Advanced C#

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Inheritance

Syntax

```
class A {                    // base class
    int a;
    public A() {...}
    public void F() {...}
}

class B : A {                // subclass (inherits from A, extends A)
    int b;
    public B() {...}
    public void G() {...}
}
```

- B inherits *a* and *F*(), it adds *b* and *G*()
  - constructors are not inherited
  - inherited methods can be overridden (see later)
- Single inheritance: a class can only inherit from one base class, but it can implement multiple interfaces.
- A class can only inherit from a class, not from a struct.
- Structs cannot inherit from another type, but they can implement multiple interfaces.
- A class without explicit base class inherits from *object*.

Asignments and Type Checks

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

Assignments

```
A a = new A();      // static type of a: the type specified in the declaration (here A)
                    // dynamic type of a: the type of the object in a (here also A)
a = new B();        // dynamic type of a is B
a = new C();        // dynamic type of a is C

B b = a;            // forbidden; compilation error
```

Run time type checks

```
a = new C();
if (a is C) ...     // true, if dynamic type of a is C or a subclass; otherwise false
if (a is B) ...     // true
if (a is A) ...     // true, but warning because it makes no sense

a = null;
if (a is C) ...     // false: if a == null, a is T always returns false
```

Checked Type Casts

Cast

```
A a = new C();
B b = (B) a;        // if (a is B) stat.type(a) is B in this expression; else exception
C c = (C) a;

a = null;
c = (C) a;          // ok ➔ null can be casted to any reference type
```

as

```
A a = new C();
B b = a as B;       // if (a is B) b = (B)a; else b = null;
C c = a as C;

a = null;
c = a as C;         // c == null
```

Overriding of Methods

Only methods that are declared as virtual can be overridden in subclasses

```
class A {
    public          void F() {...}   // cannot be overridden
    public virtual  void G() {...}   // can be overridden in a subclass
}
```

Overriding methods must be declared as override

```
class B : A {
    public          void F() {...}   // warning: hides inherited F() ➔ use new
    public          void G() {...}   // warning: hides inherited G() ➔ use new
    public override void G() {       // ok: overrides inherited G
        ... base.G();                // calls inherited G()
    }
}
```

- Method signatures must be identical
  - same number and types of parameters (including function type)
  - same visibility (public, protected, ...).
- Properties and indexers can also be overridden (virtual, override).
- Static methods cannot be overridden.

Dynamic Binding (simplified)

```
class A {
    public virtual void WhoAreYou() { Console.WriteLine("I am an A"); }
}

class B : A {
    public override void WhoAreYou() { Console.WriteLine("I am a B"); }
}
```

A message invokes the method belonging to the dynamic type of the receiver
(not quite true, see later)

```
A a = new B();
a.WhoAreYou();                    // "I am a B"
```

Every method that can work with *A* can also work with *B*

```
void Use (A x) {
    x.WhoAreYou();
}

Use(new A());      // "I am an A"
Use(new B());      // "I am a B"
```

Hiding

Members can be declared as new in a subclass.

They *hide* inherited members with the same name.

```
class A {
    public int x;
    public void F() {...}
    public virtual void G() {...}
}
```

```
class B : A {
    public new int x;
    public new void F() {...}
    public new void G() {...}
}
```

```
B b = new B();
b.x = ...;                      // accesses B.x
b.F(); ... b.G();               // calls B.F and B.G

((A)b).x = ...;                 // accesses A.x !
((A)b).F(); ... ((A)b).G();     // calls A.F and A.G !
```

Dynamic Binding (with hiding)

```
class A {
    public virtual void WhoAreYou() { Console.WriteLine("I am an A"); }
}

class B : A {
    public override void WhoAreYou() { Console.WriteLine("I am a B"); }
}

class C : B {
    public new virtual void WhoAreYou() { Console.WriteLine("I am a C"); }
}

class D : C {
    public override void WhoAreYou() { Console.WriteLine("I am a D"); }
}


C c = new D();
c.WhoAreYou();          // "I am a D"

A a = new D();
a.WhoAreYou();          // "I am a B" !!
```

Fragile Base Class Problem

Initial situation

```
class LibraryClass {
    public void CleanUp() { ... }
}
class MyClass : LibraryClass {
    public void Delete() { ... erase the hard disk ... }
}
```

Later: vendor ships new version of *LibraryClass*

```
class LibraryClass {
    string name;
    public virtual void Delete() { name = null; }
    public void CleanUp() { Delete(); ... }
}
```

- In Java the call *myObj.CleanUp()* would erase the hard disk!
- In C# nothing happens, as long as *MyClass* is not recompiled.
  MyClass still relies on the old version of *LibraryClass* (Versioning)
  ➔ old *CleanUp()* does not call *LibraryClass.Delete()*.
- If *MyClass* is recompiled, the compiler forces *Delete* to be declared as *new* or *override*.

Constructors and Inheritance

Implicit call of the base class constructor			Explicit call

class A {
    ...
}
 	
class B : A {
    public B(int x) {...}
}
	class A {
	    public A() {...}
	}
	
	class B : A {
	    public B(int x) {...}
	}
		class A {
		    public A(int x) {...}
		}
		
		class B : A {
		    public B(int x) {...}
		}
			class A {
			    public A(int x) {...}
			}
			
			class B : A {
			    public B(int x)
			    : base(x) {...}
			}

B b = new B(3);	B b = new B(3);	B b = new B(3);	B b = new B(3);
OK - default constr. A() - B(int x)	**OK** - A() - B(int x)	**Error!** - no explicit call of the A() constructor - default constr. A() does not exist	**OK** - A(int x) - B(int x)

Visibility protected *and* internal

protected Visible in declaring class and its subclasses
(more restricive than in Java)

internal Visible in declaring assembly (see later)

protected internal Visible in declaring class, its subclasses and the declaring assembly

Example

```
class Stack {
    protected int[] values = new int[32];
    protected int top = -1;
    public void Push(int x) {...}
    public int Pop() {...}
}
class BetterStack : Stack {
    public bool Contains(int x) {
        foreach (int y in values) if (x == y) return true;
        return false;
    }
}
class Client {
    Stack s = new Stack();
    ... s.values[0] ...     // compilation error!
}
```

Abstract Classes

Example

```
abstract class Stream {
    public abstract void Write(char ch);
    public void WriteString(string s) { foreach (char ch in s) Write(s); }
}

class File : Stream {
    public override void Write(char ch) {... write ch to disk ...}
}
```

Note

- Abstract methods do not have an implementation.
- Abstract methods are implicitly *virtual*.
- If a class has abstract methods it must be declared *abstract* itself.
- One cannot create objects of an abstract class.

Abstract Properties and Indexers

Example

```
abstract class Sequence {
    public abstract void Add(object x);                // method
    public abstract string Name { get; }               // property
    public abstract object this [int i] { get; set; }  // indexer
}

class List : Sequence {
    public override void Add(object x) {...}
    public override string Name { get {...} }
    public override object this [int i] { get {...} set {...} }
}
```

Note

- Overridden indexers and properties must have the same get and set methods as in the base class

Sealed Classes

Example

```
sealed class Account : Asset {
    long val;
    public void Deposit (long x) { ... }
    public void Withdraw (long x) { ... }
    ...
}
```

Note

- *sealed* classes cannot be extended (same as *final* classes in Java), but they can inherit from other classes.
- *override* methods can be declared as *sealed* individually.
- Reason:
    - Security (avoids inadvertent modification of the class semantics)
    - Efficiency (methods can possibly be called using static binding)

Interfaces

Syntax

```
public interface IList : ICollection, IEnumerable {
    int Add (object value);                    // methods
    bool Contains (object value);
    ...
    bool IsReadOnly { get; }                   // property
    ...
    object this [int index] { get; set; }      // indexer
}
```

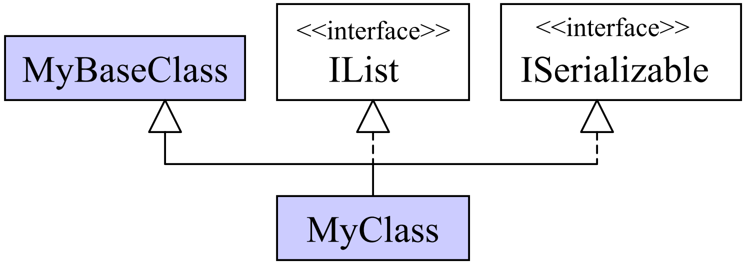
- Interface = purely abstract class; only signatures, no implementation.
- May contain methods, properties, indexers and events
  (no fields, constants, constructors, destructors, operators, nested types).
- Interface members are implicitly *public abstract* (*virtual*).
- Interface members must not be *static*.
- Classes and structs may implement multiple interfaces.
- Interfaces can extend other interfaces.

Implemented by Classes and Structs

```
class MyClass : MyBaseClass, IList, ISerializable {
    public int Add (object value) {...}
    public bool Contains (object value) {...}
    ...
    public bool IsReadOnly { get {...} }
    ...
    public object this [int index] { get {...} set {...} }
}
```

- A class can inherit from a *single base class*, but implement *multiple interfaces*.
  A struct cannot inherit from any type, but can implement multiple interfaces.
- Every interface member (method, property, indexer) must be *implemented* or *inherited* from a base class.
- Implemented interface methods must *not* be declared as *override*.
- Implemented interface methods can be declared *virtual* or *abstract* (i.e. an interface can be implemented by an abstract class).

Working with Interfaces



Assignments:

```
MyClass c = new MyClass();
IList list = c;
```

Method calls:

```
list.Add("Tom");          // dynamic binding => MyClass.Add
```

Type checks:

```
if (list is MyClass) ...   // true
```

Type casts:

```
c = list as MyClass;
c = (MyClass) list;

ISerializable ser = (ISerializable) list;
```

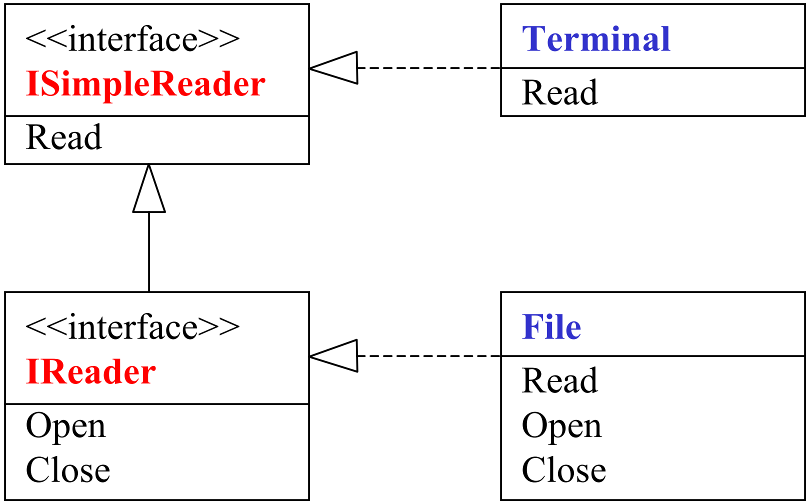
Example

```
interface ISimpleReader {
    int Read();
}

interface IReader : ISimpleReader {
    void Open(string name);
    void Close();
}

class Terminal : ISimpleReader {
    public int Read() { ... }
}

class File : IReader {
    public int Read() { ... }
    public void Open(string name) { ... }
    public void Close() { ... }
}
```



```
ISimpleReader sr = null;    // null can be assigned to any interface variable
sr = new Terminal();
sr = new File();

IReader r = new File();
sr = r;
```

Delegates and Events

Delegate = Method Type

Declaration of a delegate type

```
delegate void Notifier (string sender);      // ordinary method signature
                                             // with the keyword delegate
```

Declaration of a delegate variable

```
Notifier greetings;
```

Assigning a method to a delegate variable

```
void SayHello(string sender) {
    Console.WriteLine("Hello from " + sender);
}

greetings = new Notifier(SayHello);
```

Calling a delegate variable

```
greetings("John");                           // invokes SayHello("John") => "Hello from John"
```

Assigning Different Methods

Every matching method can be assigned to a delegate variable

```
void SayGoodBye(string sender) {
    Console.WriteLine("Good bye from " + sender);
}

greetings = new Notifier(SayGoodBye);

greetings("John");    // SayGoodBye("John") => "Good bye from John"
```

Note

- A delegate variable can have the value *null* (no method assigned).
- If null, a delegate variable must not be called (otherwise exception).
- Delegate variables are first class objects: can be stored in a data structure, passed as parameter, etc.

Creating a Delegate Value

new *DelegateType* (*obj*.*Method*)

- A delegate variable stores a method and its receiver, but no parameters !
  new Notifier(myObj.SayHello);

- *obj* can be *this* (and can be omitted)
  new Notifier(SayHello)

- *Method* can be *static*. In this case the class name must be specified instead of *obj*.
  new Notifier(MyClass.StaticSayHello);

- *Method* must not be *abstract*, but it can be *virtual*, *override*, or *new*.

- *Method* signature must match the signature of *DelegateType*
  - same number of parameters
  - same parameter types (including the return type)
  - same parameter kinds (ref, out, value)

Multicast Delegates

A delegate variable can hold multiple values at the same time

```
Notifier greetings;
greetings = new Notifier(SayHello);
greetings += new Notifier(SayGoodBye);
```

```
greetings("John");              // "Hello from John"
                                // "Good bye from John"
```

```
greetings -= new Notifier(SayHello);
```

```
greetings("John");              // "Good bye from John"
```

Note

- if the multicast delegate is a function, the value of the last call is returned
- if the multicast delegate has an *out* parameter, the parameter of the last call is returned

Events = Special Delegate Variables

```
class Model {
    public event Notifier notifyViews;
    public void Change() { ... notifyViews("Model"); }
}
```

```
class View1 {
    public View1(Model m) { m.notifyViews += new Notifier(this.Update1); }
    void Update1(string sender) { Console.WriteLine(sender + " was changed"); }
}
class View2 {
    public View2(Model m) { m.notifyViews += new Notifier(this.Update2); }
    void Update2(string sender) { Console.WriteLine(sender + " was changed"); }
}
```

```
class Test {
    static void Main() {
        Model m = new Model(); new View1(m); new View2(m);
        m.Change();
    }
}
```

Why events instead of normal delegate variables?
Only the class that declares the event can fire it (better abstraction).

Exceptions

try Statement

```
FileStream s = null;
try {
    s = new FileStream(curName, FileMode.Open);
    ...
} catch (FileNotFoundException e) {
    Console.WriteLine("file {0} not found", e.FileName);
} catch (IOException) {
    Console.WriteLine("some IO exception occurred");
} catch {
    Console.WriteLine("some unknown error occurred");
} finally {
    if (s != null) s.Close();
}
```

- *catch* clauses are checked in sequential order.
- *finally* clause is always executed (if present).
- Exception parameter name can be omitted in a *catch* clause.
- Exception type must be derived from *System.Exception*.
  If exception parameter is missing, *System.Exception* is assumed.

System.Exception

Properties

e.Message	the error message as a string; set in *new Exception(msg);*
e.StackTrace	trace of the method call stack as a string
e.Source	the application or object that threw the exception
e.TargetSite	the method object that threw the exception
...	

Methods

e.ToString()	returns the name of the exception
...	

Throwing an Exception

By an invalid operation (implicit exception)

Division by 0

Index overflow

Acess via a null reference

...

By a throw statement (explicit exception)

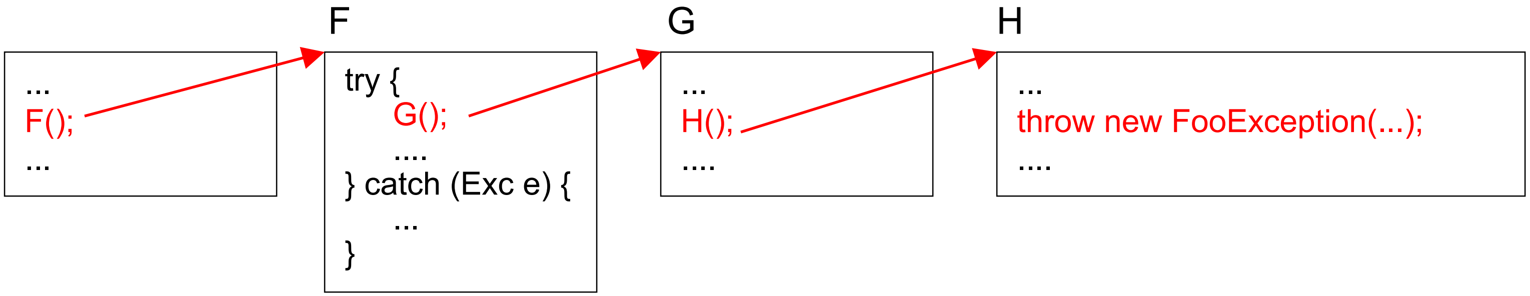
```
throw new FunnyException(10);
```

```
class FunnyException : ApplicationException {
    public int errorCode;
    public FunnyException(int x) { errorCode = x; }
}
```

Exception Hierarchy (excerpt)

- **Exception**
  - **SystemException**
    - ArithmeticException
      - DivideByZeroException
      - OverflowException
      - ...
    - NullReferenceException
    - IndexOutOfRangeException
    - InvalidCastException
    - ...
  - **ApplicationException**
    - ... custom exceptions
    - ...
  - **IOException**
    - FileNotFoundException
    - DirectoryNotFoundException
    - ...
  - **WebException**
  - ...

Searching for a catch Clause



```
...
F();
...
```

F

```
try {
    G();
    ....
} catch (Exc e) {
    ...
}
```

G

```
...
H();
....
```

H

```
...
throw new FooException(...);
....
```

Caller chain is traversed backwards until a method with a matching catch clause is found.
If none is found => Program is aborted with a stack trace

Exceptions don't have to be caught in C# (in contrast to Java)

No distinction between
- *checked exceptions* that have to be caught, and
- *unchecked exceptions* that don't have to be caught

Advantage: convenient
Disadvantage: less robust software

No Throws Clause in Method Signature

Java

```
void myMethod() throws IOException {
    ... throw new IOException(); ...
}
```

Callers of *myMethod* must either

- catch *IOException* or
- specify *IOExceptions* in their own signature

C#

```
void myMethod() {
    ... throw new IOException(); ...
}
```

Callers of *myMethod* may handle *IOException* or not.

+ convenient

- less robust

Namespaces and Assemblies

C# Namespaces vs. Java Packages

C#

A file may contain multiple namespaces

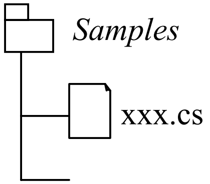
xxx.cs

```
namespace A {...}
namespace B {...}
namespace C {...}
```

Namespaces and classes are not mapped to directories and files

xxx.cs

```
namespace A {
    class C {...}
}
```



Java

A file may contain just 1 package

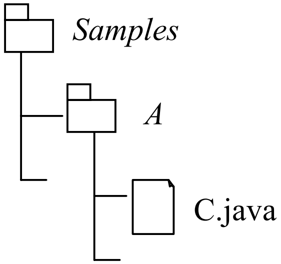
xxx.java

```
package A;
...
...
```

Packages and classes are mapped to directories and files

C.java

```
package A;
class C {...}
```



Namespaces vs. Packages (continued)

C#

Imports *namespaces*

```
using System;
```

Namespaces are imported in other Namesp.

```
using A;
namespace B {
    using C;
    ...
}
```

Alias names allowed

```
using F = System.Windows.Forms;
...
F.Button b;
```

for explicit qualification and short names.

Java

Imports *classes*

```
import java.util.LinkedList;
import java.awt.*;
```

Classes are imported in files

```
import java.util.LinkedList;
```

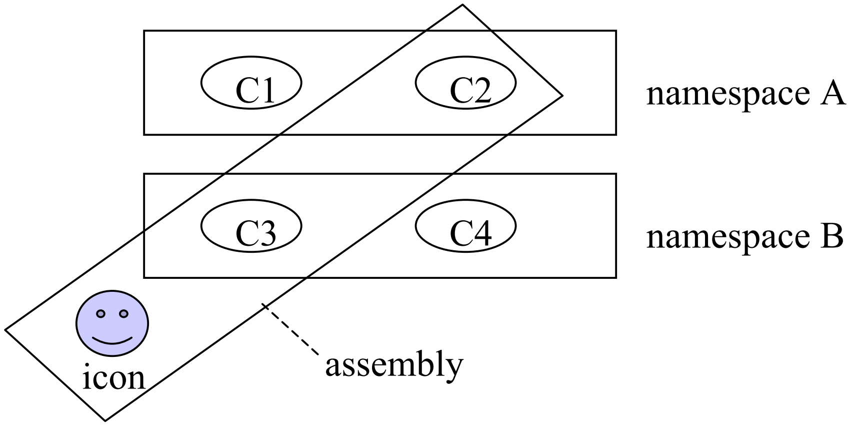
Java has visibility *package*

```
package A;
class C {
    void f() {...}  // package
}
```

C# has only visibility *internal* (!= namespace)

Assemblies

Run time unit consisting of types and other resources (e.g. icons)



- Unit of deployment: assembly is smallest unit that can be deployed individually
- Unit of versioning: all types in an assembly have the same version number

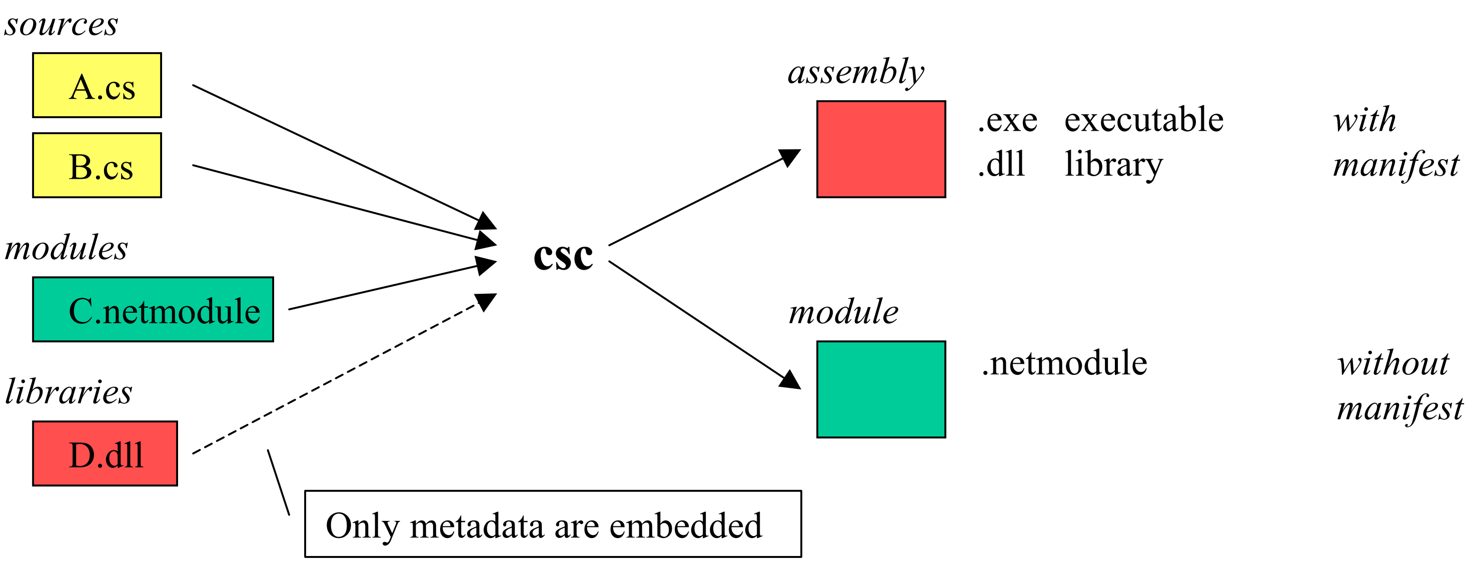
Often: 1 assembly = 1 namespace = 1 program

But:
- one assembly may consist of multiple namespaces.
- one namespace may be spread over several assemblies.
- an assembly may consist of multiple files, held together by a *manifest* ("table of contents")

Assembly	JAR file in Java
Assembly	Component in .NET

How are Assemblies Created?

Every compilation creates either an *assembly* or a *module*



Other modules/resources can be added with the assembly linker (al)

Difference to Java: Java creates a *.class file for every class

Compiler Options

Which output file should be generated?

/t[arget]: exe	output file = console application (default)
| winexe	output file = Windows GUI application
| library	output file = library (DLL)
| module	output file = module (.netmodule)

/out:*name*	specifies the name of the assembly or module	
	default for /t:exe	*name*.exe, where *name* is the name of the source file containing the *Main* method
	default for /t:library	*name*.dll, where *name* is the name of the first source file
	Example:	csc /t:library /out:MyLib.dll A.cs B.cs C.cs

/doc:*name*	generates an XML file with the specified name from /// comments

Compiler Options

How should libraries and modules be embedded?

/r[eference]:*name* makes metadata in *name* (e.g. *xxx.dll*) available in the compilation.
name must contain metadata.

/lib:dirpath{,dirpath} specifies the directories, in which libraries are searched that are referenced by /r.

/addmodule:name {,name} adds the specified modules (e.g. *xxx.netmodule*) to the generated assembly.
At run time these modules must be in the same directory as the assembly to which they belong.

Example

```
csc /r:MyLib.dll  /lib:C:\project   A.cs B.cs
```

Examples for Compilations

csc A.cs	=> A.exe
csc A.cs B.cs C.cs	=> B.exe (if *B.cs* contains *Main*)
csc /out:X.exe A.cs B.cs	=> X.exe
csc /t:library A.cs	=> A.dll
csc /t:library A.cs B.cs	=> A.dll
csc /t:library /out:X.dll A.cs B.cs	=> X.dll
csc /r:X.dll A.cs B.cs	=> A.exe (where *A* or *B* reference types in *X.dll*)
csc /addmodule:Y.netmodule A.cs	=> A.exe (*Y* is added to this assembly)

Attributes

Attributes

User-defined metainformation about program elements

- Can be attached to types, members, assemblies, etc.
- Extend predefined attributes such as *public*, *sealed* or *abstract*.
- Are implemented as classes that are derived from *System.Attribute*.
- Are stored in the metadata of an assembly.
- Often used by CLR services (serialization, remoting, COM interoperability)
- Can be queried at run time.

Example

```
[Serializable]
class C {...}                                  // makes the class serializable
```

Also possible to attach multiple attributes

```
[Serializable] [Obsolete]
class C {...}

[Serializable, Obsolete]
class C {...}
```

Attribute with Parameters

Example

positional parameter

name parameters come after pos. parameters

```
[Obsolete("Use class C1 instead", IsError=true)]    // causes compiler message saying
public class C {...}                                 // that C is obsolete
```

Positional parameter = parameter of the attribute's constructor
Name parameter = a property of the attribute

Attributes are declared as classes

```
public class ObsoleteAttribute : Attribute {            // class name ends with "Attribute"
    public string Message { get; }                       // but can be used as "Obsolete"
    public bool IsError { get; set; }
    public ObsoleteAttribute() {...}
    public ObsoleteAttribute(string msg) {...}
    public ObsoleteAttribute(string msg, bool error) {...}
}
```

Valid variants:

```
[Obsolete]
[Obsolete("some Message")]
[Obsolete("some Message", false)]
[Obsolete("some Message", IsError=false)]
```

value must be a constant

Example: ConditionalAttribute

Allows a conditional call of methods

```
#define debug                            // preprocessor command

class C {

  [Conditional("debug")]                 // only possible for void methods
  static void Assert (bool ok, string errorMsg) {
    if (!ok) {
      Console.WriteString(errorMsg);
      System.Environment.Exit(0);        // graceful program termination
    }
  }

  static void Main (string[] arg) {
    Assert(arg.Length > 0, "no arguments specified");
    Assert(arg[0] == "...", "invalid argument");
    ...
  }
}
```

Assert is only called, if *debug* was defined.
Also useful for controlling trace output.

Your Own Attributes

Declaration

```
[AttributeUsage(AttributeTargets.Class|AttributeTargets.Interface, Inherited=true)]
class Comment : Attribute {
    string text, author;
    public string Text { get {return text;} }
    public string Author { get {return author;} set {author = value;} }
    public Comment (string text) { this.text = text; author ="HM"; }
}
```

Use

```
[Comment("This is a demo class for Attributes", Author="XX")]
class C { ... }
```

Querying the attribute at run time

```
class Attributes {

    static void Main() {
        Type t = typeof(C);
        object[] a = t.GetCustomAttributes(typeof(Comment), true);
        Comment ca = (Comment)a[0];
        Console.WriteLine(ca.Text + ", " + ca.Author);
    }
}
```

search should also be continued in subclasses

Threads

Participating Types (excerpt)

```
public sealed class Thread {
    public static Thread CurrentThread { get; }        // static methods
    public static void Sleep(int milliSeconds) {...}
    ...
    public Thread(ThreadStart startMethod) {...}      // thread creation

    public string Name { get; set; }                  // properties
    public ThreadPriority Priority { get; set; }
    public ThreadState ThreadState { get; }
    public bool IsAlive { get; }
    public bool IsBackground { get; set; }
    ...
    public void Start() {...}                         // methods
    public void Suspend() {...}
    public void Resume() {...}
    public void Join() {...}                          // caller waits for the thread to die
    public void Abort() {...}                         // throws ThreadAbortException
    ...
}

public delegate void ThreadStart();                   // parameterless void method

public enum ThreadPriority {AboveNormal, BelowNormal, Highest, Lowest, Normal}
public enum ThreadState {Aborted, Running, Stopped, Suspended, Unstarted, ...}
```

Example

```
using System;
using System.Threading;

class Printer {
    char ch;
    int sleepTime;

    public Printer(char c, int t) {ch = c; sleepTime = t;}

    public void Print() {
        for (int i = 0; i < 100; i++) {
            Console.Write(ch);
            Thread.Sleep(sleepTime);
        }
    }
}

class Test {

    static void Main() {
        Printer a = new Printer('.', 10);
        Printer b = new Printer('*', 100);
        new Thread(new ThreadStart(a.Print)).Start();
        new Thread(new ThreadStart(b.Print)).Start();
    }
}
```

The program runs until the last thread stops.

Thread States

```
Thread t = new Thread(new ThreadStart(P));
Console.WriteLine("name={0}, priority={1}, state={2}", t.Name, t.Priority, t.ThreadState);
t.Name = "Worker"; t.Priority = ThreadPriority.BelowNormal;
t.Start();
Thread.Sleep(0);
Console.WriteLine("name={0}, priority={1}, state={2}", t.Name, t.Priority, t.ThreadState);
t.Suspend();
Console.WriteLine("state={0}", t.ThreadState);
t.Resume();
Console.WriteLine("state={0}", t.ThreadState);
t.Abort();
Thread.Sleep(0);
Console.WriteLine("state={0}", t.ThreadState);
```

Output

```
name=, priority=Normal, state=Unstarted
name=Worker, priority=BelowNormal, state=Running
state=Suspended
state=Running
state=Stopped
```

Example for Join

```
using System;
using System.Threading;

class Test {

    static void P() {
        for (int i = 1; i <= 20; i++) {
            Console.Write('-');
            Thread.Sleep(100);
        }
    }

    static void Main() {
        Thread t = new Thread(new ThreadStart(P));
        Console.Write("start");
        t.Start();
        t.Join();
        Console.WriteLine("end");
    }
}
```

Output

```
start--------------------end
```

Mutual Exclusion (Synchronization)

lock Statement

lock(*Variable*) *Statement*

Example

```
class Account {                         // this class should behave like a monitor
    long val = 0;

    public void Deposit(long x) {
        lock (this) { val += x; }   // only 1 thread at a time may execute this statement
    }

    public void Withdraw(long x) {
        lock (this) { val -= x; }
    }
}
```

Lock can be set to any object

```
object semaphore = new object();
...
lock (semaphore) { ... critical region ... }
```

No synchronized methods like in Java

Class Monitor

```
lock(v) Statement
```

is a shortcut for

```
Monitor.Enter(v);
try {
    Statement
} finally {
    Monitor.Exit(v);
}
```

Wait and Pulse

Monitor.Wait(lockedVar);	wait() in Java (in Java *lockedVar* is always *this*)
Monitor.Pulse(lockedVar);	notify() in Java
Monitor.PulseAll(lockedVar);	notifyAll() in Java

Example

Thread A

```
1  lock(v) {
       ...
   2   Monitor.Wait(v); 5
       ...
   }
```

Thread B

```
3  lock(v) {
       ...
   4   Monitor.Pulse(v);
       ...
   } 6
```

1. *A* comes to *lock(v)* and proceeds because the critical region is free.
2. *A* comes to *Wait*, goes to sleep and releases the lock.
3. *B* comes to *lock(v)* and proceeds because the critical region is free.
4. *B* comes to *Pulse* and wakes up *A*. There can be a context switch between *A* and *B*, but not necessarily.
5. *A* tries to get the lock but fails, because *B* is still in the critical region.
6. At the end of the critical region *B* releases the lock; *A* can proceed now.

Example: Synchronized Buffer

```
class Buffer {
    const int size = 4;
    char[] buf = new char[size];
    int head = 0, tail = 0, n = 0;

    public void Put(char ch) {
        lock(this) {
            while (n == size) Monitor.Wait(this);
            buf[tail] = ch; tail = (tail + 1) % size; n++;
            Monitor.Pulse(this);
        }
    }

    public char Get() {
        lock(this) {
            while (n == 0) Monitor.Wait(this);
            char ch = buf[head]; head = (head + 1) % size;
            n--;
            Monitor.Pulse(this);
            return ch;
        }
    }
}
```

If producer is faster

```
Put
Put
Put
Put
Get
Put
Get
...
```

If consumer is faster

```
Put
Get
Put
Get
...
```

XML Comments

Special Comments (like javadoc)

Example

```
/// ... comment ...
class C {
    /// ... comment ...
    public int f;

    /// ... comment ...
    public void foo() {...}
}
```

Compilation `csc /doc:MyFile.xml MyFile.cs`

- *Checks if comments are complete and consistent*
  e.g. if one parameter of a method is documented, all parameters must be documented;
  Names of program elements must be spelled correctly.
- *Generates an XML file with the commented program elements*
  XML can be formatted for the Web browser with XSL

Example of a Commented Source File

```
/// <summary> A counter for accumulating values and computing the mean value.</summary>
class Counter {
    /// <summary>The accumulated values</summary>
    private int value;

    /// <summary>The number of added values</summary>
    public int n;

    /// <summary>Adds a value to the counter</summary>
    /// <param name="x">The value to be added</param>
    public void Add(int x) {
        value += x; n++;
    }

    /// <summary>Returns the mean value of all accumulated values</summary>
    /// <returns>The mean value, i.e. <see cref="value"/> / <see cref="n"/></returns>
    public float Mean() {
        return (float)value / n;
    }
}
```

Generated XML File

```
<?xml version="1.0"?>
<doc>
   <assembly>
      <name>MyFile</name>
   </assembly>
   <members>
      <member name="T:Counter">
         <summary> A counter for accumulating values and computing the mean value.</summary>
      </member>
      <member name="F:Counter.value">
         <summary>The accumulated values</summary>
      </member>
      <member name="F:Counter.n">
         <summary>The number of added values</summary>
      </member>
      <member name="M:Counter.Add(System.Int32)">
         <summary>Adds a value to the counter</summary>
         <param name="x">The value to be added</param>
      </member>
      <member name="M:Counter.Mean">
         <summary>Returns the mean value of all accumulated values</summary>
         <returns>The mean value, i.e. <see cref="F:Counter.value"/> / <see cref="F:Counter.n"/></returns>
      </member>
   </members>
</doc>
```

XML file can be viewed in HTML using Visual Studio.

elements are not nested hierarchically!

XML Tags

Predefined Tags

Main tags

<summary> *short description of a program element* </summary>

<remarks> *extensive description of a program element* </remarks>

<param name="*ParamName*"> *description of a parameter* </param>

<returns> *description of the return value* </returns>

Tags that are used within other tags

<exception [cref="*ExceptionType*"]> *used in the documentation of a method: describes an exception* </exception>

<example> *sample code* </example>

<code> *arbitrary code* </code>

<see cref="*ProgramElement*"> *name of a crossreference link* </see>

<paramref name="*ParamName*"> *name of a parameter* </paramref>

User-defined Tags

Users may add arbitrary tags, e.g. <author>, <version>, ...

Summary

Summary of C#

- Familiar
- Safe
  - Strong static typing
  - Run time checks
  - Garbage Collection
  - Versioning
- Expressive
  - Object-oriented (classes, interfaces, ...)
  - Component-oriented (properties, events, assemblies, ...)
  - Uniform type system (boxing / unboxing)
  - Enumerations
  - Delegates
  - Indexers
  - ref and out parameters
  - Value objects on the stack
  - Threads and synchronization
  - Exceptions
  - User attributes
  - Reflection
  - ...