Data Engineering at the Speed of Your Disk

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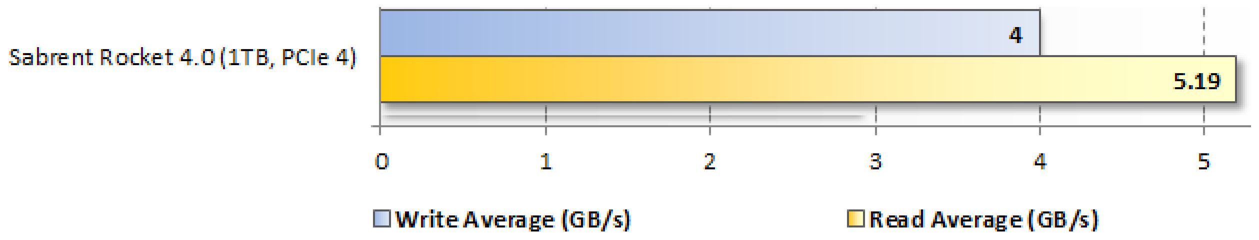
❗ Joint work with tens of smart engineers worldwide

How fast is your disk?

PCIe 4 disks: 5 GB/s reading speed (sequential)



benchmark: hothardware.com 📰

✏️ *Network speeds of 50 GB/s (400GbE) and better are coming near you.*

Unless you can eat data at gigabytes per second, you may be CPU bound when reading from disk!!!

😟😟😟😟

How fast can you allocate dynamically memory?

```
buf  = new char[size]; // virtual alloc only!
// get physical pages
for (size_t i = 0; i < size; i += page_size) buf[i] = 0;
```

3.5 GB/s (Linux, Skylake 3.4GHz, 4kB pages)

How fast can you remove spaces from a string?

```
for (i = 0; i < size; ++i) {
  double r = random();
  if (r < 0.01) {
    buffer[i] = ' ';
  } else {
    ...
  }
}
```

Let us do some C

```
for (size_t i = 0; i < howmany; i++) {
  unsigned char c = bytes[i];
  if (c > 32) {
    bytes[pos++] = c;
  }

}
```

1.6 GB/s

Working byte-by-byte

3.4 GHz implies a limit of 3.4 GB/s.

When possible, use SIMD

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

Removing spaces with SIMD

```
__m128i spaces = _mm_set1_epi8(' ');
for (i = 0; i + 15 < howmany; i += 16) {
  __m128i x = _mm_loadu_si128(bytes + i);
  __m128i anywhite = _mm_cmpeq_epi8(spaces, _mm_max_epu8(spaces, x));
  uint64_t mask16 = _mm_movemask_epi8(anywhite);
  x = _mm_shuffle_epi8(x, despace_mask16[mask16 & 0x7fff]);
  _mm_storeu_si128(bytes + pos, x);
  pos += 16 - _mm_popcnt_u64(mask16);
}
```

8 GB/s

https://github.com/lemire/despacer

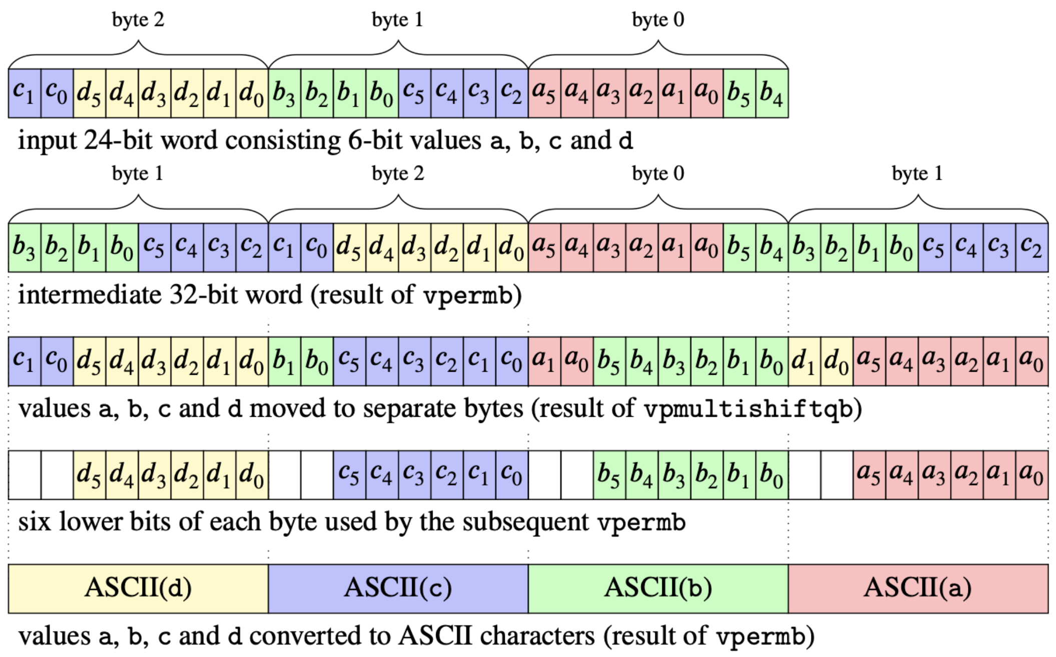
Base64

Standard to map binary data to ASCII. Used to encode most emails. Amazon SimpleDB, Amazon DynamoDB, MongoDB, Elasticsearch, Web Storage.

```
TWFuIGlzIGRpc3Rpbmd1aXNoZWQsIG5vdCBvbmx5IGJ5IGhpcyByZWFzb24sIGJ1dCBieSB0aGlz
IHNpbmd1bGFyIHBhc3Npb24gZnJvbSBvdGhlciBhbmltYWxzLCB3aGljaCBpcyBhIGx1c3Qgb2Yg
dGhlIG1pbmQsIHRoYXQgYnkgYSBwZXJzZXZlcmFuY2Ugb2YgZGVsaWdodCBpbiB0aGUgY29udGlu
dWVkIGFuZCBpbmRlZmF0aWdhYmxlIGdlbmVyYXRpb24gb2Yga25vd2xlZGdlLCBleGNlZWRzIHRo
ZSBzaG9ydCB2ZWhlbWVuY2Ugb2YgYW55IGNhcm5hbCBwbGVhc3VyZS4=
```

🔤🔤🔤🔤 ↔️ 🔢 🔢 🔢

To map 48 binary bytes into 64 ASCII


byte 2
byte 1
byte 0
input 24-bit word consisting 6-bit values a, b, c and d
byte 1
byte 2
byte 0
byte 1
intermediate 32-bit word (result of vpermb)
values a, b, c and d moved to separate bytes (result of vpmultishiftqb)
six lower bits of each byte used by the subsequent vpermb
ASCII(d)
ASCII(c)
ASCII(b)
ASCII(a)
values a, b, c and d converted to ASCII characters (result of vpermb)

▶️ Base64 encoding and decoding at almost the speed of a memory copy, Software: Practice and Experience 50 (2), 2020

Unicode fun: 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

0.3 GB/s

```
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

8 GB/s

- Load 32-byte registers
- Use ~20 instructions
- No branch, no branch misprediction

https://github.com/lemire/fastvalidate-utf-8

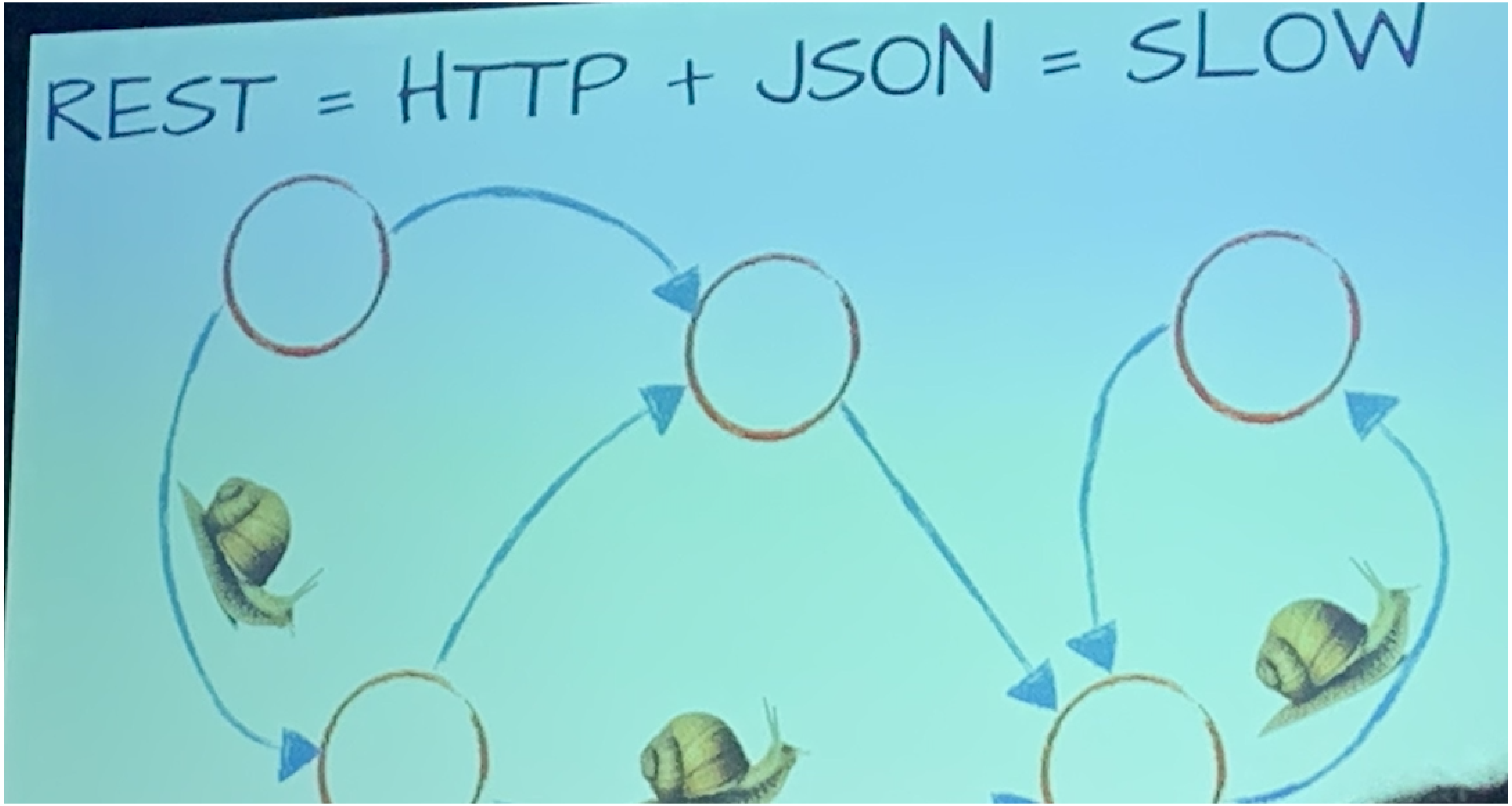
JSON

- 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}
}}
```

JSON parsing

- Read all of the content
- Check that it is valid JSON
- Check Unicode encoding
- Parse numbers
- Build DOM (document-object-model)



source: @gwenshap

JSON for Modern C++ (nlohmann-json)

0.1 GB/s (Skylake 3.4GHz, GNU GCC8, file: twitter.json)

RapidJSON

0.3 GB/s (Skylake 3.4GHz, GNU GCC8, file: twitter.json)

getline

```
size_t sumofalllinelengths{0};
  while(getline(is, line)) {
    sumofalllinelengths += line.size();
  }
```

1.4 GB/s (Skylake 3.4GHz, GNU GCC8, file: twitter.json)

simdjson

2.5 GB/s (Skylake 3.4GHz, GNU GCC8, file: twitter.json)

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)

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;
}
```

simdjson	660 MB/s
simdjson	660 MB/s
abseil, from_chars	330 MB/s
strtod	70 MB/s

https://github.com/lemire/fast_double_parser

Where to get simdjson?

- https://simdjson.org
- GitHub: https://github.com/simdjson/simdjson/
- Modern C++, single-header (easy integration)
- 64-bit ARM (e.g., iPhone), x64
- 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#