JSON

SIMD

Parsing JSON Really Quickly : Lessons Learned

🚀 🚀 🚀 🚀 🚀 🚀

Daniel Lemire

blog: https://lemire.me

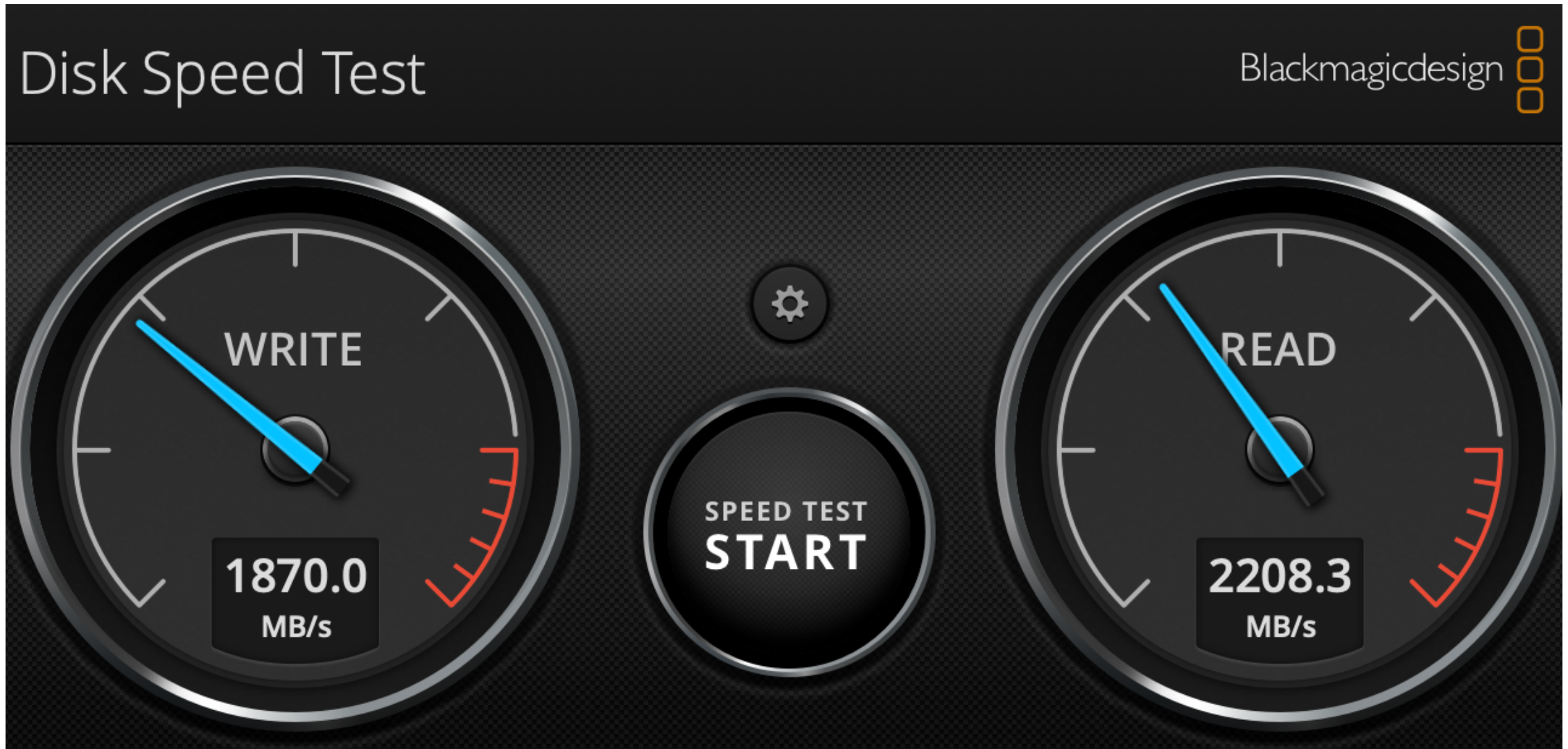twitter: @lemire

GitHub: https://github.com/lemire/

professor (Computer Science) at Université du Québec (TÉLUQ)

Montreal 🇨🇦 🍸 🍺

How fast can you read a large file?

- Are you limited by your disk or

- Are you limited by your CPU?

An iMac disk: 2.2 GB/s

Faster SSDs (e.g., 5 GB/s) are available: PCIe 4.0, 5.0, 6.0...

Reading text lines (CPU only)

~0.6 GB/s on 3.4 GHz Skylake

in Java

```java
void parseLine(String s) {
  volume += s.length();
}

void readString(StringReader data) {
  BufferedReader bf = new BufferedReader(data);
  bf.lines().forEach(s -> parseLine(s));
}
```

Source available.

Improved by JDK-8229022

Reading text lines (CPU only)

~1.5 GB/s on 3.4 GHz Skylake

in C++ (GNU GCC 8.3)

```cpp
size_t sum_line_lengths(char * data, size_t length) {
    std::stringstream is;
    is.rdbuf()->pubsetbuf(data, length);
    std::string line;
    size_t sumofalllinelengths{0};

    while(getline(is, line)) {
      sumofalllinelengths += line.size();
    }

    return sumofalllinelengths;
}
```

Source available.

Even standard C++ `getline` cannot keep up with a fast disk while reading large files!

Need to use multiple cores?

UNIPROCESSOR PERFORMANCE
(SINGLE CORE)

source
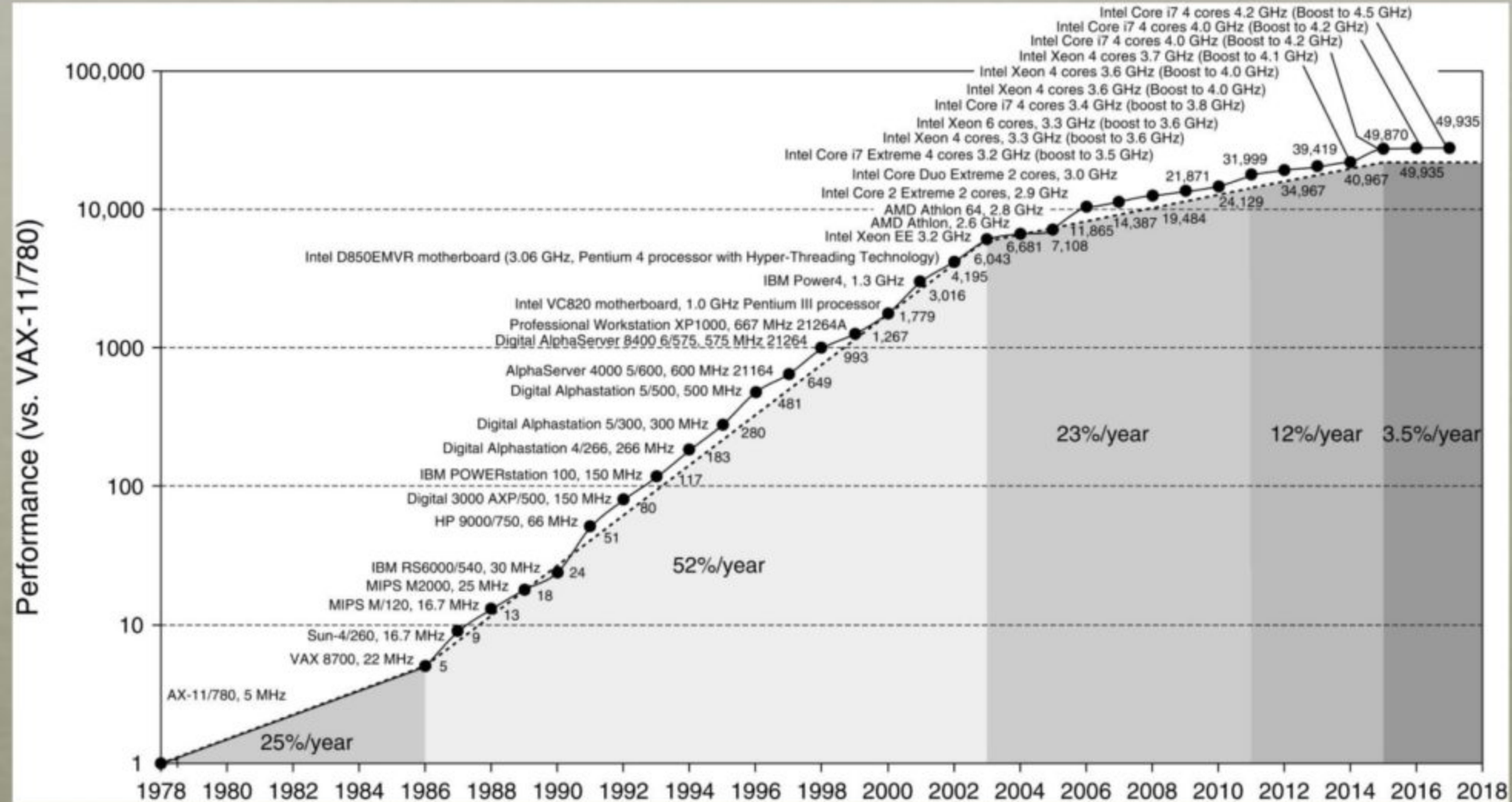
JSON

- Specified by Douglas Crockford

- RFC 7159 by Tim Bray in 2013

- Ubiquitous format to exchange data

```
{"Image": {"Width":  800,"Height": 600,
"Title":  "View from 15th Floor",
"Thumbnail": {
    "Url":    "http://www.example.com/81989943",
    "Height": 125,"Width":  100}
}
```

- "Our backend spends half its time serializing and deserializing json"

JSON parsing

- Read all of the content

- Check that it is valid JSON

- Check Unicode encoding

- Parse numbers

- Build DOM (document-object-model)

Harder than parsing lines?

Jackson JSON speed (Java)

twitter.json: **0.350 GB/s** on 3.4 GHz Skylake

Source code available.

	speed
Jackson (Java)	0.35 GB/s
readLines C++	1.5 GB/s
disk	2.2 GB/s

RapidJSON speed (C++)

twitter.json: **0.650 GB/s** on 3.4 GHz Skylake

	speed
RapidJSON (C++)	0.65 GB/s
Jackson (Java)	0.35 GB/s
readLines C++	1.5 GB/s
disk	2.2 GB/s

simdjson speed (C++)

twitter.json: **2.4 GB/s** on 3.4 GHz Skylake

	speed
simdjson (C++)	2.4 GB/s
RapidJSON (C++)	0.65 GB/s
Jackson (Java)	0.35 GB/s
readLines C++	1.5 GB/s
disk	2.2 GB/s

2.4 GB/s on a 3.4 GHz (+turbo) processor is

~1.5 cycles per input byte

Trick #1 : Use SIMD instructions

- Available on most commodity processors (ARM, x64)

- Originally added (Pentium) for multimedia (sound)

- Add wider (128-bit, 256-bit, 512-bit) words

- Adds new fun instructions: do 32 table lookup at once.

Trick #2 : avoids hard-to-predict branches

Write random numbers on an array.

```
while (howmany != 0) {
    out[index] =  random();
    index += 1;
    howmany--;
}
```

e.g., ~ 3 cycles per iteration

Write only odd random numbers:

```
while (howmany != 0) {
    val = random();
    if( val is odd) { // <=== new
      out[index] =  val;
      index += 1;
    }
    howmany--;
}
```

From 3 cycles to 15 cycles per value !
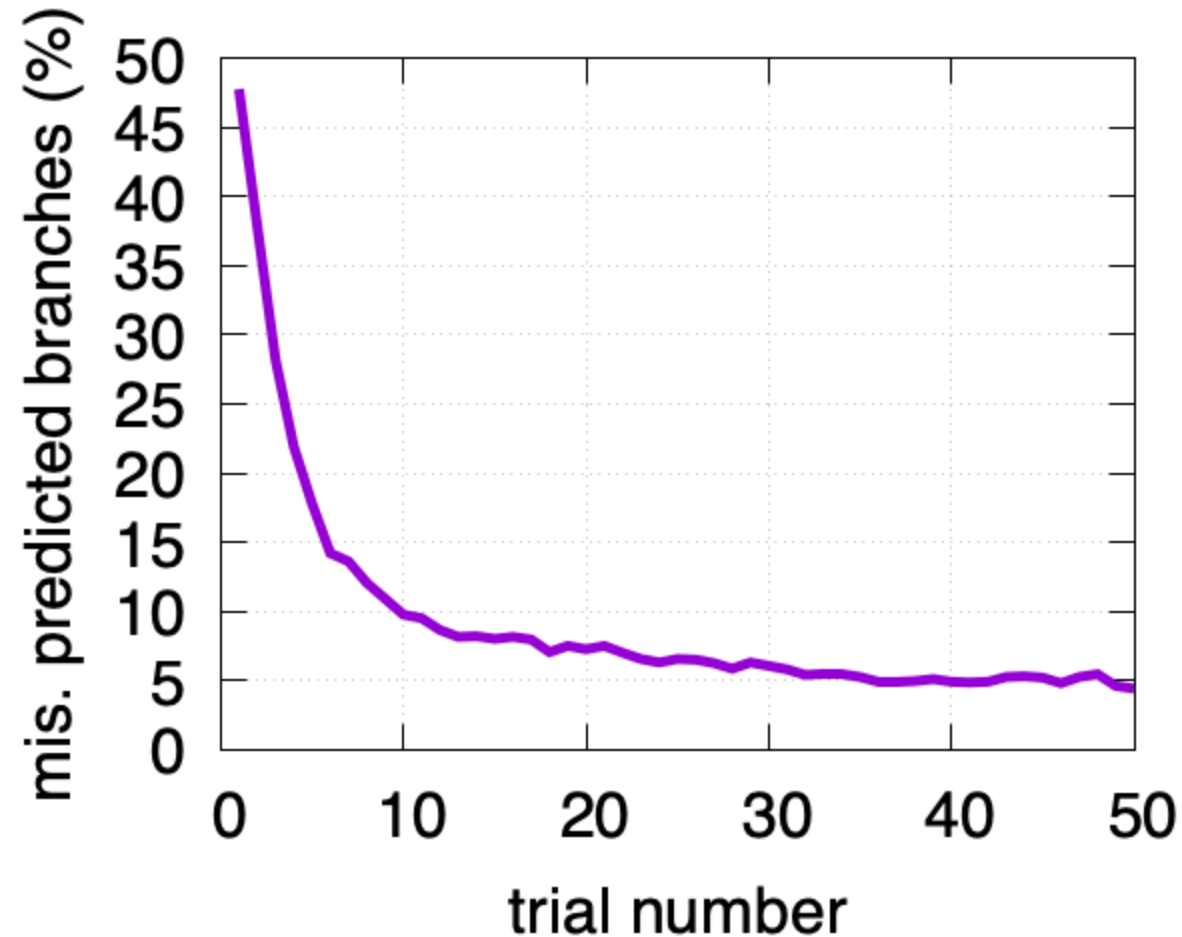
Go branchless young man!

```
while (howmany != 0) {
    val = random();
    out[index] = val;
    index += (val bitand 1);
    howmany--;
}
```

back to under 4 cycles!

Details and code available

What if I keep running the same benchmark?
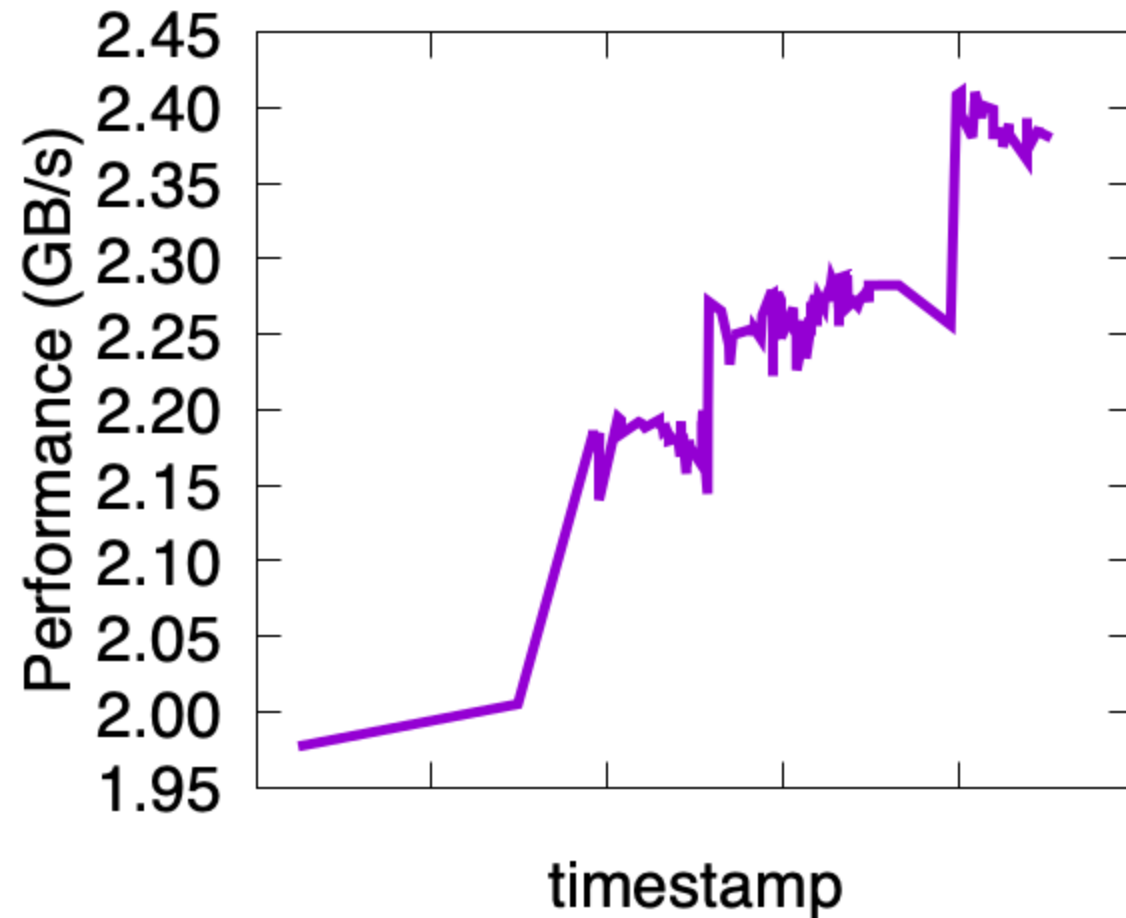
(same pseudo-random integers from run-to-run)

Trick #3 : avoids memory/object allocation

In simdjson, the DOM (document-object-model) is stored into one contiguous tape.

Trick #4 : measure the performance!

- benchmark-driven development

Continuous Integration tests

- performance regression is a bug that should be spotted early

Use precise measures

- time

- instructions

- CPU cycles

- mispredicted branches

- data accesses

Processor frequencies are not constant

- Especially on laptops

- CPU cycles different from time

- Time can be noisier than CPU cycles

Specific examples

Example 1. UTF-8

Strings are ASCII (1 byte per code point)

Otherwise multiple bytes (2, 3 or 4)

Only 1.1 M valid UTF-8 code points

Validating UTF-8 with if/else/while

```
if (byte1 < 0x80) {
        return true; // ASCII
}
if (byte1 < 0xE0) {
    if (byte1 < 0xC2 || byte2 > 0xBF) {
      return false;
    }
} else if (byte1 < 0xF0) {
    // Three-byte form.
    if (byte2 > 0xBF
        || (byte1 == 0xE0 && byte2 < 0xA0)
        || (byte1 == 0xED && 0xA0 <= byte2)
      blablabla
    ) blablabla
} else {
    // Four-byte form.
    .... blabla
}
```

Using SIMD

- Load 32-byte registers

- Use ~20 instructions

- No branch, no branch misprediction

processing random UTF-8

	cycles/char
conditions	11
simdjson	0.5

20 x faster! Source code available.

Example 2. Classifying characters

- comma (0x2c) `,`

- colon (0x3a) `:`

- brackets (0x5b,0x5d, 0x7b, 0x7d): `[, ], {, }`

- white-space (0x09, 0x0a, 0x0d, 0x20)

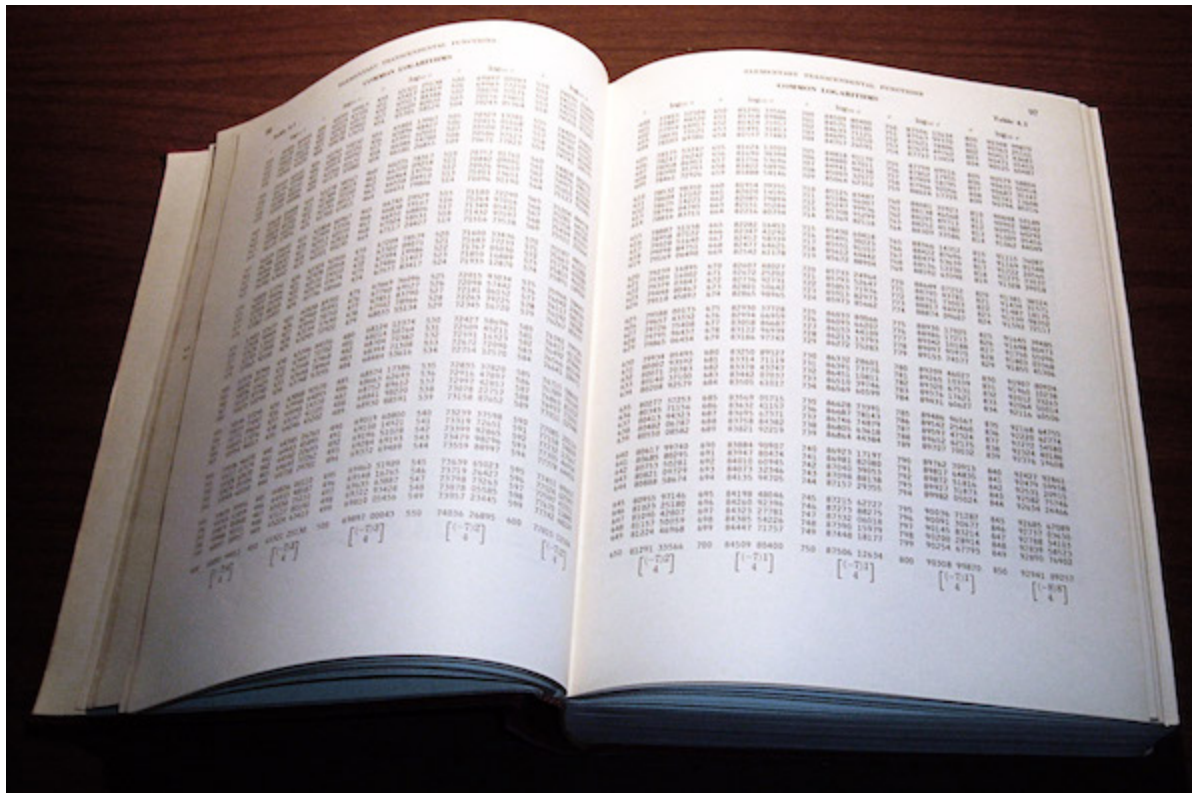- others

Classify 16 characters at once!

Divide values into two 'nibbles'

0x2c is 2 (high nibble) and c (low nibble)

There are 16 possible low nibbles.

There are 16 possible high nibbles.

ARM NEON and x64 processors have instructions to lookup 16-byte tables in a vectorized manner (16 values at a time)

Find two tables `H1` and `H2` such as the bitwise AND of the look classify the characters.

`H1(low(c)) & H2(high(c))`

- comma (0x2c): 1

- colon (0x3a): 2

- brackets (0x5b,0x5d, 0x7b, 0x7d): 4

- most white-space (0x09, 0x0a, 0x0d): 8

- white space (0x20): 16

- others: 0

Example 3. Detecting Escaped quote characters

Can you tell where the strings start and end?

```
{ "\\\"Nam[{": [ 116,"\\\\" ...
```

Without branching?

```
{ "\\\"Nam[{": [ 116,"\\\\" …
_____XX_____
```

42

Odd and even positions

- `1_1_1_1_1_1_1_1_1_1_1_1_1` : E (constant)
- `_1_1_1_1_1_1_1_1_1_1_1_1_` : O (constant)

Do a bunch of arithmetic and logical operations...

```
(((B + (B &~(B << 1)& E))& ~B)& ~E) | (((B + ((B &~(B << 1))& 0))& ~B)& E)
```

Result:

```
{ "\\\"Nam[{": [ 116,"\\\\"  ...
_____1_____
```

No branch!

From there, we can find where the string content is, using three more instructions.

Entire structure of the JSON document can be
identified (as a bitset) without any branch!

Example 4. Number parsing is expensive

`strtod` :

- 90 MB/s

- 38 cycles per byte

- 10 branch misses per floating-point number

Check whether we have 8 consecutive digits

```
bool is_made_of_eight_digits_fast(const char *chars) {
  uint64_t val;
  memcpy(&val, chars, 8);
  return (((val & 0xF0F0F0F0F0F0F0F0) |
          (((val + 0x0606060606060606) & 0xF0F0F0F0F0F0F0F0) >> 4))
          == 0x3333333333333333);
}
```

Then construct the corresponding integer

Using only three multiplications (instead of 7):

```
uint32_t parse_eight_digits_unrolled(const char *chars) {
  uint64_t val;
  memcpy(&val, chars, sizeof(uint64_t));
  val = (val & 0x0F0F0F0F0F0F0F0F) * 2561 >> 8;
  val = (val & 0x00FF00FF00FF00FF) * 6553601 >> 16;
  return (val & 0x0000FFFF0000FFFF) * 42949672960001 >> 32;
}
```

Can do even better with SIMD

Runtime dispatch

On first call, pointer checks CPU, and reassigns itself

Where to get it?

- GitHub: https://github.com/lemire/simdjson/

- Modern C++

- ARM (e.g., iPhone), x64 (going back 10 years)

- Apache 2.0 (no hidden patents)

- wrappers in Python, PHP, C#, Rust, JavaScript (node), Ruby

- ports to rust and c#

Reference

- Geoff Langdale, Daniel Lemire, Parsing Gigabytes of JSON per Second, VLDB Journal, https://arxiv.org/abs/1902.08318

Credit

Geoff Langdale (algorithmic architect and wizard)

Contributors:

Thomas Navennec, Kai Wolf, Tyler Kennedy, Frank Wessels, George Fotopoulos, Heinz N. Gies, Emil Gedda, Wojciech Muła, Georgios Floros, Dong Xie, Nan Xiao, Egor Bogatov, Jinxi Wang, Luiz Fernando Peres, Wouter Bolsterlee, Anish Karandikar, Reini Urban. Tom Dyson, Ihor Dotsenko, Alexey Milovidov, Chang Liu, Sunny Gleason, John Keiser, Zach Bjornson, Vitaly Baranov, Juho Lauri, Michael Eisel, Io Daza Dillon, Paul Dreik, Jérémie Piotte and others