The Road to ARM

An unfinished tale

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The beginning

Acorn Archimedes (1987)

- 32 bit ARM-2
- 8MHz
- 512KB RAM
- 256 colors
- 8-channel sound (mono output)

Today

- Mobile (and laptops)
- Raspberry
- Embedded
- Server

Mobile

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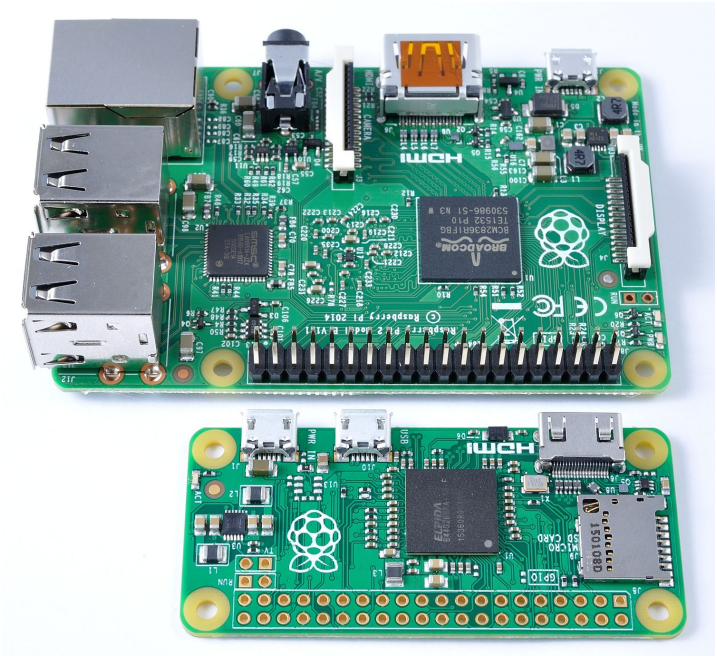
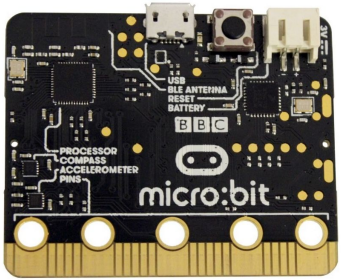
Education



Raspberry PI 3:

- 4-core ARMv8 1.2GHz
- 1GB RAM
- WiFi, Bluetooth, Ethernet, USB, HDMI, camera port



Raspberry Pi Zero:

- 1-core ARMv6 1GHz
- 512MB RAM
- 1 µUSB, miniHDMI
- WiFI/Bluetooth (W)
- Camera port, 40-pin GPIO

BBC Micro:bit

- 5 x 4 cm
- ARM Cortex-M0, 16MHz
- 256KB Flash / 16KB RAM
- USB, Bluetooth, buttons, LED matrix, accelerometer, compass
- 20 GPIO pins edge connector

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Embedded

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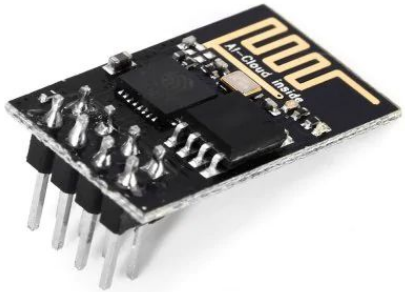
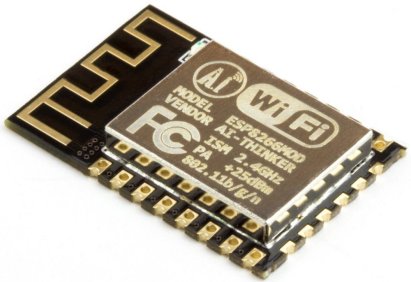
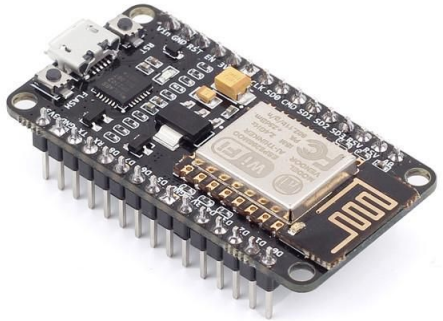
Embedded







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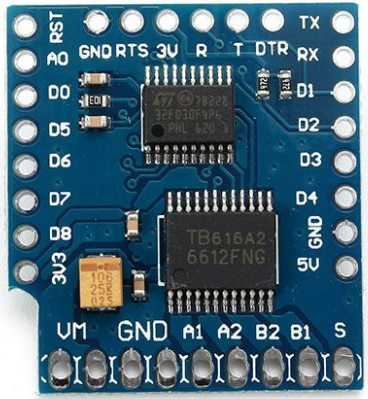
Embedded peripherals

STM32F030 :

- Cortex-M0
- 48 MHz
- 16 KB Flash / 4KB SRAM
- 5 timers, PWM
- SPI, I²C, USART, 15 GPIO pins
- 12-bit A/D



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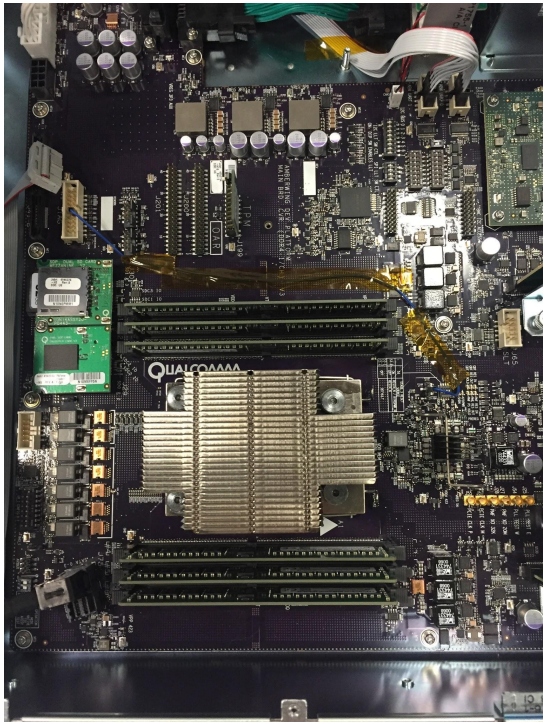
SERVERS!

Qualcomm Centriq 10nm

- ARMv8 64-bit 2.5GHz
- 46 cores/socket
- LLC : 1.25MB/core
- 120W



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CF situation

- LuaJIT
- Go
- C
- C++
- Rust
- Python
- eBPF
- JavaScript

Docker + qemu-user

```
$ docker run --rm -it stretch-arm64/master:latest
root@d955deefbaa4:/# uname -a
Linux d955deefbaa4 4.15.0-26-generic #28-Ubuntu SMP Wed Jul 4 16:24:29 UTC 2018 aarch64
GNU/Linux
root@d955deefbaa4:/# lscpu
Architecture:          aarch64
CPU op-mode(s):        32-bit, 64-bit
Byte Order:            Little Endian
CPU(s):                8
On-line CPU(s) list:   0-7
Thread(s) per core:    2
Core(s) per socket:    4
Socket(s):             1
NUMA node(s):          1
Vendor ID:             GenuineIntel
CPU family:            6
Model:                 142
Model name:            Intel(R) Core(TM) i7-8550U CPU @ 1.80GHz
Stepping:              10
```

Linux memory layout (userspace)

```
X86_64

 4KB page + 4 levels : 0000000000000000 - 00007fffffffffff (128TB, 47 bits)
 4KB page + 5 levels : 0000000000000000 - 00ffffffffffffff (64PB, 56 bits)

AArch64

 4KB page + 3 levels : 0000000000000000 - 0000007fffffffff (512GB, 39bits)
 4KB page + 4 levels : 0000000000000000 - 0000ffffffffffff (256TB, 48 bits)
64KB page + 2 levels : 0000000000000000 - 000003ffffffffff (4TB, 42 bits)
64KB page + 3 levels : 0000000000000000 - 0000ffffffffffff (256TB, 48 bits)
```

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TValue

```
** Format for 32 bit GC references (!LJ_GC64):
**
**                  ---MSW---.---LSW---
** primitive types |  itype  |         |
** lightuserdata   |  itype  |  void * |  (32 bit platforms)
** lightuserdata   |ffff|    void *    |  (64 bit platforms, 47 bit pointers)
** GC objects      |  itype  |  GCRef  |
** int (LJ_DUALNUM)|  itype  |   int   |
** number           -------double------
```

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TValue

```
** Format for 64 bit GC references (LJ_GC64):
**
** The upper 13 bits must be 1 (0xfff8...) for a special NaN. The next
** 4 bits hold the internal tag. The lowest 47 bits either hold a pointer,
** a zero-extended 32 bit integer or all bits set to 1 for primitive types.
**
**                      ------MSW------.------LSW------
** primitive types     |1..1|itype|1...................1|
** GC objects/lightud  |1..1|itype|-------GCRef--------|
** int (LJ_DUALNUM)    |1..1|itype|0..0|-----int-------|
** number               ------------double-------------
```

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Issue 0: the `lightuserdata` situation

From the manual:

«*A light userdata represents a pointer.*»

- But a full pointer no longer fits. Can we use full userdata?

«*A light userdata is equal to "any" light userdata with the same C address.*»

- Not if we want to keep value semantics.

Less than useful comments

https://github.com/LuaJIT/LuaJIT/pull/230#issuecomment-260205661

`lightuserdata` is a legacy data type, primarily intended for the classic Lua/C API. And even there, it doesn't have many good use cases.

….

- *`lightuserdata` used as a unique table key, e.g. for the registry: with `lua_pushlightuserdata(L, &x)` and x on the C stack, replace x with a static variable.*

…. but static variables are also in the top half.

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`luaL_ref()` to the rescue

```
static char thisismymodule_key;

..... // setup
     lua_pushlightuserdata(L,
               &thisismymodule_key);
     lua_createtable(L, 0, 5);
     ..... // fill it

     lua_rawset(L, LUA_REGISTRYINDEX);


..... // use
     lua_pushlightuserdata(L,
               &thisismymodule_key);
     lua_rawget(L, LUA_REGISTRYINDEX);
```

```
static int thisismymodule_ref;

..... // setup
     lua_createtable(L, 0, 5);
     ..... // fill it

     thisismymodule_ref = luaL_ref(L,
                    LUA_REGISTRYINDEX);


..... //use

     lua_rawgeti(L, LUA_REGISTRYINDEX,
thisismymodule_ref);
```

AVOIDED

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Issue 1: Interpreter bug:

```
BC_USETS: set upvalue to string constant

....
    |2:  // Check if string is white and ensure upvalue is closed.
    |  ldrb TMP0w, UPVAL:CARG1->closed
    |    tst TMP1w, #LJ_GC_WHITES // iswhite(str)
    |  ccmp TMP0w, #0, #4, ne
    |  beq <1
    |  // Crossed a write barrier. Move the barrier forward.
    |  mov CARG1, GL
    |  bl extern lj_gc_barrieruv  // (global_State *g, TValue *tv)
    |  b <1
```

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Issue 2: Traces, guards, exits and how to patch them

```
# luajit -jdump -O-loop -e 'local x=1 for _=1,100 do x=math.ceil(x) end'

---- TRACE 1 start (command line):1
0006  GGET     5   0      ; "math"
0007  TGETS    5   5   1  ; "ceil"
0008  MOV      7   0
0009  CALL     5   2   2
0000  . FUNCC               ; math.ceil
0010  MOV      0   5
0011  FORL     1 => 0006
```

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```
---- TRACE 1 IR
0001    int SLOAD  #3    I
0002    fun SLOAD  #0    R
0003    tab FLOAD  0002  func.env
0004    int FLOAD  0003  tab.hmask
0005 >  int EQ     0004  +63
0006    p64 FLOAD  0003  tab.node
0007 >  p64 HREFK  0006  "math" @54
0008 >  tab HLOAD  0007
0009    int FLOAD  0008  tab.hmask
0010 >  int EQ     0009  +31
0011    p64 FLOAD  0008  tab.node
0012 >  p64 HREFK  0011  "ceil" @0
0013 >  fun HLOAD  0012
0014 >  int SLOAD  #2    T
0015 >  fun EQ     0013  math.ceil
0016    int ADD    0001  +1
0017 >  int LE     0016  +100
---- TRACE 1 stop -> loop
```

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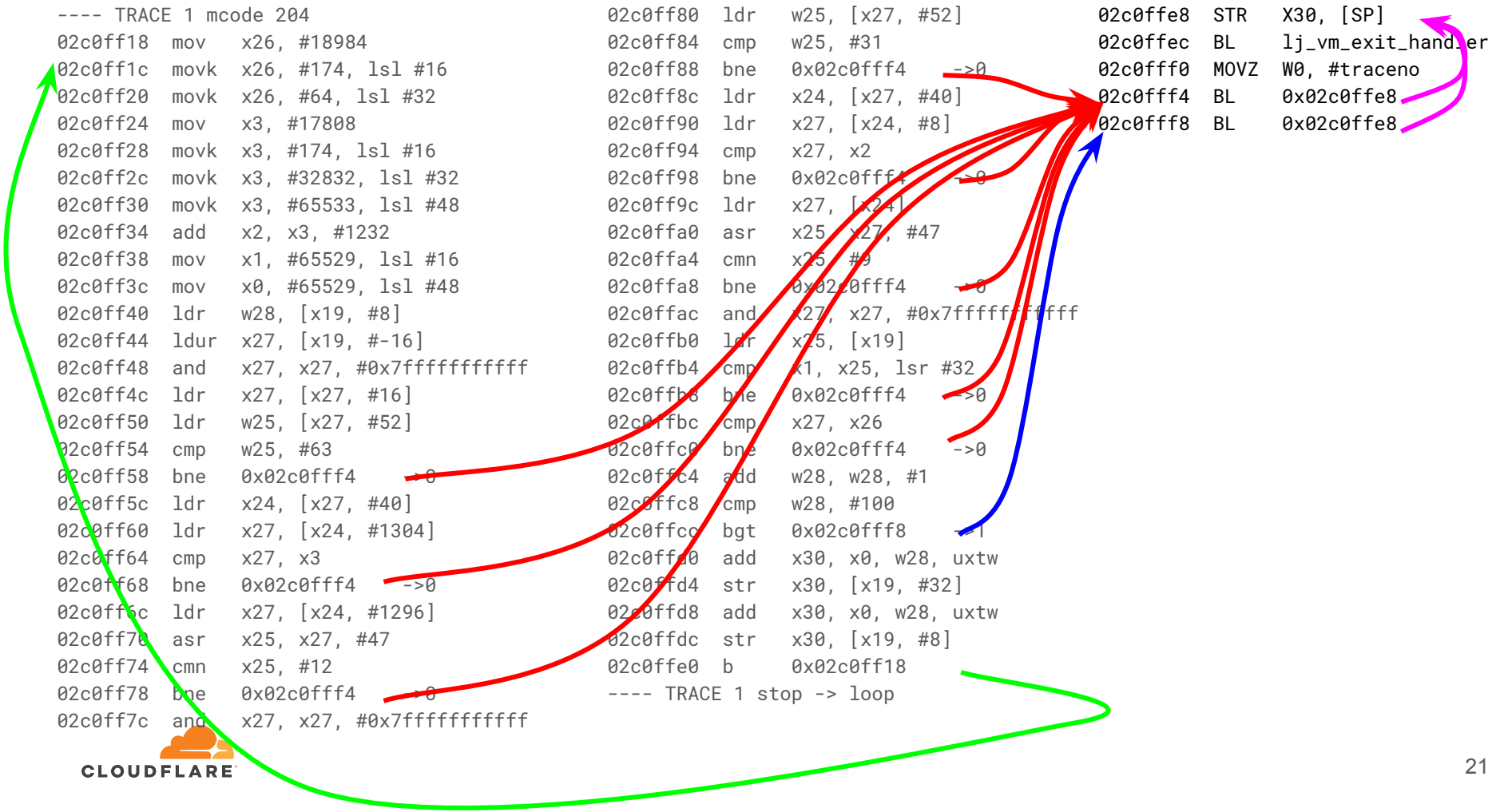
---- TRACE 1 mcode 204
02c0ff18 mov x26, #18984
02c0ff1c movk x26, #174, lsl #16
02c0ff20 movk x26, #64, lsl #32
02c0ff24 mov x3, #17808
02c0ff28 movk x3, #174, lsl #16
02c0ff2c movk x3, #32832, lsl #32
02c0ff30 movk x3, #65533, lsl #48
02c0ff34 add x2, x3, #1232
02c0ff38 mov x1, #65529, lsl #16
02c0ff3c mov x0, #65529, lsl #48
02c0ff40 ldr w28, [x19, #8]
02c0ff44 ldur x27, [x19, #-16]
02c0ff48 and x27, x27, #0x7fffffffffff
02c0ff4c ldr x27, [x27, #16]
02c0ff50 ldr w25, [x27, #52]
02c0ff54 cmp w25, #63
02c0ff58 bne 0x02c0fff4 ->0
02c0ff5c ldr x24, [x27, #40]
02c0ff60 ldr x27, [x24, #1304]
02c0ff64 cmp x27, x3
02c0ff68 bne 0x02c0fff4 ->0
02c0ff6c ldr x27, [x24, #1296]
02c0ff70 asr x25, x27, #47
02c0ff74 cmn x25, #12
02c0ff78 bne 0x02c0fff4 ->0
02c0ff7c and x27, x27, #0x7fffffffffff
02c0ff80 ldr w25, [x27, #52]
02c0ff84 cmp w25, #31
02c0ff88 bne 0x02c0fff4 ->0
02c0ff8c ldr x24, [x27, #40]
02c0ff90 ldr x27, [x24, #8]
02c0ff94 cmp x27, x2
02c0ff98 bne 0x02c0fff4 ->0
02c0ff9c ldr x27, [x24]
02c0ffa0 asr x25, x27, #47
02c0ffa4 cmn x25, #9
02c0ffa8 bne 0x02c0fff4 ->0
02c0ffac and x27, x27, #0x7fffffffffff
02c0ffb0 ldr x25, [x19]
02c0ffb4 cmp x1, x25, lsr #32
02c0ffb8 bne 0x02c0fff4 ->0
02c0ffbc cmp x27, x26
02c0ffc0 bne 0x02c0fff4 ->0
02c0ffc4 add w28, w28, #1
02c0ffc8 cmp w28, #100
02c0ffcc bgt 0x02c0fff8 ->1
02c0ffd0 add x30, x0, w28, uxtw
02c0ffd4 str x30, [x19, #32]
02c0ffd8 add x30, x0, w28, uxtw
02c0ffdc str x30, [x19, #8]
02c0ffe0 b 0x02c0ff18
---- TRACE 1 stop -> loop
02c0ffe8 STR X30, [SP]
02c0ffec BL lj_vm_exit_handler
02c0fff0 MOVZ W0, #traceno
02c0fff4 BL 0x02c0ffe8
02c0fff8 BL 0x02c0ffe8

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Patches and Ranges

CPU	LJ_TARGET_JUMPRANGE
x86	-- --
x86_64	31 (+- 2GB)
ARM	25 (+- 32MB)
ARM64	27 (+- 128MB)
PPC	25 (+- 32MB)
MIPS32	27 (+- 256MB (aligned))

But….

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Conditional branches have small ranges

«Unconditional simple relative branches can branch backward or forward up to 128MB from the current program counter location.

Conditional simple relative branches, where a condition code is appended to the B, have a smaller range of ±1MB.»

TBZ instructions have a range of +- 32KB

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```
---- TRACE 1 mcode 204
02c0ff18  mov   x26, #18984
02c0ff1c  movk  x26, #174, lsl #16
02c0ff20  movk  x26, #64, lsl #32
02c0ff24  mov   x3, #17808
02c0ff28  movk  x3, #174, lsl #16
02c0ff2c  movk  x3, #32832, lsl #32
02c0ff30  movk  x3, #65533, lsl #48
02c0ff34  add   x2, x3, #1232
02c0ff38  mov   x1, #65529, lsl #16
02c0ff3c  mov   x0, #65529, lsl #48
02c0ff40  ldr   w28, [x19, #8]
02c0ff44  ldur  x27, [x19, #-16]
02c0ff48  and   x27, x27, #0x7fffffff
02c0ff4c  ldr   x27, [x27, #16]
02c0ff50  ldr   w25, [x27, #52]
02c0ff54  cmp   w25, #63
02c0ff58  bne   0x02c0fff4    ->0
02c0ff5c  ldr   x24, [x27, #40]
02c0ff60  ldr   x27, [x24, #1304]
02c0ff64  cmp   x27, x3
02c0ff68  bne   0x02c0fff4    ->0
02c0ff6c  ldr   x27, [x24, #1296]
02c0ff70  asr   x25, x27, #47
02c0ff74  cmn   x25, #12
02c0ff78  bne   0x02c0fff4    ->0
02c0ff7c  and   x27, x27, #0x7fffffffffff
02c0ff80  ldr   w25, [x27, #52]
02c0ff84  cmp   w25, #31
02c0ff88  bne   0x02c0fff4    ->0
02c0ff8c  ldr   x24, [x27, #40]
02c0ff90  ldr   x27, [x24, #8]
02c0ff94  cmp   x27, x2
02c0ff98  bne   0x02c0fff4    ->0
02c0ff9c  ldr   x27, [x24]
02c0ffa0  asr   x25, x27, #47
02c0ffa4  cmn   x25, #9
02c0ffa8  bne   0x02c0fff4    ->0
02c0ffac  and   x27, x27, #0x7fffffffffff
02c0ffb0  ldr   x25, [x19
02c0ffb4  cmp   x25, #32
02c0ffb8  bne   0x02c0fff4    ->0
02c0ffbc  cmp   x27, x26
02c0ffc0  bne   0x02c0fff4    ->0
02c0ffc4  add   w28, w28, #1
02c0ffc8  cmp   w28, #100
02c0ffcc  bgt   << trace #2 >>
02c0ffd0  add   x30, x0, w28, uxtw
02c0ffd4  str   x30, [x19, #32]
02c0ffd8  add   x30, x0, w28, uxtw
02c0ffdc  str   x30, [x19, #8]
02c0ffe0  b     0x02c0ff18
---- TRACE 1 stop -> loop
```

```
02c0ffe8  STR   X30, [SP]
02c0ffec  BL    lj_vm_exit_handler
02c0fff0  MOVZ  W0, #traceno
02c0fff4  B     << trace #348>>
02c0fff8  B     << trace #2 >>
```

FIXED

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Issue 3: Register Clash

```
local empty = {}
local _a, _b, _c = nil, nil, nil

local function scan(vs)
   for _, v in ipairs(vs) do
      local sep = v:find("@", 1, true)
      if v:sub(sep+2, -2):byte() == 0x3f then end
      local int = empty[v]
      v:find(":", 1, true)
   end
end

local function w()
   for _ = 1, 500 do
      scan({"ab@xyz"})
   end
end
w()
```

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```
0022 [10]     p64 FLOAD  0019  tab.node
0023       >  p64 HREFK  0022  "find" @1
0024 x4    >  fun HLOAD  0023
0025       >  fun EQ     0024  string.find
0029 x0       p64 CALLN  lj_str_find  ([0x7f6ce66f4f30] [0x7f6ce66f5fb8] +6   +1  )
0030       >  p64 NE     0029  NULL
0031 x0       int SUB    0029  [0x7f6ce66f4f30]
.........
0042          p64 STRREF "ab@xyz"  0038
0044       >  p64 HREFK  0022  "byte" @11
0045 x6    >  fun HLOAD  0044
0046       >  fun EQ     0045  string.byte
0047       >  int UGE    0040  +1
0048 x4       u8  XLOAD  0042  R
0049       >  int NE     0048  +63
```

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Constant (re)materialization

```
 mov    x4, #17200
 movk   x4, #174, lsl #16
 movk   x4, #32832, lsl #32
 movk   x4, #65533, lsl #48
...
 add    x4, x4, x0
 ldrb   w4, [x4, #24]
 add    x0, x4, #24 !!!!
 cmp    w4, #63
```

Github Issue #438. No clear path yet.

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Parting thoughts

- No matter if some code is stable for months of running time, there might still be bugs in the decades-core scale.
- Maturity and wide usage matters. There are thousands of apps running LuaJIT interpreter on ARM64, making it the most mature part. (almost)
- Readability is important. Assembly mnemonics are called so for a reason.
- Some bugs happen only on resource pressure, or when there are many existing objects. It’s hard to create the conditions before seeing the bugs.
- Creating minimal code snippets to reproduce a bug can be _very_ hard, but it does pay off, especially on the weirdest cases.