

# Module 02

## "Delegates, Events, and Lambdas"



**TEKNOLOGISK**  
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# Agenda

- ▶ **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 );
```

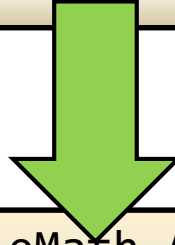
- ▶ You can define delegates with any legal signature
- ▶ Delegates can reference both static and instance methods with the same syntax



# 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!" );
```

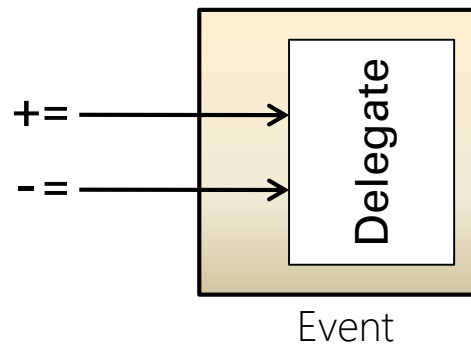


# Agenda

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

# Introducing Events

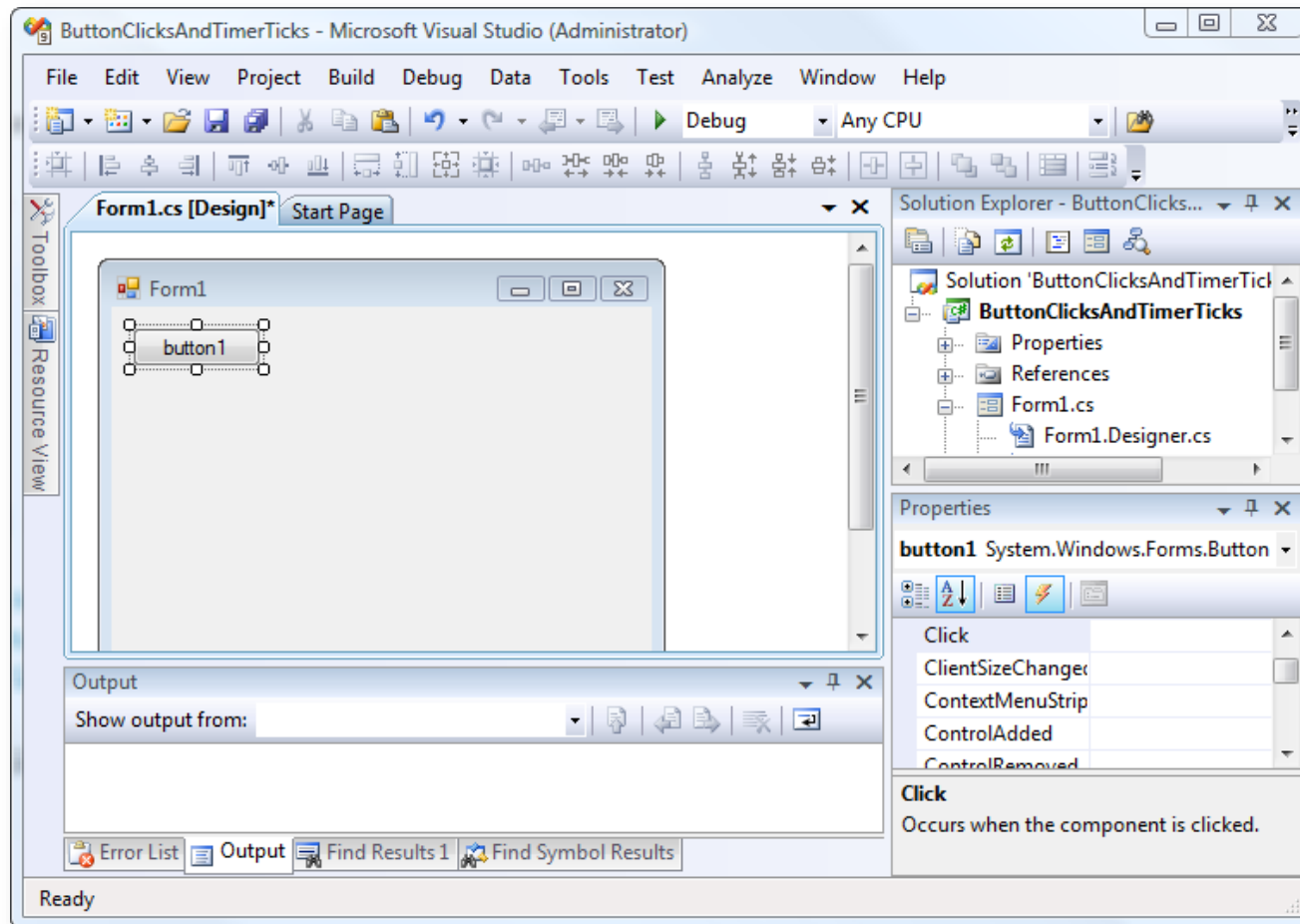
- ▶ Modern programming is event-driven
  - Occurrences of events trigger certain actions
  - Publisher-Subscriber scenario
  - E.g. button clicks in Windows applications
- ▶ Can delegates facilitate this kind of scenario?
  - Well... Yes, but...



- ▶ 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!



# Agenda

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

# 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



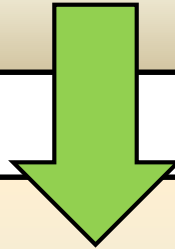
# Defining Lambda Expressions

- ▶ 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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- ▶ Delegates
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- ▶ **Type Variance**
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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

- ▶ **Actions** 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
- ▶ Events
- ▶ Anonymous Methods and Lambda Expressions
- ▶ Type Variance



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