

js.rs – A Rustic JavaScript Interpreter

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April 25, 2016

Introduction

JavaScript is an incredibly widespread language, running on virtually every modern computer and browser, and interpreters such as NodeJS allow JavaScript to be used as a server-side language. Unfortunately, modern implementations of JavaScript engines are typically written in C/C++, languages reliant on manual memory management. This results in countless memory leaks, bugs, and security vulnerabilities related to memory mismanagement.

We've chosen to build a prototype server-side JavaScript interpreter in Rust, a new systems programming language for building programs with strong memory safety guarantees and speeds comparable to C++. Our interpreter runs code either from source files or an interactive REPL (read-evaluate-print-loop), similar to the functionality of existing server-side JavaScript interpreters. We intend to demonstrate the viability of using Rust to implement JavaScript by implementing a core subset of language features. To that end, we've tested our coverage using Google's Sputnik test suite, an ECMAScript 5 conformance test suite.

The Rust Language

According to the official website, Rust is "systems programming language that runs blazingly fast, prevents segfaults, and guarantees thread safety" [1]. Designed to be safer than traditional systems programming languages, Rust's creator described Rust as designed for "frustrated C++ developers" [2]. To that end, Rust guarantees memory safety in a relatively unique way compared to most mainstream programming languages; while traditional memory-safe languages use garbage collection, which incurs significant runtime costs, Rust uses a combination of compile-time techniques including a nuanced type system, tracking of pointer lifetimes, and several other cutting-edge techniques developed by programming languages researchers over the years.

Approach

Parser

The first part of the interpreter that we implemented was the parser, which takes in a string of JavaScript and generates an "Abstract Syntax Tree", or AST. An AST contains the structure and the content of a program, but not the specific syntactic components such as whitespace.

Traditionally, the canonical way of writing a parser is to use a "parser generator". Implementing a parser with a parser generator consists of defining the grammar of the language (i.e. the valid tokens of the language and what sequences of tokens are valid); the parser

generator then generate code to parse the grammar, which is then used as a library. Although parser generators tend to be a bit slower in practice than writing an equivalent parser manually, using a parser generator greatly increases the rate of development due to the ease of use. Because of the scope and time limitations of our project, we opted to use a parser generator rather than writing a custom parser.

The two most widely used parser generators are YACC and Bison, which are implemented in C. Neither of these would be suitable for our project, as we intended to use only Rust libraries in our interpreter to maximize the safety guarantees. After some research, we decided to use LALRPOP, a pure Rust LR(1) parser generator[3].

Garbage Collector

Like other interpreted languages, JavaScript relies on garbage collection to manage the memory used by a running program. Although it would have been possible for us to write our own garbage collector, a master's student with the same advisor as us was working on implementing a JavaScript garbage collection library in Rust for his thesis. Integrating with the garbage collection library seemed mutually beneficial, so we opted not to write our own garbage collector in favor of using French Press.

Runtime

In terms of time and amount of code, the most significant part of our work was the actual evaluation of the JavaScript code, which is generally referred to as the "runtime system", or just the "runtime". In order to effectively follow the proper semantics of JavaScript code, we made heavy use of the Mozilla Developer Network's official JavaScript documentation[4]. This greatly reduced the amount of effort we had to spend on determining things like the proper precedence of operators and the correct implementation of implicit type coercions.

Functions, Scoping, and Closures

One of the most difficult parts of implementing the runtime was ensuring that it exhibited the correct behavior with regards to functions and scoping. For simple cases, French Press handled the correct scoping for local variables. However, in the case of closures, the standard scoping rules would not suffice. The following code sample demonstrates such a case:

```
function f() {
  var x = 0;
  return function() {
    return x++;
  };
}

var g = f();
console.log(g());
console.log(g());
```

Normally, when a function returns, all of its local variables are no longer in scope, so the garbage collector can deallocate the memory associated with them. However, in the above example, when `f` is called, it returns a new function which has access to `x`. This means

that `x` cannot be garbage collected at least until after `g` is no longer in scope. In order to correctly execute code cases like this, we had to add functionality for our code to detect when a function is a closure and inform the garbage collector of the special status of that function's scope.

Results

Although we did not have time to implement 100% of the JavaScript language, we implemented a significant subset of features which provide more than enough to write interesting and useful programs.

Language Features

We successfully implemented parsing and evaluation of the following types of expressions and statements:

Literal expressions

- Boolean: `true`, `false`
- Numeric: e.g. `-4`, `7.17`, `NaN`
- String: e.g. `"abc1234"`, `'foo bar baz'`
- Object: e.g. `{ x: 3, y: { z: "hello" } }`
- Array: e.g. `[1, "hello", x]`
- `null`
- `undefined`

Operator expressions

- Arithmetic: `+`, `-`, `*`, `/`, `%`
- Incrementation: `++`, `--`
- Boolean logical: `&&`, `||`, `!`
- Bitwise logical: `&`, `|`, `~`, `^`
- Shifts: `>>>`, `>>`, `<<`
- Inequalities: `>`, `>=`, `<`, `<=`
- Equalities: `==`, `!=`, `===`, `!==`
- Assignment: `=`, `+=`, `&&=`, ...
- `instanceof`
- `typeof`

Function-related expressions

- Named function definition: e.g. `function f(x) { return x + 1; }`
- Anonymous function definition: e.g. `function(x, y) { return x + y; }`
- Function calls: e.g. `foo(a, b)`

Object-related expressions

- Instance variable access: e.g. `foo.bar`
- Key-indexed access: e.g. `foo[bar]`
- Constructors: e.g. `new foobar(x, y)`

Mutation statements

- Assignment: e.g. `x = y`, `foo[bar] = 23`
- Declarations: e.g. `var x = z`

Control-flow statements

- `if/else if/else`
- `while`
- `for`
- `break`
- `continue`
- `return`
- `try/catch/finally`
- `throw`

Standard library

We implemented a small standard library for our interpreter based on some of the most widely-used features the official JavaScript standard library

Printing

Official JavaScript interpreters do console-based I/O through the global `console` object, which has methods such as `log()` and `error`. Because implementing the entire native `console` object would have taken significant time and distracted us from implementing more widely-used features, we implemented a global `log()` function which behaves like `console.log()`.

Prototypes

JavaScript typically provides a number of built-in prototypes, including **String**, **Array**, **Object**, and **Function**. Because the majority of the other features could be easily implemented natively, we decided to build in a simple **Array** prototype to demonstrate our implementation of prototype functionality in our interpreter.

Coverage

To test how complete our coverage of the JavaScript standard was, we built a framework to run the Google Sputnik test suite^[5] on our interpreter. The test suite covers the ECMAScript 3 subset of the ECMAScript 5 standard. We used two different metrics to analyze the coverage of our interpreter.

Category-based coverage

Sputnik defines several categories of tests, each with various depths of subcategories (for example, the "Expressions" category contains, among others, a "Postfix Expressions" subcategory, which in turn contains the subcategories "Postfix Increment Operator" and "Postfix Decrement Operator"). Overall, there are 111 leaf categories (i.e. categories which do not contain other categories).

In order to determine what percentage of the JavaScript language features we had implemented, we counted the number of leaf categories in which we had passed some of the tests. Of the 111, we found that we had coverage in 73 of the categories, or 65.8% of them. This indicates that while we had not implemented a full-fledged JavaScript interpreter, we covered a sizable portion of the language features.

Raw coverage

[need to fill in stuff here]

Ethical and Privacy Considerations

Although our project is novel in terms of its implementation, it isn't intended to provide any new functionality not present in existing solutions. Given that the existing JavaScript interpreters that differ only in that they do not provide the same guarantees about memory leaks and segfaults, our project has essentially no impact on ethical concerns.

Discussion

LALRPOP errata

While LALRPOP generally worked quite well for our purposes, there were a few issues we ran into during the development process.

Compilation speed

While parser generators greatly facilitate development, they tend to be less performant than custom parsers specifically written for the source language. Although we were not heavily concerned with the code execution speed of our interpreter, we were fairly inconvenienced by how long it would take LALRPOP to generate our parser. As LALRPOP only had a single author who was quite busy with other things, we understood that we would not be able to expect as good performance as more mainstream parser generators. Given more time to improve js.rs, we likely would have implemented a custom parser to alleviate the issue. That being said, several non-optimization related updates to LALRPOP released during the course of our project greatly improved the development process, including the addition of human-readable error messages for shift-reduce and reduce-reduce conflicts.

Lexing

Unlike more mainstream parser generators, LALRPOP does not provide any built-in way to use a custom lexer. By default, LALRPOP will tokenize the input by splitting on any whitespace (and throwing out the whitespace itself). While this would work well in many scenarios, JavaScript interpreters typically allow newlines to be used in place of trailing semicolons. Additionally, correctly parsing single-line comments logically requires the detection of newline characters. In order to replicate this behavior as closely as possible with LALRPOP, we resorted to preprocessing the code run through js.rs before parsing it. Like the issue with compilation speed, we likely would have solved this by writing a custom parser if we had had enough time.

Multi-package architecture

One of the choices we made early on in the development of js.rs was to split the interpreter into multiple packages. Although this originally was intended to separate the code of French Press from the rest of the interpreter, soon decided to split out other parts of the interpreter as well. We ended up with four different packages, namely a "common" package with code needed by all other packages, French Press, the parser, and the runtime. Although this logical separation made sense in the abstract, it quickly became cumbersome to ensure that each crate's dependencies were in sync (e.g. that the parser and the runtime both used the same version of the common package). Moreover, due to the slow speed at which the parser compiled, changes to the common package became rather undesirable, as each change would require the parser to recompile as well. In retrospect, using separate modules within a single package rather than multiple packages would have significantly increased our development efficiency.

References

- [1] Official Rust Language website <https://www.rust-lang.org/>
- [2] Interview on Rust, a Systems Programming Language Developed by Mozilla <http://www.infoq.com/news/2012/08/Interview-Rust>
- [3] LALRPOP, LR(1) parser generator for Rust <https://github.com/nikomatsakis/lalrpop>
- [4] Mozilla Developer Network JavaScript Documentation <https://developer.mozilla.org/en-US/docs/Web/JavaScript>
- [5] ECMAScript conformance test suite <https://code.google.com/archive/p/sputniktests/>