Lua in MetaPost

Introduction

For some years I have been wondering if we could escape to Lua inside MetaPost, or, in practice, to mplib in LuaTeX. The idea is simple: embed Lua code in a MetaPost file that gets run as soon as it's seen. In case you wonder why Lua code makes sense, imagine generating graphics using external data. The capabilities of Lua to deal with that is more flexible and advanced than in MetaPost. Of course we could generate a MetaPost definition of a graphic from data, but it often makes more sense to do the reverse. I finally found time and a reason to look into this, and in the following sections I will describe how it's done.

The basics

The approach is comparable to LuaTeX's `\directlua`. That primitive can be used to execute Lua code, and in combination with `tex.print` we can pipe strings back into the TeX input stream. There, there is a complication in that we have to be able to operate under different so-called catcode regimes: the meaning of characters can differ per regime. We also have to deal with line endings in special ways as they relate to paragraphs and such. MetaPost doesn't have that complication; being perfectly happy with simple strings. For putting back input into MetaPost a mechanism similar to `scantokens` can be used. That way we can return anything (including nothing) as long as MetaPost can interpret it and as long as it fulfils the expectations.

```
numeric n ;
n := scantokens("123.456") ;
```

A script is run as follows:

```
numeric n ;
n := runscript("return '123.456'") ;
```

This primitive doesn't have the word `lua` in its name so, in principle, any wrapper around the library can use it as a hook. In the case of LuaTeX the script language is of course Lua. At the MetaPost end we only expect a string. How that string is constructed is completely up to the Lua script. In fact, the user is completely free to implement the runner any way she or he wants, like:

```
local function scriptrunner(code)
  local f = loadstring(code)
  if f then
    return tostring(f())
  else
    return ""
  end
end
```

This is hooked into an instance as follows:

```
local m = mplib.new {
  ...
  run_script = scriptrunner,
  ...
}
```

Now, beware, this is not the ConTeXt way. We provide print functions and other helpers, which we will explain in the next section.

Helpers

After I got this feature up and running I played a bit with possible interfaces at the ConTeXt (read: MetaFun) end and ended up with a bit more advanced runner where no return value is used. The runner is wrapped in the `lua` macro.

```
numeric n ;
n := lua("mp.print(12.34567)") ;
draw textext(n) xsized 4cm withcolor maincolor   ;
```

This renders as:

12.34567

In case you wonder how efficient calling Lua is, don't worry; it's fast enough, especially if you consider suboptimal Lua code and the fact that we switch between machineries.

```
draw image (
  lua("statistics.starttiming()") ;
  for i=1 upto 5000 :
    draw lua ("mp.pair
      (math.random(-74,126),
        math.random(-35,35))" ) ;
  endfor ;
  setbounds currentpicture to
    fullsquare xyscaled (100,20) ;
  lua("statistics.stoptiming()") ;
  draw textext(lua
    ("mp.print(
      statistics.elapsedtime())")
    ) ysized 40 ;
) withcolor maincolor
  withpen pencircle scaled 1 ;
```

Here the part:

```
draw lua ("mp.pair
  (math.random(-74,126),
    math.random(-35,35))" ) ;
```

effectively becomes (for instance):

```
draw scantokens "(25,15)" ;
```

which in turn becomes:

```
draw scantokens (25,15) ;
```

The same happens with this:

```
draw textext (lua
  ("mp.print
     (statistics.elapsedtime())"
   ) ) ...
```

This becomes for instance:

```
draw textext(scantokens "1.23") ...
```

and therefore:

```
draw textext(1.23) ...
```

We can use `mp.print` here because the `textext` macro can deal with numbers. The following also works:

```
draw textext(lua
   ("mp.quoted
    (statistics.elapsedtime())"
   )
) ...
```

Now we get (in MetaPost speak):

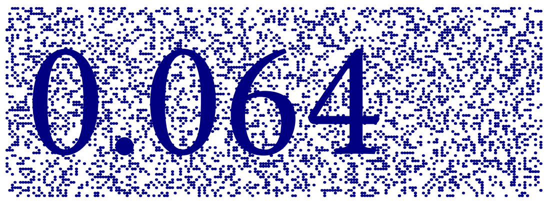
```
draw textext(scantokens
  (ditto & "1.23" & ditto) ...
```

Here `ditto` represents the double quotes that mark a string. Of course, because we pass the strings directly to `scantokens`, there are no outer quotes at all, but this is how it can be simulated. In the end we have:

```
draw textext("1.23") ...
```

The decision to use `mp.print` or `mp.quoted` depends on what the expected return value is; an assignment to a numeric can best be a number or an expression resulting in a number.

This graphic becomes:



The runtime on my current machine is some 0.25 seconds without and 0.12 seconds with caching. But to be honest, speed is not really a concern here as the amount of complex MetaPost graphics can be neglected compared to extensive node list manipulation. With LuajitTEX generating the graphic takes 15% less time.[1]

The three print commands accumulate their arguments:

```
numeric n ;
n := lua("mp.print(1) mp.print('+') mp.print(2)")
;
draw textext(n) xsized 1cm
  withcolor maincolor  ;
```

As expected we get:

Equally valid is:

1. Processing a small 8 page document like this takes about one second, which includes loading a bunch of fonts.

```
numeric n ;
n := lua("mp.print(1,'+',2)") ;
draw textext(n) xsized 1cm
   withcolor maincolor  ;
```

This gives the same result:

3

Of course all kind of action can happen between the prints. It is also legal to have nothing returned as could be seen in the 10.000 dot example; there the timer related code returns nothing, so effectively we have `scantokens("")`. Another helper is `mp.quoted`, as in:

```
draw textext
  (lua
    ("mp.quoted
      ('@0.3f',
       " & decimal n & "
      )"
    )
  ) withcolor maincolor  ;
```

This typesets 3.000. Note the `@`. When no percent character is found in the format specifier, we assume that an `@` is used instead.

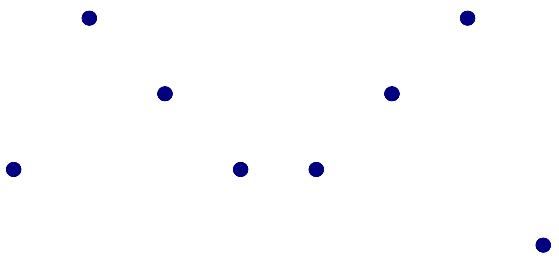
But, the real benefit of embedded Lua is when we deal with data that is stored at the Lua end. First we define a small dataset:

```
\startluacode
table.save("demo-data.lua",
  {
    { 1, 2 }, { 2, 4 }, { 3, 3 },
    { 4, 2 }, { 5, 2 }, { 6, 3 },
    { 7, 4 }, { 8, 1 },
  }
)
\stopluacode
```

There are several ways to deal with this table. I will show clumsy as well as better looking ways.

```
lua("MP = { }
MP.data = table.load('demo-data.lua')"
) ;
numeric n ;
lua("mp.print('n := ',\#MP.data)") ;
for i=1 upto n :
  drawdot
    lua("mp.pair
      (MP.data[" & decimal i & "])"
    ) scaled cm
    withpen pencircle scaled 2mm
    withcolor maincolor  ;
endfor ;
```

Here we load a Lua table and assign the size to a MetaPost numeric. Next we loop over the table entries and draw the coordinates.

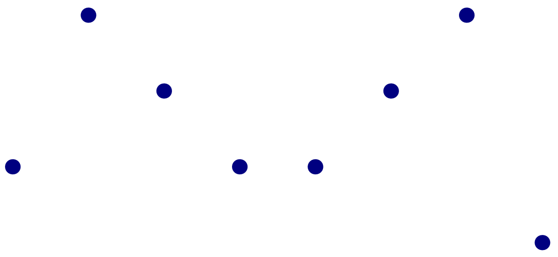


We will stepwise improve this code. In the previous examples we omitted wrapper code but here we show it:

```
\startluacode
  MP.data = table.load('demo-data.lua')
  function MP.n()
    mp.print(#MP.data)
  end
  function MP.dot(i)
    mp.pair(MP.data[i])
  end
\stopluacode
```

```
\startMPcode
  numeric n ;
  n := lua("MP.n()") ;
  for i=1 upto n :
    drawdot
      lua("MP.dot
        (" & decimal i & ")"
      ) scaled cm
      withpen pencircle scaled 2mm
      withcolor maincolor  ;
  endfor ;
\stopMPcode
```

So, we create a few helpers in the `MP` table. This table is predefined so, normally, you don't need to define it. You may, however, decide to wipe it clean.



You can decide to hide the data:

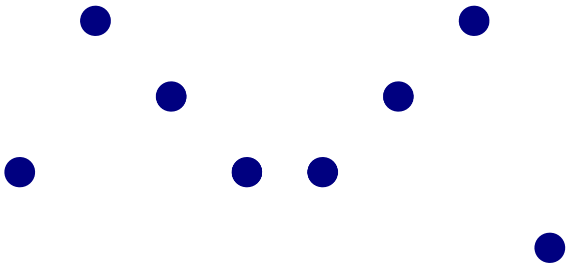
```
\startluacode
  local data = { }

  function MP.load(name)
    data = table.load(name)
  end
  function MP.n()
    mp.print(#data)
  end
  function MP.dot(i)
    mp.pair(data[i])
  end
\stopluacode
```

It is possible to use less Lua, for instance in:

```
\startluacode
  local data = { }
  function MP.loaded(name)
    data = table.load(name)
    mp.print(#data)
  end
  function MP.dot(i)
    mp.pair(data[i])
  end
\stopluacode
```

```
\startMPcode
  for i=1 upto
    lua
      ("MP.loaded
        ('demo-data.lua')"
      ) :
    drawdot
      lua("MP.dot(",i,")") scaled cm
      withpen pencircle scaled 4mm
      withcolor maincolor  ;
  endfor ;
\stopMPcode
```

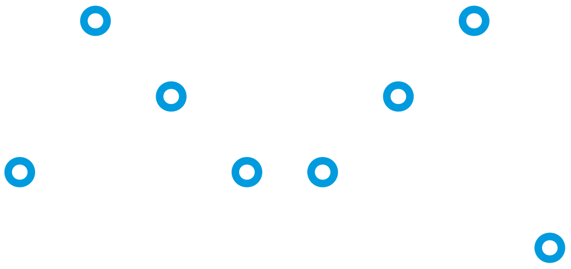
Here we also omit the `decimal` because the `lua` macro is clever enough to recognize it as a number.



By using some MetaPost magic we can even go a step further in readability:

```
\startMPcode{doublefun}
  cmykcolor maincolor;
  maincolor := (1,.15,0,0);
  lua.MP.load("demo-data.lua") ;

  for i=1 upto lua.MP.n() :
    drawdot lua.MP.dot(i) scaled cm
      withpen pencircle scaled 4mm
      withcolor maincolor  ;
  endfor ;

  for i=1 upto MP.n() :
    drawdot MP.dot(i) scaled cm
      withpen pencircle scaled 2mm
      withcolor white ;
  endfor ;
\stopMPcode
```

Here we demonstrate that it also works in `double` mode; which makes sense when processing data from other sources. Note how we omit the `lua.` prefix: the `MP` macro will deal with that.



So in the end we can simplify the code that we started with to:

```
\startMPcode{doublefun}
  for i=1 upto
    MP.loaded("demo-data.lua") :
    drawdot
      MP.dot(i) scaled cm
      withpen pencircle scaled 2mm
      withcolor maincolor  ;
  endfor ;
\stopMPcode
```

Access to variables

The question with such mechanisms is always: how far should we go. Although MetaPost is a macro language, it has properties of procedural languages. It also has more introspective features at the user end. For instance, one can loop over the resulting picture and manipulate it. This means that we don't need full access to MetaPost internals. However, it makes sense to provide access to basic variables: `numeric`, `string` and `boolean`.

```
draw textext(lua
  ("mp.quoted
    ('@0.15f',
      mp.get.numeric('pi')-math.pi
    )"
  )
)
  ysized .5cm
  withcolor maincolor  ;
```

In double mode you will get zero printed but in scaled mode we definitely get a different result:

-0.000006349878856

In the next example we use `mp.quoted` to make sure that we indeed pass a string. The `textext` macro can deal with numbers, but an unquoted `yes` or `no` is asking for problems.

```
boolean b ;
b := true ;
draw textext(
  lua
    ("mp.quoted(mp.get.boolean('b')
     and 'yes' or 'no')"
    )
)
  ysized 1cm
  withcolor maincolor  ;
```

Especially when more text is involved, it makes sense to predefine a helper in the `MP` namespace. Because MetaPost, currently, doesn't like newlines in the middle of a string, a `lua` call has to be on one line.

yes

Here is an example where Lua does something that would be close to impossible, especially if more complex text is involved.

```
string s ;
s := "" ; % ""
draw textext
  (lua
    ("mp.quoted
      (characters.lower
        (mp.get.string('s')
        )
      )"
    )
  )
  ysized 1cm
  withcolor maincolor  ;
```

As you can see here, the whole repertoire of helper functions can be used in a MetaFun definition.

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The library

In ConTEXt we have a dedicated runner, but for the record we mention the low level constructor:

```
local m = mplib.new {
  ...
  script_runner = function(s) return
    loadstring(s)() end,
  script_error  = function(s)
    print(s) end,
  ...,
}
```

An instance (in this case `m`) has a few extra methods. Instead you can use the helpers in the library.

`m:get_numeric(name)`	returns a numeric (double)
`m:get_boolean(name)`	returns a boolean (`true` or `false`)
`m:get_string (name)`	returns a string
`mplib.get_numeric(m,name)`	returns a numeric (double)
`mplib.get_boolean(m,name)`	returns a boolean (`true` or `false`)
`mplib.get_string (m,name)`	returns a string

In ConTEXt the instances are hidden and wrapped in high level macros, so there you cannot use these commands.

ConTEXt helpers

The mp namespace provides the following helpers:

`print(...)`	returns one or more values
`pair(x,y) pair(t)`	returns a proper pair
`triplet(x,y,z) triplet(t)`	returns an RGB color
`quadruple(w,x,y,z) quadruple(t)`	returns an CMYK color
`format(fmt,...)`	returns a formatted string
`quoted(fmt,...) quoted(s)`	returns a (formatted) quoted string
`path(t[,connect][,close])`	returns a connected (closed) path

The mp.get namespace provides the following helpers:

`numeric(name)`	gets a numeric from MetaPost
`boolean(name)`	gets a boolean from MetaPost
`string(name)`	gets a string from MetaPost

Paths

In the meantime we got several questions on the ConTEXt mailing list about turning coordinates into paths. Now imagine that we have this dataset:

```
10 20 20 20 -- sample 1
30 40 40 60
50 10

10 10 20 30 % sample 2
30 50 40 50
50 20

10 20 20 10 # sample 3
30 40 40 20
50 10
```

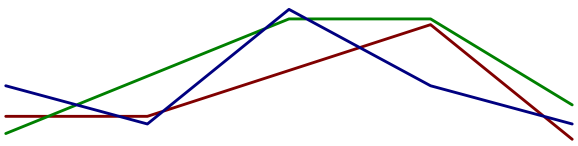
In this case I have put the data in a buffer, so that it can be shown here, as well as used in a demo. Note how we can add comments. The following code converts this into a table with three subtables.

```
\startluacode
  MP.myset =
    mp.dataset
      (buffers.getcontent("dataset"))
\stopluacode
```

We use the MP (user) namespace to store the table. Next we turn these subtables into paths:

```
\startMPcode
  for i=1 upto
    lua("mp.print(mp.n(MP.myset))") :
  draw
    lua("mp.path
      (MP.myset[" & decimal i & "]
      )"
    )
    xysized (HSize,10ExHeight)
    withpen
      pencircle scaled .25ExHeight
    withcolor basiccolors[i]/2 ;
  endfor ;
\stopMPcode
```

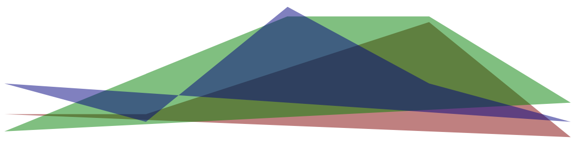
This gives:



Instead, we can fill the path; in which case we also need to close it. The true argument deals with that:

```
\startMPcode
  for i=1 upto
    lua("mp.print(mp.n(MP.myset))") :
  path p ; p :=
    lua("mp.path
      (MP.myset
        [" & decimal i & "],
        true
      )"
    )
    xysized (HSize,10ExHeight) ;
  fill p
    withcolor basiccolors[i]/2
    withtransparency (1,.5) ;
  endfor ;
\stopMPcode
```

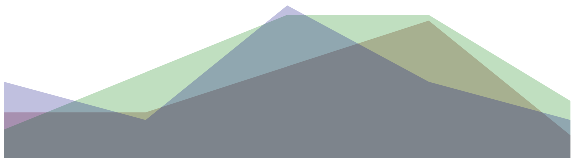
We get:



The following makes more sense:

```
\startMPcode
  for i=1 upto
    lua("mp.print
      (mp.n(MP.myset))"
    ) :
  path p ;
  p := lua("mp.path
    (MP.myset[" & decimal i & "])"
    )
    xysized (HSize,10ExHeight) ;
  p :=
    (xpart llcorner boundingbox p,0)
    -- p --
    (xpart lrcorner boundingbox p,0)
    -- cycle ;
  fill p
    withcolor basiccolors[i]/2
    withtransparency (1,.25) ;
  endfor ;
\stopMPcode
```

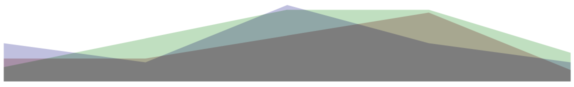
So this gives:



This (area) fill is so common, that we have a helper for it:

```
\startMPcode
  for i=1 upto
    lua("mp.size(MP.myset)") :
  fill area
    lua("mp.path
      (MP.myset[" & decimal i & "])"
    )
    xysized (HSize,5ExHeight)
    withcolor basiccolors[i]/2
    withtransparency (2,.25) ;
  endfor ;
\stopMPcode
```

So this gives:



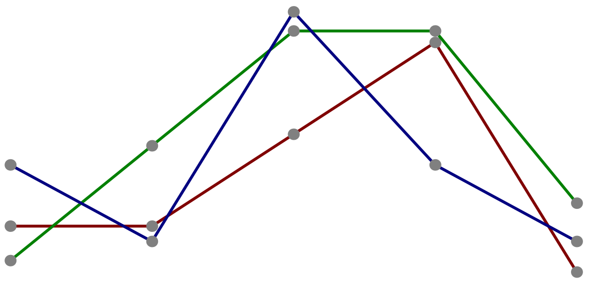
This snippet of MetaPost code still looks kind of horrible, so how can we make it look better? Here is an attempt. First we define a bit more Lua:

```
\startluacode
local data = mp.dataset
    (buffers.getcontent("dataset"))
MP.dataset = {
  Line = function(n) mp.path(data[n]) end,
  Size = function()  mp.size(data)  end,
}
\stopluacode
```

We can now make the MetaPost look more natural. Of course, this is possible because in MetaFun the lua macro does some extra work.

```
\startMPcode
  for i=1 upto
    lua.MP.dataset.Size() :
  path p ;
  p := lua.MP.dataset.Line(i)
    xysized (HSize,20ExHeight) ;
  draw
    p
    withpen
      pencircle scaled .25ExHeight
    withcolor basiccolors[i]/2 ;
  drawpoints
    p
    withpen pencircle scaled ExHeight
    withcolor .5white ;
  endfor ;
\stopMPcode
```

As expected, we get the desired result:



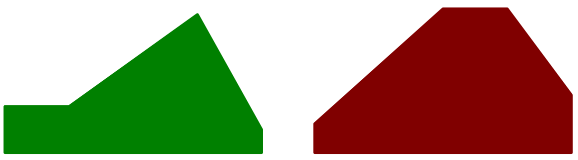
Once we start making things look nicer and more convenient to code, we quickly end up with helpers like those in the next example. First we save some demo data in files:

```
\startluacode
  io.savedata("foo.tmp","10 20 20 20 30 40 40 60
50 10")
  io.savedata("bar.tmp","10 10 20 30 30 50 40 50
50 20")
\stopluacode
```

We load the data in datasets:

```
\startMPcode
  lua.mp.datasets.load("foo","foo.tmp");
  lua.mp.datasets.load("bar","bar.tmp");
  fill area
  lua.mp.datasets.foo.Line()
  xysized (HSize/2-EmWidth,10ExHeight)
  withpen
    pencircle scaled .25ExHeight
  withcolor green/2 ;
  fill area
  lua.mp.datasets.bar.Line()
  xysized (HSize/2-EmWidth,10ExHeight)
  shifted (HSize/2+EmWidth,0)
  withpen
    pencircle scaled .25ExHeight
  withcolor red/2 ;
\stopMPcode
```

Because the datasets are stored by name, we can use them without worrying about them being forgotten:



If no tag is given, the filename (without suffix) is used as a tag, so the following is valid:

```
\startMPcode
  lua.mp.datasets.load("foo.tmp") ;
  lua.mp.datasets.load("bar.tmp") ;
\stopMPcode
```

The following methods are defined for a dataset:

method	usage
Size	the number of subsets in a dataset
Line	the joined pairs in a dataset making a non-closed path
Data	the table containing the data (in subsets, so there is always at least one subset)

Due to limitations in MetaPost suffix handling the methods start with an uppercase character.

Remark

Currently, the features described here are still experimental but the interface will not change. There might be a few more accessors and for sure more Lua helpers will be provided. As usual I need some time to play with it before I make up my mind. It is also possible to optimize the MetaPost–Lua script call a bit, but I might do that later.

When we played with this interface we ran into problems with loop variables and macro arguments. These are internally more or less anonymous. Take this:

```
for i=1 upto 100 : draw(i,i) endfor ;
```

The `i` is not really a variable with name `i` but becomes an object (capsule) when the condition is scanned, and a reference to that object when the body is scanned. The body of the for loop gets expanded for each step, but at that time there is no longer a variable `i`. The same is true for variables in:

```
def foo(expr x, y, delta) =
  draw (x+delta,y+delta)
enddef ;
```

We are still trying to get this right with the Lua interface. Interesting is that when we were exploring this, we ran into quite some cases where we could make MetaPost abort due some memory or stack overflow. Some are just bugs in the new code (due to the new number model) while others come with the design of the system: border cases that never seem to happen in interactive use while the library use assumes no interaction in case of errors.

In ConTEXt there are more features and helpers than shown here but these are discussed in the MetaFun manual.

Hans Hagen