



## Assignment of master's thesis

**Title:** Math expression evaluator for literal types in TypeScript  
**Student:** Bc. Tat Dat Duong  
**Supervisor:** Ing. Jaroslav Šmolík  
**Study program:** Informatics  
**Branch / specialization:** Web Engineering  
**Department:** Department of Software Engineering  
**Validity:** until the end of summer semester 2023/2024

### Instructions

Template literal types [1], introduced in TypeScript 4.1, expand on string literal types for narrowing down a type to a particular string constant, with the ability to expand into many string literal types.

1. Analyze and describe relevant constructs of the TypeScript type system (concatenation, recursive types, conditional types etc.)
2. Implement a typesafe math expression evaluator with a set of basic operations, using a string literal type both as the input and output of the evaluator.
3. Pick appropriate tools for testing type annotations and ensure the validity of the evaluator with functional tests.
4. Discuss the practical uses of implemented meta types and theoretical and practical shortcomings of the TypeScript type system.
5. Publish the implementation as an open-source TypeScript library, which can be used for meta-programming, including source code and corresponding documentation.

[1] <https://www.typescriptlang.org/docs/handbook/2/template-literal-types.html>



Master's thesis

# MATH EXPRESSION EVALUATOR FOR LITERAL TYPES IN TYPESCRIPT

**Bc. Tat Dat Duong**

Faculty of Information Technology  
Department of Software Engineering  
Supervisor: Ing. Jaroslav Šmolík  
March 25, 2023

Czech Technical University in Prague

Faculty of Information Technology

© 2023 Bc. Tat Dat Duong. All rights reserved.

*This thesis is school work as defined by Copyright Act of the Czech Republic. It has been submitted at Czech Technical University in Prague, Faculty of Information Technology. The thesis is protected by the Copyright Act and its usage without author's permission is prohibited (with exceptions defined by the Copyright Act).*

Citation of this thesis: Duong Tat Dat. *Math expression evaluator for literal types in TypeScript*. Master's thesis. Czech Technical University in Prague, Faculty of Information Technology, 2023.

## Contents

Acknowledgments	vi
Declaration	vii
Abstract	viii
Summary	ix
Seznam zkratek	x
<b>1 Introduction</b>	<b>1</b>
1.1 Motivation . . . . .	1
1.2 What is static type system . . . . .	1
1.3 Strucute of the work . . . . .	2
<b>2 Analysis</b>	<b>3</b>
2.1 Static Typing in JavaScript . . . . .	3
2.1.1 Elm . . . . .	3
2.1.2 ReScript . . . . .	4
2.1.3 Flow . . . . .	4
2.1.4 TypeScript . . . . .	4
2.2 Typescript syntax . . . . .	5
2.2.1 Types and their assignability . . . . .	7
2.2.2 Conditional Types . . . . .	9
2.2.3 Conditional Types . . . . .	9
2.2.4 Recursive Types . . . . .	9
2.2.5 Mapped Types . . . . .	9
2.2.6 Template Literal Types . . . . .	9
2.3 Prior Art . . . . .	9
<b>3 Implementation</b>	<b>11</b>
3.1 Structure of the project . . . . .	11
3.2 Type representation of numbers . . . . .	11
3.3 Addition and Subtraction . . . . .	11
3.4 Multiplication . . . . .	11
3.5 Division . . . . .	11

3.6	Exponentiation . . . . .	11
3.7	Other mathematical operations . . . . .	11
3.8	Statement parser & evaluator . . . . .	11
3.9	Higher kinded types . . . . .	11
3.10	Optimization and bypasses . . . . .	11
<b>4</b>	<b>Testing</b>	<b>13</b>
<b>5</b>	<b>Conclusion</b>	<b>15</b>
5.1	Advantages and disadvantages of TS . . . . .	15
5.2	Future work . . . . .	15
<b>A</b>	<b>Nějaká příloha</b>	<b>17</b>
	<b>Obsah přiloženého média</b>	<b>21</b>

## List of Figures

2.1	Types represented as sets . . . . .	8
2.2	Union of types . . . . .	9

## List of Tables

## List of Listings

2.1	Primitive Types . . . . .	5
2.2	Literal Types . . . . .	5
2.3	Data structures . . . . .	6
2.4	Duck typing . . . . .	6
2.5	Nominal typing in TS . . . . .	6

*Chtěl bych poděkovat především sit amet, consectetur adipiscing elit. Curabitur sagittis hendrerit ante. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Cras pede libero, dapibus nec, pretium sit amet, tempor quis. Sed vel lectus. Donec odio tempus molestie, porttitor ut, iaculis quis, sem. Suspendisse sagittis ultrices augue.*



## Declaration

FILL IN ACCORDING TO THE INSTRUCTIONS. VYPLŇTE V SOULADU S POKYNY.  
Lorem ipsum dolor sit amet, consectetur adipiscing elit. Curabitur sagittis hendrerit ante. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Cras pede libero, dapibus nec, pretium sit amet, tempor quis. Sed vel lectus. Donec odio tempus molestie, porttitor ut, iaculis quis, sem. Suspendisse sagittis ultrices augue. Donec ipsum massa, ullamcorper in, auctor et, scelerisque sed, est. In sem justo, commodo ut, suscipit at, pharetra vitae, orci. Pellentesque pretium lectus id turpis.

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Curabitur sagittis hendrerit ante. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Cras pede libero, dapibus nec, pretium sit amet, tempor quis. Sed vel lectus. Donec odio tempus molestie, porttitor ut, iaculis quis, sem. Suspendisse sagittis ultrices augue. Donec ipsum massa, ullamcorper in, auctor et, scelerisque sed, est. In sem justo, commodo ut, suscipit at, pharetra vitae, orci. Pellentesque pretium lectus id turpis.

In Prague on March 25, 2023

.....

## Abstract

Fill in abstract of this thesis in English language. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Cras pede libero, dapibus nec, pretium sit amet, tempor quis. Sed vel lectus. Donec odio tempus molestie, porttitor ut, iaculis quis, sem. Suspendisse sagittis ultrices augue.

**Keywords** enter, comma, separated, list, of, keywords, in, ENGLISH

## Abstrakt

Fill in abstract of this thesis in Czech language. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Cras pede libero, dapibus nec, pretium sit amet, tempor quis. Sed vel lectus. Donec odio tempus molestie, porttitor ut, iaculis quis, sem. Suspendisse sagittis ultrices augue.

**Klíčová slova** enter, comma, separated, list, of, keywords, in, CZECH

## Summary

### Summary section

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consectetur id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo. Cras viverra metus rhoncus sem.

### Summary section

Nam dui ligula, fringilla a, euismod sodales, sollicitudin vel, wisi. Morbi auctor lorem non justo. Nam lacus libero, pretium at, lobortis vitae, ultricies et, tellus. Donec aliquet, tortor sed accumsan bibendum, erat ligula aliquet magna, vitae ornare odio metus a mi. Morbi ac orci et nisl hendrerit mollis. Suspendisse ut massa.

### Summary section

Nulla malesuada porttitor diam. Donec felis erat, congue non, volutpat at, tincidunt tristique, libero. Vivamus viverra fermentum felis. Donec nonummy pellentesque ante. Phasellus adipiscing semper elit. Proin fermentum massa ac quam. Sed diam turpis, molestie vitae, placerat a, molestie nec, leo. Maecenas lacinia. Nam ipsum ligula, eleifend at, accumsan nec, suscipit a, ipsum. Morbi blandit ligula feugiat magna. Nunc eleifend consequat lorem. Sed lacinia nulla

vitae enim. Pellentesque tincidunt purus vel magna. Integer non enim. Praesent euismod nunc eu purus. Donec bibendum quam in tellus. Nullam cursus pulvinar lectus. Donec et mi. Nam vulputate metus eu enim. Vestibulum pellentesque felis eu massa.

### Summary section

Nam dui ligula, fringilla a, euismod sodales, sollicitudin vel, wisi. Morbi auctor lorem non justo. Nam lacus libero, pretium at, lobortis vitae, ultricies et, tellus. Donec aliquet, tortor sed accumsan bibendum, erat ligula aliquet magna, vitae ornare odio metus a mi. Morbi ac orci et nisl hendrerit mollis. Suspendisse ut massa. Cras nec ante. Pellentesque a nulla. Cum sociis natoque penatibus et magnis dis parturient montes, nascetur ridiculus mus. Aliquam tincidunt urna. Nulla ullamcorper vestibulum turpis. Pellentesque cursus luctus mauris.

### Summary section

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consectetur id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo. Cras viverra metus rhoncus sem. Lorem lorem lorem.

## Seznam zkratek

TC39	ECMA International, Technical Committee 39
W3C	World Wide Web Consortium

# Introduction

## 1.1 Motivation

TypeScript is a hot topic in the web development ecosystem and type-safety is eating the world. As of 2023, majority of developers are using TypeScript most of the time, skipping JavaScript entirely. Over the years, TypeScript has transformed from a basic type annotation tool to a full fledged programming language within the type system itself. Libraries such as Prisma for database type-safety, Zod for combining schema validation and static type inference and tRPC for API end-to-end type-safety across boundaries utilise the power of advanced TypeScript types to provide a better experience for developers. With smart suggestions being available right in the editor of choice, TypeScript ensures high quality of code while avoiding any runtime costs due to the type system being evaluated during compilation. Since most of the editors use a language server to provide the developer with the smart suggestions, there is an incentive to utilise the type system instead of running a daemon alongside LSP or adding an additional build step.

However, TypeScript is only as powerful as the types that you give to it. A great burden is laid to the maintainers of libraries to provide descriptive and useful types. The goal of this thesis is to laid out and highlight the capabilities of the TypeScript type system, discussing the constraints and limitations found in TypeScript.

## 1.2 What is static type system

For years, type systems in programming languages have been a well-known and heavily discussed topic. The main goal of a type system is to provide a formal specification of the types of data that can be manipulated by a program.

In statically typed languages, a data type of a variable is known at compile time. The compiler uses the additional information about data types to verify the source code during compilation. The data type itself can be deduced from the usage in the code (type inference) or a programmer explicitly specifies the data type of a variable before usage. Example of such languages using static typing are for instance Java, C#, C++, etc.

Whereas in dynamically typed languages, the type of a variable is determined at runtime based on the value being assigned. Developers do not need to explicitly declare the type of a variable. Some of the popular dynamically typed languages include Python, Ruby, PHP and most notably JavaScript, which is widely used to create interactive and dynamic user interfaces on the web platform. Dynamically typed languages tend to be more flexible and allow developers, notably beginner developers, to write code faster and iterate quicker.

Static typing offers numerous compelling benefits, that can enhance the development process. First, a large class of errors are caught earlier in the development process. This reduces the likelihood of bugs and runtime issues that can be difficult to diagnose and debug.

With static typing, developers can rely on a compiler system to ensure that their code conforms to the expected data types. Developers can also refactor existing typed code with more confidence, as the system is giving developers direct feedback when refactoring.

Furthermore, by writing types developers are actively self-documenting the code, making the code more readable and easier to understand, especially when dealing with previously unseen code. And even though developers might need to write more code to specify the types for the variable, the type system is able to determine the intent of the developer without writing additional code.

### 1.3 Structure of the work

This thesis will provide a comprehensive analysis of relevant advanced constructs found in the TypeScript type system, and how they can be used to allow robust meta-programming within the types itself. To demonstrate the capabilities of the type system and the usage of the constructs itself, we provide an implementation of a generic math expression evaluator library that operates strictly on the type level. We discuss how the library can be tested and the output validated and we evaluate the performance of implemented operations against other existing type level math libraries and the impact on which the library has on type checking and developer experience in the editor.

## Chapter 2

# Analysis

### 2.1 Static Typing in JavaScript

JavaScript is a dynamically typed programming language, where users do not need to assign types to a variable or a function and the type is inferred automatically by the JavaScript engine. This is a great feature of JavaScript, which lowers the barrier of entry to writing JavaScript code and allows developers to prototype and write code quickly, proven by the growth of popularity of JavaScript in the last decade, making it the most commonly used programming language according to the 2022 Stack Overflow Developer Survey [1].

However, dynamic typing has its own drawbacks, as it is harder to spot trivial errors in the code without running it beforehand and it is more difficult to refactor the code without breaking it, which often lead to poor software quality [2]. Proponents of static typing insist that static types allows developers to spot potential bugs and mistakes earlier during development and that it allows for better tooling, such as more rich code completion and refactoring tools.

There is an upcoming TC39 proposal for adding type annotations, broadly inspired by TypeScript syntax [3]. These annotation are only used for build-time tooling, these annotation are ignored in runtime and the proposal suggests these annotations to be erased by an additional build-step. Even though users can already provide static types using JSDoc right now, the syntax is not as clean as the proposed TypeScript-like syntax.

Regardless, there are many languages which aim to introduce static typing to JavaScript, such as Flow or TypeScript, or alternative languages which compile back to JavaScript, such as Elm or ReScript.

#### 2.1.1 Elm

Elm is a functional programming language designed specifically for building web applications [4]. The language compiles to JavaScript and has a strong static Hindley-Milner based type system, which allows to infer types more often and reliably. Elm does not provide any escape hatches such as `any` in TypeScript, thus it is harder to write unsafe code, as the types must be valid in

order for the code to be compiled.

Elm also includes a lot of quality-of-life improvements and benefits, for instance: enforced purity of functions, out of the box immutability, `case` pattern matching, JSON decoders and encoders for strict parsing, `Maybe` and `Result` monads for avoiding `null` and `undefined` references or its own virtual DOM implementation for efficient rendering of interactive user interfaces. Notably, the Elm Architecture, where the application code is organized into three parts: model, update and view [5], has greatly inspired other libraries and frameworks like Redux [6].

### 2.1.2 ReScript

ReScript is a programming language built on top of OCaml toolchain. Unlike Flow or TypeScript, ReScript is not a superset of JavaScript, instead the language compiles to JavaScript. ReScript was created as a spin-off from Reason programming language and accompanying BuckleScript compiler, aiming to vertically integrate and streamline the adoption barrier caused by the need to be familiar with multiple unrelated tools and toolchains [7].

The language aims to be more sound with more powerful type inference than TypeScript, borrowing the Hindler-Milner type system from OCaml implementation [8, 9], thus most of times the types can be inferred automatically without the need to annotate them explicitly, whereas TypeScript utilizes bidirectional type checking [10].

### 2.1.3 Flow

Flow is a static type checker for JavaScript [11, 12], which allows developers to annotate their code with static types. Flow is developed by Meta and is internally used in production by Facebook, Instagram and React Native. Type annotations in Flow are fully erasable, which means that the type annotations can be fully removed from the Flow code to emit valid JavaScript code. The checking of these types is occurring at compile-time before removal in build-time. Flow is also a superset of JavaScript, which means any JavaScript code is a valid Flow code.

One of the primary goals of Flow is to provide type soundness; the ability to catch every error that might happen in runtime at compile-time, no matter how likely it is to happen. This means, that a valid Flow code can provide developers some guarantees about the type a value has in runtime, at the expense of catching errors, which are unlikely to happen in runtime.

Both Flow and TypeScript are similar in regards to features at the time of writing. Most of the soundness differences between Flow and TypeScript has been addressed with the newer versions of TypeScript, even though soundness is a specific non-goal by the TypeScript team [13]. However, developers must opt-in to these features by setting `"strict"` to `"true"` in `tsconfig.json`, whereas in Flow these features are enabled by default.

### 2.1.4 TypeScript

TypeScript is a statically typed programming language developed and maintained by Microsoft [14]. It is a language that compiles to JavaScript and adds static type checking to JavaScript



[15]. Unlike Elm or ReScript, TypeScript is a syntactical superset of JavaScript, which means that any valid JavaScript code can be a valid TypeScript code<sup>1</sup>. Similar to Flow, type annotation provided by the developer are fully erasable either by the TypeScript `tsc` compiler or by other community build tools, such as `babel`[16], `esbuild`[17] or `swc`[18].

Type system in TypeScript is considered to be less sound and more forgiving, as soundness is stated as an explicit non-goal for the design team of TypeScript [13], emphasis on striking a balance between productivity and correctness. By default, TypeScript compiler is not strict and the language itself includes an escape hatch for developers to opt-out of type checking by using the `any` type or using `@ts-ignore` comment annotations. Nevertheless, with proper compiler configuration, the type system of TypeScript can be as sound as in Flow.

Both Flow and TypeScript support advanced features such as generics and utility types, with the latter supporting template string literal types and better support for conditional types, unlocking the potential of writing more expressive types, which this master thesis will further explore in more detail.

TypeScript has become the de-facto standard for writing JavaScript code with static types. With deep integration with Visual Studio Code [19], rich build ecosystem and high compatibility with existing JavaScript libraries and tools, TypeScript has become one of the fastest growing language according to 2022 Octoverse report by Github [20].

## 2.2 Typescript syntax

TypeScript allows us to specify types for variables, function arguments and return values in JavaScript.

Types can be interpreted as sets.

A primitive value is data, that is not an object and has no methods or properties. These primitives are immutable, thus they cannot be altered. Similar to JavaScript, TypeScript has these following types for primitive values:

### ■ Listing 2.1 Primitive Types

```
type Primitive =  
  | string | number | bigint  
  | boolean | undefined | symbol | null;
```

Some primitive values represent a singular data value, such as `null` or `undefined`, but many of these primitives can represent an infinite number of values, like `number`, `bigint` or `string`.

Literal types are a subset of primitive values, which are used to describe an exact possible value.

### ■ Listing 2.2 Literal Types

```
type Literal = "foo" | 42 | true | 100n;
```

---

<sup>1</sup>With a lax compiler configuration

To represent data structures such as objects and arrays, we can use the following types: objects, records, tuples and arrays.

■ **Listing 2.3** Data structures

```
type Structures =  
  | { foo: string, bar: number }    // object  
  | { [key in keyof Keys]: number } // record  
  | [number, string]               // tuple  
  | number[]                       // array
```

TypeScript uses structured typing, which means that TypeScript only validates the shape of the data. Essentially, if the data has the same shape as the type, it is considered to be of that type. This is also known as duck typing, essentially if it walks like a duck and quacks like a duck, it is a duck.

■ **Listing 2.4** Duck typing

```
type DuckLike = { quack: () => void; type: string };  
  
const Duck: DuckLike = {  
  quack: () => console.log("duck!"),  
  type: "duck",  
};  
  
// this will be still valid  
const Goose: DuckLike = {  
  quack: () => console.log("goose!"),  
  type: "goose",  
};
```

Structured typing does include some drawbacks unlike in nominal type system, where each type is unique and same data cannot be assigned across types, but these can be easily mitigated using literal types to act as brands.

■ **Listing 2.5** Nominal typing in TS

```
type DuckLike = { quack: () => void; type: "duck" };  
  
const Duck: DuckLike = {  
  quack: () => console.log("duck!"),  
  type: "duck",  
};  
  
// this will not be valid  
const Goose: DuckLike = {  
  quack: () => console.log("goose!"),  
  type: "goose",  
};
```

Types can be generalised into sets, where each type can contain a set of values. A type can

be a subset or a superset of an other type.

Similar to other sets in mathematics, types can be combined together using unions. With unions, we can broaden the scope of the type to represent multiple values.

Types can also intersect each other to create a more narrower type.

Set theory behind types.

- Union
- Intersection
- `never`
- `unknown`
- `any` - it doesn't fit anywhere, essentially acting as a way to opt-out of typechecking.

Enums `TODO: Enums`

Functions and `void`

Void `TODO: Enums`

Arrays

`any`, `never`, `unknown`

Object

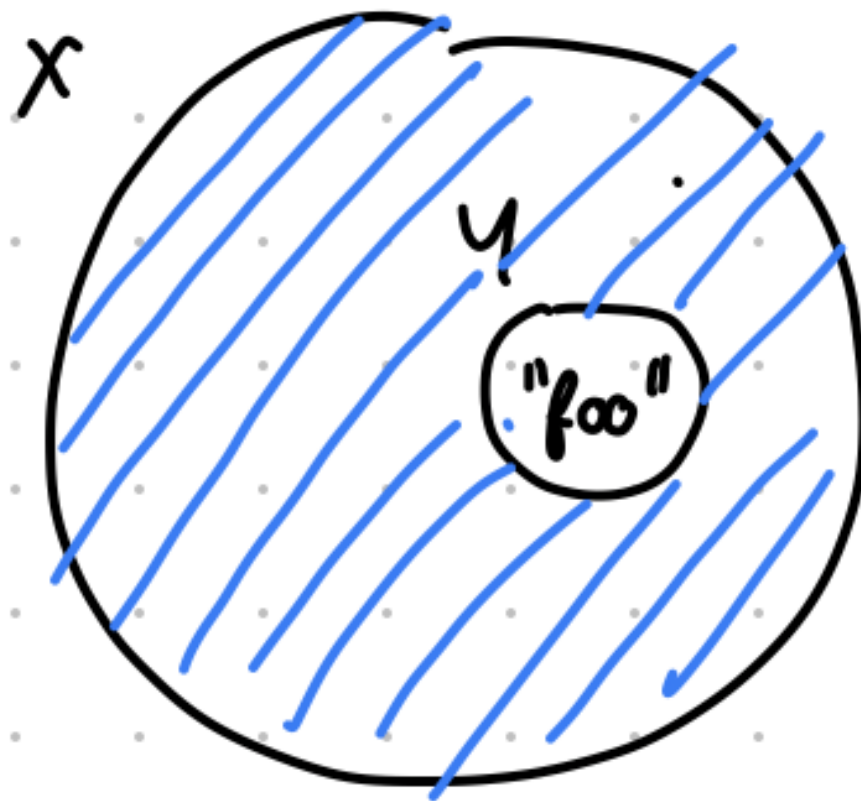
Generics

- Terminology - generics, type arguments, return type
- Conditional types
- Recursive types
- Mapped types
- Template Literal Types

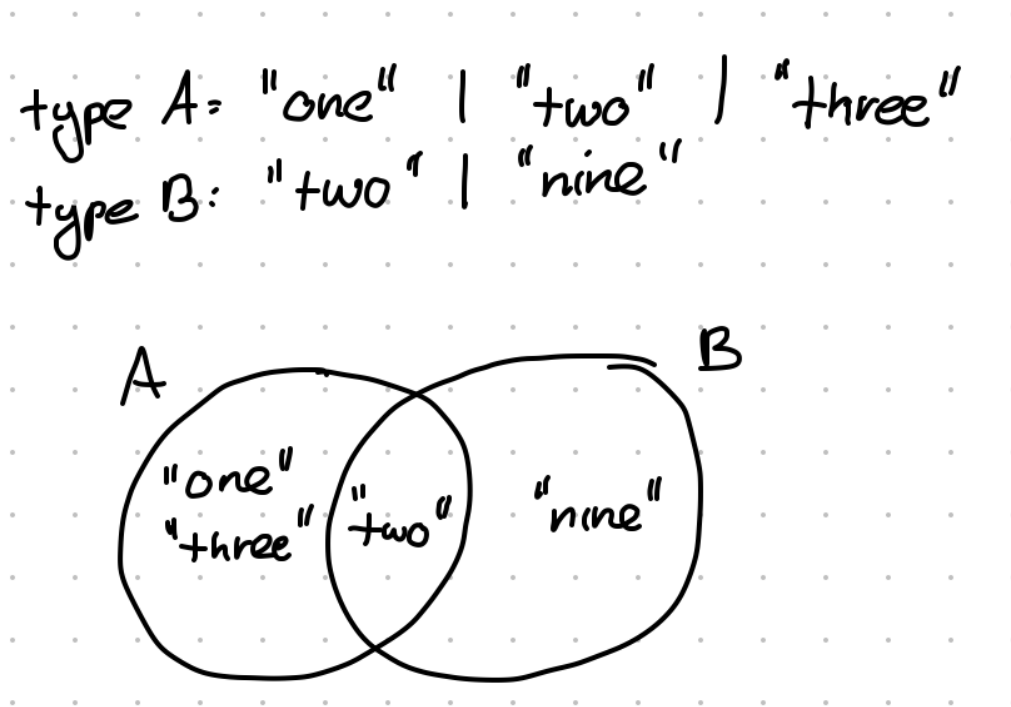
## 2.2.1 Types and their assignability

- Primitive Types
- Literal Types
- `unknown`, `never`, `any`
- Structures (nominal vs structural typing)
- Unions and Intersections

type  $X = \text{string}$   
type  $y = \text{"foo"}$



■ Figure 2.1 Types represented as sets



■ Figure 2.2 Union of types

### 2.2.2 Conditional Types

### 2.2.3 Conditional Types

### 2.2.4 Recursive Types

### 2.2.5 Mapped Types

### 2.2.6 Template Literal Types

## 2.3 Prior Art

■ [kawayiLinLin/typescript-lodash](#)

■ [arielhs/ts-arithmetic](#)

■ [ts-belt](#)

■ [type-fest](#)



# Implementation

- 3.1 Structure of the project
- 3.2 Type representation of numbers
- 3.3 Addition and Subtraction
- 3.4 Multiplication
- 3.5 Division
- 3.6 Exponentiation
- 3.7 Other mathematical operations
- 3.8 Statement parser & evaluator
- 3.9 Higher kinded types
- 3.10 Optimization and bypasses







## Chapter 4

# Testing

- Unit tests, integration tests ([eslint](#), [eslint-plugin-expect-type](#))
- Github Actions
- Performance Testing (performance tracing, extended diagnostics)
- Comparison between existing TS math libraries



## Conclusion

**5.1** Advantages and disadvantages of TS

**5.2** Future work



[illegible]

# Nějaká příloha

Sem přijde to, co nepatří do hlavní části.



# Bibliography

1. *Stack Overflow Developer Survey 2022* [online]. Stack Overflow. [visited on 2023-01-29]. Available from: [https://survey.stackoverflow.co/2022/?utm\\_source=social-share&utm\\_medium=social&utm\\_campaign=dev-survey-2022](https://survey.stackoverflow.co/2022/?utm_source=social-share&utm_medium=social&utm_campaign=dev-survey-2022).
2. FARD, Amin Milani; MESBAH, Ali. JSNOSE: Detecting JavaScript Code Smells. In: *2013 IEEE 13th International Working Conference on Source Code Analysis and Manipulation (SCAM)*. 2013, pp. 116–125. Available from DOI: 10.1109/SCAM.2013.6648192.
3. *ECMAScript Proposal: Type Annotations* [online]. Ecma TC39, 2023. [visited on 2023-01-29]. Available from: <https://github.com/tc39/proposal-type-annotations>.
4. *Elm - Delightful Language for Reliable Web Applications* [online]. [visited on 2023-01-31]. Available from: <https://elm-lang.org/>.
5. *The Elm Architecture · An Introduction to Elm* [online]. [visited on 2023-01-31]. Available from: <https://guide.elm-lang.org/architecture/>.
6. *Prior Art — Redux* [online]. 2022-02-07. [visited on 2023-01-31]. Available from: <https://redux.js.org/understanding/history-and-design/prior-art>.
7. *BuckleScript & Reason Rebranding* [online]. ReScript Blog. [visited on 2023-01-29]. Available from: <https://rescript-lang.org/blog/bucklescript-is-rebranding>.
8. *Efficient and Insightful Generalization* [online]. [visited on 2023-02-12]. Available from: <https://okmij.org/ftp/ML/generalization.html>.
9. *History — ReScript* [online]. 2022-02-12. [visited on 2023-02-12]. Available from: <https://github.com/rescript-lang/rescript-compiler/blob/master/CREDITS.md>.
10. *Reconstructing TypeScript, Part 0: Intro and Background* [online]. [visited on 2023-01-24]. Available from: <https://jaked.org/blog/2021-09-07-Reconstructing-TypeScript-part-0>.
11. CHAUDHURI, Avik; VEKRIS, Panagiotis; GOLDMAN, Sam; ROCH, Marshall; LEVI, Gabriel. Fast and Precise Type Checking for JavaScript. *Proceedings of the ACM on Programming Languages* [online]. 2017, vol. 1, 48:1–48:30 [visited on 2023-01-29]. Available from DOI: 10.1145/3133872.

12. *Flow* [online]. Meta, 2023. [visited on 2023-01-29]. Available from: <https://github.com/facebook/flow>.
13. *TypeScript Design Goals* [online]. GitHub. [visited on 2023-01-29]. Available from: <https://github.com/microsoft/TypeScript/wiki/TypeScript-Design-Goals>.
14. *TypeScript: JavaScript With Syntax For Types* [online]. [visited on 2023-02-01]. Available from: <https://www.typescriptlang.org/>.
15. *Documentation - TypeScript for JavaScript Programmers* [online]. [visited on 2023-01-14]. Available from: <https://www.typescriptlang.org/docs/handbook/typescript-in-5-minutes.html>.
16. *Babel · The Compiler for next Generation JavaScript* [online]. [visited on 2023-02-01]. Available from: <https://babeljs.io/>.
17. *Esbuild - An Extremely Fast Bundler for the Web* [online]. [visited on 2023-02-01]. Available from: <https://esbuild.github.io/>.
18. *SWC - Rust-based Platform for the Web* [online]. [visited on 2023-02-01]. Available from: <https://swc.rs/>.
19. *Visual Studio Code - Code Editing. Redefined* [online]. [visited on 2023-02-01]. Available from: <https://code.visualstudio.com/>.
20. *Octoverse 2022: The State of Open Source* [online]. The State of the Octoverse. [visited on 2023-01-29]. Available from: <https://octoverse.github.com/>.



# Obsah přiloženého média

	readme.txt.....	stručný popis obsahu média
	exe.....	adresář se spustitelnou formou implementace
	src	
	impl.....	zdrojové kódy implementace
	thesis.....	zdrojová forma práce ve formátu L <sup>A</sup> T <sub>E</sub> X
	text.....	text práce
	thesis.pdf.....	text práce ve formátu PDF