Charles University in Prague

Faculty of Mathematics and Physics

MASTER THESIS

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Debugger Visualizers for the SharpDevelop IDE

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Study programme: Computer science

Specialization: Software systems

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I would like to thank my supervisor Pavel Ježek for his time and his very helpful, constructive advice on this thesis.

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Last but not least, I thank Google for supporting students to work on interesting open source projects.

Title: Debugger Visualizers for the SharpDevelop IDE

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Abstract:
The overall goal of the thesis is to explore new approaches to debugging managed code, namely visualization of data in the program being debugged. Particular goals of the work are: (a) to build an object graph visualizer, which displays selected data structure used in the program as directed graph, (b) improve visualization of object collections by providing an overview of collection contents and supporting broad range of collection types. The work is implemented for the SharpDevelop open source IDE for .NET. The author cooperates with the SharpDevelop team and the results of the work have been already incorporated into the new version of the IDE.

Keywords: debugging, IDE, data visualization, .NET

Contents

1. Introduction

The ideas for this thesis are based on a desire for better debugging features in current IDEs. A vision about innovative ways of debugging, namely debugging object graphs and collections, was implemented in form of new functionality for SharpDevelop – the open source IDE for .NET. This thesis first describes the motivation behind this functionality – i.e. why to build new features even though developers could live without them so far. Then, detailed analysis of the work is presented, including an overview of SharpDevelop architecture and means of integration of the work into SharpDevelop. Finally, the Implementation section describes the design and highlights interesting parts of the implementation.

1.1 Style conventions

The following style conventions are used throughout the document:

- *Text in italics* denotes special terms and definitions.
- `Fixed-width font` is used for code and pseudocode listings and references to symbols.

1.2 Terminology

Debugger – a program which controls execution and observes state of another program.

Debuggee – the process being debugged by the debugger.

IDE – Integrated development environment. A collection of software development tools such as a code editor, a debugger etc.

By the term *collection* this thesis refers to .NET Lists, ObservableCollections, arrays, or any other IEnumerables. Similar classes exist in other environments and most ideas mentioned in this thesis would apply there as well.

1.3 Context

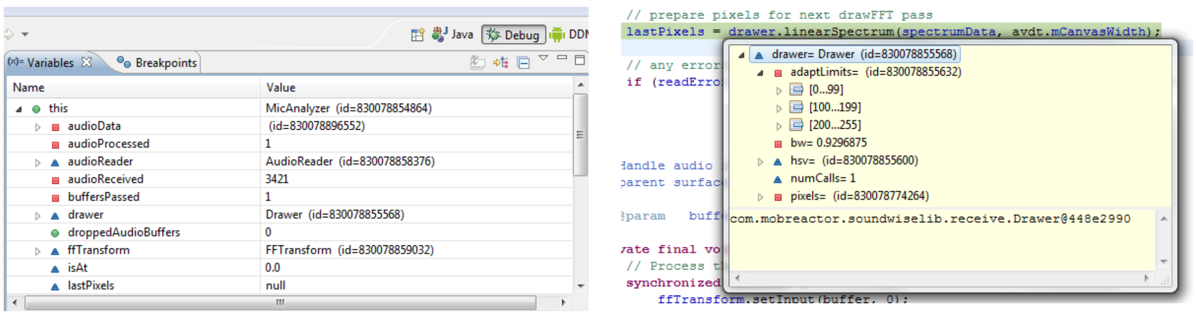
This thesis is about debugging managed programs in the context of .NET environment. Therefore, whenever the text mentions classes and their instances, it refers to managed .NET instances, references etc. Likewise, the term *object properties* in the context of this thesis refers to standard .NET properties – i.e. a getter and/or a setter method usually with a backing field. Still, a lot of concepts and ideas described in this thesis can be directly applied to other managed environments, for example Java.

1.4 Motivation

Debuggers and Integrated Development Environments are a very live topic in software engineering and they have seen a lot of improvement in the last years. However, current debuggers still do not solve some scenarios sufficiently – this section identifies such scenarios.

1.4.1 Object graphs

Currently, most visual debuggers are similar in terms of presenting data from the *debuggee* (the program being debugged) to users. The most typical way of presenting such data are *watches*, which show variables in current scope in a tree view fashion - if an object contains references to other objects, these become its children in the tree. *Debugger tooltips* are a very similar feature to watches; the difference is that debugger tooltips allow users to explore values of expressions by pointing mouse cursor directly at expressions in code. This makes debugger tooltips easier to use than watches, since users do not have switch their focus between the watch window and the code editor.



Name	Value
this	MicAnalyzer (id=830078854864)
audioData	(id=830078896552)
audioProcessed	1
audioReader	AudioReader (id=830078858376)
audioReceived	3421
buffersPassed	1
drawer	Drawer (id=830078855568)
droppedAudioBuffers	0
ffTransform	FFTransform (id=830078859032)
isAt	0.0
lastPixels	null

```
// prepare pixels for next drawFFT pass
lastPixels = drawer.linearSpectrum(spectrumData, avdt.mCanvasWidth);

// any error
if (readErro

Handle audio
parent surfac

@param   buff

vate final vo
 // Process t
 synchronized
     ffTransform.setInput(buffer, 0);
```

```
drawer= Drawer (id=830078855568)
    adaptLimits= (id=830078855632)
        [0...99]
        [100...199]
        [200...255]
    bw= 0.9296875
    hsv= (id=830078855600)
    numCalls= 1
    pixels= (id=830078774264)
com.mobreactor.soundwiselib.receive.Drawer@448e2990
```

Figure 1 – Watch window and debugger tooltips in Eclipse 3.5 (watch window is called "Variables" in Eclipse)

But neither debugger tooltips nor watches are perfect for all scenarios – take, for instance, a structure of two objects having a reference to each other:

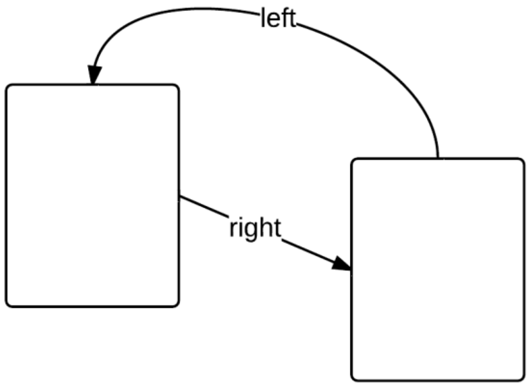
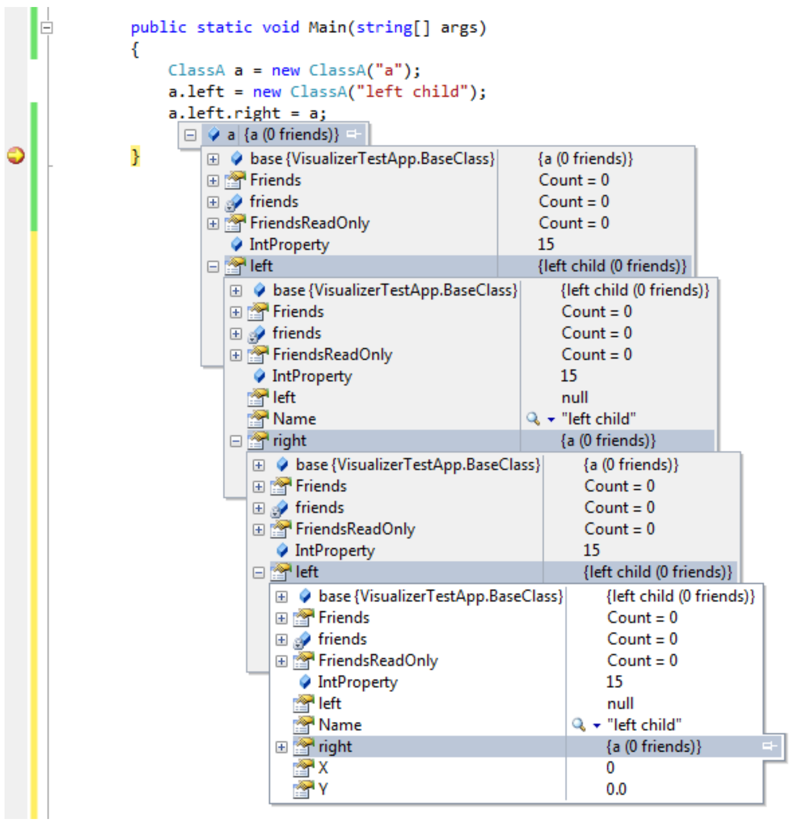


Figure 2 – Two instances having a reference to each other

Figure 2 shows a simple data structure as usually depicted by people. However, the following figure shows how such structure is presented by watches or debugger tooltips:



```
public static void Main(string[] args)
{
    ClassA a = new ClassA("a");
    a.left = new ClassA("left child");
    a.left.right = a;
}
```

```
a {a (0 friends)}
  base {VisualizerTestApp.BaseClass}   {a (0 friends)}
  Friends                              Count = 0
  friends                              Count = 0
  FriendsReadOnly                      Count = 0
  IntProperty                          15
  left                                 {left child (0 friends)}
    base {VisualizerTestApp.BaseClass}   {left child (0 friends)}
    Friends                              Count = 0
    friends                              Count = 0
    FriendsReadOnly                      Count = 0
    IntProperty                          15
    left                                 null
    Name                                 "left child"
    right                                {a (0 friends)}
      base {VisualizerTestApp.BaseClass}   {a (0 friends)}
      Friends                              Count = 0
      friends                              Count = 0
      FriendsReadOnly                      Count = 0
      IntProperty                          15
      left                                 {left child (0 friends)}
        base {VisualizerTestApp.BaseClass}   {left child (0 friends)}
        Friends                              Count = 0
        friends                              Count = 0
        FriendsReadOnly                      Count = 0
        IntProperty                          15
        left                                 null
        Name                                 "left child"
        right                                {a (0 friends)}
        X                                    0
        Y                                    0.0
```

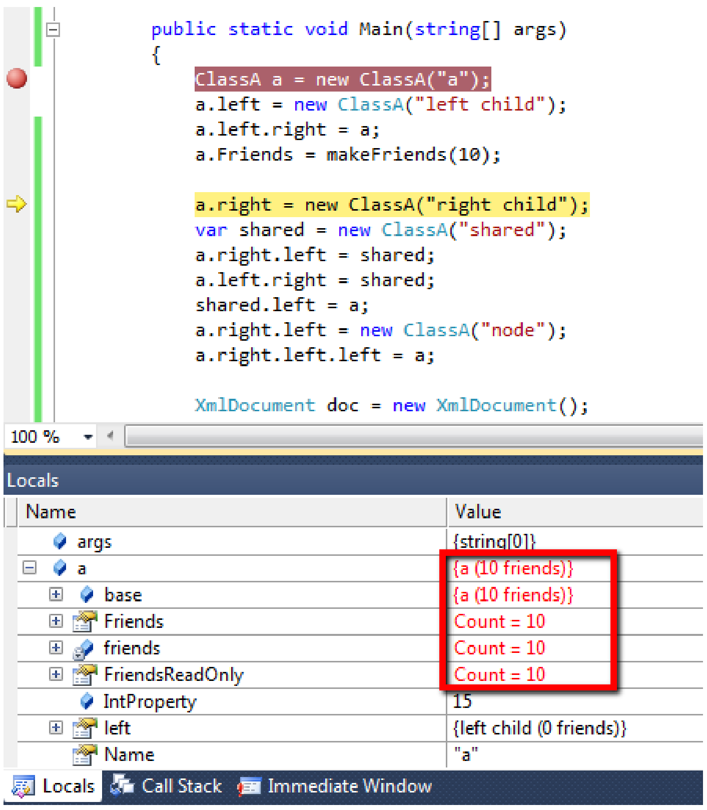
Figure 3 – Data structure from Figure 2 presented by debugger tooltips in Visual Studio 2010

The problem is that using current debugging tools, users have very little means of determining how the data structure actually looks in reality. In the example from Figure 3 the tooltips can be expanded infinitely.

Another problem which is not very well solved today is visualization of *changes*. If a user performs a step in the debugger how can he or she determine what changes occurred in the state of the program? Sometimes the change is easy to understand from the code, as in:

```
IFoo foo = GetFooImplementation(context);
```

But if the code being stepped over changes multiple variables, it can be useful to see what just happened. This is solved in some IDEs by highlighting variables whose values were just changed.



```
public static void Main(string[] args)
{
    ClassA a = new ClassA("a");
    a.left = new ClassA("left child");
    a.left.right = a;
    a.Friends = makeFriends(10);

    a.right = new ClassA("right child");
    var shared = new ClassA("shared");
    a.right.left = shared;
    a.left.right = shared;
    shared.left = a;
    a.right.left = new ClassA("node");
    a.right.left.left = a;

    XmlDocument doc = new XmlDocument();
```

Name	Value
args	{string[0]}
a	{a (10 friends)}
base	{a (10 friends)}
Friends	Count = 10
friends	Count = 10
FriendsReadOnly	Count = 10
IntProperty	15
left	{left child (0 friends)}
Name	"a"

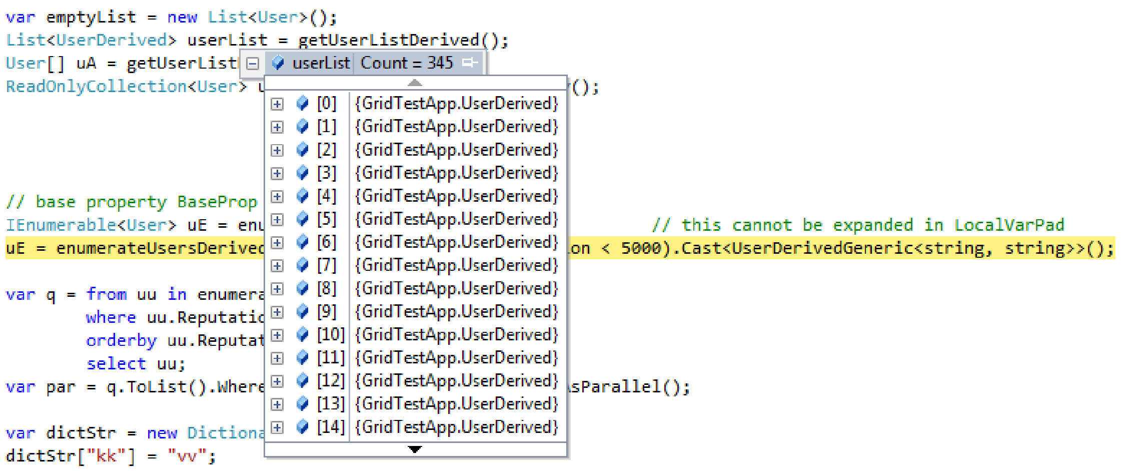
Figure 4 – In the Visual Studio 2010 Locals window, values of variables changed by debugger step are highlighted automatically.

Unfortunately, this approach is not great for visualizing changes to data structures. What if an item was inserted into a linked list, or what if a tree rotation occurred? I realized this problem when teaching Introduction to programming to university freshmen. What I frequently observed was that there was code on one side of the whiteboard and a drawing of a data structure on the other side. The teacher was explaining the code by pointing to the current "instruction pointer" with a finger and moving the finger from one line of the program to the next line. At the same time a student was updating the drawing of a data structure by erasing parts of it and drawing new parts as the structure was being modified. By seeing how each statement modified the data structure the students could clearly see how the program worked.

After several weeks of running this university class I had an idea – why not automate the process? The IDE could actually let users step through the code and draw and update data structures in a similar way we did in the class.

1.4.2 Collections

The second issue with current debuggers are insufficient possibilities to explore and understand contents of *collections of complex objects*. For example, when debugging a program that works with a collection of objects of type `Person`, such collection is commonly visualized in the following way in current debuggers:

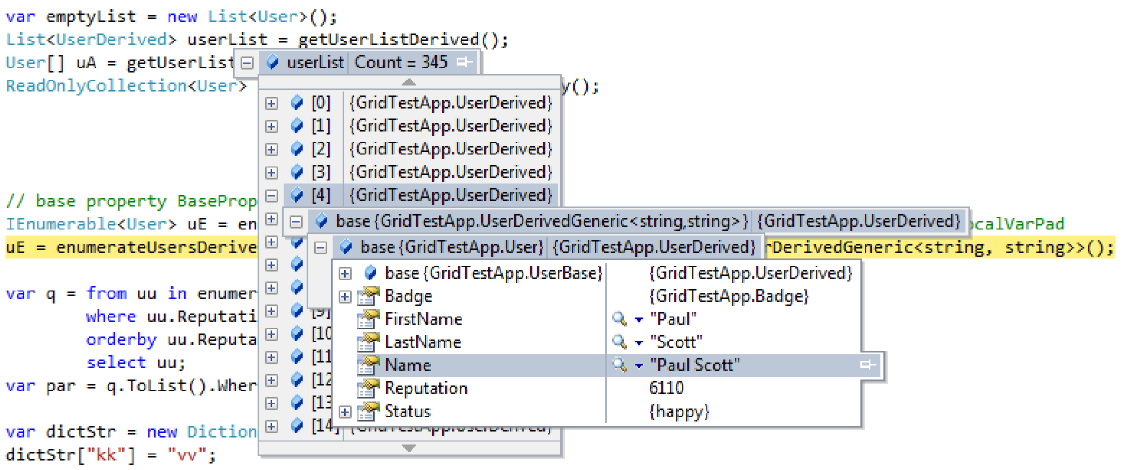


```
var emptyList = new List<User>();
List<UserDerived> userList = getUserListDerived();
User[] uA = getUserList
ReadOnlyCollection<User> u                                    ();

// base property BaseProp
IEnumerable<User> uE = enu                                             // this cannot be expanded in LocalVarPad
uE = enumerateUsersDerivec                                    on < 5000).Cast<UserDerivedGeneric<string, string>>();

var q = from uu in enumera
        where uu.Reputatic
        orderby uu.Reputat
        select uu;
var par = q.ToList().Where                                    sParallel();

var dictStr = new Dictiona
dictStr["kk"] = "vv";
```

```
userList  Count = 345
[0]  {GridTestApp.UserDerived}
[1]  {GridTestApp.UserDerived}
[2]  {GridTestApp.UserDerived}
[3]  {GridTestApp.UserDerived}
[4]  {GridTestApp.UserDerived}
[5]  {GridTestApp.UserDerived}
[6]  {GridTestApp.UserDerived}
[7]  {GridTestApp.UserDerived}
[8]  {GridTestApp.UserDerived}
[9]  {GridTestApp.UserDerived}
[10] {GridTestApp.UserDerived}
[11] {GridTestApp.UserDerived}
[12] {GridTestApp.UserDerived}
[13] {GridTestApp.UserDerived}
[14] {GridTestApp.UserDerived}
```

Figure 5 – Debugger tooltip in Visual Studio 2010 showing contents of a collection of objects

The problem is that such view does not provide almost any information – there is no way to get an overview of the contents of the collection and there is also no way to quickly locate individual items based on their properties. The only possibility is to drill down the items of the collection, opening and closing items one by one, which takes a lot of time. Combined with the fact that collections are one of the most common data structures, this is a serious shortcoming of current debuggers.



```
var emptyList = new List<User>();
List<UserDerived> userList = getUserListDerived();
User[] uA = getUserList
ReadOnlyCollection<User>                                     y();

// base property BaseProp
IEnumerable<User> uE = en                                                                  calVarPad
uE = enumerateUsersDerive                                    DerivedGeneric<string, string>>();

var q = from uu in enumer
        where uu.Reputati
        orderby uu.Reputa
        select uu;
var par = q.ToList().Wher

var dictStr = new Diction
dictStr["kk"] = "vv";
```

```
userList  Count = 345
[0]  {GridTestApp.UserDerived}
[1]  {GridTestApp.UserDerived}
[2]  {GridTestApp.UserDerived}
[3]  {GridTestApp.UserDerived}
[4]  {GridTestApp.UserDerived}
  base {GridTestApp.UserDerivedGeneric<string,string>}  {GridTestApp.UserDerived}
    base {GridTestApp.User}  {GridTestApp.UserDerived}
      base {GridTestApp.UserBase}   {GridTestApp.UserDerived}
      Badge                         {GridTestApp.Badge}
      FirstName                     "Paul"
      LastName                      "Scott"
      Name                          "Paul Scott"
      Reputation                    6110
      Status                        {happy}
```

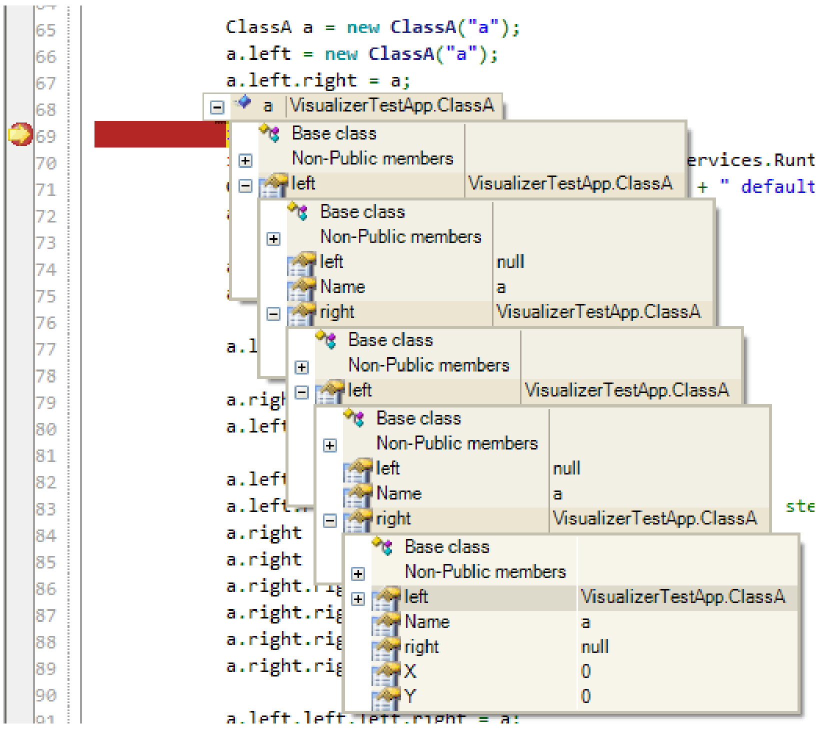
Figure 6 – Debugger tooltip in Visual Studio with one collection item expanded. The interesting property was declared in a base class so expanding multiple times was needed to locate the desired property.

In Visual Studio, debugger support for `DebuggerDisplayAttribute` and `DebuggerTypeProxyAttribute` [1], [2] partially solves this problem but these attributes have to be included in the code being debugged and also provide only hard-wired view of individual fields or properties.

Apart from general issues with debugging collections, there are issues specific to SharpDevelop. SharpDevelop's integrated debugger currently lacks support the IEnumerable type and does not support large collections efficiently (expanding contents of a large collection can block whole SharpDevelop for a long time, depending on the size of the collection).

1.4.3 Debugger tooltips

Debugger tooltips are a feature similar to watches, as shown in the following screenshot:



```
ClassA a = new ClassA("a");
a.left = new ClassA("a");
a.left.right = a;
```

```
a      VisualizerTestApp.ClassA
  Base class
  Non-Public members
  left   VisualizerTestApp.ClassA
    Base class
    Non-Public members
    left   null
    Name   a
    right  VisualizerTestApp.ClassA
      Base class
      Non-Public members
      left   VisualizerTestApp.ClassA
        Base class
        Non-Public members
        left   null
        Name   a
        right  VisualizerTestApp.ClassA
          Base class
          Non-Public members
          left   VisualizerTestApp.ClassA
          Name   a
          right  null
          X      0
          Y      0
```

Figure 7 – Debugger tooltips in SharpDevelop 3

The advantage of debugger tooltips compared to watches is that users can just point a mouse cursor at anything they are interested in. They don't have to look for variables in the watch window which typically contains more than a dozen of available variables. Debugger tooltips are a frequently used feature of Visual Studio's integrated debugger and SharpDevelop implements them as well. However, the debugger tooltips in SharpDevelop 3 are missing two very important features: support for large collections, and support for the IEnumerable type. The importance of support for IEnumerable is very high since typical programs use IEnumerable extensively. Moreover, the UI of SharpDevelop 3 was built using Windows Forms and starting with SharpDevelop version 4.0, Windows Forms has been deprecated in and the UI of SharpDevelop has been rewritten to WPF, which means that completely new tooltips implemented in WPF are needed. This thesis covers a new implementation of debugger tooltips for SharpDevelop 4.0.

1.5 Goals

To address the issues identified in section 1.4 (Motivation), this thesis sets the following goals:

- Provide a way for users to explore state of *data structures* in a debuggee in a similar way people draw data structures on a whiteboard.
- Make it possible for users to see the changes occurring to data structures caused when stepping in the debugger. The more understandable the visualization of the change, the better.

- Provide a way for users to get an overview of contents of *collections of objects*, in an easier way than using debugger tooltips.
- Add support for IEnumerable collections to SharpDevelop's integrated debugger.
- Add efficient support for large collections (tens of thousands of items) to SharpDevelop's integrated debugger.

- Reimplement SharpDevelop's debugger tooltips in WPF, also adding support for IEnumerable collections and large collections.
- Make it possible to open debugger visualizers from the debugger tooltips; make the integration extensible, enabling users to implement new debugger visualizers.

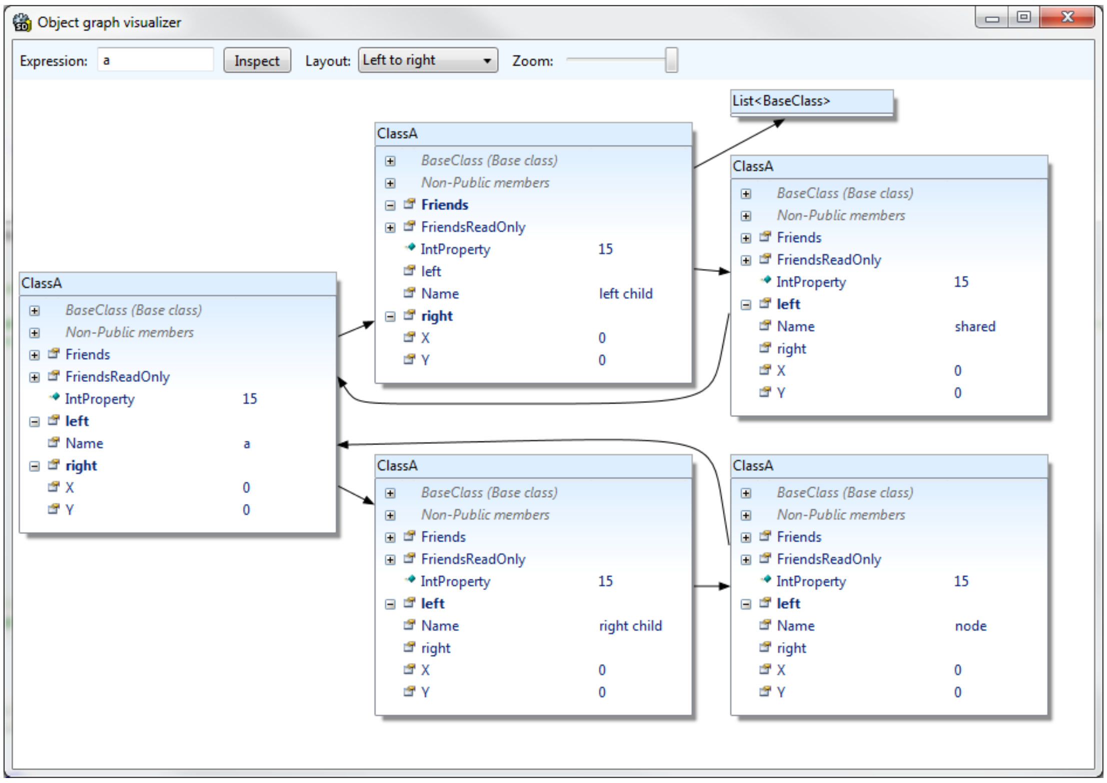
- Implemented features should work when debugging C# and VB .NET code.

1.6 Preview

To give the reader a better overview of what this thesis is about, this section presents a short preview of some of the results of this thesis.

1.6.1 Object graph visualizer

Our first addition to SharpDevelop's integrated debugger is a visualizer of object graphs.



Expression: a
Layout: Left to right

ClassA
BaseClass (Base class)	
Non-Public members	
Friends	
FriendsReadOnly	
IntProperty	15
left	
Name	a
right	
X	0
Y	0

ClassA
BaseClass (Base class)	
Non-Public members	
Friends	
FriendsReadOnly	
IntProperty	15
left	
Name	left child
right	
X	0
Y	0

ClassA
BaseClass (Base class)	
Non-Public members	
Friends	
FriendsReadOnly	
IntProperty	15
left	
Name	shared
right	
X	0
Y	0

ClassA
BaseClass (Base class)	
Non-Public members	
Friends	
FriendsReadOnly	
IntProperty	15
left	
Name	right child
right	
X	0
Y	0

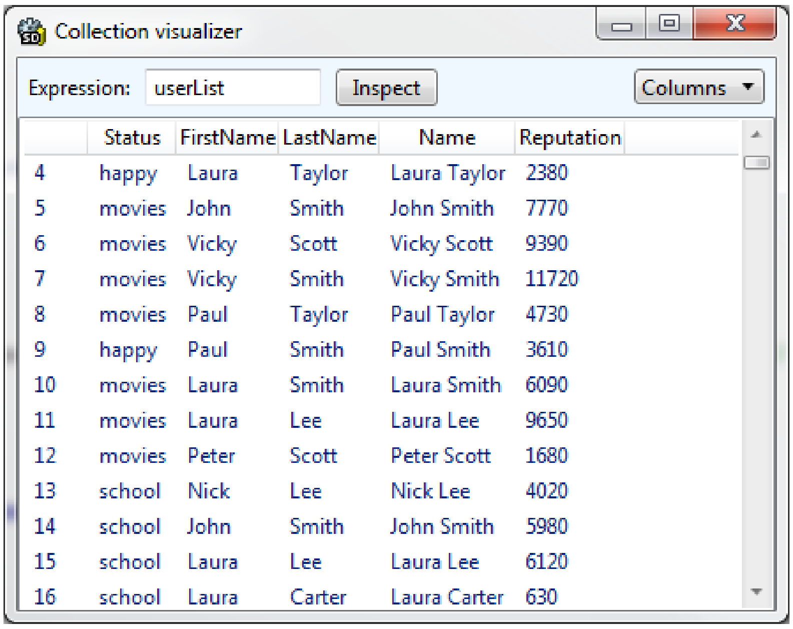
ClassA
BaseClass (Base class)	
Non-Public members	
Friends	
FriendsReadOnly	
IntProperty	15
left	
Name	node
right	
X	0
Y	0

Figure 8 – Object graph visualizer showing in-memory instances and references between them

The Object graph visualizer lets users explore data structures. The graph is updated live as the user steps in the debugger and the state of the data structure changes.

1.6.2 Collection visualizer

The second addition to SharpDevelop's integrated debugger is a collection visualizer – a new way to explore contents of collections of objects.



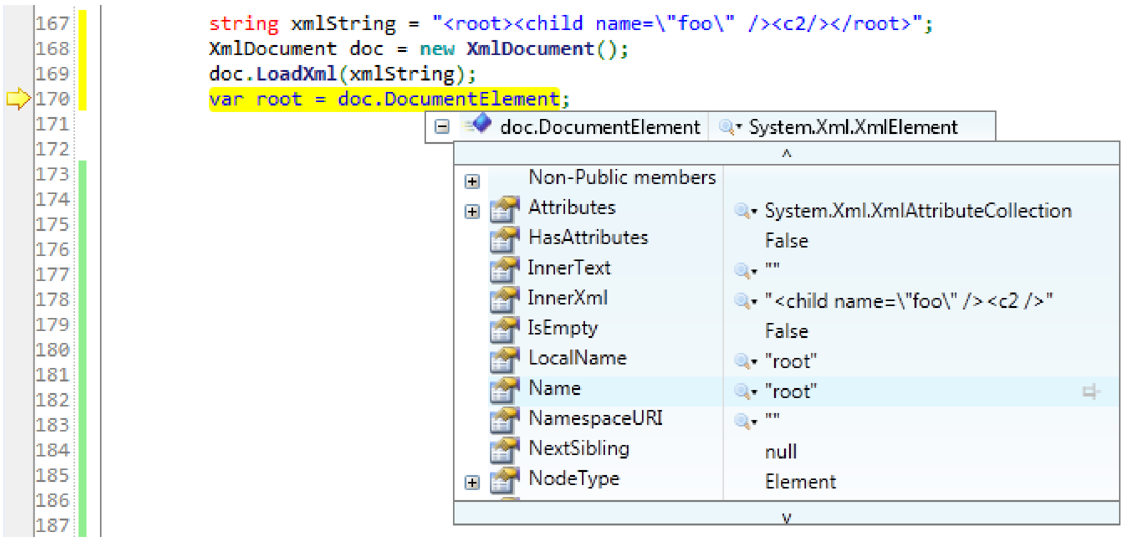
	Status	FirstName	LastName	Name	Reputation
4	happy	Laura	Taylor	Laura Taylor	2380
5	movies	John	Smith	John Smith	7770
6	movies	Vicky	Scott	Vicky Scott	9390
7	movies	Vicky	Smith	Vicky Smith	11720
8	movies	Paul	Taylor	Paul Taylor	4730
9	happy	Paul	Smith	Paul Smith	3610
10	movies	Laura	Smith	Laura Smith	6090
11	movies	Laura	Lee	Laura Lee	9650
12	movies	Peter	Scott	Peter Scott	1680
13	school	Nick	Lee	Nick Lee	4020
14	school	John	Smith	John Smith	5980
15	school	Laura	Lee	Laura Lee	6120
16	school	Laura	Carter	Laura Carter	630

Figure 9 – Collection visualizer showing contents of a collection of objects in the debugger

The Collection visualizer provides insight into the contents of collections of objects. The main point is that it displays properties of the collection items in a way which makes multiple properties of each item visible at once.

1.6.3 Debugger tooltips

The third feature implemented as part of this thesis are debugger tooltips for SharpDevelop.



```
string xmlString = "<root><child name=\"foo\" /><c2/></root>";
XmlDocument doc = new XmlDocument();
doc.LoadXml(xmlString);
var root = doc.DocumentElement;
```

doc.DocumentElement	System.Xml.XmlElement
Non-Public members	
Attributes	System.Xml.XmlAttributeCollection
HasAttributes	False
InnerText	""
InnerXml	"<child name=\"foo\" /><c2 />"
IsEmpty	False
LocalName	"root"
Name	"root"
NamespaceURI	""
NextSibling	null
NodeType	Element

Figure 10 – New debugger tooltips for SharpDevelop 4, with support for visualizers

Debugger tooltips are a popular feature of Visual Studio. SharpDevelop 3 had debugger tooltips but two important features were missing - support for IEnumerable collections, and support for large collections. As a part of this thesis the tooltips were reimplemented in WPF for SharpDevelop 4.0, including added support for IEnumerable collections and large collections.

1.7 Contribution of this thesis

As a result of this thesis SharpDevelop is currently the only IDE to have the features described in the thesis and we are expecting user feedback to see how these features help users in their everyday development tasks. Some users have already provided positive feedback – for example, they expressed a need for a better Collection debugging support in their favorite IDEs.

Note that this thesis is not about implementation of a feature similar to Visual Studio's debugger visualizers [3]. In Visual Studio, users can include debugger visualizers for custom types into their code and Visual Studio then offers these visualizers in its debugger tooltips. Since the approach used in Visual Studio would be too limiting[1] for the visualizers described in this thesis, we rather implement visualizers directly in SharpDevelop and provide extensibility points for other visualizers to be added in form of SharpDevelop AddIns. Functionality similar to Visual Studio's user defined visualizers is not supported in SharpDevelop yet.

1.8 Background

The first ideas for this thesis come from the beginning of 2009 when I was experimenting with visualizing object graphs using the Visual Studio debugger [4], thinking about improving the way people debug data structures. Then I found about the Google summer of code program. Seeing that SharpDevelop IDE was among the mentoring organizations and the team even wanted to improve their debugger, applying to SharpDevelop in Google summer of code was a no-brainer.

Google summer of code [5] is a program run by Google. Open source organizations apply to the program and Google selects the most attractive organizations to participate. Among participating organizations are such ones as Eclipse, Firefox, gcc, Haskell, Mono, Ogre3D, OpenOffice, Scala and many others. The students then apply to individual organizations with detailed proposals of their ideas. Google distributes approximately 1000 slots to the organizations, based on how popular the organization is (that is how many applications the organization received). For example, SharpDevelop had five slots in 2009. Then it is up to the mentoring organization members (that is, the long-term contributors to the open source project) to select the students they like the most. These students then work for 3 months fulltime on their projects and receive $5000 from Google, provided the mentoring organization confirms that the student did a good job. The not-so-unofficial goal of Summer of code is that students stay with the project after the summer and become contributors.

My experience with working on SharpDevelop has been very positive mainly because the SharpDevelop team is made by the best programmers I have had an opportunity to work with. They deserve a lot of respect not only for contributing their skills and free time, but also for

[1] Visual Studio's debugger visualizers use serialization to transport whole object to be visualized from the debuggee to the IDE.

the quality of their work. SharpDevelop is a very good source for learning about design, coding practices and technologies. Moreover, the team members are helpful and discussions with them are always effective.

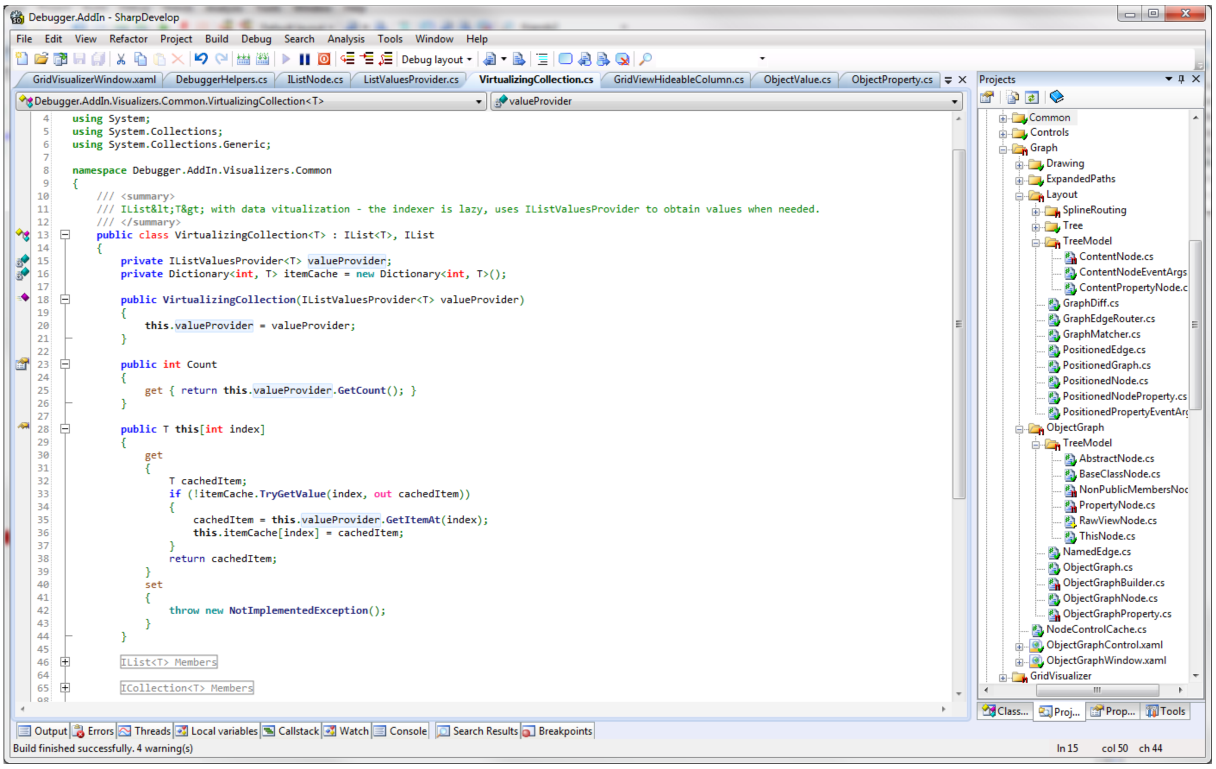
Figure 11 - SharpDevelop meeting in August 2009 in Bad Ischl, Austria. Left to right: Tomasz Tretkowski (Gsoc: C++ Backend Binding), Daniel Grunwald (Senior Developer, Architect), Martin Koníček (Gsoc: Debugger visualizers), Siegfried Pammer (Gsoc: Xaml Binding), David Srbecký (Debugger), Peter Forstmeier (SharpDevelop Reports), Christoph Wille (Project Management).

2. Analysis

Having the motivation and high-level goals for the thesis set, this section provides necessary introduction to SharpDevelop IDE and debugging and provides detailed analysis of the possible ways of reaching the goals.

2.1 Introduction to the SharpDevelop IDE

SharpDevelop [6] is a free open source IDE for .NET written almost entirely in C#. The development of SharpDevelop started in 2000 and as of April 2011 SharpDevelop supports C# 4, Visual Basic 10, F#, IronPython, Boo and C++.



```
using System;
using System.Collections;
using System.Collections.Generic;

namespace Debugger.AddIn.Visualizers.Common
{
    /// <summary>
    /// IList&lt;T&gt; with data vitualization - the indexer is lazy, uses IListValuesProvider to obtain values when needed.
    /// </summary>
    public class VirtualizingCollection<T> : IList<T>, IList
    {
        private IListValuesProvider<T> valueProvider;
        private Dictionary<int, T> itemCache = new Dictionary<int, T>();

        public VirtualizingCollection(IListValuesProvider<T> valueProvider)
        {
            this.valueProvider = valueProvider;
        }

        public int Count
        {
            get { return this.valueProvider.GetCount(); }
        }

        public T this[int index]
        {
            get
            {
                T cachedItem;
                if (!itemCache.TryGetValue(index, out cachedItem))
                {
                    cachedItem = this.valueProvider.GetItemAt(index);
                    this.itemCache[index] = cachedItem;
                }
                return cachedItem;
            }
            set
            {
                throw new NotImplementedException();
            }
        }

        IList<T> Members

        ICollection<T> Members
```

Build finished successfully. 4 warning(s)

Figure 12 – SharpDevelop IDE

The level of support for the individual languages varies. For example, F# code-completion is currently under development. Support for C# in SharpDevelop is well comparable to Visual Studio and in some areas SharpDevelop surpasses Visual Studio. Regarding C++ support, Visual Studio definitely surpasses SharpDevelop, but C++ is not the main focus of SharpDevelop. All this information is for SharpDevelop 4.0 as of April 2011.

SharpDevelop runs on Windows (for Linux there is MonoDevelop which was forked from an early version of SharpDevelop). SharpDevelop uses .NET SDK for the build process (that is MSBuild and the compilers for individual languages). SharpDevelop 4.0 supports targeting .NET versions 2.0, 3.0, 3.5 and 4.0. SharpDevelop uses the project and solution file format of Visual Studio – therefore, it can be used side-by-side with Visual Studio.

SharpDevelop (as of April 2011) does not fully support the following functionality:

- Web application development. It is possible to build and debug an ASP.NET application using SharpDevelop [7]. However, the tooling (.aspx code completion etc.) is not implemented.
- WPF designer is work in progress.

As SharpDevelop is completely free, it makes sense to compare it to the Express version of Visual Studio. SharpDevelop has the following features which are not present in Visual Studio Express:

- Integrated profiler
- NUnit integration (unit tests directly in SharpDevelop)
- Subversion and Git integration out of the box
- Code coverage
- ILSpy integration (open source .NET decompiler, developed by the SharpDevelop team)
- Reports (developed as part of SharpDevelop)
- Debugger visualizers
- Productivity features (ReSharper-like context actions, navigation shortcuts, etc.) [8]
- Extensibility

Of course, there are many small differences on both sides, but the list should provide a basic overview.

The last mentioned feature, Extensibility, is important: SharpDevelop can be extended or modified in almost any way. Its API is well designed and in case there would be an extension point missing, the team is open to good contributions. Being an open source IDE written entirely in C# makes SharpDevelop a very interesting project for programmers interested in .NET who would like to learn advanced topics and have their work used by many people (SharpDevelop is currently being downloaded around two thousand times a day).

2.2 The architecture of SharpDevelop

This section provides a high-level look at the architecture of SharpDevelop, its extensibility model and how the Debugger visualizers fit into the picture.

2.2.1 Reusable parts of SharpDevelop

Several parts of SharpDevelop are written as standalone libraries. These include:

- ICSharpCode.Core – the generic extensibility framework on which SharpDevelop is built
- NRefactory (C# and VB parser and AST)
- ICSharpCode.SharpDevelop.Dom (type system representation)
- AvalonEdit [9] (code editor with syntax highlighting and code completion window)
- Debugger
- Profiler

- Usage data collection (collecting data about how users interact with the application and uploading them to a server)
- Reports (reporting library)

All of these libraries are completely reusable. Most of them are integrated into SharpDevelop by AddIns which act as a "glue" to provide the functionality of the libraries in SharpDevelop. For example, Debugger.Core is a managed debugger library and Debugger.AddIn contains user interface and SharpDevelop-specific logic. Similarly, AvalonEdit is a code editor with support for syntax highlighting and AvalonEdit.AddIn adds SharpDevelop-specific behavior, like split-view, debugger tooltips, context actions etc.

2.2.2 ICSharpCode.Core

SharpDevelop is an application built using a generic extensibility framework called ICSharpCode.Core (further referred to as the Core). The Core provides an AddIn infrastructure, where AddIns can extend almost anything, including other AddIns. The main point of the Core is to allow users to provide extension points in their applications very easily.

The Core was developed for the purposes of SharpDevelop but it is a standalone framework on which SharpDevelop is built.

ICSharpCode.Core for WPF and Windows Forms applications

There are two versions of the Core: ICSharpCode.Core.WinForms and ICSharpCode.Core.Presentation, designed to be used in Windows Forms and WPF applications respectively. They both reference the assembly ICSharpCode.Core which contains all the non-UI-specific functionality.

The AddIn tree

The extensibility infrastructure provided by the Core is called the AddIn tree. AddIns are defined in XML files with .addin extension. There are several standard tags, the basic one being a tag called `Path` which essentially enables adding extension points. In the following example three `ToolBarItems` are being added to the AddIn tree path called "`/Browser/Toolbar`":

```xml
<Path name = "/Browser/Toolbar">
  <ToolbarItem id      = "Back"
               icon    = "Icons.16x16.BrowserBefore"
               tooltip = "${res:AddIns.HtmlHelp2.Back}"
               class   = " SharpDevelop.BrowserDisplayBinding.GoBack"/>
  <ToolbarItem id = "Separator1" type  = "Separator"/>
  <ToolbarItem id      = "Home"
               icon    = "Icons.16x16.BrowserHome"
               tooltip = "${res:AddIns.HtmlHelp2.Homepage}"
               class   = "SharpDevelop.BrowserDisplayBinding.GoHome"/>
  [...]
```

Listing 1 - .addin file defining three ToolbarItems

The application built using the Core can then use the following call to obtain a ToolStrip object with three buttons and a separator, as defined in the .addin xml file :

```
var toolStrip = ToolbarService.CreateToolStrip(this, "/Browser/Toolbar");
```

Listing 2 – Obtaining items for a Toolbar, defined in Listing 1

Such functionality by itself wouldn’t be very interesting. The interesting part comes when someone else writes an AddIn for the application, specifying the following in the .addin definition file:

```
<Path name = "/Browser/Toolbar">
  <Condition name="IsSolutionOpen" action="Disable">
    <ToolbarItem id       = "SyncHelpTopic"
                 icon     = "Icons.16x16.ArrowLeftRight"
                 tooltip  = "${res:AddIns.HtmlHelp2.SyncTOC}"
                 class    = "HtmlHelp2.SyncTocCommand"
                 insertafter = "Separator1"/>
    [...]
```

Listing 3 – A different AddIn adding another ToolbarItem

Now, the call to `ToolbarService.CreateToolStrip` will return a `ToolStrip` with four buttons thanks to the fact that the AddIn tree combines all the AddIn definitions together. By creating the toolbar using the Core API (ToolbarService), the host application has made its toolbar extensible. The more the host applications uses such calls, the more extensible it will be.

Listing 3 also shows a standard construct called `Condition`. The Condition causes the `ToolbarItem` to be enabled only if the IsSolutionOpen condition evaluates to `true`. The Condition has custom logic implemented in a C# class, which has to be registered in the following way:

```
<Runtime>
    <Import assembly=":HelpAddin">
        <ConditionEvaluator name="IsSolutionOpen"
            class="HelpAddin.IsSolutionOpenConditionEvaluator"/>
[...]
```

Listing 4 – Registering a ConditionEvaluator

In the listings 1 and 3 one can also notice that each of `ToolbarItem` xml tags has a number of attributes. The attribute *class* determines the name of the class that handles the toolbar button click. The *insertafter* attribute specifies at which position the item should be inserted. Insertafter refers to an *id* of another item. The final order of items is resolved from the insertafter relations by a topological sort algorithm.

So far the examples have shown two types of tags which can be inserted inside a Path in the AddInTree: Condition and ToolbarItem. These xml tags are called *codons* in SharpDevelop terminology. There are six types of default codons:

- `Class` – Creates object instances by invocating a type's parameterless constructor.
- `FileFilter` – Creates file filter entries for the `OpenFileDialog` or `SaveFileDialog`.

- `Include` – Includes one or multiple items from another location in the addin tree. You can use the attribute `"item"` (to include a single item) **or** the attribute `"path"` (to include all items from the target path).
- `Icon` – Used to create associations between file types and icons.
- `MenuItem` – Creates a menu item (WinForms on WPF depending on the version of Core used).
- `ToolbarItem` – Creates a toolbar item (WinForms on WPF depending on the version of Core used).

The `class` codon is very useful when providing extensibility not related to user interface. A typical usage is to register classes at a well-known Path:

```
<Path name="/SharpDevelop/Debugger/Visualizers">
        <Class class="Debugger.AddIn.Visualizers.ObjectGraphVisualizer" />
</Path>
```

Listing 5 – Registering service implementations at a well-known path

Then the host application can obtain all the available implementations:

```
AddInTree.BuildItems<IVisualizer>("/SharpDevelop/Debugger/Visualizers");
```

Listing 6 – Obtaining all implementation from a well-known path in the AddIn tree

Such call assumes that all the classes registered at the Path `/SharpDevelop/Debugger/Visualizers` implement the `IVisualizer` interface provided by the host application (that is SharpDevelop in our case).

Lazy loading

To improve application startup time, the parts of the AddIn tree are only loaded when needed. For example if an AddIn adds items to a menu, the AddIn assembly will not be loaded until the menu is opened for the first time.

Extensibility

So far, six default types of codons (`Class`, `FileFilter`, `Include`, `Icon`, `MenuItem`, `Toolbar`) were described. All these codons are actually not hardwired into the AddIn tree implementation. There is a generic mechanism of turning codons (i.e. the xml tags) into objects, and this mechanism is extensible. We will not go into details here because there is an excellent article by Daniel Grunwald [10] covering this topic and more.

Localization

ICSharpCode.Core provides support for localization. Localization strings are stored in standard .NET resource files with extensions denoting culture, such as "StringResources.de.resx". The individual strings can have arbitrary identifiers but a namespace-like convention is usually used to prevent collisions. The strings are then accessible in XAML using a markup extension:

```
"${res: AddIns.Profiler.ProfilingView.CpuCyclesText}"
```

Listing 7 – Accessing localized strings from XAML

And in code using e.g.

```
StringParser.Parse("${res:AddIns.Profiler.ProfilingView.CpuCyclesText}")
```

Listing 8 – Accessing localized strings from C#

In SharpDevelop itself, the resource files are being generated by a custom tool from a translation database filled by contributors using a translation website[1].

Remarks

For more information about SharpDevelop.Core see [10] and [11].

2.2.3 ICSharpCode.SharpDevelop

As said before, SharpDevelop is an application built using ICSharpCode.Core. The codebase of SharpDevelop itself consists of many AddIns. Even the IDE "itself" is an AddIn (defined in ICSharpCode.SharpDevelop.addin). The SharpDevelop AddIn contains the base of SharpDevelop UI and a part of functionality but it is not a working IDE - it rather provides interfaces to be implemented by other AddIns. For example, code editing, code completion, and debugger are all implemented as AddIns extending ICSharpCode.SharpDevelop.

2.2.4 NRefactory

NRefactory is a standalone library providing object model for C# and VB code. NRefactory is important to this thesis because the debugger is using NRefactory extensively to represent expressions to be evaluated.

NRefactory contains a lexer and a parser of C# and VB languages[2]. The main use of NRefactory is parsing of source code and providing a *Syntax tree* of the code. There are many possible types of nodes in the syntax tree, for example `ForStatement`, `SwitchStatement`, `MemberReferenceExpression`, `BinaryOperatorExpression` etc. For example the following code snippet is parsed into the following syntax tree:

```
var foo = Foo.Size + 2;
```

Listing 9 – Sample code to be parsed by NRefactory

```
VariableDeclaration(Name=foo)
    Intializer=
        BinaryOperatorExpression(op=Add)
            MemberReferenceExpression(MemberName=Size)
                IdentifierExpression(Identifier=Foo)
            PrimitiveExpression(Value=2)
```

Figure 13 – Parse tree for the the code snippet from Listing 9

The important fact to realize is that the syntax tree does not contain any semantic information – for example it is not known whether *Foo* is a class, a local variable, or a property.

[1] From a personal point of view, it is a rewarding feeling to add a new string into the UI and see it translated into ten languages by people from around the world.
[2] The lexer and parser are kept up to date with most recent language specifications changes.

Visitors

NRefactory uses the classical Visitor pattern for all operations on the syntax tree: the root of the class hierarchy, `INode`, defines a method `AcceptVisitor` and each specific type of node overrides `AcceptVisitor` to call a specific version – e.g. `ForStatement.AcceptVisitor` calls `visitor.VisitForStatement(this)`. The logic of the tree traversal is implemented in `AbstractAstVisitor` from which users can derive new visitors to implement new operations[1].

2.2.5 ICSharpCode.SharpDevelop.Dom

In the section 2.2.4 (NRefactory) it was stated that the NRefactory syntax tree does not contain any semantic information – in Figure 13 it can be seen that *Foo* is an *Identifier* but no more information is provided – there is no information about whether it is a class, a property, a field or a local variable.

Of course, the IDE needs a lot of semantic information about the code to provide features such as *Go to definition, Find references* and *Code completion*. The semantic understanding of the code is provided by ICSharpCode.SharpDevelop.Dom. The Dom provides an object model for representation of classes, methods, types, parameters etc. An important part of the Dom are resolvers (that is implementations of `IResolver`). Resolvers accept the identifier *Foo* from our example plus context (position in the source code file) and return information telling whether the symbol is a class, a property or other symbol, where to find its definition etc.

In order for the resolvers to be able to work correctly, the Dom representation of all the symbols in the currently open solution is needed. When a solution is opened, SharpDevelop reads and parses all the solution files to build an initial Dom representation. When files are being edited, SharpDevelop is reparsing the files in background and updating the Dom representation.

ICSharpCode.SharpDevelop.Dom depends only on NRefactory and is therefore reusable outside of SharpDevelop. The principle of programming against interfaces is strictly followed, so for example `PythonClass` (coming from the IronPython backend binding) implements `Dom.IClass` and the code in Dom can work with it without knowing anything about Python. Similarly, concrete implementations of `IResolver` provide resolvers implementing the semantic rules of C#, VB, Xaml and the other supported languages.

2.2.6 Future of NRefactory and Dom

In retrospect, the decision to split the syntactic and semantic representation of code into NRefactory and Dom was not the best one – there could be a unified representation bringing the facilities of NRefactory and Dom together. Also, NRefactory was designed when C# and VB were identical languages differing only in syntax. However, the features of C# and VB cannot be mapped 1:1 anymore. As a result, new version of NRefactory [12] has been designed to be used in the future versions of SharpDevelop.

There is also a very interesting initiative from Microsoft to open the internals of their compiler which could be very useful for SharpDevelop and many other tools dealing with

[1] AbstractAstVisitor is intented for read-only operations. If an operation needs to modify the parse tree, it should subclass AbstractAstTransformer.

source code. The problem with the current C# compiler is that it acts as a black box, consuming source code and producing binary output. In the process of turning the source code into bytecode, the compiler builds large amount of very useful semantic information about the code, and then throws it away.

IDEs and other tools have to re-implement the logic that is already present in the black-box compiler – NRefactory contains a full C# parser, the resolvers implement type inference and overload resolution exactly according to the C# language specification etc. All these features are present in the compiler but not accessible (yet).

Note that the Scala programming language already has an open compiler (called Presentation compiler [13]) exposing all its understanding of the code so for example the Scala IDE for Eclipse [14] and Ensime IDE for Emacs [15] are both using the Scala Presentation compiler.

2.2.7 Debugger

SharpDevelop ships with an integrated debugger. The overall schema of interaction of the debugger with the debuggee is the following:

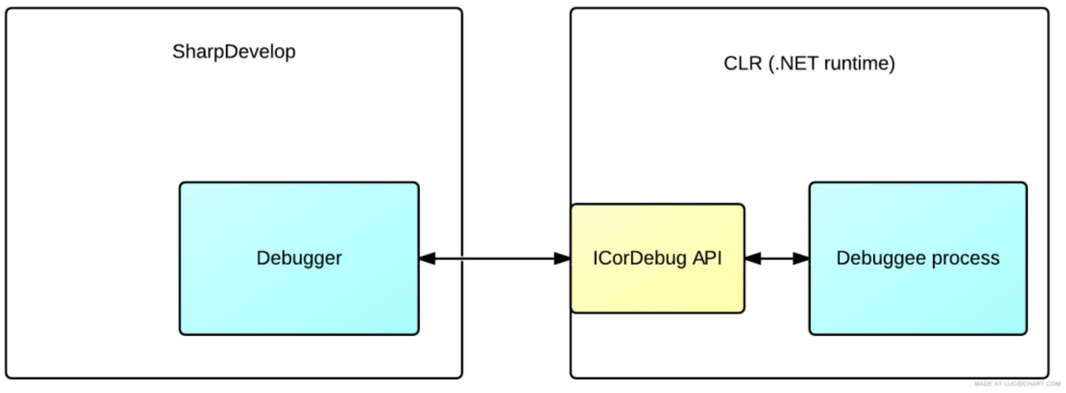


Figure 14 – Overall shema of debugging. An important fact to realize is that the debuggee lives in a separate process.

SharpDevelop's integrated debugger consists of two components – Debugger.Core and Debugger.AddIn. Debugger.Core is a standalone debugging library for .NET and Debugger.AddIn integrates this library into SharpDevelop.

Debugger.AddIn

Debugger.AddIn is essentially SharpDevelop's integrated debugger. It contains all the IDE-specific logic and user interface, including the Debugger tooltips and Debugger visualizers. Debugger.AddIn relies on Debugger.Core for most of its functionality, for example setting breakpoints, stepping, or evaluating expressions.

Debugger.Core

Debugger.Core is a standalone debugging library for .NET. It provides features typically present in debuggers: attaching to and controlling a user program, stepping, setting breakpoints, exploring state of the variables in the program etc. Debugger.Core uses a low-level debugging COM API provided by the .NET runtime [16]. Parts of this section are based on information from David Srbecký, namely [17].

Architecture

Debugger.Core consists of four cleanly separated layers. Starting from the lowest layer, these layers are:

- COM API: The low-level unmanaged debugging API of the .NET framework. The API contains interfaces such as ICorDebug or ICorDebugManagedCallback.
- COM wrappers: Auto-generated thin layer over the COM API which makes it a bit easier to use. It converts 'out' parameters to return values and tracks returned COM objects so that they can be explicitly released (this is necessary so that the debugger does not lock assemblies). The layer also contains several hand-written methods that handle marshaling of strings and other objects.
- NDebugger: The debugging library itself. It provides access to variables and types via reflection-like interface. It provides commands for setting breakpoints, stepping and basically everything usually expected from a debugger.
- ExpressionEvaluator: Extension on top of NDebugger which can evaluate C# expressions. ExpressionEvaluator depends on SharpDevelop's NRefactory.

Fundamentals of debugging

The debugger can start a new debuggee process or it can attach to an existing one. While the debuggee is running, there is not much the debugger can do. Almost all operations are forbidden. The debugger has to wait until the debuggee pauses - usually because user's breakpoint is hit. Once the debuggee is paused, the debugger can investigate its state - it can look at the call stack, read local variables and so on. Stepping or pressing "Continue" will put the debuggee into running state again. An important thing to realize is that the debugger and the debuggee are running in separate processes.

Sample

To demonstrate Debugger.Core in practice, let’s look at an example of its usage. Assume we have the following “Hello world” program:

```
class Program
{
    public static void Main(string[] args)
    {
        string message = "Hello World!";
        System.Console.WriteLine(message);
    }
}
```

Listing 10 – Sample program to be debugged

This program can be debugged using the following code:

```
NDebugger debugger = new NDebugger();
Breakpoint breakpoint = debugger.AddBreakpoint("Program.cs", 6);
breakpoint.Hit += delegate { Console.WriteLine("Breakpoint hit"); };
// Start the debugee
Process process = debugger.Start("HelloWorld.exe", "C:\\", null);
// Waits until the breakpoint is hit if it did not
// already happen.
process.WaitForPause();
// The breakpoint hit message should be shown now
// Show the name of the current method on the stackframe
Console.WriteLine("Current method =
" + process.SelectedStackFrame.MethodInfo.FullName);
// Get reference to the local variable
Value localVariable =
    process.SelectedStackFrame.GetLocalVariableValue("message");
Console.WriteLine(string.Format("message = {0} (type: {1})",
    localVariable.AsString(), localVariable.Type.Name));
// Resume execution after the breakpoint
process.AsyncContinue();
```

Listing 11 – Sample usage of the debugger

The program produces the following output:

```
Breakpoint hit
Current method = Program.Main
message = Hello World! (type: String)
```

Listing 12 – Ouput of the program from listing 10

Investigating state of variables

The sample code in the previous section showed that it is possible to obtain values of variables defined in the debuggee process. This section described how the process of obtaining values of variables works and what the design decision were when building this part of the debugger API.

Values

Listing 11 in the previous section showed a statement for obtaining the value of a variable:

```
Value localVariable =
    process.SelectedStackFrame.GetLocalVariableValue("message");
Console.WriteLine(string.Format("message = {0} (type: {1})",
    localVariable.AsString(), localVariable.Type.Name));
```

Listing 13 – Getting values of variables using the debugger

The object returned by the `GetLocalVariableValue` call is of type `Debugger.Value`. The `Debugger.Value` class has an `AsString()` method which returns a string representation of the value of the variable.

What exactly is the `Debugger.Value`? As said before, the debugger and the debuggee are running in separate processes. That means a `Debugger.Value` cannot hold a direct reference to an instance in the debuggee process (because memory spaces of individual processes are strictly separated by the operating system). Instead, some sort of interprocess communication must be used. The ICorDebug API used by the `Debugger.Value` class under the hood takes of this communication.

If the value in the debuggee is of primitive type like string or integer, its actual content can be requested. However if the value is a class, we must enumerate its fields and properties and get the values for the ones that we are interested in. We are of course free to get fields of the new values as well and drill down as much as we want to.

There is a good reason why this model is appropriate. The debugger does not know that the user will create a field "myHelloWorldMessage" and therefore it cannot reference it. Even if direct reference to the object in the other process was somehow available, the debugger would still have to use reflection to figure out what fields the object contains and then get their values one by one. In fact, most of the debugger's API inherits from the abstract reflection classes (like Type, MethodInfo) so anyone familiar with reflection should have no problems using the debugger API.

Lifetime of Values

The .NET garbage collector (GC) presents a significant complication to the debugger. When the debuggee is paused no code can be executed including the garbage collector so it is safe to investigate it as much and as long as we want. However, if the debuggee is resumed even for just a few instructions, the GC might have been run and it might have moved all variables around in memory. The GC takes care to update all references within the debuggee so that it does not even notice. However, it unfortunately does not tell the debugger. This means that whenever the debuggee is resumed, all debugger's Values become invalid because they might be pointing to wrong memory (Value holds a reference to the COM object identifying the value in the debuggee). The next time the debuggee is paused, it has to obtain all values again. This problem is more problematic than it might initially seem - getting a value of a property or calling Object.ToString() both require that the debuggee is resumed for a while so that the methods can be injected into the debuggee and executed. Imagine that we are debugger tooltips to drill down to object "foo.bar.Person" which contains two properties - FirstName and Surname. After we evaluate the "FirstName" property, all values will become invalid and we will have to obtain "foo.bar.Person" again just so that you we evaluate "Surname".

Permanent references

The ICorDebug API provides a facility to get around the problem with the lifetime of Values – it is possible to create a strong handle, which does not become invalid when the debuggee is resumed and always points to the right place in the memory where the debuggee instance resides, even after the target instance was moved by the garbage collector. This functionality is accessible using the `Value.GetPermanentReference()` method in Debugger.Core. In this thesis, we refer to Values returned from `GetPermanentReference()` as *Permanent references*.

It seems that the problem with the lifetime of `Debugger.Values` is solved by immediately obtaining a Permanent reference immediately when obtaining any `Debugger.Value`. However, the documentation states that user code should never keep many Permanent references (more than a few hundred). Therefore, the problem remains as we are allowed to create Permanent references and use them shortly but we cannot keep many of them as long as we need to.

Expressions

To get around the problem with Garbage collection invalidating Values, Debugger.Core provides *Expressions*, using `NRefactory.Ast.Expression`. An Expression is a tree which represents a way to obtain a `Debugger.Value`.

Expressions can be turned into their string representation (e.g. *"foo.bar.Person"*) and parsed from a string in C# format. This functionality is provided by NRefactory. Expressions can be evaluated by calling `Expression.Evaluate()`, producing a `Debugger.Value`. This is the main point of expressions in the debugger – instead of keeping a `Debugger.Value` and never knowing when it becomes invalid, we keep an Expression an evaluate it whenever we need its value. Indeed, this how all the UI of SharpDevelop's integrated debugger uses Expressions: When the user has *foo.bar* open in a debugger tooltip and expands *Person*, the debugger tooltip generates an expression *foo.bar.Person* and then evaluates it.

At one point in the past, the Value class was designed so that it would remember the expression using which it was obtained and automatically reevaluate itself if needed. However, this approach turned out to be quite difficult to debug since a relatively simple call could cause complicated chain of events. The expression based approach is more explicit and thus allows better reasoning about the program - both in terms of behavior and performance.

Expression evaluation

`Expression.Evaluate()` is implemented in the `ExpressionEvaluator` class which acts as a visitor, traversing the syntax tree of the Expression. This design takes advantage of the fact that expression evaluation can be defined recursively:

For example, when evaluating expressions *list[i+3].Name* or *person.Name*, *list[i+3]* or *person* is evaluated first and then the field or property called *Name* is evaluated on the result of the evaluation. To evaluate *list[i+3]*, *i+3* is evaluated and the result is passed as a parameter to the indexer of *list*.

This is exactly how `ExpressionEvaluator` works. Methods calls are also supported (so *foo.Bar(foo).Foo* can be evaluated).

Caching

For better performance, the `ExpressionEvaluator` caches results of evaluations in form of Permanent references. This is useful because often a series of Expressions like *this.Person.FirstName*, *this.Person.LastName* and so on are evaluated and thanks to caching, *this.Person* is evaluated only once. When the debuggee is resumed by user request (for example by a debugger step) the cache is cleared.

Performance tricks

There are some clever tricks used to improve performance of the evaluation. For example, in .NET it is very common to have properties with getter methods just returning a backing field, such as (in C#).

```
string Name { get { return this.name; } }
```

Listing 14 – Property with a backing field

or

```
string Name { get; set; }   // backing field is generated by the compiler
```

Listing 15 – Property with an auto-generated backing

Exploiting the fact that getting values of fiels is much faster that using getters (which requires resuming the debuggee and waiting for result), the value of the field is returned directly when possible.

This is done by looking at IL of the getter method to see if it is a method in the form `return field;`. Such IL can have four different versions when generated by Microsoft's C# compiler (depending on the property being instance/static and the backing field being explicit/generated). The pattern to recognize all four versions is the following (can be found in *DebugMethodInfo.cs*):

```
nop || nothing
ldarg.0; ldfld || ldsfld
    <field token>
stloc.0; br.s; offset+00; ldloc.0 || nothing
ret
```

Listing 16 – IL structure of a property getter returning value of a backing field

The type system

The debugger can not only provide information about the values in the debuggee, but also about their types. In fact, to be able to obtain contents of a complex value (instance of a class) we must know the type of the value to be able to iterate its fields and properties and get their values one by one. This is a very common pattern used everywhere in SharpDevelop, including the Debugger visualizers.

The API provided by the debugger to investigate the types in the debuggee is very easy to understand if one is familiar with Reflection. In fact, the API is exactly the same as the reflection API. The class `DebugType` implements the abstract class `System.Type`, so it has methods such as `GetProperties()` and `GetMethods()` which return `System.Reflection.PropertyInfo`, `MethodInfo` etc. They actually return debugger-specific implementations of these types but that is not a concern to the user.

Again, under the covers, the debugger uses the low level COM API provided by the .NET runtime (for example the `IMetadataImport` interface).

Multithreading

Unfortunately from the specification of the underlying ICorDebug API, all the debugger calls have to be invoked from the main thread. Evaluating multiple expressions at once would be a performance improvement for some parts of the code working with the Debugger API (including the Debugger visualizers) but it is unfortunately not possible.

2.3 Fundamental problem of debugging

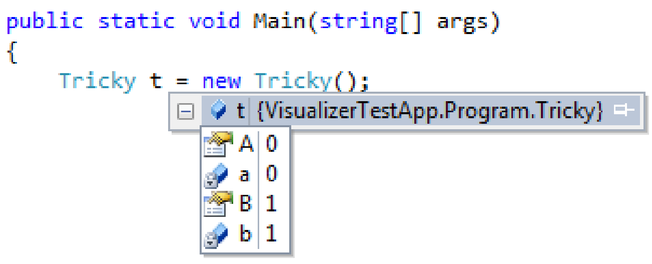
There are several important facts to realize about debugging in general when object *properties* are involved. The first fact is that the debugger is actually *changing* the state of the debuggee by observing it. This is because the only correct way to obtain a value of a property is to invoke its getter, and if the getter has some side effects it can change the state of the program.

Another fact to realize is that it is not always easy to correctly determine the values of all properties of an object. Take, for example, the following class:

```
public class Tricky
{
    int a;
    int b;
    public int A {
        get    {
            b++;
            return a;
        }
    }
    public int B {
        get    {
            a++;
            return b;
        }
    }
}
```

Listing 17 – Class with two property getters incrementing each other

After creating an instance of this class, debugger tooltips in Visual Studio 2010 show an incorrect state of the instance:



```
public static void Main(string[] args)
{
    Tricky t = new Tricky();
```

```
t {VisualizerTestApp.Program.Tricky}
    A 0
    a 0
    B 1
    b 1
```

Figure 15 – Debugger tooltip in Visual Studio 2010 showing „incorrect“ state of an instance

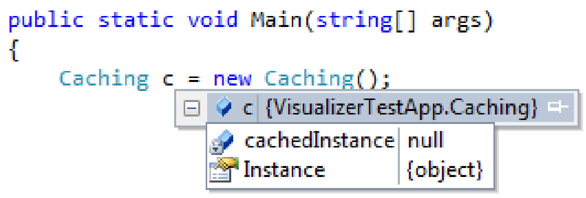
The state displayed in Figure 15 definitely does not correspond to reality – the debugger read both of the properties A and B so the actual values of the fields are a=1, b=1. But what are the actual values of properties A and B?

If a value of a property is defined by calling a getter of the property and reading the return value, then reading the value of A changes the value of B and vice versa, which means values of both A and B cannot be determined at the same time. The debugger could get around the problem with values of fields by first evaluating all properties and then all fields (here the evaluation was apparently done in aplhabetical order) but the debugger can never display „correct“ values for both properties A and B because such pair of values does not exist.

The problem might seem a little theoretical, but there are very practical scenarios which exhibit similar problems:

```
public class Caching
{
    object cachedInstance;

    public object Instance {
        get {
            if (cachedInstance == null)
                cachedInstance = new object();
            return cachedInstance;
        }
    }
}
```

Listing 18 – Property getter caching a value



```
public static void Main(string[] args)
{
    Caching c = new Caching();
```

c	{VisualizerTestApp.Caching}
cachedInstance	null
Instance	{object}

Figure 16 – Debugger tooltip in Visual Studio 2010 showing incorrect state of an instance

The situation in Figure 16 could be solved by first evaluating properties and then fields. But what if there is another property which only reads `cachedInstance`? Then the value of such property would be shown incorrectly if it were evaluated before evaluating `Instance`. Next solution would then be evaluating all properties twice, which would incur a large performance overhead (especially concerning the expensiveness of the debugger API) and still would not solve all cases – when there are more instances shown at the same time (watch window, or multiple levels of a debugger tooltip expanded), all of them would have to be updated because a property getter could also change other instances.

Probably the only relatively reasonable solution is evaluating properties first and then fields, which would solve some common scenarios like the one in Figure 16, but such solution would have to evaluate all properties even when they would be out of view (scrolled away) which would again incur mostly unnecessary performance overhead. As seen in the screenshot, current debuggers do not try to solve these problems – the user has better understanding of the code and can reevaluate relevant parts as needed.

2.4 Division of work

In the motivation section it was stated that this thesis aims to solve issues with the current state of debugging Object graphs and Collections and to improve SharpDevelop's debugger tooltips in the direction of collection support. As visualizing changes in object graphs and visualizing contents of collections are distinct topics, it was decided (after a discussion with the SharpDevelop team) that there will be two new separate features in SharpDevelop – the Object graph visualizer and the Collection visualizer. The third feature are the debugger tooltips. The debugger tooltips will conceptually stay the same as they were in SharpDevelop 3, but will be re-implemented in WPF with added proper support for debugging collections.

This thesis will analyze the Object graph visualizer, the Collection visualizer, and the Debugger tooltips mostly separately but it will also identify common functionality shared by these three features – such as collection support.

2.5 Collections

From the goals set for the Collection visualizer and Debugger tooltips, it is clear that both of them will handle collections – the Debugger tooltips need support for IEnumerable collections and large collections and the Collection visualizer will handle the same types of collections as well. As for the Object graphs – the individual nodes in actual object graphs can, indeed, also be collections, therefore it would be best to support collections in the Object graph visualizer as well.

The common requirement for all of the visualizers is that large collections are supported without significant degradation in performance. In the previous version of SharpDevelop, when a collection variable was expanded in the debugger tooltips, the tooltips first obtained all of the collection items from the debugger and only then displayed first few items. Since the communication with the debugger has to be done on the main thread (as discussed in section 2.2.7 (Debugger)), the whole IDE was blocked for up to minutes, depending on the size of the collection.

This thesis takes a lazy approach to getting items of collections from the debugger – only the first few items needed to be displayed are obtained and as the view is scrolled more items are being pulled from the debugger. This approach can be applied to all of the visualizers.

2.5.1 Types of collections

The basic inheritance hierarchy of .NET collection interfaces is the following.

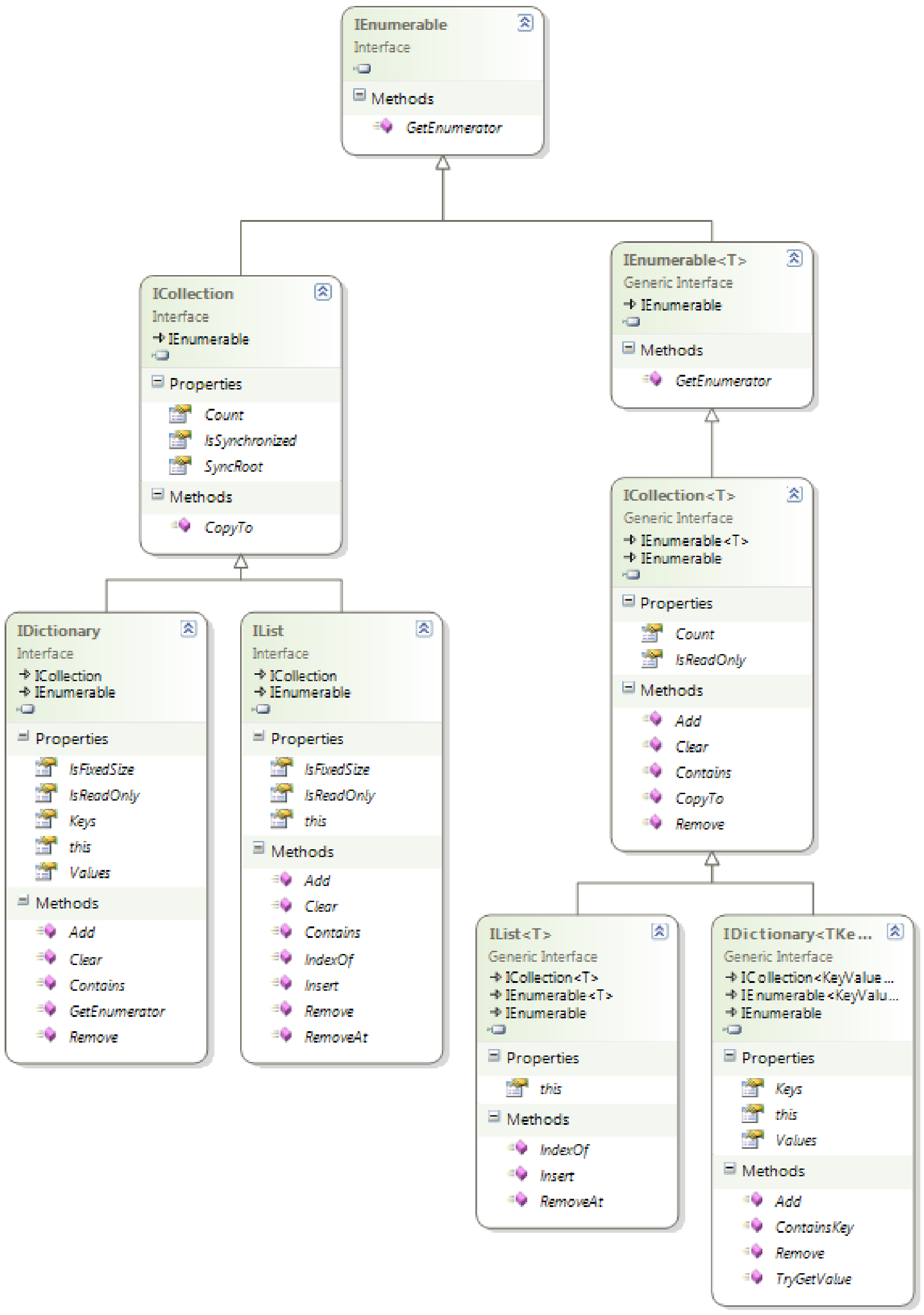


Figure 17 - .NET collections inheritance hierarchy

As seen from the diagram, all the collection types in .NET framework implement IEnumerable. Also, when dealing with user-defined collection types (including enumerators implemented using the *yield return* construct in C#), it is safe to assume that any user type that has semantics of a collection will implement IEnumerable. Therefore by supporting IEnumerable, all possible types of collections would be supported.

However, the IEnumerable interface itself is very basic – it only enables sequential iteration over the collection, without random access. The following three sections analyze possible approaches to supporting collection types in the visualizers.

2.5.2 First approach – treating all collections as IEnumerable

The starting point for all the visualizers is a `Debugger.Value` or `NRefactory.Ast.Expression` (which, when evaluated, yields a `Debugger.Value`). First, it must be verified that the debuggee instance represented by the `Debugger.Value` implements `System.Collections.IEnumerable`, which can be done by examining `Value.Type.FullName`. Then it is possible to obtain the individual `Values` representing the items: the method `GetEnumerator()` is invoked and the result is stored as a Permanent reference. Then, whenever the collection view is scrolled and more items are needed, the `MoveNext()` method and Current getter are invoked on the enumerator object to obtain a Value representing the next item. When `MoveNext()` returns false, there are no more items available.

A very important requirement in all of the visualizers is that the individual items of collections can be expanded further. To expand an item, an identification of the item is needed – either a `Debugger.Value` or an `Expression`. For `Debugger.Values` obtained from an enumerator, there are no corresponding `Expressions` – the instances returned from the enumerator can be new objects which cannot be reached through any variables in user code simply because the user code does not reference the instances. The only remaining possible identification of the `Debugger.Values` obtained from the enumerator are therefore the `Values` themselves, in form of Permanent references (because without Permanent references they would all become invalid immediately when obtaining the next item). The problem is that scrolling the view of the collection would cause more and more Permanent references to be kept and, by specification, holding many Permanent references is not allowed.

The only solution possible here would be not to hold any identification of the `Debugger.Values` and when an item at index *i* is expanded, iterate over the collection from the beginning (by obtaining a new enumerator) to the *i*-th item and expanding it. Such solution would not be very efficient and moreover, the item obtained by re-enumerating the collection could be a different instance from the one which is being expanded.

Pros

- One implementation supports all types of .NET collections.
- Supports infinite collections. It is not a problem if `MoveNext()` never returns false - first few items will be displayed immediately and more and more items will be obtained as needed.

Cons

- Expanding individual items is not really possible (only by re-enumerating the collection from the beginning).
- Fast scrolling (faster than items can be obtained from the debugger) is not possible due to the sequential nature of IEnumerable interface.
- If a collection only implements IEnumerable, the number of items (needed to display an accurate scrollbar) cannot be determined. The only possible solution would be evaluating `MoveNext()` and `Current` in loop, which is unacceptably slow. Evaluating *System.Linq.Enumerable.Count(e)* would count the items quickly but it cannot be guaranteed that the debuggee process references System.Core. The difference between evaluating `MoveNext()` in a loop and evaluating `Count()` is that each `MoveNext()` call

needs an expensive interprocess debugger API call, while `Count()` is one debugger API call and all the work is done directly in the debuggee. Injecting a foreach loop into the debuggee to emulate missing `System.Linq.Enumerable.Count()` is not possible, as the debugger API only supports expressions, not statements (foreach is a statement).

Summary

The cons of the IEnumerable solution are significant and it can be observed that all of them are caused by the simple nature of the IEnumerable interface allowing only sequential access to the items. The problem with determining the length of the collection and fast scrolling cannot be resolved. Expanding can be solved only partially by re-enumerating the collection always from the beginning, possibly obtaining wrong instances. The Pros of this solution are outweighed greatly by its Cons.

2.5.3 Second approach – special case for IList

In the .NET collection interface hierarchy there is an interface called IList which adds an indexer allowing random access to the items (the ICollection interface is not interesting in our scenario because it only adds the Count property and otherwise has exactly the same drawbacks like IEnumerable). This section explores the possibilities of dealing with collections that also implement IList. It can be verified that a `Debugger.Value` implements `System.Collections.IList` by examining `Value.Type`. The individual items from the IList can be obtained by invoking the indexer getter on the `Debugger.Value` representing the whole IList instance.

Pros

- Expanding individual items is not a problem: to expand an item at position *i*, it is sufficient to remember the Permanent reference representing the whole IList and invoke the indexer on this Permanent reference, passing *i* as a parameter.
- The length of the collection is immediately known by evaluating the "Count" property on the IList Value. A scrollbar of correct size can be displayed.
- There are no limitations on the speed of scrolling. If properly implemented, it will be possible to skip evaluation of items which are being scrolled over fast.

Cons

- Works for IList but not for IEnumerable.

Summary

The Pros of making a special case for IList are so significant that it is definitely worth it to support IList separately. When an instance does not implement IList and only implements IEnumerable, a fallback to the basic IEnumerable solution can be implemented.

2.5.4 Third approach – converting IEnumerable to IList

There is another possible approach to IEnumerable which is not immediately obvious – having an expression *e* representing an IEnumerable<T>, by evaluating an Expression "*new List<T>(e)*", the IEnumerable<T> gets fully enumerated directly in the debuggee (as if the debuggee itself called *new List<T>(e)*) and a Value representing the new List is returned. Then the visualizers can access the List items randomly and get the `Count` of the List, enabling expanding, accurate scrollbar, and fast scrolling. The constructor of List<T> is always available because List<T> resides in mscorlib.dll which is always loaded in any .NET process (mscorlib defines all the system types, like System.Int32 or System.String).

The solution is then to visualize ILists using the Second approach and visualize IEnumerable<T> by converting it into IList and then also using the Second approach.

Pros

- All the Pros of the Second approach hold not only for IList and IList<T>, but also for IEnumerable<T>.

Cons

- This solution cannot be applied to non-generic IEnumerable collections. Unfortunately, there is no method in .NET 2.0 mscorlib (we want to support .NET 2 programs) that accepts non-generic IEnumerable and returns an IList. Injecting a piece of code that would emulate this functionality into the debuggee is not possible using the debugger API, as the debugger API only supports expressions, not statements.
- Infinite IEnumerable<T> collections are not supported – the evaluation will timeout.

2.5.5 Conclusion

From the three approaches, the last one was chosen to be used in both the visualizers and the Debugger tooltips. It has very strong Pros only at the cost of not supporting non-generic IEnumerable and infinite collections, which are both rare cases. To support these two cases, the fallback to the first approach can be implemented, but it was decided not to do so – it would mean maintaining more code only to support two uncommon cases which arguably most programmers almost never encounter (actually we had the First approach implemented but removed it for maintainability reasons – the First approach works with `Debugger.Values` while the Third approach enables working with `Expression` consistently everywhere).

Note: Experiments with Visual Studio 2008 show that its integrated debugger timeouts when expanding an infinite IEnumerable collection in a debugger tooltip. This indicates that the Visual Studio debugger is probably using an approach similar to our Third approach.

Expression caching

The visualizers will be getting the individual collection items by evaluating Expressions such as *list[i].Name*. In section Expression evaluation (subsection of 2.2.7), it was stated that the `ExpressionEvaluator` internally caches Permanent references of evaluated expressions. This means that when scrolling a view of a collection, more and more Permanent references would be held by the Expression cache. To solve this problem, after a discussion with David Srbecký a method to clear the Expression cache was added to Debugger.Core and the visualizers will call this method periodically to avoid holding many Permanent references when working with large collections.

This concludes the analysis of handling collections in the visualizers.

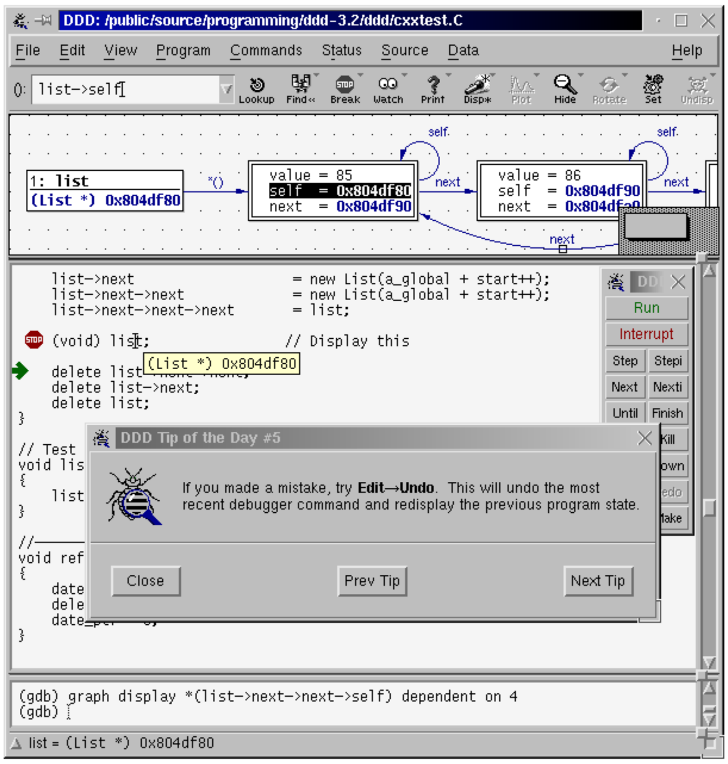
2.6 Object graph visualizer

The high level idea of the Object graph visualizer is the following:

The user enters an expression to be visualized. The visualizer explores the object graph starting at this expression and presents it to the user in a similar way people draw data structures on a whiteboard. When a step in the debugger is performed, the drawing of the graph is updated using a transition from the old state to the new state. The transition should help users understand the changes that occurred during the debugger step.

2.6.1 Existing work

There have been attempts to implement something similar. Probably the most significant effort so far has been the Data Display Debugger [18] which is a graphical frontent to the command line debuggers like GDB or a Python debugger pydb. Unfortunately, none of these debuggers support debugging managed .NET programs.



```
    list->next                  = new List(a_global + start++);
    list->next->next            = new List(a_global + start++);
    list->next->next->next      = list;

    (void) list;               // Display this

    delete list
    delete list->next;
    delete list;
}

// Test
void lis
{
    list
}

//
void ref
{
    date
    dele
    date
}
```

(List *) 0x804df80

DDD Tip of the Day #5

If you made a mistake, try **Edit→Undo**. This will undo the most recent debugger command and redisplay the previous program state.

```
(gdb) graph display *(list->next->next->self) dependent on 4
(gdb)
```

list = (List *) 0x804df80

Figure 18 – DiplayDataDebugger showing a graph of in-memory structures in a C program

2.6.2 What needs to be done

The basic requirement for the Object graph visualizer is that an object graph for a given expression is presented to the user in a similar way people draw the object graphs on a whiteboard. Can the task be split into separate parts / steps? Yes it can, at least into these two independent steps:

1. Building the graph - given an expression, determine the vertices and edges of the graph
2. Drawing the built graph to the screen

The second step can be split into two independent steps:

- Determining the layout of the graph (that is the positions of nodes and edges on a plane)
- The actual drawing to the screen

The last required feature are Graph transitions which visualize the changes caused by steps in the debugger. This leaves us with:

1. Graph building
2. Graph layout
3. Graph drawing
4. Graph transitions

As said, the first three steps can be done independently; but what about the last step – Graph transitions? Will Graph transitions be a completely separate step or will they interact with Graph building / layout / drawing?

Graph transitions

To decide how Graph transitions integrate with the rest of the algorithm, one has to realize how debugger steps work. During a debugger step, a temporary breakpoint is placed at the location of the next code segment and the debuggee is resumed to run at full speed until it hits the breakpoint. When the temporary breakpoint is hit, the control is returned to the debugger.

Graph transitions should visualize the change caused by the debugger step, by moving existing nodes to their new positions, and making it clear which nodes have been added and removed. A natural idea would be to obtain some kind of a diff from the debugger describing the changes which occurred and based on this diff then produce the transition. Unfortunately, the debugger has no control over the debuggee while the debuggee is running and obtaining such state diff directly is not possible.

However, we propose that it is still possible to infer a diff based on observations of the debuggee state before and after the step. After the debugger step is finished and the control is returned to the debugger, a new Object graph is built, reflecting the current state. The instances found in this new Object graph are compared to the instances found in the old Object graph from before the step and as a result of this comparison a diff describing the changes is obtained. Using this diff a graphical transition explaining the changes can be produced.

The conclusion to this section is that Graph building, Layout and Drawing will not depend on Graph transitions. Graph transitions will use the information obtained in the Graph building phase to infer a diff between two Object graphs and produce a graphical transition from the first graph to the second one.

2.6.3 Graph building

Definition: Object graph is an oriented graph, where vertices represent in-memory instances. Let v_A and v_B denote two vertices representing two instances A and B in the debuggee process. There is an oriented edge from v_A to v_B if and only if instance A has a direct reference to B (through a field or a property).

The problem: Given a reference to an instance in the debuggee, build an object graph representing all instances reachable from this instance (up to a maximum depth in case the graph is too large).

The algorithm

We propose the following algorithm to build an object graph given an expression e. The algorithm is quite straightforward – it does a DFS walk down the object graph in the debuggee, checking for already seen nodes. The checking for already seen nodes is done by the function `GetSeenNode` which is crucial because it enables detecting shared references and loops correctly. The result is a graph having the same "shape" as the object graph in the debuggee (in other words the graph built by this algorithm is isomorphic to the actual graph in the debuggee).

```
// evaluate the Expression e to obtain a Value
value = Evaluate(e)
// build the graph
graph = BuildGraph(value)

// value is a Debugger.Value representing an instance in the debuggee process
BuildGraph(value):
    If maximum recursion depth has been reached, return null.
    node = create a new graph node representing this value
    // get all instances this instance points to
    foreach referencedValue in GetReferencedValues(value)
        // do we already have a node reprenting this referenced instance?
        existingNode = GetSeenNode(referencedValue)
        // if yes, just add an edge to this node
        if existingNode != null then MakeEdge(node, existingNode)
        // otherwise continue recursively
        else MakeEdge(node, BuildGraph(referencedValue))
```

Listing 19 – Graph building algorithm

Will this be possible to implement? The calls `Evaluate` and `GetReferencedValues` will need to access the debugger API. Both of them will be possible to implement: evaluating expressions as well as enumerating fields and properties of objects is supported. What actually makes the Object graph special is the function `GetSeenNode`. Without this function the algorithm would be equivalent to expanding debugger tooltips or watches recursively and wouldn't follow the actual structure of the object graph. The main question therefore is *whether and how* `GetSeenNode` *will be possible to implement*.

Analysis of GetSeenNode

In our algorithm, the `GetSeenNode` function takes a reference to an instance in the debuggee (a `Debugger.Value`) and returns a graph node that has been already created for this instance, or null if such node doesn't exist in the graph yet.

To be able to distinguish which `Debugger.Values` have been seen from those which haven't, the algorithm will have to keep some unique identifiers of the `Debugger.Values`. One option would be to add some extra information directly to the instances in the debuggee, but that is not possible, as in .NET it is not possible to add fields to objects at runtime[1]. Not being able to

[1] It would be possible to create a Dictionary directly in the debuggee by evaluating an expression "*dict=new Dictionary<object, int>()*" and track instances using this Dictionary by evaluating *dict[o]* and *dict.Add(o, new_id)*. However, a Dictionary uses user defined instance equality (overridden

add unique identifiers to the instances in the debuggee process means that unique identifiers have to be added to the Values living in the debugger process. Permanent references represent a possible unique identification. Expressions represent another possibility because when evaluated they also uniquely identify Values. As it will be shown, Permanent references and Expressions are mostly interchangeable for the purposes of building the Object graph.

A first solution using Expressions follows. The algorithm works with Expressions and keeps an Expression for every node in the graph. `GetReferencedExpressions` creates Expressions by appending all field and property names to given Expression, based on the actual type of the Expression (the Type is determined by evaluating the Expression). For example, by appending property name *FooProp* to object *foo.bar* we get an expression *foo.bar.FooProp*.

```
BuildGraph(expression):
  If maximum recursion depth has been reached, return null.
  node = create a new graph node representing this expression
  foreach referencedExpression in GetReferencedExpressions(expression)
    existingNode = GetSeenNode(referencedExpression)
    if existingNode != null then MakeEdge(node, existingNode)
    else MakeEdge(node, BuildGraph(referencedExpression))
```

Listing 20 – Graph building algorithm using Expressions

In order to determine whether an Expression identifies an already seen instance, `GetSeenNode` queries the debugger to compare the Expression to all of the seen Expressions (by evaluating Expressions such as *foo.bar.Name == e,* where *e* is replaced by all the expressions seen so far, such as *foo.bar* etc.). This works because an expression *a==b* evaluates to true if an only if expressions *a* and *b* refer to the same instance in the debuggee, because evaluating an expression *a == b* is equivalent to executing *a == b* in the debuggee[1]. Pseudocode for `GetSeenNode` follows:

```
GetSeenNode(Expression exprToTest)
foreach node in graphNodesSoFar
    if Evaluate(BinaryOpExpression(op.Equals, node.Expression, exprToTest))
      return node
return null
```

Listing 21 –GetSeenNode has to compare given Expression to every other known Expression

As can be seen from the pseudocode, every call of `GetSeenNode` has to perform many `Evaluate` calls, which is the most significant problem of this algorithm because `GetSeenNode` will be called once per edge and it needs do up to *n* Evaluate calls, the total number of Evaluate calls in O(n.E) where *n* is the size of the resulting graph and *E* is the number of edges in the graph. We implemented this algorithm and found it to be too slow. Even though the graphs to visualize will usually not be very large, the `Evaluate` calls are unfortunately so expensive that this algorithm is unacceptable.

GetHashCode and Equals methods) while in the Object graph visualizer we are interested in instance equality.

[1] Evaluating *a==b* does not execute *a==b* directly in the debuggee, but is evaluated recursively using the ExpressionEvaluator (see section Expression evaluation), which must be implemented correctly so that the expected behavior is met.

The algorithm using Permanent references would be exactly the same, including the needed calls to the debugger in a loop, expect it would work with Permanent references. Permanent references provide instance addresses (offsets in the memory space of the debuggee) but these are not usable as they can be changed by the garbage collector which moves the instances around during the run of the graph building algorithm when the debuggee is being resumed and paused again. Therefore, addresses cannot be used as unique instance identifiers and the only way to use Permanent references is the same way as using Expressions.

The conclusion is that the main problem with identifying debuggee instances by Expressions or Permanent references is that `GetSeenNode` has to compare all the unique identifiers one by one by querying the debugger. The best solution to this problem would be some different form of unique identification of instances in the debuggee such that `GetSeenNode` could run faster than in O(n), ideally in O(1) in average case.

.NET hash codes

Could standard .NET hash codes serve as unique identifiers in the Object graph building algorithm?

In CLR, the runtime representation of every instance has a data member which stores the hash code for the instance. This data member is assigned by the CLR and it is accessible from managed code through `RuntimeHelpers.GetHashCode(Object)` method which returns the same value as the default `Object.GetHashCode()`. While `Object.GetHashCode()` can be overridden to define equality semantics for structures and classes, `RuntimeHelpers.GetHashCode(Object)` always returns the original hash code assigned by the runtime. In the Object graph visualizer we are interested in instance equality to display actual state of objects in memory, not user defined equality. Therefore the default hash codes (accessible through `RuntimeHelpers.GetHashCode`) will be used. The default hash codes have a good property that they never change during the lifetime of an instance and, being integers, they can be used as keys for a hash table.

However, there is no guarantee that the hash codes will be unique – there is no guarantee that two different instances will have different hash codes. The "theoretical" reason behind this is that the hash code is a 32-bit integer (on a 32-bit system), hence the space of all hash codes is limited and it can be guaranteed that sooner or later two different objects with the same hash code will be encountered. There is, however, one very practical reason. One could think that 32-bit space is large enough and in practice different instances with same hash codes would almost never be encountered in a given small object graph. However, our tests on CLR (Microsoft's implementation of CLI) are quite surprising. The following code generates new objects until two different objects with same hash code are encountered. It turns out that such case occurs very quickly, after creating as few a few thousand instances:

```
Hashtable hashCodesSeen = new Hashtable();
LinkedList<object> l = new LinkedList<object>();
int n = 0;
while (true)
{
    object o = new object();
    // remember instances to be sure they don't get collected
    l.AddFirst(o);
    int hashCode = o.GetHashCode();
    n++;
    if (hashCodesSeen.ContainsKey(hashCode))
    {
        // same hashCode seen twice for DIFFERENT instances
        Console.WriteLine("Hashcode seen twice after „ + n + „steps“);
        break;
    }
    hashCodesSeen.Add(hashCode, null);
}
```

Listing 22 – Generating instances until a hash code collision is found

During our tests, the output of the program was *Hashcode seen twice after 5322 steps*, which means that the possibility of different objects having same hash codes is very real and must definitely be accounted for. The article [19], which was the original source for this experiment, gives very similar results.

Interestingly, during our tests, the output was always the same on a given machine. This shows that the hash code generation on the current implementation of the CLR is deterministic.

The final algorithm

The final Object graph building algorithm takes advantage of the .NET hash codes while correctly accounting for different instances having same hash codes. This is done by looking up graph Nodes by hash codes and comparing instance addresses[1] in case of hash code collisions to be sure the hash code collision was not a coincidence. The main `BuildGraph` algorithm stays almost the same as in the first version, with the exception that graph Nodes are being added into a *hashcode->Nodes* hashtable. Ideally, when there are no hash code collisions, the hashtable will contain exactly one Node for every hash code.

```
hashtable: 'hashCode' -> (list of objects with hash code == 'hashCode')

BuildGraph(value):
    If a maximum recursion depth is reached, return null.
    node = create a Node for this value (holding a Permanent reference)
    add the node to the hashtable,
            key=value.HashCode    // HashCode being the in-debuggee hash code
```

[1] Each graph Node holds a Permanent reference to be able to access the address of the in-debuggee instance it represents.

```
    foreach referencedValue in GetReferencedValues(value)
        existingNode = GetSeenNode(referencedValue)
        if existingNode != null then MakeEdge(node, existingNode)
        else MakeEdge(node, BuildGraph(referencedValue))
```

Listing 23 – The final Object graph building algorithm

`GetSeenNode` then takes the advantage of the hashtable in the following way:

```
GetSeenNode(value) {
    candidates = hashtable[value.HashCode] // instances with same hashCode
    if no candidates, the object is new
    if some candidates, compare their addresses to o.Address
        if no address equal, o is new // hashCode collision was a coincidence
        if some address equal, o already seen
```

Listing 24 – The final version of GetSeenNode, using .NET hash codes for quick lookup

`GetSeenNode` only works with addresses of Permanent references, which is safe because getting addresses of `Debugger.Values` does not resume the debuggee and therefore the addresses are guaranteed to be fixed during the execution of `GetSeenNode`.

Note: As said in the previous section (.NET hash codes), the algorithm always obtains hash codes by invoking `RuntimeHelpers.GetHashCode()` in the debuggee. If the algorithm instead used `Object.GetHashCode()` and user code would override `GetHashCode` to always return zero (for example), the algorithm would still work. The whole algorithm would, however, run in O(n.E) (*n* being the number of vertices and *E* being the number of edges in the object graph) – the same as the original slow algorithm.

Expanding nodes

The graph building algorithm as described can be considered finished. It handles very large (up to infinite) graphs by limiting the maximum depth of recursion.

There is, however, one user experience aspect that deserves analysis - when the user enters an expression which evaluates to a very large object graph expanding the whole graph up to some maximum depth would be a bad user experience:

- If the maximum depth is small, nodes the user is actually interested in can be missing from the graph.
- If the maximum depth is large, too many nodes are shown while the user is not interested in most of them; the drawing is confusing. Visualization takes too much time to show nodes that are not needed.

Instead of always traversing the whole graph, a solution is proposed where users can choose which nodes to include in the graph by expanding them manually. The algorithm stays essentially the same but it is split into steps determined by user actions. The body of the Expand function called when a Node is being expanded is the same as the body of the original loop iterating over all Node properties.

```
// a property is being expanded on this node
Expand(node, propertyName)
    // get the value of the property being expande
    targetValue = EvaluateProperty(node, propertyName)
    // and add the value to the graph
    // (either an edge to an existing node, or a new node)
    existingNode = GetSeenNode(targetValue)
    if existingNode != null then MakeEdge(node, existingNode)
    else MakeEdge(node, NewNode(targetValue))
}
```

Listing 25 – Expanding a property in the Object graph

The algorithm does not recalculate the whole Object graph on every Expand action it assumes that property getters don't have any side effects on the rest of the graph, which is a reasonable tradeoff between graph correctness and expand performance. Having property getters modify other properties is rarely done in practice – the only reasonable use case is when a property getter caches a value in a field or a data structure. Such scenario would be solved by reevaluating all the properties of the instance instead of evaluating a single property. In principle, property getters could modify also anything in the any other instances of the graph, but that would a very bad programming practice and it is practically never done, therefore it was decided not to make the general case much slower in order to account for a theoretical edge case. After the graph is rebuilt completely (either when requested by user or after a debugger step) the graph is in correct state. See also section 2.3 (Fundamental problem of debugging) for more general discussion on the problems with determining debuggee state.

Of course, apart from Expanding, there will be also a Collapse feature, which consists of removing the target Node and all its inbound and outbound edges from the graph.

2.6.4 Graph layout

Having the Object graph (that is, a graph inside the debugger isomorphic to the actual graph in the debuggee) built, this section focuses on how to position the vertices and edges of the Object graph on a 2D plane so that it looks *natural* to users.

Dynamic graphs and incremental stability

There is one special requirement to the Graph layout – the Object graph visualizer deals with *dynamic* graphs, which directly relates to the Graph transitions feature.

There is a problem with calculating layout for dynamic graphs – if the layout algorithm does not account for graph dynamicity, *a small change to the graph can cause drastic changes to the layout*. Say for example that one node or edge is added to the graph and most nodes are rearranged completely in the new layout. In other words, such layout is *incrementally unstable.* In our scenario, incremental instability would mean large groups of nodes moving around randomly when a debugger step introduces only small changes to the graph, which would certainly mean bad user experience. The solution should therefore aim for incremental stability of the layout.

Existing layout engines

Graph layout is a not a new problem so naturally, existing solutions were researched. A good comprehensive list of graph layout engines can be found at [20]. The list does not include Dynagraph, which was also considered. As SharpDevelop is LGPL-licensed free software, any commercial solutions were out of question. Apart from being free, any code included in SharpDevelop must come from a live, maintained project.

Most of the layout engines also handle rendering of graphs. However, the Object graph visualizer has a special requirement for graph transitions, where existing nodes move to their new positions after the graph is changed. The visualizer needs to control these transitions and to be able to do so, the information about the positions of individual nodes is needed – if the layout engine acts as a black box producing images, it might be well usable in some scenarios but not for the Object graph visualizer.

Out of all the existing layout engines, only Graphviz and Dynagraph were considered an analyzed in detail. All the other layout engines were ruled out quickly – the reasons are summarized in the following table.

Layout engine	**free**	**maintained**	**suitable**
Graphviz			
MAGL	x		
ILOG Diagram for .NET	x		
Dynagraph		x	
Diagram.NET		x	
Omnigator		x	
Pajek		x	
Piccolo		x	
Flare			x (Flash)
UbiGraph			x (client-server)
aiSee			x (low quality output)
Graph#			x (did not exist at the time of our research)
Circos			x (only circular layouts)
Cytoscape			x (standalone app, not a library)
Treemaps			x (Java)
QuickGraph			x (graph algorithm library, does not deal with graph layout)
NodeXL			x (implemented in Excel)

Table 1 –Graph layout engines considered during our research

Dynagraph

Dynagraph [21] is an incremental layout engine based on the code of Graphviz. Being an incremental layout engine means that it is actually designed to work with dynamic, incrementally changing graphs. Dynagraph is a standalone executable with an API which works by writing text commands to standard input and parsing responses from standard output (there is also a partial, undocumented COM interface).

Pros

Dynagraph is the only layout engine dealing with *incremental* layouts by accepting commands such as *"add edges between nodes A and B"* and responding in the terms of *"node B moved down by 2cm, added edge A->B as a straight line"* [22].

Cons

Dynagraph is an unmaintained library (last update from 2007), which makes it unfortunately not suitable for being used in SharpDevelop.

Graphviz

Graphviz [23] is a mature, widely used graph layout and visualization toolkit for Linux and Windows. Graphviz consists of set of executables (*dot*, *neato*, etc.) where each of these implements one particular layout algorithm. All of the executables act as batches accepting command line parameters and standard input and returning results (text, image) using standard output or writing to a file.

Graphviz provides ways for users to control the layout to some degree using node clusters, explicitly specified edge endpoints etc. The following graph, which looks almost exactly like what the Object graph visualizer should look like, was rendered using Graphviz:

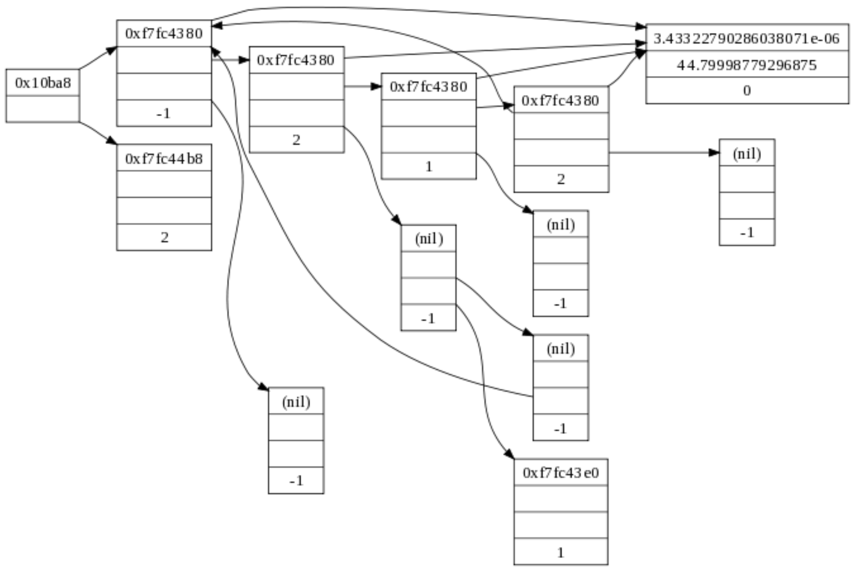


Figure 19 – A graph rendered using Graphviz

Pros

The output of *dot* layout algorithm (Figure 19) seems suitable to the needs of the Object graph visualizer.

Graphviz separates layout calculation from rendering: a graph (plain vertices and edges) can be passed to Graphviz and the same graph with added position information is returned. There are several formats in which the result can be returned, configurable using command line switches.

Graphviz is fast – for the purposes of the Object graph visualizer where the graphs are not very large (up to 20 nodes and 60 edges), the time needed to calculate graph layout including launching the dot executable was under 100ms on a modest machine[1].

Cons

As Graphviz does not have any notion of dynamic graphs, its layouts can suffer from incremental instability – when a graph is slightly changed by a debugger step and the layout is recalculated, the layout can visually differ a lot from the previous layout. Graphviz does not provide any option to calculate new layout incrementally based on old layout and a graph diff.

Including Graphviz binaries would add 10MB to the size of SharpDevelop installer, while the whole SharpDevelop setup is currently only 15MB. The problem is that the Graphviz executables statically link a lot of other libraries and even when *dot.exe* or *neato.exe* are given parameters specifying text-only input and output, these executables won't start without libraries for image encoding. This point alone is enough to say no to Graphviz because adding 10MB of binaries to SharpDevelop to support a single feature is unacceptable. The solution would be either to modify Graphviz code or ask users to install Graphviz separately in order to use the Object graph visualizer.

Graphviz API is text based – using Graphviz from an application means launching a separate executable, writing graph specification to the standard input, and parsing response from the standard output, which is not trivial. If a non-interactive rendering of the graph is sufficient, Graphviz can write the output to an image file and the host application can then read the file.

Conclusion – Tree layout algorithm

The conclusion of our research of existing graph layout engines is that no existing solution fits the scenario of the Object graph visualizer for SharpDevelop and therefore a new solution will be implemented.

One option is to design an *incremental* layout algorithm which takes an existing layout plus a description of changes (a *graph diff*) and produces a new layout, trying to make only small changes to the layout when the diff is small. When designing such algorithm, methods used in Dynagraph would be studied as a starting point.

Another option is a solution which does not deal with graph diffs at all. We propose that it is possible to design a graph layout algorithm specialized for dealing with object graphs (graphs of data structures), which has no notion of incremental layout but still produces layouts that behave well in terms of incremetal stability. The idea for the algorithm comes from two intial observations: first, object graphs are very often close to trees (the numbers of edges is not much larger than *n-1*, where *n* is the number of nodes), and second, the edges in object graphs have a special meaning – the edges represent named object fields and properties.

The algorithm is the following: when the input graph is a tree, layout it using a standard tree layout algorithm: Place the root to the top, order the child subtrees by names of properties they represent and place the child subtrees next to each other below the root. Example:

[1] Laptop with 1.6Ghz Pentium CPU, 2GB RAM.

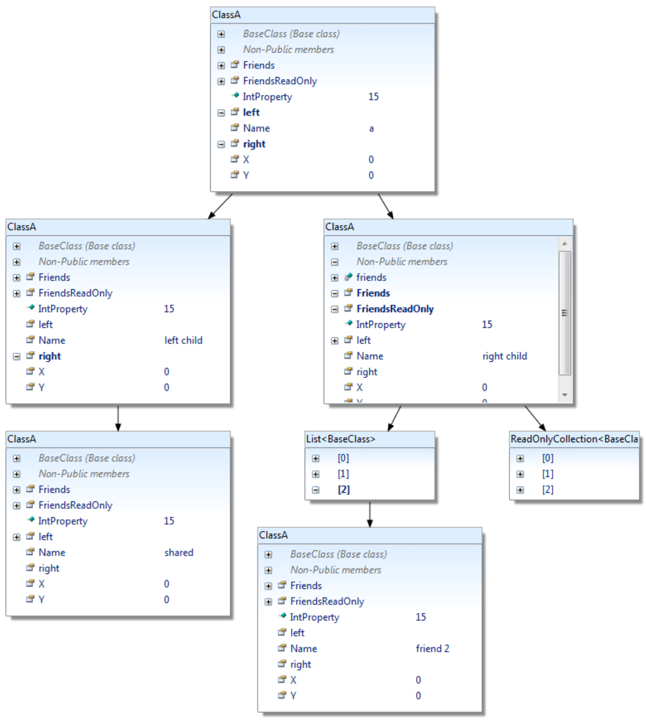


Figure 20 – Example of a tree layout

Pseudocode of the standard tree layout algorith follows. The algorithm is done in two recursive passes over the tree, which we call Measure and Arrange:

```
Measure(node):
    foreach child in node.Children
        Measure(child)
    subtreeW = node.Children.Sum(n => n.Width)
    node.treeW = max(node.ownW, subtreeW);
```

Listing 26 – Measure layout pass

```
Arrange(node, position)
    subtreeW = node.Children.Sum(n => n.treeW)
    node.Pos = CenterHorizontally(position, node.ownW, subtreeW)
    currentChildPos = position
    foreach child in node.Children
        Arrange(node, currentChildPos)
        // place next child subtree next to this child subtree
        currentChildPos.X += child.treeW
```

Listing 27 – Arrange layout pass

The important case is when the input graph is not a tree. In such case, we select some subset of *n-1* edges to obtain a tree, layout it using the tree layout algorithm, fix the layout, and then add the remaining edges to the layout. Example:

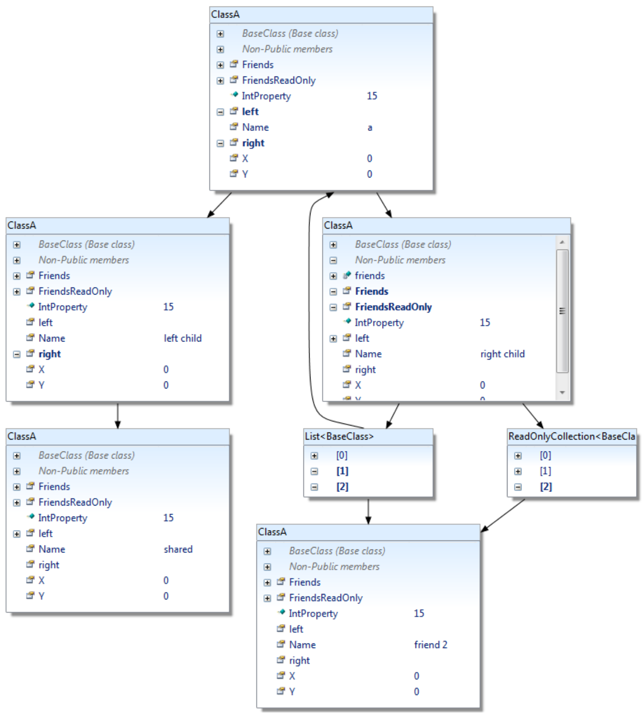


Figure 21 – Example of a tree layout when the input graph is not a tree. The graph is the graph from Figure 20 with two edges added.

The only thing remaining to be resolved is how to select the subset of the *n-1* tree edges.

Selecting tree edges

One possible approach is to start in the root of the graph and do a standard DFS[1]. The edges traversed by the DFS are declared tree edges. Because the DFS enters and leaves every node exactly once, the subgraph formed by the selected edges will indeed be a tree. Pseudocode follows: in the beginning, `Traverse(root)` is called which traverses the whole graph and marks *n-1* edges as tree edges. There is a helper structure called `nodeAlreadySeen` used to mark visited nodes.

```
Traverse(node):
    nodeAlreadySeen[node] = true
    foreach edge in node.OutgoingEdges
    if not nodeAlreadySeen[edge.target]
        edge.IsTreeEdge = true
        Traverse(edge.target)
```

Listing 28 – Selecting tree edges in a graph using DFS

This approach works, but unfortunately does not behave well in terms of incremental stability – here is an example:

[1] Depth-first search.

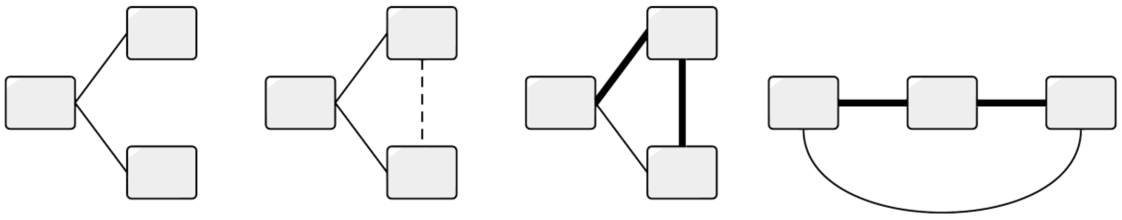


Figure 22 – From left to right: an edge is being added to a tree, tree edges are selected using DFS, and new Tree layout is calculated based on the selected tree edges.

The problem is that when a node has multiple possible parents, DFS selects one of the parents quite arbitrarily – the paths in the graph are traversed in alphabetical order, given by the names of edges. This problem can be resolved by replacing DFS by BFS[1] (using a queue instead of a stack to traverse the graph) because BFS selects the parent based on the distance from the root. BFS prefers short paths, not arbitrary paths. For comparison, here is the exact same situation as in Figure 22, now using BFS to select the tree edges:

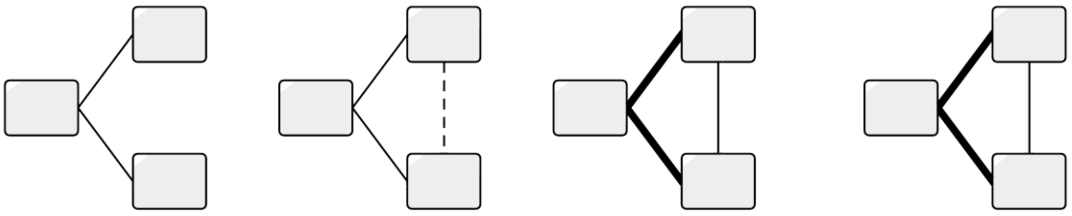


Figure 23 – The same situation as in Figure 22, but different set of tree edges is selected using BFS, resulting in much more intuitive behavior

There is no strict proof that the layout generated by the tree layout algorithm using BFS for edge selection is incrementally stable because there is no strict definition of "small change of the layout proportional to the change of the object graph". However, our tests show that in practice this is a good algorithm when dealing with incrementally changing data structures. This specific version of the tree layout algorithm also has a good property of fixed alphabetical ordering of outgoing references which is a familiar concept to users.

Edge routing

In the layout, not all edges are drawn as straight lines. When an edge drawn as straight line between two nodes would cross other nodes, it is routed as a curved line avoiding the nodes. Calculating the curved paths for edges is called edge routing. Graphviz provides a good edge routing algorithm but again, including 10MB of binaries into SharpDevelop is unacceptable and moreover the communication with Graphviz is done via standard input and output so a parser of edge routes returned from Graphviz would have to be implemented. We decided to implement an edge routing algorithm ourselves – the details are provided in the Implementation section.

2.6.5 Graph transitions

In the previous section a layout algorithm was presented which is sufficiently incrementally stable even while not accounting for incremental graph updates explicitly. This section

[1] Breadth-first search.

discusses how to produce smooth transitions between two layouts of two object graphs to visually explain changes caused by debugger steps.

The transitions should move existing nodes from the old layout to their new positions in the new layout and visually indicate which nodes were added and removed. To be able to produce such transition it must be known which nodes from the old layout and the new layout represent the same debuggee instances, which nodes were added and which nodes were removed. We call this information a *graph diff* and the process of producing a graph diff is called graph *matching*.

To realize the matching, hash codes, Permanent references and addresses can be used in a similar way they are used in Graph building. For every node in the old and the new graph, a Permanent reference and a hash code of the debuggee instance is stored. Then for every node in the new graph a matching node in the old graph can be found quickly using the stored hash code and comparing instance addresses to make sure the hash code equality was not a coincidence (like in the Object graph building algorithm). Pseudocode follows:

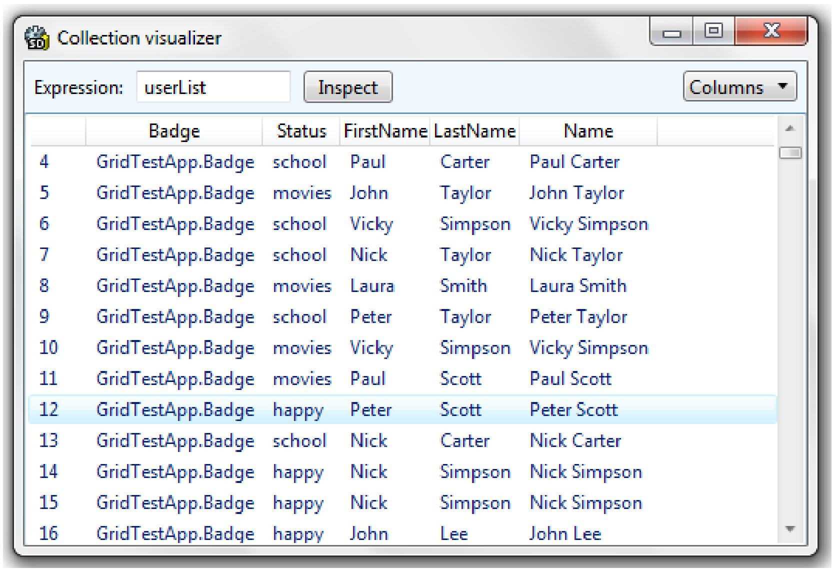
```
FindMatchingNodeInOldGraph(Node nodeInNewGraph):
    find a node in the old graph by nodeInNewGraph.hashCode
    if found, compare found.PermRef.Address and nodeInNewGraph.PermRef.Address
    if the addresses are the equal, return the found node
```

Listing 29 – Node matching in order to build a graph diff

This algorithms works because the hash codes of instances never change during their lifetime (using `RuntimeHelpers.GetHashCode`). The nodes from the new graph without matching nodes are marked added. The nodes from the old graph without matching nodes are marked removed. The graph diff then consists of a list of pairs of matching nodes, a list of removed nodes, and a list of added nodes. Given such diff and two graph layouts, a transition can be produced in the following way: fade out removed nodes, fade in added nodes and move matched nodes from their old positions to their new positions. The same technique can be applied to edges: edges connecting matched nodes are moved to their new positions, all the remaining edges from the old layout are faded out and the edges from the new layout are faded in.

2.7 Collection Visualizer

This section discusses the Collection visualizer, which should provide a new way to explore collections of objects in the debugger. The visualizer should help users understand contents of collections easier than when using watches or debugger tooltips. The following solution is proposed: Display a grid where rows represent individual items of a collection and columns represent properties of those individual items.



	Badge	Status	FirstName	LastName	Name
4	GridTestApp.Badge	school	Paul	Carter	Paul Carter
5	GridTestApp.Badge	movies	John	Taylor	John Taylor
6	GridTestApp.Badge	school	Vicky	Simpson	Vicky Simpson
7	GridTestApp.Badge	school	Nick	Taylor	Nick Taylor
8	GridTestApp.Badge	movies	Laura	Smith	Laura Smith
9	GridTestApp.Badge	school	Peter	Taylor	Peter Taylor
10	GridTestApp.Badge	movies	Vicky	Simpson	Vicky Simpson
11	GridTestApp.Badge	movies	Paul	Scott	Paul Scott
12	GridTestApp.Badge	happy	Peter	Scott	Peter Scott
13	GridTestApp.Badge	school	Nick	Carter	Nick Carter
14	GridTestApp.Badge	happy	Nick	Simpson	Nick Simpson
15	GridTestApp.Badge	happy	Nick	Simpson	Nick Simpson
16	GridTestApp.Badge	happy	John	Lee	John Lee

Figure 24 – The Collection visualizer – rows represent collection items and each column represents one public property.

This advantage of this approach is that users get a good overview of the contents of the collection and can locate individual items quickly. Compare this to using watches or debugger tooltips, where individual items have to be expanded and collapsed one by one to accomplish the same goal.

The Collection visualizer will use the same approach to accessing individual items of collections described in section 2.5 (Collections) – a special case for IList plus conversion of IEnumerable<T> to IList<T>. Therefore, the Collection visualizer inherits the properties of the solution – non-generic IEnumerable as well as infinite IEnumerable will not be supported but the number of items will be known, scrolling will be fast, and it will be possible to further expand individual rows.

2.7.1 Existing work

There are some existing tools to visualize collections in the debugger in a way similar to our proposition, for example [24] (a debugger visualizer for Visual Studio). However, this visualizer is designed only to visualize one type of objects specific to one application – e.g. a `ShoppingCart`. In other words, the visualizer is not generic. A generic visualizer for List and Dictionary types exists [25] but due to the architecture of Visual Studio Visualizers, the collection items need to marked with the `[Serializable]` attribute which can't be always guaranteed and requires users to change their code in order to view data. Also, if the visualizer wanted to support IEnumerable, every IEnumerable class would have to be registered manually by users as Visual Studio debugger visualizers can't be registered for interfaces [26].

Our collection visualizer should be completely generic – it should work for collections containing any types of objects out of the box, and it shouldn't need to transfer the whole collection from the debuggee to the debugger in order to display first few items. We haven't found any existing generic solution which accomplishes this.

2.7.2 What needs to be done

Summarizing the previous thoughts, here are the requirements for the Collection visualizer:

- Display contents of a collection of objects: rows represent objects, columns represent their properties.
- Support IEnumerable<T>, IList, IList<T> and one-dimensional arrays.
- Should not suffer a noticeable slowdown for collections containing thousands of items.
- Should work out of the box, without any need to manually register types or modify code.
- Will be a standard part of the IDE so no additional downloads are needed.

2.7.3 Grid columns, generic vs. non-generic collections

The main difference between the Collection visualizer and the Debugger tooltips is that the Collection visualizer presents values of multiple properties of all the items at once, using one column for each property. This brings us to an important question: Given a collection, how to determine what the columns will be?

If all the items of the collection were guaranteed to be of same type, it would be certainly a correct solution to make one column per each public property of this type (possibly also including properties from base classes). The problem is that the collection can, in fact, contain items of various types and it is not possible to know all these types in advance because determining them is too expensive due to the expensiveness of the debugger API calls. Realizing that it is not possible to have full information about types of all the items, there are three options:

1) Look at the first item in the collection and use its public properties.

   Pros:

   - None.

   Cons:

   - The columns for the whole collection are determined only by the type of the first item.
   - When subsequent items have additional properties, these properties will not be shown.
   - When subsequent items miss some of the properties, the cells will be empty.

2) When scrolling and evaluating new items, add columns to the grid dynamically when new properties are encountered.

   Pros:

   - All of the properties of every item are always shown.

   Cons:

   - When items miss some of the properties, the cells will be empty.

- A complicated solution.
- Columns being added when scrolling are not a good user experience.

3) Look at the generic parameter of the collection (IList<T>, IEnumerable<T>) and use the public properties of the parameter type T.

   Pros:

   - The columns represent the type of the whole collection.
   - Collection can contain only subclasses; therefore no cells will be empty.

   Cons:

   - Does not support non-generic IList (non-generic IEnumerable was decided not to be supported in general).
   - When the items are subclasses of T, the properties defined in the subclass are not shown.

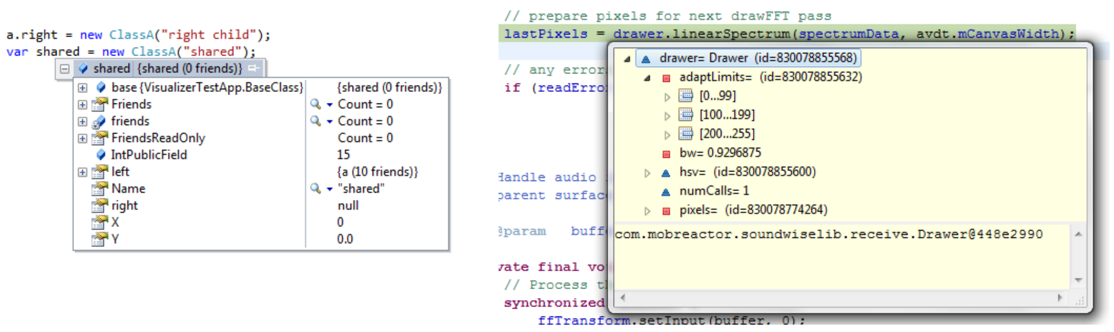
From the three solutions, the third one was chosen because its Cons are the least significant – non-generic ILists are not a common case (a fallback to the first solution could be implemented for non-generic ILists). Regarding the second Con: If the collection is of type `IEnumerable<ICar>` and the user knows that all the items are actually of type `Truck`, the user can add a cast to (`IEnumerable<Truck>`) which will cause all properties of the Truck type to be shown.

2.8 Debugger tooltips

The third feature we built as a part of this thesis are the debugger tooltips for SharpDevelop 4. The goal is to re-implement the existing debugger tooltips in WPF and add support for IEnumerable collections and large collections.

2.8.1 Existing work

SharpDevelop 3 has debugger tooltips implemented using Windows Forms and there is also a very similar feature in Visual Studio and other IDEs.



```
a.right = new ClassA("right child");
var shared = new ClassA("shared");
```

```
⊟ shared  {shared (0 friends)}
  ⊞ base {VisualizerTestApp.BaseClass}   {shared (0 friends)}
  ⊞ Friends                              Count = 0
  ⊞ friends                              Count = 0
  ⊞ FriendsReadOnly                      Count = 0
    IntPublicField                       15
  ⊞ left                                 {a (10 friends)}
    Name                                 "shared"
    right                                null
    X                                    0
    Y                                    0.0
```

```
// prepare pixels for next drawFFT pass
lastPixels = drawer.linearSpectrum(spectrumData, avdt.mCanvasWidth);

// any error
if (readErro

Handle audio
parent surfac

@param   buff

vate final vo
// Process t
synchronized
    ffTransform.setInput(buffer, 0);
```

```
drawer= Drawer  (id=830078855568)
  adaptLimits=  (id=830078855632)
    [0...99]
    [100...199]
    [200...255]
  bw= 0.9296875
  hsv=  (id=830078855600)
  numCalls= 1
  pixels=  (id=830078774264)
com.mobreactor.soundwiselib.receive.Drawer@448e2990
```

Figure 25 – Debugger tooltips in Visual Studio 2010 and Eclipse 3.5. The feature is has a different name in each IDE but it is essentially the same.

2.8.2 What needs to be done

The debugger tooltips in SharpDevelop 3 have cleanly separated user interface code from the underlying data model, which means the data model can be reused. Support for IEnumerable collections will be added to the data model according to section 2.5 (Collections). The user interface implemented in Windows Forms will be removed from SharpDevelop and re-implemented using WPF.

Integration of the Debugger visualizers with the Debugger tooltips will be implemented so that the visualizers can be opened directly from tooltips. This integration should be extensible so that new visualizers become available in the tooltips.

3. Implementation

This section highlights interesting parts of the implementation of Debugger visualizers for SharpDevelop and documents the codebase and design decisions.

In the SharpDevelop codebase [27], most of the Debugger visualizers code is located in the Debugger.AddIn project (AddIns/Debugger/Debugger.AddIn folder), specifically in subfolders Visualizers and Tooltips. The code of SharpDevelop and Debugger.Core is very well designed and needed only minor modifications to integrate the debugger visualizers and debugger tooltips. The directory structure of the code is the following (namespaces mostly follow directory structure):

- Debugger.AddIn
  - Tooltips – *logic and UI of debugger tooltips*
  - TreeModel – *data model for the debugger tooltips*
  - Visualizers
    - Commands – *opening visualizers from debugger tooltips*
    - Common – *code shared by multiple visualizers (such as collections support)*
    - GraphVisualizer –*Object graph visualizer*
      - Drawing – *rendering of the graph using WPF*
      - ExpandedPaths – *remembering expand state between debugger steps*
      - Layout – *calculation and representation of layout*
        - SplineRouting – *reusable implementation of edge routing*
      - Object graph – *building and representation of the Object graph*
    - CollectionVisualizer – *Collection visualizer*
    - Presentation – *WPF-related reusable code*
    - Utils –*generic reusable code*
- AvalonEdit.AddIn
  - CodeEditorView.cs – *integration of debugger tooltips with the code editor*

3.1 Common base for visualizing collections

All of the visualizers are dealing with collections in essentially the same way, described in section 2.5 (Collections). Each of the visualizers has a different data model for collection items (tooltips show a tree of Expressions, the Object graph visualizer has edges outgoing from property trees, and the Collection visualizer uses a grid) but they all essentially handle collections as described in the Collections section of the Analysis - converting IEnumerable to IList by constructing a List in the debuggee by evaluating an expression such as *"new List<T>(enumerable)"* where T is the generic parameter of the type of the enumerable variable in debuggee, and then accessing individual items of the List by evaluating expressions such as *list[i]*. If an instance already implements IList, the conversion is skipped (this check is implemented in `TypeResolver`). The conversion of IEnumerable to IList is implemented in `DebuggerHelpers`.

3.2 Object graph visualizer

In section 2 (Analysis), the high level architecture of the Object graph visualizer was outlined. It was decided that building and layout of the graph will be separate steps, and a Tree layout algorithm, which does not work incrementally but behaves well in terms of incremental stability, was proposed. The following diagram shows the design following the decisions from section 2.6 (Object graph visualizer):

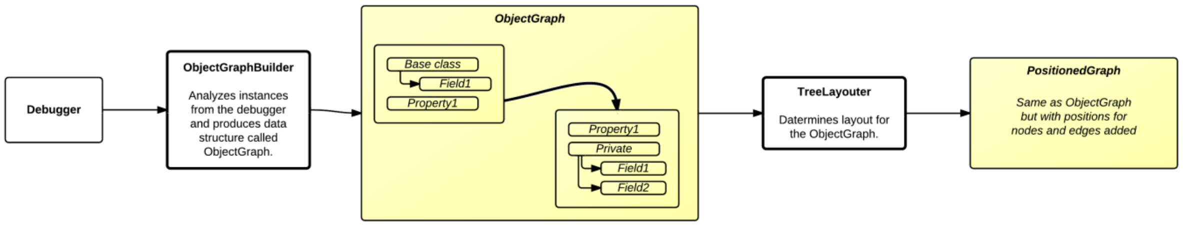

Debugger
ObjectGraphBuilder
Analyzes instances from the debugger and produces data structure called ObjectGraph.
ObjectGraph
Base class
Field1
Property1
Property1
Private
Field1
Field2
TreeLayouter
Datermines layout for the ObjectGraph.
PositionedGraph
Same as ObjectGraph but with positions for nodes and edges added

Figure 26 – Basic design of the Object graph visualizer

Of course, constructing a static `ObjectGraph` and presenting it to users is only half of the picture. As further discussed in section 2 (Analysis), the changes which occur during debugger steps are being visualized by smooth transitions between graphs. The transitions are produced using graph diffs which are inferred by comparing graph state before and after each debugger step. The following diagram explains the design of the Object graph visualizer in this dynamic context:

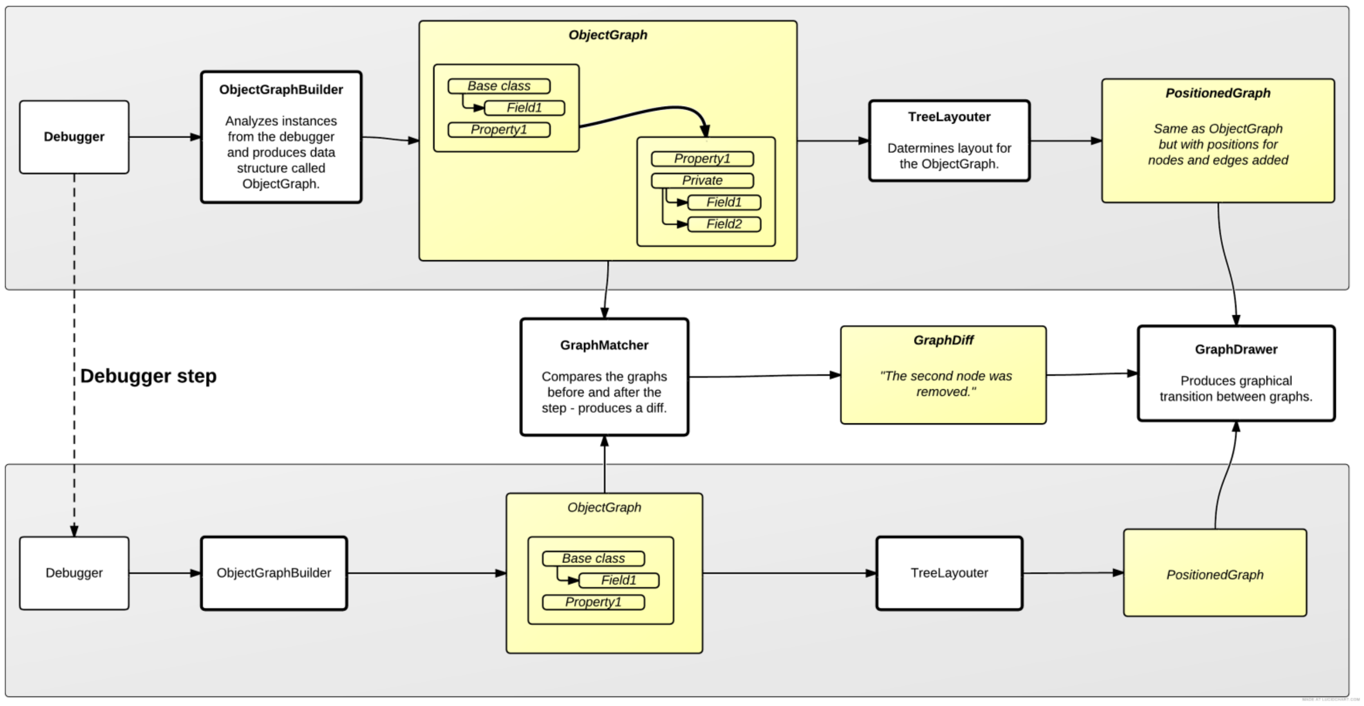

ObjectGraph
Debugger
ObjectGraphBuilder
Analyzes instances from the debugger and produces data structure called ObjectGraph.
Base class
Field1
Property1
Property1
Private
Field1
Field2
TreeLayouter
Datermines layout for the ObjectGraph.
PositionedGraph
Same as ObjectGraph but with positions for nodes and edges added
Debugger step
GraphMatcher
Compares the graphs before and after the step - produces a diff.
GraphDiff
"The second node was removed."
GraphDrawer
Produces graphical transition between graphs.
Debugger
ObjectGraphBuilder
ObjectGraph
Base class
Field1
Property1
TreeLayouter
PositionedGraph

Figure 27- Design of the Object graph visualizer

All the processes outlined in the diagram are coordinated from the Object graph visualizer main window, implemented in `ObjectGraphControl`.

3.2.1 Graph building

The graph building algorithm including the decisions behind it was largely described in the Analysis section. In the implementation, this algorithm resides in the `ObjectGraphBuilder` class. Its method `BuildGraphForExpression` takes an `NRefactory.Ast.Expression` and produces an `ObjectGraph`.

3.2.2 The ObjectGraph

The `ObjectGraph` is composed of a collection of `ObjectGraphNodes`. An `ObjectGraphNode` represents one debuggee instance and contains a tree of properties of this instance, grouping the properties by their visibility and class where they were declared. The properties are represented by `PropertyNodes`, each containing an `ObjectGraphProperty`, pointing to a target `ObjectGraphNode`, thus representing a named edge. There also also special nodes in the property tree used to group `PropertyNodes` into subtrees, like `BaseClassNode` or `NonPublicMembersNode`.

Lazy evaluation of properties

The `ObjectGraphProperties` inside `ObjectGraphNodes` are lazily-evaluated. When a node contains many properties, only the first few are evaluated and when the contents of the node are scrolled, the properties coming into view are being evaluated as needed.

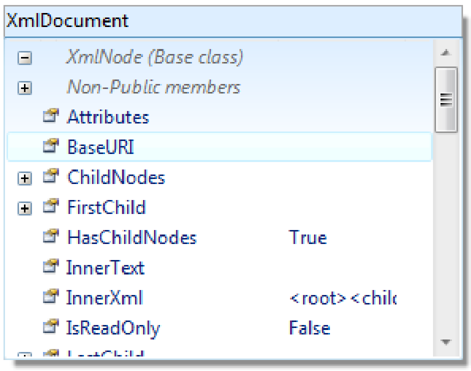


Figure 28 – UI for ObjectGraphNode (implemented by PositionedGraphNodeControl). The properties out of view have not been evaluated yet and will be evaluated when they are scrolled into view.

This saves a lot of performance especially when objects have a lot of properties. The lazy evaluation is controlled by user interface because only the UI has exact information about which properties are currently in view. The implementation exploits the fact that WPF `ListView` pulls items from its `ItemsSource` as the items come into view. As the `ItemsSource` for the `ListView`, an instance of `VirtualizingObservableCollection` is supplied. `VirtualizingObservableCollection` adds on-demand evaluation support to an existing `ObservableCollection` (Decorator pattern).

Collections

When an `ObjectGraphNode` represents a collection, the collection is converted to a List using the common approach, the `Count` property of the List is evaluated and a flat list of empty `ObjectGraphProperties` is generated quickly – each `ObjectGraphProperty` representing one item of the List (with Expressions *list[0]* up to *list[Count-1]*) – this logic is implemented in `ObjectGraphBuilder`. The lazy evaluation then works using exactly the same mechanism as the lazy evaluation of properties described in the previous section.

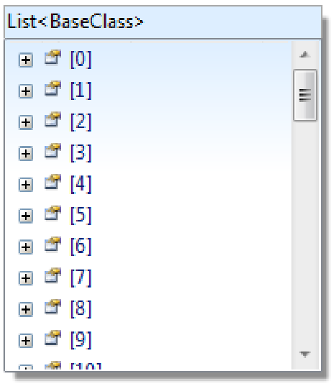


Figure 29 – ObjectGraphNode representing a collection

Expanding nodes

As discussed in section 2.6.3 (Graph building), the `ObjectGraph` returned from the `ObjectGraphBuilder` is not fully expanded up to some given maximum depth but users control which individual nodes are expanded by clicking a *plus* button next to fields and properties.

When a field or property is being expanded, its target is evaluated and either a new node is added to the graph, or only an edge to an existing node is added in case the target was already present in the graph. Then the layout for the whole graph is recalculated. When a field or property is collapsed, its target is removed from the graph including all its inbound and outbound edges. Expanding and collapsing is implemented in `ObjectGraphControl` – `PositionedNodeControls` raise events and `ObjectGraphControl` reacts to them by implementing the logic just described.

Remembering expanded nodes between debugger steps

A large part of the design of the Object graph visualizer focuses on debugger steps. The expanding of nodes must also fit into the picture – namely, when some nodes are expanded, these nodes must also stay expanded after a debugger step. Considering the fact that after the debugger step the `ObjectGraph` is being rebuilt from scratch, the information about expanded nodes must be kept somewhere separately. The structure holding this information is called simply `Expanded`. The `Expanded` structure holds the information about expanded nodes by holding a set of string expressions describing expanded paths in the graph, such as *a[0].left*, *a[0].left.right* etc. After a debugger step, the same paths are expanded again, which is equivalent to the user manually clicking the same *plus* buttons on the same nodes. Of course, these nodes might not represent the same debuggee instances anymore but this approach is quite intuitive and behaves as expected.

An implementation detail is that re-expanding of the right paths after a debugger step is not implemented by repeatedly invoking an `Expand` function but instead the expanding is incorporated right into the graph building algorithm. The `ObjectGraphBuilder` gets the `Expanded` data structure and when recursively exploring the graph, it only follows the paths which are present in the `Expanded` set.

3.2.3 Graph layout

This section describes our Tree layout algorithm in detail. The whole layout algorithm consists of two separate steps:

- Calculating the positions of nodes (node layout)
- Calculating the paths of edges (edge routing)

Naturally, edge information is involved in the first step as well. The separation into two steps means that after the node positions are determined, the positions are fixed and only then edge paths are being added to the layout. The dot algorithm implemented in Graphviz uses exactly the same separation into two steps.

As the calculation of node positions was largely described in section 2.6.4 (Graph layout), this section focuses mainly on the algorithm for calculating edge paths.

TreeLayouter, PositionedGraph

The algorithms described in this section and section 2.6.4 (Graph layout) are implemented in classes `TreeLayouter` (responsible for node layout) and `EdgeRouter` (responsible for edge routing). The `TreeLayouter` takes an `ObjectGraph` as input, calculates node positions, calls `EdgeRouter` to calculate edge routes, and produces a `PositionedGraph`.

The difference between `ObjectGraph` and `PositionedGraph` is that `ObjectGraph` is an UI-independent model of a graph of debuggee instances and `PositionedGraph` also contains position information for nodes and positioned paths for edges. The `PositionedGraph` is not produced by copying an `ObjectGraph`; it rather wraps the `ObjectGraph` and adds position and UI information.

To be able to work with real sizes, the `PositionedGraph` is WPF-dependent and contains the WPF user interface elements for graph nodes (`PositionedGraphNodeControl`) and edges (`System.Windows.Shapes.Path`).

Node layout

In section 2.6.4 (Graph layout), the Tree layout algorithm for calculating positions of nodes was proposed. The algorithm is implemented exactly as described, by selecting a tree subgraph of the input graph using BFS and then recursively traversing the tree twice – first to calculate the areas needed for the subtrees and then arranging the subtrees next to each other. The implementation can be found in the `TreeLayouter` class.

Similarity to WPF's "Measure-Arrange" layout algorithm

The two recursive passes over the tree are named *Measure* and *Arrange* in our algorithm. The fact that the two layout passes in WPF are named the same is not a coincidence – the layout algorithms in WPF and many other UI frameworks work on exactly the same principle.

In WPF the user interface elements are organized into a tree called the Visual tree. When an `UIElement` is asked for its size (`Measure()` method) it asks its children for their desired sizes so that it can determine its own desired size. When an `UIElement` is told its new position (`Arrange()` method) it also repositions its children, knowing their sizes because `Measure()` is called before `Arrange()` for any element.

In WPF the users can define their own user interface elements and completely control the layout by subclassing `FrameworkElement` and overriding the `MeasureOverride()` and `ArrangeOverride()` methods. This is also how existing `UIElements` are implemented. For example, `StackPanel` is a panel which stacks its children next to each other – this logic is implemented in the `ArrangeOverride` method of the `StackPanel`.

Edge routing

After the node positions are calculated and fixed, the paths for graph edges are determined.

The problem: Given a set of positioned rectangles on a 2D plane and a set of directed edges between pairs of rectangles, find paths for the edges so that the paths avoid the rectangles and look *natural*.

Example of a solution (Graphviz):

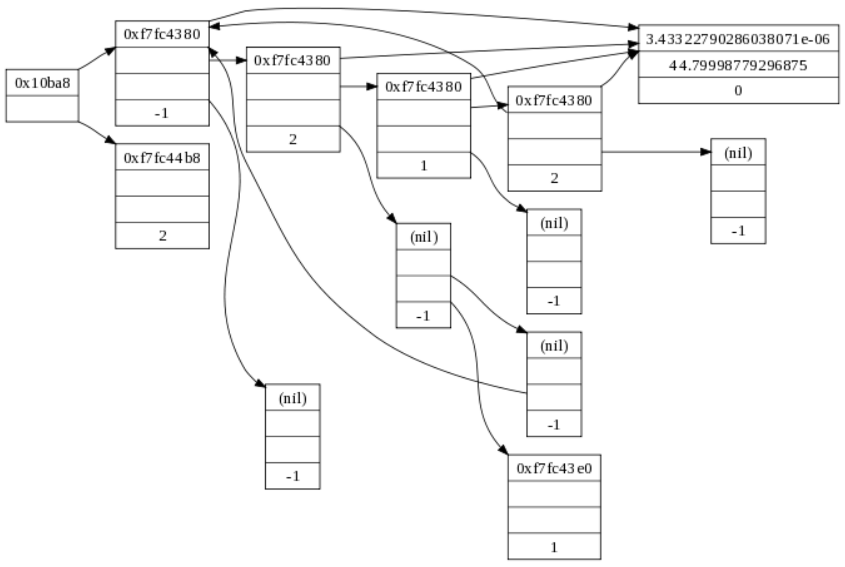


Figure 30 – Edges routed using Graphviz

As discussed in section 2.6.4 (Graph layout), after researching available solutions it was decided that a custom solution would be implemented for the purposes of the Object graph visualizer. The implementation presented in this section is not WPF-dependent and can be reused as-is in other applications; this is achieved by following a common practice of programming against interfaces.

Our algorithm

The first decision that has to be made when designing an edge routing algorithm is whether the edges will be routed globally or independently (one by one):

- Global routing tries to minimize the total number of edge overlaps while making the individual edge paths look natural.
- One-by-one routing calculates each edge path independently from others, trying to make each edge path look natural.

Like the edge routing algorithm used by Graphviz [28] [29], our algorithm processes edges one by one, treating each edge as separate input. The Graphviz paper [28] also mentions a possibility of a global algorithm that would try to make edges avoid each other or emphasis routing edges in parallel but does not provide any ideas for such algorithm.

When designing the algorithm, two important observations were made:

- The most natural path is a straight line and when there is a rectangle blocking the straight line, the path must be broken around some corners of the rectangle. There is no need to break paths in open space. Therefore, the interesting points in the plane are the corners of the rectangles.
- To make edge paths look natural to users, the edge paths should be relatively close to closest possible paths, while not bending too sharply.

The algorithm works in the following way: First a visibility graph is built, where vertices represent the corners of all the rectangles and edges connect pairs of vertices which can be connected by straight lines without intersecting any rectangles (each edge endpoint is *visible* from the opposite edge endpoint). The pairs of vertices where the edge would be blocked by a rectangle are not connected. Then, to find routes for edges, shortest path are found in the visibility graph.

Determine edge start and end points in the plane:

```
For each edge e in G:
    Determine edge start and end point of edge e:
        take a straight line from the center of edge’s source rectangle
        to the center of edge’s target rectangle.
        Where this line intersects the source rectangle is the start point $e_s$
        analogically end point $e_t$
```

Build the visibility graph:

```
Build the following graph $G_v$ (visibility graph):

V = {every 4 corners of all rectangles on input[1]} ∪ {all start and end points of all edges}

E = {pairs (u, v) from V where u is visible from v: straight line can be drawn from u to v without crossing the body of any rectangle}
```

Find edge routes (each edge independently):

```
For each edge e in G:
    In $G_v$ find shortest path from $e_s$ to $e_t$ (using A* or Dijkstra’s algorithm)
    Smoothen the path by replacing each sharp join by a bend (join smoothing)
```

Our implementation has time complexity of $O(n^3)$ where *n* is the number of rectangles due to the construction of visibility graph: $O(n^2)$ vertex pairs are tested for visibility and each test needs $O(n)$ line-rectangle intersections. The time complexity could be probably reduced but for our needs this is sufficient (note that Graphviz also uses an $O(n^3)$ implementation).

The following figure shows an example of a result of our implementation:

[1] Note: the vertices of the visibility graph do not lie exactly in the corners of the rectangles but further from the rectangles by a small offset so that the paths go around the rectangles, not directly through their corners.

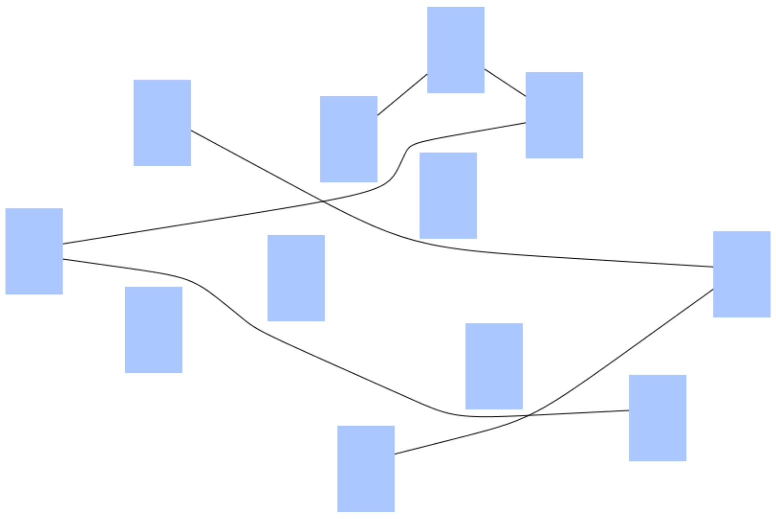


Figure 31 – Edge paths calculated using our implementation

The implementation is completely reusable and can be found in the namespace `Debugger.AddIn.Visualizers.Graph.SplineRouting`. The reusability is achieved by defining simple interfaces such as `IPoint`, `IRect`, `IEdge` and programming against them. Any representation of a graph implementing these simple interfaces is then a suitable input to the algorithm.

Join smoothing

The last step of the algorithm, join smoothing, is used to replace sharp joins on shortest paths in the visibility graph by smooth bends. As a result, the output is visually much more appealing. The following two figures show a comparison of an edge path with and without join smoothing used:

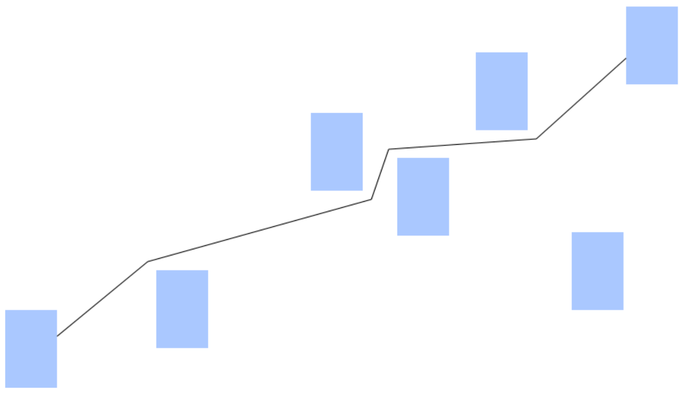


Figure 32 – Edge path without smoothing (a shortest path in the Visibility graph)

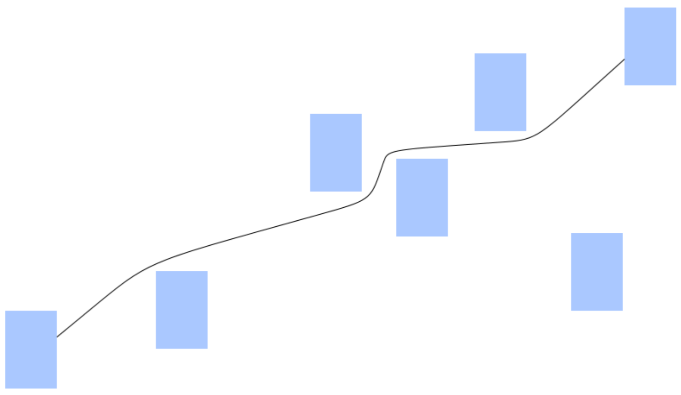


Figure 33 – The path from Figure 32 with smoothing applied

The principle of the join smoothing method is the following: Given two consecutive line segments, replace the segments by a Bezier curve of order 3 (extended by a straight line segment at each end):

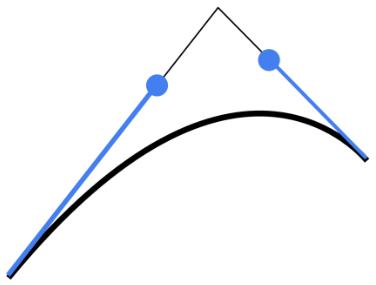


Figure 34 – Sharp join is replaced by a bezier curve

In Figure 34, the tangents of the bezier curve are aligned with the original lines of the edge path. The distance of the control points (circles in the figure) from the join point controls the smoothness of the curve. The curve continues by a straight line on both ends, following the original lines.

Edge overlaps

Routing edges independently can result in edge crossings and overlaps. To deal with possible confusion caused by edge overlaps, highlighting of edges under cursor is implemented in the `GraphDrawer`.

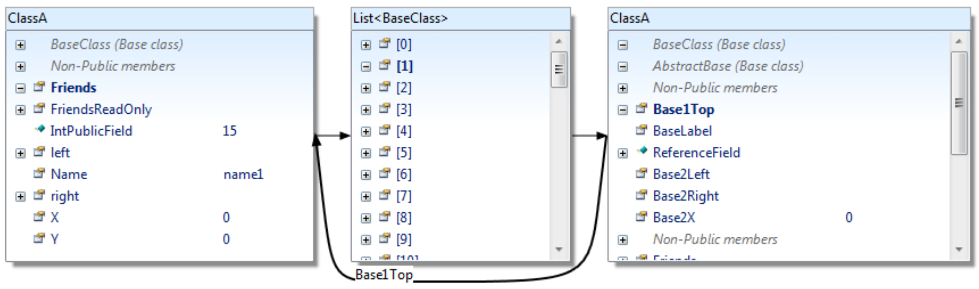


Figure 35 – Edge under mouse cursor is highlighted in bold and a tooltip is displayed.

Multiple edges, self-edges

The implementation also deals with situations when there are multiple edges between one pair of rectangles. This is solved by distributing the edge start and end points along the border of the rectangles. Self-edges are solved in the same way.

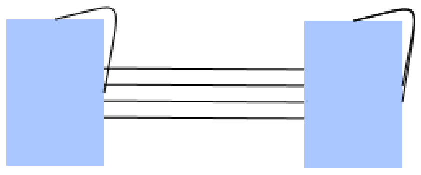


Figure 36 – Multiple edges between two rectangles and self-edges

Explicitly determined start and end points

Some layout engines (including Graphviz) let users specify starting and ending points of edges. This feature could be useful in the Object graph visualizer because the edge outgoing from an object property could start directly next to the title of the property. We considered this and concluded that the layout would get problematic when the contents of nodes are scrolled – the edge point would have to move and the edge would have to be re-routed when scrolling. Therefore it was decided not to implement this feature for now.

3.2.4 Graph matching

Graph matching is used to produce graph transitions between two graph states. Graph matching is implemented as described in the Analysis section in the class `GraphMatcher` which accepts two `ObjectGraphs` and produces a `GraphDiff` object containing a list of pairs of matched nodes, a list of nodes which were added in the new graph, and a list of nodes which were removed from the old graph. Figure 27 explains this process the best.

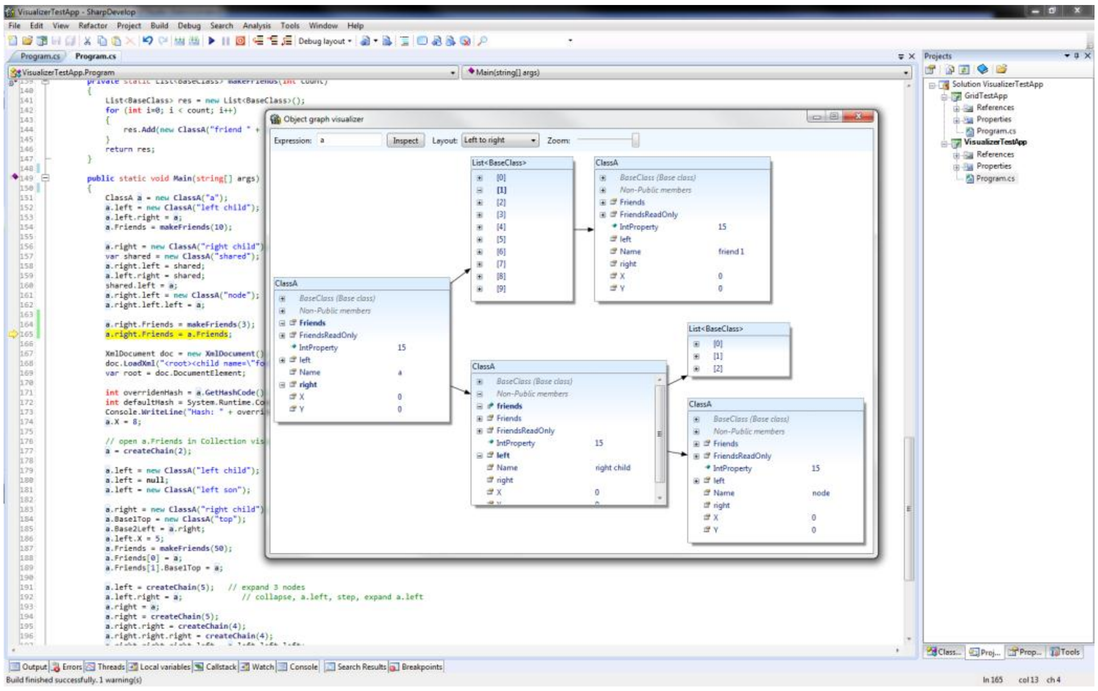
3.2.5 Graph drawing and transitions

After the layout of `ObjectGraph` is calculated by the `TreeLayouter` producing a `PositionedGraph` where nodes and edges are already represented by WPF elements, graph drawing is the final step which actually draws the `PositionedGraph` to screen. Graph drawing is implemented in the `GraphDrawer` class, which positions graph nodes and edges on a WPF Canvas. `GraphDrawer` also produces the transitions by creating a set of WPF `Animation` objects (one animation per each node and edge) based on a `GraphDiff`. The animations transform existing graph drawing to its new state.

While positioning the edges on the Canvas, `GraphDrawer` also adds tooltips to the edges, which appear when mouse cursor is hovered over the edges.

3.2.6 The result

The following two figures show the final state of the Object graph visualizer in context of SharpDevelop:



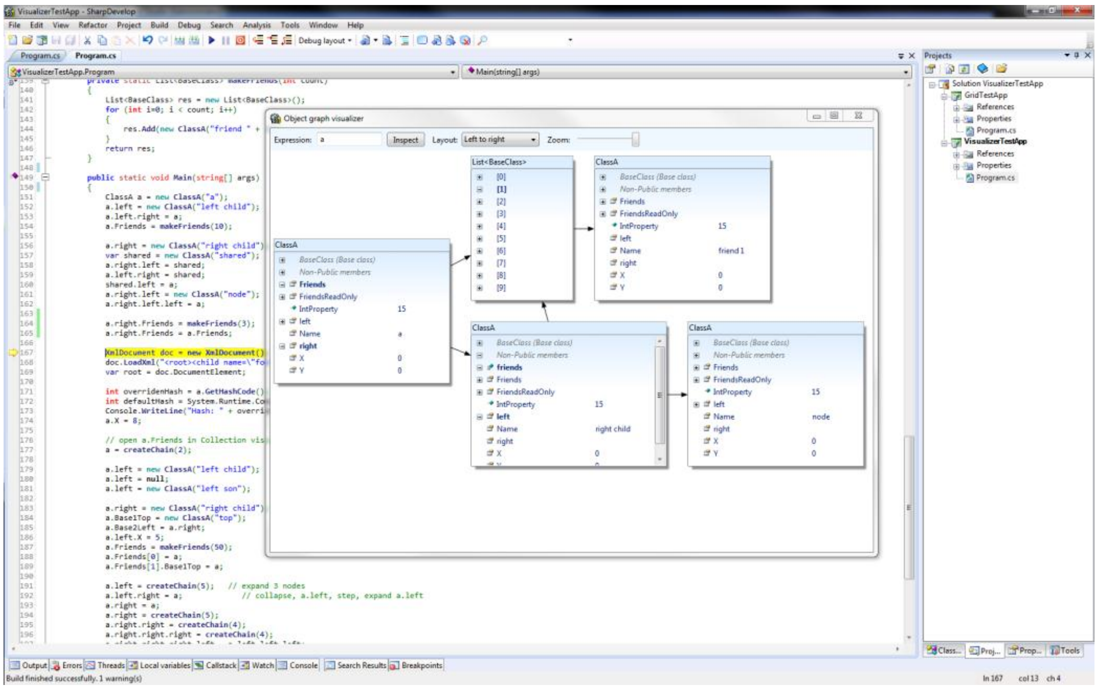
```
private static List<BaseClass> makeFriends(int count)
{
    List<BaseClass> res = new List<BaseClass>();
    for (int i=0; i < count; i++)
    {
        res.Add(new ClassA("friend " +
    }
    return res;
}

public static void Main(string[] args)
{
    ClassA a = new ClassA("a");
    a.left = new ClassA("left child");
    a.left.right = a;
    a.Friends = makeFriends(10);

    a.right = new ClassA("right child")
    var shared = new ClassA("shared");
    a.right.left = shared;
    a.left.right = shared;
    shared.left = a;
    a.right.left = new ClassA("node");
    a.right.left.left = a;

    a.right.Friends = makeFriends(3);
    a.right.Friends = a.Friends;

    XmlDocument doc = new XmlDocument()
    doc.LoadXml("<root><child name=\"fo
    var root = doc.DocumentElement;

    int overridenHash = a.GetHashCode()
    int defaultHash = System.Runtime.Co
    Console.WriteLine("Hash: " + overri
    a.X = 8;

    // open a.Friends in Collection vis
    a = createChain(2);

    a.left = new ClassA("left child");
    a.left = null;
    a.left = new ClassA("left son");

    a.right = new ClassA("right child")
    a.Base1Top = new ClassA("top");
    a.Base2Left = a.right;
    a.left.X = 5;
    a.Friends = makeFriends(50);
    a.Friends[0] = a;
    a.Friends[1].Base1Top = a;

    a.left = createChain(5);    // expand 3 nodes
    a.left.right = a;              // collapse, a.left, step, expand a.left
    a.right = a;
    a.right = createChain(5);
    a.right.right = createChain(4);
    a.right.right.right = createChain(4);
```

Build finished successfully. 1 warning(s)

Object graph visualizer — Expression: a — Layout: Left to right

Figure 37 – Object graph visualizer showing the state of the debuggee

The next figure shows the changed state of the object graph after a debugger step is performed:



```
private static List<BaseClass> makeFriends(int count)
{
    List<BaseClass> res = new List<BaseClass>();
    for (int i=0; i < count; i++)
    {
        res.Add(new ClassA("friend " +
    }
    return res;
}

public static void Main(string[] args)
{
    ClassA a = new ClassA("a");
    a.left = new ClassA("left child");
    a.left.right = a;
    a.Friends = makeFriends(10);

    a.right = new ClassA("right child")
    var shared = new ClassA("shared");
    a.right.left = shared;
    a.left.right = shared;
    shared.left = a;
    a.right.left = new ClassA("node");
    a.right.left.left = a;

    a.right.Friends = makeFriends(3);
    a.right.Friends = a.Friends;

    XmlDocument doc = new XmlDocument()
    doc.LoadXml("<root><child name=\"fo
    var root = doc.DocumentElement;

    int overridenHash = a.GetHashCode()
    int defaultHash = System.Runtime.Co
    Console.WriteLine("Hash: " + overri
    a.X = 8;

    // open a.Friends in Collection vis
    a = createChain(2);

    a.left = new ClassA("left child");
    a.left = null;
    a.left = new ClassA("left son");

    a.right = new ClassA("right child")
    a.Base1Top = new ClassA("top");
    a.Base2Left = a.right;
    a.left.X = 5;
    a.Friends = makeFriends(50);
    a.Friends[0] = a;
    a.Friends[1].Base1Top = a;

    a.left = createChain(5);    // expand 3 nodes
    a.left.right = a;              // collapse, a.left, step, expand a.left
    a.right = a;
    a.right = createChain(5);
    a.right.right = createChain(4);
    a.right.right.right = createChain(4);
```

Build finished successfully. 1 warning(s)

Object graph visualizer — Expression: a — Layout: Left to right

Figure 38 – Object graph updated after a step in the debugger

All of the work described in this thesis is included in standard releases of SharpDevelop 4.x. The easiest way to try the Object graph visualizer is to download a stable release or a nightly build of SharpDevelop (which always contains the newest version).

3.3 Collection Visualizer

Section 2.5 (Collections) identified the conceptual difference between IList and IEnumerable collections and the need for obtaining collection items lazily. An important question of how to determine the columns for the Collection visualizer's grid was also resolved. The Collection visualizer, implemented in `CollectionVisualizerWindow`, follows these decisions. This section covers the data model of the visualizer, the implementation in WPF and explains how not only rows, but also columns of the grid are evaluated lazily for best possible performance.

3.3.1 Lazy loading items when scrolling

Following the common approach to collections, any collection which is not an IList is converted to a List prior to being visualized. The implementation uses a WPF ListView (containing a GridView) and exploits the way in which ListView accesses items from its `ItemsSource`. When the `ItemsSource` is an IList, the ListView accesses the items which are needed to be rendered using the IList's indexer.

Our implementation supplies a special collection, called `VirtualizingCollection`, as the `ListView.ItemsSource`. This collection is a wrapper around some data source (in our case the debuggee collection) and when asked for an item at index *i* it queries its underlying data source for item *i*, returns it and caches it. This principle is often referred to as *data virtualization*.

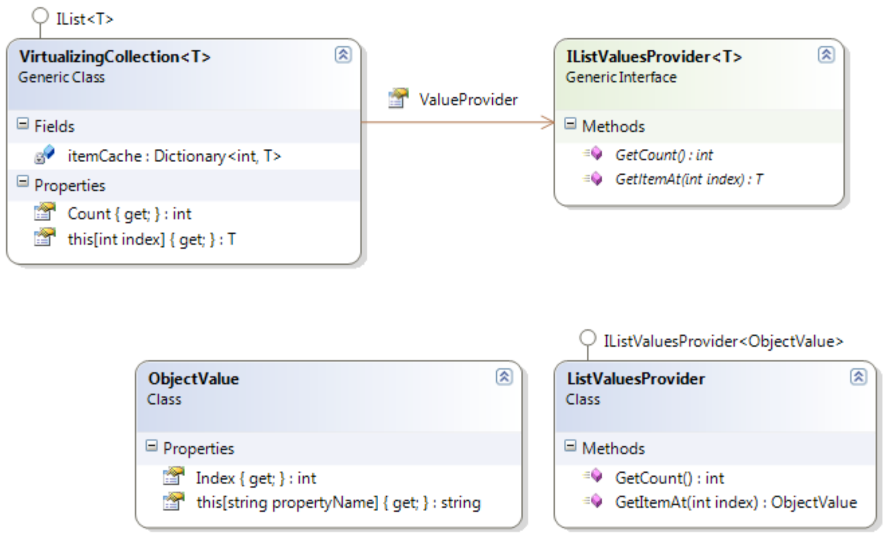


Figure 39 (Class diagram) – Data virtualization using VirtualizingCollection<T>

The top half of the class diagram in Figure 39 is a generic data virtualization implementation. The bottom half is specific to debugging. The items returned by the indexer of `ListValuesProvider` are instances of `ObjectValue` – a representation of a collection item specific to the Collection visualizer. `ObjectValue` contains the index of the item in the collection and a map of values of item's properties.

The map of property values in `ObjectValue` is used to provide indexing by property name, which is used by the data binding of dynamically created `ListView` columns (based on the generic type parameter type of the collection as discussed in section 2.7.3). The following listing shows how columns are created dynamically and prepared to be bound to `ObjectValues`.

```
foreach (var member in itemTypeMembers)    {
    var memberColumn = new GridViewColumn();
    memberColumn.Header = member.Name;
    // "{Binding Path=[Name].Value}"
    memberColumn.DisplayMemberBinding=new Binding("["+member.Name+"].Value");
    gridView.Columns.Add(memberColumn);
}
```

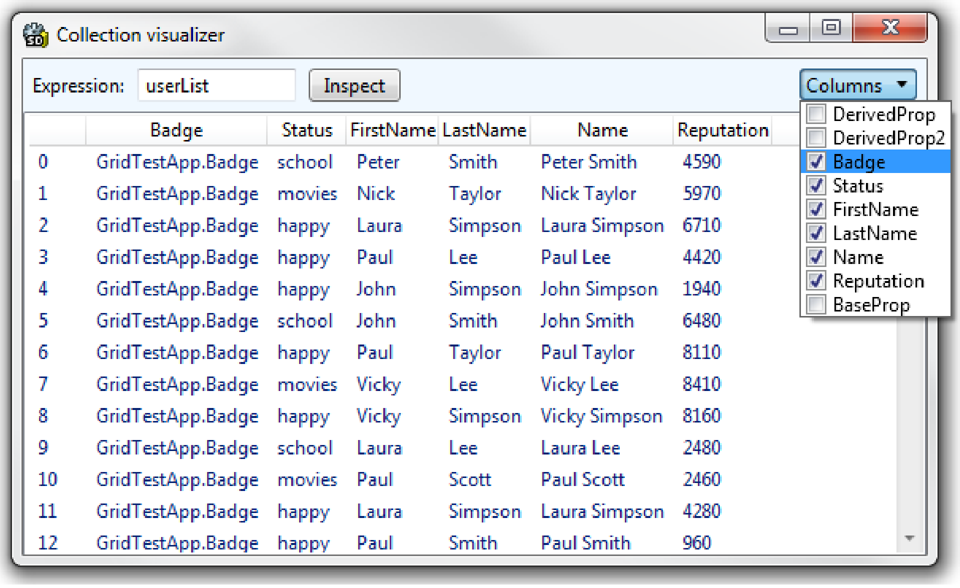
Listing 30 – Data binding of ObjectValues to GridView columns

Note on generic data virtualization

Note that in our case, the only way to get a set of items from the debugger is to query items one by one. However, there are scenarios where querying a *range* of items at once is faster than obtaining items one by one (for example relational databases). In such scenario it is reasonable to implement paging mechanism in the concrete value provider so that when the provider is asked for an item at position *i* it queries and caches a number of items around index *i* (because it is very likely that these items will be needed soon).

3.3.2 Expanding rows of the grid

Sometimes also the values shown in individual grid cells are complex objects. The values in grid cells are obtained by invoking the standard `ToString()` method which only returns the name of the type (when not overridden) which is not a desirable way of presenting complex objects.



Expression: userList

Columns:
- [ ] DerivedProp
- [ ] DerivedProp2
- [✓] Badge
- [✓] Status
- [✓] FirstName
- [✓] LastName
- [✓] Name
- [✓] Reputation
- [ ] BaseProp

	Badge	Status	FirstName	LastName	Name	Reputation
0	GridTestApp.Badge	school	Peter	Smith	Peter Smith	4590
1	GridTestApp.Badge	movies	Nick	Taylor	Nick Taylor	5970
2	GridTestApp.Badge	happy	Laura	Simpson	Laura Simpson	6710
3	GridTestApp.Badge	happy	Paul	Lee	Paul Lee	4420
4	GridTestApp.Badge	happy	John	Simpson	John Simpson	1940
5	GridTestApp.Badge	school	John	Smith	John Smith	6480
6	GridTestApp.Badge	happy	Paul	Taylor	Paul Taylor	8110
7	GridTestApp.Badge	movies	Vicky	Lee	Vicky Lee	8410
8	GridTestApp.Badge	happy	Vicky	Simpson	Vicky Simpson	8160
9	GridTestApp.Badge	school	Laura	Lee	Laura Lee	2480
10	GridTestApp.Badge	movies	Paul	Scott	Paul Scott	2460
11	GridTestApp.Badge	happy	Laura	Simpson	Laura Simpson	4280
12	GridTestApp.Badge	happy	Paul	Smith	Paul Smith	960

Figure 40 – The values of property Badge are complex objects.

Thanks to the design of general handling of collections described in section 2.5 (Collections), it is possible to implement expanding of individual rows in the following way: display an expand button next to each grid row and when it is clicked, open a Debugger tooltip for expression c[i], where *c* is the Expression referring to the whole collection instance and *i* is the index of the row. Another option would be to add columns representing properties of the inner complex object (in Figure 40 the Badge column would be replaced by columns representing individual properties of the Badge class).

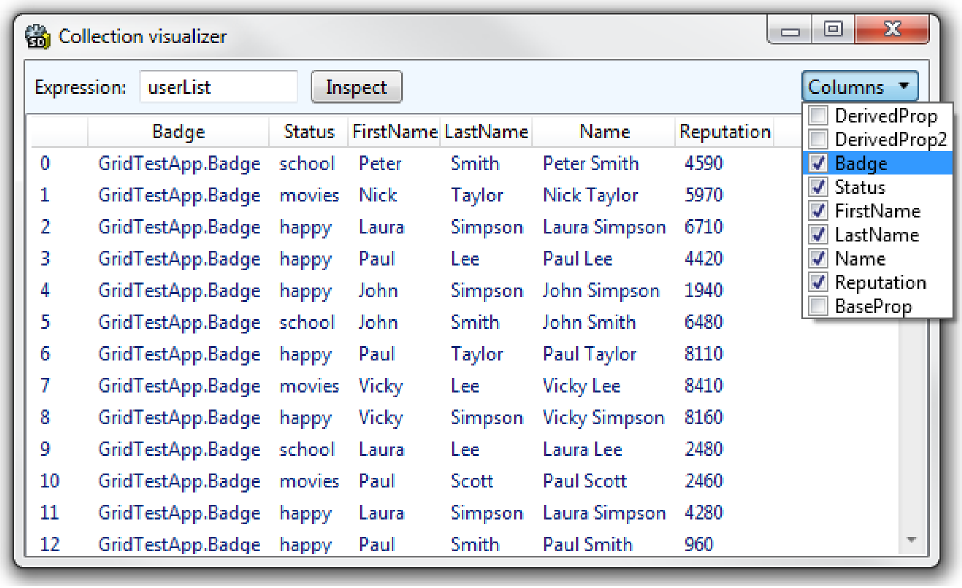
This feature is not implemented yet but will be implemented.

3.3.3 Lazy loading columns (object properties)

We implemented a column-selection feature so that users can select only the columns they are interested in (see top right corner of Figure 40). The columns which are hidden are not evaluated, which improves performance. This is achieved thanks to the way the `ObjectValues` are bound to the GridView (see Listing 30Listing 30) – when a column is hidden, it is removed from the GridView (this is implemented in `GridViewColumnHider`) and the ListView stops evaluating the binding for this column. When the column is displayed again, the ListView only evaluates the bindings for the items which are in the visible range. This means that the Collection visualizer is as lazy as possible – only what needs to be rendered is obtained from the debugger.

3.3.4 The result

The following figure shows the current state of the Collection visualizer:



Expression: userList

	Badge	Status	FirstName	LastName	Name	Reputation
0	GridTestApp.Badge	school	Peter	Smith	Peter Smith	4590
1	GridTestApp.Badge	movies	Nick	Taylor	Nick Taylor	5970
2	GridTestApp.Badge	happy	Laura	Simpson	Laura Simpson	6710
3	GridTestApp.Badge	happy	Paul	Lee	Paul Lee	4420
4	GridTestApp.Badge	happy	John	Simpson	John Simpson	1940
5	GridTestApp.Badge	school	John	Smith	John Smith	6480
6	GridTestApp.Badge	happy	Paul	Taylor	Paul Taylor	8110
7	GridTestApp.Badge	movies	Vicky	Lee	Vicky Lee	8410
8	GridTestApp.Badge	happy	Vicky	Simpson	Vicky Simpson	8160
9	GridTestApp.Badge	school	Laura	Lee	Laura Lee	2480
10	GridTestApp.Badge	movies	Paul	Scott	Paul Scott	2460
11	GridTestApp.Badge	happy	Laura	Simpson	Laura Simpson	4280
12	GridTestApp.Badge	happy	Paul	Smith	Paul Smith	960

- [ ] DerivedProp
- [ ] DerivedProp2
- [x] Badge
- [x] Status
- [x] FirstName
- [x] LastName
- [x] Name
- [x] Reputation
- [ ] BaseProp

Figure 41 – Final state of Collection visualizer

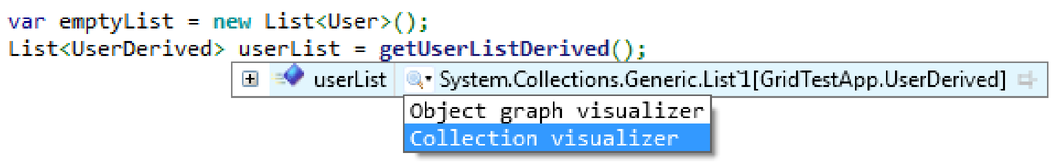
The Collection visualizer has been successfully tested on the following types: `array`, `List<T>`, `ArrayList`, `HashSet<T>`, `IEnumerable<T>`, `IQueryable<T>`, `ObservableCollection<T>`, `ReadOnlyCollection<T>` and `IParallelEnumerable<T>`. The types of collection items tested were various classes and structures (including a class with inheritance hierarchy of depth 4 containing generic classes). We are also using the Collection visualizer while working on SharpDevelop.

3.4 Debugger tooltips

Unlike with the two previous visualizers, the data model for the Debugger tooltips was already present in previous versions of SharpDevelop (see the `Debugger.AddIn.TreeModel` namespace). Thanks to the clean separation of data representation from user interface the whole tree model was reused and a new type of node called `IEnumerableNode` was added to support IEnumerable collections in the Debugger tooltips. The main part of the work on the Debugger tooltips was to implement the user interface including the lazy evaluation of values from the debugger (see the `Debugger.AddIn.Tooltips` namespace) and integrate the new implementation into SharpDevelop's code editor (see the `CodeEditorView` class in AvalonEdit.AddIn). The user interface of the tooltips is implemented using WPF Popups containing DataGrids (see `DebuggerTooltipControl`).

3.4.1 Integration of visualizers

The new implementation of Debugger tooltips adds extensible support for Debugger visualizers:



```
var emptyList = new List<User>();
List<UserDerived> userList = getUserListDerived();
```

Figure 42 – Debugger tooltips offering available Debugger visualizers for current value

To add a new debugger visualizer to SharpDevelop, one has to implement a simple interface `IVisualizerDescriptor` and register it in the .addin definition file at a well known path */SharpDevelop/Services/DebuggerService/Visualizers*. The following two listings show how existing visualizers are registered:

```
<Path name="/SharpDevelop/Services/DebuggerService/Visualizers">
  <Class class="Debugger.AddIn.Visualizers.ObjectGraphVisualizerDescriptor" />
  <Class class="Debugger.AddIn.Visualizers.CollectionVisualizerDescriptor" />
</Path>
```

Listing 31 – Object graph and Collection visualizers registered in the Debugger.AddIn.addin file

```
public class ObjectGraphVisualizerDescriptor : IVisualizerDescriptor
{
    public bool IsVisualizerAvailable(DebugType type) {
            return !type.IsAtomic() && !type.IsSystemDotObject();
    }

    public IVisualizerCommand CreateVisualizerCommand(Expression expression) {
            return new ObjectGraphVisualizerCommand(expression);
    }
}

public class ObjectGraphVisualizerCommand : ExpressionVisualizerCommand
{
    [...]
    public override string ToString() {
            return "Object graph visualizer";
    }

    public override void Execute() {
        if (this.Expression != null) {
            var objectGraphWindow = ObjectGraphWindow.EnsureShown();
            objectGraphWindow.ShownExpression = this.Expression;
        }
    }
}
```

Listing 32 – VisualizerDescriptor tells when the visualizer is available, and returns a Command which defines the logic for opening the visualizer

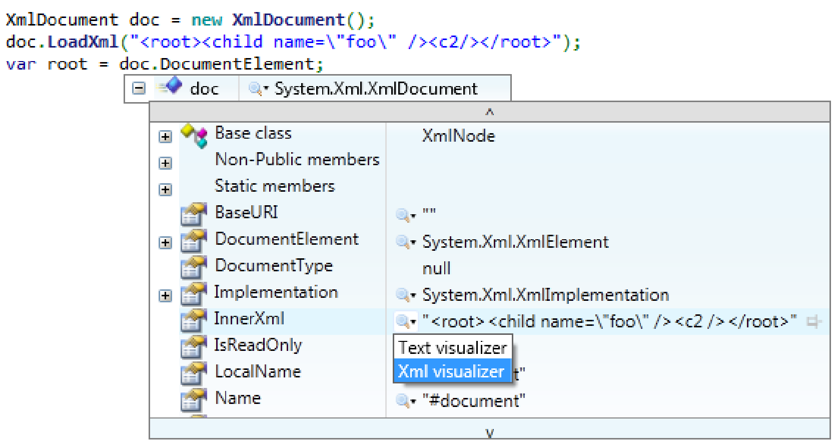
The data model for the Debugger tooltips (`ExpressionNode`) then contains a list of available visualizers, obtained using the following call (see subsection AddIn tree of section 2.2.2):

```
AddInTree.BuildItems<IVisualizerDescriptor>("/SharpDevelop/Services/DebuggerServ
ice/Visualizers", null);
```

Listing 33 – Obtaining the list of available visualizers for the Debugger tooltips

3.4.2 The result

The following figure shows the current state of the new Debugger tooltips for SharpDevelop:



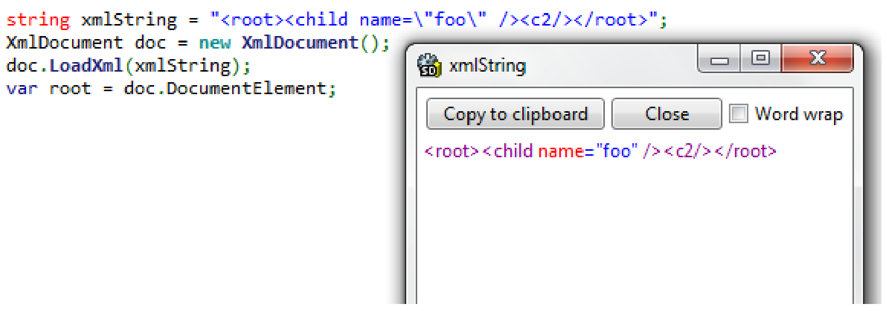
```
XmlDocument doc = new XmlDocument();
doc.LoadXml("<root><child name=\"foo\" /><c2/></root>");
var root = doc.DocumentElement;
```

```
doc                  System.Xml.XmlDocument
  Base class           XmlNode
  Non-Public members
  Static members
  BaseURI              ""
  DocumentElement      System.Xml.XmlElement
  DocumentType         null
  Implementation       System.Xml.XmlImplementation
  InnerXml             "<root><child name=\"foo\" /><c2 /></root>"
  IsReadOnly
  LocalName
  Name                 "#document"
```

Figure 43 – New Debugger tooltips for SharpDevelop 4.0

Text visualizer and XML visualizer

Apart from the Object graph visualizer and Collection visualizer, two simple visualizers which were missing in previous versions of SharpDevelop were implemented (and registered as described in section 3.4.1 (Integration of visualizers)): Text visualizer and XML visualizer. Both are used to view long strings. The XML visualizer uses the XML syntax highlighting feature built into AvalonEdit.



```
string xmlString = "<root><child name=\"foo\" /><c2/></root>";
XmlDocument doc = new XmlDocument();
doc.LoadXml(xmlString);
var root = doc.DocumentElement;
```

```
<root><child name="foo" /><c2/></root>
```

Figure 44 – Debugger visualizer for XML strings

4. Conclusion and future work

Section 1 explained the motivation for this thesis and set goals for innovative debugger features for the SharpDevelop IDE. Section 2 discussed how to design algorithms for the visualizers around numerous limitations of the Debugger API and resolved questions where multiple solutions were possible by identifying pros and cons of every solution; more often than not, compromises between feature completeness, performance and code maintainability had to be made – a constant factor in the field of Software engineering. Section 3 discussed details of the implementation, integration of the work into the SharpDevelop IDE and extensibility.

The initial goals were to implement a visualizer of data structures in the debuggee and to improve visualization of collections, in general and also specifically in SharpDevelop. These goals were met and the work is already a part of the standard release of the SharpDevelop IDE. As the Debugger tooltips and Debugger visualizers build on top of NRefactory, they are usable when debugging code written in C# and VB .NET. This thesis should provide a good starting point for anyone wanting to build on our work – SharpDevelop is a live project downloaded approximately two thousand times a day, used by developers around the globe. I plan to continue working on SharpDevelop as well.

There are many possible future improvements to SharpDevelop's integrated debugger. The following list provides several ideas:

- The Object graph visualizer could display a graph not only for one expression, but a combined graph for multiple expressions (for example all local variables). This would be useful for debugging algorithms where different variables point to different instances in a data structure, or instances are moved between data structures.
- The Object graph visualizer could also remember scroll offsets in individual nodes. Currently after a debugger step, content of nodes is scrolled to the top.

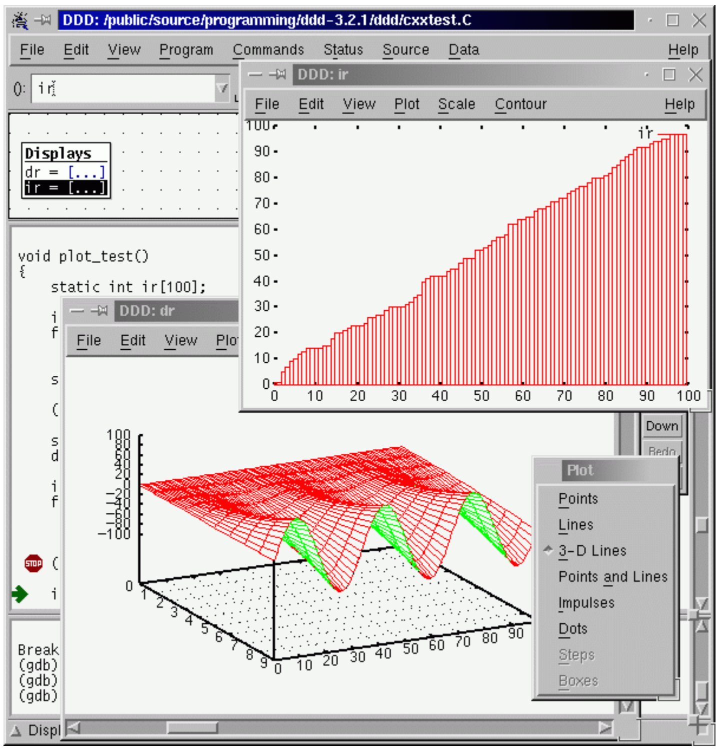
- Implement expanding of individual rows in the Collection visualizer.
- Integrate the Collection visualizer directly into the Debugger tooltips: A debugger tooltip is essentially a grid with two columns: name and value. There could be an option to expand the Debugger tooltip by adding more columns, thus having the same view the Collection visualizer provides directly in the Debugger tooltip.

- In the Debugger tooltips, an option could be added to show properties from all base classes so that users do not have to search for a property by expanding *Base class* nodes.

- Support `DebuggerDisplayAttribute` and `DebuggerTypeProxyAttribute` [1], [2].

- Implement functionality identical to Visual Studio's support for user defined debugger visualizers. The best way would be to directly support all existing visualizers for Visual Studio – this would be an interesting project as it would need some IL manipulation.

- Implement more visualizers, such as Display Data Debugger's visualizers for array of numbers.


DDD: /public/source/programming/ddd-3.2.1/ddd/cxxtest.C
File Edit View Program Commands Status Source Data Help
(): ir
Displays
dr = [...]
ir = [...]
DDD: ir
File Edit View Plot Scale Contour Help
ir
DDD: dr
File Edit View Plot
Down
Redo
Plot
Points
Lines
3-D Lines
Points and Lines
Impulses
Dots
Steps
Boxes
Displ

```
void plot_test()
{
    static int ir[100];
```

```
Break
(gdb)
(gdb)
(gdb)
```

Figure 45 – GNU Data Display Debugger's visualizers for arrays of numbers

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Appendices

Content of attached CD

The file system structure of the attached CD is the following:

overviewVideo – *short screen recording showing an overview of the features described in this thesis*

SharpDevelop – *source code of the most recent version of SharpDevelop. The source code for the work described in this thesis can be found in project Debugger.AddIn, according to the beginning of section 3 (*Implementation*). To run SharpDevelop, run SharpDevelop.exe. SharpDevelop can work with Visual Studio solutions.*

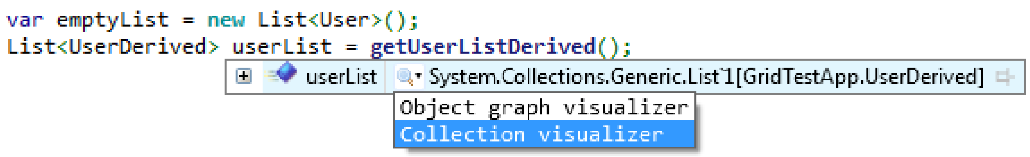
samples – *sample code to test the features described in this thesis*

thesis – *an electronic version of this thesis*

User manual

Software requirements: Installed .NET Framework 4 (SharpDevelop is built against .NET 4).

The usage of the Debugger tooltips and Debugger visualizers is quite intuitive. While debugging code in SharpDevelop and the code is paused (for example because a breakpoint was hit) hover the mouse cursor over a variable in the code - this works like in any other IDE. A debugger tooltip is displayed showing the value of the variable. If the variable is a complex object it is possible to expand the tooltip. The visualizer selector (magnifying glass icon) in the debugger tooltip offers visualizers available for the current variable. Select Object graph visualizer or Collection visualizer. Object graph visualizer is available for any complex type; collection visualizer is available for collections.



```
var emptyList = new List<User>();
List<UserDerived> userList = getUserListDerived();
```

Object graph visualizer

The Object graph visualizer displays the graph of instances in memory of the debugged program and references between them. To expand a node, click one of the plus buttons inside the displayed node (if available). The graph can be re-evaluated by clicking the Inspect button. Zooming is possible using the Zoom slider or by using Ctrl + Mouse wheel. There are two layout modes – Left to right and Top to bottom, which can be switched using the ComboBox. When a debugger step is performed, the state of the graph is updated.

Collection visualizer

The collection visualizer displays contents of collections in a form of a grid. Each grid row represents one collection item and each grid column represents one public property. To show or hide individual grid columns, use the Combobox in the top right corner.

Table of listings and figures