Profiling Memory in Lua

Lua Workshop 2015

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About Me

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About This Talk

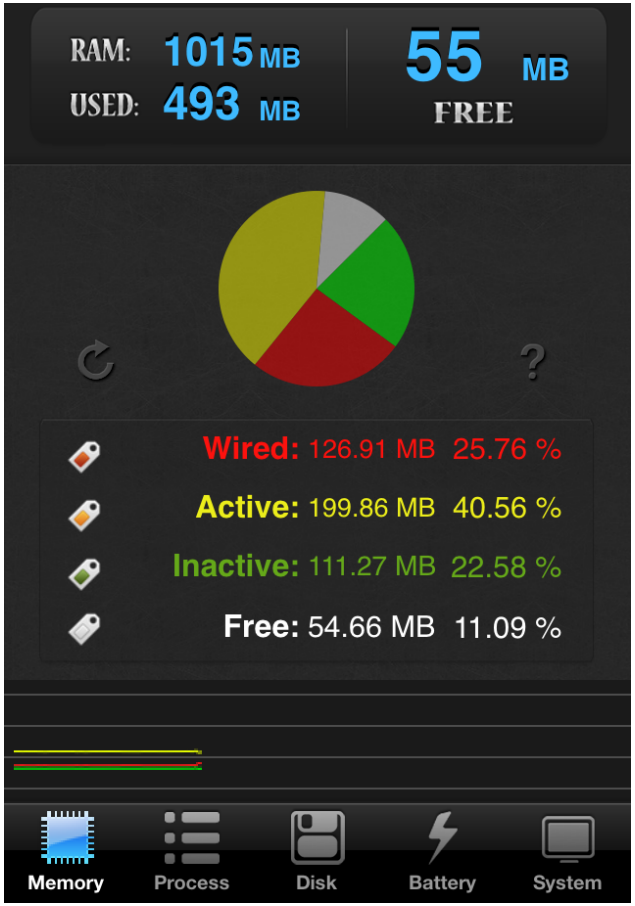
- MSc
- 2011.....@!$#.....!@#@ !@#!$@.....2015
- Garbage Collection - Memory Leak - Java

How can we help users identify and debug memory issues?

Agenda

- Problem
- Existing Tools
- Proposed Tools
- Evaluation

Memory Consumption



Memory Bloat

"Memory consumption that exceeds the programmer expectations."

Main Cases:

- Object churn
- Data structure misuse
- Memory Leak
- Memory Hoarding (not removing "useless references")

Main Problems:

- Program execution slowdown
- System slowdown
- Program crash

Existing Tools

- Lua Memory Profiler
  - Lua 5.0
  - Basic features (implemented in 5.1)
  - Recompile the interpreter
- ProFi
  - 2012
  - Execution time focus
  - One memory function (manually called)

Existing Tools

- Luatraverse
  - 2006 and last 'update' 2010
  - Traverses references to live objects applying a given function
  - `countreferences` and `findallpaths`
- microscope
  - 2013 and last update 8 months ago
  - Dump Lua values into a file using GraphViz format
  - Generate a graphical visualization of the graph

Proposed Tools

- `luamemprofiler` (https://github.com/pmusa/luamemprofiler)
- `lmprof` (https://github.com/pmusa/lmprof)

Guidelines:

- Easy to integrate into existing programs
- Not impose **too much** overhead
- Provide readable reports for a regular programmer

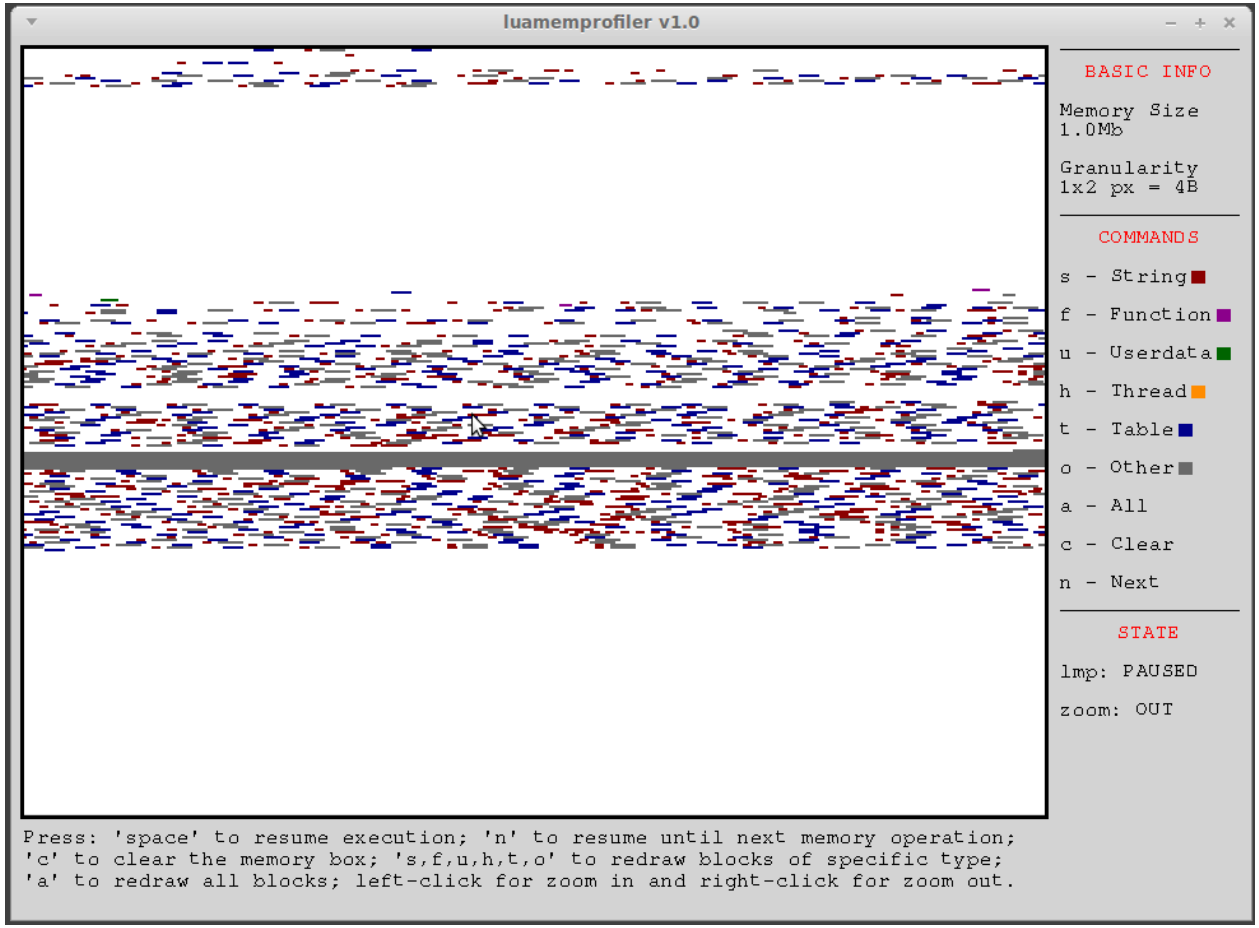
luamemprofiler

Motivation

- "Real time" vizualization
- Type/class data categorization
- Ongoing interaction

luamemprofiler

Interface



luamemprofiler

Final Report

```
Number of Mallocs  = 192     Total Malloc Size  =  17.8 Kb
Number of Reallocs = 302     Total Realloc Size = 400.0 Mb
Number of Frees    =  25     Total Free Size    =  10.5 Kb

Number of Mallocs of Each Type:
  String = 60 | Function = 11 | Userdata =   0
  Thread =  0 | Table    = 20 | Other    = 101

Maximum Memory Used = 400.0 Mb
```

luamemprofiler

Implementation

- `lua_setallocf`
- Counters
- Hash table + Auxiliary Lists

luamemprofiler

Problems

- Finalizer
- Categorization
- Display

Improf

Motivation

- gprof
  - "Function profiler"
  - After execution report (two phase)

Improf

Flat Report

```
===== Showing 3 of 10 functions that allocated memory ====

  %      shallow   retained            shallow    retained
 mem       mem       mem     calls   mem/call   mem/call   name

97.99  392.0 MB  392.0 MB      12   32.67 MB    32.7 MB    nv*
 2.00    8.0 MB    8.0 MB       1    8.00 MB     8.0 MB    RV*
 0.01    0.0 MB    0.0 MB       1    0.02 MB     0.0 MB    df*

newvec (SM.lua:29) | RandomVector (SM.lua:80) | dofile [C]
```

Improf

Call-Graph Report

```
index   %mem   retained   shallow  call(rec)   name       index
                                   call/total  children
=============================================================
[1]----100.00--160.0-MB----0.0-MB------1---------f1-------[1]
               130.0 MB   80.0 MB      2/2          f2       [2]
                30.0 MB   10.0 MB      1/1          f3       [4]
=============================================================
               130.0 MB  130.0 MB      2/2          f1       [1]
[2]-----81.25--130.0-MB---80.0-MB------2---------f2-------[2]
                50.0 MB   50.0 MB      5/12         f4       [3]
=============================================================
                50.0 MB   50.0 MB      5/12         f2       [2]
                20.0 MB   20.0 MB      2/12         f3       [4]
[3]-----43.75---70.0-MB---70.0-MB-----12(5)------f4-------[3]
=============================================================
                30.0 MB   10.0 MB      1/1          f1       [1]
[4]-----18.75---30.0-MB---10.0-MB------1---------f3-------[4]
                20.0 MB   20.0 MB      2/12         f4       [3]
=============================================================
```

Improf

Implementation

- `lua_setallocf`
- `lua_sethook`
- Smart Stack
- Hash table with caller/callee pair

Improf

Problems

- Finalizer
- All vs. Memory-Alloc functions
- Tail calls
- Cicles

Evaluation

- Ease of Use
- Report Usefulness
- Performance Analysis

Evaluation

Ease of Use

- Both tools use the same technique
- Simple

```
local lmp = require"luamemprofiler"
lmp.start()

-- original script code ...

lmp.stop()
```

- luamemprofiler: optional parameter to enable the display

Evaluation

Report Usefulness

- Extract information with superficial application knowledge
- Used 2 programs:
  - Black and Scholes — financial application that precify portfolio options
  - CAPTCHA JPEG — an application to filter CAPTCHA images in the JPEG format to make it easier to perform automatic optical character recognition (OCR)

Black and Scholes

Previous Knowledge

- Input: 1 million line file with 9 numeric columns
- Activity: calculate different values

Black and Scholes

luamemprofiler Info

```
Number of Mallocs  = 8,001,694       Total Malloc Size  = 1.14 GB
Number of Reallocs =       162       Total Realloc Size = 0.13 GB
Number of Frees    = 6,000,821       Total Free Size    = 0.61 GB

Maximum Memory Used = 700 MB

Number of Allocs of Each Type:
String = 1,001,662 | Function = 1,000,004 | Userdata =         2
Thread =         1 | Table    = 1,000,009 | Other    = 5,000,016
```

* display shows that memory allocation can be divided in 3 phases

Black and Scholes

Improf Flat Report

```
===== Showing 5 of 699 functions that allocated memory =====
   %      shallow    retained
 mem       mem          mem          calls   name
77.20     999 MB     1295 MB              1   main chunk (main.lua)
 8.65     112 MB      112 MB            147   insert [C]
 7.01      91 MB       91 MB  1,000,001   for iterator [C]
 5.89      76 MB       76 MB  1,000,000   gmatch [C]
 1.24      16 MB       16 MB              1   ? (main.lua:194)
```

Black and Scholes

Improf Call-Graph Report

```
                                    call/tot  parents
index %mem      ret   shallow self  call      name
                                    call/tot  children
=============================================================
[1]--100.00---1295-MB--999-MB-----1-----main-chunk-(main.lua)
               112 MB  112 MB  147/147  insert [C]
                76 MB   76 MB   1M/1M   gmatch [C]
... some unimportant functions
                 0 MB    0 MB    1/1    for iterator [C]
... 687 times of the same 'for' line
                 0 MB    0 MB    1/1    for iterator [C]
```

Black and Scholes

Original Code

```
-- read options data from input file, starting at line 2
datatb = {}
fnametb = { "s", "strike", "r", "divq", "v", "t",
            "optiontype", "divs", "dgrefval" }
for line in infh:lines() do
  optiontb = {}
  fnum = 1
  for field in string.gmatch( line, "[^%s]+" ) do
    optiontb[fnametb[fnum]] = field
    fnum = fnum + 1
  end
  table.insert( datatb, optiontb )
end
...
-- divide option fields into records
otype = {}; sptprice = {}; strike = {}; rate = {}; volatility = {}; otime = {}
for i = 1, numoptions, 1 do
  if ( datatb[i].optiontype == 'P' ) then table.insert( otype, 1 )
  else table.insert( otype, 0 ) end
  table.insert( sptprice, datatb[i].s );table.insert( strike, datatb[i].strike );
  table.insert( rate, datatb[i].r );table.insert( volatility, datatb[i].v );
  table.insert( otime, datatb[i].t )
end
```

Black and Scholes

Modified Code

```
-- read options data from input file, starting at line 2
fnametb = { "s", "strike", "r", "divq", "v", "t",
            "optiontype", "divs", "dgrefval" }
-- divide option fields into records
otype = {}; sptprice = {}; strike = {}; rate = {}; volatility = {}; otime = {}
optiontb = {}
for line in infh:lines() do
  fnum = 1
  for field in string.gmatch( line, "[^%s]+" ) do
    optiontb[fnametb[fnum]] = field
    fnum = fnum + 1
  end

  if ( optiontb.optiontype == 'P' ) then table.insert( otype, 1 )
  else table.insert( otype, 0 ) end
  table.insert( sptprice, optiontb.s );table.insert( strike, optiontb.strike );
  table.insert( rate, optiontb.r );table.insert( volatility, optiontb.v );
  table.insert( otime, optiontb.t )
end
```

Black and Scholes

luamemprofiler Report After Changes

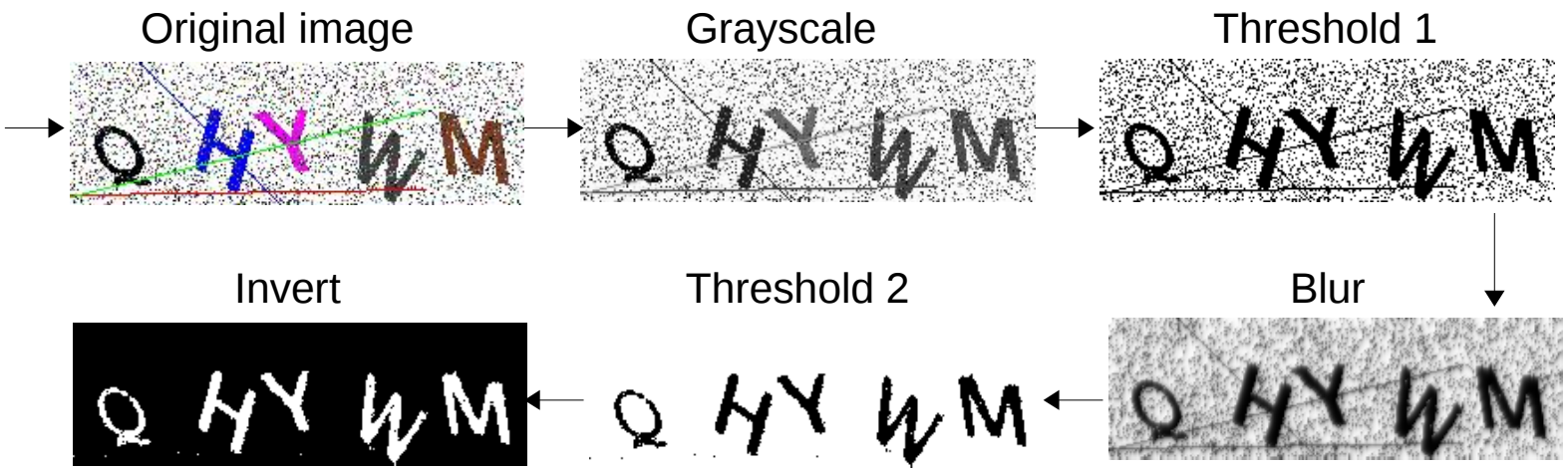
```
Number of Mallocs  = 8,001,694   Total Malloc Size  = 1,166 MB
Number of Mallocs  = 2,006,924   Total Malloc Size  =   167 MB

Number of Reallocs =       162   Total Realloc Size =   128 MB
Number of Reallocs =       142   Total Realloc Size =   112 MB

Number of Frees    = 6,000,821   Total Free Size    =   625 MB
Number of Frees    = 2,006,866   Total Free Size    =   167 MB

Maximum Memory Used = 700 MB
Maximum Memory Used = 192 MB

String = 1,001,662 | Function = 1,000,004 | Userdata = 2
String = 1,006,888 | Function = 1,000,004 | Userdata = 2

Table  = 1,000,009 | Other    = 5,000,016 | Thread   = 1
Table  =         9 | Other    =        20 | Thread   = 1
```

- 7x memory reduction (luamemprofiler) and 4x (/usr/bin/time)

CAPTCHA JPG

Previous Knowledge

- Input: 5000 images with 13kb each and 65 megabytes total
- Activity:



CAPTCHA JPG

luamemprofiler Info

```
Number of Mallocs  = 76790      Total Malloc Size  = 679.07 MB
Number of Reallocs =   294      Total Realloc Size =   0.13 MB
Number of Frees    = 71534      Total Free Size    = 678.86 MB

Maximum Memory Used = 1.36 MB

Number of Allocs of Each Type:
  String = 40970 | Function =  7 | Userdata = 35001
  Thread =     0 | Table    = 10 | Other    =   802
```

* display shows that blocks are frequently created and garbage-collected.

CAPTCHA JPG

Improf Flat Report

```
===== Showing 2 of 24 functions that allocated memory =====
   %      shallow    retained
  mem       mem         mem       calls   name
 78.93   536.6 MB    536.6 MB    25000   jpegStr [C]
 20.64   140.4 MB    140.4 MB     5000   read [C]
  0.17     1.1 MB      1.1 MB    25000   createFromJpegStr [C]
```

CAPTCHA JPG

Improf Call-Graph Report

```
                                          call/tot  parents
index %mem      ret         self          call      name
                                          call/tot  children
=============================================================
             220.6 MB   220.6 MB   10K/25K    threshold (...)
             152.9 MB   152.9 MB    5K/25K    grayscale (...)
             117.9 MB   117.9 MB    5K/25K    blur (...)
              45.2 MB    45.2 MB    5K/25K    invert (...)
[2]---78.93--536.6-MB--536.6-MB--25K-------jpegStr-[C]
=============================================================
             140.6 MB    0.0 MB    5K/5K     main chunk (...)
[5]---20.68--140.6-MB----0.0-MB---5K-------load-(...)
             140.4 MB   140.4 MB    5K/5K     read [C]
               0.3 MB     0.3 MB    5K/5K     open [C]
=============================================================
               0.5 MB     0.5 MB   10K/25K   threshold (...)
               0.2 MB     0.2 MB    5K/25K   grayscale (...)
               0.2 MB     0.2 MB    5K/25K   blur (...)
               0.2 MB     0.2 MB    5K/25K   invert (...)
[9]----0.17----1.1-MB----1.1-MB--25K------createFromJpegStr-[C]
```

CAPTCHA JPG

Original Code

```
local img, err = image.load( indir .. "/" .. f)
...
img = image.grayscale( img )
img = image.threshold( img, 220 )
img = image.blur( img, 1 )
img = image.threshold( img, 70 )
img = image.invert( img )
image.save( img, outdir .. "/" ..f)
```

```
image.grayscale = function( img )
  local gdimg = gd.createFromJpegStr( img )
  ...
  return gdimg:jpegStr(100)
end
```

CAPTCHA JPG

Modified Code

```
local img, err = image.load( indir .. "/" .. f)
...
image.grayscale( img )
image.threshold( img, 220 )
image.blur( img, 1 )
image.threshold( img, 70 )
image.invert( img )
image.save( img, outdir .. "/" ..f)
```

```
image.grayscale = function( img )
  ...
end
```

CAPTCHA JPG

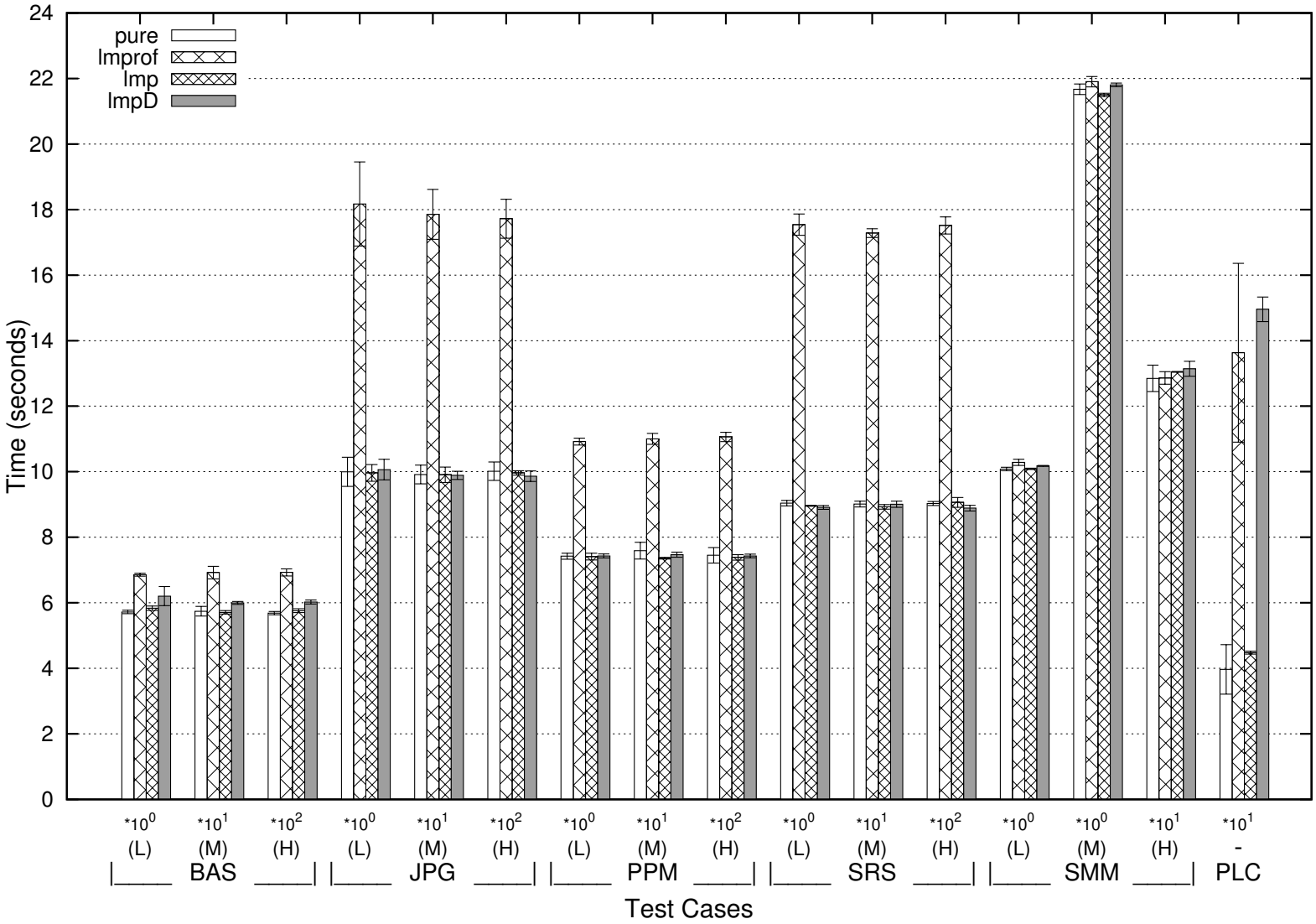
luamemprofiler Report After Changes

```
Number of Mallocs  = 76,790      Total Malloc Size  = 679.07 MB
Number of Mallocs  = 30,673      Total Malloc Size  = 141.47 MB

Number of Reallocs =    294      Total Realloc Size =   0.13 MB
Number of Reallocs =    170      Total Realloc Size =   0.13 MB

Number of Frees    = 71,534      Total Free Size    = 678.86 MB
Number of Frees    = 25,417      Total Free Size    = 141.25 MB

Maximum Memory Used = 1.36 MB
Maximum Memory Used = 1.29 MB

String = 40,970 | Function =  7 | Userdata = 35,001
String = 15,412 | Function =  7 | Userdata = 15,001

Thread =      0 | Table    = 10 | Other    =    802
Thread =      0 | Table    = 10 | Other    =    243
```

- 5x memory reduction (luamemprofiler and /usr/bin/time)

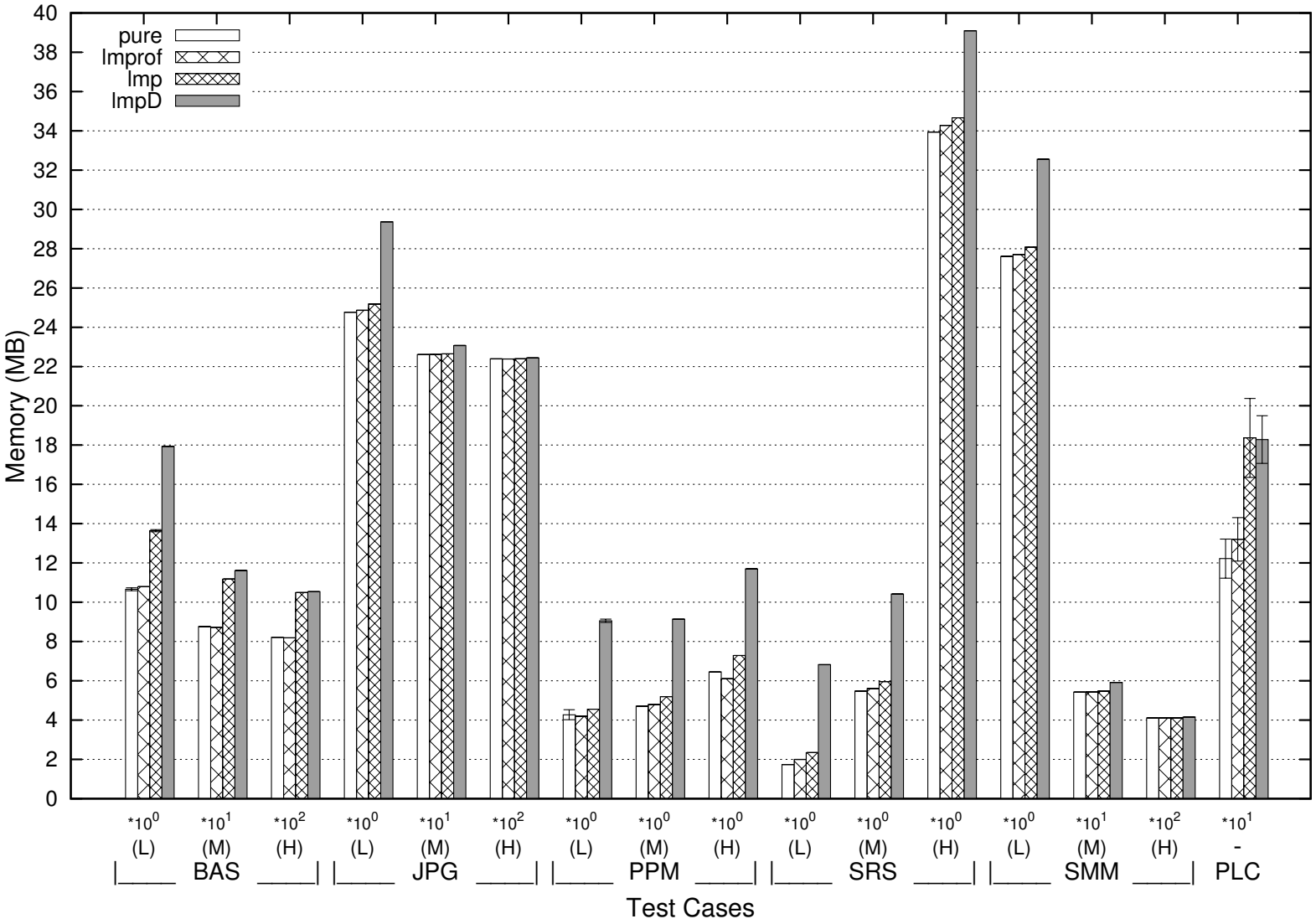
Performance Analysis

Time



Performance Analysis

Memory



Closing Remarks

Lessons Learned

- Real-time was useful to understand allocation behavior
- Ongoing interaction and data categorization not useful
- Fixed display was a bad choice
- Function profiler is very useful for new programs
- Performance is ok for profilers

Closing Remarks

Future Work

- Wrapper to use tools from command line
- luamemprofiler: several interface improvements
- luamemprofiler: debugger integration
- Improf: add information of ALL function calls
- Improf: visual call-graph

Thank you!
Questions?