Ultrafast[1] Lua JSON Parsing

Writing a Lua/JSON encoder + decoder as a LuaJIT module

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[1] At the time of submitting the talk proposal, writing ”Fastest” might have been false advertising.

About me

Software engineer at BeamNG:

- Soft-body physics vehicle simulator.
- Closed-source C++ engine, Lua code open-source (not free as in *free beer*).

I focus on:

- Linux port,
- Sandboxing untrusted Lua code,
- **Hacking on LuaJIT.**

LuaJIT

Just-In-Time Compiler (JIT) for the Lua programming language.

- Lua is a small embeddable scripting language popular in game development.
- Comes with a high-performance interpreter.
- Compatible with Lua 5.1 API.

Why do we use LuaJIT?

1. It is **small** (we run a VM for every vehicle in a single thread).
2. It is **fast** (some BeamNG systems run 2000 times per second).

The problem

- **JSON**: human-readable data interchange format.
- **Lua**: small embeddable scripting language popular in game development.

JavaScript Object Notation (string) ↔ Lua table (object)

```
"{\"foo\":3.5,\"arr\":" +
"[\"x\",true,{}]}"
```

```
{
  ["foo"] = 3.5,
  ["arr"] = {"x", true, {}}
}
```

- Concerned not only about parsing, but also construction of Lua table.

There’s no need to reinvent the wheel...

1. C++ libraries:
    - RapidJSON: `https://github.com/Tencent/rapidjson`
    - simdjson: `https://github.com/simdjson/simdjson`
2. Pure Lua libraries:
    - json.lua: `https://github.com/rxi/json.lua`
    - lunajson: `https://github.com/grafi-tt/lunajson`
3. Lua libraries using C API:
    - Lua CJSON: `https://github.com/mpx/lua-cjson`
    - RapidJSON bindings: `https://github.com/xpol/lua-rapidjson`
    - lua-simdjson: `https://github.com/FourierTransformer/lua-simdjson`
    - jit-cjson from OpenResty
        - not open-source :/

Solution: Pure Lua libraries

json.lua, lunajson, ...

- easy integration,
- easily extensible,
- quite slow (JSON → Lua less than 100 MB/s).

Solution: C++ libraries

rapidjson, **simdjson**, ...

- very fast (simdjson advertises gigabytes per seconds JSON parsing),
- extra Lua ↔ C++ bindings needed,
  - this can make it slower
- simdjson not easily extensible (and only supports *strict* JSON decoding).

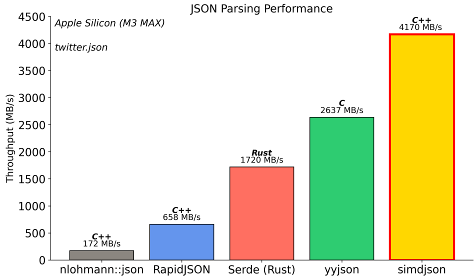


Figure: JSON Parsing Performance from `https://simdjson.org/`.

Solution: Lua libraries using C API

Lua CJSON, RapidJSON bindings, lua-simdjson

- easy integration,
- as extensible as the underlying C++ library,
- Lua C API is (surprisingly?) not very performant.

Time to reinvent the wheel.

Who put comments in my JSON?! aka JBeam (SJSON)

brakepads.jbeam:

```
{
//BASIC BRAKE PADS
"brakepad_F": {
    "information":{
        "authors"="BeamNG"
        name:"Basic Front Brake Pads",
        "value":[150 3 16],
    },
    ...
}
```

This is a valid JBeam file!

Who put comments in my JSON?! aka JBeam (SJSON)

brakepads.jbeam:

```
{
//BASIC BRAKE PADS
"brakepad_F": {
    "information":{
        "authors"="BeamNG"
        name:"Basic Front Brake Pads",
        "value":[150 3 16],
    },
    ...
}
```

JBeam (SJSON) format

Like a JSON, but:

- single-line `//` and multi-line `/* */` comments are allowed,
- object keys do not have to be enclosed in quotes,
- all commas are optional,
- = can be used instead of a colon `:`.

Also called Simplified JSON: `https://github.com/Autodesk/sjson`.

JBeam parsing alternatives

- Rigid parsers (simdjson) are not easily usable.
- We rolled our own parser written in pure Lua.

beamng-json.lua

- Pure battle-tested Lua implementation, 300 lines of code.
- Hand-written recursive descent parser.
- As JBeam is a superset of JSON, it is also a JSON parser.
  - Not a validating parser though!
- Written to be JIT friendly as we use LuaJIT.

beamng-json.lua

```lua
local function decode(str)
  if str == nil then return nil end
  gcrunning = collectgarbage("isrunning")
  collectgarbage("stop")
  s = str
  local c, i = skipWhiteSpace(1)
  local result = peekTable[c](i)
  s = nil
  if gcrunning then collectgarbage("restart") end
  return result
end
```

beamng-json.lua: pausing GC

```lua
local function decode(str)
  if str == nil then return nil end
  gcrunning = collectgarbage("isrunning")
  collectgarbage("stop") -- disable garbage collection
  s = str
  local c, i = skipWhiteSpace(1)
  local result = peekTable[c](i)
  s = nil
  if gcrunning then collectgarbage("restart") end
  return result
end
```

beamng-json.lua: whitespace skipping

```lua
local function decode(str)
  if str == nil then return nil end
  gcrunning = collectgarbage("isrunning")
  collectgarbage("stop") -- disable garbage collection
  s = str
  local c, i = skipWhiteSpace(1)
  local result = peekTable[c](i)
  s = nil
  if gcrunning then collectgarbage("restart") end
  return result
end
```

beamng-json.lua: skipWhiteSpace

```lua
local function skipWhiteSpace(i)
  local c = byte(s, i); i = i + 1
  -- matches space tab newline or comma
  while (c ~= nil and c <= 32) or c == 44 do
    c = byte(s, i); i = i + 1
  end
  if c == 47 then c, i = skipCommentSpace(i) end -- / -- read comment
  return c, i - 1
end
```

- Whitespace skipping can take a substantial portion of the parsing time!

beamng-json.lua: peekTable

```lua
local function decode(str)
  if str == nil then return nil end
  gcrunning = collectgarbage("isrunning")
  collectgarbage("stop") -- disable garbage collection
  s = str
  local c, i = skipWhiteSpace(1)
  local result = peekTable[c](i)
  s = nil
  if gcrunning then collectgarbage("restart") end
  return result
end
```

beamng-json.lua: What do we peek on?

- `n`: null
- `t`: true
- `f`: false
- `I`: Infinity
- `0-9`, `+`, `-`: numbers
- `"`: strings
- `/`: comments[2]

[2] in SJSON/JBeam only.

beamng-json.lua: peekTable value

Some of them are simple:

```lua
peekTable[116] = function(si) -- t
  local b1, b2, b3 = byte(s, si+1, si+3)
  if b1 == 114 and b2 == 117 and b3 == 101 then -- rue
    return true, si + 4
  else
    jsonError('Error reading value: true', si)
  end
end
```

beamng-json.lua: peekTable object

```lua
peekTable[123] = function(si) -- {
  local result = tablenew(0, 3)
  local c, i = skipWhiteSpace(si + 1)
  while c ~= 125 do -- }
    key, i = readKey(i, c)
    repeat c = byte(s, i); i = i + 1       -- skipWhitespace
    until (c == nil or c > 32) and c ~= 44 -- whitespace or comma
    result[key], i = peekTable[c](i - 1)
    repeat c = byte(s, i); i = i + 1       -- skipWhitespace
    until c ~= 44 and (c == nil or c > 32) -- whitespace or comma
    if c == 47 then c, i = skipCommentSpace(i) end -- / -- read comment
  end
  return result, i + 1
end
```

beamng-json.lua: peekTable object – Preallocation

```lua
peekTable[123] = function(si) -- {
  local result = tablenew(0, 3) -- narray = 0, nhash = 3
  local c, i = skipWhiteSpace(si + 1)
  while c ~= 125 do -- }
    key, i = readKey(i, c)
    repeat c = byte(s, i); i = i + 1         -- skipWhitespace
    until (c == nil or c > 32) and c ~= 44 -- whitespace or comma
    result[key], i = peekTable[c](i - 1)
    repeat c = byte(s, i); i = i + 1         -- skipWhitespace
    until c ~= 44 and (c == nil or c > 32) -- whitespace or comma
    if c == 47 then c, i = skipCommentSpace(i) end -- / -- read comment
  end
  return result, i + 1
end
```

beamng-json.lua: peekTable object – Inlining

```lua
peekTable[123] = function(si) -- {
  local result = tablenew(0, 3)
  local c, i = skipWhiteSpace(si + 1)
  while c ~= 125 do -- }
    key, i = readKey(i, c)
    repeat c = byte(s, i); i = i + 1       -- skipWhitespace
    until (c == nil or c > 32) and c ~= 44 -- whitespace or comma
    result[key], i = peekTable[c](i - 1)
    repeat c = byte(s, i); i = i + 1       -- skipWhitespace
    until c ~= 44 and (c == nil or c > 32) -- whitespace or comma
    if c == 47 then c, i = skipCommentSpace(i) end -- / -- read comment
  end
  return result, i + 1
end
```

Benchmarking protocol

- LuaJIT v2.1 rolling (`707c12b`), Ryzen 5600G (3.9 GHz), Fedora 42
- Measuring full passes through the datasets.

1. Run passes until either 1000 passes are complete or 10 seconds pass.
   - Collect garbage before every pass.
   - Flush JIT cache before every pass.
2. Take the mean pass time.
3. Repeat previous steps 5 times, take the mean of the means and calculate throughput ($\frac{\text{time}}{\text{file size}}$).

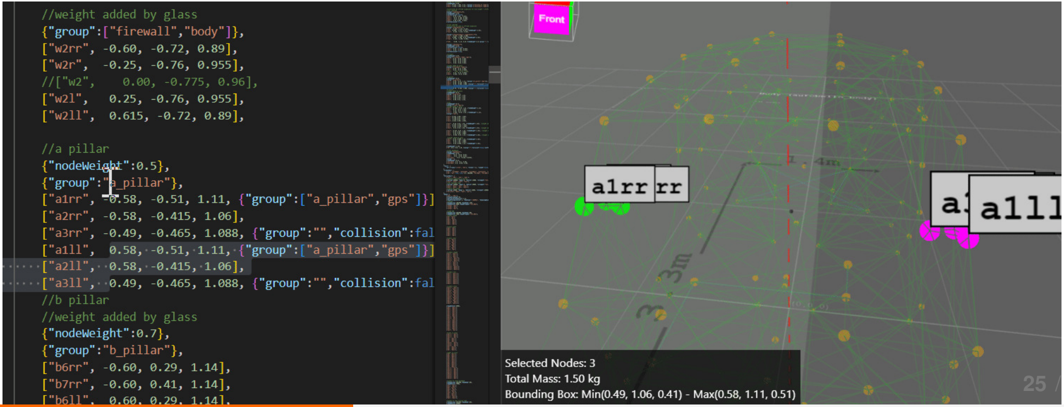
Further reducing variance:

- `nice -n -20`
- Forcing the same CPU core using `taskset`.

JBeam dataset

All 4,950 JBeam (SJSON) files from the latest release of BeamNG.drive.

- Describes the physics properties and structure of all the vehicle parts.
- Full of numbers and very short strings.



```
//weight added by glass
{"group":["firewall","body"]},
["w2rr", -0.60, -0.72, 0.89],
["w2r",  -0.25, -0.76, 0.955],
//["w2",    0.00, -0.775, 0.96],
["w2l",   0.25, -0.76, 0.955],
["w2ll",  0.615, -0.72, 0.89],

//a pillar
{"nodeWeight":0.5},
{"group":"a_pillar"},
["a1rr", -0.58, -0.51, 1.11, {"group":["a_pillar","gps"]}]
["a2rr", -0.58, -0.415, 1.06],
["a3rr", -0.49, -0.465, 1.088, {"group":"","collision":fal
["a1ll",  0.58, -0.51, 1.11, {"group":["a_pillar","gps"]}]
["a2ll",  0.58, -0.415, 1.06],
["a3ll",  0.49, -0.465, 1.088, {"group":"","collision":fal
//b pillar
//weight added by glass
{"nodeWeight":0.7},
{"group":"b_pillar"},
["b6rr", -0.60, 0.29, 1.14],
["b7rr", -0.60, 0.41, 1.14],
["b6ll",  0.60, 0.29, 1.14],
```

Selected Nodes: 3
Total Mass: 1.50 kg
Bounding Box: Min(0.49, 1.06, 0.41) - Max(0.58, 1.11, 0.51)

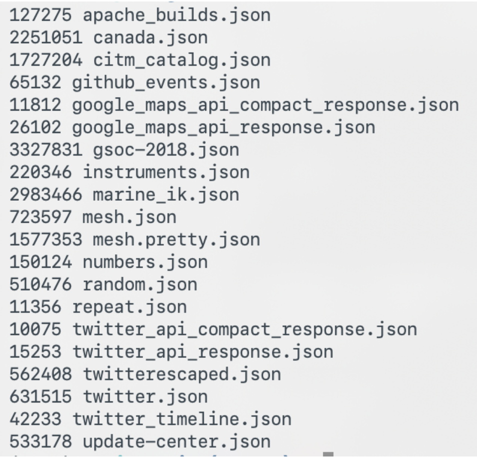
Benchmark on the JBeam dataset (93.8 MB)

Our parser is the fastest!

	JIT off	JIT on
beamng-json.lua	**30.5 MB/s**	**222.6 MB/s**
json.lua	–	–
lunajson	–	–
lua-simdjson	–	–

JSON dataset

20 files from `https://github.com/simdjson/simdjson-data`:



```
127275 apache_builds.json
2251051 canada.json
1727204 citm_catalog.json
65132 github_events.json
11812 google_maps_api_compact_response.json
26102 google_maps_api_response.json
3327831 gsoc-2018.json
220346 instruments.json
2983466 marine_ik.json
723597 mesh.json
1577353 mesh.pretty.json
150124 numbers.json
510476 random.json
11356 repeat.json
10075 twitter_api_compact_response.json
15253 twitter_api_response.json
562408 twitterescaped.json
631515 twitter.json
42233 twitter_timeline.json
533178 update-center.json
```

Benchmark on the JSON dataset (15.5 MB)

Our parser is not the fastest anymore :/

	JIT off	JIT on
beamng-json.lua	31.9 MB/s	240.7 MB/s
json.lua	16.1 MB/s	40.1 MB/s
lunajson	37.9 MB/s	43.7 MB/s
lua-simdjson	**313.7 MB/s**	**324.4 MB/s**

twitter.json dataset

A single file with Twitter statuses, JSON parsers commonly use it for testing, also part of the JSON dataset.

```
{ "statuses": [
    {
      "metadata": {
        "result_type": "recent",
        "iso_language_code": "ja"
      },
      "created_at": "Sun Aug 31 00:29:15 +0000 2014",
      "id": 505874924095815700,
      "text": "... <JAPANESE CHARACTERS>",
      ...
    },
    ...
  ]
}
```

Benchmark on twitter.json (631 kB)

	JIT off	JIT on
beamng-json.lua	34.2 MB/s	230.9 MB/s
json.lua	19.8 MB/s	78.4 MB/s
lunajson	70.6 MB/s	83.7 MB/s
lua-simdjson	**501.7 MB/s**	**500.7 MB/s**

Towards a faster JSON Lua parser

beamng-json.lua parser:

- Pure Lua, beats other pure Lua parsers in the benchmark.
- Performance heavily relies on JIT.
- Slower on JSON files than Lua bindings for simdjson.

Can going closer to the source help us?

LuaJIT source code

- C99 + hand-written assembly (we don't need to touch).
- 56 `lj_*.c` and 14 `lib_*.c` files.
- We are only interested in `lj_serialize.c` (serialization) and `lib_buffer.c` (string buffers).

LuaJIT string buffers

As LuaJIT strings are immutable and interned, the **string buffer** structure is there for efficient string manipulation. From `https://luajit.org/ext_buffer.html`:

> *The string buffer library allows high-performance manipulation of string-like data. Unlike Lua strings, which are constants, string buffers are mutable sequences of 8-bit (binary-transparent) characters. Data can be stored, formatted and encoded into a string buffer and later converted, extracted or decoded.*

- The string buffer `sbx` consists of:
  - read pointer `const char *r`,
  - write pointer `char *w`.
- If `r == w`, buffer is empty.

LuaJIT buffer serialization

- Implemented in `lj_serialize.c`.
- Internal binary format, but we can borrow the code for creating a JSON encoder and decoder.

```lua
buf = require('string.buffer').new()
buf:encode({1, 2, 3}) -- appends to buffer (moves w ptr)
obj = buf:decode()    -- consumes from buffer (moves r ptr)
assert(obj[1] == 1 and obj[2] == 2 and obj[3] == 3)
```

beamng-json.c: initial version

- Almost one-to-one rewrite of beamng-json.lua.
- Bound checking has to be explicit now.

beamng-json.c: decode

```c
char *serialize_json_get(char *r, SBufExt *sbx, TValue *o) {
  char *w = sbx->w;
  r = skip_white_space(r, w, sbx);
  if (LJ_LIKELY(r < w)) {
    switch (*r) {
    case '{':
    case '[':
      return peek_table(r, w, sbx, o);
      break;
    }
  }
}
```

beamng-json.c: skipWhiteSpace

Naive but working implementation:

```c
char *skip_white_space(char *r, char *w, SBufExt *sbx) {
  while (LJ_LIKELY(r < w) && (*r <= ' ' || *r == ',')) {
    r++;
  }
  if (LJ_LIKELY(r < w) && *r == '/') {
    r = skip_comment_space(r + 1, w, sbx); // / -- read comment
  }
  return r;
}
```

beamng-json.c: peekTable value

```c
char *peek_table(char *r, char *w, SBufExt *sbx, TValue *o) {
  if (LJ_LIKELY(r < w)) {
    switch (*r) {
    case 't': {
      const char val[4] = "true";
      if (LJ_UNLIKELY(r + sizeof(val) > w ||
          strncmp(r + 1, val + 1, sizeof(val) - 1) != 0)) {
        lj_err_callerv(sbufL(sbx), LJ_ERR_BADJSON_INVALIDVAL, val);
      }
      setboolV(o, 1);
      return r + sizeof(val);
    }
    ...
} } }
```

beamng-json.c: peekTable value

```c
char *peek_table(char *r, char *w, SBufExt *sbx, TValue *o) {
  if (LJ_LIKELY(r < w)) {
    switch (*r) {
    case 't': {
      const char val[4] = "true";
      if (LJ_UNLIKELY(r + sizeof(val) > w
          strncmp(r + 1, val + 1, sizeof(val) - 1) != 0)) {
        lj_err_callerv(sbufL(sbx), LJ_ERR_BADJSON_INVALIDVAL, val);
      }
      setboolV(o, 1);
      return r + sizeof(val);
    }
    ...
} } }
```

beamng-json.c: peekTable array

```
case '[': {
  GCtab *t = lj_tab_new(sbufL(sbx), 4, hsize2hbits(0));
  int i = 1;
  settabV(sbufL(sbx), o, t);
  r = skip_white_space(r + 1, w, sbx);
  while (LJ_LIKELY(r < w) && *r != ']') {
    TValue *v = lj_tab_setint(sbufL(sbx), t, i++);
    r = peek_table(r, w, sbx, v);
    r = skip_white_space(r, w, sbx);
  }
  if (LJ_LIKELY(r < w && *r == ']')) {
    return r + 1;
  }
}
```

beamng-json.c: peekTable array – Preallocation

```
case '[': {
  GCtab *t = lj_tab_new(sbufL(sbx), 4, hsize2hbits(0));
  int i = 1;
  settabV(sbufL(sbx), o, t);
  r = skip_white_space(r + 1, w, sbx);
  while (LJ_LIKELY(r < w) && *r != ']') {
    TValue *v = lj_tab_setint(sbufL(sbx), t, i++);
    r = peek_table(r, w, sbx, v);
    r = skip_white_space(r, w, sbx);
  }
  if (LJ_LIKELY(r < w && *r == ']')) {
    return r + 1;
  }
}
```

Benchmark on the JBeam dataset (93.8 MB)

	JIT off	JIT on
beamng-json.lua	30.5 MB/s	**222.6 MB/s**
beamng-json.c		
● initial version	**219.5 MB/s**	216.3 MB/s

No speedup when rewriting to C.

- Optimized LuaJIT code can be quite fast.
- We’re not done yet, time for optimizations.

Optimizations: Branch predictor hints

- LJ_LIKELY and LJ_UNLIKELY are existing macros from LuaJIT,
- We put the annotations to the places where the unlikely path is an error state.

```
#define LJ_LIKELY(x)   __builtin_expect(!!(x), 1)
#define LJ_UNLIKELY(x) __builtin_expect(!!(x), 0)
```

Optimizations: Number parsing

Initial implementation:

```c
char *read_number(char *r, char *w, SBufExt *sbx, TValue *o) {
  char *rbegin = r; char back = *r;
  r = ...; // find the end character of the number
  TValue tmp;
  StrScanFmt fmt = lj_strscan_scan(rbegin, r - rbegin, &tmp, ...);
  if (fmt == STRSCAN_ERROR) {
    lj_err_caller(sbufL(sbx), LJ_ERR_BADJSON_INVALIDNUM);
    return NULL;
  }
  o->u64 = tmp.u64;
  return r;
}
```

Optimizations: Number parsing

Simplify the fast path:

```c
char *read_number(char *r, char *w, SBufExt *sbx, TValue *o) {
  char *rbegin = r;
  TValue tmp; tmp.n = 0.0;
  while (LJ_JSON_LIKELY(r < sbx->w)) {
    const unsigned char digit = (unsigned char)(*r - '0');
    if (digit > 9) break;
    tmp.n = 10 * tmp.n + digit;
    r++;
  }
  ...
}
```

Optimizations: Number parsing

```c
case '.': {
  lua_Number f = 0, scale = 0.1;
  r++;
  while (LJ_JSON_LIKELY(r < sbx->w)) {
    const unsigned char digit = (unsigned char)(*r - '0');
    if (digit > 9) break;
    f += digit * scale;
    scale *= 0.1;
    r++;
  }
  tmp.n += f;
  break;
}
```

Optimizations: Number parsing

- For parsing floats of the form `6.02+e23`, `lj_strscan_scan` is still used.
- Focus on optimizing the common code path.

Optimizations: Inlining

LuaJIT contains the appropriate macros again:

```
#define LJ_INLINE  inline
#define LJ_AINLINE inline __attribute__((always_inline))
```

- `LJ_AINLINE` is used for most functions in the parser.

Optimizations: Scratch buffer

- Use a profiler to check bottlenecks.
  - I used `perf` and Visual Studio profiler.
- Substantial amount of time waas spent in `lj_alloc_realloc`, which is called when we need to grow a Lua table.
- But we don't know the size of the table before we parse all its children.
  - Also this happens at every recursion level at the same time.
- Behold the scratch buffer optimization!

Optimizations: Scratch buffer

```
char *lj_json_read_array(char *r, SBufExt *sbx, uint32_t scr) {
  while (LJ_JSON_LIKELY(r < sbx->w) && *r != ']') {
    uint32_t v = lj_json_scratch_pushn(L, 1);
    r = lj_json_deserialize_peek(r, sbx, v);
    r = lj_json_skip_white_space(r, sbx);
    asize++;
  }
  t = lj_tab_new_ah(L, asize + 1, 0);
  cTValue *base = &lj_json_scratch[lj_json_scratch_popn(L, asize)];
  TValue *array = tvref(t->array) + 1;
  memcpy(array, base, asize*sizeof(TValue));
  settabV(L, &lj_json_scratch[scr], t);
  return r;
}
```

Optimizations: Scratch buffer

```c
TValue *lj_json_scratch = lj_mem_newvec(L, 32, TValue);
// allocate space for n TValues and return index of the first one on the scratch
uint32_t lj_json_scratch_pushn(lua_State *L, uint32_t n) {
  if (LJ_UNLIKELY(lj_json_scratch_count + n >= lj_json_scratch_capacity)) {
    lj_mem_growvec(L, lj_json_scratch, lj_json_scratch_capacity, ...);
  }
  uint32_t scr = lj_json_scratch_count;
  lj_json_scratch_count += n;
  return scr;
}
// pop n TValues on the stack and return index of the first one
uint32_t lj_json_scratch_popn(lua_State *L, uint32_t n) {
  lj_json_scratch_count -= n;
  return lj_json_scratch_count;
}
```

Optimizations: Scratch buffer

- Dynamic stack for temporary Lua values.
- We only deal with one dynamically allocated scratch buffer.
- While parsing arrays/objects we can always create a table of exact size.
- TValues are still copied from the scratch buffer, but `realloc` copy is avoided.
- You cannot do this on Lua level (at least I tried and it doesn’t bring performance improvement).

Optimizations: Intrinsics

- SSE2, SSE4, ARM Neon versions.
- Two primitives:
  1. Skip until single character → find end of single-line or multi-line comments.
  2. Skip to string end → find next quote or \ character.
- Similar to RapidJSON implementation.

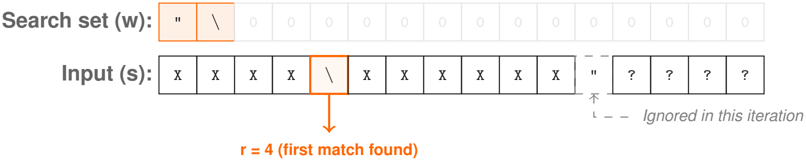
Optimizations: Intrinsics – SSE4 skipToStringEnd

Acts on 16-byte chunks.

```c
char *lj_json_skip_to_string_end_simd(char *p, SBufExt *sbx) {
  ...
  const char strend[16] = "\"\\";
  const __m128i w = _mm_loadu_si128((const __m128i *)(&strend[0]));
  for (; p <= sbx->w - 16; p += 16) {
    const __m128i s = _mm_loadu_si128((const __m128i *)(p));
    const int r = _mm_cmpistri(w, s,
      _SIDD_UBYTE_OPS | _SIDD_CMP_EQUAL_ANY | _SIDD_LEAST_SIGNIFICANT);
    if (r != 16) return p + r;
  }
  return NULL;
}
```

Optimizations: Intrinsics – SSE4 skipToStringEnd

`__mm_cmpistri` does all the heavy lifting:



Search set (w):	"	\	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Input (s):	x	x	x	x	\	x	x	x	x	x	x	"	?	?	?	?

r = 4 (first match found)

Ignored in this iteration

Let’s benchmark again.

Benchmarking protocol

- LuaJIT v2.1 rolling (`707c12b`), Ryzen 5600G (3.9 GHz), Fedora 42
- Measuring full passes through the datasets.

1. Run passes until either 1000 passes are complete or 10 seconds pass.
   - Collect garbage before every pass.
   - Flush JIT cache before every pass.
2. Take the mean pass time.
3. Repeat previous steps 5 times, take the mean of the means and calculate throughput ($\frac{\text{time}}{\text{file size}}$).

Further reducing variance:

- `nice -n -20`
- Forcing the same CPU using `taskset`.

Benchmark on the JBeam dataset (93.8 MB)

Our parser is the fastest again!

	JIT off	JIT on
beamng-json.lua	30.5 MB/s	222.6 MB/s
beamng-json.c		
• initial version	219.5 MB/s	216.3 MB/s
• final version	**368.6 MB/s**	**370.0 MB/s**

Benchmark on the JBeam dataset (93.8 MB) – Ablations

	JIT off	JIT on
beamng-json.lua	30.5 MB/s	222.6 MB/s
beamng-json.c		
● initial version	219.5 MB/s	216.3 MB/s
● final version[3]	**368.6 MB/s**	**370.0 MB/s**
● no branch hints	356.0 MB/s	353.2 MB/s
● no scratch buffer	288.0 MB/s	292.3 MB/s
● no inlining	337.8 MB/s	335.4 MB/s
● no intrinsics	335.8 MB/s	336.1 MB/s
● SSE4 intrinsics	**369.0 MB/s**	**379.7 MB/s**

[3] SSE2 intrinsics.

Benchmark on the JSON dataset (15.5 MB)

Also beats `lua-simdjson` on the JSON parsing dataset.

	JIT off	JIT on
beamng-json.c	**704.7 MB/s**	**698.3 MB/s**
beamng-json.lua	31.9 MB/s	240.7 MB/s
json.lua	16.1 MB/s	40.1 MB/s
lunajson	37.9 MB/s	43.7 MB/s
lua-simdjson	313.7 MB/s	324.4 MB/s

Benchmark on twitter.json (631 kB)

	JIT off	JIT on
beamng-json.c	**864.8 MB/s**	**856.8 MB/s**
beamng-json.lua	34.2 MB/s	230.9 MB/s
json.lua	19.8 MB/s	78.4 MB/s
lunajson	70.6 MB/s	83.7 MB/s
lua-simdjson	501.7 MB/s	500.7 MB/s

Results from the benchmark

JBeam dataset:

- 45% speedup over pure Lua parser when JIT is on.
- **More than 10x** speedup over pure Lua parser when JIT is off.

JSON dataset:

- At least 70% faster than `lua-simdjson`.
- **More than 10x** times faster than pure Lua implementations.

Tips

- Try to combine multiple optimization tricks.
- Focus on the happy common path, uncommon features can be slower (string with escape characters, scientific numbers).
- Some optimization attempts actually slow the code down, measure regularly.
- Use the profiler to find hotspots.
- Minimize data copying (realloc).

Limitations

- The benchmark measures repeated parsing performance, which is not the metric we really care about.
  - We usually parse each .json or .jbeam file once.
- Unstable performance numbers in some cases.

Are we finished?

JSON encoding

- Not our primary focus, decoding is used more often.
- Let's write a Lua → JSON encoder for completion[4].

[4] And to fit the title of the talk :)

JSON encoding: It’s really simple!

```
char *lj_json_serialize_put(char *w, SBufExt *sbx, cTValue *o) {
  if (LJ_JSON_LIKELY(tvisstr(o))) {
    w = lj_json_serialize_more(w, sbx, 1);
    *w++ = '"';
    w = lj_json_put_string(w, sbx, strV(o));
    w = lj_json_serialize_more(w, sbx, 1);
    *w++ = '"';
  } else if (tvisnum(o)) {
    w = lj_json_put_number(w, sbx, numV(o));
  } else if (tvispri(o)) {
    w = lj_json_put_bool(w, sbx, itype(o));
  } ...
```

JSON encoding: It’s really simple!

```c
char *lj_json_serialize_put(char *w, SBufExt *sbx, cTValue *o) {
  if (LJ_JSON_LIKELY(tvisstr(o))) {
    w = lj_json_serialize_more(w, sbx, 1);
    *w++ = '"';
    w = lj_json_put_string(w, sbx, strV(o));
    w = lj_json_serialize_more(w, sbx, 1);
    *w++ = '"';
  } else if (tvisnum(o)) {
    w = lj_json_put_number(w, sbx, numV(o));
  } else if (tvispri(o)) {
    w = lj_json_put_bool(w, sbx, itype(o));
  } ...
```

JSON encoding: Writing a value

```c
char *lj_json_serialize_put(char *w, SBufExt *sbx, cTValue *o) {
  if (LJ_JSON_LIKELY(tvisstr(o))) {
    w = lj_json_serialize_more(w, sbx, 1);
    *w++ = '"';
    w = lj_json_put_string(w, sbx, strV(o));
    w = lj_json_serialize_more(w, sbx, 1);
    *w++ = '"';
  } else if (tvisnum(o)) {
    w = lj_json_put_number(w, sbx, numV(o));
  } else if (tvispri(o)) {
    w = lj_json_put_bool(w, sbx, itype(o));
  } ...
```

JSON encoding: Writing a value is also really simple

```c
char *lj_json_put_bool(char *w, SBufExt *sbx, uint32_t itype) {
  w = lj_json_serialize_more(w, sbx, 5);
  switch (itype) {
  case LJ_TNIL:
    memcpy(w, "null", 4); w += 4; break;
  case LJ_TTRUE:
    memcpy(w, "true", 4); w += 4; break;
  case LJ_TFALSE:
    memcpy(w, "false", 5); w += 5; break;
  }
  return w;
}
```

Let’s benchmark again.

Benchmark on the JSON dataset – Encoding

Our encoder’s performance is not bad.

	JIT off	JIT on
beamng-json.lua	42.6 MB/s	90.2 MB/s
beamng-json.c	**224.0 MB/s**	**223.0 MB/s**
json.lua	21.5 MB/s	26.9 MB/s
lunajson	32.8 MB/s	42.6 MB/s
lua-simdjson	–	–

Note: No optimizations were attempted on beamng-json.lua and beamng-json.c.

Benchmark on the JBeam dataset – Encoding

	JIT off	JIT on
beamng-json.lua	31.1 MB/s	31.2 MB/s
beamng-json.c	**586.7 MB/s**	**590.7 MB/s**
json.lua	36.6 MB/s	39.3 MB/s
lunajson	36.7 MB/s	39.4 MB/s

The End; Questions?

Benchmark code:

- https://github.com/aivora-beamng/luajit-json-performance

LuaJIT JSON module:

- https://github.com/aivora-beamng/LuaJIT-json

Slides: available at the FOSDEM talk page.

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