



Code Contracts User Manual

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What's New?

- For each assembly, you now need to specify an explicit assembly mode according to how contracts are used on that assembly. See Section 5.1.
- [ContractArgumentValidator] methods support factoring legacy if-then-throw style parameter validation into helper methods, while still permitting the tools to recognize them. See Section 2.11.
- [ContractAbbreviator] methods support factoring commonly used combinations of Requires and Ensures into helper methods that can be used from multiple places. See Section 2.12.
- Section 4.8 describes how to turn off contract checking or inheritance at assembly, type, or method level using attributes.
- Section 5.2 describes how to migrate an existing project to take advantage of contracts.
- Section 7.8 describes how to deal with test harness setup in VS2010 when the code under test is built with .NET v3.5 and the Microsoft.Contracts.dll.

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```

1 using System;
2 using System.Diagnostics.Contracts;
3
4 namespace ContractExample1 {
5
6     class Rational {
7
8         int numerator;
9         int denominator;
10
11         public Rational(int numerator, int denominator)
12         {
13             Contract.Requires( denominator != 0 );
14
15             this.numerator = numerator;
16             this.denominator = denominator;
17         }
18
19         public int Denominator {
20             get {
21                 Contract.Ensures( Contract.Result<int>() != 0 );
22
23                 return this.denominator;
24             }
25         }
26
27         [ContractInvariantMethod]
28         void ObjectInvariant () {
29             Contract.Invariant ( this.denominator != 0 );
30         }
31     }
32 }

```

Figure 1: Example of preconditions, postconditions, and invariants

1 Code Contracts Library Overview

Contracts allow you to express preconditions, postconditions and object invariants in your code for runtime checking, static analysis, and documentation. This document covers how to author them in your code, and contains guidelines for using them effectively with the provided tools.

All of the contract methods are static methods defined in the `Contract` class which appears in the `System.Diagnostics.Contracts` namespace.

Starting with the CLR v4 (or Silverlight 4), the `Contract` class and related types reside in `mscorlib.dll`. Prior to CLR v4 (or Silverlight 4), these types appear in a separate assembly called `Microsoft.Contracts.dll` that is installed under `%PROGRAMFILES%/Microsoft/Contracts/PublicAssemblies`. You need to add a reference to this assembly if you are compiling against a pre 4.0 CLR.

If you develop for Windows Phone 7, you also need to reference the `Microsoft.Contracts.dll` that is found under `%PROGRAMFILES%/Microsoft/Contracts/PublicAssemblies/Silverlight3`, as the runtime for Windows Phone 7 does not yet contain the contract class.

1.1 Example

The code in Figure 1 illustrates how the main three features of contracts are used, namely preconditions, object invariants, and postconditions. The code defines a fragment of a rational class to represent rational numbers. In order to define a proper rational, the denominator must be non-zero. We express this as a precondition in the constructor using the `Contract.Requires` method call on line 13.

In this example, the intention is that every `Rational` object is always valid and has a non-zero denominator. We express this precisely using an `ObjectInvariant` method tagged with a `[ContractInvariantMethod]` attribute. It uses the method call `Contract.Invariant` on line 29 to express that the denominator is always non-zero.

Finally, given this invariant, we can use the `Contract.Ensures` method call on line 21 to express a postcondition that the getter `Denominator` always returns a non-zero value.

The next section discusses all features of the contract library in detail. To start using contracts right away with Visual Studio, we suggest jumping to section 5 and using the intervening sections as a reference.

2 Contracts

Most methods of the contract class are conditionally compiled, meaning the compiler only emits calls to these methods when a special symbol, the full-contract symbol, is defined. That symbol is `CONTRACTS_FULL`. This allows writing contracts in your code without the use of `#ifdef`'s, yet produce different builds, some with contracts, and some without.

If you are using Visual Studio 2008 or later (Section 6) or `msbuild` (Section A.1), then you don't need to define this symbol yourself. Instead, when you use the provided UI to enable runtime or static checking (or properties in your projects or `/p` defines in `msbuild` arguments), the build automatically defines this symbol and performs the appropriate rewrite actions. If you use your own build mechanism, then you need to define the full-contract symbol if you want the contracts to be emitted into your assemblies for further consumption by tools.

2.1 Preconditions

Preconditions are expressed using `Contract.Requires (...)`. They are contracts on the state of the world when a method is invoked. They generally are used to specify valid parameter values. All members mentioned in preconditions must be at least as accessible as the method itself (Section 5.5). Otherwise, the precondition cannot be understood (and thus satisfied) by all callers of a method. The condition should also be side-effect free (Section 5.4).

The following precondition expresses that parameter `x` must be non-null.

```
Contract.Requires( x != null );
```

If your code must throw a particular exception on failure of a particular precondition, you can use the generic overloaded form below (but please read Section 5.1 before committing to this form in your code):

```
Contract.Requires<ArgumentNullException>( x != null, "x" );
```

The runtime behavior of failed preconditions is defined in Section 7. The exception type you specify must have a public constructor accepting a single string argument. Otherwise, the runtime will construct an internal `ContractException` and throw that.

2.1.1 Legacy Requires

Most code already contains some parameter validation in the form of if-then-throw code. The contract tools recognize if-then-throw statements as preconditions in the following cases:

- the statements appear first inside a method, and
- the entire set of such statements is followed by an explicit `Contract` method call, such as a `Requires`, `Ensures`, `EnsuresOnThrow`, or `EndContractBlock`.

When if-then-throw statements appear in this form, the tools recognize them as “legacy-requires”. The `EndContractBlock` form (Section 2.6) is only necessary if no other contracts follow the if-then-throw sequences.

```
if ( x == null ) throw new ...  
Contract.EndContractBlock(); // All previous 'if' checks are preconditions
```

Note that the condition in the above test is the *negated* precondition. The actual precondition would be `x != null`. This form of precondition is highly restricted: it must be written as above, i.e., there are no else-clauses and the body of the then-clause must be a single throw statement. The if-test is subject to both the purity (Section 5.4) and visibility rules (Section 5.5), but the throw-expression is subject only to the purity rules. However, the type of the exception thrown must be as visible as the method in which the contract occurs.

2.2 Postconditions

Postconditions are contracts on the state of a method when it terminates. In other words, the condition is checked just prior to exiting a method. The runtime behavior of failed postconditions is described in Section 7.

Unlike preconditions, members with less visibility may be mentioned in a postcondition. A client may not be able to understand or make use of some of the information expressed by a postcondition using private state, but it doesn't affect the client's ability to use the API correctly.

2.2.1 Normal Postconditions

Normal postconditions are expressed using `Contract.Ensures (...)`. They express a condition that must hold on normal termination of the method.

```
Contract.Ensures( this.F > 0 );
```

2.2.2 Exceptional Postconditions

Postconditions that should hold when particular exceptions escape from a method, are specified using `Contract.EnsuresOnThrow`.

```
Contract.EnsuresOnThrow<T>( this.F > 0 );
```

The argument is the condition that must hold whenever an exception is thrown that is a subtype of `T`. There are many exception types that would be difficult to use in an exceptional postcondition. For instance, using the type `Exception` for `T` would require the method to guarantee the condition no matter what type of exception is thrown, even if it is a stack overflow or other impossible-to-control exception. It is recommended to use exceptional postconditions only for those exceptions that a caller should expect as part of the API, e.g., a socket-closed exception on a method in an API for sending messages across a socket.

2.2.3 Special Methods within Postconditions

There are several special methods that may be used only within postconditions.

Method Return Values Within postconditions the method's return value can be referred to via the expression `Contract.Result<T>()`, where `T` is replaced with the return type of the method. When the compiler is unable to infer the type it must be explicitly given. For instance, the C# compiler is unable to infer types for methods that do not take any arguments.

```
Contract.Ensures(0 < Contract.Result<int>());
```

Methods with a return type of `void` cannot refer to `Contract.Result<T>()` within their postconditions.

Prestate Values (OldValue) Within a postcondition, an old expression refers to the value of an expression from the pre-state. It uses the method `Contract.OldValue<T>(e)`, where `T` is the type of `e`. The generic type argument may be omitted whenever the compiler is able to infer its type. For instance, the C# compiler is able to infer the type since it takes an argument. There are several restrictions on what can occur in `e` and also in which contexts an old expression may appear. An old expression may appear only within a postcondition. An old expression cannot contain another old expression. A very important rule is that an old expression must refer to a value that existed in the method's pre-state, i.e., it must be an expression that can be evaluated as long as the method's precondition holds. Here are several instances of that rule.

1. The value must exist in the method's prestate. If the following old expression is in a method whose precondition implies that `xs != null`, then it is fine. But if the precondition is a disjunction `xs != null || E` for any other expression `E`, then the old expression could get evaluated in a state where `xs` is null because `E` held.

```
Contract.OldValue(xs.Length) // POSSIBLE ERROR
```

2. The method's return value cannot be referred to in an old expression:

```
Contract.OldValue(Contract.Result<int>() + x) // ERROR
```

3. Out parameters cannot be referred to within an old expression.

4. An old expression cannot depend on the bound variable of a quantifier (Section 2.7), *if* the range of the quantifier depends on the return value of the method:

```
Contract.ForAll(0, Contract.Result<int>(),
               i => Contract.OldValue(xs[i]) > 3); // ERROR
```

5. An old expression cannot refer to the parameter of the anonymous delegate within a `Contract.ForAll` or `Contract.Exists` unless it is used as an indexer or argument to a method call:

```
Contract.ForAll(0, xs.Length, i => Contract.OldValue(xs[i]) > 3); // OK
Contract.ForAll(0, xs.Length, i => Contract.OldValue(i) > 3); // ERROR
```

6. An old expression cannot occur in the body of an anonymous delegate if the value of the old expression depends on any of the parameters of the anonymous delegate unless the anonymous delegate is an argument to the methods `Contract.ForAll` or `Contract.Exists`:

```
Foo( ... (T t) => Contract.OldValue(... t ...) ... ); // ERROR
```

Out Parameters Because contracts appear before the body of the method, most compilers do not allow references to out parameters in postconditions. To get around this issue, the library provides the method `Contract.ValueAtReturn<T>(out T t)` which will not require that the parameter is already defined.

```
public void OutParam(out int x) {
    Contract.Ensures(Contract.ValueAtReturn(out x) == 3);
    x = 3;
}
```

As with `OldValue`, the generic type argument may be omitted whenever the compiler is able to infer its type. The contract rewriter will replace the method call with the value of the out-parameter. The method may appear only within postconditions. The argument to the method must be an out parameter or a field of a struct type out parameter. The latter is also useful when referring to fields in the postcondition of a `struct(ure)` constructor.

Note: Currently the tools do not check to make sure that out parameters are initialized properly disregarding their mention in the postcondition. Thus, in the above example, if the line after the contract had used the value of `x` instead of assigning to it, a compiler would not issue the error that it should. However, on a build where the `CONTRACTS.FULL` is not defined (such as `Release`), the compiler will issue an error.

2.3 Object Invariants

Object invariants are conditions that should hold on each instance of a class whenever that object is visible to a client. They express the conditions under which the object is in a “good” state.

All of an object’s invariants should be put into one or more private nullary instance methods that return void. These methods are identified by being marked with the attribute `[ContractInvariantMethod]` (Section 4.2). The invariant methods must have no other code in it than a sequence of calls to `Contract.Invariant`.

Individual invariants within invariant methods are specified using `Contract.Invariant`:

```
[ContractInvariantMethod]
private void ObjectInvariant() {
    Contract.Invariant( this.y >= 0 );
    Contract.Invariant( this.x > this.y );
    ...
}
```

Invariants are conditionally defined on the full-contract symbol. During runtime checking, invariants are checked at the end of each public method. If an invariant mentions a public method in the same class, then the invariant check that would normally happen at the end of that public method is disabled and checked only at the end of the outermost method call to that class. This also happens if the class is re-entered because of a call to a method on another class.

Invariants are not checked for object finalizers or for any method that implements `System.IDisposable.Dispose`. The runtime behavior for failed invariants is described in Section 7.

Don’t call methods marked with `[ContractInvariantMethod]` directly from your code. The contract tools will issue an error if you do.

2.4 Assert

Assertions are specified using `Contract.Assert`. They are used to state a condition that must hold at that program point.

```
Contract.Assert( this.privateField > 0 );
Contract.Assert( this.x == 3, "Why isn't the value of x 3?" );
```

Assertions are conditionally defined and so exist in the build only when the full-contract symbol or the `DEBUG` symbol is defined. See section 7 for a description of the runtime behavior for failed assertions.

2.5 Assume

Assumptions are specified using `Contract.Assume`.

```
Contract.Assume( this.privateField > 0 );
Contract.Assume( this.x == 3, "Static checker assumed this" );
```

At runtime, `Assume` works exactly like `Assert`, i.e., the condition is checked, and if it fails, some action happens (see Section 7).

However, for static verification an assumption is something that the verification will just add to the facts that it knows about the program at that program point. You should use this for conditions that you believe to hold at a program point, but that the static verification is unable to prove due to its limitations. It is probably best to start with just assertions and then change them as needed while verifying the code.

Assumptions are conditionally defined and so exist in the build only when the full-contract symbol or the DEBUG symbol is defined.

2.6 EndContractBlock

When a method's contracts contain only preconditions in the if-then-throw form (Section 2.1.1), this method is used to mark the end of the contract section. It has no other effect. All if-then-throw statements before `EndContractBlock` are assumed to be preconditions. It is also defined conditionally on the full-contract symbol.

```
if ( x == null ) throw new ArgumentNullException("x");
if ( y < 0 ) throw new ArgumentOutOfRangeException(...);
Contract.EndContractBlock( );
```

2.7 Quantifiers

Limited support is available for quantifiers within contracts. We support only those forms which are executable at runtime. This currently means that the range of quantification must be effectively computable. Also, the “body” of each quantification must be an expression, i.e., not contain any loops or assignment statements.

2.7.1 ForAll

Universal quantifications are written using `Contract.ForAll`. There are two overloads, both of which are static methods. The first form takes two parameters: a collection and a predicate. A predicate is a unary method that returns a boolean. The predicate is applied to each element in the collection. If it returns false on any element, `ForAll` stops iterating and returns false. If the predicate returns true on all of the elements in the collection, then `ForAll` returns true. Here's an example of a contract that says that all elements in the array must be non-null:

```
public int Foo<T>(IEnumerable<T> xs){
    Contract.Requires(Contract.ForAll(xs, x => x != null) );
```

Note that this overload of `ForAll` uses an enumeration. It is generic; it is parameterized by the type of elements in the collection. (That is, the first argument is of type `IEnumerable<T>` and the predicate must take an argument of type `T`.)

The other overload takes three parameters: an inclusive lower bound, an *exclusive* upper bound, and a predicate. It iterates over a range within a collection, and is not generic: the predicate must take an integer as its argument. For example, the following method has a postcondition that all returned values in the array must be positive:

```
public int[] Bar(){
    Contract.Ensures( Contract.ForAll(0, Contract.Result<int[]>().Length,
                                     index => Contract.Result<int[]>()[index] > 0));
```

It is also possible to use the extension method `System.Linq.Enumerable.All` instead of `Contract.ForAll`. The `System.Linq` namespace contains other useful extension methods usable in contracts, such as for example `Sum` to sum the elements of an `IEnumerable`.

2.7.2 Exists

Existential quantifications are written using `Contract.Exists`. There are the same two overloads with the same parameters as `Contract.ForAll`.

The predicate is applied to each element in the collection. If it returns true on any element, `Exists` stops iterating and returns true. If the predicate returns false on all of the elements in the collection, then `Exists` returns false.

It is also possible to use the extension method `System.Linq.Enumerable.Any` instead of `Contract.Exists`.

2.8 Interface Contracts

Since most languages/compiler (including C# and VB) will not let you put method bodies within an interface, writing contracts for interface methods requires creating a separate contract class to hold them. The interface and its contract class are linked via a pair of attributes (Section 4.1).

```
[ContractClass(typeof(IFooContract))]  
interface IFoo {  
    int Count { get; }  
    void Put(int value);  
}  
[ContractClassFor(typeof(IFoo))]  
abstract class IFooContract : IFoo {  
    int IFoo.Count {  
        get {  
            Contract.Ensures( 0 <= Contract.Result<int>() );  
            return default(int); // dummy return  
        }  
    }  
    void IFoo.Put(int value){  
        Contract.Requires( 0 <= value );  
    }  
}
```

The tools expect that the contract class is abstract and implements the interface it is providing contracts for.

Note how you have to produce a dummy return value. The easiest way is to always use `default(T)` for any type `T`. *Do not use `Contract.Result<T>()`, as the tools will emit an error.*

If you need to refer to interface methods within the same interface in the contracts, you may want to use implicit implementations of the methods you want to refer to.

```
[ContractClassFor(typeof(IFoo))]  
abstract class IFooContract : IFoo {  
    public int Count { // implicit interface implementation  
        get {  
            Contract.Ensures( 0 <= Contract.Result<int>() );  
            return default(int); // dummy return  
        }  
    }  
    void IFoo.Put(int value){  
        Contract.Requires( 0 <= value );  
        Contract.Requires( this.Count < 10 ); // otherwise, need to write ((IFoo)this).Count  
    }  
}
```

2.9 Contracts on Abstract Methods

Similarly to interface methods, abstract methods in an abstract class cannot contain method bodies, thus contracts for these methods need to be written separately. The mechanisms used for annotating abstract classes is the same as that for interfaces. The contract class in this case has to be abstract and implements the abstract class for which it defines contracts:

```
[ContractClass(typeof(FooContract))]
```

```

abstract class Foo {
    public abstract int Count { get; }
    public abstract void Put(int value);
}

[ContractClassFor(typeof(Foo))]
abstract class FooContract : Foo {
    public override int Count {
        get {
            Contract.Ensures( 0 <= Contract.Result<int>() );
            return default(int); // dummy return
        }
    }
    public override void Put(int value){
        Contract.Requires( 0 <= value );
    }
}

```

2.10 Overloads on Contract Methods

All of the contract methods have overloads that take a string in addition to the boolean condition:

```
Contract.Requires( x != null, "If x is null, then the missiles are fired!" );
```

The user-supplied string will be displayed whenever the contract is violated at runtime. Currently, it must be a compile-time constant.

2.11 Contract Argument Validator Methods

Important: the `ContractArgumentValidatorAttribute` type is not defined in `mscorlib.dll` 4.0. In order to use this feature, please add the file `ContractExtensions.cs` or `ContractExtensions.vb` to all of your projects that contain contract validator methods.

These files are found in `%ProgramFiles%\Microsoft\Contracts\Languages\....`

If your project uses explicit if-then-throw code to validate parameters (usage mode 3 in Section 5.1), you are likely employing helper methods that perform checks and throw particular exceptions on failure, as shown in the following example.

```

static class ValidationHelper {
    public static void NotNull(object argument, string parameterName) {
        if (argument == null) throw new ArgumentNullException(parameterName, ...);
    }
}

...

public void MyMethod(string value) {
    ValidationHelper.NotNull(value, "value");
    ...
}

```

In the above example, `MyMethod` has an effective precondition specifying that parameter `value` should not be null. In order for the contract tools to recognize that the call to `ValidationHelper.NotNull` represents a contract, the called method can be marked with the `[ContractArgumentValidator]` attribute and the `EndContractBlock()` marker should be used in order for the tools to extract the proper specifications for document generation and static checking:

```

static class ValidationHelper {
    [ContractArgumentValidator]
    public static void NotNull(object argument, string parameterName) {
        if (argument == null) throw new ArgumentNullException(parameterName, ...);
        Contract.EndContractBlock();
        ...
    }
}

```

Besides if-then-throw statements, the contract section of contract validator methods is allowed to contain calls to other contract validator methods. However, no other contracts, such as `Requires`, or `Ensures` are allowed. Code after the `EndContractBlock()` is ignored by all contract tools.

The following shows a range argument validator written in terms of an existing `NotNull` validator method:

```

static class ValidationHelper {
    [ContractArgumentValidator]
    public static void NotNull(object argument, string parameterName) { ... }

    [ContractArgumentValidator]
    public static void InRange(object[] array, int index, string arrayName, string indexName) {
        ValidationHelper.NotNull(array, arrayName);
        if (index < 0) throw new ArgumentOutOfRangeException(indexName, ...);
        if (index >= array.Length) throw new ArgumentOutOfRangeException(indexName, ...);
        Contract.EndContractBlock();
        ...
    }

    ...

    public void MyMethod(int[] data, int position) {
        ValidationHelper.InRange(data, position, "data", "position");
        ...
    }
}

```

From a specification point of view, method `MyMethod` above has the following three contracts:

```

Contract.Requires<ArgumentNullException>(data != null);
Contract.Requires<ArgumentOutOfRangeException>(position >= 0);
Contract.Requires<ArgumentOutOfRangeException>(position < data.Length);

```

In ordinary methods, calls to contract validator methods can be freely mixed with other contracts, such as `Contract.Ensures` or additional `Contract.Requires`.

2.12 Contract Abbreviator Methods

Important: the `ContractAbbreviatorAttribute` type is not defined in `mcorlib.dll` 4.0. In order to use this feature, please add the file `ContractExtensions.cs` or `ContractExtensions.vb` to all of your projects that contain contract abbreviator methods.

These files are found in `%ProgramFiles%\Microsoft\Contracts\Languages\....`

If you find yourself repeating similar sets of contracts in many methods, you can use *contract abbreviator methods* to factor these contracts and reference them in multiple places. The following example contains similar sequences of contracts in `Method1`, `Method2`, and `Method3`:

```

public class MyClass {
    public int State { get; }
    public int Data { get; }

    public void Method1(...) {
        Contract.Requires( this.State == 0);
        Contract.Ensures( this.State == Contract.OldValue(this.State));
        Contract.Ensures( this.Data == Contract.OldValue(this.Data));
        ...
    }

    public void Method2(...) {
        Contract.Requires( this.State == 0);
        Contract.Ensures( this.State == Contract.OldValue(this.State));
        Contract.Ensures( this.Data == Contract.OldValue(this.Data));
        ...
    }

    public void Method3(...) {
        Contract.Requires( this.State == 1);
        Contract.Ensures( this.State == Contract.OldValue(this.State));
        Contract.Ensures( this.Data == Contract.OldValue(this.Data));
        ...
    }
}

```

With contract abbreviator methods, the above code can be refactored as follows:

```

public class MyClass {
    public int State { get; }
    public int Data { get; }

    [ContractAbbreviator]
    private void DataAndStateUnchanged() {
        Contract.Ensures( this.State == Contract.OldValue(this.State));
        Contract.Ensures( this.Data == Contract.OldValue(this.Data));
    }

    [ContractAbbreviator]
    private void InStateZeroAndUnchanged() {
        Contract.Requires( this.State == 0);
        DataAndStateUnchanged();
    }

    public void Method1(...) {
        InStateZeroAndUnchanged();
        ...
    }

    public void Method2(...) {
        InStateZeroAndUnchanged();
        ...
    }

    public void Method3(...) {
        Contract.Requires( this.State == 1);
        DataAndStateUnchanged();
    }
}

```

```
} ...  
}
```

As shown in the example, abbreviator methods can abbreviate both **Requires** and **Ensures**, as well as contain calls to other abbreviator methods. At use sites in ordinary methods, they can be combined with any other form of contracts.

The validity of such contracts (in terms of visibility and other well-formedness criteria) is not checked in the context of the abbreviator method, but in the context of where the abbreviator method is eventually used on an ordinary method. Abbreviator methods *cannot* contain calls to contract argument validators (Section 2.11).

3 Contract Inheritance

Contracts are inherited along the same subtyping relation that the type system enforces. That is, a variable of static type **T** might have a value at runtime of type **U** where **U** is a subtype of **T**. The type system guarantees that any operation you perform on the variable that is type-correct for a value of type **T** will still be type-correct when the runtime value has a type of **U**. Contracts should behave in the same way: this is called *behavioral subtyping*.

Enforcing behavioral subtyping has the consequence that certain contracts are not allowed. For instance, suppose a method **T.M** has a precondition. If a client makes sure that they have satisfied the precondition and has a variable **o** whose static type is **T**, then the client should not get a precondition violation when they call **o.M**. This needs to be true even if the runtime value **o** has type **U**. Therefore, the method **U.M** cannot add a precondition that is *stronger* than the precondition of **T.M**. While we could allow a *weaker* precondition, we have found that the complications of doing so outweigh the benefits. We just haven't seen any compelling examples where weakening the precondition is useful. So we do not allow adding any preconditions at all in a subtype. Two important things to note:

- An interface implementation is a subtype of that interface, so this applies not just to classes which extend other classes, but also to interface implementations (implicit and explicit ones).
- Not having a precondition at all is equivalent to having one with the condition **true**, so if a supertype or interface method does not list a precondition, then it is still not allowed to add one.

As a consequence, method preconditions must be declared on the root method of an inheritance/implementation chain, i.e., the first virtual or abstract method declaration, or the interface method itself.

This problem doesn't come up for postconditions: having a stronger postcondition just gives clients more guarantees than they had before. Therefore, we allow subtypes to add postconditions which are just conjoined (i.e., "and-ed") with any existing postconditions. Object invariants also are inherited: any additional invariants are just added as additional constraints that are enforced on the type where they are declared and any subtypes.

3.1 Custom Parameter Validation and Inheritance

Custom parameter validation code in your assembly—ie., legacy requires (Section 2.1.1) or validator methods (Section 2.11)—are not inherited if your assembly mode is set to **Custom Parameter Validation** (Section 5.1.1). This mode is used when you do not use the contract rewriter on your release build. In that case, parameter validation on overriding methods cannot be inserted by our tools and you will likely do so by hand. Thus, it makes little sense for the tools to inherit them in builds where you run the contract rewriter.

Regular **Requires** are inherited normally in every usage scenario where the contract rewriter is used.

3.2 Inheriting from Multiple Methods

If a method has multiple root methods (overrides a method and at the same time implements an interface method (or implements two different interface methods)), then the effective precondition of the implementing method would be the conjunction of the preconditions of all root methods. Since this may be a stronger precondition than the precondition of any of the root methods, this is not allowed.

The contract tools cannot easily determine whether the preconditions of all root methods are equivalent, thus they emit a warning in situations where there are multiple root methods and at least one has a precondition.

3.3 Purity and Inheritance

Purity (Section 5.4) is also inherited. Once a method is pure, all of its overrides/implementations must be pure as well.

3.4 Object Invariants and Inheritance

Object invariants can be added in every subclass and they are conjoined with the base class invariants. The base class invariants are enforced at runtime automatically, provided the assembly containing the base class also has contract runtime checking enabled. Thus, you should *not* invoke the base class invariant method from your own code.

4 Contract Attributes

4.1 ContractClass and ContractClassFor

For interfaces and abstract types, contracts are written in a separate class (Section 2.8). The `ContractClass` attribute is added to the interface (or abstract type) to point to that separate class.

```
[ContractClass(typeof(ContractForJ))]  
interface J { ... }
```

The `ContractClassFor` attribute is used to provide the backwards link from a class that holds the contracts for an interface or abstract type to the interface or abstract type.

```
[ContractClassFor(typeof(J))]  
class ContractForJ : J { ... }
```

4.2 ContractInvariantMethod

This attribute is used to mark methods that contain object invariant specifications. The methods marked with this attribute must be nullary methods with void return types and contain nothing other than calls to `Contract.Invariant` (Section 2.3).

4.3 Pure

The attribute `[Pure]` may appear on methods and declares the programmer's intent that the method has no visible side-effects for callers. Methods are allowed in contracts only if they are declared pure. See Section 5.4 for an explanation of when you need to use this attribute.

In addition to methods `[Pure]` can appear on delegate type declarations to specify that all instances of this delegate type are considered side-effect free. Some existing delegates are considered pure, such as `System.Predicate<T>` and `System.Comparison<T>`.

4.4 RuntimeContracts

This assembly-level attribute is added to assemblies by the contract rewriter to flag that an assembly has already been rewritten.

4.5 ContractPublicPropertyName

This attribute is used on a field to allow it to be used in a method contract where the method is more visible than the field, e.g., a private field and a public method. This is used to be exempt from the Visibility rules (Section 5.5).

```
[ContractPublicPropertyName("PublicProperty")]  
private int _internal ;  
public int PublicProperty { get { ... } }
```

The argument to the attribute is the string name of a corresponding property. The type of the field should be assignable to the type of the corresponding property, but that is currently not checked. However, an error will result if a property with the indicated name cannot be found.

4.6 ContractVerification

This attribute is used to instruct downstream tools whether to assume the correctness of the assembly, type or member it decorates without performing any verification or not. You can use [**ContractVerification (false)**] to explicitly mark an assembly, type or member as one to not have verification performed on it. The most specific element found (member, type, parent type, then assembly) takes precedence. (That is a useful feature for turning off verification for an assembly but enabling it for one particular type in the assembly.) When it is applied to a type, then it applies to all members of the type, including nested types. When it is applied to an assembly, then it applies to all types and members of the assembly. When it is applied to a property, then it applies to both the getter and setter.

4.7 ContractRuntimeIgnored

This attribute can be placed on pure methods and properties. If a method or property is used inside a contract and the method is annotated with the [ContractRuntimeIgnored] attribute, then the entire contract in which it appears is omitted from runtime checking.

Note: Uses of [ContractRuntimeIgnored] annotated methods within **Contract.Assert** and **Contract.Assume** are not currently recognized.

4.8 ContractOption

Important: the **ContractOptionAttribute** type is not defined in **mscorlib.dll** 4.0. In order to use this feature, please add the file **ContractExtensions.cs** or **ContractExtensions.vb** to all of your projects that want to use the attribute.

These files are found in %ProgramFiles%\Microsoft\Contracts\Languages\....

The **ContractOptionAttribute** takes a category string, a settings string, and a settings value, which is either a boolean or a string. Currently, the following settings are supported:

Category	Setting	Usage	Value/Effect
"contract"	"inheritance"	assembly, types, methods	true: contract inheritance (default). false: contract inheritance is suppressed Note: this option affect both runtime and static contract checking.
"runtime"	"checking"	assembly, types, methods	true: contract checking on (default). false: contract checks omitted. Note: all checks recognized by contracts are omitted, even legacy requires.

5 Usage Guidelines

5.1 Argument Validation and Contracts

Before you start using contracts in your own code, you need to make a few decisions that influence what contract forms to use for argument validation and where (see Figure 2). Note that you can make these decisions independently for each managed assembly you produce (each project):

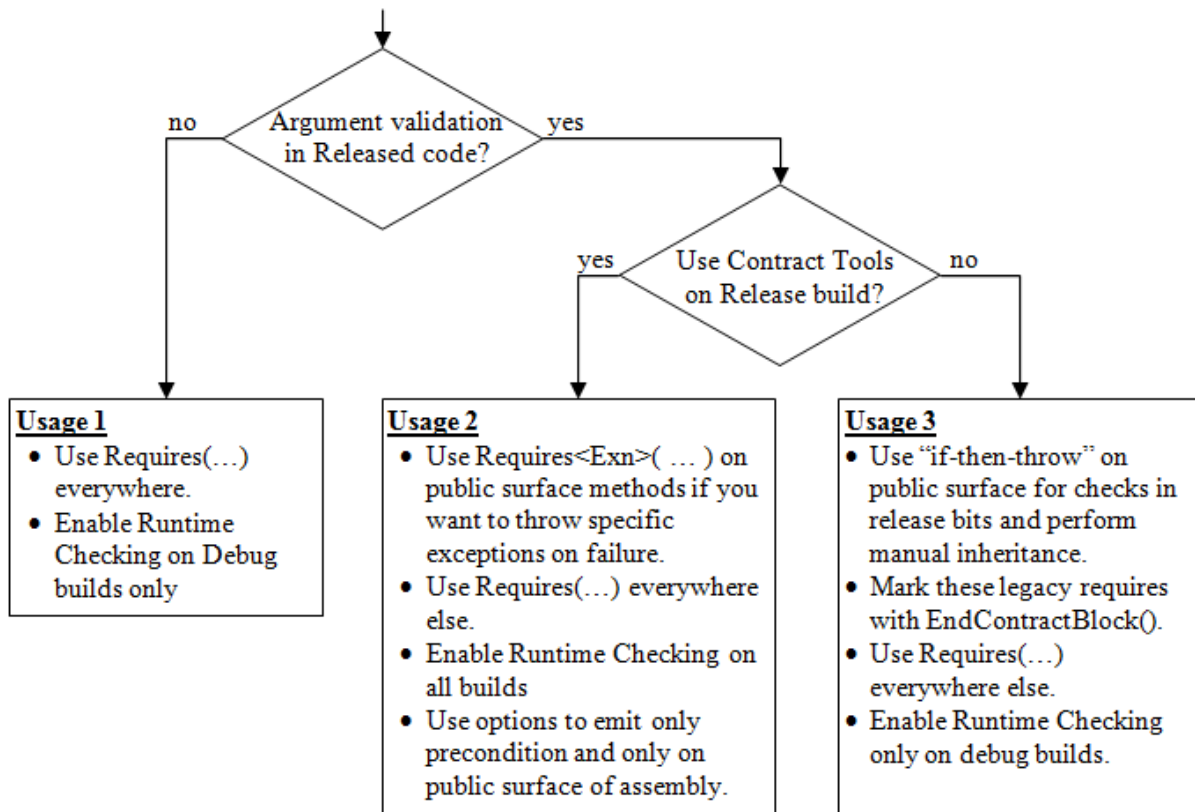


Figure 2: How to Perform Argument Validation

The easiest use of the contract tools is if you decide that you don't need to perform argument validation at runtime in release builds (Usage 1). In that case, you use the contract tools during development, but not on the shipped bits. Remember, you can ship a contract reference assembly along with your release bits so

clients can get runtime checking of your parameter validations on their debug builds via call-site requires checking.

The second easiest approach if you need argument validation in your release build is to turn on contract checking in all builds (Usage 2). You therefore take advantage of the tools to produce the runtime strings of your conditions and to perform contract inheritance for you. You can choose to produce specific exceptions for your parameter validations, or have the default `ContractException`. The risk of using the contract tools in your release build is that you depend on tools that have not reached production quality level.

The trickiest combination is when you want argument validation in release builds, but you are using the contract tool for runtime checking only in debug builds, but not in the release build (Usage 3). In that case, you have to continue writing your argument validation the way you already do, namely using if-then-throw statements (we call them legacy-requires). If you want these to be tool discoverable, add other contracts (such as `Ensures`) after them, or use `Contract.EndContractBlock()`, if no other contracts are present. Note that since you are not using the runtime checking tools in the release build, you are not going to get any inheritance of contracts and you have to manually repeat your legacy-requires on overrides and interface implementations. For interface and abstract methods, you still get the most benefit if you write contract classes with normal requires and ensures forms so you get checking in your debug builds and they appear in contract reference assemblies and are thus visible to dependent projects and to static checkers.

5.1.1 Assembly Mode

The contract tools need to know which usage mode you choose. If you use VisualStudio, select the **Assembly Mode** on the contract property pane as follows:

- Usage 1 or 2: Standard Contract Requires
- Usage 3: Custom Parameter Validation

This permits the tools to emit proper warnings when you violate the usage guidelines. If you use the tools from the command-line, pass the proper argument for the `-assemblyMode` option.

5.1.2 Difference between `Requires<Exn>` and if-then-throw

The difference between these two forms is whether we rely on tools to perform inheritance of contracts or whether programmers manually inherit them as in existing practice. `Requires<Exn>(...)` is intended to be used with tool support, meaning that they are inherited in all builds and the message strings are generated automatically to include the failing condition. Well-formedness checks of contracts do not allow specifying `Requires<Exn>` on overrides or interface implementations.

On the other hand, legacy-requires (if-then-throw) try to capture existing practice for release builds, while providing some extra support for Debug builds using the tools. In Debug builds with contract tool support, on failure of legacy-requires the contract failure hook is called. This provides the ability to detect otherwise silent failures (due to catches) in debug builds.

5.1.3 Forcing Projects to build with Contracts

If you are using scenario 2 (`Requires<Exn>`) and you make your source code available to other developers, you might want to alert them that they need to use the tools to build your source. If so, you can insert the following snippet into your project file at the end (after the import of the CSharp or VisualBasic targets):

```
<PropertyGroup>
  <CompileDependsOn>$(CompileDependsOn);CheckForCodeContracts</CompileDependsOn>
</PropertyGroup>
<Target Name="CheckForCodeContracts"
  Condition="'$(CodeContractsImported)' != 'true'">
  <Error Text="Project requires Code Contracts http://msdn.microsoft.com/en-us/devlabs/dd491992.aspx" />
</Target>
```

5.2 Migrating Projects towards Contracts

Likely, you have an existing project and you would like to start using contracts with minimal changes. If after reading Section 5.1 you determine that your project falls into usage mode 1 or 2, you don't really have a migration task to do. This section thus assumes that your project falls into usage 3, namely that it contains explicit parameter validation code throwing exceptions, that you want to ship such validation code in your release, and that the contract rewriting tool will *not* be used in your release build.

The goal of migration is to mark your existing argument validation code so that the contract tools can recognize it. Once you have made your validations recognizable, you can start to take advantage of the tools as follows:

- You can use documentation generation to augment doc-xml files with contracts and produce documentation that includes explicit descriptions of your preconditions and other contracts (Section 8).
- In your test/debug builds, you can enable the runtime contract checker to find inconsistencies in your validation code (e.g., forgetting to validate parameters in overrides or interface implementations)

5.2.1 Marking Existing Validation Code as Contracts

In methods containing argument validation code in the form of **if-then-throw** statements, you should place a `Contract.EndContractBlock()` call after the last such statement as described in Section 2.1.1.

If your code uses helper methods to validate contracts, mark these methods with a `ContractArgumentValidator` attribute as described in Section 2.11.

5.2.2 Issues with Early Return

Sometimes, you have existing code as follows:

```
void MyMethod(string data) {  
    if (data == null) return;  
    if (data.Length == 0) throw new ArgumentException(...);  
    ...  
}
```

If you add an `EndContractBlock()` marker after the if-then-throw statement, the contract tools will complain about the return statement found in the contract section. In order to fix this, you have to move the return after the parameter validation check, while at the same time weakening the parameter validation to allow for `data` to be `null`:

```
void MyMethod(string data) {  
    if (data != null && data.Length == 0) throw new ArgumentException(...);  
    Contract.EndContractBlock();  
    if (data == null) return;  
    ...  
}
```

This transformation makes the effective precondition explicit, which is that either `data` is `null`, or `data.Length` is greater than 0: `Contract.Requires<ArgumentException>(data == null || data.Length > 0)`.

5.2.3 Delegating Checks to Other Methods

Suppose you have a code pattern similar to the following code:

```
public class Base {  
    public virtual void Compute(string data) {  
        if (data == null) throw new ArgumentNullException(...);  
        Contract.EndContractBlock();  
        ...  
    }  
}
```

```

}

public class Derived : Base {
    public override void Compute(string data) {
        base.Compute(data);
        ...
    }
}

```

Then the tools will issue warning CC1055 with a message of the form:

Method 'Derived.Compute' should contain custom argument validation for 'Requires<ArgumentNullException>(data != null)' as it overrides 'Base.Compute' which suggests it does.

In this situation, the warning is not helpful, as the implementation of `Derived.Compute` delegates the parameter validation to another method (in this case the base method). To avoid the warning in this situation without repeating the validation, you can add a `SuppressMessage` attribute to the method:

```

public class Derived : Base {
    [SuppressMessage("Microsoft.Contracts", "CC1055", Justification = "Validation performed in base method")]
    public override void Compute(string data) {
        base.Compute(data);
        ...
    }
}

```

5.2.4 Writing Interface Contracts

You can specify interface contracts as explained in Section 2.8. On interfaces you don't need to use the if-then-throw form of contracts, as they are never executed directly. Instead, you can use `Requires<Exception> (...)` on interfaces. In builds where you enable the tools, they make sure that each implementation of the interface has validation code (Note: the tools currently don't check that the validation code is equivalent, only that you have any validation at all).

If you use `Requires (...)` on interface methods, these preconditions will be enforced at runtime only in builds where you enable runtime checking. Unlike for `Requires<Exception> (...)`, the inheritance of `Requires (...)` onto each implementation is done by the tools and you don't need to repeat them.

5.2.5 Going Further

When you get to the point that you have marked existing validation as contracts, and you get a clean build and test run of a debug build with runtime checking enabled, you are ready to write more contracts that are enforced in your debug/test runs.

You can add invariant methods to enforce data integrity (Section 2.3) and you can write `Contract.Requires` for additional preconditions (Section 2.1) and `Contract.Ensures` for postconditions (Section 2.2). These checks are enforced in your testing builds with runtime checking enabled, but disappear from your shipping code.

Once you feel comfortable writing contracts and understand what they do, you may want to start using the static contract checker. Please read Section 6.6 before embarking on this adventure.

5.3 Contract Ordering

Method contracts should be written with the different elements ordered as follows:

If-then-throw	Backward-compatible public preconditions
Requires, Requires(E)	All public preconditions
Ensures	All public (normal) postconditions
EnsuresOnThrow	All public exceptional postconditions
Ensures	All private/internal (normal) postconditions
EnsuresOnThrow	All private/internal exceptional postconditions
EndContractBlock	If using if-then-throw-style preconditions without any other contracts, place a call to <code>EndContractBlock</code> to indicate all previous if checks are preconditions.

5.4 Purity

All methods called within a contract must be pure: that is, they must not update any pre-existing state. (A pure method is allowed to modify objects that have been created after entry into the pure method.) Code Contract tools currently assume the following things are pure:

- Methods marked `[Pure]` (If a type is marked `[Pure]`, then that applies to all of its methods.) The pure attribute is defined in the contract library. (Section 4.3)
- Property getters.
- Operators (static methods whose names start with `op_`, have one or two parameters and a non-void return type).
- Any method whose fully qualified name begins with `System.Diagnostics.Contracts.Contract`, `System.String`, `System.IO.Path`, or `System.Type`.
- Any invoked delegate, provided that the delegate type itself is attributed with `[Pure]`. The existing delegate types `System.Predicate<T>` and `System.Comparison<T>` are considered pure.

In the future, there will be a purity checker that will enforce these assumptions.

5.5 Visibility

All members mentioned in a contract must be at least as visible as the method in which they appear. For instance, a private field cannot be mentioned in a precondition for a public method: clients wouldn't be able to validate such a contract before they call the method. However, if the field is marked with the `ContractPublicPropertyName` attribute (Section 4.5), then it is exempt from these rules.

5.6 Special Method Usage

Special methods such as `Contract.Result<T>` can only appear in `Ensures` contracts and type `T` must agree with the method return type.

6 Visual Studio Integration

When the managed contracts plugin is installed, C# and VB projects within Visual Studio are augmented with an extra property pane entitled "Code Contracts", as shown in Figure 3. This pane provides configuration specific options for enabling runtime contract checking, as well as static contract checking.

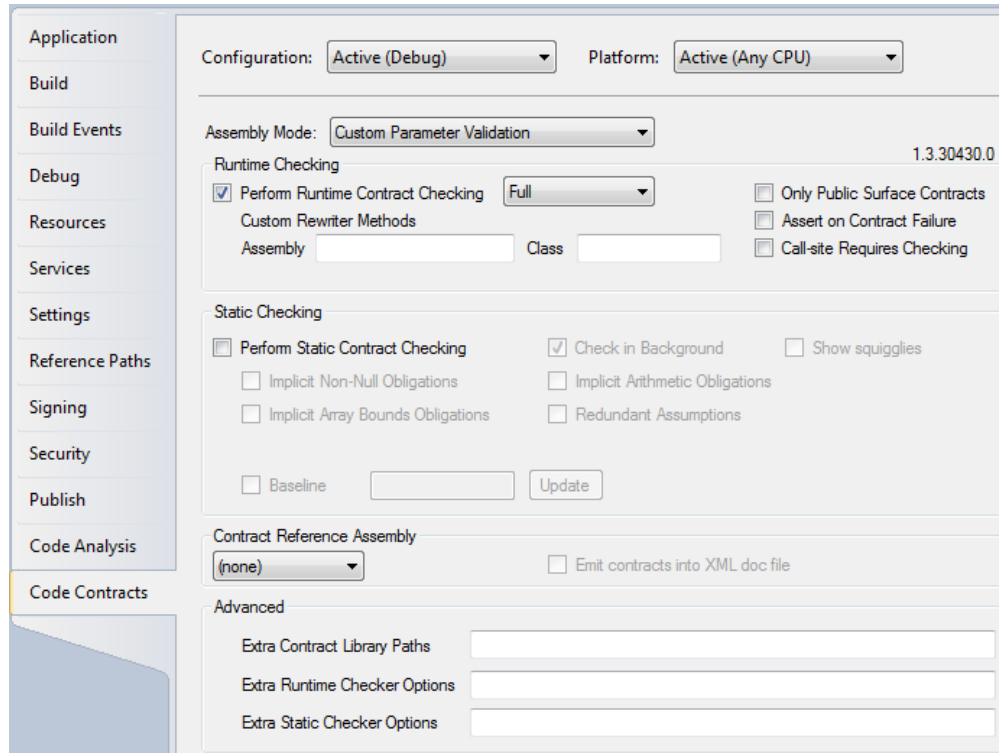


Figure 3: Contract Property Pane in Visual Studio

If you are using contracts with a target platform of 4.0 or later and you are referencing (implicitly) `mscorlib.dll`, then the `Contract` class appears in the `System.Diagnostics.Contracts` namespace. If you are using a pre-4.0 target platform, you need to add a reference to the `Microsoft.Contracts.dll` library. The library should appear under the `.NET` tab when adding project references.

6.1 Assembly Mode

Use the assembly mode selection on the UI to indicate to the tools what usage mode (Section 5.1) you want for the present project:

6.1.1 Custom Parameter Validation

Select this mode if your project falls into usage 3 (Section 5.1), i.e., you want to check parameter validation in your released version of the code *and* you *don't run the contract rewriter* on your release bits.

In this mode, you can use legacy if-then-throw statements and `[ContractArgumentValidator]` methods to express parameter validation code that you want the contract tools to recognize. You have to manually perform inheritance of such validation code and the tools warn you if it sees overrides/implementations where such validation appears to be missing. You can use ordinary `Requires(condition)` for debug only preconditions. These will be inherited automatically, but only appear in builds where you enable the contract rewriter.

In this mode, you are not allowed to use the `Requires<Exn>` form, except on contract classes for interfaces and abstract types. If you do, the tools will issue an error.

6.1.2 Standard Contract Requires

Select this mode if your project falls into usage 1 or 2 (Section 5.1), i.e., you either don't want parameter validation in your released code, or you run the contract rewriter on your released code.

In this mode, you are not allowed to use legacy if-then-throw blocks marked as contracts with `EndContractBlock` or `[ContractArgumentValidator]` methods. The tools will emit errors if you do.

6.2 Runtime Contract Checking

We suggest using either a standard `Debug` (or `Checked`) configuration or a custom configuration to use runtime contract checking. The benefit of a custom configuration is to allow separate testing of potentially expensive contract checks without affecting existing test runs with stricter timing constraints.

To enable runtime contract checking in a particular configuration, select the configuration and check the box for runtime contract checking. We also recommend you select **Build** to build a contract reference assembly (see Section 6.5).

6.2.1 Runtime Checking Level

The drop-down menu to the right let's you select the level of runtime contract checking. The enabled contract checks depending on the level are listed in the table below:

Checking Level	Enabled Runtime Checks						
	Legacy	Requires⟨E⟩	Requires	Ensures	Invariants	Asserts	Assumes
Full	X	X	X	X	X	X	X
Pre and Post	X	X	X	X			
Preconditions	X	X	X				
ReleaseRequires	X	X					
None							

By “Legacy”, we mean any if-then-throw blocks preceding any `Contract.*` methods, which are therefore recognized as declarations of preconditions.

Note that when level “None” is selected, all contracts are erased, including “Legacy requires”. This level is useful mainly for doing benchmarking without any contracts.

6.2.2 Public Surface Contract Checks

In addition to the level, the checkbox *Only Public Surface Contracts* can be used to erase all contracts on methods that are not callable from outside the assembly (even via interfaces).

Warning: if you create a delegate from a method that is not visible from outside the assembly and the delegate itself will be callable from outside the assembly, then any parameter validation on this method will not trigger with this box checked.

Warning: if you *delay* parameter validation on a method callable from outside by having it call a method not callable from outside the assembly that performs the validation, then you will get *no validation* with this box checked, as the validation on the non-visible method is erased.

6.2.3 Assert on Contract Failure

When this box is checked (default), all contract failures, including `Requires⟨E⟩` and legacy requires (marked if-then-throws) trigger the default failure behavior of the contract library, which is to display an assert dialog. Clearing this box will instead generate code that throws exceptions on failure. See Section 7 for details.

6.2.4 Call-site Requires Checking

When building a project *A* with call-site requires checking on, the rewriter will determine at each call-site within *A* if the call “potentially” calls a method defined in another assembly. In that case, the rewriter will insert the **Requires** checks for the called method at the call-site within assembly *A* (actually, we use wrapper methods to avoid duplicating the checks). Of course, in order for this to work, the contracts for the called method need to be known, which will require contract reference assemblies *B*.codeContracts, if the method is defined in assembly *B*.

Some **Requires** checks are not currently instrumented at call-sites:

- Requires of constructors
- Requires of protected methods

Call-site requires checking enables a library writer to produce a library *B* without runtime **Requires** checks (e.g., for performance reasons), while providing the **Requires** separately in a contract reference assembly *B.Contracts*. A developer of a project *A* referencing *B* and using call-site requires checking will have parameter validations checked for methods in *B*, regardless of whether *B* is actually instrumented with checks or not.

6.2.5 Build Steps

When runtime contract checking is enabled, a build will perform the following actions in addition to the regular compile:

- It determines the availability of contract reference assemblies for all referenced projects and warns if they are missing (Section 6.5).
- It applies the contract rewriter `crewrite` to the target assembly, performing well-formedness checks on the contracts, instrumenting contract runtime checks into the appropriate places, including contract inheritance (Section 7).

6.2.6 Extra Options

The boxes labeled *custom rewriter methods* can be used to customize the runtime behavior for contract failure by specifying an assembly (relative to the project output directory) and the full namespace path to the type containing the custom failure behavior (see Section 7). The specified assembly may be the project output itself.

Under the *advanced* options, extra library paths (semi-colon separated) can be specified for finding contract reference assemblies. Extra runtime checker and static checker command line options can be specified there as well.

6.2.7 Suppressing Warnings

You can suppress warnings you get from the tools by adding **SuppressMessage** attributes to methods. For example, to suppress a warning CC1055 about missing validation on a method, add the following attribute:

```
[SuppressMessage("Microsoft.Contracts", "CC1055", Justification="Check performed in DelegateTo")]  
public override void Compute(string s) {  
    DelegateTo(s);  
}
```

In general, to suppress any warning, use the above pattern with the appropriate error number you want to suppress. The error number should be visible in the output window if it is not included in the message on the Error List window.

You can place **SuppressMessage** attributes on types and properties in addition to methods. In that case, the suppression applies to the entire scope of the type or property.

6.3 C# Code Snippets

The installer adds a number of C# code snippets that are useful for authoring code contracts. Each snippet in the table below is invoked by typing the 2-3 character shortcut and hitting TAB TAB (tab twice).

cr	<code>Contract.Requires(...);</code>
ce	<code>Contract.Ensures(...);</code>
ci	<code>Contract.Invariant(...);</code>
crr	<code>Contract.Result<...>()</code>
co	<code>Contract.OldValue(...)</code>
cim	<code>[ContractInvariantMethod] private ObjectInvariant() { Contract.Invariant(...); }</code>
crn	<code>Contract.Requires(... != null);</code>
cen	<code>Contract.Ensures(Contracts.Result<...>() != null);</code>
crsn	<code>Contract.Requires(!String.IsNullOrEmpty(...));</code>
cesn	<code>Contract.Ensures(!String.IsNullOrEmpty(Contracts.Result<string>()));</code>
cca	<code>Contract.Assert(...);</code>
cam	<code>Contract.Assume(...);</code>
cre	<code>Contract.Requires(E)(...);</code>
cren	<code>Contract.Requires<ArgumentNullException>(... != null);</code>
cresn	<code>Contract.Requires<ArgumentException>(!String.IsNullOrEmpty(...));</code>
cintf	expands to an interface template and associated contract class

6.4 VB Code Snippets

The installer also adds Visual Basic code snippets similar to the ones for C#. Each snippet in the table below is invoked by typing the shortcut and hitting TAB (tab once).

creq	<code>Contract.Requires(...)</code>
cens	<code>Contract.Ensures(...)</code>
cinv	<code>Contract.Invariant(...)</code>
crr	<code>Contract.Result(Of ...)()</code>
cold	<code>Contract.OldValue(...)</code>
cim	<code><ContractInvariantMethod()> _ Private Sub ObjectInvariant() Contract.Invariant(...) End Sub</code>
crn	<code>Contract.Requires(... IsNot Nothing)</code>
cen	<code>Contract.Ensures(Contracts.Result(Of ...)() IsNot Nothing)</code>
crsn	<code>Contract.Requires(Not String.IsNullOrEmpty(...))</code>
cesn	<code>Contract.Ensures(Not String.IsNullOrEmpty(Contracts.Result(Of string)()))</code>
cca	<code>Contract.Assert(...)</code>
cam	<code>Contract.Assume(...)</code>
cre	<code>Contract.Requires(Of Exc)(...)</code>
cren	<code>Contract.Requires(Of ArgumentNullException)(... NotIs Nothing)</code>
cresn	<code>Contract.Requires(Of ArgumentException)(Not String.IsNullOrEmpty(...))</code>
cintf	expands to an interface template and associated contract class

6.5 Building a Contract Reference Assembly

Note change from previous behavior: Contract reference assemblies are not longer built automatically for all dependee projects of a project.

If your project contains contracts and is referenced by other projects, we strongly recommend that you select **Build** under the contract reference assembly section in the properties tab for CodeContracts.

The contract reference assembly for an assembly named A will be called A.Contracts.dll and appears in the project output directory. It can be distributed along with your assembly so other developers can take advantage of the contracts for your project.

This contract reference assembly is crucial to make the contracts in your project available to referencing projects. Without building a contract reference assembly, other projects cannot determine what contracts are present.

The drop down for building contract reference assemblies has three selections: (none), Build, and DoNotBuild. The behavior of these selections is described below:

- **(none)**: this is the default setting when you haven't made an explicit choice yet. If another project requires the contracts of this project, the build will warn you that no contract reference assembly was found. To get rid of this build warning, select either **Build** or **DoNotBuild**.
- **Build**: this is the recommended setting when your project has contracts. It will produce an assembly called A.Contracts.dll in the output directory of project A. It makes the contracts of A visible to other projects.
- **DoNotBuild**: this setting is recommended if this project does not contain contracts, or there are problems building the contract reference assembly. With this setting, the build warning about missing the contract reference assembly produced when other projects reference this project, will disappear.

For a description of the command line tool to build contract reference assemblies, see Section A.4.

6.6 Static Contract Checking

First, a word of caution: Static code checking or verification is a difficult endeavor. It requires a relatively large effort in terms of writing contracts, determining why a particular property cannot be proven, and finding a way to help the checker see the light.

Before you start using the static contract checker in earnest, we suggest you spend enough time using contracts for runtime checking to familiarize yourself with contracts and the benefits they bring in that domain.

6.6.1 Current Limitations of the Checker and Bugs

Below is a list of known bugs or unimplemented features in the static contract checker:

Known Bugs

- Invariants on structs are ignored.

Known Limitations

- The static contract checker does not yet deal with quantifiers **ForAll** or **Exists**.
- C# iterators: when writing iterators using the C# `yield` support, the generated code puts the contracts you may have written on the iterator into the `MoveNext` method. At the moment, the static contract checker will not be able to prove those preconditions properly. See Section 11.3 for a work-around.

6.6.2 Setting Up a Configuration

If you are still determined to go ahead with contracts, we suggest you create a separate configuration, e.g., `CodeAnalysis`—based on your `Debug` configuration—and enable static checking for that configuration. This avoids slowing down regular build flavors.

To enable static checking, check the box titled *Perform Static Contract Checking*. If static checking is enabled, a build performs the following steps:

- It builds an alternate target for the project with `CONTRACTS.FULL` symbol defined. The target is called `X.decl.dll` where `X` is the regular assembly name of the project.
- It runs the static verifier on `X.decl.dll` and displays warnings in the output and task windows.

By default, the static verification tries to prove all explicit contracts in the code under analysis (assertions, invariants, requires, and ensures), as well as requires of methods called in other assemblies, and inherited ensures and object invariants on classes extending base classes and interfaces in other assemblies.

The check box *Implicit Non-Null Obligations* enables additional checks, which warn about potential inappropriate uses of `null` in the code under analysis. Similarly, the check box *Implicit Array Bounds Obligations* causes the verifier to try to validate the following:

- Array accesses are within bounds of the array (lower and upper).
- Array creation uses a non-negative size.

We suggest you do *not* enable the implicit checks initially, as they easily lead to too many warnings if you enable the checking on an existing code base. For a new code base, feel free to enable them initially.

6.6.3 Focus Your Attention

As mentioned in the introduction, static verification is difficult and at times overwhelming. To not get lost in a sea of warnings, we suggest you focus the static contract checker on a small part of your code and drill down in that area. To do so, use the attribute

```
[assembly: ContractVerification ( false )]
```

in your assembly. This attribute at the assembly level turns off contract checking by default. Now you can focus the static contract checker on individual methods or individual types by adding the attribute

```
[ ContractVerification ( true )]
```

to a class, struct, or individual method. The attribute changes the default for the sub-tree of code it appears on. This means you can switch the default multiple times, e.g., if enabled on a particular type, you can disable it again for a nested class or individual methods.

Once you are happy with the contract checking in the small set of methods you focused on, you can grow the set incrementally. Note that you may need to write contracts on methods *called* from your set of checked methods, even if the called methods themselves are not in your focus set.

6.6.4 Dealing with Warnings

When the static verifier issues a warning about a particular contract or implicit proof obligation, it doesn't necessarily indicate an error in the code. Warnings are issued whenever the checker is *unable to prove* that the contract holds on all executions under the assumptions provided by the contracts on all other methods.

If the verifier emits a warning that the programmer deems unwarranted, it is possible for the programmer to make this explicit in a number of ways. Most often, it is possible to add a `requires` to the method where the warning occurs to make some assumption between callers and the method explicit. For example, if the method uses a parameter `p` without checking for `null`, the method wants to assume that callers never pass `null`. In order for the verifier to understand this, add a precondition of the form:

```
Contract.Requires( p != null );
```

If the warning concerns internal object state of fields that might not be visible to all callers of the method, then this might indicate the need for an object invariant. For example, if a field `f` is assumed to be non-null at all times, an object invariant should be added:

```
[InvariantMethod]
private void ObjectInvariant () {
    Contract.Invariant ( f != null );
}
```

This invariant is now assumed on all method entries of this class, and it is checked on all method exits, and in addition on exit of all constructors.

Alternatively, it might be that the method where the warning is emitted obtains a value as a result from a call to another method `M` and uses it without checking for null. Again, the method assumes that the result of `M` is non-null given the particular parameters. This can be made explicit by adding a contract to `M` of the form:

```
Contract.Ensures( Contract.Result<T>() != null );
```

where `T` is the return type of `M`. If the method returns non-null only provided certain properties hold of the parameters, that can be made explicit as well by using a disjunction in the ensures. For example, method `M` might return null if a parameter `p` is null, otherwise it returns non-null. This is expressed as follows:

```
Contract.Ensures( p == null || Contract.Result<T>() != null );
```

Another way to read the above disjunction is as an implication: `p != null ==> result != null`.

For some warnings it will either be too complicated to add all the invariants to the code to show why a particular contract should be true, or the verifier might have inherent limitations that prevent it from proving it. In cases where all else fails, it is always possible to add an explicit assumption in the code. For example, if some local `x` is known to be non-null at a given program point, but there is no other way to teach the verifier why this is so, then an explicit `Assume` statement will do the trick:

```
Contract.Assume( x != null );
```

Such assumptions are silently believed by the static verification. However, they are still checked at runtime when using runtime checks. Thus, accidental erroneous assumptions added by programmers can be discovered during testing.

6.6.5 Baseline

Bringing an existing code base to a point where the verifier emits only a few warnings is difficult and time consuming, as it requires adding numerous contracts. To make it easier to use contracts on existing code bases, and to focus warnings introduced by new code or code changes, the *Baseline* functionality can be used.

To use the baseline functionality, check the box labelled *Baseline* and provide a file name to store the baseline in. The path is relative to the project output directory. When the analysis is run and the baseline file does not exist, the baseline is created. During this run, all warnings are shown in the output and stored in the baseline file as XML.

When the analysis is run and the baseline file exists, then the baseline acts as a filter and warnings already found in the baseline are not shown again. New warnings are shown and stored in a file called `<baseline>.new`, where `<baseline>` is the file name of the baseline file. Since the files are stored as textual XML, it is possible to edit them and to add additional failures to the baseline. The format does not depend on method ordering and additional XML tags for grouping can be introduced freely.

6.6.6 Filtering Warning Messages

If using `Contract.Assume` is ineffective to quiet noise in the static contract checker warnings, a last resort is to turn off certain warnings using the `CodeAnalysis.SuppressMessage` attribute. To instruct the static contract checker not to emit a particular class of warnings for a method (a type, an assembly), annotate the method (the type, the assembly) with the attribute:

```
[System.Diagnostics.CodeAnalysis.SuppressMessage("Microsoft.Contracts", warningFamily)]
```

where `warningFamily` is one of: `Requires`, `Ensures`, `Invariant`, `NonNull`, `ArrayCreation`, `ArrayLowerBound`, `ArrayUpperBound`, `DivByZero`, `MinValueNegation`.

If necessary, the static contract checker allows filtering a single warning message (instead of an entire family) as well. To do so you can annotate a method with the attribute

```
[System.Diagnostics.CodeAnalysis.SuppressMessage("Microsoft.Contracts", warningFamily - ILOffset - MethodILOffset)]
```

where `warningFamily` is as above, and `ILOffset` and `MethodILOffset` are used by the static contract checker to determine the program point the warning refers to. The offsets can be obtained from the static contract checker by providing the `-outputwarnmasks` switch in the “Custom Options” entry in the VS pane. Check the Build Output Window for the necessary information. Code changes to the method or the contract being violated may invalidate the IL offsets and turn the suppression ineffective.

7 Runtime Contract Behavior

The runtime behavior of a contract can be configured at the time the contract rewriter is run and also during program execution.

The basic operation of the contract rewriter is to place runtime checks for contracts at appropriate places. The contracts may come from a variety of places, e.g., via inheritance from contract reference assemblies or other code in the assembly being rewritten.

7.1 Rewriter Methods

Every contract usage is translated to call a particular rewriter method according to the table below:

<code>Requires(cond)</code>	<code>CR.Requires(cond, null, "cond")</code>
<code>Requires(cond, msg)</code>	<code>CR.Requires(cond, msg, "cond")</code>
<code>Ensures(cond)</code>	<code>CR.Ensures(cond, null, "cond")</code>
<code>Ensures(cond,msg)</code>	<code>CR.Ensures(cond, msg, "cond")</code>
<code>EnsuresOnThrow<E>(cond)</code>	<code>CR.EnsuresOnThrow(cond, null, "cond", exn)</code>
<code>EnsuresOnThrow<E>(cond,msg)</code>	<code>CR.EnsuresOnThrow(cond, msg, "cond", exn)</code>
<code>Invariant(cond)</code>	<code>CR.Invariant(cond, null, "cond")</code>
<code>Invariant(cond, msg)</code>	<code>CR.Invariant(cond, msg, "cond")</code>
<code>Assert(cond)</code>	<code>CR.Assert(cond, null, "cond")</code>
<code>Assert(cond, msg)</code>	<code>CR.Assert(cond, msg, "cond")</code>
<code>Assume(cond)</code>	<code>CR.Assume(cond, null, "cond")</code>
<code>Assume(cond, msg)</code>	<code>CR.Assume(cond, msg, "cond")</code>

For contracts that already define their runtime behavior, such as `Requires<E>` and legacy `requires` (if-then-throw), the rewriting depends on a switch to the contract rewriter on whether to assert or throw on failure:

	Assert on failure (default)	Throw on failure
<code>Requires<E>(cond)</code>	<code>CR.Requires(cond, null, "cond")</code>	<code>CR.Requires<E>(cond, null, "cond")</code>
<code>Requires<E>(cond, msg)</code>	<code>CR.Requires(cond, msg, "cond")</code>	<code>CR.Requires<E>(cond, msg, "cond")</code>
(legacy <code>require</code>) if cond then throw	<code>CR.Requires(cond, null, "cond")</code>	if cond then { var m = <code>CR.RaiseContractFailedEvent(...)</code> ; if (m!=null) throw

As you can see, the different overloads are all reduced to calls on 7 distinct methods in a contract runtime class CR:

```
class CR {
    void Requires(bool cond, string userMessage, string condition);
    void Requires<E>(bool cond, string userMessage, string condition);
    void Ensures(bool cond, string userMessage, string condition);
    void EnsuresOnThrow(bool cond, string userMessage, string condition, Exception exn);
    void Invariant(bool cond, string userMessage, string condition);
    void Assert(bool cond, string userMessage, string condition);
    void Assume(bool cond, string userMessage, string condition);
}
```

The exception argument to `EnsuresOnThrow` is the actual caught exception. These runtime contract methods are either generated by the contract rewriter in the generated type `System.Diagnostics.Contracts...ContractsRuntime`, or they can be provided by the programmer as custom rewriter methods to the contract rewriter (see Section 7.7).

In the case where the contract rewriter synthesizes the methods, they all have the following form:

```
void Requires(bool cond, string userMessage, string condition) {
    if (cond) return;
    ReportFailure(ContractFailureKind.Precondition, userMessage, condition, null);
}
```

That is, the methods return if the condition is true. Otherwise, they call `ReportFailure`. The other contract methods are similar. `EnsuresOnThrow` passes the caught exception on to the `ReportFailure` method.

The method that has special pre-defined failure behavior is `Requires<E>`. It looks for a public constructor of the given exception type that takes two string arguments. It then passes the message constructed by user provided by `RaiseContractFailedEvent` and the user provided message to the exception constructor. For the standard `ArgumentException` type, the intention is that the second parameter (the optional user provided message) is the parameter name. Since `ArgumentNullException` takes these parameters in reversed order, the generated code reverses the arguments in that case. If no two argument constructor is found, constructor with a single string argument is tried. If found, it is used to construct the exception passing as a parameter the message constructed by `RaiseContractFailedEvent`.

```
void Requires<E>(bool cond, string userMessage, string condition)
    where E:Exception {
    if (cond) return;
    string str = TestRewriterMethods.RaiseContractFailedEvent(ContractFailureKind.Precondition, message, conditionText, null);
    if (str != null)
    {
        Exception exception = null;
        ConstructorInfo constructor = typeof(TException).GetConstructor(new Type[] { typeof(string), typeof(string) });
        if (constructor != null)
        {
            if (constructor.GetParameters()[0].Name == "paramName")
            {
                exception = constructor.Invoke(new object[] { message, str }) as Exception;
            }
            else
            {
                exception = constructor.Invoke(new object[] { str, message }) as Exception;
            }
        }
    }
    else
    {

```

```

        constructor = typeof(TException).GetConstructor(new Type[] { typeof(string) });
        if (constructor != null)
        {
            exception = constructor.Invoke(new object[] { str }) as Exception;
        }
    }
    if (exception == null)
    {
        throw new ArgumentException(str, message);
    }
    throw exception;
}
}

```

To use `Requires<E>` properly with `ArgumentNullException` or `ArgumentOutOfRangeException`, use the second argument to `Requires` to pass the parameter name:

```

void TestMe(string name, int index) {
    Contract.Requires<ArgumentNullException>(name != null, "name");
    Contract.Requires<ArgumentOutOfRangeException>(index >= 0, "index");
}

```

The `ReportFailure` and `RaiseContractFailedEvent` methods are discussed below.

7.2 ReportFailure Method

The `ReportFailure` method can be provided as part of the custom runtime contract class (Section 7.7). Otherwise the following method is synthesized:

```

void ReportFailure(ContractFailureKind kind, string userMessage,
                  string condition, Exception inner)
{
    var message = RaiseContractFailedEvent(kind, userMessage, condition, inner);
    if (message == null) return; // handled
    TriggerFailure(kind, message, userMessage, condition, inner);
}

```

`ReportFailure` first calls the `RaiseContractFailedEvent` method which returns either null if the failure is handled, or the message string to use when calling `TriggerFailure`.

The two methods called `RaiseContractFailedEvent` and `TriggerFailure` can also be provided by the user in the supplied custom runtime contract class (Section 7.7). Otherwise, the methods from the `Microsoft.Contracts.dll` or `mscorlib.dll` are used.

7.3 RaiseContractFailedEvent

The default implementation of `RaiseContractFailedEvent` in the library is to call each handler registered with the `Contract.ContractFailed` event. Exceptions thrown by handlers are ignored, but each handler can indicate whether the failure is handled by calling `SetHandled()` on the event argument. If any handler sets the failure as handled, the method returns null and no further action is taken.

Alternatively, handlers can call `SetUnwind()` on the event argument to ask the code to unwind. In that case, a `ContractException` is thrown after all handlers have executed.

If a handler throws an exception, it is treated as if it called `SetUnwind`. Additionally, the thrown exception will be used as the inner exception of the `ContractException` thrown after all handlers have executed. When multiple handlers throw, the inner exception used is undetermined.

7.4 TriggerFailure

The default implementation of `TriggerFailure` in the library is to break into the debugger (if attached) or display an assert dialog box.

If the option “assert on contract failure” in the Visual Studio Contract property pane is cleared, or the `/throwonfailure` option is used on the command line, the contract rewriter instead synthesizes an alternative `TriggerFailure` method that throws a `ContractException`. Note that the `ContractException` type is added internally to the assembly being runtime checked.

7.5 Rational for Runtime Behavior

Why, you might ask, is the runtime behavior for contract failure not just to throw an exception?

A lot of discussion has gone into the current design in order to address the following problem with exceptions: *thrown exception can be handled*. This means that in your debugging or test runs, you might actually fail some contracts, but the exception being thrown gets caught and silently swallowed somewhere and nothing ever gets reported about the contract failure. This is particularly annoying in the case where in your Release build, the contract disappears and no exception is thrown, thus resulting in completely different code paths.

It was thus important that our design address this point, namely:

By default, contract failure cannot be masked by catching exceptions.

Thus, without any user intervention, the default behavior of contract failure is to break into the debugger or throw up a dialog box. For hosted or non-interactive environments, the host gets control, or the process is aborted.

Now clearly, throwing up a dialog or taking the process down is not the desired behavior in your release build, test runs, or any non-development environment. That is why we have provided ways to change the default behavior.

First, in a testing environment, we need a way for the test framework to be notified and regain control of the execution when a contract fails. See Section 7.8 for more details on working in testing frameworks.

Second, in your released code, you should never trigger the default failure behavior (which is the assert dialog). This means following the guidelines of Section 5.1.

7.6 ContractException

The `ContractException` type is not a public type and is emitted as a nested private type into each assembly for which runtime contract checking is enabled. It is thus not possible to write catch handlers catching only `ContractException`. Contract exceptions can thus only be handled as part of a general exception backstop. The rational for this design is that programs should not contain control logic that depends on contract failures, just like programs should not catch `ArgumentNullException` or similar validation exceptions.

7.7 Providing a Custom Contract Runtime Class

Using the VS interface, one can specify the contract runtime class and its assembly directly. From the command-line, use the `/rw` option.

The custom runtime class provided can have any combination of the following methods:

```
public static class RuntimeFailureMethods {
    public static void Requires(bool cond, string userMsg, string condText)
    { ... }

    public static void Requires<E>(bool cond, string userMsg, string condText)
        where E : Exception
    { ... }
```

```

public static void Ensures(bool cond, string userMsg, string condText)
{ ... }

public static void EnsuresOnThrow(bool cond, string userMsg, string condText, Exception innerException)
{ ... }

public static void Assert(bool cond, string userMsg, string condText)
{ ... }

public static void Assume(bool cond, string userMsg, string condText)
{ ... }

public static void Invariant(bool cond, string userMsg, string condText)
{ ... }

public static void ReportFailure(ContractFailureKind kind, string userMsg, string condText, Exception inner)
{ ... }

public static string RaiseContractFailedEvent(ContractFailureKind kind, string userMsg, string condText,
                                             Exception inner) { ... }

public static void TriggerFailure(string message, string userMsg, string condText, Exception inner)
{ ... }
}

```

Any omitted methods are synthesized (or the default library methods are used). If you specify all seven kinds of contract methods, then `ReportFailure` and `TriggerFailure` will never be called from any generated code. `RaiseContractFailedEvent` may still be called in the case of legacy-requires.

If you provide a custom contract runtime class, the assembly containing it must be able to be found by the contract rewriter and then deployed with the rewritten assembly when it is executed. To make this easy, you can provide a custom contract runtime class within the assembly being rewritten.

If the class is a nested type, then you must use the three argument form with the option. That is, the option `/rw:A,M.N,C.D.E` will look in the assembly `A` for the nested type `E` within the nested type `D` within the top-level type `C` that is declared in namespace `M.N`. If the class is not nested, then you can use the two argument form: `/rw:A,M.N.C` will look in the assembly `A` for the type `C` that is declared in the namespace `M.N`.

7.8 Test Harness Setup

If you are using test harnesses or test environments to execute unit and regression tests that exercise code with contracts, you probably don't want the default contract failure behavior (which will put up assert dialog boxes).

There are three ways to configure contract behavior for testing:

1. The simplest form is to just clear the “assert on contract failure” box in the UI. Now contract failure results in exceptions, which test harnesses typically deal with. However, this option is not the preferred one, just the simplest, as it will potentially mask contract failures from your tests due to catch blocks in your code.
2. The better way to deal with contract failure in a testing environment is to use the `ContractFailed` event hook to notify the test framework of the failure and to unwind the stack. Unwinding is done via an exception, but even if that is caught unintentionally by the surrounding code, the failure will have been recorded.

For the Microsoft `mstest` framework, the code below in your test assembly will have the effect of turning contract failure into test failure:

```
[TestClass]
public class Test
{
    [ AssemblyInitialize ]
    public static void AssemblyInitialize (TestContext tc)
    {
        Contract.ContractFailed += (sender, e) => {
            e.SetUnwind(); // cause code to abort after event
            Assert.Fail(e.FailureKind.ToString() + ":" + e.DebugMessage);
        };
    }
}
```

One complication arises in VS2010 where test projects are always built against .NET 4.0. If your code under test is built against v3.5 (or earlier) and you reference `Microsoft.Contracts.dll` from your code under test, then the above event hook registers with the wrong hook, namely the one in .NET 4.0, instead of the one used by your code under test.

To solve this, your test project needs to reference `Microsoft.Contracts.dll` (the version for .NET v3.5). To avoid namespace ambiguity, change the `alias` property on the reference from `global` to something like `Contracts`. Now in your test project, you can reference the v3.5 contract library via the following C#:

```
extern alias Contracts; // this must be the name you used in the Aliases property of the reference
```

```
using Contracts::System.Diagnostics.Contracts; // instead of System.Diagnostics.Contracts
```

Using the `Contracts::System.Diagnostics.Contracts` namespace now refers to the v3.5 version of the contracts instead of the .NET 4.0 version and thus the event hook used should be the desired one that matches the one in your code under test.

3. Finally, by providing your own runtime contract class (Section 7.7), you can customize the behavior even further. For example, you can provide runtime contract methods that throw your own particular exceptions for contract failures.

7.9 Tests that Exercise Contract Failure

If you write tests that exercise contract failures, you should be careful. First off, are you writing any tests that intentionally exercise `Debug.Assert` failures? I didn't think so. In general, the same reasoning applies to contract failures: don't exercise them in your tests.

There is only one situation where exercising contract failures as part of regular testing is advised: if you use requires contracts for parameter validation that *are enabled in your release bits*, then you may want to test for that, in particular if you use specific exceptions to report argument validation failures (and not the internal `ContractException`).

In that situation, your test will be expecting a particular exception (other than `ContractException`), and thus the unit test framework mechanism for expected exceptions can be used nicely.

8 Contract Documentation Generation

The `ccdocgen` tool shipping with the CodeContract installer augments an existing `A.xml` doc file with XML elements describing the contracts present in the code of an assembly `A`. The original `A.xml` is produced by

C# and VisualBasic compilers from documentation comments in the code when the appropriate compilation option is used (`/doc: file`).

8.1 Contract XML Format

Contract information may appear in the existing XML doc file in the following places:

- In method elements that are neither getters, setters, nor compiler generated
- In type elements
- In property elements: Here, two sub elements are introduced when present in the code called **getter** and **setter** under which the respective contracts appear.

8.1.1 Contract Elements

requires elements may appear under method elements, property getters, and property setters. The element body is the string of the original precondition. The following attributes may optionally appear:

- **description** is the optional user provided description string of the contract.
- **inheritedFrom** is the full documentation id for the method the contract was inherited from.
- **exception** is the full documentation id for the exception type being thrown if the requires is violated.

ensures elements may appear under method elements, property getters, and property setters. The element body is the string of the original postcondition. The following attributes may optionally appear:

- **description** is the optional user provided description string of the contract.
- **inheritedFrom** is the full documentation id for the method the contract was inherited from.

ensuresOnThrow elements may appear under method elements, property getters, and property setters. The element body is the string of the original exceptional postcondition. The following attributes may optionally appear:

- **description** is the optional user provided description string of the contract.
- **inheritedFrom** is the full documentation id for the method the contract was inherited from.
- **exception** is the full documentation id for the type of thrown exceptions for which the exceptional postcondition holds.

pure elements may appear under methods marking them as pure. No additional information is present.

invariant elements may appear under classes. The element body is the string of the original invariant. The following attribute may optionally appear:

- **description** is the optional user provided description string of the contract.

8.1.2 Additional Exception Elements

The XML doc format may already contain entries for exceptions thrown by a method or property accessors. Contracts may add further **exception** elements under methods and properties. These exception elements arise if the method or property accessors contain any **requires** with an explicit exception, or any **ensuresOnThrow** element. The body of the exception element contains either the condition under which it is thrown, or the exceptional post condition that holds when it is thrown. The **cref** attribute of the exception element is the full doc id of the thrown exception.

8.2 Usage from Visual Studio

When you build your project from Visual Studio, make sure to check “XML documentation file” in your project *Build* property pane in order to generate the XML documentation file for your project. Note that the compiler may issue warnings about missing XML comments on your project when you do that. This is normal and you may want to add the missing descriptions.

On the *Code Contract* property pane, select both “**Build** for the Contract Reference Assembly” and “Emit contracts into XML doc file”. *Note:* if you select these options without also selecting the “XML documentation file” on the *Build* property pane of your project, the `ccdocgen` tool is not invoked.

8.3 Sandcastle Integration

Sandcastle (<http://www.codeplex.com/Sandcastle>) is a freely available tool that generates help files and web sites describing your APIs, based on the XML doc comments in your source code. The CodeContracts install contains a set of files that can be copied over a Sandcastle installation to take advantage of the additional contract information. The produced documentation adds a contract section to methods with declared requires and/or ensures.

In order for Sandcastle to produce Contract sections, you need to patch a number of files in its installation. Please refer to the Sandcastle Readme.txt found under Start Menu/CodeContracts/Sandcastle for instructions.

A future release of Sandcastle will hopefully support contract sections without the need for this patching step.

9 Installation

The Code Contract tools work with Visual Studio 2008 and Visual Studio 2010. They come in three flavors:

Devlab Premium The devlab premium download allows for commercial use of all tools, provided they are used with Visual Studio Premium or up, or a Team Edition. <http://msdn.microsoft.com/en-us/devlabs/dd491992.aspx>

Devlab Standard The devlab standard download allows for commercial use of the runtime contract checking tool with any Visual Studio edition (except Express). <http://msdn.microsoft.com/en-us/devlabs/dd491992.aspx>

Academic The academic download from the Microsoft Research web site allows non-commercial use of all tools (for e.g., teaching) on any Visual Studio edition (besides Express). <http://research.microsoft.com/contracts>

9.1 VS2010 Beta2

The tools work with VS2010 Beta2 and there should be no observable difference with respect to their behavior compared to VS2008 except for what is listed below.

- It appears that sometimes the first message emitted by the static checker disappears from the Visual Studio Error List. Rebuilding usually solves this issue.

9.2 VS2010 Beta1

The tools work with VS2010 Beta1 (but not the CTP). There are some discrepancies in the runtime behavior of contracts on the Beta1 w.r.t. the documentation due to the fact that the latest contract class changes did not make it into the Beta1. These discrepancies are described below and occur only if you target .NET 4.0.

If you target 3.5 or lower, the `Microsoft.Contracts.dll` library needs to be explicitly referenced and then the behavior should match what is in this document.

The Beta1 discrepancies are:

- The `Contract` class is missing the new `Requires<TException>` overload. Instead, it includes the now obsolete `RequiresAlways` (but it isn't marked obsolete in Beta1). `RequiresAlways` is temporarily supported as behaving like `Requires<ArgumentException>`.
- Use of `RequiresAlways` without turning on runtime checking (running `ccrewrite`) results in a check that stops the process if it fails. We suggest you don't use `RequiresAlways` as it is obsolete.
- The `ContractFailed` event is not raised on contract failures.
- When the failure behavior is an assert dialog box, the `System.Diagnostics.Assert` dialog is triggered without concern for whether the environment is hosted or non-interactive.

Other Beta1 issues are:

- Contract Code snippets don't seem to show up on all installations of VS2010, but do on some.

9.3 Upgrade-downgrade issues

Before upgrading or downgrading your Visual Studio 2008 installation (e.g., from Professional to Team Edition), make sure to uninstall the code contracts package.

10 Troubleshooting

10.1 ASP .NET

10.1.1 Asserts

If you use runtime contract checking on an ASP.NET assembly, please *do not check* the `Assert on Contract Failure` box in the contract property pane for that project. When running hosted inside a web server or inside internet explorer, the assertion causes the process to exit rather than provide a useful error message.

When you leave the box unchecked, you will get an exception instead which is displayed properly in these contexts.

10.1.2 Ambiguous Type Warnings

If you use contracts with ASP .NET and deploy your assemblies for IIS, it may be that the IIS server complains about ambiguous type references due to contract reference assemblies. In order to configure IIS to ignore contract reference assemblies, you can add entries to your `Web.config` file as explained on MSDN <http://msdn.microsoft.com/en-us/library/bfyb45k1.aspx>. For example, to remove `MyAssembly.Contracts`, add the entry remove as shown below:

```
assemblies>
<add assembly="System.Core, Version=3.5.0.0, Culture=neutral, PublicKeyToken=B77A5C561934E089" />
<add assembly="System.Web.Extensions, Version=3.5.0.0, Culture=neutral, PublicKeyToken=31BF3856AD364E35" />
...
<add assembly="System.Data.Linq, Version=3.5.0.0, Culture=neutral, PublicKeyToken=B77A5C561934E089" />
<remove assembly="MyAssembly.Contracts" />
</assemblies>
```

10.2 Contracts on struct constructors

A subtle issue comes up when writing contracts on constructors for structs (as opposed to classes). The compiler will not let you reference **this** before any fields are assigned to. Here is an example.

```
public struct S{
    int x;
    public bool P { get { ... } }
    public S(int y){
        this.x = y;
    }
}
```

Suppose you would like to add this postcondition to the constructor:

```
Contract.Ensures(this.P);
```

If you try that (and fill in the dots in the getter for P), then you will get the following error message from the compiler:

```
struct.cs(12,22): error CS0188: The 'this' object cannot be used before all of its fields are assigned to
```

To get around this, you can use the method `ValueAtReturn`, which is explained in Section 2.2.3:

```
public S(int y){
    Contract.Ensures(Contract.ValueAtReturn(out this).P);
    this.x = y;
}
```

10.3 Call-site Requires

When building an assembly *A* with runtime checking enabled against a library *B* that has *no* runtime requires checking enabled, but provides a contract reference assembly *B.Contracts*, the contract rewriter can insert the appropriate requires at call sites to the library *B*. Make sure to check the box *Call-site Requires Checking* on the contract property pane of project *A*.

11 Known Issues

11.1 Build Slowdown

The build within Visual Studio slows down noticeably for solutions with many projects, mainly due to the time it takes to instrument the runtime checks. We hope to address this in the future.

11.2 Contracts on Delegates

Currently, there is no mechanism to provide contracts on delegate types or delegate values. In the future, we will support a mechanism similar to contracts for interfaces that will allow associating requires and ensures to delegate types.

11.3 Iterators

You can now put contracts on iterators.

```

public class Graph
{
    public IEnumerable<Node> Nodes(Graph g)
    {
        Contract.Requires(g != null);
        Contract.Ensures(Contract.ForAll(Contract.Result<IEnumerable<Node>>(),
                                         node => node != null));
        foreach (var x in g.MethodForGettingNodes())
            yield return x;
    }
}

```

The contracts above make sure that callers don't pass in a null parameter, and the method itself guarantees that all elements in the resulting collection are non-null.

Currently, the static checker does not reason about collections and thus will not be able to prove the postcondition above.

11.4 Closures

Closures can have contracts and runtime checking works as expected. The static contract checker however performs no inference or propagation of contracts and will thus emit false warnings. One reason for this is the lack of contracts on delegates (see above). Use

```
Contract.Assume( cond );
```

in places where the static contract checker fails to prove `cond`. This should keep the contract checker quiet, while still checking this contract at runtime.

11.5 Forms and Generated Code

You may get errors from the static contract checker in generated code such as form initialization from VB or C# form applications. The main reason is that there's a lack of contracts on some of the libraries involved. To avoid having to write contracts in generated code while eliminating noisy warnings is to put an attribute on such methods (like `InitializeComponent`). In C#

```
[System.Diagnostics.Contracts.ContractVerification ( false )]
```

In VB:

```
<System.Diagnostics.Contracts.ContractVerification (False)> _
```

11.6 Old-style assembly signing

Old style assembly signing using the attribute

```
[ attribute : AssemblyKeyFile (...)]
```

is not supported in conjunction with Code Contracts.

11.7 Edit-Continue Not Working

When using runtime checking of contracts, the IL is rewritten by our tools. Edit-continue relies on being able to insert code into an existing executable. Since that feature is not aware of the contract rewriting, it won't work. There's no work-around other than not using edit-continue when also using contracts.

12 Feedback

There is a forum for bugs, feedback, discussions, and questions on Code Contracts at <http://social.msdn.microsoft.com/Forums/en-US/codecontracts/threads>.

Another way to contact us is to send feedback to codconfb@microsoft.com.

A Appendix

A.1 MsBuild Integration

The Visual Studio integration described in Section 6 is implemented using MsBuild in the following way:

- The Contract Property Pane selections simply add MsBuild properties to the project file (.csproj or .vbproj).
- An msbuild script extension `Microsoft.Contract.targets` contains the extra build actions for the runtime contract instrumentation and static verification steps.

As a result of this approach, it is possible to use the same functionality when building from the command line with the `msbuild` command. Using `msbuild` on a project or solution that uses contracts enabled via the VS user interface will perform the same actions as the corresponding build under VS.

For projects that do not have contracts enabled via the UI, the following properties can be set on the command line.

- `CodeContractsEnableRuntimeChecking`: when set to true, the contract rewriter instruments the target assembly with runtime contract checks.
- `CodeContractsAssemblyMode`: set this to 0 if you use custom parameter validation in your assembly that throw exceptions (usage mode 3). Otherwise, set this to 1.
- `CodeContractsRuntimeCheckingLevel`: set this to one of the following values: Full, Pre and Post, Preconditions, ReleaseRequires, or None.
- `CodeContractsRuntimeThrowOnFailure`: set this to true if you want contract failure to throw an exception. Otherwise, failure will result in an assertion.
- `CodeContractsRuntimeOnlyPublicSurface`: when set to true, the rewriter instruments only publicly visible methods.
- `CodeContractsRuntimeCallSiteRequires`: when set to true, the rewriter instruments preconditions at call-sites.
- `CodeContractsReferenceAssembly`: set to Build if you want to build a contract reference assembly for this project. Useful if other projects reference this assembly and need to see the contracts inside it, or if you want to generate documentation with contracts. Set it to DoNotBuild if you want to avoid building it.
- `CodeContractsEmitXMLDocs`: when set to true and a contract reference assembly for the project is produced, and xml-docs for the project are produced, then the XML is augmented with contract elements.
- `CodeContractsCustomRewriterAssembly`: set this to the assembly path containing the type with the custom rewriter methods you want to call on contract evaluation.
- `CodeContractsCustomRewriterClass`: this is the name of the class containing your custom rewriter methods. Use it in conjunction with `CodeContractsCustomRewriterAssembly`.

- `CodeContractsLibPaths`: set this to a semi-colon separated list of paths where additional contract reference assemblies are located.
- `CodeContractsRunCodeAnalysis`: when set to true, the static contract verifier is run on the build target.
- `CodeContractsNonNullObligations`: when set to true, the static analyzer will try to validate all pointer de-references against null.
- `CodeContractsBoundsObligations`: when set to true, the static analyzer will try to validate all array bounds.
- `CodeContractsArithmeticObligations`: when set to true, the static analyzer will try to validate some arithmetic obligations, such as division by zero.
- `CodeContractsRedundantAssumptions`: when set to true, the static analyzer will warn if an assumption can be proven.
- `CodeContractsRunInBackground`: when set to true, the static analyzer runs in the background without blocking the build.
- `CodeContractsExtraAnalysisOptions`: can be used to pass extra options to the static analyzer.

A.2 Contract Rewriter Command Line Options

The contract rewriter performs several tasks: postconditions are moved to the end of the method body, method return values are substituted for occurrences of `Contract.Result<T>()` and pre-state values are substituted for occurrences of `Contract.OldValue<T>()`. In addition, contract inheritance is performed.

To rewrite an assembly without VS or MsBuild integration, compile the assembly with the symbol `CONTRACTS_FULL`. Then use the `crewrite.exe` tool. Here is a full list of its options:

```
-automaticallyLookForOOBs (default=true) : Automatically load out-of-band contracts.
                                         [short form: autoRef]
-allowRewritten                        : Silently do nothing if the input assembly has already been rewritten.
-breakIntoDebugger                    : Causes the debugger to be invoked.[short form: break]
-contracts <string-arg>                : Out-of-band contract assemblies.
-debug (default=true)                  : Use debug information.
-hideFromDebugger (default=true)       : Hide rewritten contract methods from debugger.
-libpaths <string-arg>                 : Additional paths to search for referenced assemblies.
-assemblyMode (legacy | standard)      : (default=legacy)
                                         : Set to legacy if assembly uses if-then-throw parameter validation

-level <int-arg> (default=4)           : Instrumentation level: 0=no contracts, 1=ReleaseRequires, 2=Requires,
                                         3=Ensures, 4=Invariants. (Each increase includes the previous)
-recursionGuard <int-arg> (default=4) : Contract recursion level at which to stop evaluating contracts
-throwOnFailure                        : Throw ContractException on contract failure[short form: throw]
-publicSurfaceOnly                     : Remove all contracts except those visible from outside assembly
                                         [short form: publicSurface]
-callSiteRequires                      : Instrument call sites with requires checks where necessary
                                         [short form: csr]
-output <string-arg> (default=same)    : Output path for the rewritten assembly.[short form: out]
-writePDBFile (default=true)           : Write PDB file. Cannot be specified unless /debug is also specified
-keepOriginalFiles                     : Copy original files (using .original extension)
                                         [short form: originalFiles]
-rewrite (default=true)                : Rewrites the given assembly to insert runtime contract checks.
-rewriterMethods <string-arg>          : Alternative methods to use for checking contracts at runtime.
                                         Syntax: /rw:<assembly>,<class name>.[short form: rw]
-shortBranches                         : Preserve short branches in the rewritten assembly.
-extractSourceText (default=true)      : Extract the source text for the contracts. (Requires /debug.)
```

```

-targetplatform <string-arg>      : Path to alternate core library (and set of framework assemblies).
                                   [short form: platform]
-verbose <int-arg> (default=0)    : Print out extra information.
-contractLibrary <string-arg>     : Dll/Exe name containing shared contract class
                                   (if not mscorlib/Microsoft.Contracts.dll)
-assembly <string-arg>           : Assembly to process.

```

A.2.1 Troubleshooting Rewriting

When using the contract rewriter without contract reference assemblies (Section 6.5) for referenced assemblies, one must take care to rewrite the assemblies in the reverse build order.

In other words, one cannot use the contract rewriter on an assembly A, if the referenced assemblies (say B) of A have already been rewritten, and there are no contract reference assemblies (B.Contracts.dll) available for them.

The reason is that the contract rewriter needs to find contracts for assembly B possibly inherited when rewriting A. When B.Contracts.dll is available, the contracts are taken from there and B can already be rewritten.

Note that the MsBuild and VS integration use contract reference assemblies and thus do not have this limitation.

A.3 Static Contract Verifier Command Line Options

In addition to the VS and MsBuild integration, the static contract verifier can also be run from the command line via the cccheck.exe tool. The commandline options are as follows:

```
usage: <general-option>* [<analysis> <analysis-options>]+ <assembly>+
```

where <general-option> is one of

```

-assemblyMode (legacy | standard) (default=legacy)
                                   : Set to legacy if assembly uses if-then-throw parameter validation
-ca (default=true)                : Check assertions
-checkassumptions                 : Check assumptions, and suggest those that can be discharged
-trace (dfa + heap + expressions + egraph + partitions + wp) (default=)
-show (progress + il + errors + validations + unreachd + progressbar + obligations + paths +
      invariants + warnranks + analysisphases + proofobligations) (default=errors)
-stats (valid + time + mem + perMethod + arithmetic + asserts + methodasserts + slowmethods +
      abstractdomains) (default=valid,time)
-infer (requires + propertyensures + methodensures) (default=propertyensures)
-suggest (requires + propertyensures + methodensures) (default=requires)
-timeout <int-arg> (default=10) : Analysis timeout per method in seconds
-wp (default=true)               : Use weakest preconditions
-libPaths <string-arg>           : Search paths for reference assemblies
-cclib <string-arg> (default=Microsoft.Contracts) : Shared contract class library
-nologo
-outFile <string-arg>
-baseLine <string-arg>           : use baseline file, or create if absent
-xml                             : Write xml output
-logLevel <int-arg> (default=0) : 0 - none, 1 - some, 2 - verbose
-logFile <string-arg>           : Log debugging to given file
-logXml                          : Log debugging as xml
-analyzeIteratorMethods          : Analyze an iterator method if true
-joinsBeforeWiden <int-arg> (default=1) : Number of joins before applying the widening
-enforceFairJoin                 : Enforce the at lease one join for each loop path
-includeCompilerGenerated        : Analyze compiler generated code
-contract <string-arg>          : Use contract reference assembly

```

```

-nobox : Don't pop-up IDE boxes
-platform <string-arg> : Set .NET core library (must be first option)
-sortwarns (default=true) : Prioritize the warnings
-maskwarns (default=true) : Enable suppression of warnings
-outputwarnmasks : Outputs the masks to suppress warnings
-maxPathSize <int-arg> (default=25) : Limit backward WP computation length
-maxWarnings <int-arg> (default=2147483647) : Limit number of issued warnings overall
-remote : Write output formatted for remoting
-precisionlevel <int-arg> (default=0) : 0 - low, 1 - medium, 2 - high, ..

```

where derived options are of

```

-statsOnly is '-show=!! -suggest=!!'
-ide is '-stats=!! -trace=!!'
-silent is '-show=!! -stats=!! -trace=!! -nologo'

```

where <analysis> is one of

```

-arithmetic[:<comma-separated-options>]
-obl (div0 + negMin + floatEq) (default=div0,negMin,floatEq) : Set of obligations to produce
-precision (Light | Normal | Strong) (default=Normal)
-fp (default=true) : Enable analysis of floats
-type (Intervals | Leq | Karr | Pentagons | PentagonsKarr | PentagonsKarrLeq |
      PentagonsKarrLeqOctagons | SubPolyhedra | Octagons | WeakUpperBounds | Top)
      (default=Pentagons)
-reduction (Fast | Complete | Simplex | SimplexOptima | None) (default=Simplex)
      : Reduction algorithm used by subpolyhedra
-steps <int-arg> (default=1) : Number of closure steps while checking assertions
-maxeqpairs <int-arg> (default=25) : Max number of pair of equalities that can be propagated
      by karr
-ch : SubPolyhedra only : use 2D convex hulls to infer constraints
-infOct : SubPolyhedra only : infer octagonal constraints
-mpw (default=true) : Use widening with thresholds
-tp : Use trace partitioning
-diseq (default=true) : Track Numerical Disequalities
-noObl : No proof obligations for bounds
-precisionlevel <int-arg> (default=2) : 0 - low, 1 - medium, 2 - high, ..

```

```

-bounds[:<comma-separated-options>]
-type (Intervals | Leq | Karr | Pentagons | PentagonsKarr | PentagonsKarrLeq |
      PentagonsKarrLeqOctagons | SubPolyhedra | Octagons | WeakUpperBounds | Top)
      (default=PentagonsKarrLeq)
-reduction (Fast | Complete | Simplex | SimplexOptima | None) (default=Simplex)
      : Reduction algorithm used by subpolyhedra
-steps <int-arg> (default=1) : Number of closure steps while checking assertions
-maxeqpairs <int-arg> (default=25) : Max number of pair of equalities that can be propagated
      by karr
-ch : SubPolyhedra only : use 2D convex hulls to infer constraints
-infOct : SubPolyhedra only : infer octagonal constraints
-mpw (default=true) : Use widening with thresholds
-tp : Use trace partitioning
-diseq (default=true) : Track Numerical Disequalities
-noObl : No proof obligations for bounds
-precisionlevel <int-arg> (default=2) : 0 - low, 1 - medium, 2 - high, ..

```

```

-nonnull[:<comma-separated-options>]
-noObl : Don't generate proof obligations

```

To clear a list, use `-<option>=!!`

To remove an item from a list, use `-<option> !<item>`

A.4 Contract Reference Assemblies

A contract reference assembly `A.Contracts.dll` for assembly `A` contains the publicly visible interface of `A` along with its contracts, but no code bodies. Such contract reference assemblies are used both during rewriting to inherit contracts across assemblies, as well as during static verification to discover contracts on methods and types from other assemblies than the assembly under analysis.

The command line tool to produce a contract reference assembly is `ccrefgen.exe`.

```
Usage: ccrefgen [/attribute:<string>* [/backCompat[+|-]] [/contracts[+|-]] [/ignore:<string>]
              [/keep:{All|ExtVis|NonPrivate}] [/onlyTransparent[+|-]] [/keepAttributes[+|-]]
              [/out:<string>] [/rename[+|-]] [/renameOnly[+|-]] [/sourceText[+|-]]
              [/verify[+|-]] [/producePDB[+|-]] [/break[+|-]] <assemblies>* @<file>
```

<code>[/attribute:<string>]*</code>	Attribute to exempt from whatever polarity <code>keepAttributes</code> is (Short form: <code>/a</code>)
<code>[/backCompat[+ -]]</code>	Behave as the original <code>AsmMeta</code> Default value: <code>'-'</code> (Short form: <code>/b</code>)
<code>[/contracts[+ -]]</code>	Emit contracts Default value: <code>'+'</code> (Short form: <code>/c</code>)
<code>[/ignore:<string>]</code>	File listing metadata entities to skip Default value: <code>''</code> (Short form: <code>/i</code>)
<code>[/keep:{All ExtVis NonPrivate}]</code>	Specify what elements to keep Default value: <code>'All'</code> (Short form: <code>/k</code>)
<code>[/onlyTransparent[+ -]]</code>	Only emit security transparent & safe API's Default value: <code>'-'</code> (Short form: <code>/ot</code>)
<code>[/keepAttributes[+ -]]</code>	Emit attributes Default value: <code>'+'</code> (Short form: <code>/ka</code>)
<code>[/out:<string>]</code>	Output (full) path for the reference assembly. (Short form: <code>/o</code>)
<code>[/rename[+ -]]</code>	Rename the assembly itself. Default value: <code>'+'</code> (Short form: <code>/r</code>)
<code>[/renameOnly[+ -]]</code>	Just rename the assembly, don't modify it in any other way. Default value: <code>'-'</code> (Short form: <code>/ro</code>)
<code>[/sourceText[+ -]]</code>	When emitting contracts, include the source text of the condition. (Ignored if <code>/contracts</code> is not specified.) Default value: <code>'+'</code> (Short form: <code>/st</code>)
<code>[/verify[+ -]]</code>	Produce verifiable IL Default value: <code>'-'</code> (Short form: <code>/v</code>)
<code>[/producePDB[+ -]]</code>	Produce a PDB for output Default value: <code>'-'</code> (Short form: <code>/pdb</code>)
<code>[/break[+ -]]</code>	Break into debugger Default value: <code>'-'</code> (Short form: <code>/break</code>)
<code><assemblies>*</code>	Assembly to process.
<code>@<file></code>	Read response file for more options.