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BACHELOR THESIS

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Compilation of a dynamic language Generators into MSIL

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Title: Compilation of a dynamic language Generators into MSIL

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Abstract: The goal of this thesis is to design and implement support for generators within the Peachpie framework, a PHP to CIL compiler. Generators are the simplest form of methods that resume from the same state in which they returned earlier when called repeatedly. The reference PHP interpreter Zend engine supports generators natively. Due to that fact generators in PHP are support a number of features not usually seen in other languages. CIL on the other hand does not have a native support for generators. Therefore, languages build on top of CIL (e.g. C#, F#) have to implement them by other means such as by rewriting the original generator methods into state machines. In this thesis we will design and implement support for generators through semantic tree transformations. All that with the intention of keeping the maximum possible compatibility with reference PHP generators. We will also make a comparison to generators in C# whose main implementation also uses CIL as a backend.

Keywords: compiler php msil .net generators roslyn peachpie

Contents

Introduction

Despite a slow decline in recent years [TIOBE, 2017], PHP is still one of the main languages used for a server side programming on the web [Stack Overflow, 2017]. Its only two relevant implementations are the reference and almost exclusively used Zend engine[1] and slowly emerging HHVM by Facebook[2]. Both of them are standalone virtual machines and neither of them supports easy interfacing with the outside world. Hence, it is quite difficult to share code between a web backend and, for example, a mobile or traditional desktop application.

Fortunately, there is a solution in the form of a Peachpie project[3] that is being researched at the Charles University. The project aims to provide a compiler from PHP to ".NET bytecode" CIL[4] and a reimplementation of PHP base class library, thus creating a bridge between PHP and the whole .NET ecosystem. Due to it being a full compiler that takes PHP sources and spits out .NET assemblies indistinguishable from those created by other .NET languages compilers (e.g C#, F# or IronPython) it provides both ways interoperability. It enables both calling normal unmodified .NET libraries from PHP and vice versa. Also, thanks to an extensive compile-time type analysis and proven .NET just in time compiler (RiuJIT) it achieves better performance than reference Zend engine in certain operations [Míšek, 2017], [Fistein and Míšek, 2016 - 2017].

PHP, like many other modern languages, has a first class support for generators. Simply put, generators are methods that resume computation from the very place and with the same state they returned at previously when called repeatedly. They are usually used for generating large sequences of data lazily, hence the name generators. Since the execution state gets saved automatically on the special pause and return places (usually called yields) one can write an algorithm as if the sequence was being created at once and only insert yields at appropriate times, e.g. when a new item gets created. The language handles the rest. Each subsequent call to the generator method resumes computation from the last evaluated yield and continues to the next one, e.g. creating a new element each time.

The Zend engine has a native support for generators. It intrinsically understands yields and is, on their evaluation, able to save the state of current execution [Popov, 2017]. CIL has no such first class support. For that reason languages built on top of CIL have to implement generators through other means [Lippert, 2008]. Usually by rewriting generator methods into state machines with explicit state saving before each yield and state retrieval in the beginning.

That is exactly what this thesis covers. It describes the design and implementation of support for PHP generators within the Peachpie compiler through semantic tree transformations, implementation of new semantic tree nodes, and extensions to Peachpie runtime library. In the implementation parts it tries to not only plainly cover the code but also to depict the decision process that led to choosing certain approaches over others. During the whole work we will compare

[1] zend.com/en/community/php
[2] hhvm.com/
[3] peachpie.io/
[4] Chapter 2.1

our approach with the one taken by C# team and its compiler Roslyn. C# was chosen as a reference language due to it being the prominent language in .NET platform.

While the goal is to implement support for generators with as much original PHP semantic as possible, due to the scope of this work we will not discuss the specific implementation of all PHP generators features. Namely, we will not cover handling yields in exception control blocks (try, catch, finally) in detail and will leave its implementation for future work.

Thesis structure

This thesis is divided into six chapters. The first one covers general concepts of generators both in PHP and in other languages, explaining what they are, what features and limitations do they have, and where they stand in regards to iterators.

The second chapter briefly introduces the .NET platform and its intermediate language CIL. The third is all about the Peachpie project. It describes its architecture focusing mainly on the semantic tree data structure and CIL emit phase of the compiler. In fourth chapter we take a look at how generators are implemented in C#'s Roslyn and PHP's Zend engine. Especially the Roslyn's approach is important because it serves as a basis for our own implementation.

Generators within Peachpie is the focus of the fifth chapter which itself is further divided into five more sections. First describes an implementation of generators limited to circa C# generators. It builds on the theoretical basis described in previous section about Roslyn's approach. Second proposes theoretical algorithm to handle yield as expression. Third talks about implementation of said algorithm within peachpie. Fourth briefly mentions possible solutions for yields in exception handling blocks. And the fifth is about possible future work that could be done for generators support within peachpie.

The sixth chapter concludes and summarizes the whole thesis. And last but not least the final chapter provides a lightweight user documentation for the peachpie project and overview of attachments.

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Attachments

Attached to this thesis is a snapshot of Peachpie project's git repository. It contains not only the implementation that was done as the practical part of this thesis but also the rest of the complete project. A more up to date version can be found on github[1].

To query only commits done by the author of this thesis please filter out author *Petr Houška* or email *houskape@gmail.com*.

Compilation

The project's only implicit dependency is .NET Core runtime and optionally its CLI SDK. If you want to compile the project yourself you can download both of them from the official site[2], for Linux, Windows, or MacOSX.

After obtaining the .NET Core SDK please navigate to the folder with the Peachpie repository in your favourite terminal and:

```
dotnet restore  //download all external packages required
dotnet build    //build the complete solution
```

Structure

There are three components relevant for this thesis within the repository. The compiler binaries, the compiler implementation, and the generators tests. Below are listed paths to them and in case of the compiler's implementation also to some files containing the majority of our work to support generators.

1. src/Compiler/peach
2. src/CodeAnalysis
   (a) ./Semantics/SemanticsBinder.cs
   (b) ./Semantics/Graph/BuilderVisitor.cs
   (c) src/Peachpie.Runtime/std/Generator.cs
3. tests/generators

Manual testing

To compile an arbitrary PHP file into a .NET assembly with Peachpie invoke the compiler with a path to the PHP file as its first argument. The compiler assembly resides at aforementioned path and is called peach.exe or peach.dll depending of whether it was compiled for full .NET framework or .NET Core.

[1] github.com/peachpiecompiler/peachpie
[2] microsoft.com/net/download/core

```
$\src\Compiler\peach> dotnet run .\test.php
```

Please do note that an assembly compiled this way will require PHP runtime libraries to run. These libraries can be found, for example, in the bin output of the compiler (peach) project.

Alternatively it is possible to use a Peachpie console application sample[3]. It includes a .msbuildproj file that configures the .NET Core CLI to download and use both the Peachpie compiler toolchain and required runtime libraries automatically. More about that approach can be found on a peachpie blog[4].

Automatic testing

The Peachpie project includes a comprehensive set of automatic tests. These consist of PHP files that get compiled by the Peachpie compiler and run by a .NET runtime. If there is a PHP runtime present in the current path environment variable they get run by it as well. The results are then compared to ensure Peachpie compilation keeps the original PHP semantics and is, in terms of runtime behaviour, indistinguishable from the reference implementation.

There is a number tests created as part of this thesis that ensure the implementation of generators support works correctly. They are located in a subfolder tests/generators. While they are in no particular order it is generally true that the higher their number the more complex aspect of generators they test. Below is a command that invokes all peachpie tests, including generator ones.

```
$\src\Tests\Peachpie.ScriptTests> dotnet test
```

Please do note that two tests usually fail on some machines because of encoding issues.

[3] github.com/iolevel/peachpie-samples/tree/master/console-application
[4] peachpie.io/2017/04/tutorial-vs2017.html

Bibliography

Benjamin Fistein and Jakub Míšek. Peachpie benchmarks, 2016 - 2017. URL `http://www.peachpie.io/2017/06/optimizing-php-code-1.html/`. Accessed: 2017-06-25.

Eric Lippert. Iterator block implementation details: auto-generated state machines/, 2008. URL `http://csharpindepth.com/Articles/Chapter6/IteratorBlockImplementation.aspx`. Accessed: 2017-06-25.

Jakub Míšek. Optimizing php code with peachpie – part 1, June 2017. URL `http://www.peachpie.io/2017/06/optimizing-php-code-1.html/`. Accessed: 2017-06-25.

Nikita Popov. Php 7 virtual machine, April 2017. URL `http://nikic.github.io/2017/04/14/PHP-7-Virtual-machine.html#generators/`. Accessed: 2017-06-25.

Stack Overflow. Stack overflow developer survey results 2017, 2017. URL `https://insights.stackoverflow.com/survey/2017#technology/`. Accessed: 2017-06-13.

TIOBE. Tiobe index, 2017. URL `https://www.tiobe.com/tiobe-index`. Accessed: 2017-06-13.

List of Figures

List of Abbreviations

CLI Common language infrastructure, open standard for runtime environment implemented by .NET, Mono, and others.

CIL Common intermediate language, object oriented assembler defined by *CLI* (also known as MSIL or IL).

CLR Common language runtime, virtual machine implementing the execution engine specified by *CLI*.

DLR Dynamic language runtime, set of libraries providing compiler and runtime services for dynamic languages build on top of *CLR*.

AST Abstract syntax tree, structured representation of the source code.

CFG Control flow graph, a semantic graph representing a method.