C# Adds Useful Features

- Events and delegates are included to handle asynchronous actions (like keyboard or mouse actions).
- Properties allow user-defined read and write actions for fields. You can add get and set methods to the definition of a field. For example,
  
  ```csharp
  class Customer {
    private string name;
    public string Name {
      get { return name; }
    }
  }
  Customer c; ...
  string s = c.Name;
  ```

- Indexers allow objects other than arrays to be indexed. The [] operator is overloadable. This allows you to define the meaning of `obj[123]` or `obj["abc"]` within any class definition.

- Collection classes may be directly enumerated:
  ```csharp
  foreach (int i in array) ...
  ```

- Fields, methods and constructors may be defined within a struct as well as a class. Structs are allocated within the stack instead of the heap, and are passed by value. For example:
  ```csharp
  struct Point {
    int x, y;
    void reset () {
      x=0; y=0; }
  }
  ```

When an object is needed, a primitive (int, char, etc.) or a struct will be automatically boxed or unboxed without explicit use of a wrapper class (like Integer or Character). Thus if method List.add expects an object, you may write
  ```csharp
  List.add(123);
  and 123 will be boxed into an Integer object automatically.
  ```

- Enumerations are provided:
  ```csharp
  enum Color {Red, Blue, Green};
  ```

- Rectangular arrays are provided:
  ```csharp
  int [,] multi = new int[5,5];
  ```

- Reference, out and variable-length parameter lists are allowed.
- Pointers may be used in methods marked unsafe.

Reading Assignment

- Pizza Tutorial
  (linked from class web page)
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:

\[
\text{LinkedList } L = \text{new LinkedList(new Integer(123))};
\]
\[
\text{int } i = \text{((Integer) L.head()).intValue();}
\]

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

\[
\text{LinkedList(int) or LinkedList(Integer)}
\]

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

\[
\text{class LinkedList<T> {}
\]
\[
\text{\hspace{1em}T value; LinkedList<T> next;}
\]
\[
\text{\hspace{1em}T head() {return value;}}
\]
\[
\text{\hspace{1em}LinkedList<T> tail() {}
\]
\[
\text{\hspace{2em}return next;}}
\]
\[
\text{\hspace{1em}LinkedList(T O) {}
\]
\[
\text{\hspace{2em}value = O; next = null;}}
\]
\[
\text{\hspace{1em}LinkedList(T O,LinkedList<T> L) {}
\]
\[
\text{\hspace{2em}value = O; next = L;}}
\]
\[
\text{}}
\]

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

\[
\text{LinkedList<int> } L1 = \text{new LinkedList(123)};\]
\[
\text{int } i = L1.head();\]
\[
\text{LinkedList<String> } L2 = \text{new LinkedList("abc");}\]
\[
\text{String } s = L2.head();\]
\[
\text{LinkedList<LinkedList<int>> } L3 = \text{new LinkedList(L1)};\]
\[
\text{int } j = L3.head().head();\]

Bounded Polymorphism

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

Recall our Compare interface:

\[
\text{interface Compare {}
\]
\[
\text{\hspace{1em}boolean lessThan(Object o1, Object o2);}}
\]
\[
\text{}}
\]

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

\[
\text{class LinkedList<T implements Compare> { \hspace{1em} . . . \}}
\]
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 run-time correctness checks) when lessThan is implemented for a particular type:

```java
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 can now define Compare as

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

Now we define class LinkedList as

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

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

```java
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,

```java
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:

```java
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

\((T_1, T_2, \ldots) \rightarrow T_0\)

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

\((\text{int}) \rightarrow \text{int}\)

represents the type of a method like

\[
\text{int} \text{ plus1(int i) \{return i+1;\}
\]

The notation used by Java for fixed functions still works. Thus

\[
\text{static int f(int i)} \{\text{return 2*i;}\};
\]

denotes a function constant, \(f\). The definition

\[
\text{static (int)\rightarrow int g = f;}
\]

defines a field of type \((\text{int}) \rightarrow \text{int}\) named \(g\) that is initialized to the value of \(f\). The definition

\[
\text{static int call((int)\rightarrow int f, int i)} \{\text{return f(i);}\};
\]

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

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

\[
\text{fun } (T_1 \ a_1, T_2 \ a_2, \ldots) \rightarrow T_0
\]

\{\text{Body}\}

defines a nameless function with arguments declared as \((T_1 \ a_1, T_2 \ a_2, \ldots)\) and a result type of \(T_0\). The function’s body is computed by executing the block \{\text{Body}\}. For example,

\[
\text{static (int)\rightarrow int compose(}
\]

\[
\text{(int)\rightarrow int f, (int)\rightarrow int g)} \{
\text{return fun (int i) \rightarrow int}
\]

\[
\text{\{return f(g(i));\};}
\]

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

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

\[
\text{return f(g(i));}
\]

Thus we can now have a call like

\[
\text{compose(f1,f2)}(100)
\]

which computes \(f_1(f_2(100))\).
With function parameters, some familiar functions can be readily programmed:

```java
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:

```java
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):

```java
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:

```java
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();
    }
}
```

Enumerations as Algebraic Data Types

We can use algebraic data types to obtain a construct missing from Java and Pizza—enumerations.

We simply define an algebraic data type whose constructors are not parameterized:

```java
class Color {
    case Red;
    case Blue;
    case Green;
    String toString() {
        switch(this) {
            case Red: return "red";
            case Blue: return "blue";
            case Green: return "green";
        }
    }
}
```

This approach is better than simply defining enumeration values as constant (final) integers:

```java
final int Red = 1;
final int Blue = 2;
final int Green = 3;
```

With the algebraic data type approach, Red, Blue and Green, are not integers. They are constructors for the type Color. This leads to more thorough type checking.