MoonRust

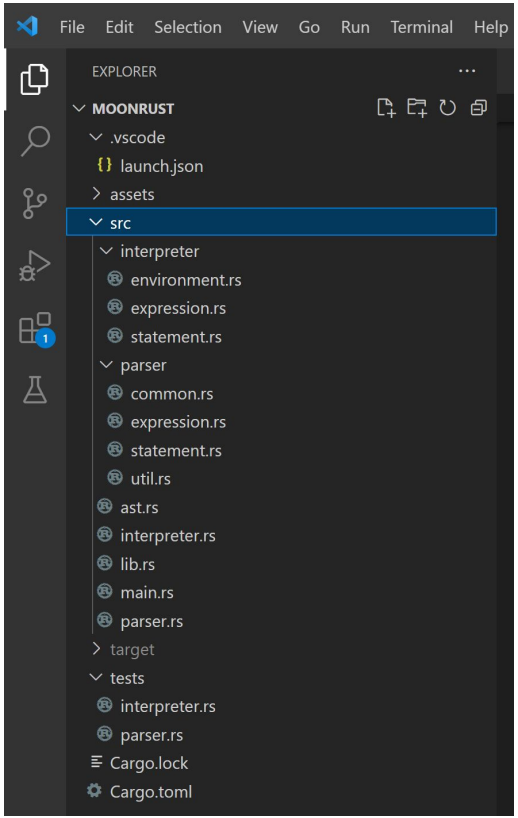
Memory Safe Lua Interpreter

Project Description

- Goal: Build an interpreter to execute a subset of Lua from a file
- MVP Features:
  - Parser (excluding some syntactic sugars)
  - Variable assignments
  - Binary expression
  - Unary expressions
  - Control statement evaluation (if, else, break)
  - Loop statement evaluation (for, while, repeat - excluding for generics)
  - Function definition/call
  - Visibility rules and scoping
  - Table evaluation
  - Some standard library functions (print, read, random)

Demo

Code Structure



- Entry Point
  - main.rs
  - Program text and command line args
- Parser
  - Input file → AST
  - Separate parsing files for statement & expression
- Interpreter
  - Evaluation
  - Environment represents scope

Parser

- What: Converts the input file into an Abstract Syntax Tree
- How: Nom parser combinator library
- Our main challenge: The Lua manual's specified syntax grammar is left recursive
  - Why: Nom is a top-down parser
  - How we solved this issue: factor out left recursion
    - Parse expressions according to the specified operator precedence
    - Flatten rules into one unambiguous rule

```
prefixexp ::= var | functioncall | '(' exp ')'

functioncall ::=  prefixexp args | prefixexp ':' Name args
```

AST

```rust
pub enum Statement {
    Assignment((Vec<Var>, Vec<Expression>, bool)), // bool flag: true if
    FunctionCall(FunctionCall),
    Break,
    DoBlock(Block),
    While((Expression, Block)),
    Repeat((Block, Expression)),
    If((Expression, Block, Vec<(Expression, Block)>, Option<Block>)),
    ForNum((String, Expression, Expression, Option<Expression>, Block)),
    ForGeneric((Vec<String>, Vec<Expression>, Block)),
    FunctionDecl((String, ParList, Block)),
    LocalFuncDecl((String, ParList, Block)),
    Semicolon,
}
```

```rust
pub struct Block {
    pub statements: Vec<Statement>,
    pub return_stat: Option<Vec<Expression>>,
}
```

```rust
pub enum Expression {
    Nil,
    False,
    True,
    Numeral(Numeral),
    LiteralString(String),
    DotDotDot, // Used for a variable number of arguments
    FunctionDef((ParList, Block)),
    PrefixExp(Box<PrefixExp>),
    TableConstructor(Vec<Field>),
    BinaryOp((Box<Expression>, BinOp, Box<Expression>)),
    UnaryOp((UnOp, Box<Expression>)),
}
```

Interpreter

```rust
impl Expression {
    pub fn eval<'a, 'b>(&'a self, env: &'b mut Env<'a>) -> Result<Vec<LuaValue<'a>>, ASTExecError> {
```

```rust
impl Statement {
    pub fn exec<'a, 'b>(
        &'a self,
        env: &'b mut Env<'a>,
    ) -> Result<Option<Vec<LuaValue>>, ASTExecError> {
```

Interpreter

```rust
pub struct LuaValue<'a>(Rc<LuaVal<'a>>);
```

```rust
pub enum LuaVal<'a> {
    LuaTable(LuaTable<'a>),
    LuaNil,
    LuaBool(bool),
    LuaNum([u8; 8], bool), // numerals as an array of 8 bytes, bool for is_float
    LuaString(String),
    Function(LuaFunction<'a>),
    Print,
    TestPrint(Rc<RefCell<Vec<String>>>),
    Read,
    Random,
}
```

Environment

```rust
pub struct EnvTable<'a>(Rc<RefCell<HashMap<String, LuaValue<'a>>>>);

pub struct LocalEnv<'a>(Vec<Option<EnvTable<'a>>>);

pub struct Env<'a> {
    global: EnvTable<'a>,
    local: LocalEnv<'a>,
}
```

Environment

- New EnvTable is added when exiting the “Block”
- For the example code, “a” and “b” will be in the same scope, but they will be stored in different “EnvTable”
- Output “1” and “nil”
- Eg. [None, EnvTable1, EnvTable2, None, EnvTable3]
- It behaves like Lua!

```
local a = 1
function g()
    print(a)
    print(b)
end
local b = 3
g()
```

Rusty Code

- Match Expressions for Enums
  - Covered all possible variants
- Use of Rc and RefCell
  - Multiple owners and interior mutability
- Display trait
  - Verify AST parsing
  - LuaValue

```rust
pub fn eval<'a, 'b>(&'a self, env: &'b mut Env<'a>) -> Result<Vec<LuaValue<'a>>, ASTExecError> {
        let val = match self {
            Expression::Nil => vec![LuaValue::new(LuaVal::LuaNil)],
            Expression::False => vec![LuaValue::new(LuaVal::LuaBool(false))],
            Expression::True => vec![LuaValue::new(LuaVal::LuaBool(true))],
            Expression::Numeral(n) => match n {
                Numeral::Integer(i) => vec![LuaValue::new(LuaVal::LuaNum(i.to_be_bytes(), false))],
                Numeral::Float(f) => vec![LuaValue::new(LuaVal::LuaNum(f.to_be_bytes(), true))],
            },
            // more ......
        };
        Ok(val)
    }
```

Difficult in Rust

- Environment Implementation
  - Various attempts on how to place Rc and RefCell
  - Linking lifetimes
- Function Default Parameters
  - Block::exec and Block::exec_without_pop

Testing

- 92 unit tests and 33 integrations tests
- Verify edge cases

```
$ cargo test -q

running 92 tests
.......................................................................................... 88/92
....
test result: ok. 92 passed; 0 failed; 0 ignored; 0 measured; 0 filtered out; finished in 0.15s


running 0 tests

test result: ok. 0 passed; 0 failed; 0 ignored; 0 measured; 0 filtered out; finished in 0.00s


running 33 tests
.................................
test result: ok. 33 passed; 0 failed; 0 ignored; 0 measured; 0 filtered out; finished in 0.03s


running 0 tests

test result: ok. 0 passed; 0 failed; 0 ignored; 0 measured; 0 filtered out; finished in 0.00s
```

Execution Time

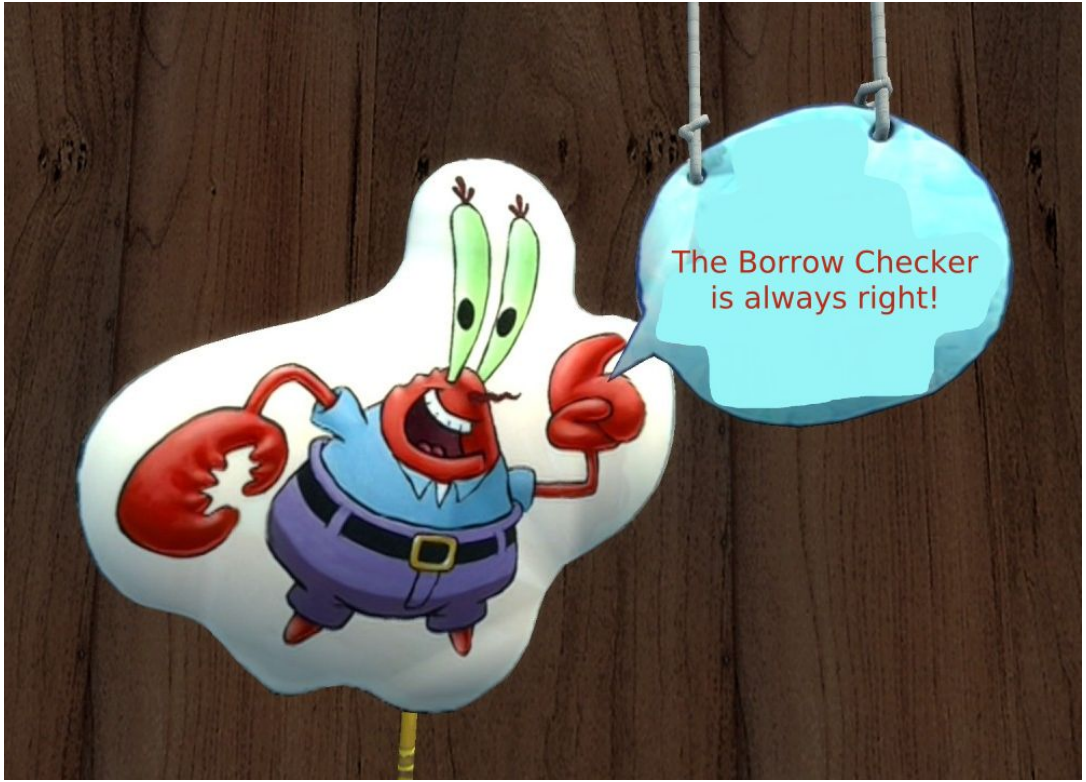
- Prime number test (n = 4829449)
  - Official Lua: < 1 second
  - MoonRust: ~34 seconds
- Fibonacci numbers 1 to 30
  - Official Lua: ~1 second
  - MoonRust: ~163 seconds

Conclusion

- Challenging project, but finished MVP
- Multiple design changes
- Using Rust helped to write readable code and to catch easy-to-miss errors
- A lot of optimizations are needed in the interpreter
- Acknowledgment: Dr. Fluet for almost being a fourth member of the team

Thank you!

Any Questions?



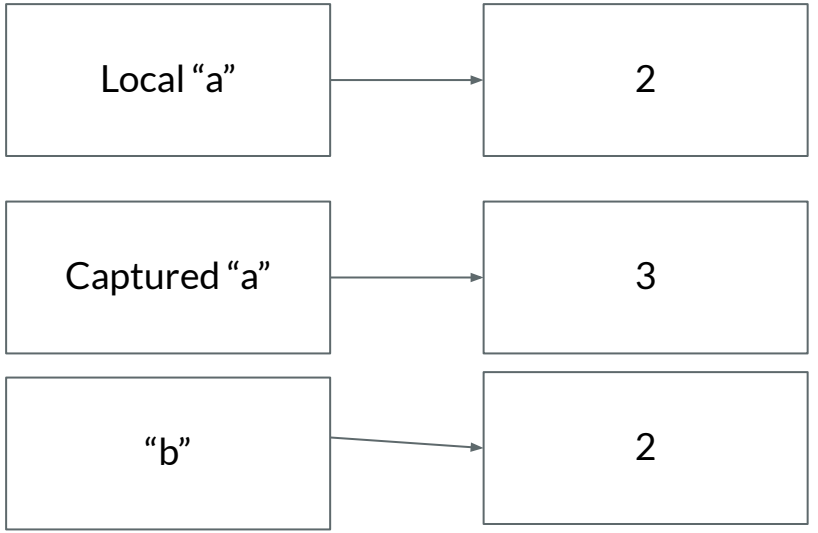
Extra slides

Capturing Variables

- A Lua function can act like a closure
- Well, LuaValue is Rc, so we can iterate through closure body and clone the Rc
- Little bit of overhead for defining, but Rc clone should be cheap!
- Create “capture_varaible” function for all types in AST
- However, ...

Capturing Variables

```
local a = 2
function f()
    a = a + 1
end
b = a
f()
print(a)
print(b)
```



- Should output 3 and 2, but output 2 and 2
- Captured “a” and local “a” will be pointing to the different values after re-assignment!
- Using “RefCell” will also not solve the problem

Environment

```
pub struct EnvTable<'a>(HashMap<String, LuaValue<'a>>);

pub struct LocalEnv<'a>(Vec<EnvTable<'a>>);

pub struct Env<'a> {
    global: EnvTable<'a>,
    local: LocalEnv<'a>,
}
```

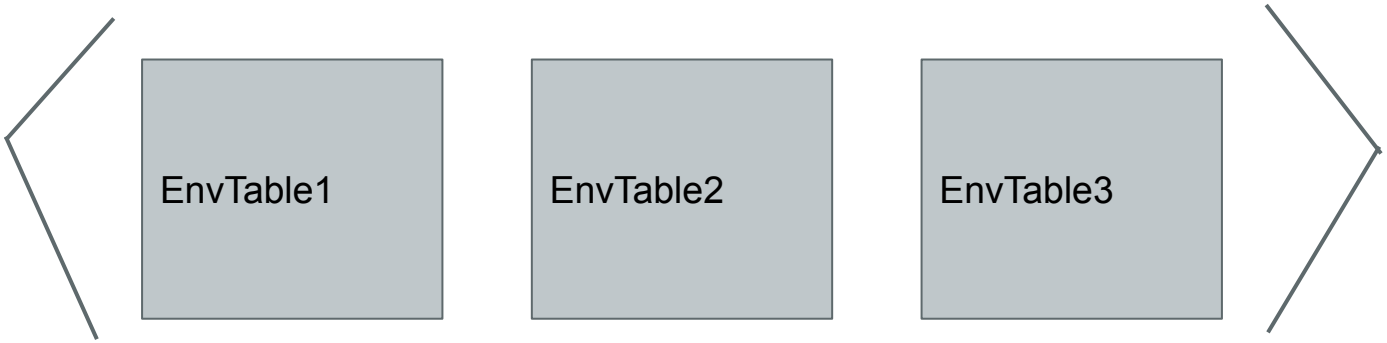
Environment

```rust
pub struct EnvTable<'a>(Rc<RefCell<HashMap<String, LuaValue<'a>>>>);

pub struct LocalEnv<'a>(Vec<EnvTable<'a>>);

pub struct Env<'a> {
    global: EnvTable<'a>,
    local: LocalEnv<'a>,
}
```

- Capture the scope when closure is defined!

Environment

Each EnvTable represents **scope** in local environment



Environment

```
local a = 1
function g()
    print(a)
    print(b)
end
local b = 3
g()
```

- “b” is added to the scope after closure is defined!
- Need to differentiate variables captured and not captured in the same scope