

Kipper - Programming Language for Improved Runtime Type-Safety

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Abstract

Brief summary of our amazing work. In English. This is the only time we have to include a picture within the text. The picture should somehow represent your thesis. This is untypical for scientific work but required by the powers that are. Suspendisse vel felis. Ut lorem lorem, interdum eu, tincidunt sit amet, laoreet vitae, arcu. Aenean faucibus pede eu ante. Praesent enim elit, rutrum at, molestie non, nonummy vel, nisl. Ut lectus eros, malesuada sit amet, fermentum eu, sodales cursus, magna. Donec eu purus. Quisque vehicula, urna sed ultricies auctor, pede lorem egestas dui, et convallis elit erat sed nulla. Donec luctus. Curabitur et nunc. Aliquam dolor odio, commodo pretium, ultricies non, pharetra in, velit. Integer arcu est, nonummy in, fermentum faucibus, egestas vel, odio.



Contents

1	Introduction	1
2	Background	2
2.1	Dissecting the current issues	2
2.2	How could it have been better	6
2.3	Tackling the issue at its core	7
3	Technology	8
4	Implementation	9
5	Compiler Reference	11
6	Demo & Showcase	12
7	Conclusion & Future	13
	Bibliography	IV
	List of Figures	V
	List of Tables	VI
	Source Code References	VII
	Appendix	VIII

1 Introduction

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2 Background

2.1 Dissecting the current issues

2.1.1 The JavaScript problem

Currently, the web space is dominated by JavaScript, a language developed solely for the purpose of creating interactive websites which has become the standard for any modern browser. Originally, when Netscape started development in 1995, it wasn't even intended to get as big as it did, so it comes as no surprise that the programming language, which would become the future of the web, wasn't exactly properly future-proofed or secured for complex operations and architectures.

In the modern age of web development, JavaScript is no longer exclusively a front-end language. Wherever you go you will find JavaScript used in an application. Its usage has grown so much that there is now an incredibly large pool of available frameworks, technologies, and applications that you can use with the language. This though comes with a major problem, since the language powering so many systems today is a fairly harsh environment to work in, as it is filled with many problems ranging from minor inconveniences to major design issues that are impossible to ignore. The most egregious example of this is the type system of JavaScript. It provides neither type checks nor warnings, doesn't allow for objects to be matched against types and requires the user to always know what the value of a variable will be at runtime, making it a constant game of remembering and guessing.

Naturally, as a result, this has caused a lot of solutions to pop up, which all aim to resolve this issue. One of the most well-known and accepted solutions in this regard is TypeScript.

2.1.2 TypeScript - One of many solutions

TypeScript is as of now the most widely used alternative to JavaScript, or more accurately a super-set of it, allowing standard object-oriented functionality and compile-time type-checking similar to that present in Java or C#. In its core principle, TypeScript provides

everything that a developer needs for developing type-safe applications, as you can simply use the type annotations and let the TypeScript compiler check for your errors while working on your project. This though has certain limitations, as TypeScript is bound to the restrictions of a simple linter that aims to be fully compatible with JavaScript, no matter the circumstances. While that allows the developer to import any code from an old code base directly, it also heavily impacts and limits the functionality, which the TypeScript compiler can implement. As a result, the compiler is bound to the constraints of a language that is not even designed for type checking and type annotations. More specifically this means that all type checks are compile-time only and are not checked against at runtime, which means TypeScript works on a trust-based system, where the developer is often used as the root of trust.

Unchecked compile-time casts

As already mentioned TypeScript works on a compile-time-only basis, which does not allow for any runtime type checks. That also naturally means any standard functionality like casts can also not be checked for, since such type functionality requires the language to be able to reflect on its type structure during runtime. Given the fact though that casts, which allow the developer to narrow the type of a value down, are a necessity in everyday programs, TypeScript is forced to provide what you can call "trust-based casts". The developer can, like in any other language, specify what a specific value is expected to be, but unlike usual casts are primarily unchecked, meaning you can, if you want, cast anything to anything with no determined constraint.

While in principle this maintains the status quo and provides the developer with more freedom, it also opens up another challenge that must be looked out for when writing code. If one of those casts goes wrong and isn't actually valid, the developer will only know that at runtime and will have no assistance to fix it. To overcome this developers can themselves implement runtime type checks, which prevent type mismatches in ambiguous contexts. While it is a common approach, it is fairly impractical and adds a heavy burden on the developer as it requires constant maintenance and recurring rewrites to ensure the type checks are up-to-date and valid.

Let's look at an example:

```
1 class SuperClass {  
2   name: string = "Super class";  
3 }  
4  
5 class MiddleClass extends SuperClass {
```

```
6   superField: SuperClass = new SuperClass();
7
8   constructor() {
9       super();
10  }
11 }
12
13 class LowerClass extends MiddleClass {
14     classField: MiddleClass = new MiddleClass();
15
16     constructor() {
17         super();
18     }
19 }
20
21 const c1 = <MiddleClass>new SuperClass(); // Unchecked
      cast
22 console.log(c1.superField.name); // Runtime Error!
      Doesn't actually exist
23
24 const c2 = <LowerClass>new MiddleClass(); // Unchecked
      cast
25 console.log(c2.classField.superField.name); // Runtime
      Error! Doesn't actually exist
```

Here we have a simple example of an inheritance structure, where we access the properties of a child that is itself also another object. Due to the nature of TypeScript operations such as casts are mostly unchecked and usually work on the base of trusting the developer to know what they're doing. That means that in the example given above, the compiler does not realise that the operation the developer is performing is actually invalid and will result in a failure at runtime (can't access property "name", `c1.superField` is undefined). Furthermore, given that JavaScript only reports on such errors when a property on an undefined value is accessed, the undefined variable may go unused for a while before it is actually the cause of any problem. This leads to volatile code that can in many cases not be guaranteed to work unless the developer actively pays attention to such errors and makes sure that their code does not unintentionally force unchecked casts or other similar untyped operations.

Ambiguous dynamic data

Another similar issue occurs when dealing with dynamic or untyped data, which does not report on its structure and as such is handled as if it were a JavaScript value, where all type checks and security measures are disabled. This for one makes sense given the goal of ensuring compatibility with the underlying language, but it also creates another

major problem where errors regarding any-typed values can completely go undetected. Consequently, if we were to receive data from a client or server we can not ensure that the data we received is fully valid or corresponds to the expected pattern. This is a problem which neither has a proper workaround nor a solution in TypeScript.

For example:

```
1 interface Data {
2   x: number;
3   y: string;
4   z: {
5     z1: boolean;
6   }
7 }
8
9 function receiveUserReq(): { [key: string]: any } {
10  // ...
11  return {
12    x: "1",
13    y: "2",
14    z: true
15  }
16 }
17
18 var data = <Data>receiveUserReq(); // Unsafe casting
19   with unknown data
20 console.log(data.z.z1); // No Runtime Error! But returns
21   "undefined"
```

For the most part, developers are expected to simply watch out for such cases and implement their own security measures. There are potential libraries which can be utilised to add runtime checks which check the data received, but such solutions require an entirely new layer of abstraction which must be managed manually by a developer. This additional boilerplate code also increases the complexity of a program and has to be actively maintained to keep working.

Good examples of technologies that provide runtime object schema matching are "Zod" (<https://github.com/colinhacks/zod>) and "joi" (<https://github.com/hapijs/joi>). Both are fairly popular and actively used by API developers who need to develop secure endpoints and ensure accurate request data. While they are a good approach to fixing the problem after the fact, they still create their own difficulties. We will examine these later in the implementation section, where we will more thoroughly compare Kipper's approach to other tools.

2.2 How could it have been better

2.2.1 Case study: Java

Java is a statically typed OOP programming language, which is next to C# one of the primary languages used throughout the world of programming. It runs on a VM-based architecture designed to allow the developer to deploy cross-platform applications and work with powerful dynamic object structures. Like other high-level languages, it provides reflection, a concept essential for the purpose of runtime type checking and validations. Unlike JavaScript or TypeScript, operations in the code are always checked during compile time and runtime if necessary, and can never be simply ignored by the developer. As such when you work with the language and deploy an application you can be sure that the casts and type operations are safe, or at least will have an error thrown in the case of failure. This is a heavy contrast to the entirely dynamic and type-less structure present in JavaScript, which doesn't provide such safeguards and relies on the developer for security.

2.2.2 Case study: Rust

Rust is a systems programming language designed to offer memory safety without a garbage collector. One of the standout features of Rust is its ownership system, which enforces strict rules for memory allocation and deallocation, preventing common bugs like null pointer dereferencing or data races in concurrent programming. This guarantees memory safety at compile-time without needing a runtime environment to manage memory, unlike languages such as Java and JavaScript, which use garbage collection to manage memory dynamically.

Rust's type system is strongly and statically typed, like Java, but it emphasizes immutability and borrowing concepts to manage data lifetimes and concurrency safely. Unlike Java, Rust does not have reflection, but it provides powerful meta-programming features via macros. Rust also promotes zero-cost abstractions, ensuring that high-level abstractions have no runtime overhead, making it a popular choice for applications requiring both performance and safety. Despite working on the basis of a completely different programming paradigm it still manages to be type-safe or more accurately memory-safe. The compiler makes sure that there are no ambiguities left that could potentially lead to runtime errors and provides absolute safety in a way that still allows certain freedom to the developer.

2.2.3 Drawing comparisons to JavaScript

2.3 Tackling the issue at its core

3 Technology

4 Implementation

Siehe tolle Daten in Tab. 1.

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	Regular Customers	Random Customers
Age	20-40	>60
Education	university	high school

Table 1: Ein paar tabellarische Daten

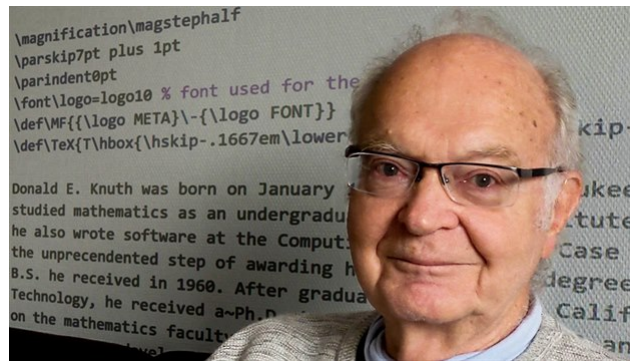


Figure 1: Don Knuth – CS Allfather

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Listing 1: Some code

```

1  # Program to find the sum of all numbers stored in a
    list (the not-Pythonic-way)
2
3  # List of numbers
4  numbers = [6, 5, 3, 8, 4, 2, 5, 4, 11]
5
6  # variable to store the sum
7  sum = 0
8
9  # iterate over the list
10 for val in numbers:
11     sum = sum+val
12
13 print("The sum is", sum)

```

5 Compiler Reference

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6 Demo & Showcase

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7 Conclusion & Future

Bibliography

List of Figures

1	Don Knuth – CS Allfather	10
---	------------------------------------	----

List of Tables

1	Ein paar tabellarische Daten	9
---	--	---

Source Code References

1	Some code	10
---	---------------------	----

Appendix