Game development with PICO-8

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06. August 2024

Motivation

As a gamer, I always wanted to develop a small game by myself.

Prerequisites:

- Platform without much overhead.
- Language that is easy to use and learn.
- Inspiration for a “small” game.

The fantasy game console: PICO-8

- Video game console, but without real hardware.
- Emulates an 8-bit system.
- Retro aesthetics.
- Very limited on purpose.
- Encourages creativity and ingenuity.

The PICO-8 ecosystem

Language:

- Subset of Lua.
- Powerful API.

Editors:

- Code Editor with tab support.
- Sprite Editor with pixel, shape, stamp, etc. functions.
- Map Editor: use sprites to draw maps, images, etc.
- SFX Editor with pitch or tracker mode.
- Music Editor: combine multiple “instruments” to “music”.

Distribution

- Save as `.png` files and load in PICO-8.
- Or export as web-player.
- Publish the "Cartridge" (or "Cart") in BBS and explore BBS easily with `splore`.

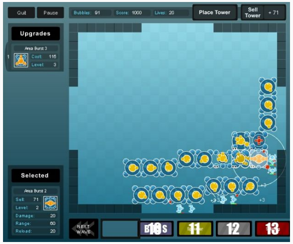
PICO-8
WWW.PICO-8.COM
BUBBLE TOWERS
BUBBLE TOWERS
BY LANGCHR86
PICO-8 CARTRIDGE

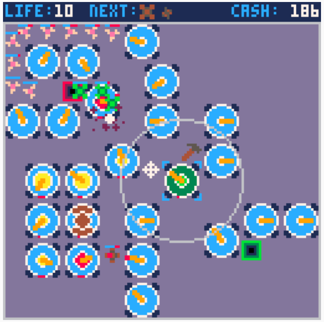
My game: Bubble Towers

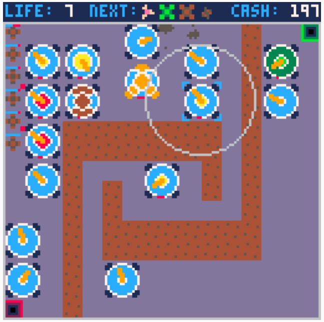
My goals:

- 2D graphics.
- No story, pure mechanics.
- Easy to learn but hard to master.
- Long-term motivation.

Result: Inspired by Bubble Tanks Tower Defence







Development with Lua

What is Lua?

Lightweight scripting language

- Dynamic typed.
- Bytecode that runs on a virtual machine.
- Automatic memory management with incremental garbage collection.

Fast and portable

- Similar speed to native C programs.
- Easy integration
  $\rightarrow$ useful for plugins and scripting.

Programming styles

- procedural
- object-oriented
- functional

Core concepts of Lua

Primitives:

- `nil`
- `boolean`
- `number` (always a double floating point)
- `string`
- `table`
- `function` (this is a first-class citizen)

Table can be used as:

- Array/List accessed by integer index (usually 1-based).
- Map accessed by `string` key.
- Struct collecting data.
- Class not only containing data but also functions.

Basics

Creation of number variable:

```
a = 1
b = a
b = 2
-- current state: a=1 ; b=2
```

This is a primitive type and therefore has value semantics (like in C/C++).

Creation of anonymous table referenced by `t` and `u`:

```
t = {}
u = t
u['x'] = 42     -- create and assign the field 'x' in t/u
print(u['x'])   -- print "42"
```

This is an object and therefore has reference semantics (like in Java/Python).

Arrays and loops

```
list = { 1, 2, 3 }

for i=1, #list do
  v = list[i]
end
```

- #list returns the size of the list.
- Lists use 1-based indices (by default).

Maps and structs

```
map = { x=2, y=4 }

print(map['x'])
print(map.x)      -- syntactic sugar for the above

assert(map.z == nil)
```

Inexistent or unset variables return `nil` (including non-existing table fields).

Enhanced iteration

```
for value in all(list) do
  print(value)
end
```

```
for index,value in ipairs(list) do
  print(index)
  print(value)
end
```

```
for key,value in pairs(map) do
  print(key)
  print(value)
end
```

Conditionals

```
if <condition> then
  <body>
elseif <condition> then
  <body>
else
  <body>
end
```

- Conditionals evaluate `false` and `nil` to `false`
- Everything else (including `0` and `""`) to `true`

Scope

- Everything is global by default.
- Limit scope with `local` keyword:
  - in functions
  - in loops
- Table/Package scope:
  - access data members with `.`
  - access functions with `.`
  - access methods with `:`

Object-oriented programming

Member functions

Functions are “normal” values.
We can access members
with the `.` operator.

```
obj = { x = 42 }

-- "nested" function
function obj.Print(self)
  print(self.x)
end

obj.Print(obj)
```

We can improve this
with the `:` operator.

```
obj = { x = 42 }

-- member function
function obj:Print()
  print(self.x)
end

obj:Print()
```

Metatables & metamethods

Metatables can define special behavior of a table:

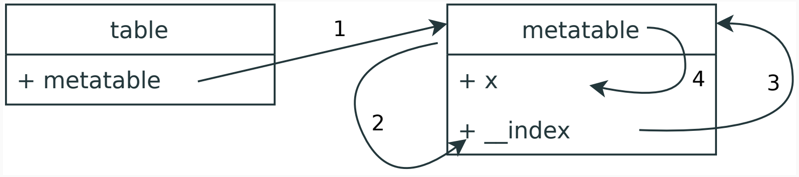
- comparison of tables (e.g. __eq for == operator)
- arithmetic (e.g. __add for + operator)
- etc.

The `__index` metamethod defines how to handle “unknown” access:

```lua
metatable = { x = 42 }
metatable.__index = metatable

table = {}        -- no 'x'
setmetatable(table, metatable)

print(table.x)   -- access 'x' in metatable
```

How the interpreter works

```lua
metatable = { x = 42 }
metatable.__index = metatable

table = {}        -- no 'x'
setmetatable(table, metatable)

print(table.x)  -- access 'x' in metatable
```



Class and instantiation

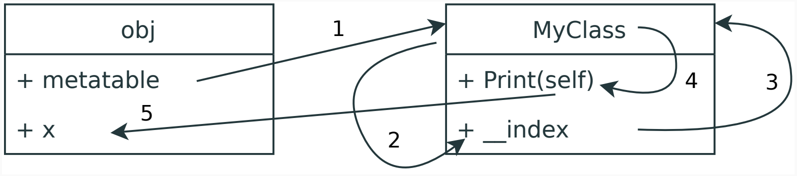
- We do not want to define functions per instance.
- Define a metatable with `__index` metamethod as “Class”.
- Define member functions in “Class” table.

```lua
MyClass = {}
MyClass.__index = MyClass

function MyClass.New()
  obj = { x = 42 }
  return setmetatable(obj, MyClass)
end

function MyClass:Print()
  print(self.x)
end
```

How the interpreter works

```lua
MyClass = {}
MyClass.__index = MyClass              -- 2 + 3

function MyClass.New()
  obj = { x = 42 }
  return setmetatable(obj, MyClass)    -- 1
end

function MyClass:Print()               -- 4
  print(self.x)                        -- 5
end
```

```lua
obj = MyClass.New()
obj:Print()
```



Example class: `Point`

```lua
Point = {}
Point.__index = Point

function Point.New(x, y)
  local o = {
    x = x;
    y = y;
  }
  return setmetatable(o, Point)
end

function Point.__sub(lhs, rhs)
  return Point.New(lhs.x - rhs.x, lhs.y - rhs.y)
end

function Point:Distance(other)
  local diff = other - self
  return math.sqrt(diff.x * diff.x + diff.y * diff.y)
end
```

```lua
-- usage
p1 = Point.New(1, 1)
p2 = Point.New(2, 2)

dist = p1:Distance(p2)
print("dist=", dist)

p3 = p1 - p2
print("x=", p3.x)
print("y=", p3.y)
```

Additional

- The caller needs to use the matching `.` or `:` operator!
- This concept can be extended to implement inheritance.
- Lua can also be used as imperative or functional language.
- It also supports Coroutines.

Development tools for Lua

Common problems in dynamic languages

Access variables with:

- wrong names
- wrong hierarchy

```
table = {
  inner = {
    x = 1
  },
  y = 2
}

print (table.x)
-- shoud use "table.inner.x"
```

Use classes with:

- wrong operator
- missing `self`

```
table = { x = 42}

function table:Get()
  return x
  -- should use "self.x"
end

print (table.Get())
-- should use "table:Get()"
```

Those problems would be detected during compile time in a static typed language.

Static code analysis

Static code analysis can help for such common problems:

- wrong names
- wrong hierarchy
- wrong operators
- missing `self`
- support for refactoring tools

Tools like:

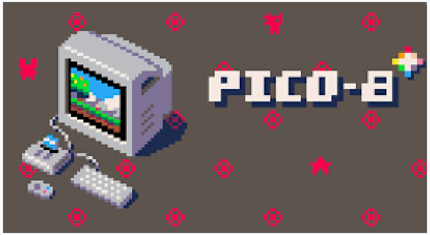
- Luanalysis
- EmmyLua

Type annotations

```lua
---@class Point
---@field x number
---@field y number
Point = {}
Point.__index = Point

---@param x number
---@param y number
---@return Point
function Point.New(x, y)
  local o = {
    x = x;
    y = y;
  }
  return setmetatable(o, Point)
end
```

Creativity because of limitations

PICO-8 Limitations



Display:	128x128, fixed 16 colour palette
Input:	6-button controllers
Carts:	32k data encoded as .png files
Sound:	4 channel, 64 definable chip blerps
Code:	P8 Lua (max 8192 tokens of code)
CPU:	4M VM instructions/sec
Sprites:	Single bank of 128 8x8 sprites (+128 shared)
Map:	128 x 32 Tilemap (+ 128 x 32 shared)

Wave Definition

- Code size is limited to 8192 tokens.
- Each enemy wave definition takes 6 tokens.
- E.g. the “insane” difficulty level has 42 waves defined like this $\rightarrow$ 252 tokens.

```
AddEnemyToList(list, 2, EnemyType.NORMAL)
AddEnemyToList(list, 4, EnemyType.HEAVY)
AddEnemyToList(list, 5, EnemyType.FAST)
AddEnemyToList(list, 3, EnemyType.GHOST)
AddEnemyToList(list, 3, EnemyType.REGENERATE)
...
```

Wave Parser

Solution:

- Replace “Add” calls by a string that is parsed into the wave list.
- `ParseWaveString` takes ~100 tokens.
- Each difficulty level is 1 string = 1 token.

```
ParseWaveString(list, "0204,0414,0524,0334,0344,...")
```

Trade-off:

- Bad readability/maintainability
  $\rightarrow$ String could be generated with an external script.

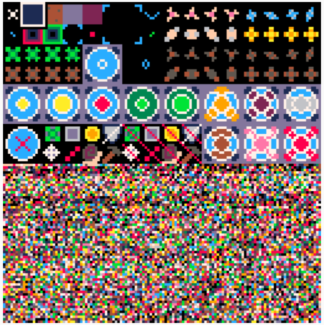
Wave Parser

```
function ParseWaveString(list, data)
  local cnt = 0
  local type = 0

  for i = 1, #data do
    local num = char2num(sub(data, i, i))
    local mode = (i - 1) % 5

    if mode == 0 then
      cnt = 10 * num           --- c
    elseif mode == 1 then
      cnt = cnt + num          --- c
    elseif mode == 2 then
      type = num               --- t
    elseif mode == 3 then
      local value_mul = num / 4 --- v
      add(list, WaveNew(cnt, EnemyNew(type, value_mul)))
    end
  end
```

```
function char2num(char)
  for num = 1, 10 do
    if char ==
        sub("0123456789", num, num) then
      return num - 1
    end
  end
end
```

Title image compression

- Title screen fills the whole 128x128 pixels.
- This is equals to 256 sprites.
- But we only can define 256 sprites at maximum.

BUBBLE
TOWERS


Use compression algorithms like PX9 with trade-off:

- Save half of the data (pixels)
- but introduce ~240 tokens in code.

Game development basics

Program flow

Each PICO-8 program must define the following functions:

```lua
function _init()
  -- startup handling
end

function _update()
  -- logic calculations
end

function _draw()
  -- image rendering
end
```

Basic engine execution

The engine internally will call them similarly like:

```
_init()
while true do
  _update()
  if enough_time() then
    _draw()
  end
  sleep_until_next_frame()
end
```

- The engine runs by default with 30 FPS.
- If execution of one loop takes too long the next iteration will only call `_update()`.
- This ensures correct behavior of the game logic (e.g. physics) and only reduce graphical “smoothness”.

This is handled similarly in other game engines (e.g. Android)

Function delegation

- Do not call all processing functions directly in `_update()`.
- Introduce a hierarchy of objects/agents that have their own `_update()` function.
- Same for `_draw()`

Main:

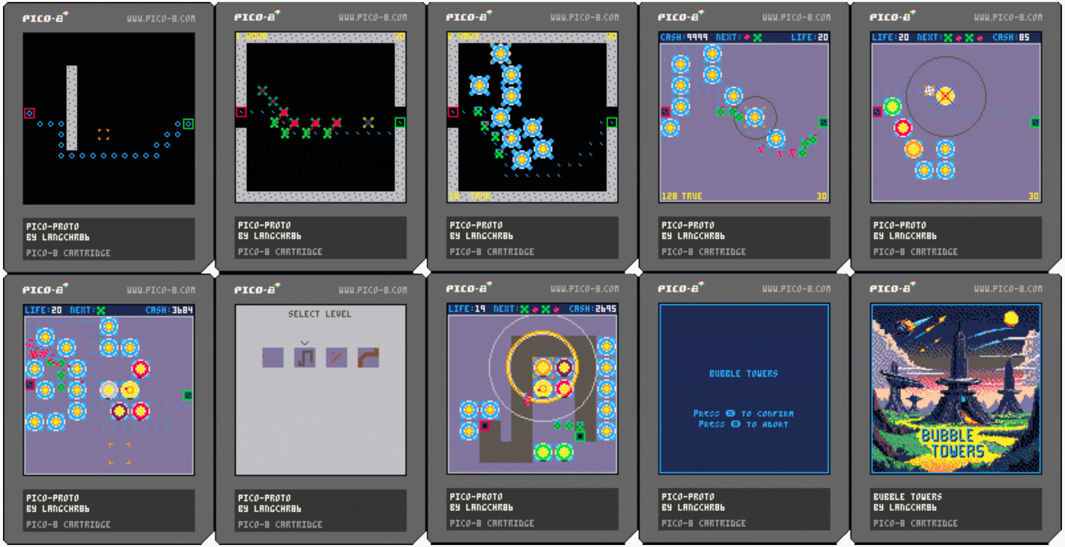
- `StartScreen`
- `DifficultySelection`
- `MapSelection`
- `GameSession`
  - List of `Towers`
  - List of `Enemys`
    - List of `Bullets`
- EndScreen

The _update() hierarchy

```
function _update()
  active_session:Update()
end



function GameSession:Update()
  -- other logic

  for tower in all(self.tower_list) do
    tower:Update(self.enemy_list)
  end

  for enemy in all(self.enemy_list) do
    enemy:Update()
  end
end
```

```
function Enemy:Update()
  -- other logic

  for bullet in all(self.bullet_list) do
    if bullet:InTarget() then
      self:Hit(bullet)
    else
      bullet:Update()
    end
  end
end



function Bullet:Update()
  -- logic
end
```

Development history



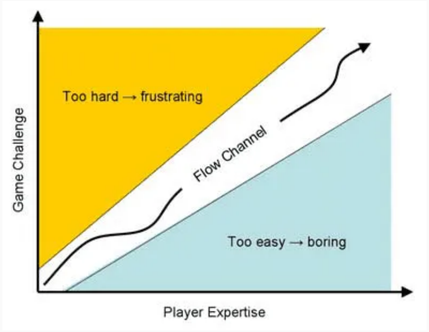
Rapid prototyping

- Create basic variant of new mechanics and test it.
- Add more mechanics and fine tune.
- Or create separate prototypes for individual concepts.
- A/B tests for groups of mechanics or in test groups.
- Get feedback from testers.
- Iterate.
- Graphic details, title screen, etc. come last.

Game balancing

Requirements:

- The game should be challenging but not too hard.
- It should attract beginners and experts.
- All mechanics should be almost equal important and useful.



Approaches:

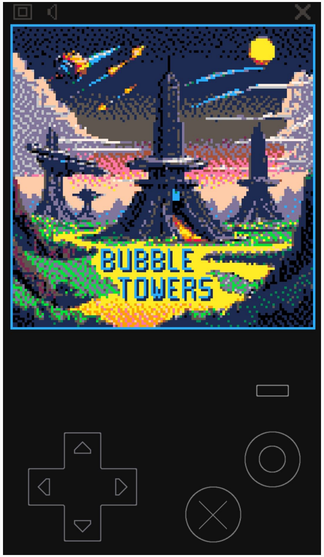
- "Buff" and "Nerf" elements to get mechanics into balance.
- Test various strategies to find unbalanced elements.
- Change enemy strengths or rewards.

Other interesting topics

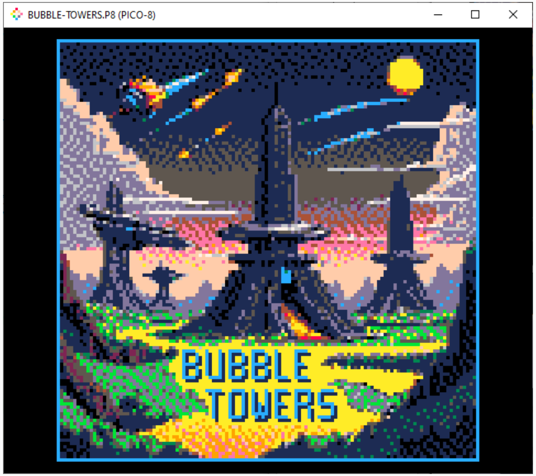
- Sprite flags.
- Sound/music design.
- Angle calculations:
- Collision detection.
- Weight algorithms:
  - Target selection.
  - Shoot only on "alive" targets.
- Path finding:
  - A-Star.
- Animations:
  - Particle animations for explosions.
  - Sprite animations.

Addendum

Software-Players



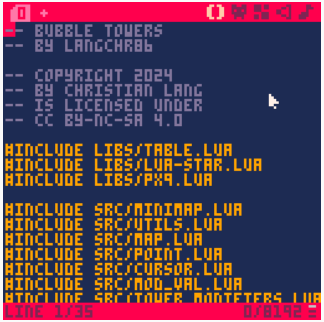
Web-Player (Mobile)



Desktop-Player

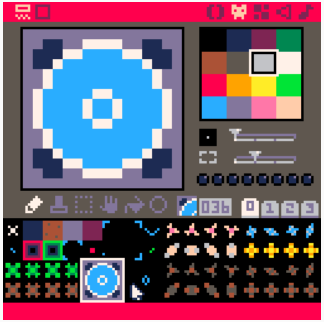
Handhelds

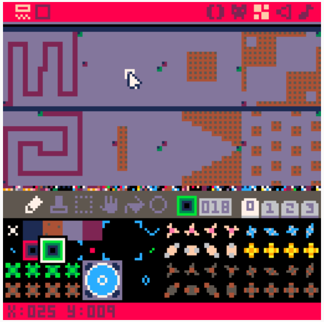
- Powkiddy RGB30
- Anbernic RG35XX Plus

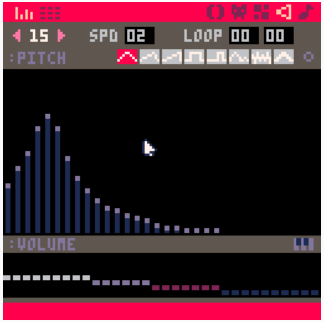


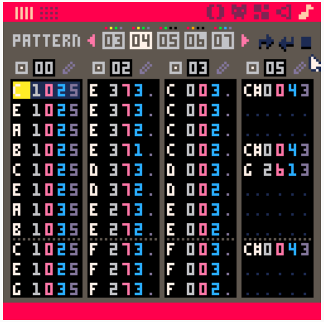
```
-- BUBBLE TOWERS
-- BY LANGCHR86

-- COPYRIGHT 2024
-- BY CHRISTIAN LANG
-- IS LICENSED UNDER
-- CC BY-NC-SA 4.0

#INCLUDE LIBS/TABLE.LUA
#INCLUDE LIBS/LUA-STAR.LUA
#INCLUDE LIBS/PX9.LUA

#INCLUDE SRC/MINIMAP.LUA
#INCLUDE SRC/UTILS.LUA
#INCLUDE SRC/MAP.LUA
#INCLUDE SRC/POINT.LUA
#INCLUDE SRC/CURSOR.LUA
#INCLUDE SRC/MOD_VAL.LUA
#INCLUDE SRC/TOWER_MODIFIERS.LUA
```

LINE 1/35 0/8192









```
PATTERN ◀ 03 04 05 06 07 ▶

00        02        03        05
C 1025    E 373.    C 003.    C#0043
E 1025    E 373.    C 003.    ......
A 1025    E 372.    C 002.    ......
B 1025    E 371.    C 002.    C#0043
C 1025    D 373.    D 003.    G 2613
E 1025    D 372.    D 002.    ......
A 1035    E 273.    E 003.    ......
B 1035    E 272.    E 002.    ......
C 1025    F 273.    F 003.    C#0043
E 1025    F 273.    F 003.    ......
G 1035    F 273.    F 002.    ......
```

PICO-8 Resources

My Project:

- Bubble Towers github
- Bubble Towers BBS

Others:

- awesome list for PICO-8
- Pico-8 Hero Tutorials

Official:

- PICO-8 Resources
- PICO-8 FAQ
- PICO-8 User Manual
- PICO-8 BBS Carts
- PICO-8 Wiki

Lua Resources

- Lua About
- Lua Getting started
- Programming in Lua
- Online Compiler