Module 02

"Delegates, Events, and Lambdas"

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Agenda

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- **Delegates**
- Events
- Anonymous Methods and Lambda Expressions
- Type Variance
- Lab 2
- Discussion and Review

Introducing Delegates

- We have covered values in C#
- We have covered references to objects in C#
- It is in fact also possible to construct type-safe references to methods
  - Or possibly a list of methods
- Thus method invocation is delegated to such an entities
- These entities are called *Delegates* and form the basis for event-driven programming in .NET

Defining a Delegate

- Use the **`delegate`** keyword to define delegates

```
public delegate void MathOperation( int i, int j );
```

- Instances of this type are references to methods with this signature

```
class SimpleMath
{
   public static void Add( int i, int j ) { ... }
}
```

```
MathOperation m = new MathOperation( SimpleMath.Add );
```

- You can define delegates with any legal signature
- Delegates can reference both static and instance methods with the same syntax

Method Group Conversions

- This feature allows you to use delegates with the method name only

```
MathOperation m = new MathOperation( SimpleMath.Add );
```

```
MathOperation m = SimpleMath.Add;
```

- This is still type-safe..!
- C# compiler just silently does the conversion for us
- Much more convenient, maintainable, and readable
- Use this whenever you can!

Invoking a Delegate

- A delegate can be invoked with the same syntax as method invocations

```
MathOperation m = SimpleMath.Add;
...
m( 5, 7 );
```

```
m.Invoke( 5, 7 );
```

- And return values are used like conventional methods

```
public static string SayHello( string name )
{
   return string.Format( "Hello, {0}", name );
}
...
public delegate string HelloDelegate( string s );
```

```
HelloDelegate hello = SayHello;
Console.WriteLine( hello( "World" ) );
```

Multicasting Delegates

- C# delegates are in fact multicasting

```
MathOperation m = SimpleMath.Add;
m += SimpleMath.Multiply;
m( 5, 7 );
```

- Each delegate actually references a *list of methods* to be invoked – not just a single method!
- It has an internal invocation list

```
foreach( Delegate d in m.GetInvocationList() )
{
   Console.WriteLine( "Method Name: {0}", d.Method );
   Console.WriteLine( "Type Name: {0}", d.Target );
}
```

Removing Targets from Invocation List

- As demonstrated earlier, the **+=** operator adds a target to the invocation list.

```
MathOperation m = null;
m += SimpleMath.Add;
m += SimpleMath.Multiply;
...
m -= SimpleMath.Add;
m( 5, 7 );
```

- In a similar vein, the **-=** operator removes targets from the invocation list
- Note: It doesn't have to be the exact same reference which was added.
  - So you don't have to store original reference
  - Equality will ensure that the correct target gets removed

Delegates as Parameters

- Delegates can be supplied as parameters to methods

```
static void ShowInvocationList( Delegate del )
{
   foreach( Delegate d in del.GetInvocationList() )
   {
      Console.WriteLine( "Method Name: {0}", d.Method );
      Console.WriteLine( "Type Name: {0}", d.Target );
   }
}
```

- Similarly, delegates can be returned from methods

```
static MathOperation CreateDelegate()
{
   return SimpleMath.Add;
}
```

Generic Delegates

```
public delegate void MyGenericDelegate<T>( T arg );
```

```
static void StringTarget( string arg )
{
   Console.WriteLine( "arg in uppercase is: {0}",
arg.ToUpper() );
}
static void IntTarget( int arg )
{
   Console.WriteLine( "++arg is: {0}", ++arg );
}
```

```
MyGenericDelegate<int> it = IntTarget;
it( 87 );

MyGenericDelegate<string> st = StringTarget;
st( "Yo!" );
```

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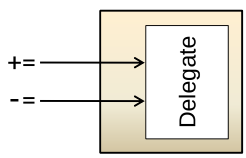
Introducing Events

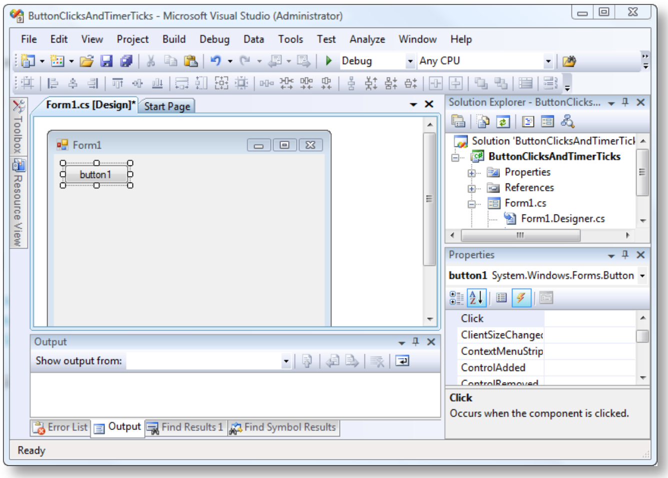
- Modern programming is event-driven
  - Occurrences of events trigger certain actions
  - Publisher-Subscriber scenario
  - E.g. button clicks in Windows applications
- Can delegates facilitate this kind of scenario?
  - Well... Yes, but...



Event

- Events provide a convenient wrapper around delegates!

Button Clicks and Timer Ticks



The **event** Keyword

- Events are constructed from some delegate signature with the **event** keyword

```
delegate void SubscriberDelegate( object publisher,
                                  SubscriptionInfo info );
```

```
public class Publisher
{  ...
   public event SubscriberDelegate NewInfo;
}
```

- Subscribers can now subscribe and unsubscribe to the event with **+=** and **-=**

```
Publisher p = new Publisher();
Subscriber s1 = new Subscriber( "Ted" );
p.NewInfo += new SubscriberDelegate( s1.PublisherUpdated );
...
p.NewInfo -= new SubscriberDelegate( s1.PublisherUpdated );
```

Event Arguments

- The recommended event pattern is that the parameters consists of
  - object raising the event
  - Subclass of System.EventArgs
- The event info class name is to be called *event name* + *"EventArgs"*
- The delegate name is to be called *event name* + *"EventHandler"*

```
delegate void NewInfoEventHandler( object sender,
                                   NewInfoEventArgs args );
public class NewInfoEventArgs : EventArgs
{
   public NewInfoEventArgs() { timeStamp = DateTime.Now; }
   public DateTime timeStamp;
}
```

```
public class Publisher
{
   public event NewInfoEventHandler NewInfo;
}
```

The **EventHandler<T>** Delegate

- Since all event delegates preferably obey the same pattern, this is captured in a generic eventhandler delegate which you should always use!

```
public delegate void EventHandler<T>( object sender, T e )
   where T: EventArgs
```

- Thus

```
delegate void NewInfoEventHandler( object sender,
                                   NewInfoEventArgs args );
```

```
public class Publisher
{
   public event EventHandler<NewInfoEventArgs> NewInfo;
}
```

Raising Events

- Events are raised by treating the event as the underlying delegate

```
if( NewInfo != null )
{
   NewInfo( this, new NewInfoEventArgs() );
}
```

- Remember to check whether event is null
  - This checks if there are any subscribers
- To be honest, this is a design flaw in .NET! ☹
- Third-party helper classes are crucial here, e.g.
  - `EventsHelper` from http://www.idesign.net
- Note: Only the class declaring the event can raise it! Not even subclasses!

Event Accessors

- If you want to exclusively control adding and removing subscribers, you can use a property-like syntax called *event accessors*

```
public event EventHandler<NewInfoEventArgs> NewInfo
{
   add
   {
      m_NewInfo += value;
      Console.WriteLine( "{0} is subscribing", value.Target );
   }
   remove { ... }
}
private EventHandler<NewInfoEventArgs> m_NewInfo;
```

- Warning: You must then handle the underlying delegate invocation list yourself!

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Defining Anonymous Methods

- When method code is only used once, the method code can be inlined as a delegate in an *anonymous method*

```
p.NewInfo += delegate
{
   Console.WriteLine( "NewInfo event was raised" );
};
```

- Note: The final "`;`" must be present!

- Parameters can be supplied to anonymous methods as usual

```
p.NewInfo += delegate( object sender, NewInfoEventArgs e )
{
   Console.WriteLine( "New info: {0}", e.TimeStamp );
};
```

Accessing Outer Variables

- Anonymous methods can access *"outer variables"* outside the anonymous method itself

```
int eventOccurrences = 0;
...
p.NewInfo += delegate( object sender, NewInfoEventArgs e )
{
   Console.WriteLine( "New info: {0}", e.TimeStamp );
   eventOccurrences++;
};
```

- Note that these are shared!
  - Shared by all invocations
  - Can be modified in between invocations of the anonymous method by somebody else

Defining Lambda Expressions

- Lambda expressions are a compact notation of the form

```
( Type1 arg1, ..., Typen argn ) =>
   Statements to Process Arguments
```

- They are just short-hands for anonymous methods

```
p.NewInfo += delegate( object sender, NewInfoEventArgs e )
{
   Console.WriteLine( "New info: {0}", e.TimeStamp );
};
```

```
p.NewInfo +=
   ( sender, e ) => Console.WriteLine( "New info: {0}",
                                        e.TimeStamp );
```

Arguments with Multiple Statements

- You can use multiple statements for argument processing by enclosing them in statement blocks, i.e. `{ … }`

```
p.NewInfo += ( sender, e ) =>
{
   Console.WriteLine( "New info: {0}", e.TimeStamp );
   eventOccurrences++;
};
```

- Outer variables can be accessed exactly as for anonymous methods

Expressions with Zero or One Parameters

- Lambda expressions could be parameterless

```
public delegate int SimpleNumberDelegate();
SimpleNumberDelegate d = () => 87;
Console.WriteLine( d.Invoke() );
```

- The parentheses can be left out altogether if exactly one parameter

```
// Built into .NET
public delegate bool Predicate<T>( T obj );

Predicate<int> p = ( i => i == 87 );
```

- `Array.FindAll()` works perfectly with predicates
- This is where Lambda Expressions really rock! ☺

Quiz: Lambda Expressions – Right or Wrong?

```
p.NewInfo += e => Console.WriteLine( "New info: {0}", e.TimeStamp );
```

```
Predicate<int> p = ( i => i * 42 );
```

```
List<int> list = new List<int>{ 42, 87, 112, 59, 33, 128 };
List<int> unfiltered = list.FindAll( _ => true );
```

```
List<int> unfiltered = list.FindAll( () => true );
```

```
List<int> filtered = list.FindAll( i => { Console.WriteLine( i );
                                          return i < 87; } );
```

```
int j = 112;
List<int> filtered = list.FindAll( i =>
{
   return i != j;
} );
```

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The **Func** Delegates

- `Predicate<T>` is a special case of the range of built-in `Func` delegates

```
delegate TResult Func<out TResult>();
delegate TResult Func<in T1, out TResult>(T1 arg1);
delegate TResult Func<in T1, in T2, out TResult>(T1 arg1, T2 arg2);
...
```

- `Func<T1, T2, TResult>` describes functions mapping arguments of type `T1` and `T2` to a result of type `TResult`

```
Func<double> vat = () => 25.0;
Console.WriteLine( "Denmark's VAT is {0}%", vat() );
```

```
Func<int,int,bool> lessThan = ( x, y ) => x < y;
int i = 42, j = 87;
Console.WriteLine( "{0} is {2}less than {1}",
   i, j, ( lessThan( i, j ) ? "" : "not " )
);
```

The **Action** Delegates

- `Action`s are similarly functions "returning void"
  - i.e. operations of the specified arguments

```
delegate void Action();
delegate void Action<in T>(T arg);
delegate void Action<in T1, in T2>(T1 arg1, T2 arg2);
...
```

- `Action<T1, T2>` describes an operation taking arguments of type `T1` and `T2` and returning `void`

```
Action show = () => { Console.WriteLine( "Hello, world" ); };
show();
```

```
Action<string,DateTime> showMessage =
   ( message, dt ) => {
      Console.WriteLine( dt + " : " + message );
   };
showMessage( "Hello, world", DateTime.Now );
```

Introducing Variance

- Assignment Compatibility

```
string s = "Hello, World!";
object o = s;
```

- Covariance = "Assignment Compatibility is **preserved**"

```
IEnumerable<string> strings = new List<string>();
IEnumerable<object> objects = strings;
```

- Contravariance = "Assignment Compatibility is **reversed**"

```
Action<object> objectAction = DoStuff;
Action<string> stringAction = objectAction;
```

```
void DoStuff( object o )
{
   // ...
}
```

Array Covariance in C# 1.0

- Arrays have been covariant in C# since the very beginning

```
object[] array = new string[ 5 ];
array[ 0 ] = "Hello, World!";
array[ 1 ] = "Covariance";
```

- Covariance in arrays are generally considered "not safe"

```
object[] array = new string[ 5 ];
array[ 0 ] = 87; // ???
```

- What will happen here?

Delegate Return Value Covariance in C# 2.0

- Delegates mix well with return value inheritance through *covariance* of delegates (a.k.a. *relaxed delegates*)

```
class A { ...}
class B : A { ... }

delegate A ADelegate();
```

```
static A AMethod () { return new A(); }
static B BMethod () { return new B(); }
```

```
ADelegate del = AMethod;
del += BMethod;            // Covariance
```

Delegate Parameter Contravariance in C# 2.0

- Delegates mix well with method parameter inheritance through *contravariance* of delegates

```
class A { ...}
class B : A { ... }

delegate void DelegateA( A a );
delegate void DelegateB( B b );
```

```
static void MethodA ( A a ) { ... }
static void MethodB ( B b ) { ... }
```

```
DelegateA delA = MethodA;
DelegateB delB = MethodA;    // Contravariance
```

- I.e. a method taking the base class type can handle subclasses as well

Generic Interface and Type Parameter Variance in C# 4.0

- Generic types unfortunately cannot be covariant in general. Imagine if...:

```
List<Manager> managers = new List<Manager> { ... };
List<Employee> employees = managers; // ???
employees.Add( new Developer() );       // Argh!!
```

- But... generic interfaces can use type parameters in restricted ways allowing either covariance or contravariance under some circumstances
- C# 4.0 adds new keywords for type parameters
  - `out` = covariance
  - `in` = contravariance

```
public interface IEnumerable<out T> : IEnumerable
{
   IEnumerator<T> GetEnumerator();
}
```

```
public interface IComparable<in T>
{
   int CompareTo( T other );
}
```

Generic Interface and Type Parameter Variance in C# 4.0

- Restrictions apply
  - Works with generic interfaces and delegates only
  - Type parameters must be reference types
    - `IEnumerator<int>` does not convert to `IEnumerator<object>`
    - Must preserve representation!
- .NET 4.0 supplies updated versions of several types using in and out, e.g.
  - Updated interfaces, e.g.
    - `IEnumerable<T>` — T is covariant
    - `IEnumerator<T>` — T is covariant
    - `IComparable<T>` — T is contravariant
    - `IComparer<T>` — T is contravariant
  - Updated delegates, e.g.
    - `Action<T>` — T is contravariant
    - `Action<T1,T2>` — T1, T2 are contravariant
    - `Func<TResult>` — TResult is covariant
    - `Func<T,TResult>` — T is contravariant
    - `Predicate<T>` — T is contravariant

Lab 2: Using Delegates, Events and Lambda Expressions

- Lab 2.1 – 2.4

Discussion and Review

- Delegates
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