hello World” in C++

```
using namespace std;
#include <iostream>
// My first C++ program!
int main(void)
{
  cout << "hello world!" << endl;
  return 0;
}
```

“Hello World” in C++

Use the standard namespace

```
using namespace std;
#include <iostream>
// My first C++ program!
int main(void)
{
  cout << "hello world!" << endl;
  return 0;
}
```

“Hello World” in C++

Use the standard namespace

Include standard iostream classes

```
using namespace std;
#include <iostream>
// My first C++ program!
int main(void)
{
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}
```

"Hello World" in C++

Use the standard namespace

Include standard iostream classes

A C++ comment

```
using namespace std;
#include <iostream>
// My first C++ program!
int main(void)
{
  cout << "hello world!" << endl;
  return 0;
}
```

“Hello World” in C++

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Include standard iostream classes

A C++ comment

cout is an instance of ostream

```
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int main(void)
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"Hello World" in C++

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```
using namespace std;
#include <iostream>
// My first C++ program!
int main(void)
{
  cout << "hello world!" << endl;
  return 0;
}
```

cout is an instance of ostream

operator overloading
(two *different* argument types!)

Makefiles / Managed Make in CDT

You could compile it all together by hand:

```
c++ helloWorld.cpp -o helloWorld
```

Makefiles / Managed Make in CDT

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Or you could use a *Makefile* to manage dependencies:

```
helloWorld : helloWorld.cpp
   c++ $@.cpp -o $@
```

```
make helloWorld
```

Makefiles / Managed Make in CDT

You could compile it all together by hand:

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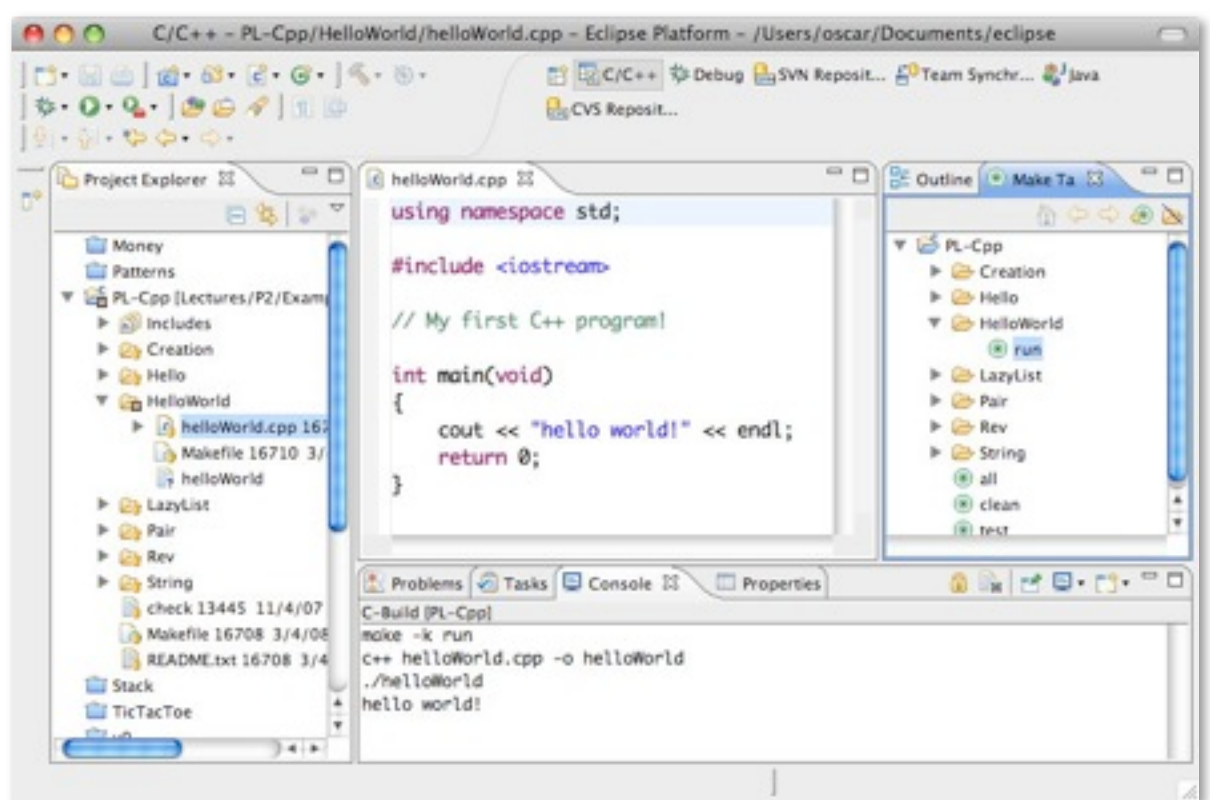
```

Or you could use a *Makefile* to manage dependencies:

```
helloWorld : helloWorld.cpp
	c++ $@.cpp -o $@
```

```
make helloWorld
```

Or you could use *cdt with eclipse* to create a standard managed make project



C++ Design Goals

"C with Classes" designed by Bjarne Stroustrup in early 1980s:

> Originally a translator to C
  - —Initially difficult to debug and inefficient

> Mostly *upward compatible* extension of C
  - —"As close to C as possible, but no closer"
  - —Stronger type-checking
  - —Support for object-oriented programming

> Run-time efficiency
  - —Language primitives close to machine instructions
  - —*Minimal cost for new features*

C++ Features

C with Classes	Classes as structs Inheritance; virtual functions Inline functions
C++ 1.0 (1985)	Strong typing; function prototypes new and delete operators
C++ 2.0	Local classes; protected members Multiple inheritance
C++ 3.0	Templates Exception handling
ANSI C++ (1998)	Namespaces RTTI (Runtime Type Information)

Java and C++ — Similarities and Extensions

Some Java Extensions:

- >garbage collection
- >standard abstract machine
- >standard classes (came later to C++)
- >packages (now C++ has namespaces)
- >final classes
- >autoboxing
- >generics instead of templates

Java Simplifications of C++

- no pointers — **just references**
- no functions — can declare **`static`** methods
- no global variables — use **`public static`** variables
- no destructors — **garbage collection** and **`finalize`**
- no linking — dynamic class loading
- no header files — can define **`interface`**
- no operator overloading — only method overloading
- no member initialization lists — call **`super`** constructor
- no preprocessor — **`static final`** **constants** and automatic inlining
- no multiple inheritance — **implement multiple interfaces**
- no structs, unions — **typically not needed**

New Keywords

In addition to the keywords inherited from C, C++ adds:

Exceptions	`catch, throw, try`
Declarations:	`bool, class, enum, explicit, export, friend, inline, mutable, namespace, operator, private, protected, public, template, typename, using, virtual, volatile, wchar_t`
Expressions:	`and, and_eq, bitand, bitor, compl, const_cast, delete, dynamic_cast, false, new, not, not_eq, or, or_eq, reinterpret_cast, static_cast, this, true, typeid, xor, xor_eq`

***(see** http://www.glenmccl.com/glos.htm)*

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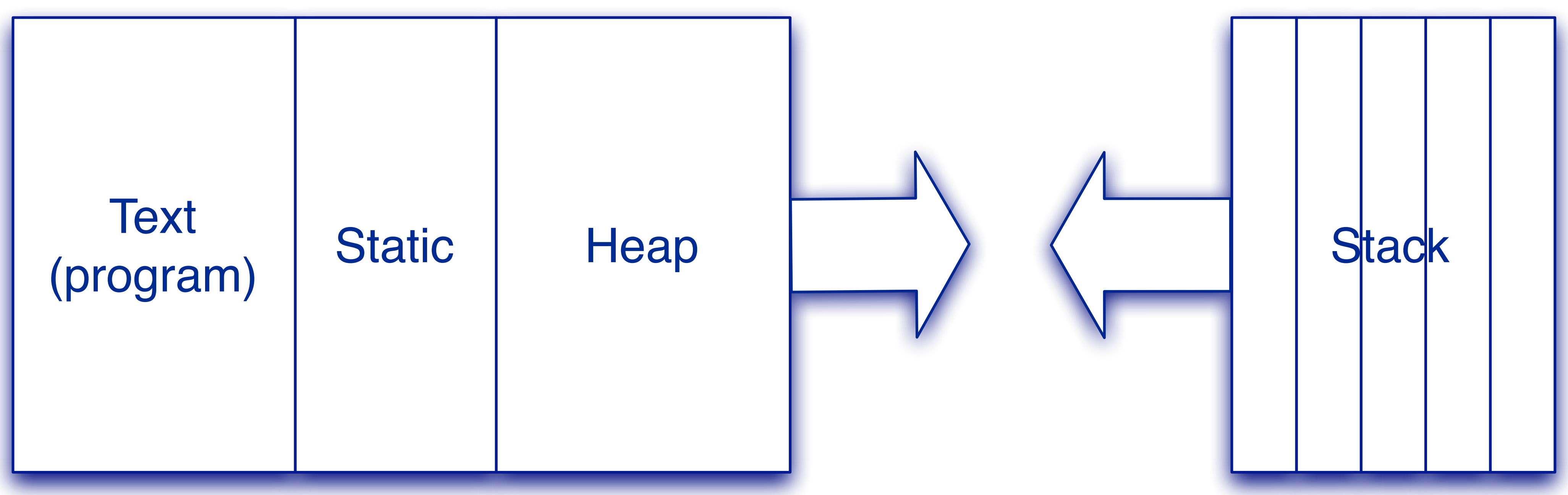
Memory Layout

The address space consists of (at least):

Text:	executable program text (not writable)
Static:	static data
Heap:	dynamically allocated global memory (grows upward)
Stack:	local memory for function calls (grows downward)



Pointers in C and C++

```
int i;
int *iPtr; // a pointer to an integer

iPtr = &i; // iPtr contains the address of I
*iPtr = 100;
```

variable	value	Address in hex
	...	
i	100	456FD4
iPtr	456FD4	456FD0
	...	

References

A <u>reference</u> is an ***alias*** for another variable:

```
int i = 10;
int &ir = i;   // reference (alias)
ir = ir + 1;   // increment i
```

Once initialized, references cannot be changed.

References are especially useful in ***procedure calls*** to avoid the overhead of passing arguments by value, without the clutter of explicit pointer dereferencing (y = *ptr;)

```
void refInc(int &n)
{
    n = n+1; // increment the variable n refers to
}
```

References vs Pointers

References should be preferred to pointers ***except*** *when:*

> manipulating dynamically allocated objects
>
> — `new` returns an object pointer

> a variable must range over a set of objects
>
> — use a **pointer** to walk through the set

C++ Classes

C++ classes may be instantiated either *automatically* (on the stack):

```
MyClass oVal;     // constructor called
                    // destroyed when scope ends
```

or *dynamically* (in the heap)

```
MyClass *oPtr;          // uninitialized pointer

oPtr = new MyClass;   // constructor called
                         // must be explicitly deleted
```

Constructors and destructors

```
#include <iostream>
#include <string>

using namespace std;
class MyClass {
private:
    string name;
public:
    MyClass(string name) : name(name) {        // constructor
        cout << "create " << name << endl;
    }
    ~MyClass() {
        cout << "destroy " << name << endl;
    }
};
```

Constructors and destructors

Include standard iostream and string classes

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#include <iostream>
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public:
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};
```

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   }
   ~MyClass() {
      cout << "destroy " << name << endl;
   }
};
```

Use initialization list in constructor

Constructors and destructors

Include standard iostream and string classes

Use initialization list in constructor

Specify cleanup in destructor

```
#include <iostream>
#include <string>

using namespace std;
class MyClass {
private:
    string name;
public:
    MyClass(string name) : name(name) {        // constructor
        cout << "create " << name << endl;
    }
    ~MyClass() {
        cout << "destroy " << name << endl;
    }
};
```

Automatic and dynamic destruction

```
MyClass& start() {                     // returns a reference
   MyClass a("a");                     // automatic
   MyClass *b = new MyClass("b");      // dynamic
   return *b;                          // returns a reference (!) to b
}                                      // a goes out of scope

void finish(MyClass& b) {
   delete &b;                          // need pointer to b
}
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}
```

```
#include "MyClass.h”
using namespace std;
int main (int argc, char **argv) {
   MyClass aClass("d");
   finish(start());
   return 0;
}
```

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#include "MyClass.h”
using namespace std;
int main (int argc, char **argv) {
    MyClass aClass("d");
   finish(start());
    return 0;
}
```

create d

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```
create d
create a
```

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}
```

```
create d
create a
create b
destroy a
destroy b
destroy d
```

Roadmap

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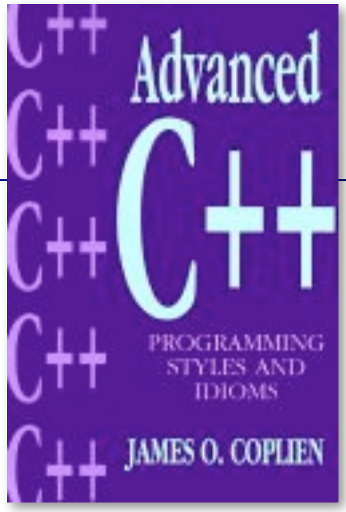
Orthodox Canonical Form

Most of your classes should look like this:

```
class myClass {
public:
   myClass(void);                             // default constructor
   myClass(const myClass& copy);              // copy constructor
      ...                                     // other constructors
   ~myClass(void);                            // destructor
   myClass& operator=(const myClass&);        // assignment
      ...                            // other public member functions
private:
      ...
};
```



Why OCF?

If you don't define these four member functions, *C++ will generate them:*

> ***default constructor***
>
> — will call default constructor for each data member
>
> ***destructor***
>
> — will call destructor of each data member
>
> ***copy constructor***
>
> — will *shallow copy* each data member
>
> — pointers will be copied, not the objects pointed to!
>
> ***assignment***
>
> — will *shallow copy* each data member

Example: A String Class

We would like a `String` class that protects C-style strings:

> strings are indistinguishable from `char` pointers

> string updates may cause memory to be corrupted

Strings should support:

> creation and destruction

> initialization from char arrays

> copying

> safe indexing

> safe concatenation and updating

> output

> length, and other common operations ...

A Simple String.h

```
class String
{
    friend ostream& operator<<(ostream&, const String&);
public:
    String(void);                           // default constructor
    ~String(void);                          // destructor
    String(const String& copy);         // copy constructor
    String(const char*s);                   // char* constructor
    String& operator=(const String&);       // assignment

    inline int length(void) const { return ::strlen(_s); }
    char& operator[](const int n) throw(exception);
    String& operator+=(const String&) throw(exception);     // concatenation
private:
    char *_s; // invariant: _s points to a null-terminated heap string
    void become(const char*) throw(exception);  // internal copy function
};
```

A Simple String.h

A friend function prototype declaration of the String class

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class String
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    friend ostream& operator<<(ostream&, const String&);
public:
    String(void);                           // default constructor
    ~String(void);                          // destructor
    String(const String& copy);         // copy constructor
    String(const char*s);                   // char* constructor
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A Simple String.h

Operator overloading

A friend function prototype declaration of the String class

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public:
    String(void);                               // default constructor
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A Simple String.h

Returns a reference to ostream

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A Simple String.h

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A friend function prototype declaration of the String class

Operator overloading of =

```
class String
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public:
    String(void);                           // default constructor
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Returns a reference to ostream

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A friend function prototype declaration of the String class

Operator overloading of =

inline

Default Constructors

Every constructor should *establish the class invariant:*

```
String::String(void)
{
    _s = new char[1];        // allocate a char array
    _s[0] = '\0';               // NULL terminate it!
}
```

The *default constructor* for a class is called when a new instance is declared without any initialization parameters:

```
String anEmptyString;         // call String::String()
String stringVector[10];      // call it ten times!
```

Default Constructors

Every constructor should *establish the class invariant:*

Allocate memory for the string

```
String::String(void)
{
    _s = new char[1];           // allocate a char array
    _s[0] = '\0';                  // NULL terminate it!
}
```

The *default constructor* for a class is called when a new instance is declared without any initialization parameters:

```
String anEmptyString;          // call String::String()
String stringVector[10];       // call it ten times!
```

Destructors

The `String` destructor must *explicitly free* any memory allocated by that object.

```
String::~String (void)
{
   delete [] _s;
}
```

free memory

Every new must be matched somewhere by a delete!

- use `new` and `delete` for *objects*
- use `new[]` and `delete[]` for *arrays*!

Copy Constructors

Our `String` copy constructor must create a *deep copy:*

```
String::String(const String& copy)
{
   become(copy._s);              // call helper
}

void String::become(const char* s) throw (exception)
{
   _s = new char[::strlen(s) + 1];
   if (_s == 0) throw(logic_error("new failed"));
   ::strcpy(_s, s);
}
```

From std

A few remarks ...

> We **must** define a copy constructor,
> … else copies of Strings will *share the same representation!*
> — Modifying one will modify the other!
> — Destroying one will invalidate the other!

> We **must** declare `copy` as `const`,
> … else we won't be able to construct a copy of a `const String`!
> — Only const (immutable) operations are permitted on const values

> We **must** declare `copy` as `String&`, not `String`,
> … else a *new copy* will be made before it is passed to the constructor!
> — Functions arguments are always passed by value in C++
> — The "value" of a pointer is a pointer!

> **The abstraction boundary is a class**, *not an object*. Within a class, **all private members are visible** (as is `copy._s`)

Other Constructors

Class constructors may have arbitrary arguments, as long as their signatures are unique and unambiguous:

```
String::String(const char* s)
{
   become(s);
}
```

Since the argument is not modified, we can declare it as **`const`**. This will allow us to construct `String` instances from constant `char` arrays.

Assignment Operators

Assignment is different from the copy constructor because *an instance already exists:*

```
String& String::operator=(const String& copy)
{
    if (this != &copy) {        // take care!
        delete [] _s;
        become(copy._s);
    }
    return *this;              // NB: a reference, not a copy
}
```

- Return **`String&`** rather than void so the result *can be used in an expression*
- Return **`String&`** rather than `String` so the result *won't be copied!*
- **`this`** is a pseudo-variable whose value is a pointer to the current object
  - —so **`*this`** is the value of the current object, which is *returned by reference*

Implicit Conversion

When an argument of the “wrong” type is passed to a function, the C++ compiler looks for a constructor that will convert it to the “right” type:

```
str = "hello world";
```

is implicitly converted to:

```
str = String("hello world");
```

NB: compare to autoboxing in Java

Operator Overloading (indexing)

Not only assignment, but other useful operators can be "overloaded" provided their signatures are unique:

```
char& String::operator[] (const int n) throw(exception)
{
   if ((n<0) || (length()<=n)) {
      throw(logic_error("array index out of bounds"));
   }
   return _s[n];
}
```

NB: a non-const reference is returned, so can be used as an ***lvalue*** *in an assignment.*

Overloadable Operators

The following operators may be overloaded:

<table>
<tr><td>+</td><td>-</td><td>*</td><td>/</td><td>%</td><td>^</td><td>&</td><td>|</td></tr>
<tr><td>~</td><td>!</td><td>,</td><td>=</td><td><</td><td>></td><td><=</td><td>>=</td></tr>
<tr><td>++</td><td>--</td><td><<</td><td>>></td><td>==</td><td>!=</td><td>&&</td><td>||</td></tr>
<tr><td>+=</td><td>-=</td><td>/=</td><td>%=</td><td>^=</td><td>&=</td><td>|=</td><td>*=</td></tr>
<tr><td><<=</td><td>>>=</td><td>[]</td><td>()</td><td>-></td><td>->*</td><td>new</td><td>delete</td></tr>
</table>

NB: arity and precedence are fixed by C++

Friends

We would like to be able to write:

```
cout << String("TESTING ... ") << endl;
```

But:

- **It can't be a member function of `ostream`, since we can't extend the standard library.**
- It can't be a member function of `String` since the target is **`cout`.**
- But it must have access to `String`'s **private data**

So ... we need a binary *function* << that takes a `cout` and a `String` as arguments, and is a *`friend`* of `String`.

Friends ...

We ***declare****:*

```
class String
{
 friend ostream&
        operator<<(ostream&, const String&);
    ...
};
```

And ***define****:*

```
ostream&
operator<<(ostream& outStream, const String& s)
{
   return outStream << s._s;
}
```

Roadmap

> C++ vs C
> C++ vs Java
> References vs pointers
> C++ classes: Orthodox Canonical Form
> **A quick look at STL — The Standard Template Library**

Standard Template Library

STL is a general-purpose C++ library of generic algorithms and data structures.

1. Containers store *collections of objects*
   — `vector, list, deque, set, multiset, map, multimap`
2. Iterators *traverse containers*
   — random access, bidirectional, forward/backward ...
3. Function Objects encapsulate *functions as objects*
   — arithmetic, comparison, logical, and user-defined ...
4. Algorithms implement *generic procedures*
   — `search, count, copy, random_shuffle, sort, ...`
5. Adaptors provide an *alternative interface* to a component
   — `stack, queue, reverse_iterator, ...`

An STL Line Reverser

```
#include <iostream>
#include <stack>                        // STL stacks
#include <string>                           // Standard strings

void rev(void)
{
    typedef stack<string> IOStack;    // instantiate the template
    IOStack ioStack;                // instantiate the template class
    string buf;

    while (getline(cin, buf)) {
        ioStack.push(buf);
    }
    while (ioStack.size() != 0) {
        cout << ioStack.top() << endl;
        ioStack.pop();
    }
}
```

What we didn’t have time for ...

- virtual member functions, pure virtuals
- public, private and multiple inheritance
- default arguments, default initializers
- method overloading
- const declarations
- enumerations
- smart pointers
- static and dynamic casts
- Templates, STL
- template specialization
- namespaces
- RTTI
- ...

What you should know!

- ✎ *What new features does C++ add to C?*
- ✎ *What does Java remove from C++?*
- ✎ *How should you use C and C++ commenting styles?*
- ✎ *How does a reference differ from a pointer?*
- ✎ *When should you use pointers in C++?*
- ✎ *Where do C++ objects live in memory?*
- ✎ *What is a member initialization list?*
- ✎ *Why does C++ need destructors?*
- ✎ *What is OCF and why is it important?*
- ✎ *What's the difference between delete and delete[]?*
- ✎ *What is operator overloading?*

Can you answer these questions?

- ✎ *Why doesn't C++ support garbage collection?*
- ✎ *Why doesn't Java support multiple inheritance?*
- ✎ *What trouble can you get into with references?*
- ✎ *Why doesn't C++ just make deep copies by default?*
- ✎ *How can you declare a class without a default constructor?*
- ✎ *Why can objects of the same class access each others private members?*