C++ for Java Programmers – III

WL101.1c

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Classes and Templates

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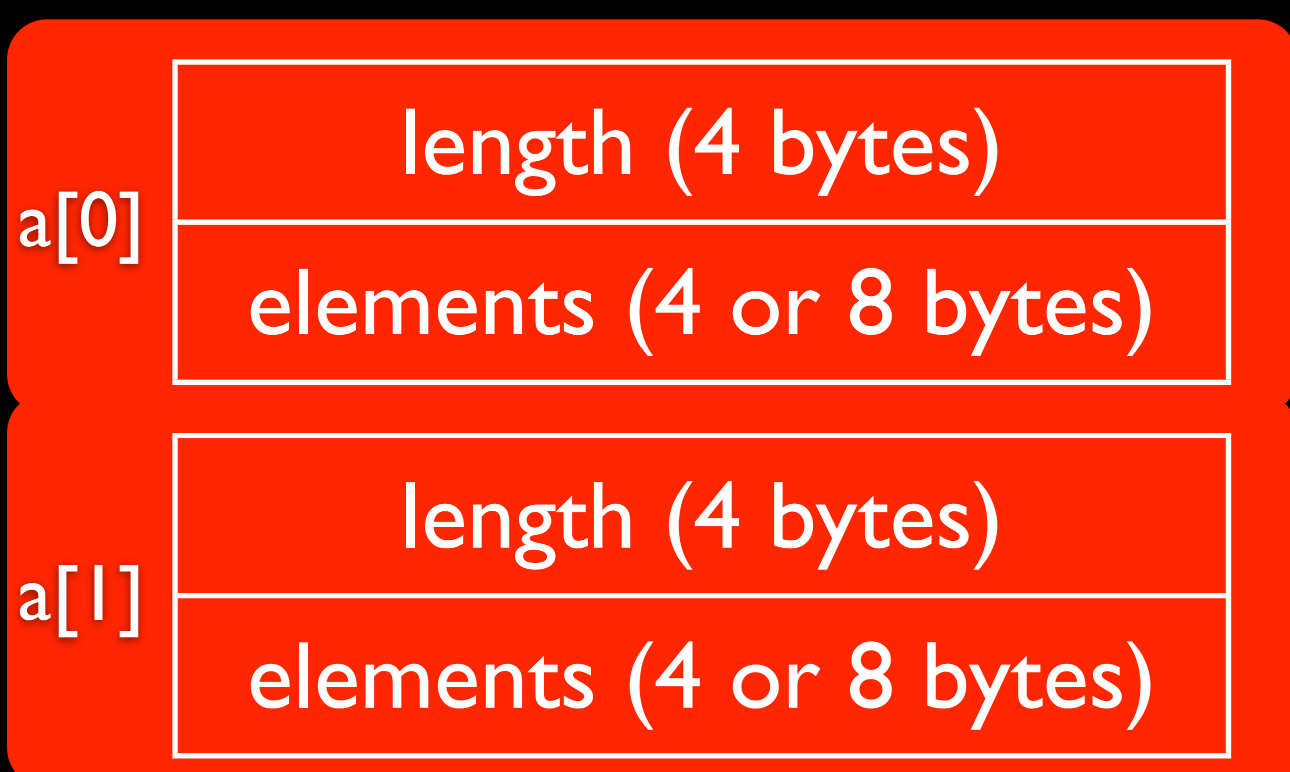
POD Structs

POD Structs

- POD (Plain Old Data) Structs group instances of variables together.
- Basically a Java class with only data.
- Memory layout is ***highly predictable***.




```
struct IntArray {
  int length;
  int *elements;
};
IntArray a[2];
```

Struct Declaration

```
struct StructName {
 type fields;
};
```

Note the semi-colon at the end.

Example:

```
struct Stuff {
 int length;
 int *elements;
 char name[8];
};
```

POD Struct

- A POD Struct (or structs in general) are types.
- Use and declare them as such.
- Array-type initializers can be used (the order follows the order of declaration in the struct)

```
struct IntArray {
  int length;
  int *elements;
};
IntArray a = {2, new int[2]};
```

Alternate instance declaration.

Declare variables upon structure definition.

```c
struct IntArray {
  int length;
  int *elements;
};
IntArray a, b;
```

```c
struct IntArray {
  int length;
  int *elements;
} a, b;
```

Struct

- Structs should fully know the size of its members upon definition.
- There's no way to a struct to have a member of the same type.
- Pointers must be used since they more or less have fixed sizes.

Struct sizes

```
struct Node {
 void *data;
 Node next;
 Node prev;
};
```

```
sizeof(Node) == ?
```

```
struct Node {
 void *data;
 Node *next;
 Node *prev;
};
```

```
sizeof(Node) == sizeof(uintptr_t) * 3;
```

Access

- Use the `.` operator for values or references
- Use the `->` operator for pointers.

```
struct IntArray {
  int length;
  int *elements;
};
IntArray a, *b;
```

```
b = new IntArray();
a.length = 1;
b->length = 2;
```

Constructors

Constructors (ctor)

- Declared similar to Java
- A public constructor with no arguments is called the *default constructor.*

```
struct IntArray {
  int length;
  int *elements;
  IntArray(int length) {
     this->length = length;
     this->elements = new int[length];
  }
  IntArray() {
     this->length = 0;
     this->elements = 0;
  }
};
```

```
IntArray a;
IntArray *b;
IntArray c(10);
b = new IntArray(5);
```

Member Initialization List

- An alternative (and preferred) way to initialize members in constructors.
- The ***only*** way to initialize (non-static) const members and references.
- The initialization order is ***not*** according to the initialization list but according to declaration order.

```
struct IntArray {
  int length, *elements;
  IntArray(int arrLen) :
      length(arrLen), elements(new int[arrLen]) {
  }
};
```

MIL Scope

- The syntax of the MIL is similar to how objects are initialized with parameters.
- The left-hand has class scope while the right-hand has parameter scope.
- You can do something like this:

```
struct IntArray {
  int length, *elements;
  IntArray(int length) :
    length(length), elements(new int[length]) {
  }
};
```

Copy Constructor

Copy Constructor

- A special kind of constructor that's always called when a like object is copied upon construction.

```
IntArray b = a; //b copies a
```

- It is *only* called upon construction.

```
IntArray c;
//does not call copy constructor
c = a;
```

Copy Constructor

- They are also invoked when objects are copied to function parameters.

```
IntArray a(10);

void f(IntArray p);
f(a);
```

- As what was said before: *Passing objects as references eliminates copying.*

Copy Constructor

- A copy constructor is a construct that takes a ***const reference of the same type***.

```
struct IntArray {
  int length, *elements;
  IntArray(const IntArray &rhs) :
     length(rhs.length), elements(new int[length]) {
     for ( int i = 0; i < length; ++i)
       elements[i] = rhs.elements[i];
  }
};
```

Copy Constructor

- A class can be made non-copyable by making its copy constructor private.
- More details on access modifiers later.

```
struct NonCopyable {
 int field;

private:
 NonCopyable(const NonCopyable &) {}
};
```

Destructors

Destructors (dtors)

- C++ is a non-GC runtime.
- Destruction of objects is predictable (see WL101.1b).
- Destructors get called every time an object gets destroyed.

Destructors

- Declared similar to ctors (just prepend the name with a ~) but...
- There can only be one dtor per class.
- Dtors accept no parameters.

```
struct IntArray {
 int length, *elements;
 ~IntArray() {
   delete [] elements;
 }
};
```

Checkpoint 3.1

Given the following struct:

```
struct Test {
  Test() { cout << "Default ctor\n"; }
  Test(const Test &) { cout << "Copy ctor\n"; }
  ~Test() { cout << "Dtor\n"; }
};
```

What does the following print?

```
void foo(Test a) {
  cout << "In foo\n";
}

int main() {
  Test *a;
  cout << "Start here\n";
  Test b;
  cout << "Pre foo\n";
  foo(b);
  cout << "Post foo\n";
  return 0;
}
```

The Big 4

- Usually, a custom implementation one of the following will result in the custom implementation of the rest:
  - Default Constructor (weaker case)
  - Copy Constructor
  - Destructor
  - Assignment Operator (later)

non-POD Structs

- Usually, implementing any of the Big 4 will result in the struct being non-POD.
- Additional overhead may appear, layout and addressing may not be predictable.
- Refer to other C++ references for specific conditions (they are changed in C++0x).

RAII Technique

Resource Acquisition Is Initialization

RAII

- RAII is one of the more powerful C++ tools for properly managing resources.
- Principle:
    - initialize resources on initialization
    - release on destruction
- “Abuses” the scoping system.

RAII Example

```
struct IntArray {
  const int length;
  int * const elements;
  IntArray(int length) :
     length(length), elements(new int[length]) {}

  ~IntArray() {
     delete [] elements;
  }
};
```

```
try {
  int len;
  cin >> len;
  IntArray arr(len);
  //Do something to arr...
} catch ( ... ) {
  //Will arr leak at this point?
}
```

RAII

In Java, when using IO resources (especially network IO) , close() has to be called explicitly.

```
public static void main(String [] args) {
  FileWriter f = new FileWriter("a.out");
  //write something
  f.close(); //important!
}
```

In C++, when using IO resources with RAII, close() is called automatically.

```
int main() {
  ofstream f("a.out");
  //write something
  return 0; //f.close() implicitly called.
}
```

Garbage Collection doesn't solve everything.

Classes

Declaration

- Classes are declared much like structs.
- Classes are exactly like struct except that by default, all their members are *private*.
- Everything you've learned about structs also apply here.

```
class IntArray {
 const int length;
 int * const elements;
 IntArray(int length) :
    length(length), elements(new int[length]) {}
};
```

Access Modifiers

- Unlike Java, C++ access modifiers are *fields*.
- They apply to all members below it.
- Changed by another access modifier.

```
class A {
  //private members
  int a;
public:
  //public members
  int b;
  A() {}
protected:
  //protected members
  A(int a) : a(a) {}
};
```

```
class B {
  int a;
  void doFoo() {}
public:
  A() {}
private:
  A(int a) : a(a) {}
  int b;
};
```

Access Modifiers

- Like Java, ctors can be declared private or protected.
- Disable object copying by declaring copy ctors private.

```
class A {
 int a;
 A() {}
 A(const A&) {}
public:
 A(int a) : a(a) {}
};
```

Member Functions

- Member functions are declared similarly to global functions.
- They are still subject to ordering rules.

```
class IntArray {
  int length;
  int *elements;
public:
  IntArray(int length) : length(length), elements(new int
[length]) {}
  void resize(int newLength) {
     //resize the array.
  }
};
```

Member Functions

- Separating definition and declaration of member functions is a bit trickier.
- More info on WL101.1d

```
class Class {
public:
 void bar();
};

void Class::bar() {
 //stuff
}
```

Scope resolution operator.

Defined *outside* of class definition.

Checkpoint 3.1

Implement an IntArray class:

- Private copy ctor (non-copyable).
- Dtor (releases resources).
- Public default ctor.
- Public `IntArray(const int length)` ctor.
- Public members:
  - `void resize(const int length)`
  - `void clear()`
  - `int& get(const int index)`
  - `void add(const int item)`
  - `int length()`
  - `int size()`

`this` Pointer

- In Java, `this` refers to the current object's.
- In C++, it's almost the same except that `this` is a pointer.
- Access `this` as a pointer (see earlier slide and WL101.1b).
- `this` can't be modified.

Example 3.1: Method Chaining

```cpp
class Acc {
  double a;
public:
  Acc(double a = 0) : a(a) {}
  double get() { return a; }
  Acc& plus(double b) { a += b; return *this; }
  Acc& minus(double b) { a -= b; return *this; }
  Acc& times(double b) { a *= b; return *this; }
};
```

```cpp
Acc().plus(1).minus(10).times(-2).plus(1).get();
```

Const Member Functions

Const Member Functions

- Declared by adding `const` after the function parameter list.

```
struct S {
 void f() { cout << "normal\n"; }
 void f() const { cout << "const\n"; }
};
```

Const Member Functions

- `const` member functions are the only functions that can be called when the objects is `const`.

```
struct S {
  void h() { cout << "h-normal\n" };
  void f() { cout << "f-normal\n"; }
  void f() const { cout << "const\n"; }
};
```

```
S a;
const S b = S();
a.f();
b.f();
b.h(); //compiler error!
```

Const Member Functions

- `const` member functions cannot modify any non-`mutable` member variables.
- i.e. `this` is a `const` in a `const` m.f. regardless to whether the object is actually `const` or not.

```
struct S {
 int a;
 mutable int b;
 void f() const { a = 10; } //error!
 void h() const { b = 20; } //allowed
};
```

Const Member Functions

- `const` member functions, if calling functions of itself, can only call other `const` member functions.

```
void g() { /*stuff*/ }

struct S {
  void notConst() { /*stuff*/ }
  void f() const { /*stuff*/ }
  void h() const {
      f(); //ok
      g(); //ok
      notConst(); //compiler error!
  }
};
```

Checkpoint 3.2

Get your `IntArray` code from Checkpoint 3.1

Which of the functions should be turned `const`?

Add (not replace) a `const` version of the following:

```
int& get(const int index)
```

Static Members

Static Members

- Behaves like those in Java.
- Static member functions are more straightforward to define.
- Static member fields are trickier to initialize.

Static Mem Fun

- When separating definition from declaration, the definition does not need the `static` keyword.

```
struct S {
 static void foo();
};

void S::foo() {
 //stuff
}
```

Static Mem Fi

- Static member fields are initialized outside of the class.
- Initialization order not guaranteed across files (more on WL101.1d).

```
struct S {
 static S *singleton;
};

S* S::singleton = 0;
```

Checkpoint 3.3

Implement the Singleton Design Pattern in C++.

Equivalent Java code:

```
class JavaSingleton {
  private JavaSingleton() {}
  private static JavaSingleton s = null;
  public static JavaSingleton getInstance() {
     if ( s == null )
       s = new JavaSingleton();
     return s;
  }
}
```

Inheritance

Inheritance

- The syntax is different.
- There is no distinction between interface and abstract classes (more info later).

```
class Base {
};

class Derived : public Base {
};
```

Inheritance

- There are nine types of inheritance: `public`, `protected` and `private` and their `virtual` counterparts.
- Only `public` will be discussed, the rest are advanced and not really used often.

Inheritance

- By default all ctors are inherited.
- But the moment *any* ctor is defined in the class, the rest are "cancelled".
- That is, if you want the same ctors to appear in the derived, they have to be repeated.
- Base dtors are automatically inherited and is automatically called when the derived dtor is returns.

Inheritance

- MIL are used for calling base ctors.
- If nothing was specified, the default base ctor will be called.

```
class Base {
 int a;
public:
 Base(int a) : a(a) {}
};

class Derived : public Base {
public:
 Derived() : Base(0) {}
};
```

Let’s try it!

```
class Base {
public:
  Base() {
      cout << "Base ctor\n";
  }
  ~Base() {
      cout << "Base dtor\n";
  }
};

class Derived : public Base {
public:
  Derived() {
      cout << "Derived ctor\n"
  }
  ~Derived() {
      cout << "Derived dtor\n";
  }
};
```

```
int main() {
  {
      cout << "pre init\n";
      Derived d;
      cout << "post init\n";
  }
  cout << "post dtor\n";
}
```

Inheritance

- When functions with the same name but different signature are declared in the derived class, the base implementation is “hidden”.
- Expose them again with `using`.

```
struct Base {
  void foo() {}
};

struct Derive
: public Base  {
  void foo(int a) {}
};
```

```
struct Base {
  void foo() {}
};

struct Derive
: public Base  {
  using Base::foo;
  void foo(int a) {}
};
```

Virtual Functions

Virtual Functions

- Unlike Java (and like C#), methods are not automatically overridden.
- This is because adding overriding functionality to a class will create overhead.
- If you want a function to be overridable, declare them `virtual` in the base class.
- If you tried to override a function without declaring it `virtual`, weird things will happen.

What "weird things"?

```cpp
struct Base {
  int n;
  Base(int n) : n(n) {}
  virtual void foo() {
      cout << n << " Base::foo\n";
  }
};

struct Derived : public Base {
  Derived(int n) : Base(n) {}
  void foo() {
      cout << n << " Derived::foo\n";
  }
};
```

```cpp
int main() {
 Base b(0);
 b.foo();
 Derived d(1);
 d.foo();
 Base *p = &d;
 p->foo();
}
```

Then try removing `virtual` from `foo` and see what happens.

Virtual Functions

- Functions are not automatically `virtual`... *even the **dtor***.
- If a root class is meant to be inherited, always *always* declare a `virtual` dtor even if it doesn't do anything.
- If you don't, the derived dtor won't get invoked when deleting polymorphically.

Virtual Dtors

```
struct Base {
  int n;
  Base(int n) : n(n) {}
  ~Base() {
      cout << n << " Base dtor\n";
  }
};

struct Derived : public Base {
  Derived(int n) : Base(n) {}
  ~Derived() {
      cout << n << " Derived dtor\n";
  }
};
```

```
int main() {
  {
      Base b(0);
  }
  {
      Derived d(1);
  }
  Base *p = new Derived(2);
  delete p;
}
```

Now declare the Base dtor as `virtual` and see....

Pure Virtual Functions

- A "virtual function" may be declared pure virtual by setting it to `0`

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

- This is akin to declaring the class abstract and setting that function as abstract.
- There's no distinction between an interface against an abstract class in C++

Friends

Friends

- Friends are entities that have access to a class' private members.
- Declared in the class.
- The entity should at least be declared beforehand.
- Some people say they should not be used because they break encapsulation.

Friend Examples

```
void a(); //fxn declaration

class B; //class declaration

class C {
private:
 void foo() {}
 friend a; //function friend
 friend class B; //class friend
};

void a() {
 C c;
 c.foo(); //ok
}
```

Friends

- Just because I'm your friend doesn't mean you're my friend. (friending is not symmetric)
- Your friend is not automatically my friend. (friending is not transitive)
- Just because I'm your friend doesn't mean that your child is my friend. (friending is not inherited)
- Just because I'm your friend doesn't mean our parents are friends. (converse of the previous point)

Friends

They can access your privates.

Operator Overloading

"See that plus? I can turn that to a times."

Operator Overloading

- Remember the C++ type principle.
- Operator Overloading is a way to make your classes behave like primitives.
- Allows you to define what operators do.
- One of the targets must be a *class* type (you can't redefine what operators do between primitives!)

Basic Principles

- Looks like functions with names starting with `operator`
- Most can be declared in-class or off-class.
- The in-class is similar to the off-class with the first parameter to be implicitly `this`.

```
class FiniteField {
  int a;
public:
  FiniteField(int a) : a(a%7) {}
  FiniteField& operator=(int r) { a = r % 7; return *this; }
  FiniteField& operator+=(int r) { a = (a+r) % 7; return *this; }
};
FiniteField operator+(int lhs, const FiniteField &rhs) {
  return FiniteField(lhs + rhs.a);
}
```

Preamble

- Nearly all operators are overloadable.
- Specified returns values are optional but highly recommended.
- Some legends:
  - `C` the class the operator is on.
  - `S,T,U` other classes or primitives.

Assignment Op.

- `=`, `+=`, `-=`, `*=`, `/=`
- Need to return a reference to self to allow chaining (e.g. a = b = c).
- RHS can be the same class or a different one.
- The `const` reference is optional.
- in-class:

```
C& operator=(const S &rhs)
```

- off-class:

```
C& operator=(C &lhs, const S &rhs)
```

Checkpoint 3.4a

Take out your `IntArray` code again.

Implement the marked field.

```
class IntArray {
  /* private members */
  IntArray(const IntArray &rhs) { /*copy ctor*/ }
public:
  IntArray() { /*default ctor*/ }
  IntArray(const int len) { /*...*/ }
  IntArray& operator=(const IntArray& lhs) { /* implement this */ }
}
```

In the assignment, do a ***deep copy***.
Also, ***check for self-assignment.***

Checkpoint 3.4b

Implement a `Vector2` class (a 2-dimensional vector)

Use the template below and implement:

- Assignment.
- Vector subtraction (base it on the addition code).

```
struct Vector2 {
  double x, y;
  Vector2() {}
  Vector2(double x, double y) : x(x), y(y) {}
  Vector2(const Vector2& rhs) : x(rhs.x), y(rhs.y) {}

  Vector2& operator+=(const Vector2 &rhs) {
      x += rhs.x;
      y += rhs.y;
      return *this;
  }
  //also do = and -=
};
```

Checkpoint 3.4c

Implement scalar multiplication and divsion in `Vector2`

Use the template below (implement `/=` as well)

```
struct Vector2 {
  double x, y;
  Vector2() {}
  Vector2(double x, double y) : x(x), y(y) {}
  Vector2(const Vector2& rhs) : x(rhs.x), y(rhs.y) {}

  /* operators =, += and -= */
  Vector2& operator*=(const double s) { /* implement this */ }
};
```

Comparison Op.

- `==`, `!=`
- Returns `bool` (for comparison, duh)
- You can compare two different things.
- Usually declared as `const` functions.
- in-class:

```
bool operator==(const S &rhs) const
```

- off-class:

```
bool operator==(const C &lhs, const S &rhs)
```

Binary Arithmetic Op.

- `+`, `-`, `/`, `*`, `%`, `&&`, `||`
- Usually returns an instance of a new object (optionally a `const`).
- Also implemented as a `const` function.
- in-class:

```
C operator+(const S &rhs) const
```

- off-class:

```
C operator+(const C &lhs, const S &rhs)
```

Checkpoint 3.5a

Implement binary arithmetic operator versions of vector subtraction, scalar multiplication and scalar division.

Try to implement them off-class (to get a feel).

Here's something to get started:

```
Vector2 operator+(const Vector2 &lhs, const Vector2 &rhs) {
  return Vector2(lhs.x + rhs.x, lhs.y + rhs.y);
}
```

Checkpoint 3.5b

Given **a** and **b** which are 2d vectors...

Implement the dot product:

*(**a**,**b**) = **a**.x * **b**.x + **a**.y * **b**.y

Implement the cross product:

%(**a**,**b**) = **a**.x * **b**.y - **a**.y * **b**.x

Unary Op.

- `!`
- Can return anything (usually returns a `bool`)
- Also usually a `const` function.
- In-class:

```
bool operator!() const
```

- Off-class:

```
bool operator!(const C &rhs)
```

Index Op

- `[]`
- Makes your class behave like an array.
- This is how `std::vector` does it.
- `const` is optional (depends on your use).
- Accepts a single parameter and returns anything.
- In-class:

```
S operator[](T parameter)
```

- Off-class: no way.

Function Op

- `( )`
- Makes your class behave like a function.
- Objects that behaves like a functions are called `functors`.
- Very important when dealing with `<algorithms>`
- In-class:

```
S operator()(/*parameters*/)
```

- Off-class: no way.

Post Incr./Decr. Op

- Postfix increment (++) and decrement(−−)
- Don't make them return a reference to the current object (remember how they work).
- In-class:

```
C operator++(int dummy)
```

- Off-class:

```
C operator++(C& lhs, int dummy)
```

Pre Incr./Decr. Op

- Prefix increment (++) and decrement(--)
- In-class:

```
C& operator++()
```

- Off-class:

```
C& operator++(int dummy, C& lhs)
```

Pointer Resolution Op.

- `*`, `->`
- Both have to return pointers of non-void.
- Automatically gets dereferenced.
- Used to have classes that disguises as pointers (like managed pointers).
- In-class:

```
S* operator*()
```

- Off-class:

```
S* operator*(C& rhs)
```

Templates

Templates

- Equivalent to generics in Java.
- Usage of template type are similar to Java (how do you use `java.util.ArrayList`?)
- Trickier, but more powerful.
- It's how `std::vector` can be used to store any type.

```
template <typename T>
void fill_zero(std::vector<T> &v) {
  for (int i = 0; i < v.size(); ++i )
      v[i] = static_cast<T>(0);
}
```

Basics

- Before the start of the declaration, add template <
- Follow it with a list of parameters which could be `typename`s or `int`.
- end with >

```
template <typename T, int N>
T foo() { /*...*/ }
```

Let’s try it!

Take out your `IntArray` code again...

Let’s make it type-agnostic!

1. Rename `IntArray` to just `Array`
2. Add `template<typename T>` before `class` (`T` is an identifier, so you can replace it with any other name).
3. Replace declarations of `int` with `T` (which ones? not all of them should be replaced).

Default Template Params.

- Like default function parameters, it's possible to specify default template parameters.
- Same as how default function parameters are done.
- The <> are still needed even if all parameters are defaulted.

```
template <typename T = int>
struct S {
 T n;
};

S<> a;
```

Function Templates

- Function templates are similarly declared to class templates.
- Function templates can resolve automatically.

```
template <typename T>
T cross(T x0, T y0, T x1, T y1) {
  return x0 * y1 - x1 * y0;
}

cross(1, 2, 3, 4);
cross(1.0f, 2.0f, 3.0f, 4.0f);
cross(1.0, 2.0, 3.0, 4.0);
```

Template Instantiation

- If classes are "skeletons" of objects...
- Templates are "skeletons" of classes.
- A declared class template isn't really "initialized" unless it's been "instantiated" (i.e. upon first declaration of a variable).
- Over-instantiation of templates *may* cause code bloat.

A Template Trick

- It's possible to "reflect" template types via `typedef`s.
- Useful at times.

```
template <typename T>
class Array {
public:
  typedef T Type;
};

typedef Array<int> IdList;

IdList::Type studentId;
```