Small is Beautiful: the design of Lua

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Language design

- many tradeoffs
  - similar to any other design process
- designers seldom talk about them
  - what a language is not good for

Typical tradeoffs

- security x flexibility
  - static verification
- readability x conciseness
- performance x abstraction
  - specially in an interpreted language

A special tradeoff

- simplicity x *almost everything else*
- several other conflicts can be solved by adding complexity
  - smarter algorithms
  - multiple mechanisms ("There's more than one way to do it")

Lua

- a scripting language
- simplicity as one of its main goals
  - small size too
- "real" language
  - many users and uses
- tricky balance between "as simple as possible" x "but not simpler"

Lua uses

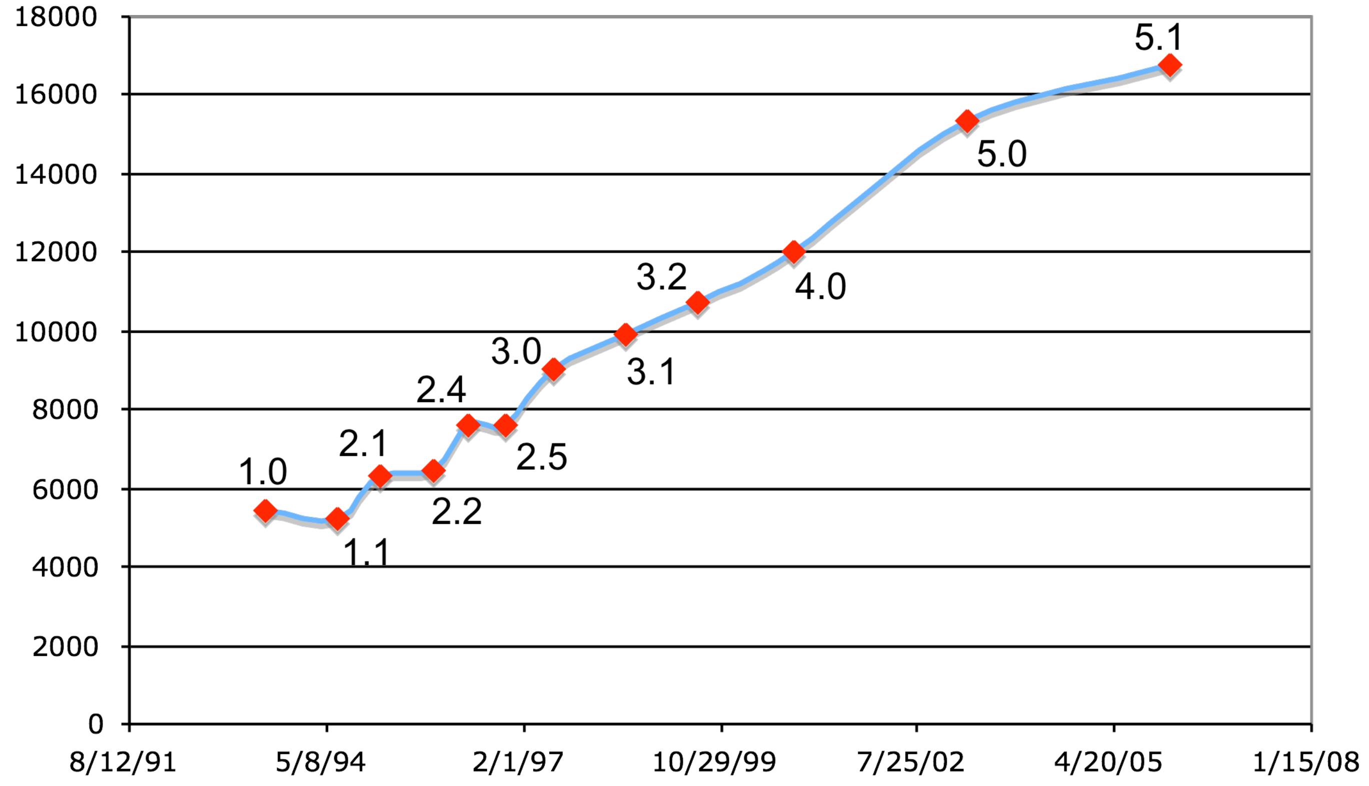
- niche in games
  - "Is Lua the ultimate game scripting language?" (GDC 2010)
- embedded devices
  - cameras (Canon), keyboards (Logitech), printers (Olivetty & Océ)
- scripting applications
  - Wireshark, Snort, Nmap

Lua main goals

- simplicity/small size
- portability
- "embedabability"
    - scripting!

Small size

- source lines of code (proxy for complexity)



Portability

- runs on most machines we ever heard of
  - Symbian, DS, PSP, PS3 (PPE & SPE), Android, iPhone, etc.
- written in ANSI C ∩ ANSI C++
  - avoids `#ifdefs`
  - avoids dark corners of the standard

Embedability

- provided as a library
- simple API
  - simple types
  - low-level operations
  - stack model
- embedded in C/C++, Java, Fortran, C#, Perl, Ruby, Python, Ada, etc.

An overview of Lua

- Conventional syntax
  - somewhat verbose

```
function fact (n)
  if n == 0 then
    return 1
  else
    return n * fact(n - 1)
  end
end
```

```
function fact (n)
  local f = 1
  for i=2,n do
    f = f * i
  end
  return f
end
```

An overview of Lua

- semantically quite similar to Scheme
- dynamically typed
- functions are first-class values with static scoping

BTW...

```
function fact (n)
  local f = 1
  for i=2,n do f = f * i; end
  return f
end
```

$\Downarrow$ syntactic sugar

```
fact = function (n)
         local f = 1
         for i=2,n do f = f * i; end
         return f
       end
```

An overview of Lua

- proper tail recursive
- Lua does not have full continuations, but have one-shot continuations
  - in the form of coroutines

Design

- tables
- coroutines
- the Lua-C API

Tables

- associative arrays
  - any value as key
- only data-structure mechanism in Lua

Why tables

- VDM: maps, sequences, and (finite) sets
  - collections
- any one can represent the others
- only maps represent the others with simple *and* efficient code

Data structures

- tables implement most data structures in a simple and efficient way
- records: syntactical sugar `t.x` for `t["x"]`:

```
t = {}
t.x = 10
t.y = 20
print(t.x, t.y)
print(t["x"], t["y"])
```

Data Structures

- arrays: integers as indices

```
a = {}
for i=1,n do a[i] = 0 end
```

- sets: elements as indices

```
t = {}
t[x] = true         -- t = t ∪ {x}
if t[x] then        -- x ∈ t?
  ...
```

Other constructions

- tables also implement modules
  - `print(math.sin(3))`
- tables also implement objects
  - with the help of a delegation mechanism and some syntactic sugar

Objects

- first-class functions + tables ≈ objects
- syntactical sugar for methods
  - handles self

```
a:foo(x)
```

$\Rightarrow$

```
a.foo(a,x)
```

```
function a:foo (x)
  ...
end
```

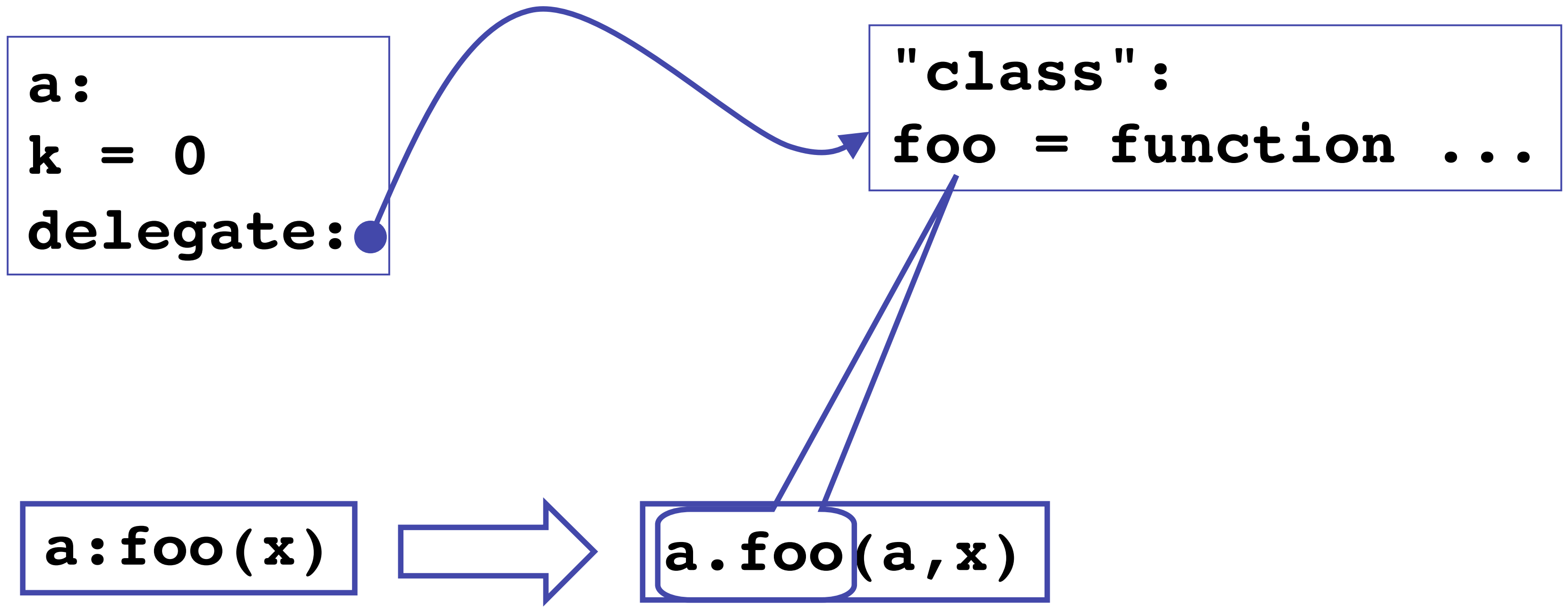
$\Downarrow$

```
a.foo = function (self,x)
  ...
end
```

Delegation

- field-access delegation (instead of method-call delegation)
- when `a` delegates to `b`, any field absent in `a` is got from `b`
  - `a[k]` becomes `(a[k] or b[k])`
- allows prototype-based and class-based objects
- allows single inheritance

Delegation at work



```
a:
k = 0
delegate:
```

```
"class":
foo = function ...
```

```
a:foo(x)
```

```
a.foo(a,x)
```

Tables: problems

- the implementation of a concept with tables is not as good as a primitive implementation
  - access control in objects
  - length in sequences
- different implementations confound programmers
  - DIY object systems

Coroutines

- old and well-established concept, but with several variations
- variations not equivalent
  - several languages implement restricted forms of coroutines that are not equivalent to one-shot continuations

Coroutines in Lua

```
c = coroutine.create(function ()
                       print(1)
                       coroutine.yield()
                       print(2)
                     end)

coroutine.resume(c)   --> 1
coroutine.resume(c)   --> 2
```

Coroutines in Lua

- first-class values
  - in particular, we may invoke a coroutine from any point in a program
- *stackful*
  - a coroutine can transfer control from inside any number of function calls
- asymmetrical
  - different commands to resume and to yield

Coroutines in Lua

- simple and efficient implementation
  - the easy part of multithreading
- first class + stackful = complete coroutines
  - equivalent to one-shot continuations
  - we can implement call/1cc
- coroutines present one-shot continuations in a format that is more familiar to most programmers

Coroutines x continuations

- most uses of continuations can be coded with coroutines
  - "who has the main loop" problem
    - producer-consumer
    - extending x embedding
  - iterators x generators
    - the same-fringe problem
  - collaborative multithreading

Coroutines x continuations

- multi-shot continuations are more expressive than coroutines
- some techniques need code reorganization to be solved with coroutines or one-shot continuations
  - oracle functions

The Lua-C API

- Lua is a library
  - formally, an ADT (a quite complex one)
  - 79 functions
- the entire language actually describes the argument to one function of that library: **`load`**
  - **`load`** gets a stream with source code and returns a function that is semantically equivalent to that code

The Lua-C API

- most APIs use some kind of "Value" type in C
  - **`PyObject`** (Python), **`jobject`** (JNI)
- problem: garbage collection
  - Python: explicit manipulation of reference counts
  - JNI: local and global references
- too easy to create dangling references and memory leaks

The Lua-C API

- Lua API has no "LuaObject" type
- a Lua object lives only inside Lua
- two structures keep objects used by C:
  - the stack
  - the registry

The Stack

- keep all Lua objects in use by a C function
- *injection functions*
  - convert a C value into a Lua value
  - push the result into the stack
- *projection functions*
  - convert a Lua value into a C value
  - get the Lua value from anywhere in the stack

The Stack

- example: calling a Lua function from C
    -

```
/* calling f("hello", 4.5) */
lua_getglobal(L, "f");
lua_pushstring(L, "hello");
lua_pushnumber(L, 4.5);
lua_call(L, 2, 1);
if (lua_isnumber(L, -1))
  printf("%f\n", lua_getnumber(L, -1));
```

The Stack

- example: calling a Lua function from C
  - push function

```
/* calling f("hello", 4.5) */
lua_getglobal(L, "f");
lua_pushstring(L, "hello");
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if (lua_isnumber(L, -1))
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```

The Stack

- example: calling a Lua function from C
  - push function, push arguments,

```
/* calling f("hello", 4.5) */
lua_getglobal(L, "f");
lua_pushstring(L, "hello");
lua_pushnumber(L, 4.5);
lua_call(L, 2, 1);
if (lua_isnumber(L, -1))
  printf("%f\n", lua_getnumber(L, -1));
```

The Stack

- example: calling a Lua function from C
  - push function, push arguments, do the call

```
/* calling f("hello", 4.5) */
lua_getglobal(L, "f");
lua_pushstring(L, "hello");
lua_pushnumber(L, 4.5);
lua_call(L, 2, 1);
if (lua_isnumber(L, -1))
  printf("%f\n", lua_getnumber(L, -1));
```

The Stack

- example: calling a Lua function from C
  - push function, push arguments, do the call, get result from the stack

```
/* calling f("hello", 4.5) */
lua_getglobal(L, "f");
lua_pushstring(L, "hello");
lua_pushnumber(L, 4.5);
lua_call(L, 2, 1);
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  printf("%f\n", lua_getnumber(L, -1));
```

The Stack

- example: calling a C function from Lua
  -

```
static int l_sqrt (lua_State *L) {
  double n = luaL_checknumber(L, 1);
  lua_pushnumber(L, sqrt(n));
  return 1;  /* number of results */
}
```

The Stack

- example: calling a C function from Lua
  - get arguments from the stack

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static int l_sqrt (lua_State *L) {
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The Stack

- example: calling a C function from Lua
  - get arguments from the stack, do computation

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static int l_sqrt (lua_State *L) {
  double n = luaL_checknumber(L, 1);
  lua_pushnumber(L, sqrt(n));
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}
```

The Stack

- example: calling a C function from Lua
  - get arguments from the stack, do computation, push arguments into the stack

```
static int l_sqrt (lua_State *L) {
  double n = luaL_checknumber(L, 1);
  lua_pushnumber(L, sqrt(n));
  return 1;  /* number of results */
}
```

The Registry

- sometimes, a reference to a Lua object must outlast a C function
  - `NewGlobalRef` in the JNI
- the *registry* is a regular Lua table always accessible by the API
  - no new concepts
  - to create a new "global reference", store the Lua object at a unique key in the registry and keeps the key

The Lua-C API: problems

- too low level
  - some operations need too many calls
- stack-oriented programming sometimes is confusing
  - what is where
- no direct mapping of complex types
  - may be slow for large values

Conclusions

- any language design involves conflicting goals
- designers must solve conflicts
  - consciously or not
- to get simplicity we must give something
  - performance, easy of use, particular features or libraries,

Conclusions

- simplicity is not an absolute goal
- it must be pursued incessantly as the language evolve
- it is much easier to add a feature than to remove one
  - start simple, grow as needed
- it is very hard to anticipate all implications of a new feature
  - clash with future features

Conclusions

- "Mechanisms instead of policies"
  - e.g., delegation
  - effective way to avoid tough decisions
  - this itself is a decision...

www.lua.org