

## Pizza

Pizza is an extension to Java developed in the late 90s by Odersky and Wadler.

Pizza shows that many of the best ideas of functional languages can be incorporated into a “mainstream” language, giving it added power and expressability.

Pizza adds to Java:

### 1. Parametric Polymorphism

Classes can be parameterized with types, allowing the creation of “custom” data types with full compile-time type checking.

### 2. First-class Functions

Functions can be passed, returned and stored just like other types.

### 3. Patterns and Value Constructors

Classes can be subdivided into a number of value constructors, and patterns can be used to structure the definition of methods.

## PARAMETRIC POLYMORPHISM

Java allows a form of polymorphism by defining *container classes* (lists, stacks, queues, etc.) in terms of values of type **Object**.

For example, to implement a linked list we might use:

```
class LinkedList {
    Object value;
    LinkedList next;
    Object head() {return value;}
    LinkedList tail(){return next;}
    LinkedList(Object O) {
        value = O; next = null;}
    LinkedList(Object O,
               LinkedList L){
        value = O; next = L;}
}
```

We use class **Object** because any object can be assigned to **Object** (all classes must be a subclass of **Object**).

Using this class, we can create a linked list of any subtype of **Object**.

*But,*

- We can't guarantee that linked lists are *type homogeneous* (contain only a single type).
- We must unbox **Object** types back into their “real” types when we extract list values.
- We must use wrapper classes like **Integer** rather than **int** (because primitive types like **int** aren't objects, and aren't subclass of **Object**).

For example, to use `LinkedList` to build a linked list of `ints` we do the following:

```
LinkedList L =
    new LinkedList(new Integer(123));
int i =
    ((Integer) L.head()).intValue();
```

This is pretty clumsy code. We'd prefer a mechanism that allows us to create a "custom version" of `LinkedList`, based on the type we want the list to contain.

We can't just call something like `LinkedList(int)` OR `LinkedList(Integer)` because types can't be passed as parameters.

*Parametric polymorphism* is the solution. Using this mechanism, we *can* use type parameters to

build a "custom version" of a class from a general purpose class.

C++ allows this using its *template* mechanism. Pizza also allows type parameters.

In both languages, type parameters are enclosed in "angle brackets" (e.g., `LinkedList<T>` passes `T`, a type, to the `LinkedList` class).

In Pizza we have

```
class LinkedList<T> {
    T value; LinkedList<T> next;
    T head() {return value;}
    LinkedList<T> tail() {
        return next;}
    LinkedList(T O) {
        value = O; next = null;}
    LinkedList(T O,LinkedList<T> L)
        {value = O; next = L;}
}
```

When linked list objects are created (using `new`) no type qualifiers are needed—the type of the constructor's parameters are used. We can create

```
LinkedList<int> L1 =
    new LinkedList(123);
int i = L1.head();
LinkedList<String> L2 =
    new LinkedList("abc");
String s = L2.head();
LinkedList<LinkedList<int> > L3 =
    new LinkedList(L1);
int j = L3.head().head();
```

## Bounded Polymorphism

In Pizza we can use interfaces to bound the type parameters a class will accept.

Recall our `Compare` interface:

```
interface Compare {
    boolean lessThan(Object o1,
                     Object o2);
}
```

We can specify that a parameterized class will only takes types that implement `Compare`:

```
class LinkedList<T implements
    Compare> { ... }
```

In fact, we can improve upon how interfaces are defined and used.

Recall that in method `lessThan` we had to use parameters declared as type `Object` to be general enough to match (and accept) any object type. This leads to clumsy casting (with runtime correctness checks) when `lessThan` is implemented for a particular type:

```
class IntCompare implements Compare {
    public boolean lessThan(Object i1,
                           Object i2) {
        return ((Integer) i1).intValue() <
               ((Integer) i2).intValue();
    }
}
```

Pizza allows us to parameterize class definitions with type parameters, so why not do the same for interfaces?

In fact, this is just what Pizza does. We now define `Compare` as

```
interface Compare<T> {
    boolean lessThan(T o1, T o2);
}
```

Now class `LinkedList` is

```
class LinkedList<T> implements
    Compare<T> > { ... }
```

Given this form of interface definition, no casting (from type `Object`) is needed in classes that implement `Compare`:

```
class IntCompare implements
    Compare<Integer> {
    public boolean lessThan(Integer i1,
                           Integer i2) {
        return i1.intValue() <
               i2.intValue();
    }
}
```

## FIRST-CLASS FUNCTIONS IN PIZZA

In Java, functions are treated as constants that may appear only in classes.

To pass a function as a parameter, you must pass a class that contains that function as a member. For example,

```
class Fct {
    int f(int i) { return i+1; }
}
class Test {
    static int call(Fct g, int arg)
    { return g.f(arg); }
}
```

Changing the value of a function is even nastier. Since you can't assign to a member function, you have to use subclassing to override an existing definition:

```
class Fct2 extends Fct {
    int f(int i) { return i+111; }
}
```

Computing new functions during executions is nastier still, as Java doesn't have any notion of a lambda-term (that builds a new function).

Pizza makes functions first-class, as in ML. You can have function parameters, variables and return values. You can also define new functions within a method.

The notation used to define the type of a function value is

$$(T_1, T_2, \dots) \rightarrow T_0$$

This says the function will take the list  $(T_1, T_2, \dots)$  as its arguments and will return  $T_0$  as its result.

Thus

$$(int) \rightarrow int$$

represents the type of a method like

```
int plus1(int i) {return i+1;}
```

The notation used by Java for fixed functions still works. Thus `static int f(int i){return 2*i;};` denotes a function constant,  $f$ .

The definition

```
static (int)->int g = f;
```

defines a field of type  $(int) \rightarrow int$  named  $g$  that is initialized to the value of  $f$ .

The definition

```
static int call((int)->int f,
               int i)
    {return f(i);};
```

defines a constant function that takes as parameters a function value of type  $(int) \rightarrow int$  and an  $int$  value. It calls the function parameter with the  $int$  parameter and returns the value the function computes.

Pizza also has a notation for anonymous functions (function literals), similar to `fn` in ML and `lambda` in Scheme. The notation

$$\text{fun } (T_1 \ a_1, T_2 \ a_2, \dots) \rightarrow T_0 \\ \{ \text{Body} \}$$

defines a nameless function with arguments declared as

$(T_1 \ a_1, T_2 \ a_2, \dots)$  and a result type of  $T_0$ . The function's body is computed by executing the block `{Body}`.

For example,

```
static (int)->int compose(
    (int)->int f, (int)->int g){
    return fun (int i) -> int
        {return f(g(i));};
}
```

defines a method named `compose`. It takes as parameters two functions,  $f$  and  $g$ , each of type  $(int) \rightarrow int$ .

The function returns a function as its result. The type of the result is  $(int) \rightarrow int$  and its value is the composition of functions  $f$  and  $g$ :

```
return f(g(i));
```

Thus we can now have a call like

```
compose(f1, f2) (100)
```

which computes `f1(f2(100))`.

With function parameters, some familiar functions can be readily programmed:

```
class Map {
  static int[] map((int)->int f,
                  int[] a){
    int [] ans =
      new int[a.length];
    for (int i=0;i<a.length;i++)
      ans[i]=f(a[i]);
    return ans;
  };
}
```

And we can make such operations polymorphic by using parametric polymorphism:

```
class Map<T> {
  private static T dummy;
  Map(T val) {dummy=val;};
  static T[] map((T)->T f,
                T[] a){
    T [] ans = (T[]) a.clone();
    for (int i=0;i<a.length;i++)
      ans[i]=f(a[i]);
    return ans;
  };
}
```

## ALGEBRAIC DATA TYPES

Pizza also provides “algebraic data types” which allow a type to be defined as a number of cases. This is essentially the pattern-oriented approach we saw in ML.

A list is a good example of the utility of algebraic data types. Lists come in two forms, null and non-null, and we must constantly ask which form of list we currently have. With patterns, the need to consider both forms is enforced, leading to a more reliable programming style.

In Pizza, patterns are modeled as “cases” and grafted onto the existing switch statement (this formulation is a bit clumsy):

```
class List {
  case Nil;
  case Cons(char head,
            List tail);
  int length(){
    switch(this){
      case Nil: return 0;
      case Cons(char x, List t):
        return 1 + t.length();
    }
  }
}
```

And guess what! We can use parametric polymorphism along with algebraic data types:

```
class List<T> {  
  case Nil;  
  case Cons(T head,  
            List<T> tail);  
  int length(){  
    switch(this){  
      case Nil: return 0;  
      case Cons(T x, List<T> t):  
        return 1 + t.length();  
    }  
  }  
}
```