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BACHELOR THESIS

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Client-side execution of PHP applications compiled to .NET

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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 divide web applications into two types by roles of server and client. However, they use different technologies for their purpose. We will start with common parts. An internet protocol, HTTP, usually carries out the communication between a server and a client. A client uses a web browser for requesting a server. A markup language HTML is essential for describing a page's structure. A browser is responsible for interpreting and rendering the page's content. It is a web application's environment for further interaction. The need to adjust content by different styles initiates standardizing CSS language, which enriches pages with a wide graphical content.

The first type is server-based web applications. A server prepares the page, makes additional computations related to the request, and sends it back to the client. Having a business logic on a server-side is the main objective. The most popular language for server-side scripting becomes PHP.

Add a statistic for the popularity of PHP

The second type is client-based web applications, where major business logic is moved to a client's browser. However, the combination of CSS and HTML is sometimes sufficient. This type of application needs dedicated technologies, which allow manipulation with a page structure, reacts to on-page events, and controls the browser's behavior. Many languages were enabling the manipulation, but they were not usually supported by most browsers like Google Chrome, Safari, Opera, and Mozzila. The scripting language Javascript became a browser standard from these supports.

However, Javascript is a powerful language. There are language-specific features, which are harder replaceable by the language. Despite the urge, 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. There appeared a portable binary-code format for executing programs, WebAssembly (abbreviated WASM) [1] in 2015. WebAssembly aims to secure high-performance applications on web pages. Interop with Javascript makes the format as powerful as the language. The advantage of WebAssembly is a being compilation target for many programming languages. Since December 2019, when the W3 Consortium 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]. It enables running PHP script inside our browser using predefined Javascript API or standard tag for HTML script. Another project is an open-source framework Blazor [3] developed by Microsoft. It provides a runtime, libraries, and interop 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] tries to make use of the .NET platform and offers PHP compilation to .NET. It is a modern compiler enabling interop between PHP and C#.

The project opens the PHP door to Blazor. An integration between Peachie and Blazor can yield to following benefits. A community of PHP developers

is significant. Thus, many PHP libraries apply to working with client's data, cooperation with databases, and other server tasks. 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.

This thesis uses the compilation of PHP scripts to .NET in order to execute PHP in a browser powered by Blazor. The approach tries to achieve two goals. The first goal is to enable web development on a client-side with PHP. There are not libraries supporting this integration. The second goal is to design the support to offer a convenient way to combine a PHP code with a Blazor.

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 the beginning, we will observe conventions in web applications, and we will map ways of user interaction with the applications to utilize it later in the proposed solution. We will explore a server-side web application using PHP language and a client-side web application using Javascript language in other to obtain these observations. Afterward, it will present a WebAssembly, which will be followed by the existing project relating to run PHP in a browser. It will give short information about the .NET platform and C# language. In the end, it will introduce Blazor and Peachpie, which will be integrated.

1.1 PHP and server-based web application

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. An HTTP protocol uses a dedicated format of messages for communication. The protocol does not require any authentication at all. Statelessness is a typical characteristic of the protocol. 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 all 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 an URL address or in the HTTP message body. HTML presents a tag Form that makes sending the data easier for a client. Listing 1.1 contains an example of a Form tag. The form can contain other tags, which are displayed as various types of fields. A client fills these fields, and the browser sends the data as a new HTTP 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 a example of an URL `http://www.example.com/index.php?par1=hello&par2=2&arr=hello&arr=2`. A query part begins with a question mark. Parameters of the query part are described in the table 1.1. Another method is called post, which encodes it in the request body,

Key	Value
par1	$hello$
par2	2
arr	$[hello, 2]$

Table 1.1: Parameters of the query part.

which does not appear in the URL.

PHP [5] was designed for user page templating on the 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 listing 1.1 as an example.

Listing 1.1: A PHP code.

```php
1  <?php
2     inlude("header.php");
3  ?>
4
5  <h1>Superglobal POST</h1>
6  <?php
7     foreach($_POST as $key => $value) { ?>
8     <p><?php echo $key; ?> => <?php echo $value; ?></p>
9  <?php } ?>
10
11 <h1>File content:</h1>
12 <p>
13 <?php
14    if($_FILES["file"])
15    {
16       echo file_get_contents($_FILES["file"]["tmp_name"]);
17    }
18 ?>
19 </p>
20
21 <form action="/index.php" method="post">
22  <label for="name">Name:</label>
23  <input type="text" id="name" name="name"><br>
24  <label for="file">File:</label>
25  <input type="file" id="file" name="file"><br>
26  <input type="submit" value="Submit">
27 </form>
28
29 <?php
30    inlude("footer.php");
31 ?>
```

An HTML interleaving has appeared to be a helpful method for data binding. The feature allows inserting a PHP code between HTML. These fragments do not have to form individual independent blocks of code closed in curly brackets. The interleaving is related to code execution when an interpreter executes a script from top to bottom. Everything outside a PHP section 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 uploaded files.

Maybe add information about SESSION.

We can divide code in several ways. Global functions are the most notable characteristic of PHP despite wide-spread object-oriented programming. They

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are defined in the global scope and accessible from anywhere. The next option is an object inspired by object-oriented programming. There is also namespace support. We can include a PHP code from other scripts. The execution continues after the inclusion, which is a common execution of the defined script.

The nature of the request-response semantic usually results in a one-way pass of the application. After dealing with a request, the whole application state is terminated. 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 listing 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.

Uploaded files sent by the client reside in two places. The file's information is stored in $_FILES. 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.

1.2   Javascript and client-based web application

Since a client-based web application aims to do a major business logic in a browser, it needs to control the rendered page and access a web interface providing additional services. The interface is usually available from Javascript. 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.

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

We can image a web page as an XML 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 (abbreviated 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. Afterward, there is a document node representing the whole document together with its root node.

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 event onclick which triggers when a client clicks on the button as we ca see in listing 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 is a Javascript standard recommending across browsers. It is abravieted as ES. We can see later an abbreviation ES2015 which relates to the ECMAscript version. Javascript is a high-level language usually executed by a browser's dedicated Javascript engine but can also be run on a desktop. Node.js is an example of a Javascript runtime running outside a browser. Listing 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.

Listing 1.2: A Javascript code.

```
1   <!DOCTYPE html>
2   <html>
3     <head>
4     </head>
5     <body>
6       <button id="alert">Click to alert </button>
7       <script>
8         var handler = function (arg) {
9           var timer = new Promise((resolve) => {
10             setTimeout(resolve, 1000);
11           });
12
13           timer.then(() => window.alert("Hello world."));
14         };
15
16         var button = window.document.getElementById("alert");
17         button.addEventListener("click", handler);
18       </script>
19     </body>
20   </html>
```

At first glance, we can see the type system is dynamic as well as PHP. A 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 the listing.

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

Javascript is single-threaded, which can be confusing with its constructs for promises. The promise is a structure representing an unfinished process. These processes can be chained. However, the structure can give an illusion of multi-threading. It uses the scheduler for planning the next task executed by the main thread. The single thread is critical for blocking operations which causes thread freezing.

Web workers [11] are a browser feature enabling to run the script in the background. There are wrapped as Worker objects. The worker limitation is communication with UI thread only by handling message events. Messages have to be serialized and deserialized.

Javascript module is the last thing, which we will need to present. It gathers a collection of code. Global entities of this code can be exported to another script. These exports make an API of the module. The module's advantage is defining the API and hiding the internal code, which is not relevant for the user.

1.3   WebAssembly

WebAssembly [9] is a new code format that can be run in today's browsers. It has a compact byte format, and its performance is near to a native code. WebAssembly 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++. The advantage of this format is a similarity with Javascript modules ES2015 after compilation into a machine code. This enables browsers to execute it by a JavaScript runtime. So its security is as good as a code written in Javascript. Because of the same runtime, WebAssembly can call Javascript and vice versa.

Threads [10] support is currently discussed nowadays and appears to be promising. After all, new versions of Google Chrome experiments with proper multi-threading support despite the chance of vulnerability. A replacement of multi-threading can be Web workers mentioned in Javascript section.

Despite supporting to run WebAssembly 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   Project 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 php-wasm. A PHP code is evaluated by writing a specialized script block or manually by JavaScript and API. PHP can afterward interact with JavaScript using a specialized API. At first glance, that might be a good enough solution, but they are several parts that can be problematic due to PHP semantics. The solution doesn't solve superglobals. This is reasonable because this is the server's job, but you are not able to get information about a query part or handling forms without writing a JavaScript code. The next problem is navigating how a script can navigate to another script without an additional support code which has to be JavaScript.

1.5   CSharp and Mono

We have to introduce .NET [17] in other to understand the following sections fully. .NET is a free and open-source project primarily developed by Microsoft. It is a cross-platform successor to .NET Framework. It consists of core libraries and runtime, which runs a unique code format CIL standing for Common Intermediate language on various environments. The runtime is often named CLR (Common Language Runtime) and represents a virtual machine interpreting the code into

the machine code. The libraries can represent whole frameworks like ASP.NET, which aims to web development. The CIL is a compilation target of languages like CSharp, Visual Basic, or FSharp. The most common granularity of .NET projects is an assembly formed from a bunch of code representing a library or an executable program.

1.5.1 Mono

Mono is a .NET runtime that aims to mobile platforms. 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 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 .NET.

1.5.2 Language specification

CSharp 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 CSharp is a good language for a huge project which needs discipline from developers to hold the code understandable and manageable. CSharp is used on the server-side as well as PHP.

1.6 Blazor

Blazor is a framework that provides a convenient way how to write dynamic web pages using CSharp. Blazor platform is divided into two hosting models 13 which have different approaches to creating web applications. The first one is referred to as Blazor Server App and has a similar methodology to a standard website written in PHP. An interesting innovation is SignalR which is a communication protocol between the server and a client. However, this thesis uses the second model, which Microsoft refers to as Blazor WebAssembly App enabling offline support after loading the app into a browser.

1.6.1 Blazor WebAssembly App

From now on, I will use Blazor App to refer Blazor WebAssembly App. Blazor App can be divided into two parts. The first part serves the main WebAssembly application and its additional resources, which can be requested during runtime. The second part is WebAssembly wrapped together with an additional user code. The division enables to choose of a place for the implementation of business logic. If there is a bad connection, we can move the majority of business logic to the client and use the server for connection to a database; otherwise, we can use the client only for rendering the page. It consists of the following components. Kestrel with ASP.NET libraries provides the server part of an application. Mono runtime compiled to WebAssembly runs CSharp code inside a browser. WebAssembly is essential for being able to interact with DOM and JavaScript using CSharp

without an additional plugin, which was necessary for older technologies like Microsoft Silverlight. Blazor's libraries provide constructs for manipulation with DOM and WebAPI together with rendering the page and JavaScript interop. And there is a user's code that using the libraries for creating dynamic pages with CSharp. A better imagination, how the app is situated on the client-side, can be represented by the figure 1.1 copied from the article 15.
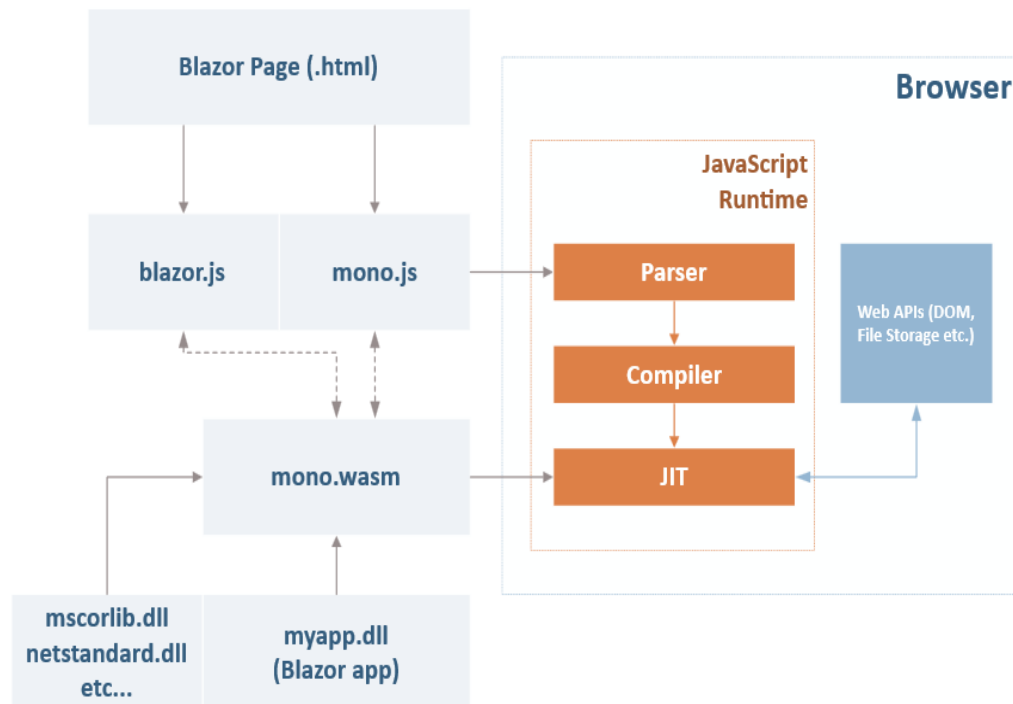

Figure 1.1: Running a Blazor WebAssembly App on client-side.

The interop with a browser are one part of the Blazor App. The main part is the architecture of the libraries. A common approach how to create a page is using the markup language Razor. There already exists Razor in standard ASP.NET website where .cshtml extensions consist of this markup. Unfortunately, the markup used in BlazorApp has the same name. From now on, I will use Razor for the markup language, which is the content of .razor files in Blazor App. Because interleaving HTML with other languages turns out to be helpful, the Razor uses special characters to identify CSharp code in HTML and convert it to rich content pages. A significant purpose of Razor is for generating CSharp structures, which represent parts of a page, during compilation time. These structures have a complex interface for rendering a page, so the markup is there in order to free users using a complicated mechanism for putting a page together. We can see an example of web page in listing 1.3.

Listing 1.3: Example of Razor page.

```
1  @page "/example"
2  @inject HttpClient Http
3
4  <h1>Example</h1>
```

```
 5   @if (!loaded)
 6   {
 7     <p>Loading...</p>
 8   }
 9   else
10   {
11     <p>Ticks: @ticks</p>
12   }
13
14   @code {
15     private bool loaded = false;
16     private int ticks = 0;
17
18     protected override async Task OnInitializedAsync() {
19       ticks = await Http.GetFromJsonAsync<int>("ticks.json");
20       loaded = true;
21     }
22   }
```

Razor provides a special sign at which follows with dedicated keywords. We can see a page keyword determining the path of the page. An inject keyword represents a service injection. An if keyword determines a standard condition, and a code keyword contains a regular CSharp code. These features are afterward transformed into CSharp entities forming a special class.

Blazor introduces a Component class that can represent a whole page or the part of it. Components can be arbitrarily put together in order to form the desired page. We can see the generated Component from listing 1.3 in listing 1.4.

Listing 1.4: Razor page generated to the CSharp class.

```
 1   [Route("/example")]
 2   public class Index : ComponentBase {
 3     private bool loaded = false;
 4     private int ticks = 0;
 5
 6     [Inject] private HttpClient Http { get; set; }
 7
 8     protected override void BuildRenderTree(RenderTreeBuilder
          __builder) {
 9       __builder.AddMarkupContent(0, "<h1>Example</h1>");
10       if (!loaded)
11       {
12         __builder.AddMarkupContent(1, "<p>Loading...</p>");
13         return;
14       }
15       __builder.OpenElement(2, "p");
16       __builder.AddContent(3, "Ticks: ");
17       __builder.AddContent(4, ticks);
18       __builder.CloseElement();
19     }
20
21     protected override async Task OnInitializedAsync() {
```

```
22        ticks = await Http.GetFromJsonAsync<int>("ticks.json");
23        loaded = true;
24      }
25  }
```

We can assign the Razor keywords to parts of the code in the listing. Page keyword stands for Route attribute. Inject keyword stands for parameter attribute. The parameter is assigned by a dispatcher, mentioned later, during the initialization. Code keyword is a part of class content. Another markup is transformed into calling a specialized method in the BuildRenderTree function, which renders the page. There will be more information about rendering later in this section.

The components can have different purposes. For example, a Router takes care of routing the right page whenever the navigation is triggered. Alongside components, a dispatcher supplies additional services like logger to components when they are creating. The dispather is a specialized class initialized in the begining of the application.

The last item, which is not used transparently, is a WebAssemblyHost builder. The builder configures the application and prepares the renderer used by components to render their content.

Balzor presents its own virtual DOM to reduce changing a DOM directly in a browser to its demanding performance. A component works with RenderTree-Builder, which provides an interface for adding content to the virtual DOM. The usage of RenderTreeBuilder is complex due to Blazor's diff algorithm, which is used afterward. RenderTreeBuilder is just a superstructure over Renderer, which is responsible for updating the page. The diff algorithm is used to minimize the browser's 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 respond to an order of RenderTree-Builder's instructions in the source code. A benefit of this information is detecting loops and conditional statements to generating smaller updates of DOM. It follows the browser's DOM update, which is executed by Blazor's JavaScript support code called through Mono runtime.

The process of bootstrapping the Blazor App to a browser follows these steps. Kestrel gets a request for a page that is contained in Blazor App. The server responses with the index.html page, which contains references to JavaScript support code (This code is referred to as blazor.js and mono.js in the figure 1.1) responsible for loading and running the runtime with the application part. The runtime runs the application using the Main method in Blazor App. The remaining interactions are maintained by event handling. I distinguish two types of events. The first type is navigation. The navigation [14] can be triggered by an anchor, form, or filling up the URL bar. The URL bar is handled separated by a browser. JavaScript can influence the remainings elements. Blazor App handles only an anchor by. After clicking on an anchor, predefined methods in blazor.js try to invoke navigation handler in Blazor App using a Mono WebAssembly gateway. A user can modify this handler, but a specialized component Router implements a default behavior. The Router finds out all components, which implements an IComponent interface, by a reflection and tries to render the page according to path matching RouteAttribute of a component. The navigation can be redi-

rected to the server if there is no match. The second type is events invoked by UI like onchange. These event's callbacks call right CSharp callbacks thanks to RenderTreeBuilder, connecting CSharp callback with element's event.

> Add cutting unneccessarly references to make the app smaller.

1.7 Peachpie

Peachpie [16] is a modern compiler based on Roslyn and Phalanger project. It allows compiling PHP into a .NET assembly, which can be executed alongside standard .NET libraries. Peachpie introduces several structures representing states, scripts, and variables of PHP written in Csharp. The first of them is a context representing one request to PHP code. The context consists of superglobals, global variables, declared functions, declared and included scripts. The possibility of saving the context and using it later is a significant advantage used in the solution. The 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 compiler offers a dedicated type of assembly for PHP libraries. Using this assembly can add additional functions, which can provide an extra nonstandard functionality as an interaction with a browser. Another advantage of the compiler is the great interoperability between PHP and .NET. An option to work with Csharp objects, attributes and calling methods will become crucial for achieving advanced interaction between Blazor and PHP.

> Saving script information in the assembly

> Inheriting the CSharp classes

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 CSharp code which gives equivalent results. The time and memory complexity of this code can be tricky in Blazor. The previously mentioned interoperability has limits as well. Csharp constructs like structs and asynchronous methods are undefined in PHP.

2. Problem analysis

This chapter describes the main problems together with using technologies to help to solve them. In the end, we will introduce the proposed solution to the problem.

Current problems of migrating PHP to a browser divides into different types of tasks that have to be done. In the beginning, we have to load scripts alongside the Blazor app into a browser. Afterward, navigation to the scripts is essential for making the PHP website client-side. The ability to find the desired script should be adopted to Blazor's environment in order to combine PHP scripts with Razor pages. Mocking the server role on the client-side will be another important feature to make this migration familiar with standard PHP usage. It consists of managing superglobals like GET or POST, file management. Because we can save the application state, we bring a new feature of choosing the preservation of the script's context to the next evaluation. The interaction with a user is a challenge for PHP due to its server role. And the last problem will be with evaluating the PHP code. Rendering the whole page is a demanding computation. It can be critical for sections, which tend to change their content often.

2.0.1 Proposed solution

The main idea of migrating PHP to a browser is to integrate Peachpie with Blazor. In the beginning, we have to think of how we can put the scripts into a browser. Peachpie can solve it. It compiles our scripts into .NET assembly, which consists of all information about the scripts. We can reference it from a Blazor app as a standard CSharp code when we have the assembly. We have to ensure that compiler will think the application uses the assembly due to cutting unnecessarily assemblies mentioned in the Blazor section. The process results in loading the assembly alongside the Blazor application into a browser. However, this could be considered as the major part of the problem. How to reference and evaluate the scripts is not clear, and there will be many decisions that will not be silver bullets.

We can use a Blazor component class in order to represent a particular script in the Blazor application. This component should be able to find and evaluate a specified script from the assembly. This approach can benefit from the component's reusability. Afterward, we will be able to compose the component with others to make the desired layout. Before that, we have to make finding and evaluation the script clear.

From this time, we have to distinguish between the purposes of the PHP code. We will create two components for each of them. We make the reason clear later in the section and describe detail in the following chapter.

The first purpose is to free the script from Blazor. It is done by finding the script by the name obtained from a component's parameter or the URL. The script's evaluation is done via caching its output and adding it as markup text to the RenderTreeBuilder. It is is a good approach for transparent use of Blazor, but it is ineffective for often rendering.

User interaction -¿ forms

The second purpose is to offer the complete interface of Blazor. An inheritance can achieve this. The PHP class can inherit the CSharp component class due to Peachpie. The consequence of this is accessible Blazor functions for rendering the content.

However, these purposes are different. They can be combined due to a Component interface.

Conclusion

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List of Abbreviations

A. Attachments

A.1   First Attachment