SIMD

JSON

Parsing JSON Really Quickly : Lessons Learned

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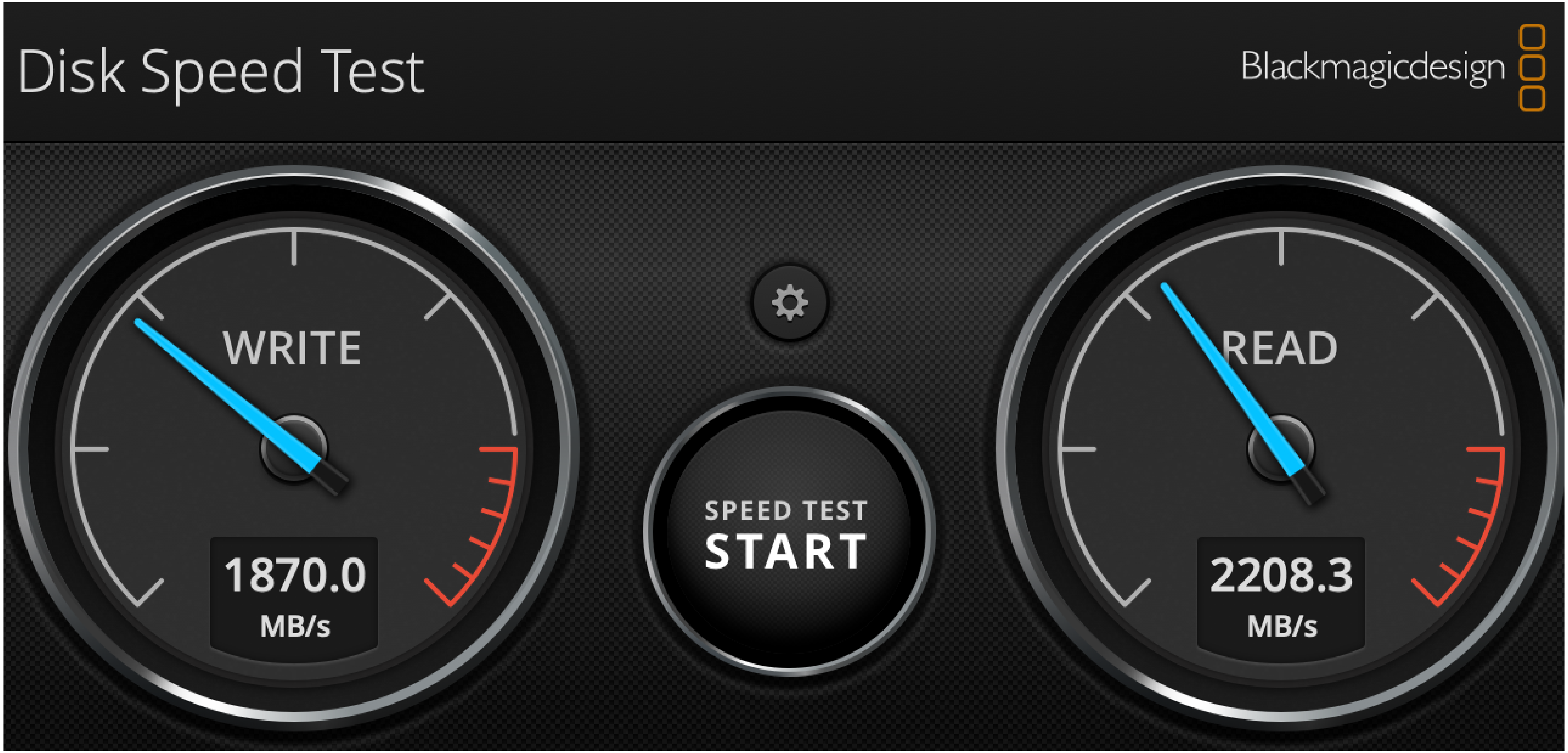
How fast can you read a large file?

- 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



Reading text lines (CPU only)

~0.6 GB/s on 3.4 GHz Skylake in 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)

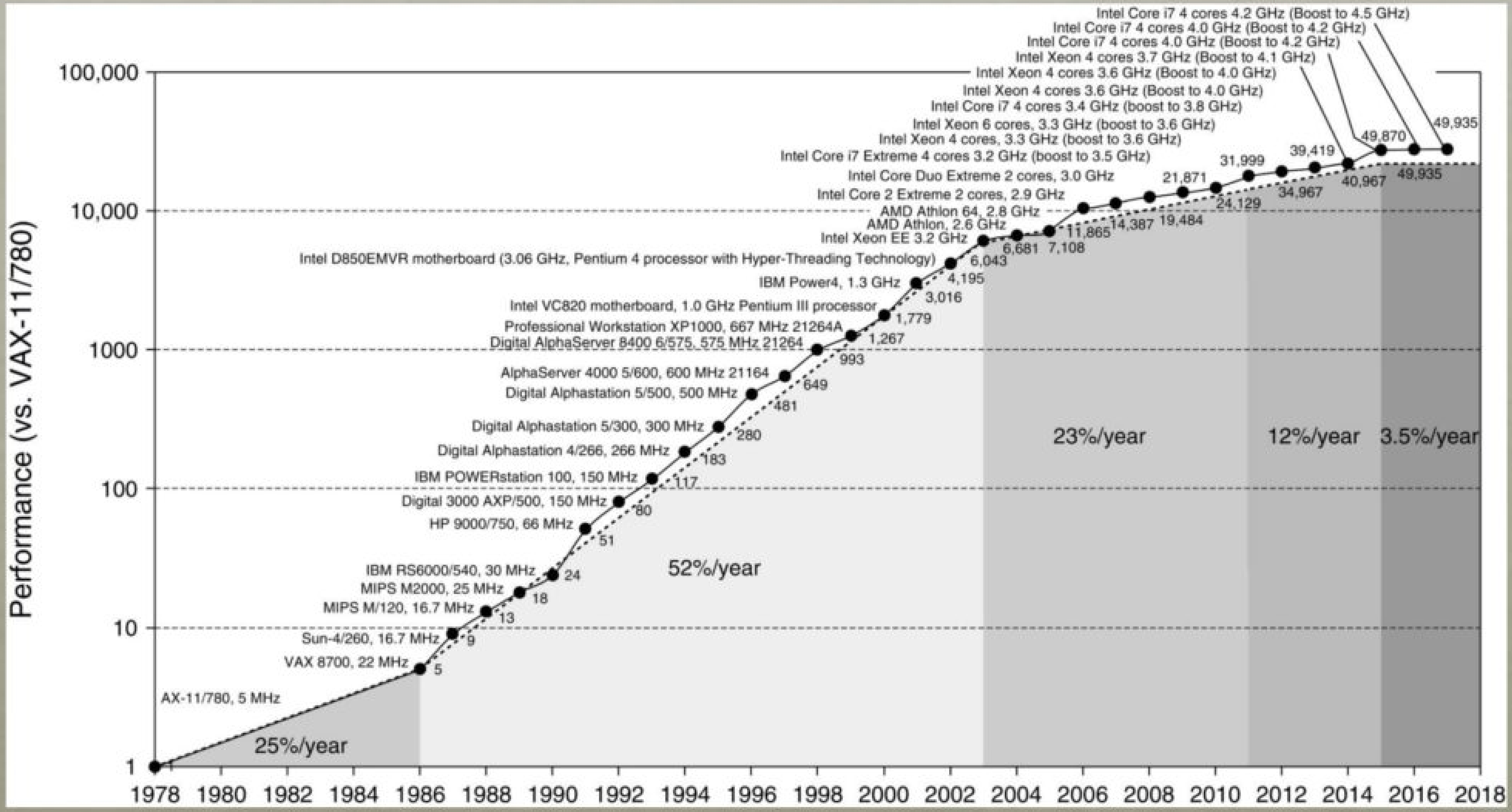
```
size_t sum_line_lengths(char * data, size_t length) {
   std::stringstream is;
   is.rdbuf()->pubsetbuf(data, length);
   std::string line;
   size_t sumofalllinelengths{0};

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

   return sumofalllinelengths;
}
```

Source available.

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: 0.35 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 : avoid 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!

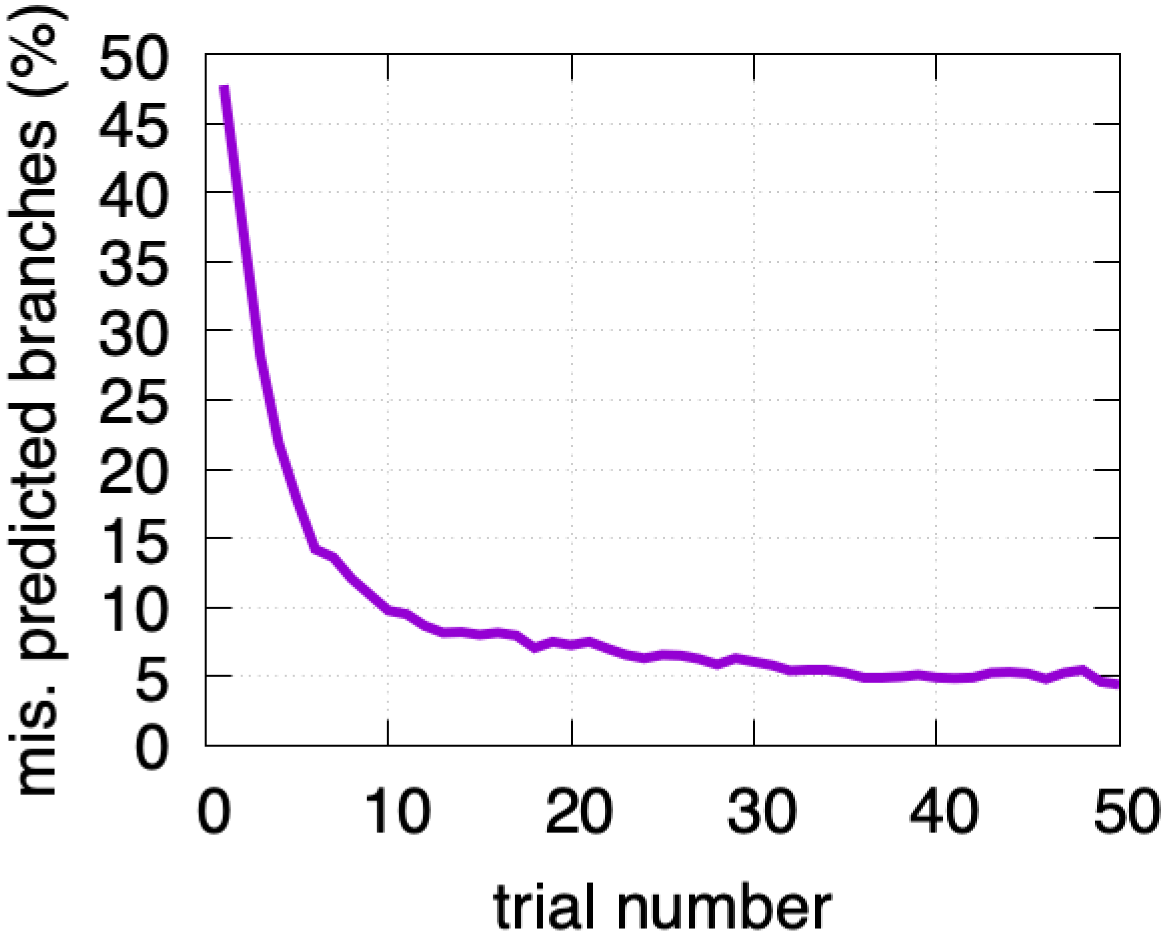
```
while (howmany != 0) {
    val = random();
    out[index] = val;
    index += (val bitand 1);
    howmany--;
}
```

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 #2 : Use wide "words"

Don't process byte by byte

When possible, use SIMD

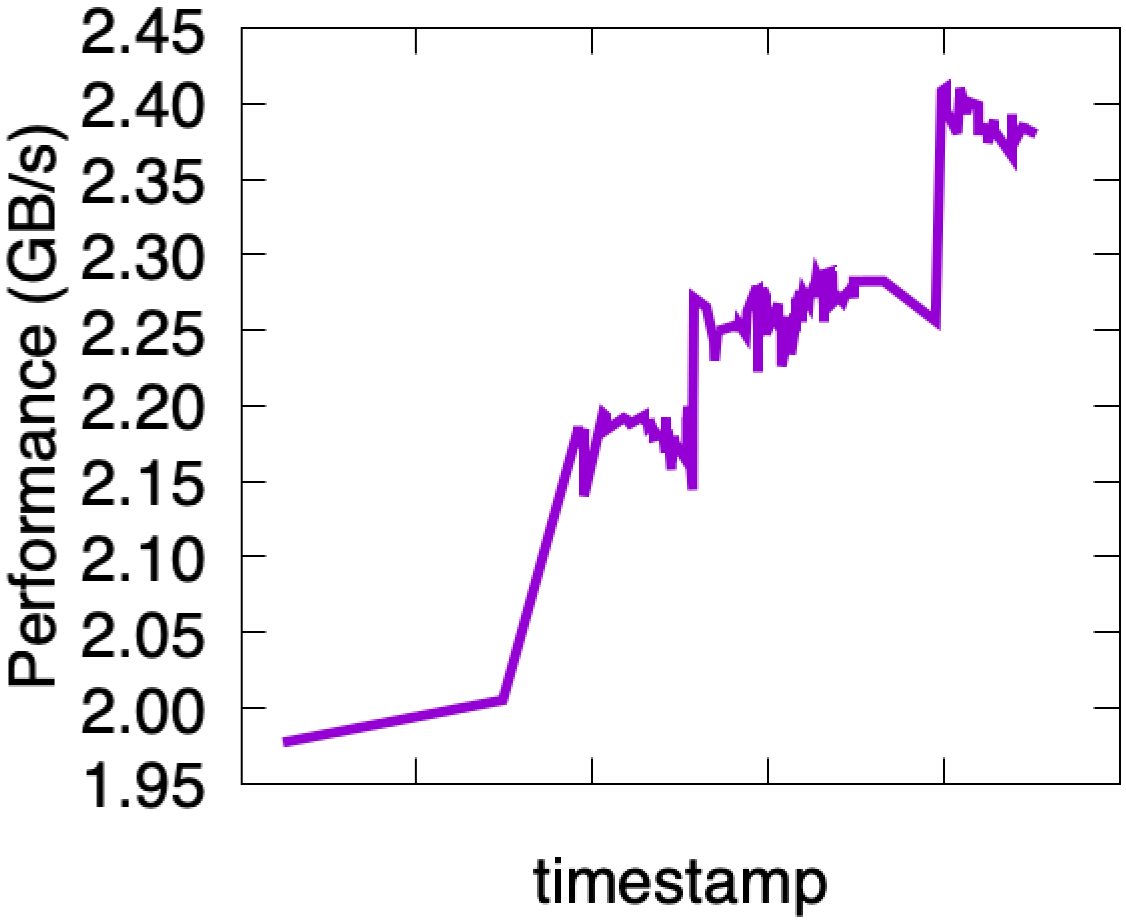
- Available on most commodity processors (ARM, x64)
- Originally added (Pentium) for multimedia (sound)
- Add wider (128-bit, 256-bit, 512-bit) registers
- Adds new fun instructions: do 32 table lookups at once.

Trick #3 : avoid memory/object allocation

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

Trick #4 : measure the performance!

- benchmark-driven development



Continuous Integration Performance tests

- performance regression is a bug that should be spotted early

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

Example: Verify that all byte values are no larger than 244

Saturated subtraction: `x - 244` is non-zero if an only if `x > 244`.

```
_mm256_subs_epu8(current_bytes, 244 );
```

One instruction, checks 32 bytes at once!

processing random UTF-8

	cycles/byte
branching	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, 32 or 64 characters at once!

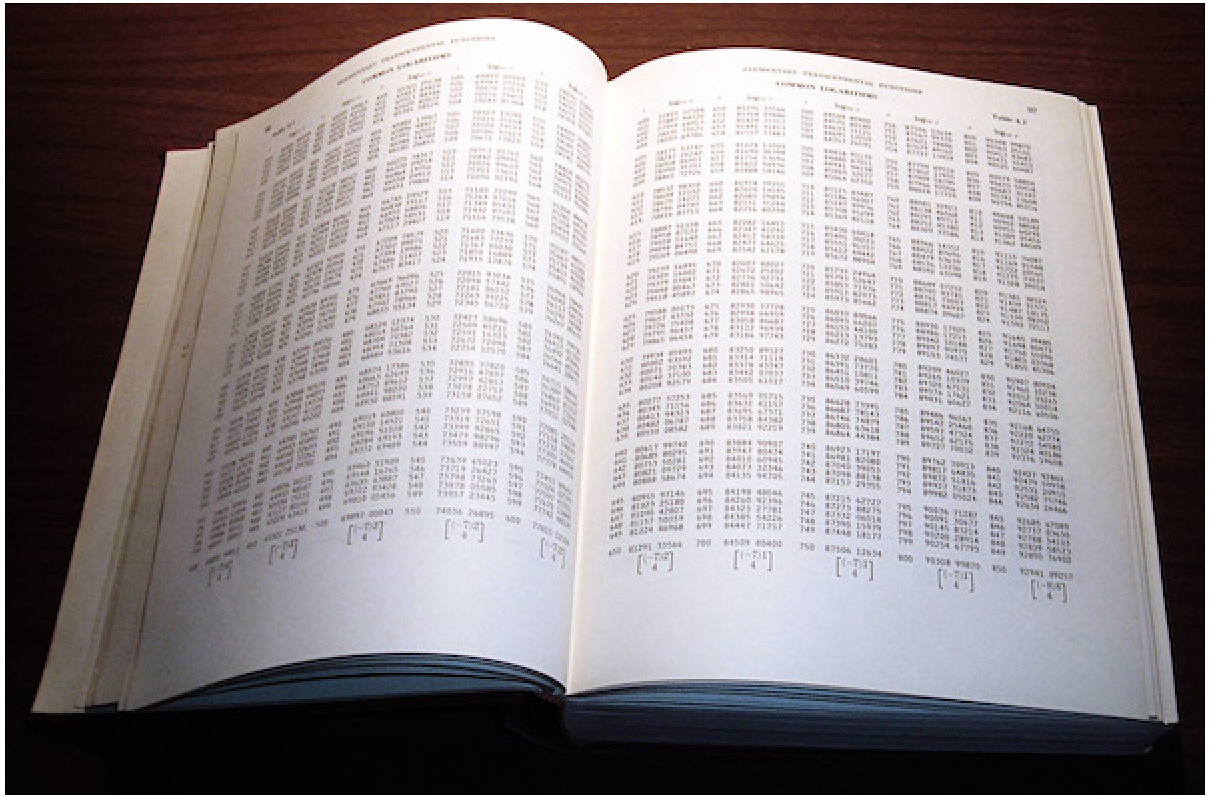
Divide values into two 'nibbles'

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): pshufb, tbl



Start with an array of 4-bit values

[1, 1, 0, 2, 0, 5, 10, 15, 7, 8, 13, 9, 0, 13, 5, 1]

Create a lookup table

[200, 201, 202, 203, 204, 205, 206, 207, 208, 209, 210, 211, 212, 213, 214, 215]

0 ➡️ 200, 1 ➡️ 201, 2 ➡️ 202

Result:

[201, 201, 200, 202, 200, 205, 210, 215, 207, 208, 213, 209, 200, 213, 205, 201]

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

```
const uint8x16_t low_nibble_mask =
      (uint8x16_t){16, 0, 0, 0, 0, 0, 0, 0, 0, 8, 12, 1, 2, 9, 0, 0};
const uint8x16_t high_nibble_mask =
      (uint8x16_t){8, 0, 18, 4, 0, 1, 0, 1, 0, 0, 0, 3, 2, 1, 0, 0};
const uint8x16_t low_nib_and_mask = vmovq_n_u8(0xf);
```

Five instructions:

```
    uint8x16_t nib_lo = vandq_u8(chunk, low_nib_and_mask);
    uint8x16_t nib_hi = vshrq_n_u8(chunk, 4);
    uint8x16_t shuf_lo = vqtbl1q_u8(low_nibble_mask, nib_lo);
    uint8x16_t shuf_hi = vqtbl1q_u8(high_nibble_mask, nib_hi);
    return vandq_u8(shuf_lo, shuf_hi);
```

Example 3. Detecting escaped characters

- " ➡️ \"
- \ ➡️ \\
- \" ➡️ \\\"

Can you tell where the strings start and end?

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

Without branching?

Escape characters follow an *odd* sequence of backslashes!

- Identify backslashes:

`{ "\\\"Nam[{": [ 116,"\\\\"`
`___111________________1111_` : B

Odd and even positions

- `1_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_1_` : O (constant)

Do a bunch of arithmetic and logical operations...

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

Result:

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

```
______1____________________
```

No branch!

Remove the escaped quotes, and

the remaining quotes tell you where the strings are!

```
{ "\\\"Nam[{": [ 116,"\\\\"
__1___1_____1________1____1 : all quotes
______1____________________ : escaped quotes
__1_________1________1____1 : string-delimiter quotes
```

Find the span of the string

```
mask = quote xor (quote << 1);
mask = mask xor (mask << 2);
mask = mask xor (mask << 4);
mask = mask xor (mask << 8);
mask = mask xor (mask << 16);
...
```

`__1_________1________1____1` (quotes)

becomes

`__1111111111_________11111_` (string region)

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

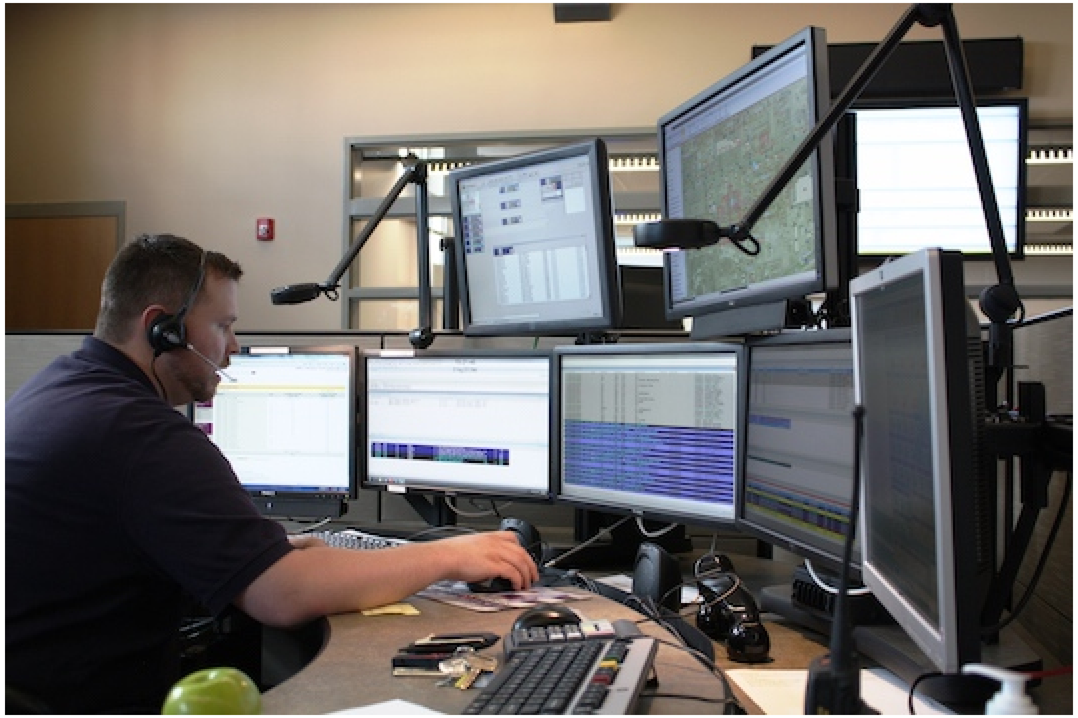
Using only three multiplications (instead of 7):

```
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. No language support.



```
int json_parse_dispatch(...) {
  Architecture best_implementation = find_best_supported_implementation();
  // Selecting the best implementation
  switch (best_implementation) {
  case Architecture::HASWELL:
    json_parse_ptr = &json_parse_implementation<Architecture::HASWELL>;
    break;
  case Architecture::WESTMERE:
    json_parse_ptr= &json_parse_implementation<Architecture::WESTMERE>;
    break;
  default:
    return UNEXPECTED_ERROR;
  }

  return json_parse_ptr(....);
}
```

Where to get it?

- GitHub: https://github.com/lemire/simdjson/
- Modern C++, single-header (easy integration)
- ARM (e.g., iPhone), x64 (going back 10 years)
- Apache 2.0 (no hidden patents)
- Used by Microsoft FishStore and Yandex ClickHouse
- wrappers in Python, PHP, C#, Rust, JavaScript (node), Ruby
- ports to Rust, Go 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)

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