Lua - The Language You Forgot to Learn

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About Me

- Partner and Distinguished Software Engineer at Object Computing, Inc. in St. Louis, Missouri USA
- 43 years of professional software development experience
- Writer and teacher
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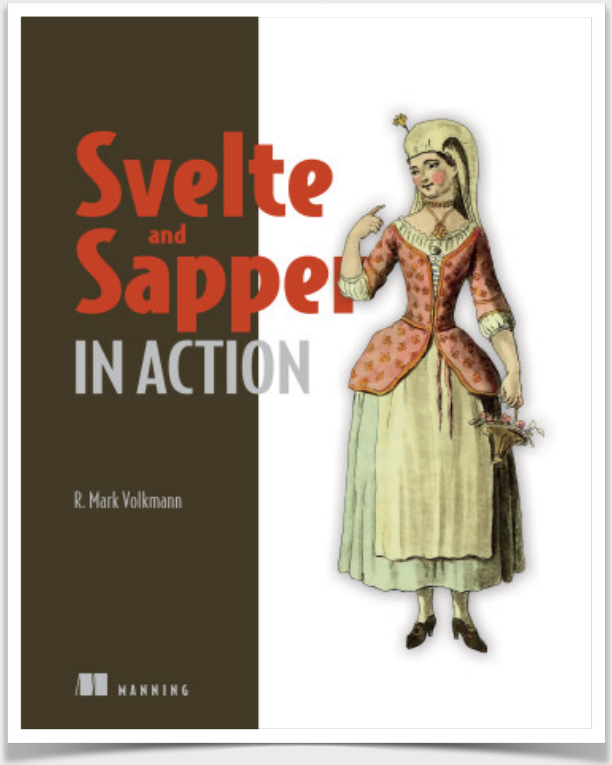


Lua Overview

- Dynamically typed scripting language
- Strongly typed with type inference
- Created in 1993 by a team at
  Pontifical Catholic University of Rio de Janeiro in Brazil
- “Lua” means “Moon” in Portuguese
  - logo depicts Moon orbiting Earth and casting its shadow onto Earth

- Free and open source under MIT license
- Excellent integration with C and C++
- Has relatively small standard library, but
  more libraries can be installed using LuaRocks

Lua Goals

- **Simplicity**
  - easy to use by non-professional programmers
  - small number of keywords (22)
  - indexing from 1 instead of 0, like matrices in math
  - reference manual is ~100 pages
- **Small size**
  - supports embedding in non-Lua applications
- **Scripting**
  - easy to invoke from system languages such as C and C++
- **Portability**
  - runs on any OS targeted by ANSI C compiler

Where Used

- **Games**
  - Angry Birds, Minecraft, Roblox, World of Warcraft
- **Lego Mindstorms** NXT robotics platform
- **Neovim** text editor
  - fork of vim; can be configured with Lua; plugins can be written in Lua
- **Redis** database
  - “lets users upload and execute Lua scripts on the server”
- **TI-Nspire** graphing calculators

Pros of Lua

- Simple syntax with only 22 keywords
- Easy to embed in C/C++ applications

interpreter is ~ 250K
standard libraries are ~ 500K

- Easy to run C code from Lua and run Lua code from C
- Highly portable; runs on all major OSes and most microcontrollers
- Free and open source under the MIT license
- Uses dynamic variables that do not require specifying types
- Provides automatic, incremental garbage collection
- Functions are first class and are closures
- Implements tail call optimization
- Supports collaborative multitasking with coroutines

Cons of Lua

- Lack of type checking
  - typed dialects exist
- Lack of direct support for object-oriented programming (OOP)
  - although it can be simulated with metatables and functions
- Limited support for error handling
  - see **`pcall`**, **`xpcall`**, and **`error`** functions
- Uses string “patterns” which are
  a simplified version of regular expressions
- Limited Unicode support

Keywords (22)

- Boolean values: **`true`** and **`false`**
- Conditional logic: **`if`**, **`then`**, **`elseif`**, and **`else`**
- Functions: **`function`** and **`return`**
- Iteration: **`for`**/**`in`**, **`while`**, **`repeat`**/**`until`**, and **`break`**
- Logical operators: **`and`**, **`or`**, and **`not`**
- Variables: **`local`**
- Other: **`do`**, **`end`**, **`goto`**, **`nil`**

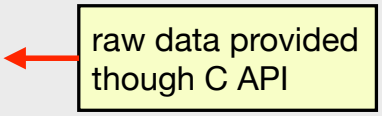
Comment Syntax

- `--` for single-line comments
- `--[[ ... ]]` for multiline comments

`[[ ... ]]` is the syntax for multi-line strings.

Lua Types (8)

- Primitives
  - `nil`
  - `boolean`
  - `number`
  - `string`
- Non-primitives
  - `function`
  - `table`
  - `thread`
  - `userdata`



Variables

- Global by default

useful when used as
a configuration format

- Make scoped with **`local`** keyword

```
local b = true -- type is boolean
local s = "test" -- type is string
local i = 19 -- type is number
local d = 3.14 -- type is number
local a = {1, 2, 3} -- type table
local scores = { Mark = 19, Tami = 21} -- type is table
local local fn = function (p1, p2) code-goes-here end -- type is function
local local function fn(p1, p2) code-goes-here end -- type is function
local thread = coroutine.create(fn) -- type is thread
```

- Constants cannot be modified

```
local name <const> = "Mark"
```

Strings ...

- Literal strings have short and long form
  - short form - surround with double or single quotes

```
local s1 = "demo"
local s2 = 'demo'
```

  - long form - surround with double square brackets
    - supports multi-line strings
    - can include a matching number of equal signs between the square brackets to handle content with a double square brackets

```
local s3 = [[demo]]
local s4 = [=[crazy[[content]=]
local haiku = [[
Out of memory.
We wish to hold the sky.
But we never will.]]
```

... Strings

- `..` operator performs concatenation of strings and numbers

```
local firstName = "Mark"
local lastName = "Volkmann"
local fullName = firstName .. " " .. lastName
```

- # operator returns length

```
print(#firstName) -- 4
```

String Functions

- **`string`** library provides functions for operating on strings
  - **`find`**, **`format`**, **`gmatch`**, **`gsub`**, **`lower`**, **`match`**, **`sub`**, **`upper`**, and more

```
-- Find start end end index of first occurrence.
local text = "abcdefgh"
local startIndex, endIndex = string.find(text, "def")
print(startIndex, endIndex) -- 4, 6

startIndex, endIndex = string.find(text, "not")
print(startIndex, endIndex) -- nil, nil

-- Get substring.
local chunk = string.sub(text, 4, 6)
print(chunk) -- "def"
```

Indexes passed to **`string`** library functions start at **`1`**.

```
-- Replace all occurrences.
local sentence = "The dog jumped over the log."
local changed, count = string.gsub(sentence, "og", "ake")
print(changed) -- The dake jumped over the lake.
print(count) -- 2

-- Replace the first n occurrences (1 in this case).
sentence = "The dog jumped over the log."
changed = string.gsub(sentence, "og", "eer", 1)
print(changed) -- The deer jumped over the log.
```

Patterns ...

- Similar to regular expressions
- Used in place of those in order to keep Lua runtime small
- Passed to the string library functions **`find`**, **`match`**, **`gmatch`**, and **`gsub`**
- Uses “magic characters” that are the same as in regular expressions
  - except for using `%` to escape

Magic Character	Meaning
`^`	start anchor or negates a character class
`$`	end anchor
`.`	matches any single character
`?`	zero or one
`*`	zero or more
`+`	one or more
`[`	begins a character class
`]`	ends a character class
`-`	forms a range in a custom character class
`(`	begins a capture group
`)`	ends a capture group
`%`	escapes a magic character (ex. `%$` represents `$`)

... Patterns

- Uses character classes similar to those in regular expressions

Character Class	Meaning
`%a`	letters
`%c`	control characters
`%d`	digits
`%g`	printable characters except spaces
`%l`	lowercase letters
`%p`	punctuation characters
`%s`	space characters
`%u`	uppercase letters
`%w`	alphanumeric characters
`%x`	hexadecimal digits

```
-- Find string that matches a pattern.
sentence = "The date today is Apr 14, 2023."
local datePattern = "%u%l%l%s%d%d?,%s%d%d%d%d"
startIndex, endIndex = string.find(sentence, datePattern)
print(startIndex, endIndex) -- 19, 30
local date = string.sub(sentence, startIndex, endIndex)
print(date) -- Apr 14, 2023

sentence = "The date today is April 14, 2023."
startIndex, endIndex = string.find(sentence, datePattern)
print(startIndex, endIndex) -- nil, nil
```

Control Flow Syntax

```
if condition then
  ...
elseif condition then
  ...
else
  ...
end
```

no `switch` statement

```
local result =
  condition and true_value or false_value
```

no ternary operator; this is an alternative

```
for number = start, end, step {
  ...
}

for k, v in pairs(table) do
  ...
end

for i, v in ipairs(table) do
  ...
end
```

```
while condition do
  ...
end

repeat
  ...
until condition
```

Tables

- Only data structure in Lua
- Can be array-like, dictionary-like, or both

```
local scores = { 7, 19, 12 }
local colors = { "red", "green", "blue" }
local point = { x = 1.3, y = 2.7 }
local mixed = { 7, color = "green" }
```

Implementation Detail

Access to array-like entries is optimized by storing them in an actual array and storing key/value pairs in a hash map. So internally tables have two parts.

- To iterate over array-like values

```
for i, v in ipairs(table) do
  ...
end
```

indexes start at 1

- To iterate over dictionary-like values

```
for k, v in pairs(table) do
  ...
end
```

- Keys can be any value except **`nil`**

Defining Functions

- Defined with **`function`** keyword
- Parameters are positional

```
local name = function (p1, p2)
  ...
end

-- All functions are anonymous.
-- This is just syntactic sugar for above.
local function name(p1, p2)
  ...
end
```

varargs

```
function sum(...)
  local result = 0
  for _, v in ipairs({ ... }) do
    local n = tonumber(v)
    if n then result = result + n end
  end
  return result
end
```

no ++, --,
or shorthand assignment
operators like +=

- Can return zero or more results
  - **`return`** keyword followed by comma-separated list
- All functions are closures

Calling Functions

- Syntax is

```
local result = some_name(arg1, arg2)
```

- Excess arguments are ignored
- Missing arguments default to **`nil`**
- Parentheses can be omitted when there is only one argument and it is a string literal or table constructor

```
some_name "text"
some_name {1, 2, 3}
```

Modules

- Modules are collections of variables and function held in a table
- Typically defined in their own source file
- Made available in other source files using **`require`** function

time.lua

```
local M = {}
M.hours_per_day = 24
M.seconds = function (minutes, hours, days)
  minutes = minutes or 0
  hours = hours or 0
  days = days or 0
  return 60 * ((days * 24 + hours) * 60 + minutes)
end
return M
```

providing default parameter values

demo.lua

```
local time = require "time"
print(time.seconds(1, 2, 3)) -- 266460
```

Strings passed to **`require`** omit the **`.lua`** file extension.

The list of directories searched by **`require`** is in **`package.path`**.

Error Handling

- No **`try`**, **`catch`**, or **`throw`**; use **`pcall`** and **`error`**

```
local function process()
  local dividend = read_number("Enter a dividend")
  if not dividend then
    error({message = "dividend is invalid", code = 1})
  end

  local divisor = read_number("Enter a divisor")
  if not divisor then
    error({message = "divisor is invalid", code = 2})
  end
  if divisor == 0 then
    error({message = "cannot divide by zero", code = 3})
  end

  local quotient = dividend / divisor
  io.write(string.format(
    "The quotient is %.3f\n\n", quotient
  ))
end
```

```
local function read_number(prompt)
  io.write(prompt .. ": ")
  local number = io.read("*number")
  local _ = io.read() -- consumes newline
  return number
end
```

```
while true do
  local success, err = pcall(process)
  if not success then
    if err then
      print(string.format("%s (code %d)", err.message, err.code))
    end
    -- print(debug.traceback()) -- prints stack trace
    print() -- extra newline
  end
end
```

Metatables

- **Metatables** are tables that define metamethods
- **Metamethods** are called when
  - operators are applied to table instances
    - ex. adding with + operator
  - certain operations are performed on table instances
    - ex. lookup of the value of a key
- To associate a metatable with a table, call **`setmetatable(t, mt)`**
- To get the metastable associated with a table, call **`getmetatable(t)`**

Metamethods for Operators

Math Operators

Metamethod	Operator
`__add`	`+`
`__sub`	`-`
`__mul`	`*`
`__div`	`/`
`__idiv`	`//`
`__mod`	`%`
`__pow`	`^`

Logical Operators

Metamethod	Operator
`__eq`	`==`
`__lt`	`<`
`__le`	`<=`

The **~=**, **>**, and **>=** operators are derived from these.

Bitwise Operators

Metamethod	Operator
`__band`	`&`
`__bor`	`|`
`__bxor`	`~`
`__bnot`	`!`
`__shl`	`<<`
`__shr`	`>>`

Other Operators

Metamethod	Operator
`__concat`	`..`
`__len`	`#`
`__unm`	- (unary)

Metamethods for Operations

Special Operations

Metamethod	Operation
`__call`	called when the table is called like a function
`__gc`	called after garbage collection runs
`__index`	called if a key is not found in the table
`__metatable`	prevents changes to metatable
`__mode`	returns a string; see below
`__newindex`	called when an entry is added to the table
`__pairs`	`pairs` function
`__tostring`	returns a string representation

Colon Operator

- Provides **syntactic sugar** for an alternate way to call a function that is defined as a table entry
- For example, the metatable of all string instances is the **`string`** library table
- Two ways to get uppercase version of a string

```
local s = "test"

-- Using the dot operator is
-- like calling an OO class method.
print(string.upper(s))

-- Using the colon operator is
-- like calling an OO instance method
print(s:upper())
```

Lua attempts to find an **`upper`** function in the value of **`s`**.
But **`s`** refers to a string rather than a table,
so the **`upper`** function is not found there.
Next Lua gets the metatable of **`s`** and looks for **`upper`**
in the table that is the value of its **`__index`** entry.
It finds **`upper`** defined there and calls it,
passing it the value before the colon which is **`s`**.

Simulating Classes

- **`__index`** metamethod is key to simulating OO classes and subclasses
  - value can be a table or a function

```lua
local t = { apple = "red" }
local mt = {
  __index = { banana = "yellow" }
}
setmetatable(t, mt)
print(t.apple) -- red
print(t.banana) -- yellow
```

```lua
local t = { apple = "red" }
local mt = {
  -- first parameter is t
  __index = function(_, key)
    return "unknown"
  end
}
setmetatable(t, mt)
print(t.apple) -- red
print(t.banana) -- unknown
```

- See the **`class`** and **`subclass`** functions defined at https://mvolkmann.github.io/blog/topics/#/blog/lua/#simplifiying-classes
  - these enables code like on next two slides

Point Class Example

```lua
local oo = require "oo"

Point = oo.class {
  -- Properties
  x = 0,
  y = 0,

  -- Methods
  distanceFromOrigin = function(p)
    return math.sqrt(p.x ^ 2 + p.y ^ 2
  end,

  -- Metamethods
  __add = function(p1, p2)
    return Point.new {
      x = p1.x + p2.x,
      y = p1.y + p2.y
    }
  end,
  __tostring = function(p)
    return string.format(
      "(%.2f, %.2f)", p.x, p.y
    )
  end
}
```

my custom module

```lua
local p1 = Point.new { x = 3, y = 4 }
print(p1) -- (3.00, 4.00)
print(p1:distanceFromOrigin()) -- 5.0

local p2 = Point.new { x = 5, y = 1 }
local p3 = p1 + p2
print(p3) -- (8.00, 5.00)

local p4 = Point.new { y = 7 }
p4:print() -- (0.00, 7.00)
```

Shape Subclasses Example

```lua
local oo = require "oo"

Shape = oo.class {
  abstract = true,
  report = function (self)
    print(string.format(
      "%s has %d sides and area %0.1f",
      self.name,
      self.sides,
      self:area()
    ))
  end
}
```

```lua
Rectangle = oo.subclass(Shape, {
  name = "rectangle",
  sides = 4,
  area = function(self)
    return self.width * self.height
  end
})
local rectangle = Rectangle.new { width = 4, height = 6 }
print(rectangle:area()) -- 24
rectangle:report() -- rectangle has 4 sides and area 24.0
```

```lua
Triangle = oo.subclass(Shape, {
  name = "triangle",
  sides = 3,
  area = function(self)
    return 0.5 * self.base * self.height
  end
})
local triangle = Triangle.new { base = 4, height = 6 }
print(triangle:area()) -- 12.0
triangle:report() -- triangle has 3 sides and area 12.0
```

```lua
Square = oo.subclass(Rectangle, {
  name = "square",
  area = function(self)
    return self.side ^ 2
  end
})
local square = Square.new { side = 5 }
print(square:area()) -- 25.0
square:report() -- square has 4 sides and area 25.0
```

Coroutines

- Lua is single-threaded like JavaScript
- Coroutines provided collaborative multitasking
- One coroutine at a time is running
- Call **`coroutine.yield`** to return values and gives up control

coroutine.create

contrived example

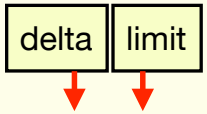
```
local function nextNumber(delta, limit, previous)
  local next = (previous or 0) + delta
  if next <= limit then
    coroutine.yield(next)
    nextNumber(delta, limit, next) -- recursive call
  end
end

local thread = coroutine.create(nextNumber)
print(type(thread)) -- thread
print(coroutine.status(thread)) -- "suspended"

-- We only need to pass arguments
-- in the first call to resume.
local success, v = coroutine.resume(thread, 3, 15)

while success and v do
  print(v) -- 3, 6, 9, 12, and 15
  success, v = coroutine.resume(thread)
end

print(coroutine.status(thread)) -- "dead"
```



loop exits when calling **resume** no longer yields

coroutine.wrap

- Alternative to **`coroutine.create`**
- Returns a function rather than a thread
- Simplifies code
- Loses ability to get thread status
- Calls to returned function raise errors instead of returning an error description

```
-- nextNumber function remains unchanged

local iterator = coroutine.wrap(nextNumber)

print(type(iterator)) -- function

local v = iterator(3, 15)
while v do
  print(v) -- 3, 6, 9, 12, and 15
  v = iterator()
end
```

Lua Standard Library ...

Lua provides **10** standard libraries.

- **basic**
  - **`assert`**, **`error`**, **`getmetatable`**, **`ipairs`**, **`pairs`**, **`pcall`**, **`print`**, **`setmetatable`**, **`tonumber`**, **`tostring`**, **`type`**, and more
- **coroutine**
  - **`close`**, **`create`**, **`resume`**, **`status`**, **`wrap`**, **`yield`**, and more
- **debug**
  - **`debug`**, **`traceback`**, and more
- **io**
  - **`close`**, **`input`**, **`lines`**, **`open`**, **`output`**, **`read`**, **`write`**, and more

... Lua Standard Library ...

- **math**
  - `abs`, `acos`, `asin`, `atan`, `ceil`, `cos`, `deg`, `exp`, `floor`, `log`, `max`, `min`, `pi`, `rad`, `random`, `randomseed`, `sin`, `sqrt`, `tan`, `type`, and more
- **modules**
  - `require`, `package.path`, and more
- **os**
  - `clock`, `date`, `execute`, `exit`, `getenv`, `remove`, `rename`, `setlocale`, `time`, and more

... Lua Standard Library

- **string**
  - **`find`**, **`format`**, **`gmatch`**, **`gsub`**, **`len`**, **`lower`**, **`match`**, **`rep`**, **`reverse`**, **`sub`**, **`upper`**, and more
- **table**
  - **`concat`**, **`insert`**, **`move`**, **`pack`**, **`remove`**, **`sort`**, and **`unpack`**
- **utf8**
  - **`char`**, **`codes`**, **`codepoint`**, **`len`**, **`offset`**, and more

Lua C API

- Enables embedding Lua interpreter in a C/C++ application
- C/C++ can
  - create any number of new Lua states
  - load all or selected standard libraries
  - execute Lua source files and strings containing Lua code
  - operate on Lua stack (push, get, and pop specific value types)
  - call Lua functions
  - register C functions so they can be called by Lua functions
  - get and set Lua global variables
  - operate on Lua tables (get and set key/value pairs)

Each Lua state has its own environment and stack.

For example, not loading the “io” library prevents reading and writing files.
Can also load a library and selectively disable some of its functions.

Calling Lua from C

main.c

```c
#include "lauxlib.h" // for most luaL_* functions
#include "lualib.h" // for luaL_openlibs

int main(void) {
  lua_State *L = luaL_newstate();
  luaL_openlibs(L); // loads ALL standard libraries

  luaL_dofile(L, "config.lua");

  // Get and print the value of a Lua global variable.
  lua_getglobal(L, "message");
  const char *message = lua_tostring(L, -1);
  lua_pop(L, 1);
  printf("message = %s\n", message);

  // Call Lua function that takes no arguments
  // and returns no values.
  lua_getglobal(L, "demo");
  if (lua_pcall(L, 0, 0, 0) != LUA_OK) {
    error("error at %s", lua_tostring(L, -1));
  }

  lua_close(L);
  return 0; // success
}
```

config.lua

```lua
message = "Hello from Lua!"

-- Determine color based on Node environment.
if os.getenv("NODE_ENV") == "production" then
  color = "red"
else
  color = "green"
end

function demo()
  print("config.lua: demo called")
end
```

It's easy to create C helper functions that remove the verbosity of the Lua C API. See **`helpers.c`** in https://github.com/mvolkmann/SwiftUICallsC.

```c
void error(const char *fmt, ...) {
  va_list argp;
  va_start(argp, fmt);
  vfprintf(stderr, fmt, argp);
  va_end(argp);
}
```

variable argument list

Lua Configuration Files

- Using Lua as an application configuration format has many advantages over formats like JSON and YAML
  - simpler syntax for non-developers
  - can include comments
  - can dynamically determine values with code

See examples in **`config.lua`** on previous slide.

JSON

```
{
  "color": "red",
  "size": {
    "width": 800,
    "height": 480
  }
}
```

Lua

```
color = "red"
size = {
  width = 800,
  height = 480
}
```

Lua Flavors ...

- **Standard Lua** - https://lua.org
  - has an interpreter and a virtual machine, both implemented in C
  - interpreter produces bytecode that runs in virtual machine
  - compiling to bytecode can be done at runtime or ahead of time (using **`luac`**)
- **LuaJIT** - https://luajit.org/
  - alternative to **`luac`** that produces smaller bytecode files
  - provides runtime optimizations that typically result in **better performance**
  - implemented by a separate team from the one that maintains Lua
  - based on Lua 5.1, so **missing features** of Lua added since then

... Lua Flavors

- **Teal** - https://github.com/teal-language/tl
  - typed dialect of Lua
  - supported types are **`any`**, **`nil`**, **`boolean`**, **`integer`**, **`number`**, **`string`**, **`function`**, **`enum`**, **`record`**, **`thread`**, and table types described by their allowed key and value types
- **Pallene** - https://github.com/pallene-lang/pallene
  - statically typed and ahead-of-time compiled sister language to Lua
  - for writing performance sensitive code that interacts with Lua; alternative to writing C modules or using LuaJIT
  - better syntax and performance for interacting with Lua data types than using Lua C API
  - can write performance-critical modules in Pallene and require them in Lua code

Pallene is the name of one of the moons of Saturn. The name of the moon is pronounced "puh lee nee", but the language designer pronounces it "pah lean".

Languages Based on Lua

- **Ravi** - http://ravilang.github.io/
  - “dialect of Lua with limited optional static typing and JIT/AOT compilers”
  - name comes from Sanskrit word for “Sun”
- **MoonScript** - https://moonscript.org/
  - “programmer friendly language that compiles into Lua”
  - “gives you the power of the fastest scripting language combined with a rich set of features”
- **Terra** - https://terralang.org/
  - “low-level system programming language that is designed to interoperate seamlessly with the Lua programming language”
  - “shares Lua’s syntax and control-flow constructs”
- **Squirrel** - http://squirrel-lang.org/
  - “high level imperative, object-oriented programming language, designed to be a light-weight scripting language”
  - “inspired by languages like Python, Javascript, and especially Lua”

Wrap Up

- Lua can be used as an alternative to other scripting languages like JavaScript and Python
- Lua can be embedded in non-Lua applications and used to allow users to script functionality
- Lua has a syntax that is easier for non-developers to learn than other programming languages
- Lua is fun!