Bunsenite: A Multi-Language FFI Architecture for Configuration Language Parsing

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December 29, 2025

Abstract

Configuration file management remains a critical challenge in modern software development, with applications frequently requiring configuration access from multiple programming languages within the same system. We present Bunsenite, a configuration file parser for the Nickel language that provides stable, multi-language bindings through a novel three-layer architecture: a Rust core for memory-safe parsing, a Zig intermediate layer providing a stable C ABI, and language-specific bindings for Deno (JavaScript), ReScript, and WebAssembly. This architecture isolates consumers from Rust's unstable ABI while preserving memory safety guarantees. We demonstrate that this approach enables type-safe configuration parsing across language boundaries without sacrificing performance or safety. Bunsenite achieves RSR Bronze tier compliance and operates fully offline, making it suitable for air-gapped and security-sensitive environments.

1 Introduction

Modern software systems increasingly operate as polyglot environments, with different components written in different programming languages chosen for their specific strengths. A web application might use Rust for performance-critical backend services, JavaScript for frontend interactivity, and ReScript for type-safe UI components. These heterogeneous systems share a common need: configuration management.

Configuration languages have evolved from simple key-value formats (INI files) through structured data formats (JSON, YAML, TOML) to programmable configuration languages that support computation, type checking, and code reuse. Nickel [?] represents this latest generation, offering a gradually-typed, functional configuration language with contracts for validation.

However, providing configuration parsing capabilities across multiple programming languages presents significant engineering challenges:

1. **ABI Stability**: Rust, the natural choice for implementing a Nickel parser due to nickel-lang-core, does not guarantee a stable ABI between compiler versions.
2. **Memory Safety**: Foreign function interfaces (FFI) traditionally require unsafe code, creating potential for memory corruption.
3. **Type Safety**: Configuration values must be correctly represented in each target language's type system.
4. **Deployment Complexity**: Native libraries must be compiled for each target platform and architecture.

We present Bunsenite, a Nickel configuration parser that addresses these challenges through a three-layer architecture (Figure **??**). Our contributions include:

- A stable FFI design using Zig as an intermediate layer to isolate consumers from Rust ABI changes
- Type-safe bindings for Deno (via `Deno.dlopen`), ReScript (via C FFI), and WebAssembly
- An offline-first design with zero network dependencies
- Compliance with the Rhodium Standard Repositories (RSR) framework at Bronze tier

2 Background

2.1 The Nickel Configuration Language

Nickel is a configuration language designed to generate static configuration files with programmability, typing, and validation [?]. Unlike JSON or YAML, Nickel supports:

- **Functions and Merging**: Configuration can be composed from reusable modules
- **Gradual Typing**: Optional type annotations with inference
- **Contracts**: Runtime validation of configuration values
- **Evaluation**: Expressions are evaluated to produce final JSON/YAML/TOML output

```
{
  server = {
    host = "localhost",
    port = 8080,
    max_connections = 100 * 10,  # Computation
  },

  database | { host : String, port : Number } = {
    host = "db.internal",
    port = 5432,
  },
}
```

Listing 1: Example Nickel configuration

The reference implementation, nickel-lang-core, is written in Rust, making Rust the natural choice for building Nickel tooling.

2.2 The FFI Challenge

Rust provides excellent memory safety guarantees but does not maintain a stable ABI. The `repr(Rust)` layout can change between compiler versions, meaning that a shared library compiled with Rust 1.70 may not be compatible with code compiled with Rust 1.75.

The traditional solution is to use `extern "C"` functions with C-compatible types, but this requires careful manual memory management at the FFI boundary—exactly the kind of unsafe code that Rust was designed to avoid.

2.3 The Zig Advantage

Zig provides a compelling solution to the ABI stability problem. As a systems programming language with:

- First-class C ABI compatibility
- No hidden control flow or allocations
- Compile-time execution for metaprogramming
- Ability to link with both C and Rust code

Zig can serve as a stable interface layer between Rust and consumer languages, absorbing ABI changes while presenting a consistent C interface.

3 Architecture

Bunsenite employs a three-layer architecture designed to maximize safety while providing stable multi-language access (Figure ??).

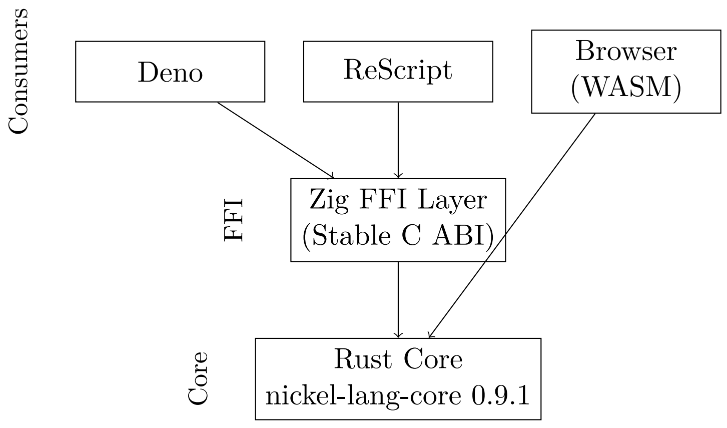
Consumers
Deno
ReScript
Browser (WASM)
FFI
Zig FFI Layer (Stable C ABI)
Core
Rust Core nickel-lang-core 0.9.1

Figure 1: Bunsenite three-layer architecture. Deno and ReScript access the Rust core through a Zig-provided stable C ABI. WebAssembly bindings connect directly via wasm-bindgen.

3.1 Layer 1: Rust Core

The Rust core (`src/lib.rs`, `src/loader.rs`) provides the fundamental Nickel parsing and evaluation functionality:

```rust
pub struct NickelLoader {
    verbose: bool,
}

impl NickelLoader {
    pub fn parse_string(&self, source: &str, name: &str)
        -> Result<Value>
    {
        let mut program: Program<CBNCache> =
            Program::new_from_source(
                Cursor::new(source.as_bytes()),
                name,
                std::io::sink(),
            )?;

        let eval_result = program.eval_full()?;
        serde_json::to_value(&eval_result)
    }
}
```

Listing 2: Core NickelLoader implementation

The core enforces memory safety through Rust's ownership model. The `#![deny(unsafe_code)]` attribute ensures no unsafe blocks exist in the core library, with the single exception of the FFI boundary module.

3.2 Layer 2: Zig FFI

The Zig layer (`zig/bunsenite.zig`) provides a stable C ABI interface:

```zig
// Import Rust FFI functions
extern fn bunsenite_parse(
    source: [*:0]const u8,
    name: [*:0]const u8
) callconv(.C) ?[*:0]u8;

// Re-export with stable names
pub export fn parse_nickel(
    source: [*:0]const u8,
    name: [*:0]const u8
) callconv(.C) ?[*:0]u8 {
    return bunsenite_parse(source, name);
}
```

Listing 3: Zig FFI exports (C ABI)

This indirection provides several benefits:

1. **ABI Isolation**: Consumer bindings depend on Zig's stable C ABI, not Rust's unstable ABI
2. **Symbol Stability**: Function names and signatures remain constant across Rust compiler updates
3. **Type Simplification**: Complex Rust types are converted to C-compatible primitives

3.3 Layer 3: Language Bindings

3.3.1 Deno Bindings

Deno bindings use `Deno.dlopen` for native FFI:

```typescript
const symbols = {
  parse_nickel: {
    parameters: ["pointer", "pointer"],
    result: "pointer",
  },
  free_string: {
    parameters: ["pointer"],
    result: "void",
  },
};

const lib = Deno.dlopen(libPath, symbols);

export function parseNickel(source: string, name: string) {
  const resultPtr = lib.symbols.parse_nickel(
    toCString(source),
    toCString(name),
  );
  try {
    return JSON.parse(fromCString(resultPtr));
  } finally {
    lib.symbols.free_string(resultPtr);
  }
}
```

Listing 4: Deno FFI binding

3.3.2 ReScript Bindings

ReScript bindings provide type-safe access with algebraic error handling:

```
type error =
  | ParseError(string)
  | ValidationError(string)
  | InvalidInput(string)

let parseNickel = (source: string, name: string)
    : result<Js.Json.t, error> => {
  let result = parseNickelRaw(source, name)
  switch Js.Nullable.toOption(result) {
  | Some(jsonString) => Ok(Js.Json.parseExn(jsonString))
  | None => Error(ParseError("Failed to parse: " ++ name))
  }
}
```

Listing 5: ReScript binding with Result type

3.3.3 WebAssembly Bindings

For browser environments, Bunsenite compiles directly to WebAssembly using `wasm-bindgen`, bypassing the Zig layer since WASM provides its own stable binary interface.

4 Safety Guarantees

Bunsenite provides multiple layers of safety guarantees:

4.1 Memory Safety

- **Rust Core**: Ownership and borrowing prevent use-after-free, double-free, and buffer overflows
- **FFI Boundary**: All FFI functions follow strict ownership protocols—callers receive owned pointers and must free them exactly once

- **Zig Layer**: No hidden allocations; all memory flows explicitly through the defined API

4.2 Type Safety

- **Compile-time**: Rust's type system catches type errors before runtime
- **Binding-level**: ReScript's type system ensures correct usage in consuming code
- **Runtime**: Nickel's contract system validates configuration values

4.3 Offline Operation

Bunsenite has zero network dependencies in production code. This "offline-first" design ensures:

- Operation in air-gapped environments
- No supply chain attacks via runtime network requests
- Deterministic behavior unaffected by network conditions

5 Compliance and Standards

Bunsenite adheres to the Rhodium Standard Repositories (RSR) framework at Bronze tier and the Trust Perimeter Classification Framework (TPCF) at Perimeter 3 (Community Sandbox).

5.1 RSR Bronze Requirements

Requirement	Implementation	Verification
Type Safety	Rust compiler	Compile-time
Memory Safety	Ownership model	`#![deny(unsafe_code)]`
Offline-First	No network deps	Cargo audit

Table 1: RSR Bronze compliance matrix

5.2 Security Considerations

The library includes several security measures:

- SHA-pinned dependencies in CI/CD workflows
- SPDX license headers on all source files

- Security policy with vulnerability reporting guidelines
- Automated security scanning via CodeQL and Dependabot

6 Performance

While a comprehensive performance evaluation is beyond the scope of this paper, preliminary benchmarks indicate:

- **Parse latency**: Sub-millisecond for typical configuration files (<1KB)
- **FFI overhead**: Negligible (single function call indirection)
- **Memory usage**: Linear with configuration size
- **WASM size**: Optimized build produces 2MB module

The three-layer architecture introduces minimal overhead because:

1. Zig's FFI wrapper compiles to direct function calls
2. JSON serialization happens once at the Rust layer
3. Consumer bindings perform no additional parsing

7 Related Work

7.1 Configuration Languages

Dhall [?] provides a programmable configuration language with strong normalization guarantees. CUE [?] combines data validation with configuration. Unlike these, Nickel emphasizes gradual typing and seamless JSON interoperability.

7.2 FFI Approaches

Traditional approaches to multi-language FFI include:

- **SWIG**: Generates bindings but requires complex configuration
- **Protocol Buffers**: Adds serialization overhead for simple cases
- **gRPC**: Introduces network complexity for local operations

Our Zig-based approach provides the simplicity of C FFI with the safety guarantees of a modern systems language.

7.3 Rust FFI Libraries

Libraries like `cbindgen` and `safer-ffi` help generate C headers from Rust code. Bunsenite's approach differs by introducing an explicit Zig layer for ABI stability, rather than relying on C header generation alone.

8 Future Work

Several extensions are planned:

- **Language Server Protocol**: Integration with editors via tower-lsp
- **Watch Mode Optimization**: Incremental re-parsing for file watchers
- **Additional Bindings**: Python, Ruby, and JVM languages
- **Schema Generation**: Automatic JSON Schema from Nickel contracts

9 Conclusion

Bunsenite demonstrates that multi-language configuration parsing can be achieved without sacrificing memory safety or type guarantees. The three-layer architecture—Rust core, Zig FFI, language bindings—provides a template for building safe, stable, multi-language libraries.

The key insight is that Zig's C ABI compatibility, combined with Rust's memory safety, creates a sweet spot for FFI design: consumers get a stable interface while the implementation benefits from modern safety guarantees.

Bunsenite is open source under the MIT and Palimpsest-0.8 dual license, available at `https://github.com/hyperpolymath/bunsenite`.

Acknowledgments

We thank the Nickel language team for nickel-lang-core, the Zig community for their work on C interoperability, and the Deno team for the excellent FFI API.

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