The Language

- Originally “C with classes”, now much more.
- Intended to be a superset of C
- Has many new features, all add complexity
- Useful for writing fast, generic code
- Can become extremely verbose
- Only covering the most widely used features
Printing, C++ Style

- C++ supports operator overloading
- Best example: standard i/o streaming library
- Overloads `<<` operator to mean “write this object to the stream”
- `std::cout` and `std::cerr` are streams for `stdout/stderr`
- Say goodbye to `printf` format specifiers ación

```cpp
#include <iostream>

int main(int argc, char **argv) {
    std::cout << "Hello, World!\n";
    std::cout << "argc: " << argc << '\n';
    std::cout << "argv[0]: " << argv[0] << '\n';
}
```
Classes and Structs

- Can have private members, like Foo::a and Bar::d
- Classes default to private, structs to public, otherwise equivalent
- No need for typedef as in C
- See trailing semi-colon

```cpp
class Foo {
    int a;
    public:
        int b;
};
struct Bar {
    Foo f;
    int c;
    private:
        int d;
};

int main(void) {
    Bar bar;
    bar.c = 1;
    bar.f.b = 2;
    // invalid:
    bar.d = 3;
    bar.f.a = 3;
}
```
New and Delete

- new operator allocates memory and calls ctor
- delete operator calls dtor and frees memory
- Always use new instead of malloc, or object will be uninitialized

```c
struct Foo {
    int a_;  // struct Foo {
    Foo(int a);  //     int a_;  
    ~Foo();  //     Foo(int a)
};

Foo::Foo(int a) {
    printf("a: %d\n", a);  //     Foo(int a) {
    this->a_ = a;  //         printf("a: %d\n", a);
}

Foo::~Foo() {
    printf("destructor\n");  //     this->a_ = a;
}

int main(void) {
    Foo *f = new Foo(5);  //     Foo::~Foo()
    delete f;  //     }  // int main(void) {
}  // struct Foo {
```
Constructors and Destructors

- Foo::Foo(int a) is a constructor (ctor) for Foo
- Foo::~Foo() is destructor (dtor)
- “this” is a pointer to the object (like Java)
- Prints:
  - a: 5
  - destructor

```c
struct Foo {
    int a_;  
    Foo(int a); 
    ~Foo(); 
};  
Foo::Foo(int a) {  
    printf("a: %d\n", a);  
    this->a_ = a;  
}  
Foo::~Foo() {  
    printf("destructor\n");  
}  
int main(void) {  
    Foo *f = new Foo(5);  
    delete f;  
}
```
Constructors and Destructors

- Ctors should initialize all member variables
- Dtors should clean up any resources owned by the object
- In this case, Str “owns” buf, so it deletes it
- If no ctor is declared, compiler generates implicit default ctor with no initialization!

```cpp
struct Str {
    int len;
    char *buf;
    Str(int l, char *b);
    ~Str();
};

Str::Str(int l, char *b) {
    len = l;
    buf = b;
}

Str::~Str() {
    delete buf;
}
```
Methods

- Methods are defined similarly to constructors.
- Methods are called using -> and .
- “member function” is another name for method.

```cpp
struct Foo {
    int thing_;  
    void setThing(int thing);  
    int getThing();
};
void Foo::setThing(int thing) {
    thing_ = thing;
}
int Foo::getThing() {
    return thing_;  
}
int main(void) {
    Foo *f = new Foo();
    f->setThing(20);
    printf("thing: %d\n",  
            f->getThing());
    delete f;
}
```
Class definitions live in header (.h) files

Method definitions live in source files (.cpp, .cc)

If class Foo is in Foo.h and Foo.cpp, #include “Foo.h” to call Foo’s methods

C++ headers are large, so use header guards!

```
// Foo.h
#ifndef FOO_H
#define FOO_H
struct Foo {
    int thing_
    void setThing(int thing);
    int getThing();
};
#undef FOO_H
#endif // FOO_H

// Foo.cpp
void Foo::setThing(int thing) { thing_ = thing; }
int Foo::getThing() { return thing_; }

// Bar.cpp
#include "Foo.h"
int main(void) {
    Foo *f = new Foo();
    f->setThing(20);
    printf("thing: %d\n", f->getThing());
    delete f;
}
Inline Methods

- Function calls are too expensive for just get/set
- Compiler cannot inline across modules
- Solution: move definitions into header file
- Use for short routines, especially ctors/dtors

```c
// Foo.h
struct Foo {
    int thing_;
    void setThing(int thing) {
        thing_ = thing;
    }
    int getThing() {
        return thing_;}
};

// Bar.cpp
#include "Foo.h"
int main(void) {
    Foo *f = new Foo();
    f->setThing(20);
    printf("thing: %d\n", f->getThing());
    delete f;
}
```
Virtual Methods

- Uses dynamic dispatch and indirect function call
- Subclasses can override virtual methods
- Java: default is virtual
- C++: default is final
- Virtual methods are slower and cannot be inlined
- Perf numbers:
  - inline: 8ms
  - direct: 68ms
  - virtual: 160ms
- Use when writing base classes
Virtual Methods

- "= 0" means "pure virtual", aka abstract
- A and B inherit from Base
- Output is:
  - A
  - B

```c
#include <stdio.h>

struct Base {
    void virtual printName() = 0;
};

struct A : public Base {
    void virtual printName() {
        printf("A\n");
    }
};

struct B : public Base {
    void virtual printName() {
        printf("B\n");
    }
};

int main(void) {
    Base *p = new A();
    p->printName();
    p = new B();
    p->printName();
}
```
References

- **Reference vs. pointers:**
  - int& a = b;
  - int* a = &b;

- **References are like pointers, except:**
  - Must always be initialized where declared
  - Cannot be reassigned
  - Use . instead of -> to access fields and methods
  - Never need to use * to dereference, compiler will “do the right thing”
  - Cannot take address of reference variable, you get the address of the referenced object
References: Simple Example

- p and r point to a
- Prints:
  - 0 0 0
  - 1 1 1
  - 2 2 2
- Can convert from pointer to reference with *
- Can convert from reference to pointer with &

```c
#include <stdio.h>
int main(void) {
    int a = 0;
    int *p = &a;
    int &r = a;
    printf("%d %d %d\n", a, *p, r);
    *p = 1;
    printf("%d %d %d\n", a, *p, r);
    r = 2;
    printf("%d %d %d\n", a, *p, r);
    // Conversion
    int *p2 = &r;
    int &r2 = *p;
    printf("%d %d %d\n", a, *p, r);
}
```
References: Swap Example

- ref_swap automatically takes addresses of args
- In both cases, a and b are modified in place
- Assembly is identical

Output:
- 2 1
- 1 2

```c
#include <stdio.h>

void ptr_swap(int *a, int *b) {
    int c = *a;
    *a = *b;
    *b = c;
}

void ref_swap(int &a, int &b) {
    int c = a;
    a = b;
    b = c;
}

int main(void) {
    int a = 1, b = 2;
    ptr_swap(&a, &b);
    printf("%d %d\n", a, b);
    ref_swap(a, b);
    printf("%d %d\n", a, b);
}
```
Const

- Const does not mean immutable

- A const reference or pointer means “I promise not to modify this data through this pointer”

- However, someone else may change the data

- Can also have pointers whose value does not change, like `cant_reseat`

```c
const char *str;
char * const cant_reseat = NULL;
bool isLowerCase() {
    for (int i = 0; i < 26; i++)
        if (str[i] < 'a' || str[i] > 'z')
            return false;
    return true;
}
int main(void) {
    char buf[26];
    str = buf; // Note buf is not const
    // cant_reseat = buf; // illegal
    for (int i = 0; i < 26; i++) {
        buf[i] = 'A' + i;
    }
    // Prints 0
    std::cout << isLowerCase() << '\n';
    for (int i = 0; i < 26; i++) {
        buf[i] += 'a' - 'A';
    }
    // Prints 1
    std::cout << isLowerCase() << '\n';
}
```
Stack vs. Heap Allocation

- new is used to allocate on the heap
- Simply declaring a stack variable calls the default constructor
- Can call other constructors by “calling” the variable

```cpp
#include <iostream>

struct Foo {
    int a_;  
    Foo() {
        a_ = 0;
        std::cout << "default ctor\n";
    }  
    Foo(int a) {
        a_ = a;
        std::cout << "a: " << a << '\n';
    }
    ~Foo() {
        std::cout << "dtor a: " << a_ << '\n';
    }
};

int main(void) {
    Foo a; // default
    Foo b(3); // other
}
```
Stack vs. Heap Allocation

- Destructors are called in reverse order of construction.
- Program prints:
  - default ctor
  - a: 1
  - dtor a: 1
  - dtor a: 0

```cpp
#include <iostream>
struct Foo {
  int a_;  
  Foo() {   
    a_ = 0;  
    std::cout << "default ctor\n";  
  }   
  Foo(int a) {    
    a_ = a;    
    std::cout << "a: " << a << '\n';    
  }    
  ~Foo() {    
    std::cout << "dtor a: " << a_ << '\n';    
  }
};
int main(void) {
  Foo f0; // default  
  Foo f1(1); // other
}
```
Resource Allocation is Initialization

- Want to allocate a resource (lock, memory, file or socket) on entry, release on exit
- Accomplished in C with gotos and booleans
- In C++, exceptions make this harder
- Insight: destructors for stack allocated variables are always called when exiting a scope
- Works when leaving via return, exceptions, break, continue, goto, or normal flow
- Idea: write lightweight class to manage the resource
RAII: Mutexes

- Consider a shared FIFO queue
- Both push and pop have error conditions
- `lock_guard` is an RAII-style class that calls lock when created, and unlock when destroyed
- Unlocks even if we return early

```cpp
#include <vector>
#include "cilk_mutex.h"
#include "lock_guard.h"

struct Queue {
  std::vector<int> data_
  cilk::mutex lock_

  void push(int e);
  int pop();
};

void Queue::push(int e) {
  cilk::lock_guard<cilk::mutex> guard(lock_);
  if (data_.size() > 100)
    return; // Still unlocks
  data_.push_back(e);
}

int Queue::pop() {
  cilk::lock_guard<cilk::mutex> guard(lock_);
  if (data_.size() == 0)
    return -1; // Still unlocks
  int t = data_.front();
  data_.erase(data_.begin());
  return t;
}
Pass by Value

- Can pass objects “by value”
- Allocates new stack memory
- Calls copy constructor passing original
- Copy ctor for Foo would be:
  - Foo::Foo(const Foo &f) {...}
- See this frequently for std::string and std::vector, objects are < 24 bytes

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

std::string getstr() {
    std::string s("Hello, World!");
    return s;
}

void println(std::string s) {
    std::cout << s << '\n';
}

int main(void) {
    std::string s = getstr();
    println(s);
}
```
Templates

- Templates are like Java generics (sort of)
- Templates are “instantiated” at compile time
- Two versions of my_min generated, one for strings and one for ints
- Very efficient! No virtual calls

Prints:
- 4
- book

```cpp
template <typename T>
T my_min(T l, T r) {
    return (l < r) ? l : r;
}

int main(void) {
    std::cout << my_min(10, 4) << '\n';
    std::string a("staple");
    std::string b("book");
    std::cout << my_min(a, b) << '\n';
}
```
The Standard Template Library (STL) provides many useful generic containers:

- `std::vector<T>` : resizeable array
- `std::deque<T>` : double-ended queue
- `std::map<T>` : red-black tree map
- `std::set<T>` : red-black tree set

Similar to `java.util.*` data structures
Vectors

- Similar to ArrayList in Java
- Dynamically resizeable array
- Subscript operator overloaded to support array-style indexing

```cpp
#include <string>
#include <vector>
#include <iostream>

int main(void) {
    std::vector<int> nums;
    for (int i = 0; i < 10; i++) {
        nums.push_back(i);
    }
    int sum = 0;
    for (int i = 0; i < nums.size(); i++) {
        sum += nums[i];
    }
    std::cout << "sum 0-9: " << sum << '
';

    std::vector<std::string> strs;
    strs.push_back("Lorem");
    strs.push_back("Ipsum");
    for (int i = 0; i < strs.size(); i++) {
        std::cout << strs[i] << " ";
    }
    std::cout << '
';
}
```
STL Iterators

- Similar to Java iterators
- Uses operator overloading to match pointer iteration
- No special foreach loop in C++?
- Can become verbose
- At -O3, generates same assembly as pointer version
- Much more efficient than Java iterators, which involve 2 virtual calls on each iteration

```cpp
int main(void) {
    std::vector<int> nums;
    for (int i = 0; i < 10; i++)
        nums.push_back(i);
    int sum = 0;
    for (std::vector<int>::iterator i = nums.begin(), e = nums.end(); i != e; ++i) {
        sum += *i;
    }
    std::cout << sum << '
';
}
```

// equivalent (for vectors) to:
```cpp
int *i, *e;
for (i = &nums[0], e = &nums[nums.size()]; i != e; ++i) {
    sum += *i;
}
std::cout << sum << '
';
```
Namespaces

- Avoids name collisions between libraries
  - Example: use mm namespace instead of mm_ prefix
- Can access mm namespace with mm::
- Starting :: means root namespace
- Needed to call libc malloc instead of mm::malloc

```
// mm.h
namespace mm {
    void *malloc(size_t size);
    void free(void *ptr);
};
// mm.c
namespace mm {
    void *malloc(size_t size) {
        return ::malloc(size);
    }
    void mm::free(void *ptr) {
        ::free(ptr);
    }
// app.c
int main(void) {
    void *ptr = mm::malloc(10);
    mm::free(ptr);
    ptr = malloc(10);
    free(ptr);
}
Namespaces

- Can import names
- “using namespace std” makes all names in std available
- “using std::vector” redeclares vector in the global namespace of this file
- Alternatively, just use std:: always

```cpp
// app1.c
using namespace std;
int main(void) {
    vector<int> nums;
}
// app2.c
using std::vector;
int main(void) {
    vector<int> nums;
}
// app3.c
int main(void) {
    std::vector<int> nums;
}
```
Conclusion

- That’s it!
- C++ is a large and complex language
- These are the most widely used bits
- Skipped exceptions, RTTI, multiple inheritance, and template specialization
- Check out cplusplus.com/reference/ for C/C++ library reference
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