Module 03

"LINQ"

Agenda

- Introducing LINQ
- LINQ Query Keywords
- LINQ Query Operator Methods
- LINQ to Entities
- LINQ to XML
- Expression Trees
- Lab 3
- Discussion and Review

Motivation for LINQ

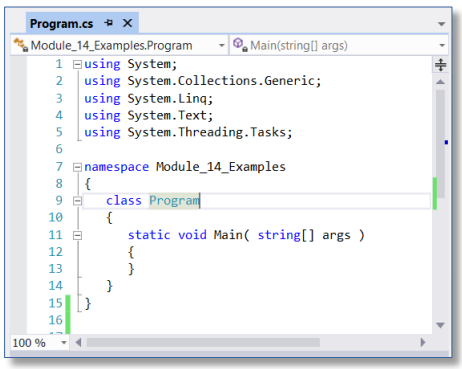
- LINQ = Language INtegrated Query
- Several distinct motivations for LINQ
  - Uniform programming model for any kind of data
  - A better tool for embedding SQL queries into type-safe code
  - Another data abstraction layer
  - …
- All of these descriptions to some extent hold true

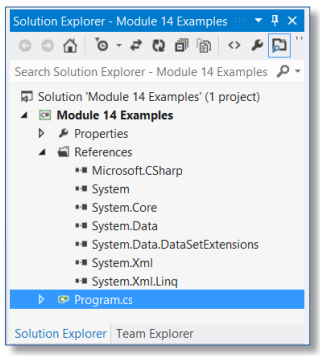
LINQ Components

- LINQ to Objects
- LINQ to XML
- LINQ to SQL
- LINQ to DataSet
- LINQ to Entities
- Parallel LINQ
- …
- Later we will see
  - LINQ to Entities
  - LINQ to XML
  - Parallel LINQ (in Module 5)

Starting LINQ to Objects

- Main LINQ features live in **`System.Core.dll`** in the **`System.Linq`** namespace





A First Example

- Find all games with more that 18 characters in the title

```
string[] wiiGames = {
   "Super Mario Galaxy",
   "FIFA 09",
   "Guitar Hero III",
   "Wii Sports",
   "Wii Fit",
   "Legend of Zelda: Twilight Princess"
};

IEnumerable<string> query = from g in wiiGames
                            where g.Length >= 18
                            select g;
```

```
foreach( string s in query )
{
   Console.WriteLine( s );
}
```

Implicitly Typed Variables

- Query results can be of a multitude of types

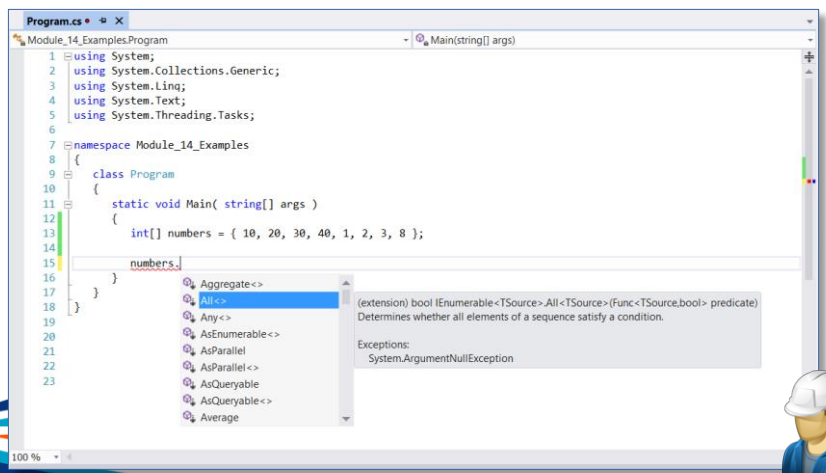
```
int[] numbers = {10, 20, 30, 40, 1, 2, 3, 8};
IEnumerable<int> query = from i in numbers
                         where i < 10 select i;
foreach( int i in query )
{
   Console.WriteLine( i );
}
```

- Innocently-looking modifications might change underlying type
- Make all query variables implicitly typed…!

```
int[] numbers = {10, 20, 30, 40, 1, 2, 3, 8};
var query = from i in numbers where i < 10 select i;
foreach( var i in query )
{
   Console.WriteLine( i );
}
```

`Enumerable` Extension Methods

- The `System.Linq.Enumerable` class provides a lot of extension methods



Deferred Execution

- Query expressions are not evaluated until they're enumerated!
- This is called *Deferred Execution*

```
int[] numbers = { 10, 20, 30, 40, 0, 1, 2, 3, 8 };
var query = from i in numbers where i < 10 select 87 / i;

foreach( var i in query )
{
   Console.WriteLine( i );
}
```

- You can force evaluation through the Visual Studio debugger
  - Use the Results View of the query variable

Immediate Execution

- You can force evaluation by using conversion extension methods

```
int[] numbers = { 10, 20, 30, 40, 0, 1, 2, 3, 8 };
var query = from i in numbers where i < 10 select i;

int[] intNumbers = query.ToArray();
List<int> listNumbers = query.ToList();
```

- There are other such extension methods, e.g.
  - `ToDictionary<T,K>`

LINQ and Generic Collections

- LINQ can query data in various members of `System.Collections.Generic`

```
Stack<int> stack = new Stack<int>( new int[]{ 42, 87, 112, 255 } );
var query = from i in stack where i < 100 select i;
```

```
List<Car> cars = new List<Car>() {
   new Car{ PetName="Henry", Color="Silver", Speed=100, Make="VW" },
   new Car{ PetName="Daisy", Color="Tan", Speed=90, Make="BMW" },
   new Car{ PetName="Mary", Color="Black", Speed=55, Make="VW" },
   new Car{ PetName="Clunker", Color="Rust", Speed=5, Make="Yugo" },
   new Car{ PetName="Melvin", Color="White", Speed=43, Make="Ford" }
};

var query = from c in cars
            where c.Speed > 90 && c.Make == "BMW"
            select c;
```

LINQ and Nongeneric Collections

- Nongeneric collections lack the `IEnumerable<T>` infrastructure for querying
- This can be provided using the `OfType<T>` extension method

```
ArrayList cars = new ArrayList() {
   new Car{ PetName="Henry", Color="Silver", Speed=100, Make="BMW" },
   new Car{ PetName="Daisy", Color="Tan", Speed=90, Make="BMW" },
   new Car{ PetName="Mary", Color="Black", Speed=55, Make="VW" },
   new Car{ PetName="Clunker", Color="Rust", Speed=5, Make="Yugo" },
   new Car{ PetName="Melvin", Color="White", Speed=43, Make="Ford" }
};

IEnumerable<Car> enumerableCars = cars.OfType<Car>();
var query = from c in enumerableCars
            where c.Speed > 90 && c.Make == "BMW"
            select c;
```

LINQ and Custom Collections

- LINQ queries can be performed directly on any `IEnumerable<T>` type
  - Even your own types!

```
Node<int> tree = new Node<int>(
   42,
   new Node<int>( ... ),
   new Node<int>( 256 )
);

var query = from i in tree
            where i % 2 == 0
            select i;
```

```
class Node<T> : IEnumerable<T>
{
   protected T _value;

   protected Node<T> _left;
   protected Node<T> _right;

   ...
}
```

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The **from** Clause

- Range variables and data source are specified in the **from** clause

```
Stack<int> stack = new Stack<int>( new int[]{ 42, 87, 112, 255} );
var query = from i in stack where i < 10 select i;
```

- It can define the type of the range variable as well

```
ArrayList cars = new ArrayList {
   new Car{ PetName="Henry", Color="Silver", Speed=100, Make="BMW" },
   ...
};
var query = from Car c in cars
            where c.Speed > 90 && c.Make == "BMW"
            select c;
```

Can in fact have multiple **from** clauses…

The **where** Clause

- Filtering conditions are specified by a boolean expression in a **where** clause

```
List<Car> cars = new List<Car> {
   new Car{ PetName="Henry", Color="Silver", Speed=100, Make="BMW" },
   ...
};
var query = from c in cars
            where c.Speed > 90 && c.Make == "BMW"
            select c;
```

```
var query = from c in cars
            where c.Speed > 90
            where SomePredicate( c )
            select c;
```

Can have multiple **where** clauses also

The **select** Clause

- Projections of results are done through the **select** clause

```
List<Car> cars = new List<Car> {
   new Car{ PetName="Henry", Color="Silver", Speed=100, Make="BMW" },
   ...
};
var query = from c in cars
            where c.Speed > 90 && c.Make == "BMW"
            select c.Make;
```

```
var query = from c in cars
            where c.Speed > 90 && c.Make == "BMW"
            select new { c.Make, c.Color };
```

- Projections can create new (anonymous) data types

The **orderby** Clause

- Results can be sorted using the **orderby** clause

```
List<Car> cars = new List<Car> {
   new Car{ PetName="Henry", Color="Silver", Speed=100, Make="BMW" },
   ...
};
var query = from c in cars
            where c.Speed >= 55
            orderby c.PetName
            select c;
```

- The order can be **ascending** (the default) or **descending**

```
var query = from c in cars
            where c.Speed >= 55
            orderby c.PetName descending, c.Color
            select c;
```

The **group** Clause

- Use the **group** keyword or the **GroupBy()** method
  - Resulting query yields a set of keyed result groups

```
var query = from i in numbers
            group i by i % 2;

foreach ( var group in query )
{
   Console.WriteLine( group.Key );
   foreach ( var i in group )
   {
      Console.WriteLine( "\t" + i );
   }
}
```

- There is also a more sophisticated **group into** syntax

The **join** Clause

- Use the join keyword to join elements on equality

```
var query = from c in customers
            join o in orders on c.Id equals o.CustomerId
            select new
            {
               Name = c.Name,
               Product = o.Product
            };
foreach ( var cop in query )
{
   Console.WriteLine( "{0} bought {1}", cop.Name,
                                        cop.Product.Name );
}
```

- Other variations of join can be expressed in a number of ways…

The `let` Clause

- Local expression or queries can be stored in variables for use later in the query

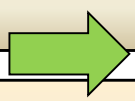
```
string[] sentences = { ... }

var query = from sentence in sentences
            let words = sentence.Split( ' ' )
            orderby words.Length
            select sentence;
```

- Locally introduced variable
  - can be a simple type or a full query
  - is read-only

Query Operators Resolution

- These query operators are keywords with syntax highlighting and IntelliSense
- But they are resolved as extension methods in the `Enumerable` class

```
var query = from g in wiiGames
            where g.Length >= 18
            orderby g.Length, g
            select g.ToUpper();
```



```
var query = wiiGames.Where( g => g.Length >= 18 )
                    .OrderBy( g => g.Length )
                    .ThenBy( g => g )
                    .Select( g => g.ToUpper() );
```

- You can use either syntax or use delegates instead of anonymous methods etc.

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Count<T>

- You can compute the number of items in the result set with **Count<T>**

```
string[] wiiGames = {
   "Super Mario Galaxy",
   "FIFA 09",
   "Guitar Hero III",
   "Wii Sports",
   "Wii Fit",
   "Legend of Zelda: Twilight Princess"
};
var query = from g in wiiGames
            where g.Length >= 18
            select g;
Console.WriteLine( "{0} games match the query", query.Count() );
```

- This forces an evaluation of the query expression!

Reverse<T>

- You can reverse the result sequence with **Reverse<T>**

```
string[] wiiGames = {
   "Super Mario Galaxy",
   ...
};

var query = ( from g in wiiGames select g ).Reverse();
```

- Note that this does not evaluate the query expression…!

Set Operations: **Except<T>**

- Differences between queries can be computed with **Except<T>**

```
string[] wiiGames = {
   "Super Mario Galaxy", ...
};
string[] xbox360Games = {
   "Halo", ...
};

var query = ( from g in wiiGames select g ).Except(
   from g in xbox360Games select g );
var query2 = wiiGames.Except( xbox360Games );
```

- Do you think this will evaluate the query expression? ☺
- **Union<T>**, **Intersect<T>**, and **Except<T>** constitute the set operations (**Distinct<T>** is also helpful!)

Singleton Operations

- A single element can be retrieved from a query result
  - `First<T>`
  - `Last<T>`
  - `Single<T>`

```
var query = wiiGames.Intersect( xbox360Games );

var first = query.First();
var last = query.Last();
var theOnlyOne = query.Single();

Console.WriteLine( first );
Console.WriteLine( last );
Console.WriteLine( theOnlyOne );
```

- Each of these has an `…OrDefault<T>` version
  - `FirstOrDefault<T>`
  - `LastOrDefault<T>`
  - `SingleOrDefault<T>`

Partitioning Operators

- `Take()` and `Skip()`

```
string[] wiiGames = {
   "Super Mario Galaxy", ...
};
string[] xbox360Games = {
   "Halo", ...
};

var query1 = wiiGames.Union( xbox360Games ).Take( 7 );
var query2 = wiiGames.Union( xbox360Games ).Skip( 3 );
```

- There are also
  - `TakeWhile()`
  - `SkipWhile()`

Aggregation Operators

- `Aggregate()` computes a running value

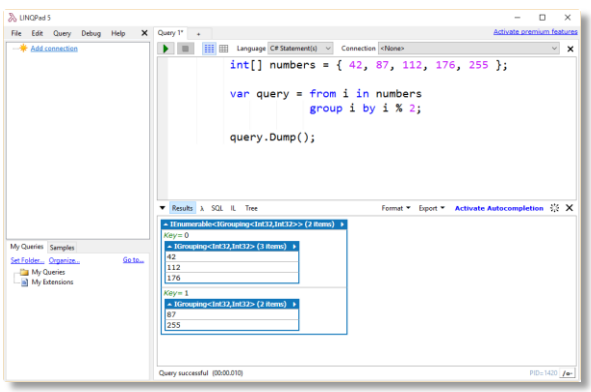
```
int[] numbers = { 42, 87, 112, 176, 255 };
var result = numbers.Aggregate( 1, ( product, i ) => product * i );

Console.WriteLine( "The product of numbers is " + result );
```

- Other aggregation operators include
  - Count()
  - Sum()
  - Min()
  - Max()
  - Average()

LINQPad

- LINQPad by Joseph Albahari is indispensable!



- Get it from http://www.linqpad.net

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ADO.NET Entity Framework

- The de-facto standard for disconnected data access providing
  - Entity Data Models (EDM)
  - Entity SQL
  - Object Services
- It supports
  - Writing code against a conceptual model
  - Type-safe data access
  - Robustness and indepedance across storage systems
  - Maintainability
- Tools and wizards supporting
  - Database-first design
  - Code-first design

Querying and Updating Data

- Using LINQ to Entities to query data

```
using( ShopEntities entities = new ShopEntities() )
{
   var query = from c in entities.Customers
               where c.Orders.Count > 0
               select c;
   ...
}
```

- `DbContext`-generated class
  - keeps tracks of updates
  - saves back to database

```
using( ShopEntities entities = ... )
{
   ...
   entities.SaveChanges();
}
```

Customizing Classes

- Never modify the auto-generated classes!!
  - Instead, augment the auto-generated partial classes

```
public partial class Customer
{
   public string FullName
   {
      get
      {
         return FirstName + " " + LastName;
      }
   }
   public int Age
   {
      get { return ...; }
   }
}
```

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Introducing LINQ to XML

- Provides querying facilities over XML documents
  - Introduces a new **`XDocument`** class set deriving from **`Xobject`**
  - In **`System.Xml.Linq`** namespace

- **`XAttribute`**
- XNode
  - *`XContainer`*
    - **`XDocument`**
    - **`XElement`**
  - `XComment`
  - `XText`
    - `XCData`
- `...`

XDocument

- Provides main access to XML document handling
- `XDocument.`
  - `Load()` static
  - `Parse()` static
  - `Save()`

```
XDocument doc = XDocument.Load( @"C:\Tmp\Movies.xml" );
```

```
XDocument doc = XDocument.Parse( "<Customers>...</Customers>" );
```

```
doc.Save( @"C:\Tmp\CustomersOrders.xml" );
```

Querying with LINQ to XML

- Use LINQ queries over the DOM provided by the `XDocument` hierarchy classes

```
XDocument doc = XDocument.Load( @"C:\Tmp\CustomersOrders.xml" );
var query = from order in doc.Descendants( "Order" )
            where order.Attribute( "OrderID" ).Value == "10677"
            select new
            {
               OrderID = (int) order.Attribute( "OrderID" ),
               CustomerID =
                 (string) order.Parent.Attribute( "CustomerID" ),
               Freight = (decimal) order.Attribute( "Freight" )
            };
```

- The full power of LINQ is available, e.g. `join`, `group` etc.

Transforming XML to Objects

- LINQ to XML is perfect for transforming XML
  - XML -> objects
  - XML -> text
  - XML -> XML

```
List<Customer> customersOrders =
   ( from c in doc.Descendants( "Customer" )
     select new Customer
     {
        Id = c.Attribute( "CustomerID" ).Value,
        Name = c.Attribute( "CompanyName" ).Value,
        Orders = ( from o in c.Elements( "Order" )
                   select new Order
                   {
                      Id = (int) o.Attribute( "OrderID" ),
                      Freight = (decimal) o.Attribute( "Freight" )
                   } ).ToList()
     } ).ToList();
```

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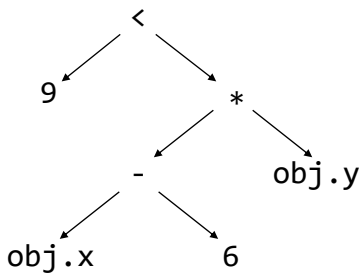
What is an Expression Tree?

- The expression `9 < ( obj.x - 6 ) * obj.y` is



- The `Expression` class captures expression trees
  - Each node derive from `Expression`

Expression Types

- `Expression`
  - `ConstantExpression`
  - `MemberExpression`
  - `ParameterExpression`
  - `UnaryExpression`
  - `BinaryExpression`
  - `LambdaExpression`
    - **`Expression<TDelegate>`**
  - …
- Abstract base class providing static methods
  - 15 classes derive from `Expression` with 46 operands

Compiling Lambda Expression Trees

- Expression trees can be compiled to the underlying delegate type at runtime!
  - Expression<TDelegate>.Compile()

```
Expression<Func<int, int, int>> addition = ( x, y ) => x + y;
Func<int, int, int> add = addition.Compile();
Console.WriteLine( add( 5, 7 ) );
```

- Main purpose is not necessarily the compilation in itself – but to "treat code as data"
- Perfect tool to construct dynamic LINQ queries…!

```
Expression<Func<object,bool>> predicate = ...;
var query = data.Where( predicate.Compile() );
```

- But…

IQueryable<T>

- Remote LINQ providers has to be based upon `IQueryable<T>` instead of `IEnumerable<T>`, e.g.
  - Entity Framework
  - LINQ to SQL

```
public interface IQueryable : IEnumerable
{
   Type ElementType { get; }
   Expression Expression { get; }
   IQueryProvider Provider { get; }
}
```

- Otherwise data retrieval would be hopelessly inefficient! ☺
- The actual providers implement `IQueryProvider`
  - Instructs .NET what to actually do when manipulating queries

`Queryable` Extension Methods

- `Queryable` static class implements `IQueryable<T>` extension methods!
  - LINQ query methods are essentially doubly implemented

```
public static class Enumerable
{
   public static IEnumerable<T> Where<T>(
      this IEnumerable<T> source,
      Func<T, bool> predicate
   );
   ...
}
```

```
public static class Queryable {
   public static IQueryable<T> Where<T>(
      this IQueryable<T> source,
      Expression<Func<T, bool>> predicate
   );
   ...
}
```

Lab 3: Creating LINQ Queries

- Lab 3.1 – 3.6

Discussion and Review

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