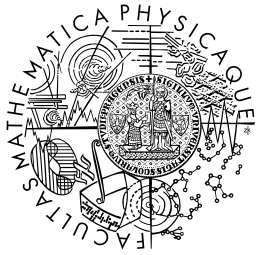

FACULTY
OF MATHEMATICS
AND PHYSICS
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BACHELOR THESIS

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Client-side execution of PHP applications compiled to .NET

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Study programme: Computer Science (B1801)

Study branch: ISDI (1801R049)

Prague 2021

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Dedication.

Title: Client-side execution of PHP applications compiled to .NET

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Abstract:

Write an abstract.

Keywords: PHP .NET Blazor Peachpie

Contents

Introduction

We can say a web application runs on two sides, that we call a server and client. The sides communicate with each other by Internet Protocols, where Hypertext Transfer Protocol (HTTP) is a fundamental communication standard. A user uses a web browser for requesting a server, which sends a response containing desired data back. The data can represent a web page or attachment like a file or raw data. A browser is responsible for interpreting and rendering a web page described by HyperText Markup Language (HTML). The Cascading Style Sheets (CSS) language accompanies HTML by enriching the web page with broad graphical content.

A server task is to process, collect and serve data requested by a client. The most popular language for server-side scripting is currently PHP.

Add a statistic for the popularity of PHP

The combination of CSS and HTML is sometimes sufficient for a web page. However, a modern web application needs to manipulate a web page structure depending on user behavior more sophisticatedly than the languages offer. This type of application utilizes a browser as an execution environment to change the web page structure, react to the events, save an application state, and control browser behavior. The scripting language Javascript became a browser standard for writing a client code inside most browsers like Google Chrome, Safari, Opera, and Mozzila.

Although Javascript is a powerful language, it is not appropriate for all scenarios and users. The reason can be dynamic typing or just a user practice with other languages. Despite the urge to write a client-side code in a different language, many technologies like Silverlight, which runs C# code in a browser, or Adobe Flash Player with Actionscript were deprecated due to insufficient support across the browsers. WebAssembly (WASM) was developed to offer a portable binary-code format for executing programs inside a browser [1] in 2015. WASM targets to enable secure and high-performance web applications. The advantage of WebAssembly is a being compilation target for many programming languages. Browsers support interoperability between WASM and Javascript to utilize both language advantages. Since December 2019, when World Wide Web Consortium (W3C) has begun recommending WebAssembly, it is easy to migrate other languages to the browsers supporting this recommendation.

Many projects use the WASM as a target of compilation. For example, the project PHP in browser [2] enables running a PHP script inside our browser using predefined Javascript API or standard HTML tag. Another project is an open-source framework Blazor [3] developed by Microsoft. It provides runtime, libraries, and interoperability with Javascript for creating dynamic web pages using C#.

Add a statistic for popularity of .NET

The .NET and PHP popularity led to the creation of the Peachpie compiler. Peachpie [4] compiles PHP to .NET and enables interoperability between the languages. Peachpie is usually used to connect a frontend written in PHP with a backend written in C# to utilize both aspects of languages on a server side.

Peachpie allows applying PHP to Blazor. Although Blazor can straightfor-

wardly reference compiled PHP by Peachpie, the collaboration between the code and Blazor seems complicated. Methods of how to utilize PHP scripts as a part of a Blazor website are not clear. This thesis targets to identify use-cases that will make use of the integration between Peachpie and Blazor and suggests a solution, which creates a library to execute and render compiled PHP scripts in a browser. Blazor is used as an execution environment for these scripts. The solution tries to achieve two goals. The first goal is to implement the support for using compiled PHP scripts with Blazor because no existing library supports the integration. The second goal is to enable web development on a client-side with PHP.

The integration between Peachie and Blazor can yield to following benefits. A community of PHP developers is significant. Thus, many PHP libraries apply to work with client's data, pdf, graphics and offer handy tools. The possibility to migrate the language PHP together with its conventions to a browser will impact developing dynamic web applications due to the PHP community and the libraries. It can join PHP and C# developers to collaborate with their programming languages using a minimum knowledge of the integration. Another interesting functionality of this idea is a full C#, PHP, and JavaScript interop which offers more options for developers and future extensions.

The first chapter addresses the analysis of related work, alongside descriptions of the technologies used in the integration. The second chapter analyses running PHP on the client-side and other problems related to used technologies. The third gives a detailed problem's solution. There are examples that demonstrate how to use all aspects of the created solution in chapter 4. In chapter 5, we can see benchmarks that explore the limits of the implementation and compare them with the already existing project. And the last chapter relates to a conclusion of this solution.

1. Existing technologies

In this chapter, we will give a short overview of web application functionality. We will explore server-side scripting using PHP and client-side scripting using Javascript in order to obtain observations of user conventions for interaction with web applications. Afterward, we will introduce WASM, followed by the existing project enabling to execute PHP in a browser. We will give short information about the .NET platform and C# language. In the last sections, we will introduce Blazor and Peachpie.

1.1 PHP

The basic principle of obtaining a web page is a request-response protocol, where a client sends a request for the web page using an HTTP protocol and receives a response with requested data. The protocol uses a dedicated message format for communication. Statelessness is a typical characteristic, meaning that a server has to retain information about clients and add additional information to the messages in order to distinguish between the clients.

Since the server contains business logic, a browser has to send necessary data for required actions by an HTTP message. The data are usually encoded as a part of Uniform Resource Locator (URL) or in the HTTP message body. HTML presents a tag `<form>` that enables interaction with the web application by a web form. Figure 1.1 contains an example of the tag. `<form>` can contain other tags, which are displayed as various types of fields. A user fills these fields, and the browser sends the data as a new request to the server. We can specify how the data will be encoded. `get` method is one of the basic ways. It encodes the data as a pair of keys and its values to the query part of the URL. There is an example of URL `http://www.example.com/index.php?par1=hello&par2=world`. A query part begins with a question mark. We can see parameter keys `par1` and `par2` containing values `hello` and `world`. Another method is called `post`, which encodes it in the request body, which does not appear in the URL.

Although PHP [5] was originally designed for user page templating on a server side, it has been adjusted gradually to enable writing application logic. PHP is an interpreted language maintained by The PHP Group.

We will describe the language by using figure 1.1 as an example. The script includes a header, which adds a proper beginning of an HTML document. Then, it prints a `post` content together with a file content whenever the file `file` was obtained. There is a form enabling to send information about a name and attach a file to the massage. A browser sends the message to the server via `post` method when the form is submitted. The request is handled by `index.php` defined in `action`. In the end, the script includes a proper ending of the document by `footer.php`.

As we can see, the PHP code interleaves the HTML code, which has appeared to be a helpful method for data binding. We call the feature HTML interleaving, which allows inserting PHP code in `<?php ... ?>` tag. These fragments do not have to form individual independent blocks of code closed in curly brackets, as the example demonstrates by using the `foreach` cycle. An interpreter executes

```
<?php
    include("header.php");
?>

<h1>Superglobal POST</h1>
<?php
    foreach($_POST as $key => $value) { ?>
    <p><?php echo $key; ?> => <?php echo $value; ?></p>
<?php } ?>

<h1>File content:</h1>
<p>
<?php
    if($_FILES["file"])
    {
        echo file_get_contents($_FILES["file"]["tmp_name"]);
    }
?>
</p>

<form action="/index.php" method="post">
    <label for="name">Name:</label>
    <input type="text" id="name" name="name"><br>
    <label for="file">File:</label>
    <input type="file" id="file" name="file"><br>
    <input type="submit" value="Submit">
</form>

<?php
    inlude("footer.php");
?>
```

Figure 1.1: An example of PHP code in file index.php.

a script from top to bottom. Everything outside the PHP tag is copied into the body of the request.

We do not see any specification of type next to variables. This is because the type system is dynamic. A variable represents just a reference to the heap. Its type is determined during runtime.

PHP has superglobals [6], which are built-in variables accessible from all scopes of the script. Following superglobals are relevant to the thesis. The `$_GET` variable stores parsed query part of the URL. The `$_POST` variable stores variables which are sent by post method. The `$_FILES` variable contains information about uploaded files sent by a client. The uploaded file is saved as a temporary file, and standard reading operations can obtain the content. This is demonstrated in the previously mentioned example by `file_get_contents` function.

Maybe add information about SESSION.

The nature of the request-response semantic usually results in a one-way pass of the application. After dealing with a request, the script is terminated, meaning that the request is sent, and variables are disposed. One of the well-known design patterns relating to PHP is the Front controller. Usually, the main script invokes other parts of the program, based on the request, to deal with it and send the response back. The idea of this pattern can be shown in figure 1.1. In the beginning, we delegate header rendering to `header.php` script. Then we render the body and include `footer.php`, which cares about the proper ending of the HTML page.

We can divide code in several ways. Global functions are the most notable characteristic of PHP despite wide-spread object-oriented programming. They are defined in the global scope and accessible from anywhere. The next option is an object inspired by object-oriented programming. We can include a PHP code from other scripts. They can be recursively included during runtime, where variables remain across the inclusion. Scripts can be composed into a package, which another code can reuse.

1.2 Javascript

A client-side code needs to control the rendered page and access a web interface providing additional services, which is usually accessible via Javascript, in order to interact with a user. We will start with a description of loading Javascript in a browser. We will introduce a page representation in a browser alongside page events. In the end, we will present Javascript as a scripting language for the creation of a responsive web page.

We can image a web page structure as an tree. Its nodes are tags or text fragments, and its edges connect nodes with their children. One representation of this tree is Document Object Model (DOM). Each node is represented by an object with special parameters relating to HTML and CSS. The nodes can contain other nodes representing their children. Afterwards, there is a document node representing the whole document together with its root node.

The process of generating a web page follows several steps. A browser parses the HTML page line by line. If a script occurs, the browser starts to execute the code, which can access already parsed tags. The order of processing is important

```
<!DOCTYPE html>
<html>
    <head>
    </head>
    <body>
        <button id="alert">Click to alert</button>
        <script>
            var handler = function (arg) {
                var timer = new Promise((resolve) => {
                    setTimeout(resolve, 1000);
                });

                timer.then(() => window.alert("Hello world."));
            };

            var button = window.document.getElementById("alert");
            button.addEventListener("click", handler);
        </script>
    </body>
</html>
```

Figure 1.2: A Javascript code.

for manipulation with an HTML structure. This limitation can be solved by web events mentioned later, but it is a convention to add scripts to the end of the body part after all HTML tags are parsed.

Events are the most common method of how to react to changing a web page state. Every event can have some handlers(listeners). Whenever an event occurs, it calls all its listeners. There are many event types, but we will mention the ones that are important for us. HTML tags are the most common entities which can have some events. For example, a button has an `onclick` event which triggers when a client clicks on the button as we can see in figure 1.2. Other events can represent a state of a page like `onload` which fires when the whole HTML document is parsed.

A browser provides more APIs valuable for the application, like fetching extra data from a server or local storage. These APIs are mentioned as Web API [7].

ECMAScript (ES) is a Javascript standard recommending across browsers. We can see later an abbreviation ES2015 which determines the ECMAScript version. Javascript is a high-level language usually executed by a browser's dedicated Javascript engine. Browsers run scripts in a sandbox to prevent potential threats of harmful code. However, it can also be run on a desktop by Node.js, a Javascript runtime running outside a browser. Figure 1.2 will be used to show the language in the simple scenario. The page contains a button that invokes an alert with a second delay when a client clicks on it.

At first glance, we can see the type system is dynamic, which is similar to PHP. `window` is an essential global variable, which is an object representing the browser window of the running script. The window object consists of all defined global variables. It also contains a document property, which is an API for manipulating

the DOM tree. We can see the usage of the document property in the example. Javascript object is often used as a wrapper of Web APIs.

Functions are first-class citizens in Javascript. We can treat them as common variables. Javascript supports an event-driven style that helps to react to events conveniently. There is a handler assigned to the click event in figure 1.2.

Maybe add a section about async functions. Compare it with PHP

Javascript is single-threaded, but allows effective synchronous execution. This can be achieved by `Promise`, which is a structure representing an unfinished process. We can separate a large task into smaller ones in other to offer the processing time for other parts of the application. These processes can be chained. Although the structure can give an illusion of multi-threading, it uses the scheduler for planning the next task executed by the main thread after the previous task is completed or an event triggered it. The single thread is critical for blocking operations like time demanding computatitons which causes thread freezing.

`Worker` object represents a web worker [11], provided by a browser, enabling to run the script in the background. The worker limitation is communication with UI thread only by handling message events. Messages have to be serialized and deserialized.

Javascript can organize a code by function and objects similar to PHP. A module can gather a larger collection of code. Global entities of the code can be exported to another script. These exports make an API of the module. The module advantage is to define the API and to hide the internal code, which is not relevant for the user.

1.3 WebAssembly

WASM [9] is a new code format that can be run in current browsers. It has a compact byte format, and its performance is near to a native code. WASM is designed to be a compiling target of popular low-level languages like C or C++ due to its memory model. It results in the possibility to run other languages in a browser because its runtime is often written in C or C++. Browsers enable to run Javascript alongside WebAssembly, and even more, their code can call each other. WASM code is secure as same as a code written in Javascript because of the sandbox.

Thread [10] support is currently discussed nowadays, and it will probably be added in future browser versions. After all, new versions of Google Chrome experiments with proper multi-threading support. A replacement of multi-threading can be Web workers mentioned in Javascript section.

Despite supporting to run WASM in a browser, the browser cannot load it as a standard ES2015 module yet. WebAssembly JavaScript API was created in order to be able to load a WebAssembly to a browser using JavaScript.

1.4 PHP in Browser

The project [2] aims to use compiled PHP interpreter into WebAssembly, which allows evaluating a PHP code. The page has to import a specialized module

```
<script type = "text/php">
    <?php vrzno_run('alert', ['Hello, world!']);
</script>
```

Figure 1.3: An example of PHP script block.

`php-wasm`. A PHP code is evaluated by using JavaScript API or writing a specialized script block as we can see in figure 1.3. PHP can afterward interact with JavaScript using a specialized API. In the figure, the code calls Javascript `alert` function with the parameter.

At first glance, that might be a good enough solution, but several parts can be problematic due to PHP semantics. The solution does not offer additional support for using PHP scripts on the client side. For example, superglobals are unused due to a missing server. This issue is reasonable because this is the server task, but we cannot get information about a query part or handling forms without writing a JavaScript code. The next problem relates to how a script can navigate to another script without an additional support code, JavaScript.

1.5 C# and .NET 5

We will introduce the Common Language Infrastructure (abbreviated CLI) [18] before diving into .NET, which is an overused name for several technologies. CLI is a specification describing executable code and runtime for running it on different architectures. CLI contains descriptions of a type system, rules, and the virtual machine (runtime), which executes specified Common Intermediate Language (abbreviated CIL) by translating it to a machine code. The virtual machine is named CLR (Common Language Runtime). CIL's advantage is a compilation target of languages like C#, F#, and VisualBlasic, which gives us great interoperability. .NET Framework, .NET 5, and Mono are implementations of CLI. These implementations are usually uniformly called .NET.

.NET 5 [17] is the lastest version of .NET Core, which is a cross-platform successor to .NET Framework. From now on, we will refer .NET 5 as .NET, since it should be the only supported framework in the future. .NET is an open-source project primarily developed by Microsoft. It consists of runtime for executing CIL and many libraries that can represent whole frameworks like ASP.NET, which aims to web development. A large collection of code is usually compiled into an assembly containing the code and additional metadata. As assembly can represent either a library or an executable program.

Mono aims at cross platform exection of CIL. Recently, they started to support compilation [12] into WebAssembly. This support allows executing CIL inside browsers. The compilation has two modes. The first one is compilation Mono runtime with all using assemblies. The second one only compile Mono runtime, which then can execute .dll files without further compilation of them into WebAssembly. A consequence of these compilations into WebAssembly is enabling to call Javascript and WebAPI from C#.

.NET Standard represents API specifications of .NET libraries across different implementations. .NET Standard offers to specify minimum requirements for the

code.

C# is a high-level language using strong typing and a garbage collector. It has a multi-paradigm, but its common characteristic is the objected-oriented style. These features cause that C# is a good language for a huge project which needs discipline from developers to hold the code understandable and manageable.

1.6 Blazor

Blazor is a part of the open-source ASP.NET Core framework. Blazor allows creating client-side web applications written in C# language. Blazor framework offers two hosting models [13] which have different approaches to creating web applications. The first one is referred to as Blazor Server App and represents a server-side web application using specific communication between a client for better functionality. The thesis uses the second model, which Microsoft refers to as Blazor WebAssembly App, enabling to move business logic to a client-side without using Javascript.

From now on, we will use Blazor App to refer Blazor WebAssembly App. The application can be hosted by a standalone project representing a standard ASP.NET Core web server. The hosting consists of serving application .dlls and static files like HTML, CSS. The division enables a choice of a place for the implementation of business logic. Thus, we can move the majority of business logic to the client and use the server for connection to a database or, we can use the client only for rendering the page. When we chose the template, there are two main projects to describe.

As we can see in figure 1.4, there is a server, which serves the Blazor App to a client. The project contains a standard builder of a host using a StartUp class,

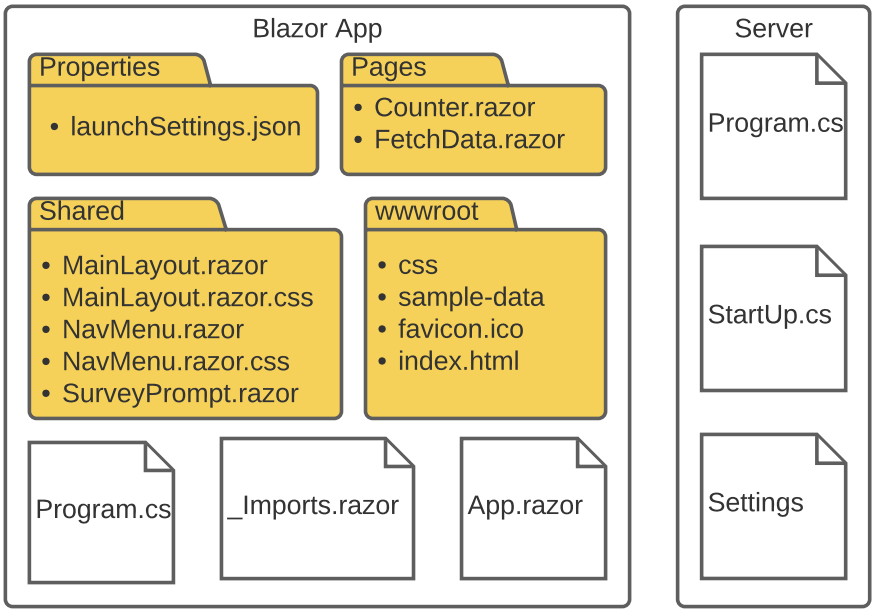

Figure 1.4: Server and WebAssembly App projects.

```
@page "/example"
@inject HttpClient Http

<h1>Example</h1>
@if (!loaded)
{
    <p>Loading...</p>
}
else
{
    <p>Ticks: @ticks</p>
}

@code {
    private bool loaded = false;
    private int ticks = 0;

    protected override async Task OnInitializedAsync() {
        ticks = await Http.GetFromJsonAsync<int>("ticks.json");
        loaded = true;
    }
}
```

Figure 1.5: Example of Razor page.

which configures an HTTP request pipeline processing requests in `StartUp.cs` file. A middleware is a segment of an HTTP request pipeline, which cares about some functionality related to request processing. The pipeline contains a middleware providing the Blazor files.

We will describe the second project (Blazor App) in figure 1.4 to explain basic entities and their interaction with each other. We will start with a new format Razor to get familiar with it. Razor is a markup language interleaving HTML with C#. Razor uses special sign at with keywords to identify C# code in HTML. Razor compilation results in a pure C# code representing the web page fragment. We can see an example of Razor in figure 1.5.

Although the format is self-explaining, we describe the keywords. The first line begins with a `page` keyword determining a part of the page URL. The next keyword is `inject`, representing a `HttpClient` service injection. An `if` keyword is an control structure iterleaved by an HTML code. A `code` keyword contains a regular C# code, which can be used in the whole `razor.` file.

A Razor file is compiled into a C# dedicated class. The class inherits from `ComponentBase` or implements `IComponent`, which provides necessary methods for rendering the page. Components can be arbitrarily put together in order to form the desired page. We can see the generated component from figure 1.5 in figure 1.6.

We can assign the Razor keywords to parts of the code in the figure. `page` keyword stands for `Route` attribute. `inject` keyword stands for parameter attribute. The parameter is assigned by a dispatcher, during the component initialization.

```
[Route("/example")]
public class Index : ComponentBase {
    private bool loaded = false;
    private int ticks = 0;

    [Inject] private HttpClient Http { get; set; }

    protected override void BuildRenderTree(
                                RenderTreeBuilder __builder) {
        __builder.AddMarkupContent(0, "<h1>Example</h1>");
        if (!loaded)
        {
            __builder.AddMarkupContent(1, "<p>Loading...</p>");
            return;
        }
        __builder.OpenElement(2, "p");
        __builder.AddContent(3, "Ticks: ");
        __builder.AddContent(4, ticks);
        __builder.CloseElement();
    }

    protected override async Task OnInitializedAsync() {
        ticks = await Http.GetFromJsonAsync<int>("ticks.json");
        loaded = true;
    }
}
```

Figure 1.6: Razor page generated to the C# class.

`code` keyword is a part of class content. Another markup is transformed into calling a specialized method in the `BuildRenderTree` function, which describes the page content for rendering.

A component has several stages, which can be used for initialization or action. Virtual methods of `ComponentBase` represent these stages. We can see the textttOnInitializedAsync method, which is invoked after setting the component parameters.

We should mention asynchronous processing because it helps render a page with long-loading content. Blazor allows using Tasks and async methods, separating the code into smaller tasks planned by a scheduler. Blocking operations in Blazor are projected into UI because it is single-threaded due to Javascript and WASM.

We return to the project description. Folders `Pages` and `Shared` contains parts of Blazor pages written in Razor. _Imposts.razor contains namespaces, which are automatically included in others `.razor` files. The next folder is `wwwroot`, containing static data of the application. We can see `index.html`, which cares about loading parts of the Blazor application to the browser. We will call all static files in `wwwroot`, additional Javascript scripts and WASM runtime Static Web Assets.

```
<body>
    <div id="app">Loading...</div>
    <div id="blazor-error-ui">
        An unhandled error has occurred.
        ...
    </div>
    <script src="_framework/blazor.webassembly.js"></script>
</body>
```

Figure 1.7: index.html

We will describe the loading of Blazor into the browser to fully understand the interaction between Blazor and the browser. We have the server, the Blazor App, and other optional user's defined projects. When we start the server and tries to navigate the web application, the following process is done. The server maps the navigation to `index.html` and sends it back.

The `index.html` contains a script initializing Blazor as we can see in figure 1.7. The first step is to load all resources, which are defined in a separate file. Blazor cuts all unnecessary `.dll` files to reduce the size. For this reason, all `.dll` files have to be used in the Blazor App code in order to be contained in the file. These resources comprise Mono runtime compiled into WASM, additional supporting scripts, and all `.dll` files containing the whole application (Blazor App with referenced libraries). The supporting scripts initiate the runtime and execute it. The runtime includes the `.dll` into the application and calls the `Main` method in `Program.cs` defined in Blazor App project. We can see the process in figure 1.8.

`Main` method uses `WebAssemblyHostBuilder` to set the application. It defines services, which will be able through the dispatcher. It sets a root component, which will be rendered as the first. The host is run. Afterward, the application provides the dispatcher, cares about rendering, and communicates with the runtime to offer interop with Javascript.

`App.razor` is the last file for clarification. It is the root component in default. It contains a specialized component, `Router`, enabling to navigate the pages.

In the end, we will describe page navigation and rendering and handling events. The navigation [14] can be triggered by an anchor, form, or filling up the URL bar. The URL bar is handled separatly by a browser. JavaScript can influence the remainings elements by adding a listener to their events. Blazor App handles only an anchor by default. After clicking on an anchor, a navigation event is fired. One of the handlers is a javascript function, which invokes C# method through Mono WASM and prevents a browser navigation, when Blazor App handles it. The method represents a navigation handler in Blazor App. A user can add listeners to the handler, but the Router implements default behavior for navigating. `Router` finds out all components which implement an `IComponent` interface and tries to render the page according to path matching `RouteAttribute` of a component whenever the navigation is triggered. It creates an instance of the class and fills in its parameters. `Router` calls `BuildRenderTree`, which enables running the rendering process. Previous created intences of components are disposed. The navigation can be redirected to the server if there is no match.

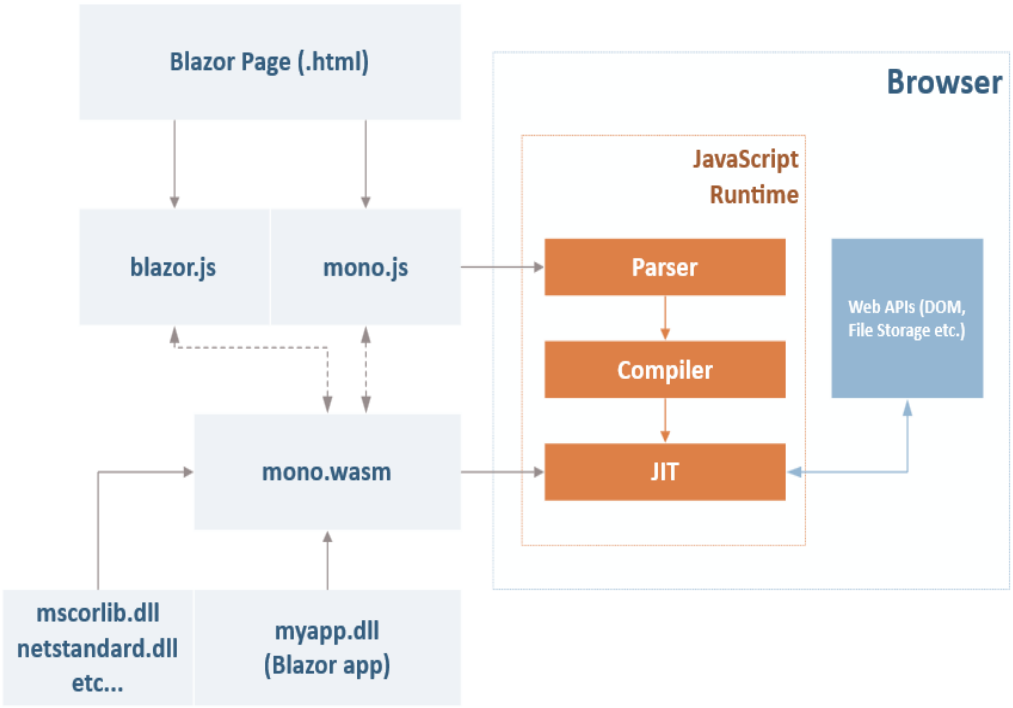

Figure 1.8: Running a Blazor WebAssembly App on client-side.

The rendering process begins with the Renderer initialized in the application builder. Renderer keeps a copy of DOM in memory, creates page updates, and calls Javascript API for changing the web page DOM in a browser, using the runtime interop support. Blazor provides API for invoking Javascript functions and vice-versa. Renderer provides `RenderTreeBuilder` for describing page contents. The builder provides an API for adding various types of content to `Batch`, which is a specialized structure for describing previous and present DOM. Although DOM changes is performance-expensive, a diff algorithm recognizes and tries to reduce the updates in `Batch`. The usage of `RenderTreeBuilder` is complecated, because it has to be adapted to the algorithm. The purpose of Razor is to make the usage more effortless when the compilation implements the `RenderTreeBuilder` for us. When the Renderer prepares `Batch`, it calls specialized Javascript API for changing the page through Mono runtime.

The diff algorithm is used to minimize the browser DOM update after all components used `RenderTreeBuilder` to render their content. This algorithm used sequence numbers for parts of HTML to identify modified sections. Sequence numbers are generated in `RenderTreeBuilder` instructions during a compilation. A benefit of this information is detecting loops and conditional statements to generating smaller updates of DOM.

Event handling is just clever usage of the Renderer with dedicated Javascript API for updating, where the API registers the listener. When the event is fired, the listener invokes C# method representing the handler through the WASM runtime.

1.7 Peachpie

Peachpie [16] is a modern compiler based on Roslyn and Phalanger project. It allows compiling PHP scripts into a .NET assembly, which can be executed alongside standard .NET libraries. All information about the scripts are saved in the assembly. We will describe the basics.

Because the languages have a different type system, Peachpie brings dedicated types for representing PHP variables in .NET. Some of these types are `PhpValue` representing a standard PHP variable, `PhpArray`, or `PhpAlias` which is a reference to `PhpValue`.

Another abstraction is the `Context` class. We can imagine `Context` as a state of the script while it runs. `Context` consists of superglobals, global variables, declared functions, declared and included scripts. It also manages an input and output, where we can choose a resource. `Context` can also be considered as a configuration of the incoming script's execution. All information about a request can be arranged to mock every situation on the server-side. The possibility of saving `Context` and using it later is a significant advantage. We can use the class API to obtain information about compiled scripts.

Because some PHP extensions are written in C or C++, Peachpie implements them using .NET libraries, which can add additional functions providing an extra nonstandard functionality such as an interaction with a browser.

The main advantage of the compiler is the great interoperability between PHP and .NET. An option to work with C# objects, attributes, and calling methods will become crucial for achieving advanced interaction between Blazor and PHP.

The compiler successfully compiled well-known web frameworks like WordPress or Laravel. Thus many companies use it for combining the existing frameworks with a C# backend.

However, there are limitations following from differences in the languages and the stage of development. Availability of PHP extensions depends on binding these functions to C# code which gives equivalent results. The .NET libraries can be executed in an independent environment. However, the code can have performance issues in WebAssembly. The previously mentioned interoperability has limits as well. Csharp constructs like structs and asynchronous methods are undefined in PHP.

V dobe psani prace tady byly nejake komplikace

2. Problem analysis

We divide the analysis into three steps. In the first section, we think of potential users of the integration in order to define realistic use cases for them. Four use cases describe the user's intentions. Then, we specify requirements, which are demanded by the use cases. In the last section, we propose a high-level architecture of our solution, where we aim at utilizing Blazor and Peachpie to cover the requirements.

2.1 Use Cases

We remind technologies of interest to introduce a context of our use cases. PHP is used for server scripting, where it is designed to process a request, create the website, and send it back. Blazor is a web framework for creating a client-side UI using C#. Peachpie is a PHP compiler, which compiles a collection of PHP scripts, representing a standalone project, to a .NET assembly.

We consider four types of potential users. The first type is a C# programmer, Blake, excited to Blazor and read our thesis.

The second type is a PHP programmer, Alice, who has no experience with Blazor but knows Peachpie basics. Alice creates standard websites written in PHP, whereas she uses techniques introduces in the PHP section. One day she wants to move the website to a client side. Blake tells her about our thesis proposing a solution to migrate the scripts to a browser using Blazor and Peachpie. She is excited by the solution and looks forward to using it. However, she does not want to learn the Blazor framework. Her point of interest is to use the solution for helping her to migrate her website to a browser. The solution should provide an effortless manual on how to deploy it. The manual should support most of the PHP conventions, which we could see in the PHP section.

The third type is a PHP programmer, Bob, who has already tried to write a simple website using Blazor and knows Peachpie basics. He creates standard websites similar to Alice's. One day he wants to contribute to a website powered by Blazor. He has a great idea of adding a new widget, which can be implemented by a few PHP scripts, which use some libraries. Blake tells him about our thesis, and his wish is to use the solution to help him inject his scripts into the website. The solution should be adopted to his skills.

The fourth type is an enthusiastic PHP programmer, Chuck, who has advanced experience with Blazor and knows Peachpie basics. He does not avoid exploring new technology to utilize all their aspects. Again, there is an existing Blazor project, and he wants to add a new feature to it. The PHP language offers the best way to implement it, but the feature is so render demanding that he wants to make use of Blazor to make the UI rendering more effective. Blake tells him about our thesis, and Chuck wishes that the solution offers him to collaborate with Blazor by PHP.

These descriptions should help us determine the following use cases, which are realistic to both potential users. We call the first use case **Web** relating to Alice. We suppose she has a simple PHP website, which contains some information about her company. The website does not work with a database and consists

of pages containing images and references interconnect them. Some pages are adjustable by specifying the query part of the URL, and they include other scripts to add some basic layout. One day the website notices many accesses, and Alice wants to migrate the website in order to a client side to save server resources. The migration should download most of the website to a browser. Afterward, navigation between scripts and script execution should be maintained on the client side. Even more, Alice does not want to adjust the website for a client side too much, and she wishes for a simple solution that is understandable by a novice.

We call the second use case **OneScript** aiming at Bob, who already has some experience with Blazor. There is an existing Blazor website, and he has an idea of a brilliant widget displaying the user's graph by HTML. Because he is used to PHP, the HTML is rendered by PHP scripts. The idea consists of let the user choose to load graph data from a file or generate a predefined graph as a demo. After that, the widget renders HTML markup representing the graph. Bob uses forms to interact with a user. Unfortunately, Bob uses forms to interact with a user, and he is not willing to learn Javascript or interoperability between PHP and Blazor. Thus, he needs a solution, which offers interaction with a user and uses standard PHP conventions mentioned earlier.

We call the third use case **PhpComponent** relating to Chuck. He wants to create a real-time web game similar to Asteroids written in PHP. PHP programmers have not been used to saving variables or defined functions across scripts because of the HTTP policy mentioned in the PHP section. Now, Chuck wants to try a new approach, where he relies on state persistent and saves a state of all game entities in variables. One script execution should render one game scene as an HTML markup. There is a timer, which executes the scripts every defined period of time. The game is render demanding due to redrawing the scenes. So he decides to target on a client side and utilizes Blazor, Peachpie, and our solution. A client side execution should prevent network latency by loading the game in the beginning. After that, the game will be independent of the network connection due to running the game and saving the game state by a browser. Because he has previous experience with Blazor infrastructure, he will appreciate utilizing all Blazor aspects to run this game. Thus, he needs some representation of Blazor in PHP, which he will use for interacting with a browser.

We can see an illustration of the fourth use case, which we call **AllTogether**, in Figure 2.1. The goal of the use case is to allow collaboration between PHP and Blazor programmers, where a difference of languages is not a barrier. We can image two teams creating a web application. They agreed on developing a client-side web application, where both teams aim at different parts of the website. For example, one team wants to create a fun zone where a user can play some web game, we can imagine something like Asteroids, and the second team wants to create some online documentation about the game and the widget for the graph representation mentioned in *OneScript*. Because Blazor targets client-side web applications, they want to utilize Blazor. Unfortunately, these teams use a different favorite language, where the first team uses PHP and the second team uses C#. Even more, these teams want to arbitrarily choose what part they want to develop. They need some environment where the PHP team can code alongside the Blazor team, and they can focus on an arbitrary part of the web

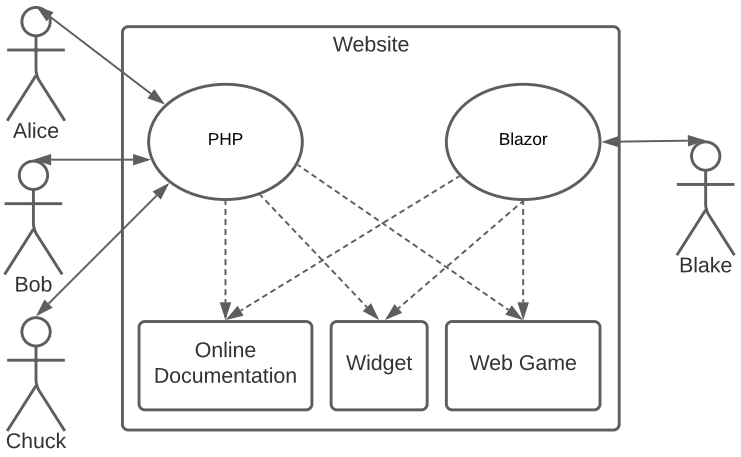

Figure 2.1: The AllTogether use case describing the combination of the rest. Double-headed arrows represent the person's used language. Dashed arrows represent a possible usage, where the head aims to an implementation written in the language.

application. We can see the intention in Figure 2.1 where each team can create a part aiming at the web game, the online documentation, and widget. We can see the PHP team consists of Alice, Bob, and Chuck, having different skills with Blazor, so the environment should reflect it. Even more, Blake should be able to manipulate their part of the application to customize it using C#. For example, he should change the layout of the website without complex refactoring.

2.2 Requirements

The goal of this section is to describe requirements based on mentioned use cases. If the proposed solution covers the requirements, then PHP scripts will become a valuable part of a Blazor website.

Navigation is the first requirement that our solution should provide. We demonstrate navigation posibilities in Figure 2.2. Basic functionality should provide script routing, which finds a script by its name and executes it. The solution should offer a straightforward router making a Php website accessible, as we can see in the figure. The simplicity is a necessary condition for Alice and should be reflected. Blazor should navigate the component defined in `script.php`, because Peachpie enables inheriting `ComponentBase`, which results in a routable component.

Injectability of script is an important feature to make *OneScript* use case reusable. Thus, Bob can inject the widget in different contexts, meaning that he can create a new web page containing some content and inject the widget into it, as we can see in Figure 2.2 where the Blazor component is generated from a PHP script and a Razor file.

Rendering should be maintained in two ways. The first way aims at Alice when a script output is transparently displayed as a web page or its fragment. The approach hides Blazor infrastructure for rendering a markup and makes creating

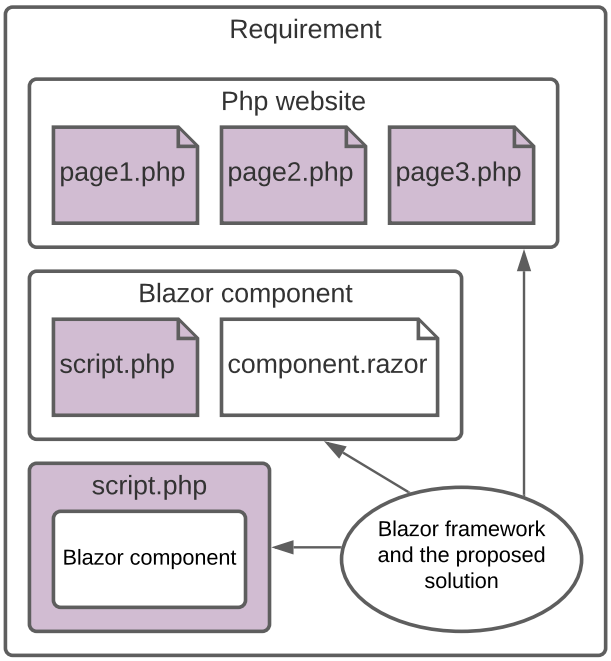

Figure 2.2: The requirement describing navigation between different types of entities. The first one represents a collection of script routable by default `Router`. The second represents a standard component contenting a PHP code, and the last contains a defined Blazor component in the script. The proposed solution with Blazor connects these types into a single website, where they can live together.

a UI easier for PHP programmers. The second way aims at Chuck when the solution provides an interface for the interaction with Blazor. It is also necessary when we want to use already defined components in a PHP code.

State preservation is a new feature, which should be available for creating a web application by a collection of scripts saving their variables after the execution. This feature is not a standard because of HTTP policy and conventions, where programmers are used to deletion of variables and function definitions after the request termination. However, the state described by the variables needs to be preserved in order to interact with a user. The feature is a new way, how to save the application state and can be seen in the *PhpComponent* use case where we have to save the game state. However, we should be able to choose whether it is intended behavior because scripts lose their state after every request on a server side.

Server simulation should be the main advantage of the solution. We could see superglobals are commonly used methods how to obtain information about navigation or submitted data. The solution should support superglobals for examples like the *Web* use case, where the website uses information about URL query part, via `$_GET` variable, to make decisions.

Forms should be maintained by the solution. They should not be sent to a server but parsed and provided in superglobals. After navigation to a script defined in the `action` attribute, the script should access the form data. Data processing also contains a file managment, where it should be possible to upload

and download files.

Interoperability between PHP and Javascript should be supported for situations when forms, the server abstraction, or Blazor are not sufficient. We should be able to call Javascript functions from PHP and vice-versa.

2.3 Architecture

The basic principle of our solution consists of PHP scripts compilation into .NET assembly by Peachpie. After that, a Blazor App references the assembly with `Peachpie.Blazor`, which is a support library providing a mechanism for navigating and executing the scripts. Then, a server serves the application to a browser, where Mono runtime executes it. We will describe the architecture from the view point of compilation time and runtime.

When we think about PHP script compilation, there are two possibilities. We can compile the scripts ahead of time and reference them from a Blazor App. The second way is to regard the scripts as Static Web Assets and load them into a browser as scripts. Afterward, the Peachpie compiles and executes them. Both approaches have different advantages. Thus, there is no silver bullet. The first approach saves time by ahead compilation and compilation check. However, the second approach can save browser memory when the web application is larger, and a client uses only a part of it. We are inclined to the first approach because the static compilation is a standard way in Peachie. We think that the first approach is valuable for the use cases mentioned earlier. The *Web* use case wants to save additional requests. The rest of the use cases intends to utilize PHP scripts as a part of the website, so we suppose that the advantage of using smaller browser memory is unimportant.

We have to figure out how to attach a PHP code, which is compiled into the assembly, to the Blazor App. Although Peachpie supports calling functions written in PHP from Blazor by default, we want to create an abstraction over the Blazor environment in order to simplify the interface. The abstraction should offer a representation of PHP scripts in Blazor. It should allow an option for accessing the Blazor interface for advanced features. It should be compatible with the Blazor environment in other to allowing a smooth collaboration between the abstraction and the Blazor pages. A Blazor page consists of components, which can collaborate with each other. Thus, we can utilize them to represent PHP scripts. Componets can be arbitrarily put together, which offers to place our PHP code in the desired place in the Razor code. Even more, we can replace a root component, `Router` by default, with the component representing PHP scripts. Afterward, scripts will care about the whole Blazor website content. The component provides a sufficient Blazor interface for rendering control and interaction with a browser.

We can think about how to represent PHP scripts as components. There can be one type of component, which will provide the abstraction for all the PHP code in scenarios. A problem with this approach is that the use cases need different levels of abstraction. The *PhpComponent* use case wants to use the component for offering the Blazor interface accessible from PHP code. The offer should contain identical or similar options, which are given in a C# code. The *OneScript* use case wants to free a programmer from Blazor. Thus, we want to

use the component as an adjustable provider finding and executing PHP scripts. Its purpose is to keep the user away from knowing about the detailed structure of Blazor and the integration. Another important thing is a provider role in a Blazor App. The provider can behave either as the Router or as a routable component, which enables the navigation of PHP scripts. As a consequence, we need to create more types of components for different proposes. These types will provide the abstraction for the particular use cases. The solution will reach two types of components. The first one wants to bring Blazor to PHP in order to utilize the whole environment. The second one aims at presenting a transparent execution of standard PHP script without knowing about the connection between Blazor and PHP. We can illustrate out intention in Figure 2.3.

We will focus on the first component, which we will call `PhpComponent` due to the effort of moving the component concept to PHP. `PhpComponent` aims at the third use case. Despite language differences, we can utilize the common concept of classes and inheritance when Peachpie allows inheriting C# class in a PHP code. This feature results in full support of component interface without creating new structures for managing component behavior from PHP. We can inherit `ComponentBase` class in PHP and use its methods in the same way as C# class. The inheritance offers the required interface in the *PhpComponent* use case. At the time of writing, there are also subproblems with the differences of languages. The current Peachpie version does not support some C# specifics fully. The reason can be a hard or impossible representation of C# entities in

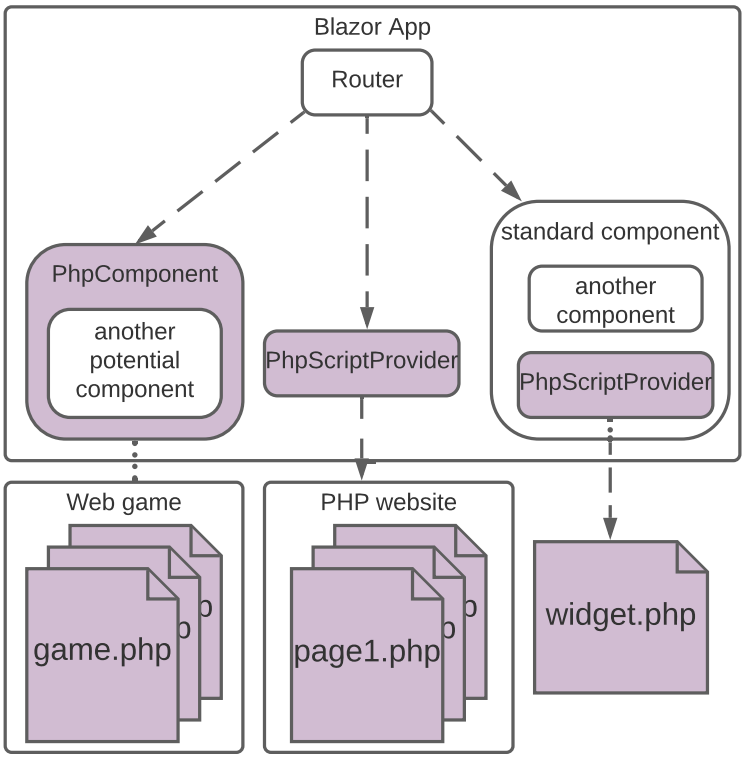

Figure 2.3: Components representing PHP scripts. Arrows represent navigation. Dot lines connect a runtime object with the implementation.

PHP. It should be developed some PHP support for making the usage of the interface easier. The support will replace the missing usage of the interface.

We will call the second type of component `PhpScriptProvider` expressing an environment for executing standard PHP scripts. `PhpScriptProvider` solves the requirements of the remaining use cases as a single component. The provider should be able to navigate and execute PHP scripts. Because the remaining use cases try to hide the integration between PHP and Blazor, the provider should support the following features. It should pretend a server behavior, which copies everything in the output of PHP script to an HTTP response body rendered by a browser. Superglobals are often used for obtaining additional information given by the user. Thus, an ability to fill `$_GET` variable with the URL query part should be presented. It should change a standard form functionality, which is sending the form to a server, to saving the form information into superglobals and execute the script again. Loading and saving files submitted by form is essential for avoiding using Javascript. A possibility of saving the script context to the next execution is a new opportunity how to keep an application state in PHP script. These abilities are the same for the remaining use cases except *PhpComponent*. We will describe the provider modes. These modes are intended to solve the rest use cases.

The first mode aims at the *Web* use case. It enables to set the provider as a root component. It handles all navigation events, determines the script name, finds it, and executes the script. PhpComponents can also be a navigation's target.

The second mode aims at the *OneScript* use case. It enables the provider insertion into a Razor page. Afterward, the provider executes the specified script.

The third mode aims at the *AllTogether* use case. It enables to navigate the set of scripts with respect to URL. The navigation is generally maintained by the default `Router`. The component only provides navigation to scripts.

These observations lead us to make sure having two different components are rational ways how to separate the problems and offer an understandable difference between the components.

3. Solution

This chapter describes the complete solution, solving the use cases. We start with an overview of the solution parts. Then, we give a detailed description of each part.

The solution consists of four projects, which will form the resulting Blazor website containing PHP scripts. In Figure 3.1, we can see these projects as green rectangles. The *Server* project references *Blazor App*, containg a part of the website, and *Peachpie.Blazor*, containing an additional support code. The server cares about serving the Blazor website and its Static Web Assets. The next project is our library containing an API for including PHP scripts to the website. There are `PhpComponent` and `PhpScriptProvider`, mentioned earlier, together with additional code support necessary for the correct functionality. There is the Blazor App project, which becomes the environment for running PHP scripts in a browser. The project references *PHP scripts* and *Peachpie.Blazor*, which content is used to maintain PHP scripts. We can see the user's defined scripts as .NET project compiled by Peachpie in *PHP scripts*. *Blazor App* injects the scripts using the components.

The first section aims at `PhpComponent`. It introduces the implementation problems connected to creating render demanding applications and solves them. The second section talks about `PhpScriptProvider`. It suggests a convenient way how to include the scripts into a browser, and it presents the component design. The last section aims at the server settings.

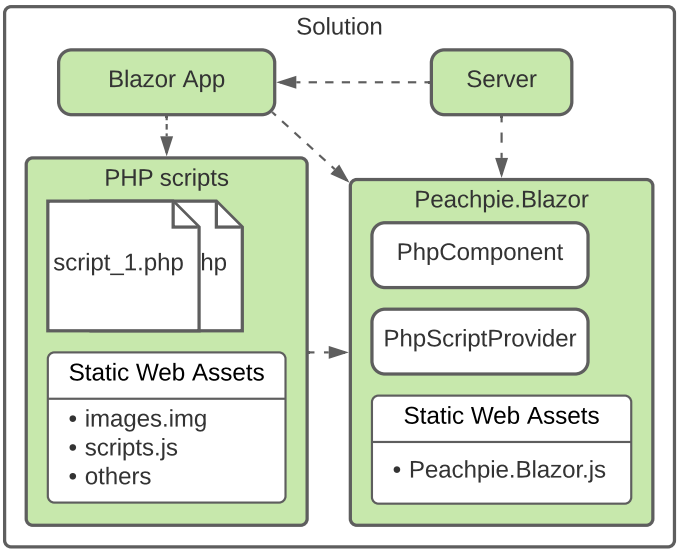

Figure 3.1: The solution infrastructure. Green rectangles represent projects. Arrows represent a references.

```
__builder.OpenElement(5, "button");
__builder.AddAttribute(7, "onclick",
        EventCallback.Factory.Create<MouseEventArgs>((object)this,
                (Action)IncrementCount));
__builder.AddContent(8, "Click me");
__builder.CloseElement();
```

Figure 3.2: Fragment of code adding a button element with an event handler.

3.1 PhpComponent

In the beginning, we introduce problems, which are related to the *PhpComponent* use case. Then, we suggest a solution and design `PhpComponent` class.

The first problem causes PHP, which does not know structs and method overloading. Structs are necessary to work with `RenderTreeBuilder`, which contains API for adding callbacks handling element events, as we can see in Figure 3.2. This API uses method overloading in many methods. `AddAttribute` is an example where we can write various types of the attribute value. One of the values can be `EventCallback` struct representing an event handler. The struct contains static property `Factory`, which is a class containing methods for creating callbacks.

Peachpie enables using structs in PHP code. However, there are limitations at the time of writing, which force us to make workarounds. We try to rewrite the previous example in PHP code using Peachpie. We create a component, which inherits textttComponentBase. Afterward, we override the method for building a render tree and implements the body. The fragment of the body can be seen in Figure 3.3, where we try using workarounds to make the example functional. There is the first issue in line 5, where Peachpie does not allow us to access a static property of struct. It results in a runtime error, which can be solved by `Helper` written as a C# class containing a method, which returns the property. The second issue causes method overloading when Peachpie can not choose the correct version of the `Create` method in line 8. Peachpie defines a type of PHP function, `IPhpCallable`, which can cause the issue However, if we wrap this function into the correct type by a helper function, the problem remains. The workaround can be another helper method, which will have a different name for each overload of this method. However, we come to a compilation error when we want to get an instance of `EventCallback`. As we can see in the figure, we tried to use many workarounds, but it is impossible to use some Blazor structures directly in PHP code.

To make the example functional, we can hide the struct from PHP code by implementing a C# helper method using the struct. The method should have only parameters compatible with PHP types. The overloading can be replaced by a different method name for each overload. Afterward, Peachpie allows us to call the methods from PHP code. We can use this approach in the `AddAtribute` method. Defining a new method for each overload is a reasonable approach due to a small number of overloads. Although defining global methods are not the best way, how to do it. It is a pity that the builder is sealed. Although, we can create a wrapper containing the builder and defining method for each overload,

```
use \Microsoft\AspNetCore\Components;
...
$builder->OpenElement(1, "button");

//$factory = Components\EventCallback::Factory;
$factory = \ClassLibrary2\Helper::GetFactory();

//$action = function() {\System\Console::WriteLine("Click");};
$action = \ClassLibrary2\Helper::GetAction(function() {
    \System\Console::WriteLine("Click");});

//$callback = $factory->
//  Create<Components\Web\MouseEventArgs>($this, $action);
$callback = \ClassLibrary2\Helper::
    GetCallback<Components\Web\MouseEventArgs>($factory,
        $this, $action);

$builder->AddAttribute(2, "onclick", $callback);
$builder->AddContent(3, "Click me");
$builder->CloseElement();
```

Figure 3.3: Problem of using structs and method overloading. Helper is a class defining workarounds.

which calls the original method in C# code. This decision leads us to make a new `RenderTreeBuilder` in a different namespace as a wrapper of the original builder.

The next issue relates to rendering time. `RenderTreeBuilder` provides a method for adding arbitrary markup text. The text can contain `<script>`, but its content is not executed. At first glance, one can see the method as a convenient way to render the whole content, avoiding using other dedicated methods for building the tree. These methods accept a sequence number used by the diff algorithm. Although using the one method for rendering, the whole component causes slow rendering, which is critical in some applications like games. The diff algorithm relies on marking the blocks of markup by sequence numbers for optimization in page updates. When we have only one big block, the diff algorithm can not do anything better than generate an update, which renders the whole page. This issue can be seen in the Benchmark section, where we compare the difference between using the one method and utilizing all methods. Because the builder usage can be complex, we introduce a library for representing tags, helping implement the code using the builder for rendering. We present library class diagram in Figure 3.4. The main idea is to implement the `iBlazorWritable` interface, which writes the class content into the builder. An example of a class is `Tag`, which represents an arbitrary tag. Because a tag can contain other tags using sequence numbers, we have to keep the currently used sequence number used in the diff algorithm. For this purpose, the `writeTreeBuilder` method gets the actual sequence number and returns the last unused number. This API should hide separated class logics for rendering. We offer the basic implementation of

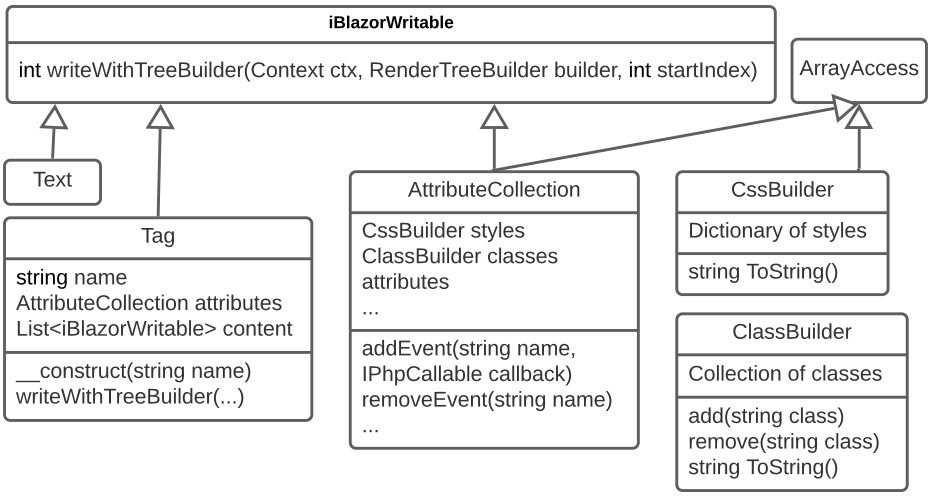

Figure 3.4: Class diagram of supporting library for writting tags.

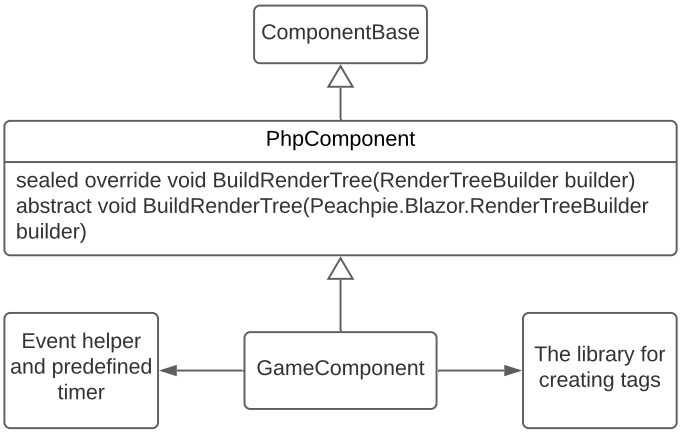

Figure 3.5: Class diagram of the use case solution.

this method, which renders the content with a dynamic sequence numbering. However, a programmer can override the method because sequence numbering is impossible to predefine in advance to make the most effective updates. Another abstraction is `AttributeCollerction`, which offers convenient interface for working with attributes by implementing PHP `ArrayAccess`.

The next barrier is assigning handlers to C# events in PHP code. Peachpie does not either support accessing the events. Thus, we can not directly use a class like `Timer`, which is useful in *PhpComponent* use case for updating the screen every period. The issue can be solved by helper methods defined in C# accepting the object, handler, and event name. Afterward, we can use reflection for obtaining the desired event by name from the object and then assign the `IPhpCallable` handler to it. Because `Timer` is a common object, we create an additional PHP wrapper class, which uses the timer. Then a programmer avoids to use the workaround defined above.

When we already presented the problems, we can introduce the architecture of

`PhpComponent` and solution of *PhpComponent* use case. The component hides the original function for rendering and replaces it with our version of the builder, as shown in Figure 3.5. It results in transparent usage of the builder in the inherited class. The builder is just a wrapper, so the programmer can use the original builder by accessing its property. Additional, there is a library for creating tags, which should make the builder usage easier. For assigning PHP handlers to C# events, there is a universal helper. Furthermore, the last feature is a timer wrapper, which uses the C# timer, offering a convenient API.

The last necessary thing is to get assembly references containing the components to `Router`, which is a standard duty in Blazor.

3.2 PhpScriptProvider

At the beginning of this section, we introduce the main component parts, which gives us an overview of the component composition. We divide component duties like navigation or script execution into subsections because the component consists of many processes, which are complex to describe at once in the structure. The component functionality should be explained in these sections.

We start with Figure 3.6 describing the connections between the main parts. `PhpScriptProvider` is a class, representing a Blazor component. The component manages the following features. It handles the navigation. It finds the script by name based on provider mode. It creates and keeps a PHP context, which is used for script execution. It executes the script. These duties contain several steps, which are maintained by the parts. As we can see, there is `PhpComponentRouteManager`, which finds the components, inheriting `PhpComponent`, based on `RouteAttribute`. It enables navigation of Blazor components defined in PHP scripts. The next part is `BlazorContext`, which is Peachpie `Context` designed for Blazor enviroment. The context initializes superglobals based on URL and submitted forms, manages files uploaded by a form, and controls `BlazorWriter` which redirects the script output to the render tree. In the end, `FileManager` reads submitted files, downloads them, or deleting them from Browser memory.

We zoom in on `PhpScriptProvider` structure in order to prepare a context for explaining the feature functionalities. The provider consists of many properties. Some of them are injected by the dispatcher like `NavigationManager` or `IJSRuntime`, which is a service providing interoperability with Javascript. Others can be parametrized, like `Type` determining the mode of provider, `ContextLifetime`

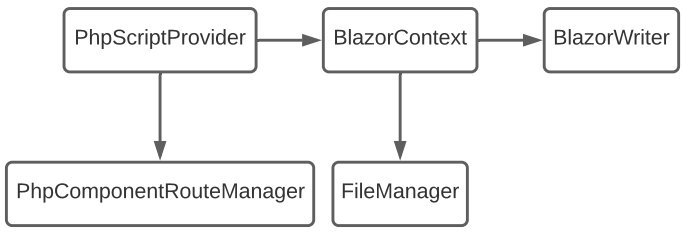

Figure 3.6: Diagram illustrating usage of PhpScriptProvider main parts.

determining the persistency of the script context, or `ScriptName` determining the executing script when the mode *Script* is set. These properties influence the component methods. The first method is `Attach`, which assigns a render handle providing `RenderTreeBuilder`, and registers a navigation handler creating the context and calling `Refresh`. The second method,`SetParameters`, cares about calling `Refresh`, and creating the context as well. `Refresh` finds a script or a component based on properties, assigns the superglobals, and calls `Render` which renders the component or executes the script. `OnAfterRender` cares about enabling the forms to send data back to Blazor. Some of these methods are called by Blazor framework providing the component lifecycle.

3.2.1 Navigation

Now, we explain navigation in `PhpScriptProvider` for each its mode. We have to clarify how the component is instantiated and maintained by Blazor. There are two ways how to use the component. The first of them is to set it in `WebAssemblyBuilder` as a root component, which is rendered after the first application launch in Blazor. The component is alive for the whole application life because there is no `Router`, which disposes components representing a previous page. It results in calling the `Attach` method and the `SetParameters` method only once. The second way is to use a Razor page containing the component and let the navigation to the page on `Router`, which is a root component by default. When the page is navigated, the component is instantiated as well. The difference is the possibility of calling the `SetParameters` method multiple times when the page is parameterized. Then, when the parameters are changed, Blazor automatically calls the inner component `SetParameters` methods when the components have no primitive types. This fact is because the Blazor framework can not decide if the parameters, which are complex types, were changed.

The *Router* mode is designed to be used when the component is a root component. Then we are sure, that `Attach` and `SetParameters` methods are called only once. Thus, we register navigation handler in the `Attach` method, which should handle further navigation. When the navigation occurs, we create a new context if the context should not be persistent and call `Refresh`. We create a new context and call `Refresh` method in `SetParameters` as well, which can be problematic with its multiple calling, but in this case, it is all right. Then the `Refresh` method parses the query part of URL, obtained from `NavigationManager` and gets the script name from the URL. When we determine the script name, we call the `Render` method, where we decide if it is a script or a component defined in a script based on `.php` extension. If the extension is missing, we try to find a component defined in scripts, which has correct `RouteAttribute` by `PhpComponentRouteManager`. Additional manager duty is to assign assembly references containing scripts, to the context, at the beginning of the application. Otherwise, we ask the Peachpie context for obtaining the script representation as `ScriptInfo`. The context does not have to know the script name, or the component does not have to exist. Then we render predefined *not found* page, which can be set by `PhpScriptProvider` parameters. Otherwise, we render the script or the component.

Next modes, *ScriptProvider* and *Script*, are similar. They are defined in a

Razor page and initialized when the page is navigated. The difference is finding the script by name, where the *Script* always uses the name defined in the component parameter and *ScriptProvider* finds script based on URL. As we said, the `SetParameters` can be called multiple times, so we call `Refresh` only by the first time in the method. Additional rendering is initiated by the navigation handler. Thus, when the navigation occurs, we find and update the page, or we are disposed if the `Router` match another Razor page. We should check if the component has not already been disposed by `Router` before calling the `Refresh`. Obtaining the script is similar to *Router* mode.

3.2.2 Script Execution

We start with `BlazorWriter`, which inherits `TextWriter`. The inheritance allows using the writer as `BlazorContext` output writer, which manipulates with script output. The writer consists of a buffer and `RenderTreeBuilder`. The main usage is to write any string to the writer, which adds it to the buffer. In the end, the writer flushes it into the builder by `AddMarkUpContent`. It results in treating the whole script output as one modification by diff algorithm, which causes the whole page update instead of smaller necessary updates. This disadvantage relates to the following limitations. `AddMarkUpContent` does not allow to add incomplete markup text, meaning that tags are not properly closed. Thus, we can not divide the text into smaller parts because of the HTML nature, where tags are coupled by other tags. The second possibility is to parse the output and recognize the types of HTML entities, which can use specialized builder API. However, it is not suitable because of parser complexity. It is important to dispose the writer after the rendering because the same builder can not be repeatedly used.

`BlazorContext` maintains the writer and interoperability with Javascript. It provides methods for initializing and ending the rendering. The script represented by `ScriptInfo` is executed by its method `Execute`. This method accepts the context, which maintains the script output by redirecting it to the render tree. It also allows setting superglobals like `$_GET` to provide the query part of URL and turns forms to client-side handling, which is described in the following section.

3.2.3 Forms

Forms are sent to the server by default. We use Javascript interoperability to evaluate them on the client side. It starts in `AfterRender` method, where we call our Javascript function, which finds all already rendered forms and assigns them an event handler for submitting. When submit occurs, the handler collects all data from the form, does ordinary navigation to the page defined in `action` attribute, and prevents default behavior, which is sending the form to the server. When the navigation is handled by `PhpScriptProvider`, it gets all collected data and assigns the context superglobals by them. Afterward, the script is executed, and it can access the superglobals.

In the previous paragraph, we hid the file management. When a user loads a file by form, Javascript obtains only the information about files. When we want to read the content, we have to use a reading operation, which is done asynchronously by `Promise` mentioned in the Javascript section. Thus, when

we get the data during navigation, we have to wait until the content is read. This operation could take a long time, so the page shows old content. For this reason, we provide an additional parameter for defining the content, which is shown during navigation. An alternative is initializing reading by a PHP script when it is executed. It uses interoperability between PHP, C#, and Javascript in order to call desired reading methods. Unfortunately, Blazor does not allow us to wait until the reading operation is done, and we have to provide callbacks, which handle the end of the reading. We suppose that it is confusing for potential PHP programmers, which will use our solution to define PHP callbacks. We decide to prefetch the file content before the execution to provide the data synchronously in PHP code.

3.3 Server

We have to set the server in order to provide additional static resources demanded by PHP scripts, as we can see in Figure 3.7. The code fragment is cut from the `StartUp` class of the server. It inserts middlewares providing the resources into the request pipeline. Afterward, these resources can be referenced by URLs and downloaded from the server. For example, we can reference an image with the path `Demo-PhpComponent/Asteroids/wwwroot/image.jpg` as `/Asteroids/image.jpg` in HTML document on the client side. The second middleware provides Javascript helpers of our library to Blazor App on client side.

```
var fileProvider = new ManifestEmbeddedFileProvider(
    typeof(PhpBlazor.BlazorContext).Assembly);
app.UseStaticFiles(new StaticFileOptions() {
    FileProvider = fileProvider });

app.UseStaticFiles(new StaticFileOptions
{
    FileProvider = new PhysicalFileProvider(Path.Combine(
    Full name of parent directory,
    "Demo-PhpComponent\\Asteroids\\wwwroot")),
    RequestPath = "/Asteroids"
});
```

Figure 3.7: Fragment of code adding middlewares.

4. Examples

4.1 Web

4.2 OneScript

4.3 PhpComponent

4.4 AllTogether

5. Benchmarks

Rendering speed(Asteroids first version vs. the current)

Problem with gd library

Conclusion

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List of Abbreviations

HTTP Hypertext Transfer Protocol

HTML HyperText Markup Language

CSS Cascading Style Sheets

WASM WebAssembly

W3C World Wide Web Consortium

URL Uniform Resource Locator

DOM Document Object Model

ES ECMAScript

A. Attachments

A.1 First Attachment