



Parsing JSON Really Quickly : Lessons Learned



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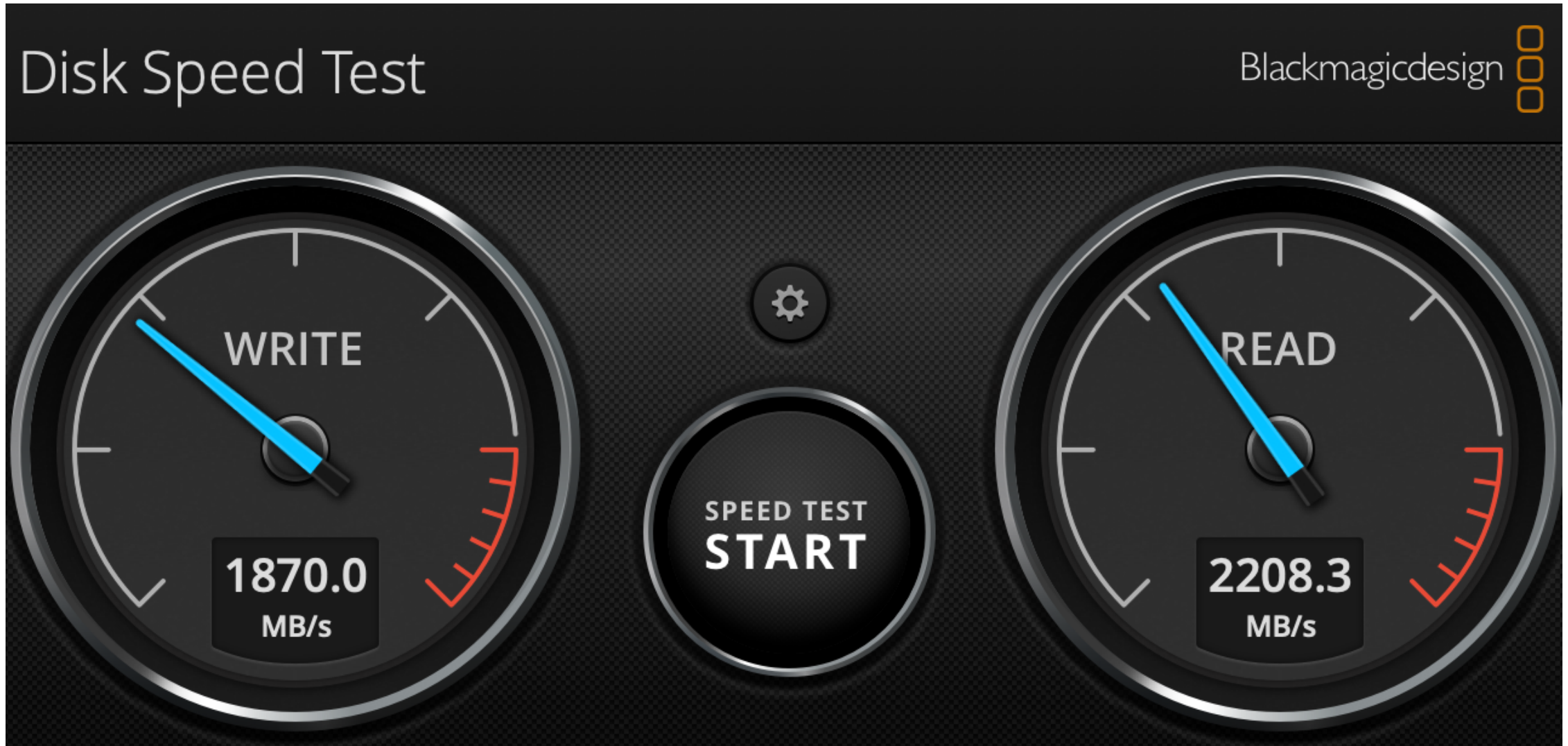
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How fast can you read a large file?

- 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](#)

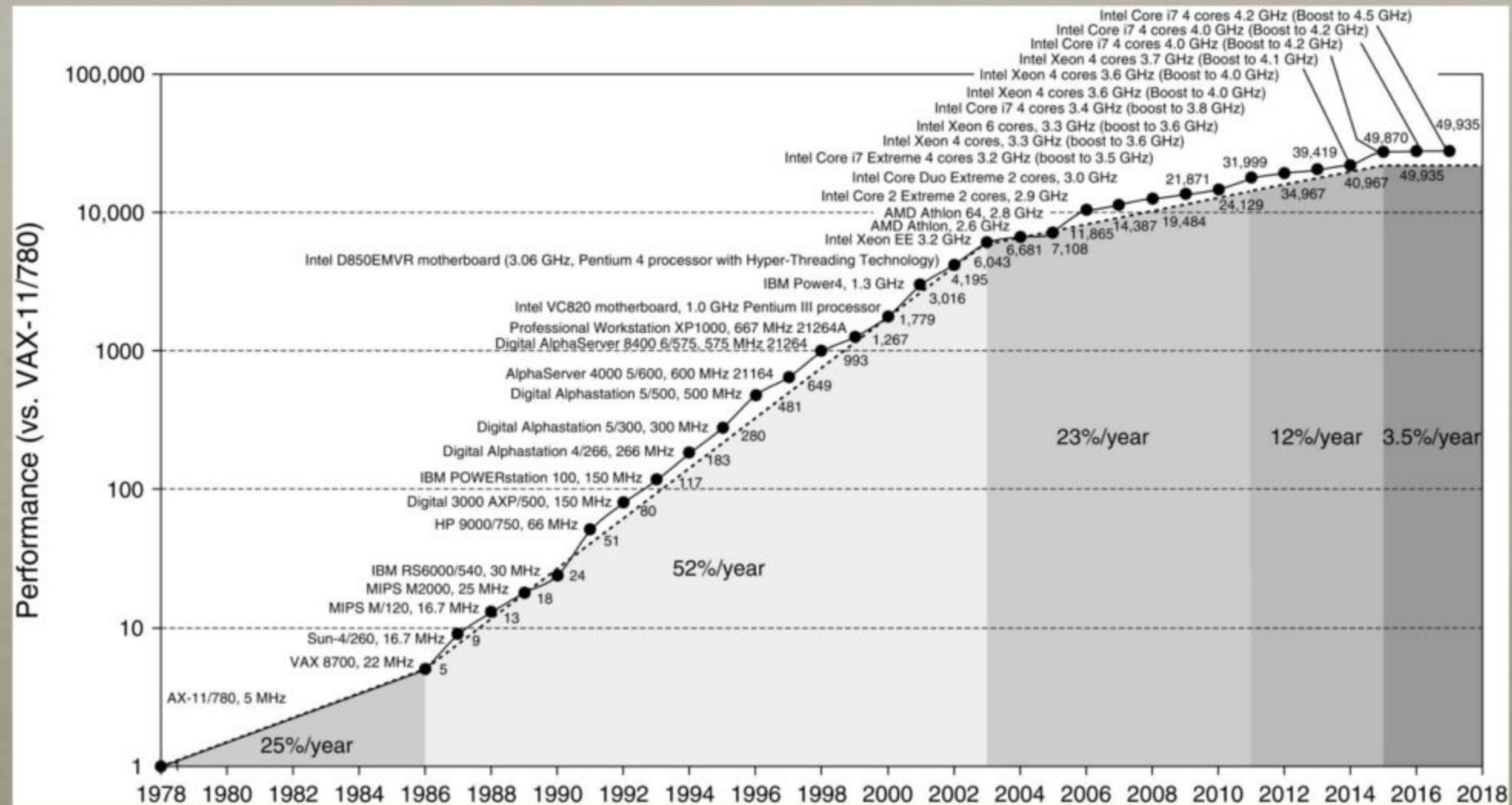
Reading text lines (CPU only)

~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)



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!

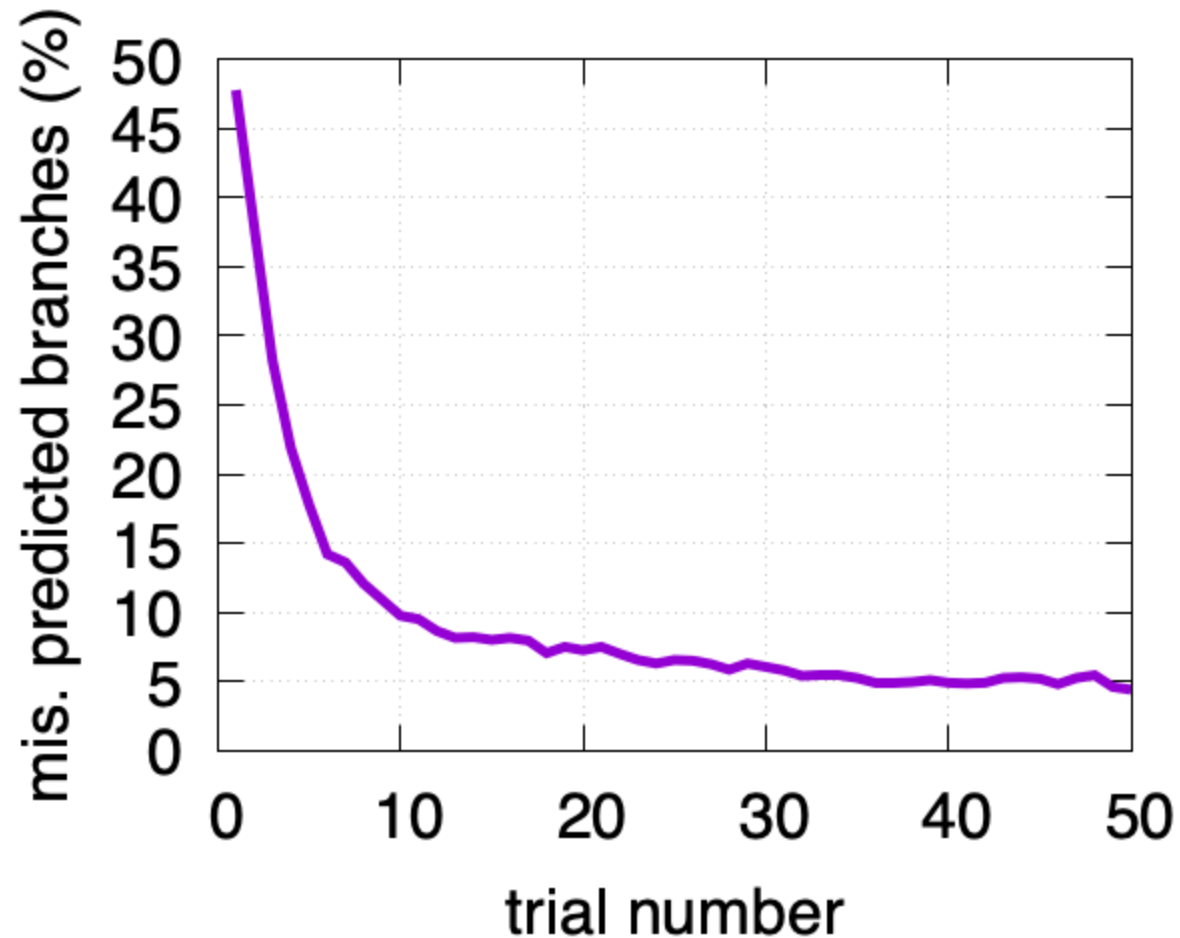
```
while (howmany != 0) {  
    val = random();  
    out[index] = val;  
    index += (val bitand 1);  
    howmany--;  
}
```

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.

ISA	where	max. register width
ARM NEON (AArch64)	mobile phones, tablets	128-bit
SSE2... SSE4.2	legacy x64 (Intel, AMD)	128-bit
AVX, AVX2	mainstream x64 (Intel, AMD)	256-bit
AVX-512	latest x64 (Intel)	512-bit

- "Intrinsic" functions (C, C++, Rust, ...) mapping to specific instructions on specific instructions sets ❤️ ❤️ ❤️
- Higher level functions (Swift, C++, ...): [Java Vector API](#)
- Autovectorization ("compiler magic") (Java, C, C++, ...)
- Optimized functions (some in Java)
- Assembly (e.g., in crypto)

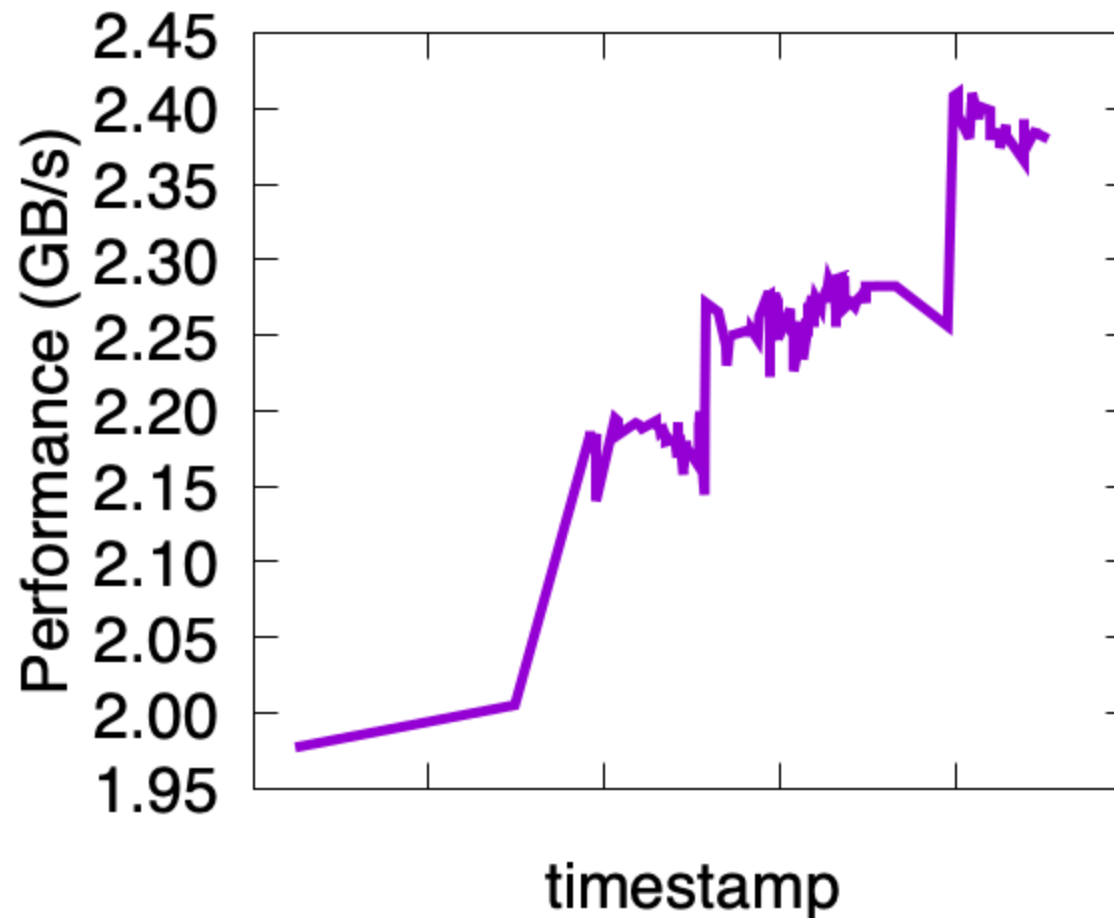
Trick #3 : avoid memory/object allocation

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 and 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!

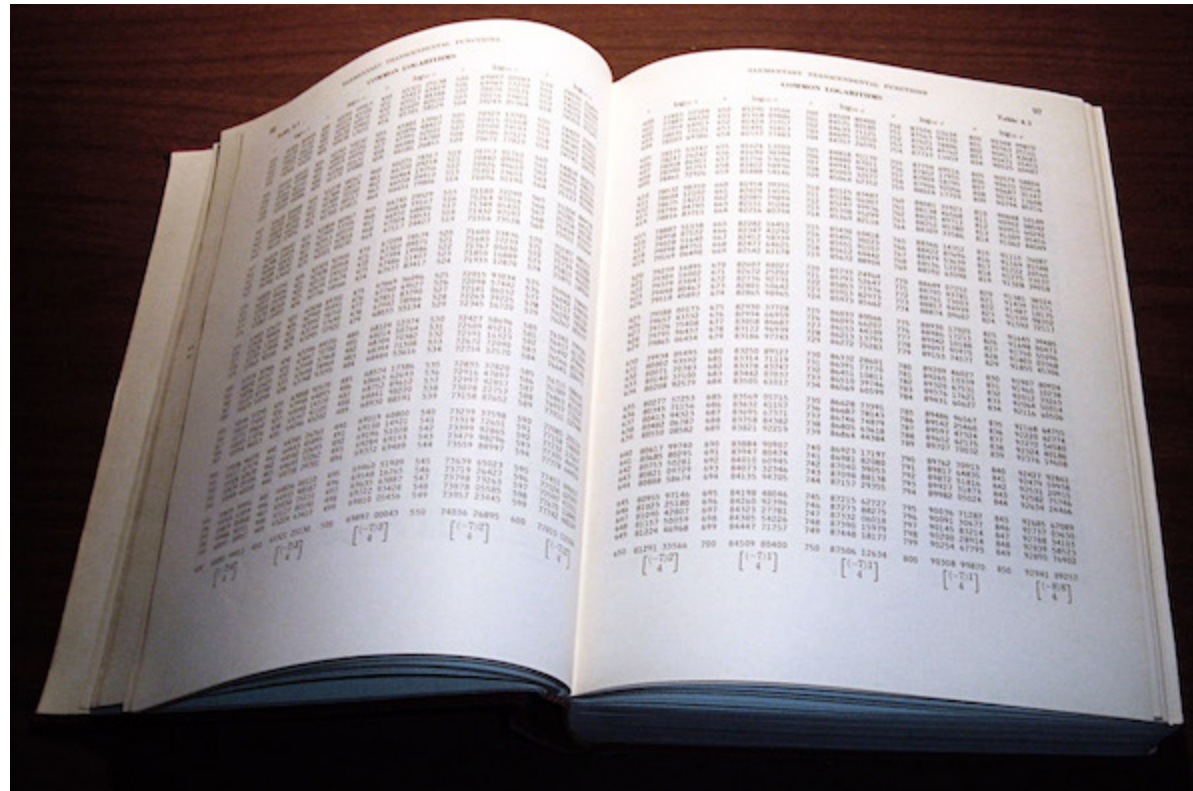
Divide values into two 'nibbles'

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 : 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!

**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

__111111111____1111__ (string region)

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

Example 4. Decode bit indexes

Given the bitset `1000100010001`, we want the location of the 1s (e.g., 0, 4, 8 12)

```
while (word != 0) {  
    result[i] = trailingzeroes(word);  
    word = word & (word - 1);  
    i++;  
}
```

If number of 1s per 64-bit is hard to predict: lots of mispredictions!!!

Instead of predicting the number of 1s per 64-bit, predict whether it is in

- {1, 2, 3, 4}
- {5, 6, 7, 8}
- {9, 10, 11, 12}

Easier!

Reduce the number of misprediction by doing more work per iteration:

```
while (word != 0) {  
    result[i] = trailingzeroes(word);  
    word = word & (word - 1);  
    result[i+1] = trailingzeroes(word);  
    word = word & (word - 1);  
    result[i+2] = trailingzeroes(word);  
    word = word & (word - 1);  
    result[i+3] = trailingzeroes(word);  
    word = word & (word - 1);  
    i+=4;  
}
```

Discard bogus indexes by counting the number of 1s in the word directly (e.g.,
`bitCount`)

Example 5. 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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