

Buffalo: An Aspect Oriented Programming Framework for C#

by

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Dedication

To Jackson and Evan

Acknowledgments

I am grateful for my adviser Prof. Heliotis, whose insightful advices, guidance and support from the beginning not only enabled me to complete the project on time, but also to a better understanding of the subject area.

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Abstract

Buffalo: An Aspect Oriented Programming Framework for C#

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Aspect Oriented Programming (AOP) is a paradigm that let programmer isolate and separate crosscutting concerns from their programs. The concept has not been widely adopted by modern languages; support in tooling such as Integrated Development Environment (IDE) is also rare. In this project I designed and implemented Buffalo, an AOP framework to provide this capability for the .NET platform.

Buffalo performs Common Intermediate Language instruction set modification according to the aspects written by developer, with the help of the Mono Cecil library. Buffalo is .NET attribute based, which mean developers with existing .NET skills will have little or no learning curve to get started. Buffalo will help increase developer productivity in many area such as unhandled exception catching, tracing and logging, and many other areas.

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Chapter 1

Introduction

Object Oriented Programming (OOP) languages have given programmers a lot of freedom in expressing themselves in Object Oriented Design. However, they are still lacking in some areas when it comes to particular software design decision such as cross-cutting concern [1].

In this project, a framework called "Buffalo" is designed and implemented to solve this type of problem on the .NET platform. Buffalo makes use of the .NET attribute system to weave aspect code to any targeted methods. The design and rationale of the framework is discussed in section 2. The implementation detail is given in section 3.

The result indicates that by using Buffalo, developers can separate cross-cutting concerns from the core of the program for easy maintenance, and ultimately be more productive. The analysis is discussed in section 4.

The report concludes in section 5 with the current project status. A set of planned future works is also discussed and what is learned from undergoing this project.

Buffalo comprises of around 1,200 line of codes, which is fully included in Appendix A. A user manual is included in Appendix B, which contains some usage examples and how to integrate Buffalo with MS-Build.

Chapter 2

Design

2.1 Compiler Support

There are several broad approaches to implementing an AOP framework. The ideal approach would be to extend the compiler of the target language to provide built-in support, thus making AOP the first class citizen. However there are very few languages out there that take this approach, among the few are Delphi Prism [2] and AspectJ [3, 4].

Microsoft is currently in the "wait and see" mode regarding support of AOP development in the C# compiler [5]. Alternative compiler such as Mono C# [6] is open source, so technically anyone can build AOP support into it. While that would have been a fun challenge, however that would have been a fairly big undertaking, and there is concern that the project might not be finished in the time frame wanted.

That leaves framework support as the other viable option. There are several implementation techniques to provide AOP capabilities [7, 8, 9] via framework.

2.2 Run-time Interception

Early on the implementation techniques were narrowed down to between Run-time Interception and Compile Time Weaving. As its name suggested, run-time interception operates while the program is in execution. It uses the proxy pattern where client communicate with the target object via a proxy, and aspects are injected to the proxy. This enables run-time behavior of the program to be modified. Figure 2.1 illustrates this process.

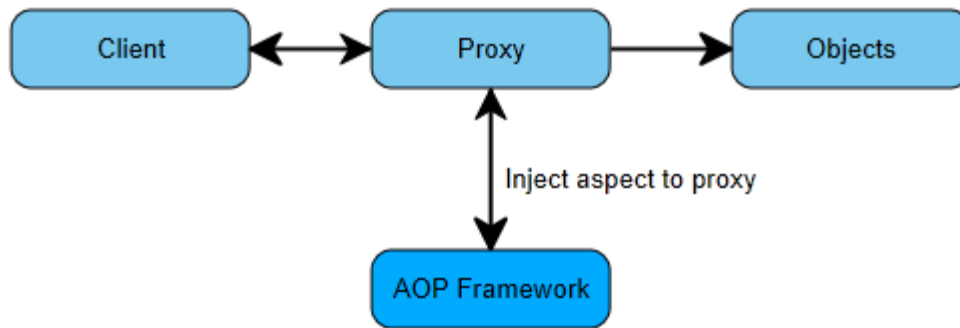


Figure 2.1: AOP Framework Using Proxy Pattern

New functionality can be added to the target object via the proxy. The disadvantage of this approach is that it involves the generation of proxy object at run-time. The run-time performance of the application will be impacted as the result. It is also restricting in that both target object and the proxy must implement a common interface for this to work, and that only virtual methods are exposed for interception.

From the end user's perspective, to use it the developer usually have to provide some type of mapping between the target object and the proxy via a configuration file so the actual proxy generation can occur. This approach although is easier to implement, but not as easy and friendly to use. Buffalo is not taking this approach mainly because one of the goal is to be flexible and simple to use.

2.3 Compile Time Weaving

The approach Buffalo takes is Compile Time Weaving. The idea is after compilation of the assembly, the framework takes over and disassembles the assembly. Buffalo then weaves in the defined aspect code to all targeted methods. This approach is more difficult to implement as it involves modifying the underlying assembly by changing Common Intermediate Language (CIL) instructions [10]. But the advantage is that no run-time performance of proxy generation will be needed.

Since injection happens post-compilation, the whole process can be integrated into the MS-Build system to have the weaving invoked automatically if needed. This will further

reduce the steps needed from the developer.

Figure 2.2 shows an overview of the compilation process and where Buffalo will fit in.

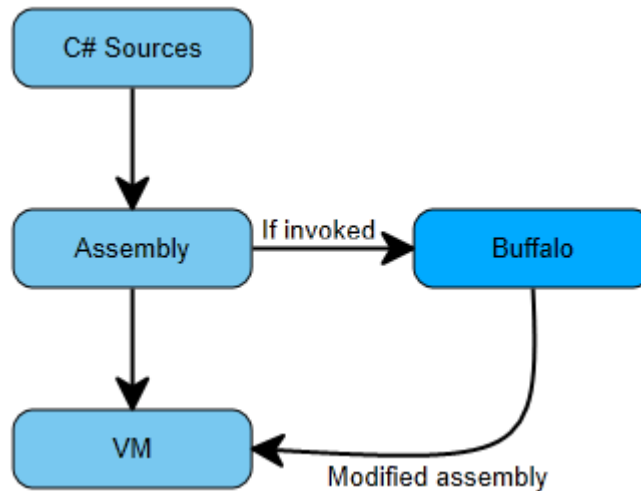


Figure 2.2: Buffalo Model

2.4 What is a Buffalo Aspect

When performing post compilation weaving, Buffalo has to be able to discover what aspect is applied to what method in an assembly. In order to achieve that the target assembly has to carry some extra meta-data, so that Buffalo can use that to identify aspects.

A given .NET assembly already carries a great deal of such meta-data for various purpose. .NET has the `System.Attribute` type that exists primarily for the purpose of inserting meta-data into the assembly during compilation. When we compile the source code, it is converted into CIL [11] and put inside a portable executable (PE) file, with the meta-data generated by the compiler.

Buffalo takes advantage of this characteristic in two areas.

1. An aspect defined in Buffalo will be in the form of an attribute, by sub-classing `System.Attribute`. Since the aspect is a class type, it can contains any valid .NET code. But specifically an aspect needs to override various predefined methods in

order to do something useful. Figure 3.2 shows the relationship between various aspect types.

2. After compilation, the assembly will now contain the meta-data about the aspect. Buffalo can inspect the assembly for the information, and perform CIL code injection accordingly.

In other word, a Buffalo aspect is a .NET attribute in disguise.

2.5 MethodBoundaryAspect

What functionality does Buffalo support exactly? What type of weaving does it do? These were the intial questions that needs a definitive anwsers. For this inspiration were obtained from AspectJ [3] and PostSharp [8], specifically Buffalo will intercept the various point of an executing method. Those points are namely: before a method executes; after a method executes; whether or not the method executed successfully without error; or whether the method throws an exception any point during the execution. These various point of interception is group into the MethodBoundaryAspect.

MethodBoundaryAspect can be cleanly mapped to the try-catch-finally statements of the .NET languages. As far as the run-time is concern [12, 13], try-catch can be used liberally without serious performance degradation. For example, a simple method shown in Figure 2.1:

```
1 public void SomeFunction () {  
2     //Perform some action...  
3 }
```

Listing 2.1: Sample function

Can be transformed into something shown in Figure 2.2. That clearly captures the spirit of the MethodBoundaryAspect.

```
1 public void SomeFunction () {  
2     try {  
3         OnBefore();
```

```
4      //Perform some action
5      OnSuccess();
6  }
7  catch (Exception e) {
8      OnException(e);
9  }
10 finally {
11     OnAfter();
12 }
13 }
```

Listing 2.2: Sample try-catch-finally

Transformed method in Figure 2.2 still does what the original method intends to do, only now at various point execution are being intercepted to provide more functionality.

2.6 MethodAroundAspect

Another type of aspect that Buffalo supports is the MethodAroundAspect. Rather than intercepting various execution points of a method, the method can be completely replaced by another method defined in an aspect, while preserving the option to call back into the original method if necessary.

At first glance MethodAroundAspect sounds straightforward to do, but it turns out to be much more involved than the MethodBoundaryAspect.

Since the option to call back into the original method is preserved, it is critical that under no circumstance should the original method be modified. If the method body instructions are simply overridden with that of the replacement, the call back to the original method will be meaningless since the method is now changed. The original method must be intact for the call back to happen.

To get around this obstacle, whenever Buffalo encounters the MethodAroundAspect applied to a method, it dynamically generates a replacement method in CIL with the same method signature as the original.

The body of this replacement method is also completely different than the original. It

simply instantiate the aspect and makes call to the aspects `Invoke()` method, which is the actual aspect code that will be ran.

Inside the `Invoke` method, developer can make a call back to the original method via a call to the `Proceed()` method. Then throughout the program, for any calls made to the original method, Buffalo would change them to call the replacement method instead. This is illustrated in figure 2.3.

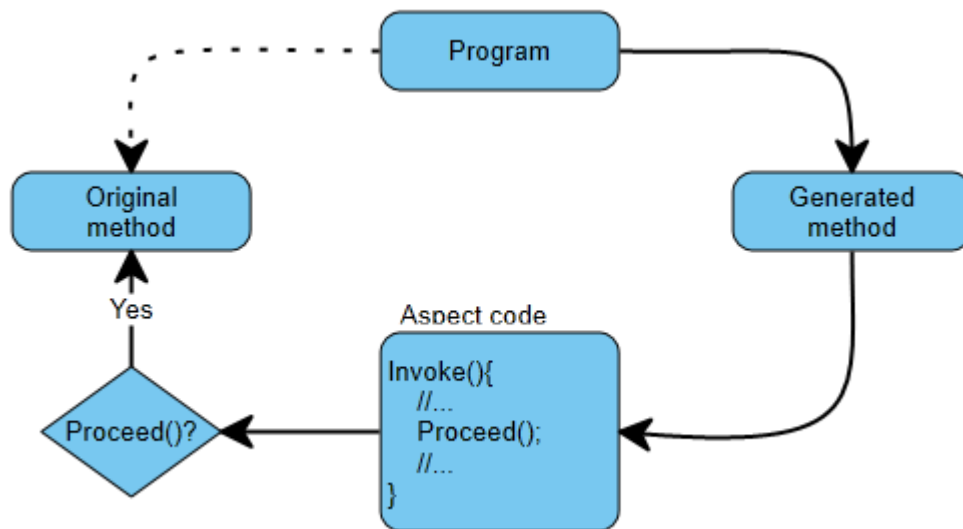


Figure 2.3: Method Around Aspect

The dotted line from `Program` to the `Original method` indicates that once the `MethodAroundAspect` is applied to it, from the perspective of CIL the program cannot directly access that method any more. Access to the original method now has to come from inside the aspect. Also note that the original method is not changed at any given time.

Chapter 3

Implementation

3.1 How to Apply an Aspect

Since an aspect is a .NET attribute, it can be used just like any other attribute. But code annotated with an aspect is special in that it can be understood only by Buffalo.

Normally an aspect can be applied in three level:

1. Method level - an individual method.
2. Class level - if applied to a class, all public methods including the public properties automatically get applied.
3. Assembly level - if applied to an assembly, #2 will apply but for all the public classes within the assembly.

An exception to the above rule is the `MethodAroundAspect`, where it can only be applied on a method level, as will be shown later on.

An aspect can also be excluded on any given level. If excluded the target and its nested children will be skipped during the weaving process.

No matter how the aspect is applied, ultimately it will result in a list of the methods that are annotated. This simply mean if the aspect is applied to a single method, that method is the only one that will get CIL modified. If the aspect is applied on the whole assembly, then all public methods will be CIL modified.

To get the list of the eligible methods for CIL modification, Buffalo attempts various checking according to figure 3.1 to see if it should include a given method.

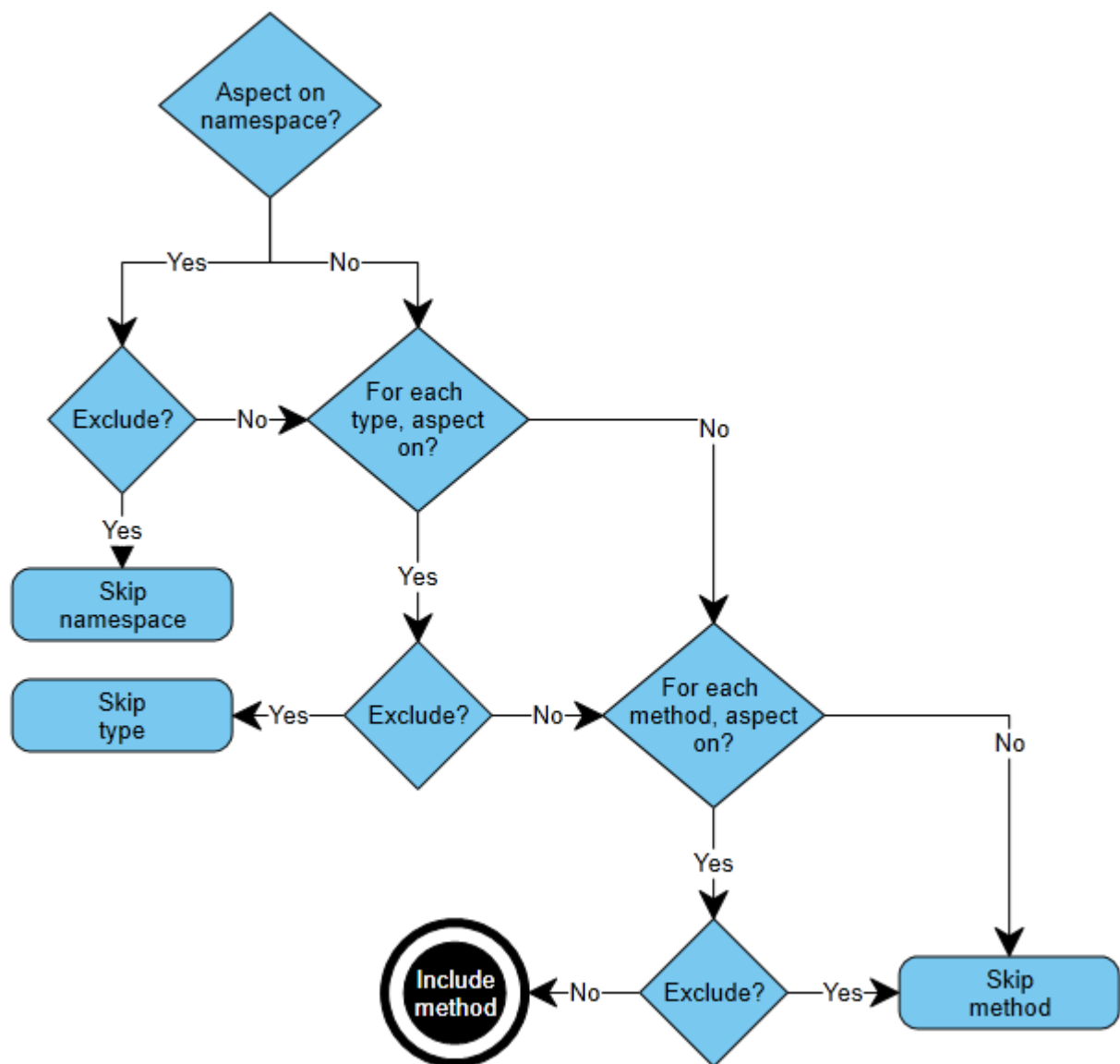


Figure 3.1: Logical Inclusion

If no aspect is applied on the assembly, that does not necessarily mean no aspect is applied anywhere, the aspect might still be applied on any given class or method.

The take away from the above diagram, is that Buffalo first checks if an aspect is applied to the target, then check if it is set to be excluded. At the end it will end up with a list of methods that should be CIL modified.

3.2 Aspect Interface

Figure 3.2 shows the relationship of various aspect types in Buffalo. This is used by Buffalo to identify aspects during reflection.

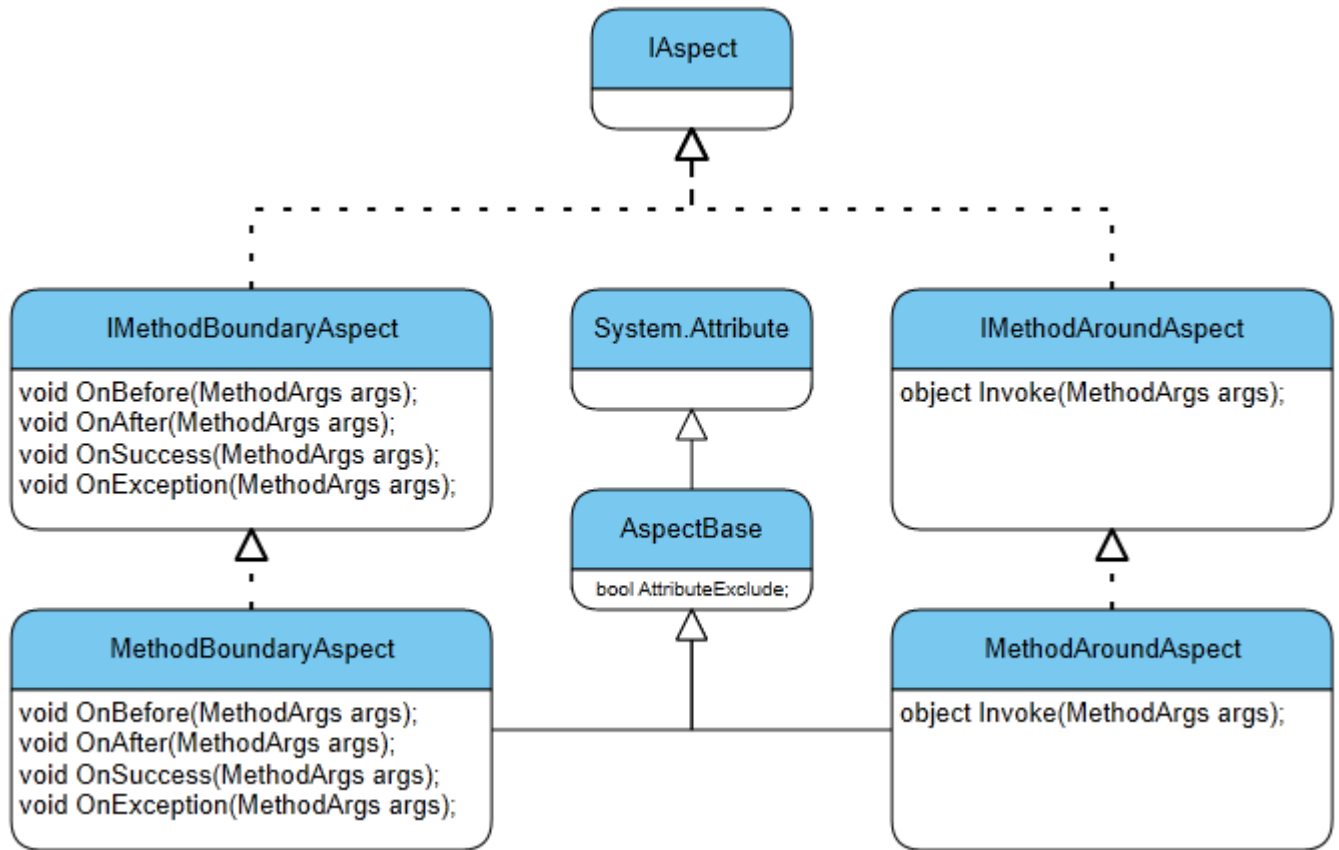


Figure 3.2: Aspect Inheritance

All aspects ultimately implements the IAspect interface, therefore it can be reasoned that for all the public types in an assembly, if it implements IAspect, then it must be an aspect itself.

All aspects have a property named AttributeExclude, if set to true then the annotated target will not be included in the weaving.

Buffalo supports more than one aspect applied at any given level. This will allow developers more flexibility while developing multiple aspects and applying them as needed.

Furthermore, by default, an aspect will be automatically excluded from applying to itself. This is implemented to prevent stack overflow in some cases. Although argument can be made that an aspect should be able to be applied to a different aspect, however that is not currently implemented in Buffalo.

3.3 MethodArgs

As mentioned above, when its all said and done, an aspect ultimately gets injected into each *individual* method. When developing an aspect, a developer can access various information about the target method, via the MethodArgs object passed in as parameter to the aspect. Currently the full method signature, the method name, return type and parameter list including parameter name, type and value are captured for each target method.

The parameter list capturing is especially of interest, it enables developer to peek inside the method that is executing at various point and inspect its parameter values. This will be useful in case such as exception handling, where it will be useful to actually see what the values were at the time of the exception.

3.4 Visual Studio Solution Structure

Originally Buffalo was implemented as one executable, that includes the various aspects and the program that initiates the weaving. It was later on separated into two assemblies. One is a class library that contains the actual implementation. Another is a command line executable that calls into the class library to perform the weaving, as shown in figure 3.3. This separation is necessary so developer can perform weaving from the command line or hook into MS-Build if necessary.

To actually write the aspect, developer only need to reference the class library which is much cleaner than referencing an executable.

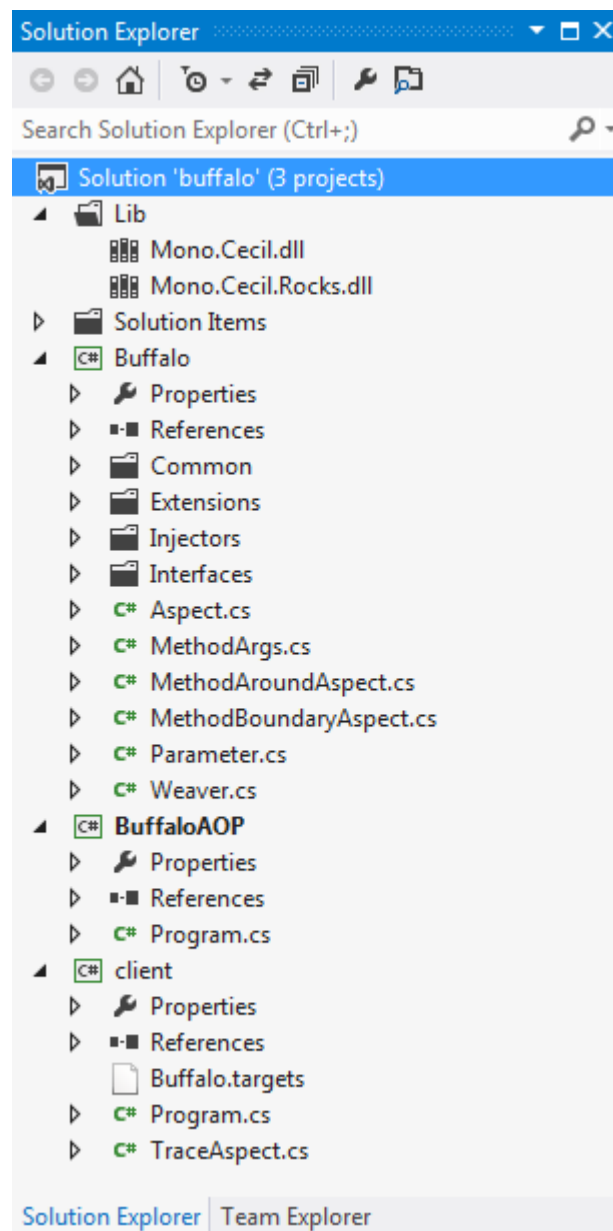


Figure 3.3: Solution Structure

The client project shown above is just a simple program included in the solution for testing. The full source code is included in Appendix A.

3.5 Implementation Overview

The overall implementation process can be illustrated as figure 3.4, where the first step of finding all eligible methods using the logical diagram mentioned in figure 3.1.

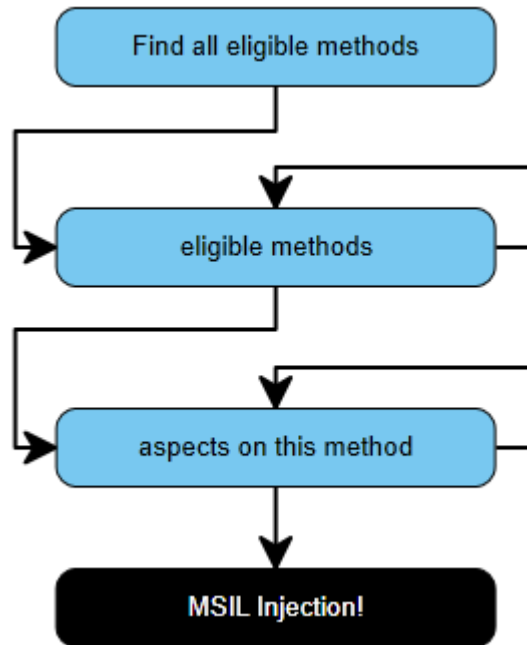


Figure 3.4: Implementation Overview

Then it loops through each eligible method, and for each aspect associated with the eligible method do the CIL injection. The actual injection phrase depends on the type of aspect.

3.6 MethodBoundaryAspect Implementation Detail

Each type of aspect has its own injector that implements the `IInjectable` interface. This interface contains only one method contract - `Inject(..)`. It takes the list of eligible methods and inject the appropriate aspect to them.

`MethodBoundaryAspect` is pretty straightforward to implement. Take the following hello world example, wrapped in a `try..catch..finally` block as mentioned previously:

```
1 public void SayHello()
2 {
3     try{
4         Console.WriteLine("Hello World!");
5     }catch(Exception ex){
6     }finally{
7     }
8 }
```

Listing 3.1: SayHello function

The generated CIL shown in figure 3.2. For ease of display it has been cleaned up a bit:

```
1 .try
2 {
3     .try
4     {
5         IL_0002: Ldstr "Hello World!"
6         IL_0007: call void [mscorlib]System.Console::WriteLine(string)
7         IL_000e: leave.s IL0015
8     }
9     catch [mscorlib]System.Exception
10    {
11        IL_0010: stloc.0
12        IL_0013: leave.s IL_0015
13    }
14    IL_0015: leave.s IL_001c
15 }
16 finally
17 {
18     IL_001a: endfinally
19 }
20 IL_001c: ret
```

Listing 3.2: CIL generated for sample C# function

Figure 3.2 shows the standard emission of the CLR when it encounters the try-catch-finally statement. In CLR there is a concept of the protected region, where each region is associated with a handler. A try-catch-finally is actually encapsulated in two such regions: a catch and a finally. From here it can be easily figured out where to inject the various

boundary aspects, as shown in the following figure 3.5

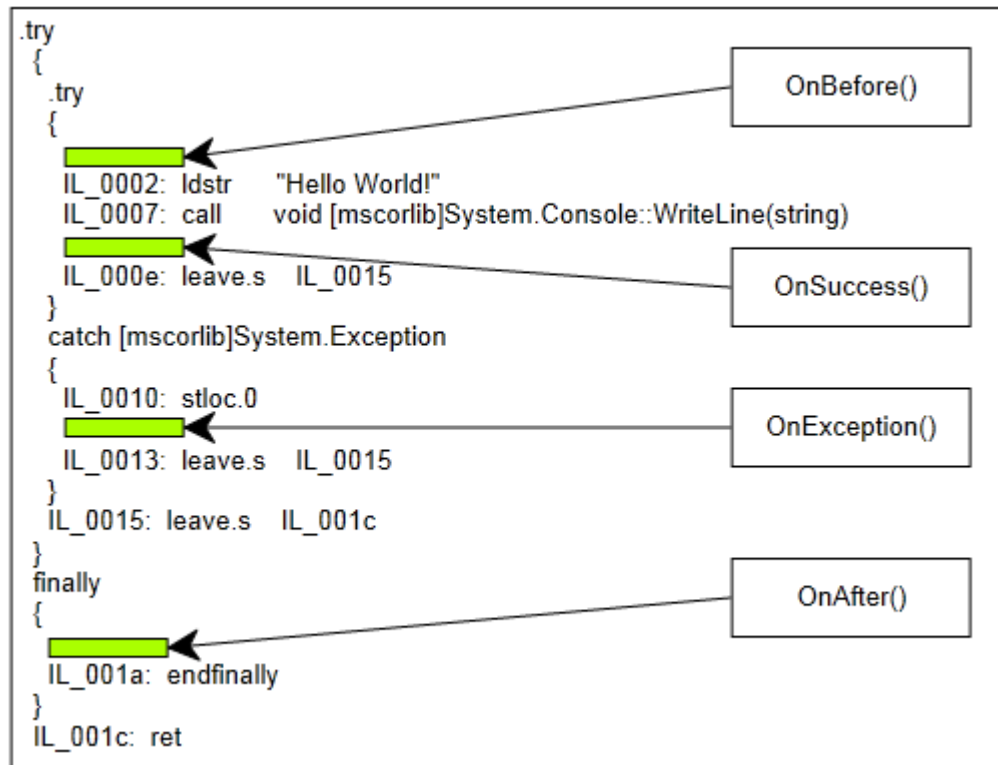


Figure 3.5: CIL Interception Points

The actual implementation is in provided in Listing A.9

3.7 MethodAroundAspect Implementation Detail

The Around aspect on the other hand is a much more complicated compared to the Boundary aspect.

MethodAroundAspect implements IMethodAroundAspect which has the following contract:

```

1 internal interface IMethodAroundAspect : IAspect
2 {
3     void Invoke(MethodArgs arg)
4 }

```

Listing 3.3: IMethodAroundAspect Contract

From a developers perspective, when writing an aspect he can issue a `Proceed()` to signal a call back into the original method. The steps taken to implement `MethodAroundAspect` in CIL is roughly as follow:

1. Create a replacement for the annotated function with exactly the same method signature.
2. Create and store a variable pointing to the aspect.
3. Copy all parameters from original method to the newly created replacement function.
4. Create a variable to hold `MethodArgs`.
5. Issue a call to `Invoke()` from the replacement function, passing in the `MethodArgs` variable.
6. Handle the return value appropriately.
 - (a) If original method returns non void type, put the return value back on the stack.
 - (b) If original method returns void, we need to discard the return value from `Invoke()`.
7. Handle `Proceed()` that might be issued from inside the `Invoke()`.
 - (a) Load all the parameters onto the stack.
 - (b) Call back into the original method.
 - (c) Handle the return value appropriately.
8. Modify all calls from original method to the replacement method.

As figure 2.3 shown, the actual calling of either the original or replacement method is abstracted away. This is also a testament of the saying in Software Engineering that "anything can be resolved by another layer of abstraction".

Another important distinction is that `MethodAroundAspect` currently can be applied only on the method level, and that it should be applied to one method only. This is by design because a replacement method might not be appropriate to replace more than one method. Especially if it is applied on the assembly level, all the public methods will be replaced by a single replacement method!

3.8 MethodArgs

When developing an aspect, a developer can access information about the annotated method. Details such as the name of the method; its signature and return type. Also the list of parameters that are being passed into the method including type, name and value.

To achieve the above `MethodArgs` is used. This is the object passed into each aspect. During the weaving, an instance of `MethodArgs` is injected into each method, with all properties assembled dynamically to capture the information of the current executing method.

Being able to capture some information about the annotated methods will be useful. For example, in case of a profiling aspect, those information about the method at the time it was access will be helpful. Being able to look at the parameter values in case of error will also be extremely useful in case of debugging.

An early implementation instantiated a distinct instance of `MethodArgs` for each boundary aspects. Later on as an optimization only one instance is instantiated at the beginning of the method body and that instance is used in all the boundary aspects for a target method.

An example of how to use `MethodArgs` is presented in the user manual.

Chapter 4

Analysis

The project hypothesized that by using Buffalo, programmers can separate the cross-cutting concerns from their applications quickly and easily. Since the concerns are encapsulated in a distinct unit of code, it also enable programmers to easily maintain the aspects and modify them as needed.

One of the analysis performed is to write an aspect to catch unhandled exceptions in test programs. The size of the test programs varies from comprising of 50 methods to 1,000 methods. Suppose that to manually implement the exception handling, a programmer will have to write on average 5 lines of code to catch the exception.

Programs	Lines (Traditions)	Lines (Buffalo)
50	250	0-1
500	2,500	0-1
1,000	5,000	0-1

Table 4.1: Line counts

If exception handling is implemented for every method by hand, more line of the same try-catch block of code will have to be written as the application adds more methods. The number of line of repetitive code would increase linearly.

Lines of code have a direct correlation to the cost of the development as it will take programmers more time. And this will also have a direct impact on application release schedule.

By using a framework like Buffalo, unhandled exception can be centralized in one aspect, and then simply apply it to every method by applying it on the assembly level.

As a result the source code is free from the repetitive try-catch-finally blocks. The line of code we have to write is one line at most, and will stay constant even as more types and methods are added to the application. This will also give developer a peace of mind that every method will be handled automatically.

Buffalo allows developer to quickly create aspects that act as a complete profiler of the application. This is especially useful in case of debugging. If a problem is encountered with the application, it would be helpful if developer knows where in the method it goes wrong, and have a look at the internal state of the method at the time of failure.

A developer can easily access all those information to show the state of each annotated method. Information such as the method signature, and what parameters are being passed in, what their types are, and even record their respective values when they were passed in. This information will be very helpful to aid in bug fixing.

Buffalo has performed well in isolating cross-cutting concerns into single unit of code, that is easily maintained and modified.s

Chapter 5

Conclusions

5.1 Current Status

Buffalo is currently at version 0.2. It contains two types of aspect: `MethodBoundaryAspect`, where various execution points can be intercepted. And `MethodAroundAspect`, where a method can be completely replaced while preserving the option to call back into the original method.

5.2 Future Work

There are couple areas where Buffalo can be improved upon. Usability wise, currently there is no automatic setup program that install Buffalo onto users computer and integrate into MS-Build System. Some manual steps are needed in order to provide a more seamless experience.

Functionality wise, when Buffalo does post compilation weaving it starts fresh each time, it would be interesting to see how incremental weaving can be used here.

5.3 Lessons Learned

While framework such as Buffalo mitigates the problem of cross-cutting concerns. Still, to efficiently tackle the root of the problem, compiler vendors have to actively embrace the AOP concept and support it in the their languages natively.

Developers also have to understand the existant of such problems and solutions available to better educate themselves.

Only when the concept is widely understood and supported by both developers and vendors can there hope to begin eliminating such problems.

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Appendix A

Code Listing

Buffalo is a fairly compact framework for the current functionality. The full source code is around 1,200 lines, which is fully included here. Note the short listing entitled "buffalo/BufferAOP/Program.cs" at the end is the entire BufferAOP.exe program that kicks off the weaving.

```
1
2 namespace Buffalo
3 {
4     [System.AttributeUsage(System.AttributeTargets.Method,
5         AllowMultiple = false)]
6     public abstract class MethodAroundAspect : AspectBase, IMethodAroundAspect
7     {
8         public virtual object Invoke(MethodArgs args) { return null; }
9     }
10 }
```

Listing A.1: ../buffalo/MethodAroundAspect.cs

```
11 using System.Collections.Generic;
12
13 namespace Buffalo
14 {
15     public sealed class MethodArgs
16     {
17         private string name;
18         private string fullName;
19         private string returnTypeStr;
20         private string parameterStr;
21         private List<Parameter> parameters;
22         private object[] parameterArray;
23         private Exception exception;
24         private Object instance;
25
26         public MethodArgs()
27         {
28             this.parameters = new List<Parameter>();
29         }
30 }
```

```
31     public string Name
32     {
33         get { return this.name; }
34     }
35
36     public string FullName
37     {
38         get { return this.fullName; }
39     }
40
41     public Type ReturnType
42     {
43         get { return Type.GetType(this.returnTypeStr); }
44     }
45
46     public List<Parameter> Parameters
47     {
48         get { return this.parameters; }
49     }
50
51     public Exception Exception
52     {
53         get { return this.exception; }
54     }
55
56     public object Instance
57     {
58         get { return this.instance; }
59     }
60
61     public object[] ParameterArray
62     {
63         get { return this.parameterArray; }
64     }
65
66     public void SetProperties(string name,
67                             string fullname,
68                             string returnTypeStr,
69                             string parameterStr,
70                             object[] parameterArray,
71                             object instance = null)
72     {
73         this.name = name;
74         this.fullName = fullname;
75         this.returnTypeStr = returnTypeStr;
76         this.parameterStr = parameterStr;
77         this.parameterArray = parameterArray;
78         this.instance = instance;
79
80         var splits = this.parameterStr.Split(new char[] { '|' }, StringSplitOptions.RemoveEmptyEntries);
81         foreach (var split in splits)
82         {
83             var p = split.Split(new char[] { ':' }, StringSplitOptions.RemoveEmptyEntries);
84             this.parameters.Add(new Parameter { Name = p[0], Type = Type.GetType(p[1]) });
85         }
86
87         for (int i = 0; i < this.Parameters.Count; ++i)
88         {
```

```
89         this.Parameters[i].Value = this.parameterArray[i];
90     }
91 }
92
93 public void SetException(Exception exception)
94 {
95     this.exception = exception;
96 }
97
98 public object Proceed()
99 {
100     return null;
101 }
102 }
103 }
```

Listing A.2: ../buffalo/MethodArgs.cs

```
104 using Buffalo.Common;
105 using Mono.Cecil;
106
107 namespace Buffalo
108 {
109     internal class Aspect : IAspect
110     {
111         public Aspect()
112         {
113             this.AssemblyLevelStatus = Enums.Status.NotApplied;
114         }
115
116         public string Name { get; set; }
117
118         public Enums.Status AssemblyLevelStatus { get; set; }
119
120         public TypeDefinition TypeDefinition { get; set; }
121
122         public Buffalo.Common.Enums.BuffaloAspect BuffaloAspect { get; set; }
123
124         public override string ToString()
125         {
126             return this.Name;
127         }
128     }
129 }
```

Listing A.3: ../buffalo/Aspect.cs

```
130
131 namespace Buffalo
132 {
133     public abstract class MethodBoundaryAspect : AspectBase, IMethodBoundaryAspect
134     {
135         public virtual void OnBefore(MethodArgs args) { }
136
137         public virtual void OnAfter(MethodArgs args) { }
138
139         public virtual void OnSuccess(MethodArgs args) { }
```

```

140
141     public virtual void OnException(MethodArgs args) { }
142     }
143 }

```

Listing A.4: ../buffalo/MethodBoundaryAspect.cs

```

144 {
145     [System.AttributeUsage(System.AttributeTargets.All,
146         AllowMultiple = false)]
147     public abstract class AspectBase : System.Attribute
148     {
149         public AspectBase(bool attributeExclude = false)
150         {
151             this.AttributeExclude = attributeExclude;
152         }
153
154         public bool AttributeExclude { get; set; }
155     }
156 }

```

Listing A.5: ../buffalo/AspectBase.cs

```

157 using Buffalo.Extensions;
158 using Buffalo.Injectors;
159 using Buffalo.Interfaces;
160 using Mono.Cecil;
161 using Mono.Cecil.Cil;
162 using System;
163 using System.Collections.Generic;
164 using System.Collections.Specialized;
165 using System.IO;
166 using System.Linq;
167 using Reflection = System.Reflection;
168 using Mono.Collections.Generic;
169
170 namespace Buffalo
171 {
172     internal class Weaver
173     {
174         public Weaver(string assemblyPath)
175         {
176             //TODO: Maybe just don't do anything if file not found
177             if (!File.Exists(assemblyPath))
178                 throw new FileNotFoundException();
179
180             AssemblyPath = assemblyPath;
181             this.Init();
182         }
183
184         static internal string AssemblyPath { get; set; }
185
186         static internal List<Aspect> Aspects { get; set; }
187
188         static internal Dictionary<string, Type> UnderlyingAspectTypes { get; set; }
189
190         internal Dictionary<MethodDefinition, List<Aspect>> EligibleMethods { get; set; }

```

```

191
192     internal List<TypeDefinition> TypeDefinitions { get; set; }
193
194     internal AssemblyDefinition AssemblyDefinition { get; set; }
195
196     internal StringCollection NewMethodNames { get; set; }
197
198     internal void Inject()
199     {
200         var injectors = new List<IInjectable>();
201
202         //apply the around aspect if necessary
203         var aroundAspectExist = this.EligibleMethods.Values.Any(x =>
204             x.Any(y => y.BuffaloAspect == Enums.BuffaloAspect.MethodAroundAspect));
205         if (aroundAspectExist)
206             injectors.Add(new MethodAroundInjector());
207
208         //apply the boundary aspect if necessary
209         var boundaryAspectExist = this.EligibleMethods.Values.Any(x =>
210             x.Any(y => y.BuffaloAspect == Enums.BuffaloAspect.MethodBoundaryAspect));
211         if (boundaryAspectExist)
212             injectors.Add(new MethodBoundaryInjector());
213
214         //inject
215         injectors.ForEach(x => x.Inject(this.AssemblyDefinition, this.EligibleMethods));
216
217         //write out the modified assembly
218         this.AssemblyDefinition.Write2(AssemblyPath);
219         Console.WriteLine("DONE");
220     }
221
222     private void Init()
223     {
224         //initialize the variables
225         Aspects = new List<Aspect>();
226         NewMethodNames = new StringCollection();
227         this.TypeDefinitions = new List<TypeDefinition>();
228         this.EligibleMethods = new Dictionary<MethodDefinition, List<Aspect>>();
229         //set the resolver in case assembly is in different directory
230         var resolver = new DefaultAssemblyResolver();
231         resolver.AddSearchDirectory(new FileInfo(AssemblyPath).Directory.FullName);
232         var parameters = new ReaderParameters { AssemblyResolver = resolver };
233         this.AssemblyDefinition = AssemblyDefinition.ReadAssembly(AssemblyPath, parameters);
234         //populate the type definition first
235         foreach (var m in this.AssemblyDefinition.Modules)
236             m.Types.ToList().ForEach(x => this.TypeDefinitions.Add(x));
237         //if aspects are defined in a different assembly?
238         var typedefs = this.FindAspectTypeDefinition();
239         this.TypeDefinitions = this.TypeDefinitions.Union(typedefs).ToList();
240         //extract aspects from the type definitions
241         this.TypeDefinitions
242             .Where(x => x.BaseType != null)
243             .ToList()
244             .ForEach(x =>
245             {
246                 Buffalo.Common.Enums.BuffaloAspect? ba = null;
247                 if (x.BaseType.FullName == typeof(MethodBoundaryAspect).FullName)
248                     ba = Enums.BuffaloAspect.MethodBoundaryAspect;

```

```

249         else if (x.BaseType.FullName == typeof(MethodAroundAspect).FullName)
250             ba = Enums.BuffaloAspect.MethodAroundAspect;
251         if(ba.HasValue)
252             Aspects.Add(new Aspect { Name = x.FullName, TypeDefinition = x, BuffaloAspect = ba.Value });
253     });
254     Aspects.ForEach(x => x.AssemblyLevelStatus = this.CheckAspectStatus(this.AssemblyDefinition, x));
255     //finally, get all the eligible methods for each aspect
256     Aspects
257         .Where(x => x.AssemblyLevelStatus != Enums.Status.Excluded)
258         .ToList()
259         .ForEach(x =>
260             {
261         #if DEBUG
262             Console.WriteLine("Aspect {0}: {1}", x.Name, x.AssemblyLevelStatus.ToString());
263             Console.WriteLine("=====");
264         #endif
265             this.CheckEligibleMethods(x);
266             Console.WriteLine("");
267         });
268     }
269
270     private List<TypeDefinition> FindAspectTypeDefinition()
271     {
272         //look for aspect in this assembly, if aspect is defined in a different
273         //assembly, import it here.
274         var types = this.AssemblyDefinition.MainModule.Types;
275         var tdefs = this.FindAspectsFromAttributes(this.AssemblyDefinition.CustomAttributes);
276
277         //loop thru the custom attributes of each type, resolve them to find aspects
278         foreach (var type in types)
279         {
280             //if (type.CustomAttributes.Count == 0) continue;
281             var tmp = this.FindAspectsFromAttributes(type.CustomAttributes);
282             tdefs.AddRange(tmp);
283             foreach (var m in type.Methods)
284             {
285                 tdefs.AddRange(this.FindAspectsFromAttributes(m.CustomAttributes));
286             }
287         }
288
289         return tdefs;
290     }
291
292     private List<TypeDefinition> FindAspectsFromAttributes(Collection<CustomAttribute> customAttributes)
293     {
294         var tdefs = new List<TypeDefinition>();
295         foreach (var ca in customAttributes)
296         {
297             var car = ca.AttributeType.Resolve();
298             if (car.BaseType.FullName == typeof(MethodBoundaryAspect).FullName
299                 || car.BaseType.FullName == typeof(MethodAroundAspect).FullName)
300             {
301                 if (!tdefs.Contains(car))
302                     tdefs.Add(car);
303             }
304         }
305         return tdefs;
306     }

```

```

307
308     private void PrintEligibleMethods()
309     {
310         foreach (var de in this.EligibleMethods)
311         {
312             Console.WriteLine(de.Key.FullName);
313             foreach (var a in de.Value)
314                 Console.WriteLine("\t" + a.Name);
315         }
316     }
317
318     private void CheckEligibleMethods(Aspect aspect)
319     {
320         foreach (var t in this.TypeDefinitions.Where(x => !x.Name.Equals("<Module>")
321             && (x.BaseType == null || (x.BaseType.FullName != typeof(MethodBoundaryAspect).FullName
322             && x.BaseType.FullName != typeof(MethodAroundAspect).FullName))))
323         {
324             var status = this.CheckAspectStatus(t, aspect);
325             #if DEBUG
326             Console.WriteLine("\t{0}: {1}", t.Name, status.ToString());
327             #endif
328             if (status == Enums.Status.Excluded)
329                 continue;
330
331             var mths = this.GetMethodDefinitions(t, status, aspect);
332             mths.ForEach(x =>
333             {
334                 if (!this.EligibleMethods.ContainsKey(x))
335                 {
336                     this.EligibleMethods.Add(x, new List<Aspect>() { aspect });
337                 }
338                 else
339                 {
340                     var aspects = this.EligibleMethods[x];
341                     aspects.Add(aspect);
342                 }
343             });
344         }
345     }
346
347     private List<MethodDefinition> GetMethodDefinitions(TypeDefinition typeDef, Enums.Status typeStatus, Aspect aspect)
348     {
349         var list = new List<MethodDefinition>();
350         foreach (var method in typeDef.Methods)
351         {
352             var status = this.CheckAspectStatus(method, aspect);
353             if (status == Enums.Status.Applied)
354             {
355                 list.Add(method);
356             }
357             else
358             {
359                 if (typeStatus == Enums.Status.Applied && status != Enums.Status.Excluded)
360                 {
361                     status = Enums.Status.Applied;
362                     list.Add(method);
363                 }
364             }
365         }

```

```

365 #if DEBUG
366         Console.WriteLine("\t\t{0}: {1}", method.Name, status.ToString());
367 #endif
368     }
369
370     return list;
371 }
372
373 /// <summary>
374 /// A TypeDefinition and MethodDefinition both implement the
375 /// ICustomAttributeProvider interface, so it can be used here
376 /// to determined if a method is marked as exclude or not.
377 /// </summary>
378 private Enums.Status CheckAspectStatus(ICustomAttributeProvider def, Aspect aspect)
379 {
380     Enums.Status status = aspect.AssemblyLevelStatus;
381
382     bool attrFound = false;
383     for (int i = 0; i < def.CustomAttributes.Count; ++i)
384     {
385         if (def.CustomAttributes[i].AttributeType.FullName.Equals("System.Runtime.CompilerServices.CompilerGeneratedAttribute"))
386         {
387             status = Enums.Status.Excluded;
388             break;
389         }
390
391         if (aspect.TypeDefinition != null
392             && (aspect.BuffaloAspect == Enums.BuffaloAspect.MethodBoundaryAspect
393                 || aspect.BuffaloAspect == Enums.BuffaloAspect.MethodAroundAspect)
394             && def.CustomAttributes[i].AttributeType.FullName.Equals(aspect.Name))
395         {
396             attrFound = true;
397             if (def.CustomAttributes[i].Properties.Count == 0)
398             {
399                 status = Enums.Status.Applied;
400             }
401             else
402             {
403                 var exclude = def.CustomAttributes[i].Properties.FirstOrDefault(x => x.Name == "AttributeExclude");
404                 if (exclude.Argument.Value != null && (bool)exclude.Argument.Value == true)
405                 {
406                     status = Enums.Status.Excluded;
407                     def.CustomAttributes.RemoveAt(i);
408                 }
409             }
410         }
411     }
412
413     if (!attrFound && aspect.AssemblyLevelStatus == Enums.Status.Applied)
414     {
415         //this aspect is applied on the assembly level and
416         //as a result the type and method might not have the
417         //attributed annotated, this is to programmatically add
418         //in the annotation so IL can be generated correctly.
419         var ctor = aspect.TypeDefinition.Methods.First(x => x.IsConstructor);
420         var ctoref = this.AssemblyDefinition.MainModule.Import(ctor);
421         def.CustomAttributes.Add(new CustomAttribute(ctoref));
422     }

```



```

423
424         return status;
425     }
426 }
427 }

```

Listing A.6: ../buffalo/Weaver.cs

```

428
429 namespace Buffalo
430 {
431     public sealed class Parameter
432     {
433         public Type Type { get; set; }
434
435         public string Name { get; set; }
436
437         public object Value { get; set; }
438     }
439 }

```

Listing A.7: ../buffalo/Parameter.cs

```

440 using Buffalo.Interfaces;
441 using Mono.Cecil;
442 using Mono.Cecil.Cil;
443 using System;
444 using System.Collections.Generic;
445 using System.Collections.Specialized;
446 using System.Linq;
447
448 namespace Buffalo.Injectors
449 {
450     internal class MethodAroundInjector : IInjectable
451     {
452         AssemblyDefinition AssemblyDefinition;
453         Dictionary<MethodDefinition, List<Aspect>> EligibleMethods;
454
455         public void Inject(Mono.Cecil.AssemblyDefinition assemblyDefinition,
456             Dictionary<Mono.Cecil.MethodDefinition, List<Aspect>> eligibleMethods)
457         {
458             /* The around aspect is to intercept all calls to the target method, and
459              * replace those calls with a completely different method. While preserving
460              * the option to call back to the target method when necessary.
461              */
462             this.AssemblyDefinition = assemblyDefinition;
463             this.EligibleMethods = eligibleMethods;
464             var NewMethodNames = new StringCollection();
465             var eligibleAroundMethods = this.EligibleMethods.Where(x => x.Value.Any(y =>
466                 y.BuffaloAspect == Common.Enums.BuffaloAspect.MethodAroundAspect));
467             foreach (var d in eligibleAroundMethods)
468             {
469                 var method = d.Key;
470                 var aspects = d.Value;
471                 var il = method.Body.GetILProcessor();
472                 var methodType = method.DeclaringType;
473                 var maInstructions = new List<Instruction>();

```

```

474     var aspectVarInstructions = new List<Instruction>();
475     var aroundInstructions = new List<Instruction>();
476
477     foreach (var aspect in aspects.Where(x =>
478         x.BuffaloAspect == Common.Enums.BuffaloAspect.MethodAroundAspect))
479     {
480         //if aspect is from a different assembly, need to work from that context
481         var aspect = aspect;
482         var writedll = false;
483         AssemblyDefinition ass = null;
484         if (!aspect.TypeDefinition.Module.FullyQualifiedName.Equals(
485             this.AssemblyDefinition.MainModule.FullyQualifiedName))
486         {
487             ass = AssemblyDefinition.ReadAssembly(aspect.TypeDefinition.Module.FullyQualifiedName);
488             var asp = ass.MainModule.Types.FirstOrDefault(x => x.FullName == aspect.Name);
489             if (asp != null)
490             {
491                 var newaspect = new Aspect { Name = asp.FullName, TypeDefinition = asp, BuffaloAspect = Common.Enums.BuffaloAspect.MethodAroundAspect };
492                 aspect = newaspect;
493                 writedll = true;
494             }
495         }
496
497         var varTicks = System.DateTime.Now.Ticks;
498
499         //create a replacement for the annotated function
500         var methodName = string.Format("{0}{1}", method.Name, varTicks);
501         MethodDefinition newmethod =
502             new MethodDefinition(methodName, method.Attributes, method.ReturnType);
503         methodType.Methods.Add(newmethod);
504         NewMethodNames.Add(methodName);
505         //newmethod.Body.SimplifyMacros();
506         newmethod.Body.InitLocals = true;
507
508         //create aspect variable
509         var varAspectName = "asp" + varTicks;
510         var varAspectRef = this.AssemblyDefinition.MainModule.Import(aspect.TypeDefinition);
511         var varAspect = new VariableDefinition(varAspectName, varAspectRef);
512         newmethod.Body.Variables.Add(varAspect);
513         var varAspectIdx = newmethod.Body.Variables.Count - 1;
514         var ctor = aspect.TypeDefinition.Methods.First(x => x.IsConstructor);
515         var ctoref = this.AssemblyDefinition.MainModule.Import(ctor);
516         //store the newly created aspect variable
517         newmethod.Body.Instructions.Add(Instruction.Create(OpCodes.Newobj, ctoref));
518         newmethod.Body.Instructions.Add(Instruction.Create(OpCodes.Stloc, varAspect));
519         //copy all the paramters
520         method.Parameters.ToList().ForEach(x =>
521             newmethod.Parameters.Add(new ParameterDefinition(x.Name, x.Attributes, x.ParameterType)));
522         //create a MethodArgs
523         var var = newmethod.AddMethodArgsVariable(this.AssemblyDefinition);
524
525         #region Calling MethodArgs.Invoke
526         newmethod.Body.Instructions.Add(Instruction.Create(OpCodes.Ldloc, varAspect));
527         newmethod.Body.Instructions.Add(Instruction.Create(OpCodes.Ldloc, var.Var));
528         var aspectInvoke = aspect.TypeDefinition.Methods.First(x => x.Name.Equals("Invoke"));
529         var aspectInvokeRef =
530             this.AssemblyDefinition.MainModule.Import(aspectInvoke, newmethod);
531         newmethod.Body.Instructions.Add(Instruction.Create(OpCodes.Callvirt, aspectInvokeRef));

```

```

532         #endregion
533
534     #region Handling return value
535     if (!newmethod.ReturnType.FullName.Equals("System.Void"))
536     {
537         //create an object variable to hold the return value
538         var varObj = new VariableDefinition("obj" + varTicks,
539             this.AssemblyDefinition.MainModule.Import(typeof(object)));
540         newmethod.Body.Variables.Add(varObj);
541         newmethod.Body.Instructions.Add(
542             Instruction.Create(OpCodes.Stloc, varObj));
543         newmethod.Body.Instructions.Add(
544             Instruction.Create(OpCodes.Ldloc, varObj));
545         newmethod.Body.Instructions.Add(
546             Instruction.Create(OpCodes.Unbox_Any, newmethod.ReturnType));
547     }
548     else
549     {
550         //pop the return value since it's not used?
551         newmethod.Body.Instructions.Add(
552             Instruction.Create(OpCodes.Pop));
553     }
554     #endregion
555
556     #region Handling Proceed()
557     var invoke = aspect.TypeDefinition.Methods.FirstOrDefault(
558         x => x.FullName.Contains("::Invoke(Buffalo.MethodArgs)"));
559     var containProceed = invoke.Body.Instructions.Any(x => x.ToString().Contains("System.Object Buffalo.MethodArgs::Proceed"));
560
561     while (containProceed)
562     {
563         bool found = false;
564         int instIdx = 0;
565         for (; instIdx < invoke.Body.Instructions.Count; ++instIdx)
566         {
567             if (invoke.Body.Instructions[instIdx].ToString()
568                 .Contains("System.Object Buffalo.MethodArgs::Proceed"))
569             {
570                 found = true;
571                 break;
572             }
573         }
574
575         if (found)
576         {
577             #region Modified the call
578             var invokeInstructions = new List<Instruction>();
579             invoke.Body.Instructions.RemoveAt(instIdx);
580             var startIdx = instIdx;
581
582             //create a var to hold the original method type instance
583             var instance = new VariableDefinition("instance" + DateTime.Now.Ticks,
584                 this.AssemblyDefinition.MainModule.Import(typeof(object)));
585             invoke.Body.Variables.Add(instance);
586             invoke.Body.InitLocals = true;
587
588             //get the instance obj from MethodArgs
589             var getInstance = typeof(MethodArgs).GetMethod("get_Instance");

```

```

590     var getInstanceRef = this.AssemblyDefinition.MainModule.Import(getInstance);
591     var getInstanceRef2 = aspect.TypeDefinition.Module.Import(getInstance);
592     invokeInstructions.Add(Instruction.Create(OpCodes.Callvirt, getInstanceRef2));
593     invokeInstructions.Add(Instruction.Create(OpCodes.Stloc, instance));
594
595     //create object array to hold ParameterArray
596     var objType = this.AssemblyDefinition.MainModule.Import(typeof(object));
597     var objArray = new ArrayType(objType);
598     var varArray = new VariableDefinition("va" + DateTime.Now.Ticks,
599         (TypeReference)objArray);
600     invoke.Body.Variables.Add(varArray);
601     var getParameterArray = typeof(MethodArgs).GetMethod("get_ParameterArray");
602     var getParameterArrayRef = this.AssemblyDefinition.MainModule.Import(getParameterArray);
603     var getParameterArrayRef2 = aspect.TypeDefinition.Module.Import(getParameterArray);
604     invokeInstructions.Add(Instruction.Create(OpCodes.Ldarg_1));
605     invokeInstructions.Add(Instruction.Create(OpCodes.Callvirt, getParameterArrayRef2));
606     invokeInstructions.Add(Instruction.Create(OpCodes.Stloc, varArray));
607
608     //modify the Invoke() instruction to make a call to the original method
609     invokeInstructions.Add(Instruction.Create(OpCodes.Ldloc, instance));
610     var classref = aspect.TypeDefinition.Module.Import(method.DeclaringType);
611     invokeInstructions.Add(Instruction.Create(OpCodes.Unbox_Any, classref));
612     if (method.Parameters.Count > 0)
613     {
614         for (int i = 0; i < method.Parameters.Count; ++i)
615         {
616             var ptype = aspect.TypeDefinition.Module.Import(method.Parameters[i].ParameterType);
617             invokeInstructions.Add(Instruction.Create(OpCodes.Ldloc, varArray));
618             invokeInstructions.Add(il.Create(OpCodes.Ldc_I4, i));
619             invokeInstructions.Add(il.Create(OpCodes.Ldelem_Ref));
620             invokeInstructions.Add(Instruction.Create(OpCodes.Unbox_Any, ptype));
621         }
622     }
623
624     //make the call
625     var methodRef = aspect.TypeDefinition.Module.Import(method);
626     invokeInstructions.Add(Instruction.Create(OpCodes.Callvirt, methodRef));
627
628     #region Handling return value
629     if (!method.ReturnType.FullName.Equals("System.Void"))
630     {
631         //create an object variable to hold the return value
632         var varObj = new VariableDefinition("obj" + DateTime.Now.Ticks,
633             this.AssemblyDefinition.MainModule.Import(typeof(object)));
634         var retype = aspect.TypeDefinition.Module.Import(method.ReturnType);
635         invoke.Body.Variables.Add(varObj);
636         invokeInstructions.Add(
637             Instruction.Create(OpCodes.Box, retype));
638     }
639     else
640     {
641         //method is suppose to return void, but since
642         //previously it calls Proceed() which returns object type,
643         //we need to handle that.
644         invoke.Body.Instructions[instrIdx] = Instruction.Create(OpCodes.Nop);
645     }
646     #endregion
647

```

```

648         //write out the instruction
649         invokeInstructions.ForEach(
650             x => invoke.Body.Instructions.Insert(startIdx++, x));
651
652         #endregion
653     }
654
655     containProceed = invoke.Body.Instructions.Any(x => x.ToString().Contains("System.Object Buffalo.MethodArgs::Proceed"));
656 }
657
658 #endregion
659
660 #region Modify all calls from origin to the generated method
661 foreach (var type in this.AssemblyDefinition.MainModule.Types
662     .Where(x => x.BaseType == null || !x.BaseType.FullName.Equals("Buffalo.MethodAroundAspect")))
663 {
664     var methods = type.Methods.Where(x => !NewMethodNames.Contains(x.Name));
665     foreach (var m in methods)
666     {
667         for (int j = 0; j < m.Body.Instructions.Count; ++j)
668         {
669             if (m.Body.Instructions[j].ToString().Contains(method.FullName))
670             {
671                 m.Body.Instructions[j].Operand = newmethod;
672                 //MethodArgs.Invoke returns an object, need to unbox it here to the original type
673                 //However, unboxing is needed only if the original method has a return type
674                 //other than void
675                 if (!newmethod.ReturnType.FullName.Equals("System.Void"))
676                 {
677                     //var unbox = Instruction.Create(OpCodes.Unbox_Any, newmethod.ReturnType);
678                     //var il2 = m.Body.GetILProcessor();
679                     //il2.InsertAfter(m.Body.Instructions[j], unbox);
680                 }
681             }
682         }
683     }
684 }
685 #endregion
686
687 newmethod.Body.Instructions.Add(Instruction.Create(OpCodes.Ret));
688 if (wroteIl)
689 {
690     ass.Write2(ass.MainModule.FullyQualifiedName);
691 }
692 }
693 }
694 }
695 }
696 }

```

Listing A.8: ../buffalo/Injectors/MethodAroundInjector.cs

```

697 using Buffalo.Extensions;
698 using Buffalo.Interfaces;
699 using Mono.Cecil;
700 using Mono.Cecil.Cil;
701 using System;
702 using System.Collections.Generic;

```

```

703 using System.Linq;
704
705 namespace Buffalo.Injectors
706 {
707     internal class MethodBoundaryInjector : IInjectable
708     {
709         AssemblyDefinition AssemblyDefinition;
710         Dictionary<MethodDefinition, List<Aspect>> EligibleMethods;
711
712         public void Inject(AssemblyDefinition assemblyDefinition, Dictionary<MethodDefinition, List<Aspect>> eligibleMethods)
713         {
714             this.AssemblyDefinition = assemblyDefinition;
715             this.EligibleMethods = eligibleMethods;
716
717             var ems = this.EligibleMethods.ToList();
718             var eligibleBoundaryMethods = ems.Where(x => x.Value.Any(y =>
719                 y.BuffaloAspect == Enums.BuffaloAspect.MethodBoundaryAspect));
720             foreach (var d in eligibleBoundaryMethods)
721             {
722                 var method = d.Key;
723                 if (method.Body == null)
724                 {
725                     #if DEBUG
726                         Console.WriteLine(string.Format("{0} has empty body, skipping", method.FullName));
727                     #endif
728                     continue;
729                 }
730                 var aspects = d.Value;
731                 var il = method.Body.GetILProcessor();
732                 var voidType = method.ReturnType.FullName.Equals("System.Void");
733                 var ret = il.Create(OpCodes.Ret);
734
735                 var maInstructions = new List<Instruction>();
736                 var aspectVarInstructions = new List<Instruction>();
737                 var beforeInstructions = new List<Instruction>();
738                 var successInstructions = new List<Instruction>();
739                 var exceptionInstructions = new List<Instruction>();
740                 var afterInstructions = new List<Instruction>();
741
742                 #region Method detail
743                 //create a MethodArgs
744                 var var = method.AddMethodArgsVariable(this.AssemblyDefinition);
745                 #endregion
746
747                 #region Before, Success, Exception, After
748                 var varExpTypeRef = this.AssemblyDefinition.MainModule.Import(typeof(System.Exception));
749                 for (int i = 0; i < aspects.Count; ++i)
750                 {
751                     #region Create an aspect variable
752                     var varAspectName = "asp" + System.DateTime.Now.Ticks;
753                     var varAspectRef = this.AssemblyDefinition.MainModule.Import(aspects[i].TypeDefinition);
754                     var varAspect = new VariableDefinition(varAspectName, varAspectRef);
755                     method.Body.Variables.Add(varAspect);
756                     var varAspectIdx = method.Body.Variables.Count - 1;
757                     var ctor = aspects[i].TypeDefinition.Methods.First(x => x.IsConstructor);
758                     var ctoref = this.AssemblyDefinition.MainModule.Import(ctor);
759                     aspectVarInstructions.Add(Instruction.Create(OpCodes.Newobj, ctoref));
760                     aspectVarInstructions.Add(Instruction.Create(OpCodes.Stloc, varAspect));

```

```

761         #endregion
762
763     #region Before, success, exception
764     var before = method.FindMethodReference(aspects[i], Enums.AspectType.OnBefore);
765     if (before != null)
766     {
767
768         beforeInstructions.Add(Instruction.Create(OpCodes.Ldloc, varAspect));
769         beforeInstructions.Add(Instruction.Create(OpCodes.Ldloc, var.Var));
770         var aspectBefore = aspects[i].TypeDefinition.Methods.FirstOrDefault(
771             x => x.Name == Enums.AspectType.OnBefore.ToString());
772         //this import is needed in case this aspect is defined in different assembly?
773         var aspectBeforeRef = this.AssemblyDefinition.MainModule.Import(aspectBefore);
774         beforeInstructions.Add(Instruction.Create(OpCodes.Callvirt, aspectBeforeRef));
775     }
776
777     var success = method.FindMethodReference(aspects[i], Enums.AspectType.OnSuccess);
778     if (success != null)
779     {
780         successInstructions.Add(Instruction.Create(OpCodes.Ldloc, varAspect));
781         successInstructions.Add(Instruction.Create(OpCodes.Ldloc, var.Var));
782         var aspectSuccess = aspects[i].TypeDefinition.Methods.FirstOrDefault(
783             x => x.Name == Enums.AspectType.OnSuccess.ToString());
784         var aspectSuccessRef = this.AssemblyDefinition.MainModule.Import(aspectSuccess);
785         successInstructions.Add(Instruction.Create(OpCodes.Callvirt, aspectSuccessRef));
786     }
787
788     var exception = method.FindMethodReference(aspects[i], Enums.AspectType.OnException);
789     if (exception != null)
790     {
791         var expName = "exp" + System.DateTime.Now.Ticks;
792         var varExp = new VariableDefinition(expName, varExpTypeRef);
793         method.Body.Variables.Add(varExp);
794         exceptionInstructions.Add(Instruction.Create(OpCodes.Stloc, varExp));
795         exceptionInstructions.Add(Instruction.Create(OpCodes.Ldloc, var.Var));
796         exceptionInstructions.Add(Instruction.Create(OpCodes.Ldloc, varExp));
797         var maSetException = typeof(MethodArgs).GetMethod("SetException");
798         var maSetExceptionRef = this.AssemblyDefinition.MainModule.Import(maSetException, method);
799         exceptionInstructions.Add(Instruction.Create(OpCodes.Callvirt, maSetExceptionRef));
800
801         exceptionInstructions.Add(Instruction.Create(OpCodes.Ldloc, varAspect));
802         exceptionInstructions.Add(Instruction.Create(OpCodes.Ldloc, var.Var));
803         var aspectException = aspects[i].TypeDefinition.Methods.FirstOrDefault(
804             x => x.Name == Enums.AspectType.OnException.ToString());
805         var aspectExceptionRef = this.AssemblyDefinition.MainModule.Import(aspectException);
806         exceptionInstructions.Add(Instruction.Create(OpCodes.Callvirt, aspectExceptionRef));
807     }
808
809     var after = method.FindMethodReference(aspects[i], Enums.AspectType.OnAfter);
810     if (after != null)
811     {
812         afterInstructions.Add(Instruction.Create(OpCodes.Ldloc, varAspect));
813         afterInstructions.Add(Instruction.Create(OpCodes.Ldloc, var.Var));
814         var aspectAfter = aspects[i].TypeDefinition.Methods.FirstOrDefault(
815             x => x.Name == Enums.AspectType.OnAfter.ToString());
816         var aspectAfterRef = this.AssemblyDefinition.MainModule.Import(aspectAfter);
817         afterInstructions.Add(Instruction.Create(OpCodes.Callvirt, aspectAfterRef));
818     }

```

```

819         #endregion
820     }
821
822     int varIdx = var.VarIdx;
823     //mainInstructions.ForEach(x => method.Body.Instructions.Insert(varIdx++, x));
824     aspectVarInstructions.ForEach(x => method.Body.Instructions.Insert(varIdx++, x));
825
826     int beforeIdx = varIdx;
827     //perform this only if user overrides Before() in the aspect
828     if (beforeInstructions.Count > 0)
829     {
830         beforeInstructions.ForEach(x => method.Body.Instructions.Insert(beforeIdx++, x));
831     }
832
833     /* the last instruction after success should jump to return, or 3 instruction before
834     * return if return type is not void, or as an optimization, maybe we can even skip
835     * directly to last() - 2?
836     */
837     var successRet = voidType ? method.Body.Instructions.Last() :
838         method.Body.Instructions[method.Body.Instructions.Count - 3];
839     Instruction successLeave = il.Create(OpCodes.Leave, successRet);
840     ///TODO: need to double check the format of the MSIL return
841     ///br.s, ldloc, ret when return type is not void, thereby decrement by 3
842     int successIdx = voidType ? method.Body.Instructions.Count - 1 : method.Body.Instructions.Count - 3;
843     //perform this only if user overrides Success() in the aspect
844     successInstructions.Add(successLeave);
845     if (successInstructions.Count > 0)
846     {
847         successInstructions.ForEach(x => method.Body.Instructions.Insert(successIdx++, x));
848     }
849
850     int exceptionIdx = voidType ? method.Body.Instructions.Count - 1 : method.Body.Instructions.Count - 3;
851     int exceptionIdxConst = exceptionIdx;
852     var exceptionRet = voidType ? method.Body.Instructions.Last() :
853         method.Body.Instructions[method.Body.Instructions.Count - 3];
854     Instruction exceptionLeave = il.Create(OpCodes.Leave, exceptionRet);
855     //perform this only if user overrides Exception() in the aspect
856     if (exceptionInstructions.Count > 0)
857     {
858         exceptionInstructions.Add(exceptionLeave);
859         exceptionInstructions.ForEach(x => method.Body.Instructions.Insert(exceptionIdx++, x));
860     }
861
862     var afterRet = voidType ? method.Body.Instructions.Last() :
863         method.Body.Instructions[method.Body.Instructions.Count - 3];
864     var endfinally = il.Create(OpCodes.Endfinally);
865     int afterIdx = voidType ? method.Body.Instructions.Count - 1 : method.Body.Instructions.Count - 3;
866     int afterIdxConst = afterIdx;
867     //perform this only if user overrides After() in the aspect
868     if (afterInstructions.Count > 0)
869     {
870         afterInstructions.Add(endfinally);
871         afterInstructions.ForEach(x => method.Body.Instructions.Insert(afterIdx++, x));
872     }
873
874     #endregion
875
876     #region Catch..Finally..

```



```

877         //add the catch block only if user overrides Exception() in the aspect
878         if (exceptionInstructions.Count > 0)
879         {
880             var catchHandler = new ExceptionHandler(ExceptionHandlerType.Catch)
881             {
882                 TryStart = method.Body.Instructions[varIdx],
883                 TryEnd = successLeave.Next,
884                 HandlerStart = method.Body.Instructions[exceptionIdxConst],
885                 HandlerEnd = exceptionLeave.Next,
886                 CatchType = varExpTypeRef,
887             };
888             method.Body.ExceptionHandlers.Add(catchHandler);
889         }
890
891         //add the finally block only if user overrides After() in the aspect
892         if (afterInstructions.Count > 0)
893         {
894             var finallyHandler = new ExceptionHandler(ExceptionHandlerType.Finally)
895             {
896                 TryStart = method.Body.Instructions[varIdx],
897                 TryEnd = method.Body.Instructions[afterIdxConst],
898                 HandlerStart = method.Body.Instructions[afterIdxConst],
899                 HandlerEnd = afterRet,
900                 CatchType = null,
901             };
902             method.Body.ExceptionHandlers.Add(finallyHandler);
903         }
904         #endregion
905     }
906 }
907 }
908 }

```

Listing A.9: ../buffalo/Injectors/MethodBoundaryInjector.cs

```

909 using System.Runtime.CompilerServices;
910 using System.Runtime.InteropServices;
911
912 // General Information about an assembly is controlled through the following
913 // set of attributes. Change these attribute values to modify the information
914 // associated with an assembly.
915 [assembly: AssemblyTitle("Buffalo")]
916 [assembly: AssemblyDescription("")]
917 [assembly: AssemblyConfiguration("")]
918 [assembly: AssemblyCompany("Microsoft")]
919 [assembly: AssemblyProduct("Buffalo")]
920 [assembly: AssemblyCopyright("Copyright Microsoft 2012")]
921 [assembly: AssemblyTrademark("")]
922 [assembly: AssemblyCulture("")]
923
924 // Setting ComVisible to false makes the types in this assembly not visible
925 // to COM components. If you need to access a type in this assembly from
926 // COM, set the ComVisible attribute to true on that type.
927 [assembly: ComVisible(false)]
928
929 // The following GUID is for the ID of the typelib if this project is exposed to COM
930 [assembly: Guid("625c6e79-7034-48cf-8689-b9e44f3bf96d")]
931

```

```
932 // Version information for an assembly consists of the following four values:
933 //
934 // Major Version
935 // Minor Version
936 // Build Number
937 // Revision
938 //
939 // You can specify all the values or you can default the Build and Revision Numbers
940 // by using the '*' as shown below:
941 // [assembly: AssemblyVersion("1.0.*")]
942 [assembly: AssemblyVersion("0.1.0.0")]
943 [assembly: AssemblyFileVersion("0.1.0.0")]
944 [assembly: InternalsVisibleTo("BuffaloAOP")]
```

Listing A.10: ../buffalo/Properties/AssemblyInfo.cs

```
945
946 namespace Buffalo.Common
947 {
948     internal struct BeginEndMarker
949     {
950         public int BeginIndex { get; set; }
951         public int EndIndex { get; set; }
952     }
953 }
```

Listing A.11: ../buffalo/Common/BeginEndMarker.cs

```
954 {
955     internal class Enums
956     {
957         internal enum Status
958         {
959             Applied,
960             NotApplied,
961             Excluded
962         }
963
964         internal enum AspectType
965         {
966             OnBefore,
967             OnAfter,
968             OnSuccess,
969             OnException,
970             Invoke
971         }
972
973         internal enum BuffaloAspect
974         {
975             MethodBoundaryAspect,
976             MethodAroundAspect
977         }
978     }
979 }
```

Listing A.12: ../buffalo/Common/Enums.cs


```

1037         continue;
1038
1039         instructions.Add(Instruction.Create(OpCodes.Ldloc, varArray));
1040         instructions.Add(Instruction.Create(OpCodes.Ldc_I4, i));
1041         if (method.IsStatic)
1042             instructions.Add(il.Create(OpCodes.Ldarg, i));
1043         else
1044             instructions.Add(il.Create(OpCodes.Ldarg, i + 1));
1045
1046         isValueType = false;
1047         var pType = method.Parameters[i].ParameterType;
1048         if (pType.IsByReference)
1049         {
1050             typeSpec = pType as TypeSpecification;
1051             if (typeSpec != null)
1052             {
1053                 switch (typeSpec.ElementType.MetadataType)
1054                 {
1055                     case MetadataType.Boolean:
1056                     case MetadataType.SByte:
1057                         instructions.Add(Instruction.Create(OpCodes.Ldind_I1));
1058                         isValueType = true;
1059                         break;
1060                     case MetadataType.Int16:
1061                         instructions.Add(Instruction.Create(OpCodes.Ldind_I2));
1062                         isValueType = true;
1063                         break;
1064                     case MetadataType.Int32:
1065                         instructions.Add(Instruction.Create(OpCodes.Ldind_I4));
1066                         isValueType = true;
1067                         break;
1068                     case MetadataType.Int64:
1069                     case MetadataType.UInt64:
1070                         instructions.Add(Instruction.Create(OpCodes.Ldind_I8));
1071                         isValueType = true;
1072                         break;
1073                     case MetadataType.Byte:
1074                         instructions.Add(Instruction.Create(OpCodes.Ldind_U1));
1075                         isValueType = true;
1076                         break;
1077                     case MetadataType.UInt16:
1078                         instructions.Add(Instruction.Create(OpCodes.Ldind_U2));
1079                         isValueType = true;
1080                         break;
1081                     case MetadataType.UInt32:
1082                         instructions.Add(Instruction.Create(OpCodes.Ldind_U4));
1083                         isValueType = true;
1084                         break;
1085                     case MetadataType.Single:
1086                         instructions.Add(Instruction.Create(OpCodes.Ldind_R4));
1087                         isValueType = true;
1088                         break;
1089                     case MetadataType.Double:
1090                         instructions.Add(Instruction.Create(OpCodes.Ldind_R8));
1091                         isValueType = true;
1092                         break;
1093                     case MetadataType.IntPtr:
1094                     case MetadataType.UIntPtr:

```

```

1095         instructions.Add(Instruction.Create(OpCodes.Ldind_I));
1096         isValueType = true;
1097         break;
1098     default:
1099         if (typeSpec.ElementType.IsValueType)
1100         {
1101             instructions.Add(Instruction.Create(OpCodes.Ldobj, typeSpec.ElementType));
1102             isValueType = true;
1103         }
1104         else
1105         {
1106             instructions.Add(Instruction.Create(OpCodes.Ldind_Ref));
1107             isValueType = false;
1108         }
1109         break;
1110     }
1111 }
1112 }
1113
1114 if (pType.IsValueType || isValueType)
1115 {
1116     if(isValueType)
1117         instructions.Add(Instruction.Create(OpCodes.Box, typeSpec.ElementType));
1118     else
1119         instructions.Add(Instruction.Create(OpCodes.Box, pType));
1120 }
1121
1122 instructions.Add(Instruction.Create(OpCodes.Stelem_Ref));
1123 }
1124 #endregion
1125
1126 StringBuilder sb = new StringBuilder();
1127 method.Parameters.ToList()
1128     .ForEach(x =>
1129     {
1130         sb.Append(string.Format("{0}:{1}|", x.Name, x.ParameterType.FullName));
1131     });
1132
1133 var maType = typeof(MethodArgs);
1134 var maName = "ma" + DateTime.Now.Ticks;
1135 var maSetProperties = maType.GetMethod("SetProperties");
1136 var varMa = new VariableDefinition(maName, assemblyDef.MainModule.Import(maType));
1137 method.Body.Variables.Add(varMa);
1138 var vaMaldx = method.Body.Variables.Count - 1;
1139 var maCtr = maType.GetConstructor(new Type[] { });
1140 MethodReference maCtrRef = assemblyDef.MainModule.Import(maCtr);
1141 instructions.Add(Instruction.Create(OpCodes.Newobj, maCtrRef));
1142 instructions.Add(Instruction.Create(OpCodes.Stloc, varMa));
1143 instructions.Add(Instruction.Create(OpCodes.Ldloc, varMa));
1144 instructions.Add(Instruction.Create(OpCodes.Ldstr, method.Name));
1145 instructions.Add(Instruction.Create(OpCodes.Ldstr, method.FullName));
1146 instructions.Add(Instruction.Create(OpCodes.Ldstr, method.ReturnType.FullName));
1147 instructions.Add(Instruction.Create(OpCodes.Ldstr, sb.ToString()));
1148 instructions.Add(Instruction.Create(OpCodes.Ldloc, varArray));
1149 if (method.IsStatic)
1150     instructions.Add(Instruction.Create(OpCodes.Ldnull));
1151 else
1152     instructions.Add(Instruction.Create(OpCodes.Ldarg_0));

```

```

1153
1154     var maSetPropertiesRef = assemblyDef.MainModule.Import(maSetProperties, method);
1155     instructions.Add(Instruction.Create(OpCodes.Callvirt, maSetPropertiesRef));
1156
1157     int idx = 0;
1158     instructions.ForEach(x => method.Body.Instructions.Insert(idx++, x));
1159
1160     var.Var = varMa;
1161     var.ParamArray = varArray;
1162     var.VarIdx = idx;
1163     return var;
1164 }
1165
1166 internal static void Write2(this AssemblyDefinition assembly, string outputPath)
1167 {
1168     //write out the modified assembly
1169     var fi = new FileInfo(outputPath);
1170     var folderpath = string.Format(@"{0}\modified", fi.Directory.FullName);
1171     var fn = fi.Name;
1172     if (!Directory.Exists(folderpath)) Directory.CreateDirectory(folderpath);
1173     var n = Path.Combine(folderpath, fn);
1174     assembly.Write(n);
1175 }
1176 }
1177
1178 internal class VariableResult
1179 {
1180     public VariableDefinition Var { get; set; }
1181     public VariableDefinition ParamArray { get; set; }
1182     public int VarIdx { get; set; }
1183 }
1184 }

```

Listing A.13: ../buffalo/Extensions/Extensions.cs

```

1185 {
1186     internal interface IMethodAroundAspect : IAspect
1187     {
1188         object Invoke(MethodArgs args);
1189     }
1190 }

```

Listing A.14: ../buffalo/Interfaces/IMethodAroundAspect.cs

```

1191 using Mono.Cecil;
1192
1193 namespace Buffalo.Interfaces
1194 {
1195     internal interface IInjectable
1196     {
1197         void Inject(AssemblyDefinition assemblyDefinition, Dictionary<MethodDefinition, List<Aspect>> eligibleMethods);
1198     }
1199 }

```

Listing A.15: ../buffalo/Interfaces/IInjectable.cs

```
1200 {
1201     internal interface IMethodBoundaryAspect : IAspect
1202     {
1203         void OnBefore(MethodArgs args);
1204         void OnAfter(MethodArgs args);
1205         void OnSuccess(MethodArgs args);
1206         void OnException(MethodArgs args);
1207     }
1208 }
```

Listing A.16: ../buffalo/Interfaces/IMethodBoundaryAspect.cs

```
1209 {
1210     /// <summary>
1211     /// This is the base aspect interface
1212     /// </summary>
1213     internal interface IAspect
1214     {
1215     }
1216 }
```

Listing A.17: ../buffalo/Interfaces/IAspect.cs

```
1217 using System.Collections.Generic;
1218 using System.Linq;
1219 using System.Text;
1220 using System.Reflection;
1221 using Buffalo;
1222
1223 namespace BuffaloAOP
1224 {
1225     class Program
1226     {
1227         static string path;
1228         static void Main(string[] args)
1229         {
1230             if (args == null || args.Count() == 0)
1231             {
1232                 Console.WriteLine("USAGE: BuffaloAOP.exe <assembly_path>");
1233                 Environment.Exit(1);
1234             }
1235
1236             path = args[0];
1237             new Weaver(path).Inject();
1238         }
1239     }
1240 }
```

Listing A.18: ../../buffalo/BufferaloAOP/Program.cs

Appendix B

User Manual

It is easy to get start using Buffalo. I assume you are reasonably familiar with the Visual Studio IDE and the general layout of a VS solution. I also assume you know how to compile a solution and where to find the compiled assembly. Buffalo is developed in VS2012, it is recommended you have the same version of the IDE installed.

B.1 Compiling

To begin, first download the full source code from <https://github.com/wliao008/buffalo>. Open buffalo.sln in VS2012 and compile the source code. This will produce the Buffalo.dll and BuffaloAOP.exe in their respective bin/debug folder.

For this example we will perform the weaving from a command prompt. So create a folder name under the C drive, here I will call it "Buffalo". Ccopy Buffalo.dll, BuffaloAOP.exe and Mono.Cecil.dll to C:\Buffalo. Note this folder can be located anywhere in your system, I am just putting it on the C drive for simplicity.

Now let us create an aspect.

B.2 Simple Profiler

In this example we will create a profiler for our application. Suppose we have the following simple program.

```
1 using System;  
2  
3 namespace Hello
```



```
4  {
5      class Program
6      {
7          static void Main(string[] args)
8          {
9              Hello h = new Hello();
10             h.SayHello();
11             h.Say("Hey Buffalo how's it going!");
12
13             //pause the console
14             Console.Read();
15         }
16     }
17
18     public class Hello
19     {
20         public void SayHello()
21         {
22             Console.WriteLine("Hello World!");
23         }
24
25         public void Say(string msg)
26         {
27             Console.WriteLine(msg);
28         }
29     }
30 }
```

Listing B.1: Hello program

When the program runs, it will display the following output:

```
1 Hello World!
2 Hey Buffalo how's it going!
```

Listing B.2: Hello program output

And suppose that we want to monitor the program, we want to know when a method was accessed and exited. We can easily create a aspect to do such work.

```
1 using Buffalo;
2 using System;
3
4 public class TraceAspect : MethodBoundaryAspect
5 {
6     public override void Before(MethodArgs args)
7     {
8         Display("ENTERING", args);
9     }
10
11     public override void After(MethodArgs args)
12     {
13         Display("EXITING", args);
14     }
15
16     public override void Success(MethodArgs args)
```

```

17     {
18         Display("SUCCESSFULLY EXECUTED", args);
19     }
20
21     public override void Exception(MethodArgs args)
22     {
23         Display("EXCEPTION ON", args);
24     }
25
26     void Display(string title, MethodArgs args)
27     {
28         Console.WriteLine("{0} {1}", title, args.FullName);
29         foreach (var p in args.Parameters)
30         {
31             Console.WriteLine("\t{0} ({1}) = {2}", p.Name, p.Type, p.Value);
32         }
33     }
34 }

```

Listing B.3: TraceAspect

With the aspect defined, now we can apply this aspect on any of the three different levels. Lets apply it to the Hello class for example.

```

1 [TraceAspect]
2 public class Hello
3 {
4     //...
5 }

```

Listing B.4: Apply Aspect to the Hello Class

Now everything is in place. We can now invoke the BuffaloAOP.exe to perform the weaving. Open a command prompt and navigate to C:\Buffalo. And issue this command:

```

1 C:\Buffalo>BuffaloAOP.exe <path_to_the_hello_program.exe>

```

Listing B.5: Invoking BuffaloAOP.exe

Replace path to the hello program exe with the actual complete path to the program assembly. Suppose the program assembly is located at C:\Projects\Hello\bin\Hello.exe, we would issue the command as follow:

```

1 C:\Buffalo>BuffaloAOP.exe C:\Projects\Hello\bin\Hello.exe

```

Listing B.6: Invoking BuffaloAOP.exe Example

If everything goes well BuffaloAOP.exe will perform the injection and put the final assembly in the Modified folder inside the folder of the target assembly. In this case it will

be at C:\Projects\Hello\bin\Modified\Hello.exe. Now when the program runs, it will display the following output:

```
1 ENTERING System.Void Hello.Program::Main(System.String[])
2     args (System.String[]) = System.String[]
3 ENTERING System.Void Hello.Hello::ctor()
4 SUCCESSFULLY EXECUTED System.Void Hello.Hello::ctor()
5 EXITING System.Void Hello.Hello::ctor()
6 ENTERING System.Void Hello.Hello::SayHello()
7 Hello World!
8 SUCCESSFULLY EXECUTED System.Void Hello.Hello::SayHello()
9 EXITING System.Void Hello.Hello::SayHello()
10 ENTERING System.Void Hello.Hello::Say(System.String)
11     msg (System.String) = Hey Buffalo how's it going!
12 Hey Buffalo how's it going!
13 SUCCESSFULLY EXECUTED System.Void Hello.Hello::Say(System.String)
14     msg (System.String) = Hey Buffalo how's it going!
15 EXITING System.Void Hello.Hello::Say(System.String)
16     msg (System.String) = Hey Buffalo how's it going!
```

Listing B.7: TraceAspect output

Line 7 and 12 are the original method output, the rest are the output of the various interception points. Note that line 11 also capture the parameter value passed into each method and is available from the aspect.

B.3 Integrate With MS-Build System

Buffalo can be integrated with MS-Build, so weaving can be invoked automatically when a project is compiled from the Visual Studio IDE. Note that the following instructions are just the bare minimum to get this working, a lot of bell and whistle are omitted.

MS-Build is integrated with Visual Studio IDE via configuration file. For example, a C# project has the associated .csproj, if open in a text editor you will see a line that reference a different configuration file: Microsoft.CSharp.targets. This file in term reference Microsoft.Common.targets.

Each .NET version has a Microsoft.Common.targets file. Depending on the version you are using, open up this file in a text editor. For example, for .NET 4.0, this file is located in C:\Windows\Microsoft.NET\Framework\v4.0.30319\Microsoft.Common.targets.

Under the Compile section, around line 2013, add the line to import the Buffalo.targets file as shown in figure B.1



Figure B.1: Adding Buffalo.targets

If you open Buffalo.targets in a text editor, it contains the following context:

```

1 <Project xmlns="http://schemas.microsoft.com/developer/msbuild/2003">
2   <PropertyGroup>
3     <CompileDependsOn>
4       $(CompileDependsOn);
5       Buffalo
6     </CompileDependsOn>
7   </PropertyGroup>
8
9   <Target Name="Buffalo">
10    <Message Text="Hello Buffalo! @(IntermediateAssembly)"/>
11    <Exec Command="&quot;C:\Buffalo\BuffaloAOP.exe&quot; &quot;%(IntermediateAssembly)&quot;"/>
12  </Target>
13 </Project>

```

Listing B.8: Buffalo.targets

This is how Buffalo get hooked into MS-Build, what this mean is that when user compiles a project, everything defined in the CompileDependsOn property group will be performed first, then a new target named "Buffalo" will be called immediately, which will invoke the BuffaloAOP via the Exec Command. Note that for the Exec Command, a complete path to BuffaloAOP.exe must be provided, including the decoded quotation marks as shown.

Make sure to save all the changes.

Now every time a C# project is compiled, Buffalo will be invoked automatically to perform the weaving.