Object-Oriented Programming

CSCI-UA 0470-001
Class 12
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Java Generics & C++ Templates

Parametric Polymorphism

- *Parametric polymorphism* is a way to make a language more expressive, while still maintaining *static type-safety*.
- A function or a class can be written such that it can handle *values* identically without depending on their *type*.
- Such functions and data types are called *generic* and form the basis of *generic programming*.

Generic Programming

- *generic programming* is a style of programming in which algorithms are written in terms of *types to-be-specified-later*
- These types that are then instantiated when needed for specific types, provided as parameters
- Moreover, generics allow you to abstract over types.
- A common case is container types, such as a list or a set.

Those are words

Motivation

- We have a compiler for a reason. It finds bugs for us. Runtime bugs are generally much more difficult to solve.

    - Remember our BetterPoint.java where we were able to use Enums to prevent runtime errors in our getCoordinate method?

      https://github.com/nyu-oop/point-java/blob/master/src/main/java/edu/nyu/oop/BetterPoint.java#L41

      vs

      https://github.com/nyu-oop/point-java/blob/master/src/main/java/edu/nyu/oop/Point.java#L36

- Similarly, generics give us another way of expressing some constraints to the compiler and therefore to prevent certain types of bugs.

- Generic programming also allows us in some cases to write less code, which is always good thing.

Java Generics

- Java Generics is an example of a generic programming language construct.
- Common examples are found in the Collections library.
- Have you seen something like this before?

```
List<String> list = new ArrayList<String>();
```

Use in Java Collections

```java
1 // Without Generics
2 ArrayList l1 = new ArrayList();
3 l1.add("hello");
4 String s1 = (String) l1.get(0);  // Note the cast
5
6 // With Generics
7 ArrayList<String> l2 = new ArrayList <String>();
8 l2.add("hello");
9 String s2 = l2.get(0);
```

- Note the cast on line 4
- The programmer knows what kind of data has been placed into the list.
- The compiler can only guarantee that an Object will be returned.
- To ensure the assignment to a variable of type String is type safe, the cast is required.

Use in Java Collections

```java
1 // Without Generics
2 ArrayList l1 = new ArrayList();
3 l1.add("hello");
4 String s1 = (String) l1.get(0);  // Note the cast
5
6 // With Generics
7 ArrayList<String> l2 = new ArrayList <String>();
8 l2.add("hello");
9 String s2 = l2.get(0);
```

- There is the possibility of a runtime error, since the programmer may be mistaken.
- Enter Generics. Notice the type declaration on line 7.
- It specifies that this is a List of of String, written ArrayList<String>.
- Why? Type-safety! The compiler can now catch certain errors.

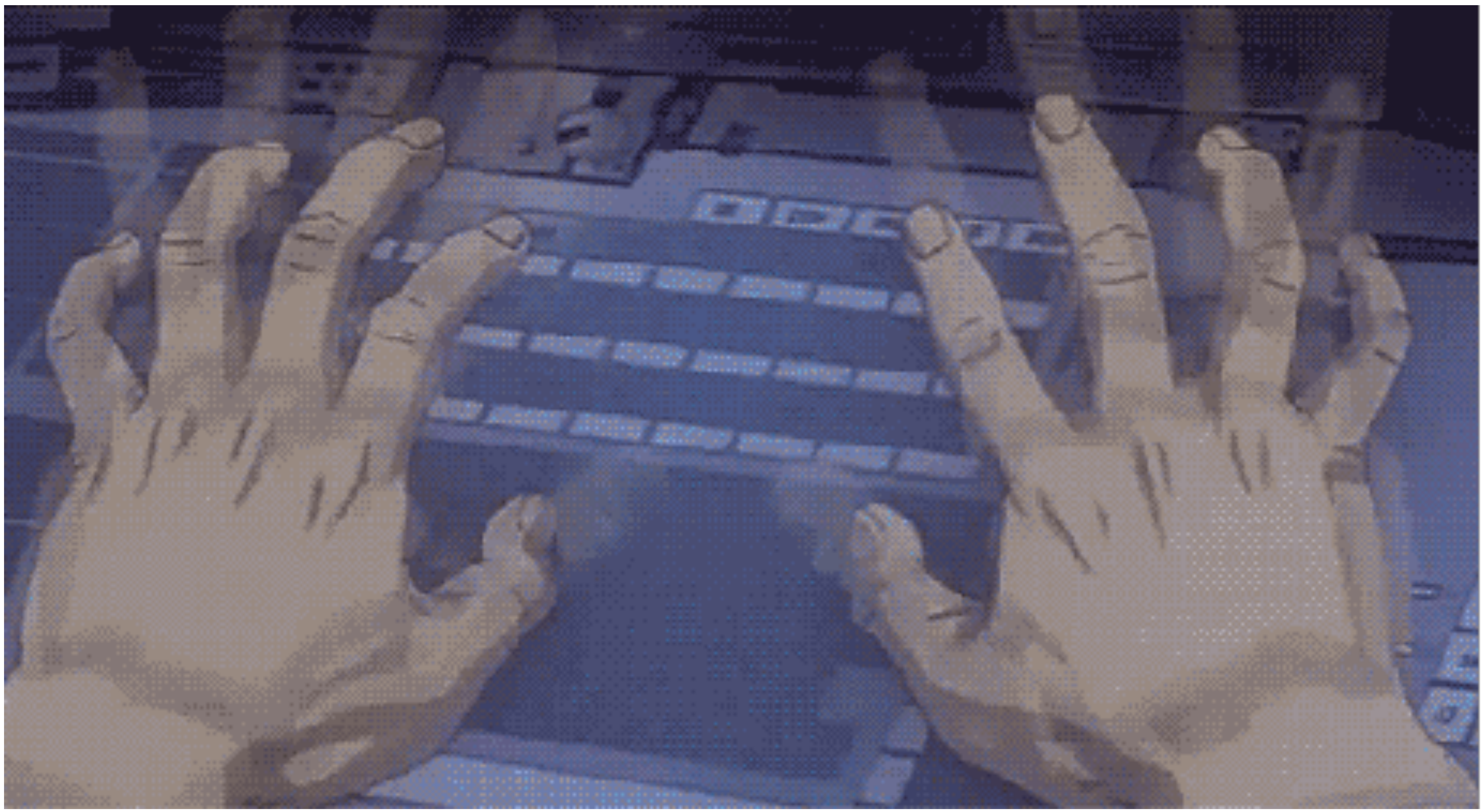
Stack Implementation

```java
class NonGenericStack {
  private ArrayList contents = new ArrayList();

  public void push(Object element) {
      contents.add(element);
  }

  public Object pop() {
      int top = contents.size()-1;
      Object result = contents.get(top);
      contents.remove(top);
      return result;
  }
}

// Somewhere else in the codebase...

NonGenericStack ngStack = new NonGenericStack();
ngStack.push("String");
ngStack.push(123);
String str1 = (String) ngStack.pop();
```

```java
class GenericStack<E> {
  private ArrayList<E> contents = new ArrayList<E>();

  public void push(E element) {
      contents.add(element);
  }

  public E pop() {
      int top = contents.size()-1;
      E result = contents.get(top);
      contents.remove(top);
      return result;
  }
}

// Somewhere else in the codebase...

// This is a compile error
GenericStack<String> gStack = new GenericStack<String>();
gStack.push("String");
gStack.push(123); // <-- here
String str2 = (String) ngStack.pop();
```

- We can use Generics in our own data structures as well!

Lets look at some code…



https://github.com/nyu-oop/generics

Generic Implementation

- How are generics implemented by the Java compiler?
  - Type erasure -- removes generic type information from source code, adds casts as needed, and produces byte code
  - Essentially, the type parameters go away and the compiler generates exactly the same naive code we saw in our RawList.java
- Why is this the way the compiler works?
  - Backwards compatibility. this approach did not require the JVM to be changed

Generic Issues

- No generic arrays
- No instantiations of generic types
  - i.e. E e = new E(); where E is a type parameter.
- No primitive types, which require wrapper classes. int => Integer
  - There is "auto-boxing" to ease conversions from primitive types to boxed types and back again, but this has an overhead cost.
- Type information lost at runtime.
  - Can be very annoying, Especially when using reflection.

C++ Templates

- Templates are the C++ analog to Java Generics
- They are somewhat more flexible
- As with Java, templates can be made for classes and functions, and said templates allow classes and functions to intake many different types
- Different than Java, they work with primitives, you can instantiate type parameters and there are generic *arrays*.

C++ Templates

- As stated Generics are implemented by *erasure*
- C++ templates are implemented by *expansion*
  - Each instance of a template with a new type is generated and compiled
  - Moreover, if you have lists of strings, ints and doubles, you have 3 different functions generated.
  - This could lead to *code bloat.* In practice this is usually fine.

Template Example

- Class definition preceded by template keyword followed by type parameter.
- Similar syntax precedes *implementation* of functions
- In both cases, type param name used in definition where concrete type would appear.

```
template <class T>
class mypair {
    T a, b;
  public:
    mypair (T first, T second):
      a(first), b(second) {}
    T getmax ();
};

template <class T>
T mypair<T>::getmax ()
{
  T retval;
  retval = a>b? a : b;
  return retval;
}

int main () {
  mypair <int> intPair (100, 75);
  cout << intPair.getmax() << endl;

  mypair <string> stringPair ("a", "b");
  cout << stringPair.getmax() << endl;

  return 0;
}
```

Template Example

- At construction, the caller provides the type parameters after the typename and before the identifier.
- Any type that supports operations performed on it will work just fine.
- What does this code output?

```
template <class T>
class mypair {
    T a, b;
  public:
    mypair (T first, T second):
      a(first), b(second) {}
    T getmax ();
};

template <class T>
T mypair<T>::getmax ()
{
  T retval;
  retval = a>b? a : b;
  return retval;
}

int main () {
  mypair <int> intPair (100, 75);
  cout << intPair.getmax() << endl;

  mypair <string> stringPair ("a", "b");
  cout << stringPair.getmax() << endl;

  return 0;
}
```

Template Example

- Key idea
    - Data structures can be created and used to handle many different types without declaring separate classes for each.
- Anybody see an application for our translator?

```
template <class T>
class mypair {
    T a, b;
  public:
    mypair (T first, T second):
      a(first), b(second) {}
    T getmax ();
};

template <class T>
T mypair<T>::getmax ()
{
  T retval;
  retval = a>b? a : b;
  return retval;
}

int main () {
  mypair <int> intPair (100, 75);
  cout << intPair.getmax() << endl;

  mypair <string> stringPair ("a", "b");
  cout << stringPair.getmax() << endl;

  return 0;
}
```

Declaring and Defining Templates

- Class templates must be *declared* in the header file
- The *compiler* creates the template for that type, replacing all instances of T with the actual type.
  - Very different than Java!
- Class templates must also be *defined* in the header file.

Template Specialization

- Specialized versions of class templates can be created for specific types
- Defined in .cpp (implementation) files because they don't need to be instantiated by the compiler
- Motivation, for a specific type we want to override the behavior of a certain method.

```
template<class T>
class mycontainer {
  T element;
public:
  mycontainer(T arg) : element(arg) { }

  T increase() { return ++element; }
};

// class template specialization for char
template<>
class mycontainer<char> {
  char element;
public:
  mycontainer(char arg) : element(arg) { }

  char increase() {
    if ((element >= 'a') && (element <= 'z'))
      element += 'A' - 'a';
    return element;
  }
};

int main() {
  mycontainer<int> myint(7);
  mycontainer<char> mychar('j');
  cout << myint.increase() << endl;
  cout << mychar.increase() << endl;
  return 0;
}
```

Moar Code Plz

https://github.com/nyu-oop/templates

Templates in the Project

- We can use templates to make our translation of arrays much easier.
- Much better than implementing a array-class-per-type! (Especially since we cannot use inheritance).
- This is the **only** place we may use templates.

Templates in the Project

- Array templates along with a few specializations are implemented for you in java-lang-3
- However, *you* must copy it to your translator project.
- But before you do that, we will have an in-class exercise next week on this subject.

Arrays in java-lang-3

- Although you cannot see it here, we've moved our array into the __rt namespace
- We have our forward declarations, those are templates as well.
- No typedefs, why?

```cpp
template <typename T>
struct Array;

template <typename T>
struct Array_VT;

template <typename T>
struct Array {
  Array_VT<T>* __vptr;
  const int32_t length;
  T* __data;

  // The constructor (defined inline).
  Array(const int32_t length)
    : __vptr(&__vtable), length(length), __data(new T[length]()) {
  }

  // The function returning the class object for the array.
  static java::lang::Class __class();

  // The vtable for the array.
  static Array_VT<T> __vtable;
};

// The vtable for arrays.
template <typename T>
Array_VT<T> Array<T>::__vtable;

// But where is the definition of __class()???
```

Arrays in java-lang-3

- Our data layout looks basicall the same, with the exception of utilizing the type parameter
- Note that the constructor is defined inline. Since for template ‘implementation’ should go in the headers.

```
template <typename T>
struct Array;

template <typename T>
struct Array_VT;

template <typename T>
struct Array {
  Array_VT<T>* __vptr;
  const int32_t length;
  T* __data;

  // The constructor (defined inline).
  Array(const int32_t length)
    : __vptr(&__vtable), length(length), __data(new T[length]()) {
  }

  // The function returning the class object for the array.
  static java::lang::Class __class();

  // The vtable for the array.
  static Array_VT<T> __vtable;
};

// The vtable for arrays.
template <typename T>
Array_VT<T> Array<T>::__vtable;

// But where is the definition of __class()???
```

Arrays in java-lang-3

- As previously stated, all template ‘implementation’ code should go in header.
- So on line 26 we see our instantiation for the __vtable member.
- Where is the definition of __class()? Why is it not here?

```
1  template <typename T>
2  struct Array;
3
4  template <typename T>
5  struct Array_VT;
6
7  template <typename T>
8  struct Array {
9    Array_VT<T>* __vptr;
10   const int32_t length;
11   T* __data;
12
13   // The constructor (defined inline).
14   Array(const int32_t length)
15     : __vptr(&__vtable), length(length), __data(new T[length]()) {
16   }
17
18   // The function returning the class object for the array.
19   static java::lang::Class __class();
20
21   // The vtable for the array.
22   static Array_VT<T> __vtable;
23 };
24
25 // The vtable for arrays.
26 template <typename T>
27 Array_VT<T> Array<T>::__vtable;
28
29 // But where is the definition of __class()???
```

Arrays in java-lang-3

- New vtable code, “now even more hard-to-readness!”

  (don’t you just love C++?)

- We have a typedef here to alias a pointer to an array of containing some type.

- Otherwise, really not much different than what we have seen in the past.

```
template <typename T>
struct Array_VT {
  typedef Array<T>* Reference;

  java::lang::Class __isa;
  int32_t (*hashCode)(Reference);
  bool (*equals)(Reference, java::lang::Object);
  java::lang::Class (*getClass)(Reference);
  java::lang::String (*toString)(Reference);

  Array_VT()
    : __isa(Array<T>::__class()),
      hashCode((int32_t(*)(Reference))
                 &java::lang::__Object::hashCode),
      equals((bool(*)(Reference,java::lang::Object))
                &java::lang::__Object::equals),
      getClass((java::lang::Class(*)(Reference))
                 &java::lang::__Object::getClass),
      toString((java::lang::String(*)(Reference))
                 &java::lang::__Object::toString) {
  }
};
```

Arrays in java-lang-3

- Here is the specialization for and array of Objects
- Basically just an implementation of the __class() method.
- Why?
- Hmm.. that __Class constructor look a little different, I think.

```
// Template specialization for arrays of objects.
template<>
java::lang::Class Array<java::lang::Object>::__class() {
  static java::lang::Class k =
    new java::lang::__Class(literal("[Ljava.lang.Object;"),
                            java::lang::__Object::__class(),
                            java::lang::__Object::__class());
  return k;
}
```

Arrays in java-lang-3

- Here is the specialization for and array of ints
- And now that I see this..there are definitely some changes to the Class constructor.
- Any guesses as to why?

```
// Template specialization for arrays of ints.
template<>
java::lang::Class Array<int32_t>::__class() {
  static java::lang::Class ik =
    new java::lang::__Class(
        __rt::literal("int"),
        (java::lang::Class)__rt::null(),
        (java::lang::Class)__rt::null(),
        true
    );

  static java::lang::Class k =
    new java::lang::__Class(
      literal("[I"),
      java::lang::__Object::__class(),
      ik);

  return k;
}
```

Arrays in java-lang-3

- Note line 4
- Since we don't have a class representing an int, we have to construct the class.

```
1  // Template specialization for arrays of ints.
2  template<>
3  java::lang::Class Array<int32_t>::__class() {
4    static java::lang::Class ik =
5      new java::lang::__Class(
6         __rt::literal("int"),
7         (java::lang::Class)__rt::null(),
8         (java::lang::Class)__rt::null(),
9         true
10     );
11
12   static java::lang::Class k =
13     new java::lang::__Class(
14       literal("[I"),
15       java::lang::__Object::__class(),
16       ik);
17
18   return k;
19 }
```

In-class exercise

- Next class we will do an in-class exercise to get you familiar with templates and the new arrays in java-lang
- In the meantime, work on your translator.
- The new java-lang version with templated arrays is on Github https://github.com/nyu-oop/java-lang-3