

# C++26 Reflection for JSON Serialization

## A Practical Journey

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# JSON

- Portable, simple
- Used by ~97% of API requests. [Landscape of API Traffic 2021 - Cloudflare](#)
- scalar values
  - strings (must be escaped)
  - numbers (but not NaN or Inf )
- composed values
  - objects (key/value)
  - arrays (list)

```
{  
  "username": "Alice",  
  "level": 42,  
  "health": 99.5,  
  "inventory": ["sword", "shield", "potion"]  
}
```

# JSON downside?

Reading and writing JSON can be *slow*. E.g., 100 MB/s to 300 MB/s.

- Slower than fast disks or fast networks

```
$ go run parse_twitter.go  
Parsed 0.63 GB in 6.961 seconds (90.72 MB/s)
```

REST = HTTP + JSON = SLOW



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# Micron shows off world's fastest PCIe 6.0 SSD, hitting 27 GB/s speeds — Astera Labs PCIe 6.0 switch enables impressive sequential reads

News

By [Sunny Grimm](#) published March 8, 2025

The next-gen of networking and storage is hitting the trade shows

# Performance

- simdjson was the first library to break the gigabyte per second barrier
  - Parsing Gigabytes of JSON per Second, VLDB Journal 28 (6), 2019
  - On-Demand JSON: A Better Way to Parse Documents? SPE 54 (6), 2024
- JSON for Modern C++ (nlohmann/json) can be  $100\times$  slower!



## **SIMD (Single Instruction, multiple data)**

- Allows us to process 16 (or more) bytes or more with one instruction
- Supported on all modern CPUs (phone, laptop)
- Data-parallel types (SIMD) (recently added to C++26)



# Not all processors are equal

processor	year	arithmetic logic units	SIMD units
Apple M*	2019	6+	$4 \times 128$
Intel Lion Cove	2024	6	$4 \times 256$
AMD Zen 5	2024	6	$4 \times 512$

# SIMD support in simdjson

- x64: SSSE3 (128-bit), AVX-2 (256-bit), AVX-512 (512-bit)
- ARM NEON
- POWER (PPC64)
- Loongson: LSX (128-bit) and LASX (256-bit)
- RISC-V: *upcoming*

# simdjson: Parsing design

- First scan identifies the structural characters, start of all strings at about 10 GB/s using SIMD instructions.
- Validates Unicode (UTF-8) at 30 GB/s.
- Rest of parsing relies on the generated index.
- Allows fast skipping. (Only parse what we need)



<https://openbenchmarking.org/test/pts/simdjson>

# Usage

The simdjson library is found in...

- Node.js, Electron, ...
- ClickHouse
- Velox
- Milvus
- QuestDB
- StarRocks



ClickHouse

# The Problem

Imagine you're building a game server that needs to persist player data.



## Player

username: string

level: int

health: double

inventory: string, string, ...

You start simple:

```
struct Player {  
    std::string username;  
    int level;  
    double health;  
    std::vector<std::string> inventory;  
};
```

# The Traditional Approach: Manual Serialization

Without reflection, you may write this tedious code:

```
// Serialization - converting Player to JSON
fmt::format(
    "{{"
    "\"username\": \"{}\", "
    "\"level\": {}, "
    "\"health\": {}, "
    "\"inventory\": {}"
    "}}",
    escape_json(p.username),
    p.level,
    std::isfinite(p.health) ? p.health : -1.0,
    p.inventory| std::views::transform(escape_json)
);
```



# Manual Deserialization (simdjson)

```
object obj = val.get_object();
p.username = obj["username"].get_string();
p.level = obj["level"].get_int64();
p.health = obj["health"].get_double();
array arr = obj["inventory"].get_array();
for (auto item : arr) {
    p.inventory.emplace_back(item.get_string());
}
```

# When Your Game Grows...

```
struct Equipment {
    std::string name;
    int damage; int durability;
};
struct Achievement {
    std::string title; std::string description; bool unlocked;
    std::chrono::system_clock::time_point unlock_time;
};
struct Player {
    std::string username;
    int level; double health;
    std::vector<std::string> inventory;
    std::map<std::string, Equipment> equipped;           // New!
    std::vector<Achievement> achievements;              // New!
    std::optional<std::string> guild_name;               // New!
};
```

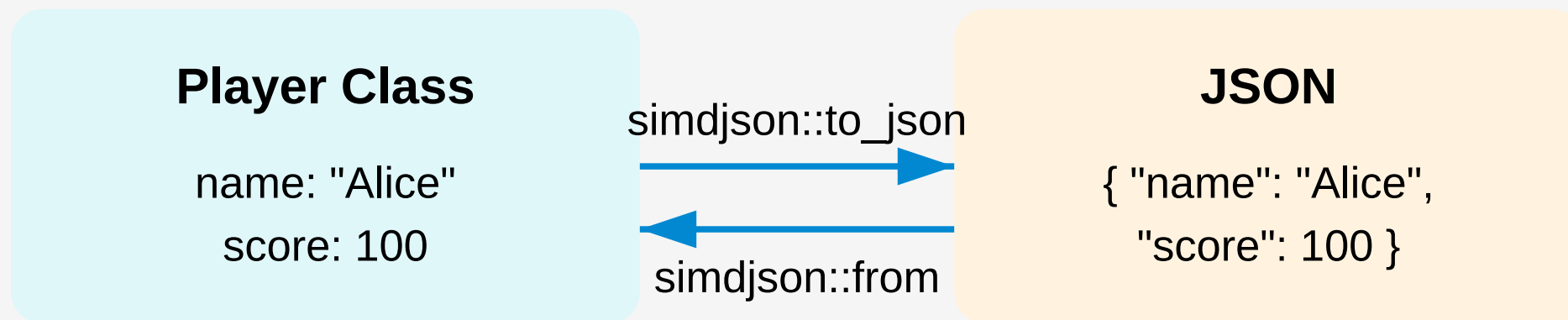


# The Pain Points

This manual approach has several problems:

1. **Maintenance Nightmare:** Add a new field? Update both functions!
2. **Error-Prone:** Typos in field names, forgotten fields, type mismatches

# Our goal: Seamless Serialization/Deserialization



How do other  
languages do  
it?

# C#

```
string jsonString = JsonSerializer.Serialize(player, options);  
Player deserializedPlayer = JsonSerializer.Deserialize<Player>(jsonInput, options);
```



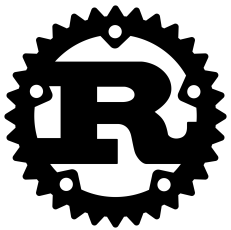
# Why can C# implementation be so elegant?

It is using **reflection** to access the attributes of a struct during runtime.



# Rust (serde)

```
// Rust with serde  
let json_str = serde_json::to_string(&player)?;  
let player: Player = serde_json::from_str(&json_str)?;
```



# Rust reflection

- Rust does not have any built-in reflection capabilities.
- Serde relies on annotation and macros.



# Reflection as accessing the attributes of a struct.

language	runtime reflection	compile-time reflection
C++ 26	✗	✓
Go	✓	✗
Java	✓	✗
C#	✓	✗
Rust	✗ (macros)	✗

# Now it's our turn to have reflection!

With C++26 reflection and simdjson, **all that boilerplate disappears:**

```
// Just define your struct - no extra code needed!  
struct Player {  
    std::string username;  
    int level;  
    double health;  
    std::vector<std::string> inventory;  
    std::map<std::string, Equipment> equipped;  
    std::vector<Achievement> achievements;  
    std::optional<std::string> guild_name;  
};
```

# Automatic Serialization

```
// Serialization - one line!  
void save_player(const Player& p) {  
    std::string json = simdjson::to_json(p); // That's it!  
    // Save json to file...  
}
```

# Automatic Deserialization

```
// Deserialization - one line!  
Player load_player(std::string& json_str) {  
    return simdjson::from(json_str); // That's it!  
}
```

Runnable example at <https://godbolt.org/z/Efr7bK9jn>

# Benefits of our implementation

- No manual field mapping
- Minimal maintenance burden
- Handles nested and user-defined structures and containers automatically
- You can still customize things if and when you want to

# What Happens Behind the Scenes

```
// What you write:
Player p = simdjson::from(runtime_json_string);

// What reflection generates at COMPILE TIME (conceptually):
Player deserialize_Player(const json& j) {
    Player p;
    p.username = j["username"].get<std::string>();
    p.level = j["level"].get<int>();
    p.health = j["health"].get<double>();
    p.inventory = j["inventory"].get<std::vector<std::string>>();
    // ... etc for all members
    return p;
}
```



# The Actual Reflection Magic

```
// Simplified snippet, members stores information about the class
// obtained via std::define_static_array(std::meta::nonstatic_data_members_of(^^T, ...))...
ondemand::object obj;

template for (constexpr auto member : members) {
    // These are compile-time constants
    constexpr std::string_view field_name = std::meta::identifier_of(member);
    constexpr auto member_type = std::meta::type_of(member);

    // This generates code for each member
    obj[field_name].get(out.[:member:]);
}
```

See full implementation on [GitHub](#)

# Compile-Time vs Runtime: What Happens When

```
struct Player {  
    std::string username;    // ← Compile-time: reflection sees this  
    int level;              // ← Compile-time: reflection sees this  
    double health;          // ← Compile-time: reflection sees this  
};  
  
// COMPILE TIME: Reflection reads Player's structure and generates:  
// - Code to read "username" as string  
// - Code to read "level" as int  
// - Code to read "health" as double  
  
// RUNTIME: The generated code processes actual JSON data  
std::string json = R("{\"username\":\"Alice\",\"level\":42,\"health\":100.0}");  
Player p = simdjson::from(json);  
// Runtime values flow through compile-time generated code
```

Try out this example at <https://godbolt.org/z/WWGjhnjWW>

```
struct Meeting {
    std::string title;
    long long start_time;
    std::vector<std::string> attendees;
    std::optional<std::string> location;
    bool is_recurring;
};

// Automatically serializable/deserializable!
std::string json = simdjson::to_json(Meeting{
    .title = "CppCon Planning",
    .start_time = std::chrono::duration_cast<std::chrono::milliseconds>(
        std::chrono::system_clock::now().time_since_epoch()
    ).count(),
    .attendees = {"Alice", "Bob", "Charlie"},
    .location = "Denver",
    .is_recurring = true
});

Meeting m = simdjson::from(json);
```

# The Container Challenge

We can say that serializing/parsing the basic types and custom classes/structs is pretty much effortless.

How do we automatically serialize ALL these different containers?

- `std::vector<T>` , `std::list<T>` , `std::deque<T>`
- `std::map<K, V>` , `std::unordered_map<K, V>`
- `std::set<T>` , `std::array<T, N>`
- Custom containers from libraries
- **Future containers not yet invented**

# The Naive Approach

```
// The OLD way - repetitive and error-prone! 🤖  
void serialize(string_builder& b, const std::vector<T>& v) { /* ... */ }  
void serialize(string_builder& b, const std::list<T>& v) { /* ... */ }  
void serialize(string_builder& b, const std::deque<T>& v) { /* ... */ }  
void serialize(string_builder& b, const std::set<T>& v) { /* ... */ }  
// ... 20+ more overloads for each container type!
```

**Problem:** New container type? Write more boilerplate!

# The Solution: Concepts as Pattern Matching

Concepts let us say: "If it walks like a duck and quacks like a duck..."

```
// The NEW way - one function handles ALL array-like containers!
template<typename T>
    requires(has_size_and_subscript<T>) // "If it has .size() and operator[]"
void serialize(string_builder& b, const T& container) {
    b.append('[');
    for (size_t i = 0; i < container.size(); ++i) {
        serialize(b, container[i]);
    }
    b.append(']');
}
```

✓ Works with `vector`, `array`, `deque`, custom containers...

# Concepts + Reflection = Automatic Support

When you write:

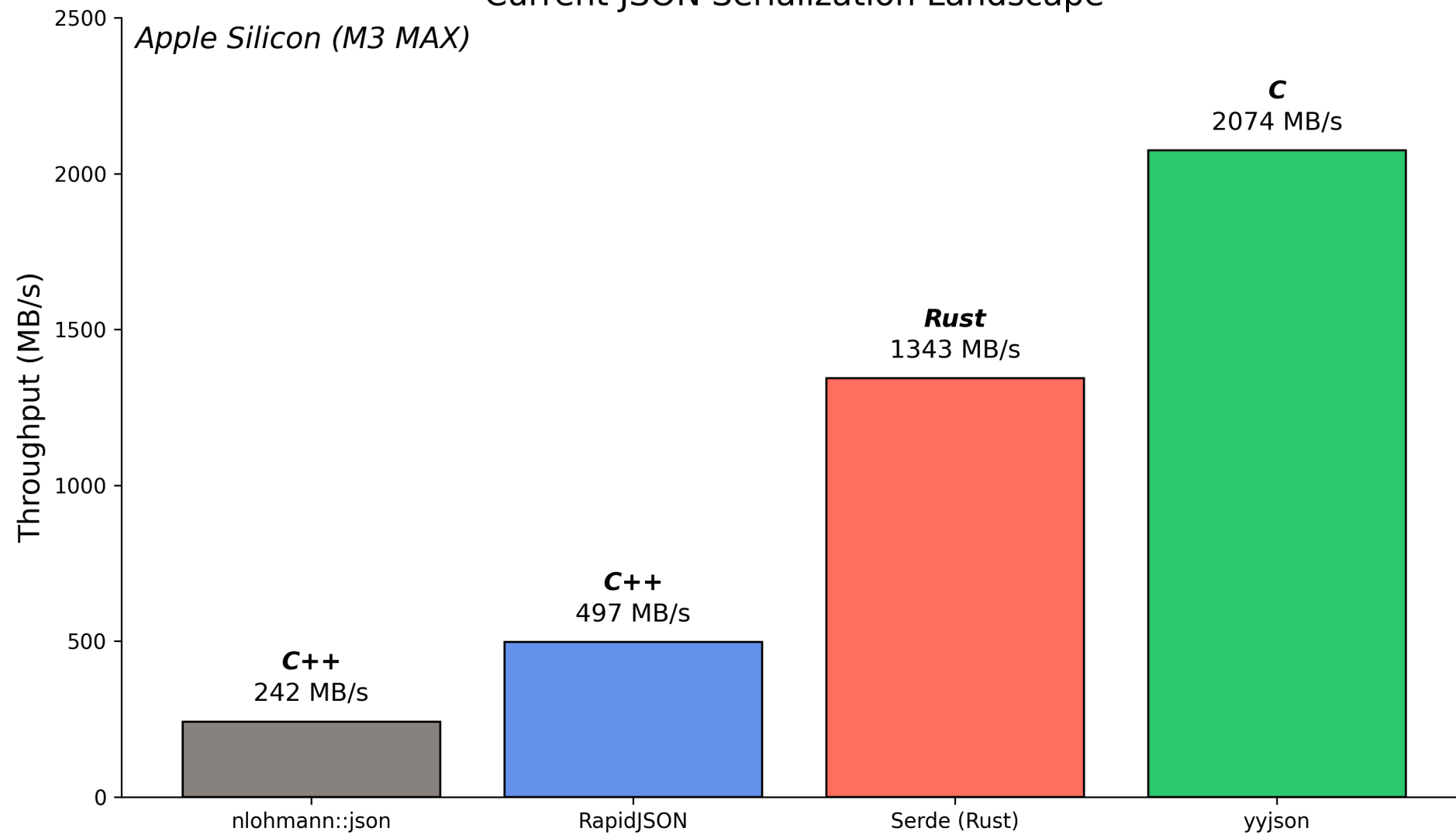
```
struct GameData {  
    std::vector<int> scores;           // Array-like → [1,2,3]  
    std::map<string, Player> players; // Map-like → {"Alice": {...}}  
    MyCustomContainer<Item> items;    // Your container → Just works!  
};
```

The magic:

1. **Reflection** discovers your struct's fields
2. **Concepts** match container behavior to serialization strategy
3. **Result**: ALL containers work automatically - standard, custom, or future!

**Write once, works everywhere™**

## Current JSON Serialization Landscape





# How fast are we?



# Ablation Study: How We Achieved 3.4 GB/s

## What is Ablation?

From neuroscience: systematically remove parts to understand function

## Our Approach (Apple Silicon M3 MAX):

1. **Baseline:** All optimizations enabled (3,400 MB/s)
2. **Disable one optimization** at a time
3. **Measure performance impact**
4. **Calculate contribution:**  $(\text{Baseline} - \text{Disabled}) / \text{Disabled}$

# Five Key Optimizations

1. **Consteval**: Compile-time field name processing
2. **SIMD String Escaping**: Vectorized character checks
3. **Fast Integer Serialization**: Optimized number handling

## Combined Performance Impact

Optimization	Twitter Contribution	CITM Contribution
<b>Consteval</b>	+100% (2.00x)	+141% (2.41x)
<b>SIMD Escaping</b>	+42% (1.42x)	+4% (1.04x)
<b>Fast Digits</b>	+6% (1.06x)	+34% (1.34x)

# Optimization #1: Consteval

## The Power of Compile-Time

**The Insight:** JSON field names are known at compile time!

**Traditional (Runtime):**

```
// Every serialization call:  
write_string("\"username\""); // Quote & escape at runtime  
write_string("\"level\"");    // Quote & escape again!
```

**With Consteval (Compile-Time):**

```
constexpr auto username_key = "\"username\""; // Pre-computed!  
b.append_literal(username_key); // Just memcpy!
```

# Optimization #2: SIMD String Escaping

**The Problem:** JSON requires escaping `"`, `\`, and control chars

**Traditional (1 byte at a time):**

```
for (char c : str) {  
    if (c == '"' || c == '\\ ' || c < 0x20)  
        return true;  
}
```

**SIMD (16 bytes at once):**

```
auto chunk = load_16_bytes(str);  
auto needs_escape = check_all_conditions_parallel(chunk);  
if (!needs_escape)  
    return false; // Fast path!
```

## Optimization #3: Fast Integer serialization

( std::to\_chars )

```
while(number >= 10) {  
    *write_pointer-- = char('0' + (number % 10));  
    number /= 10;  
}  
*write_pointer = char('0' + number);
```

Writing from the end

## Two digits at a time

```
while(number >= 100) {  
    memcpy(write_pointer - 1, &decimal_table[(pv % 100)*2], 2);  
    write_pointer -= 2;  
    pv /= 100;  
}  
if(number >= 10) {  
    *write_pointer-- = char('0' + (number % 10));  
    number /= 10;  
}  
*write_pointer = char('0' + number);
```



# Know where to start writing

- Useful to compute quickly the number of digits

```
template <typename number_type>
int int_log2(number_type x) {
    return 63 - leading_zeroes(uint64_t(x) | 1);
}

int fast_digit_count_64(uint64_t x) {
    static uint64_t table[] = {9,
                                99,
                                999,
                                // ...
                                999999999999999999ULL,
                                999999999999999999ULL,
                                999999999999999999ULL,
                                999999999999999999ULL};

    int y = (19 * int_log2(x) >> 6);
    y += x > table[y];
    return y + 1;
}
```

# Could use SIMD if we wanted to

Don't try to understand:

```
__m128i to_string_avx512ifma(uint64_t n) {
    uint64_t n_15_08 = n / 1000000000;
    uint64_t n_07_00 = n % 1000000000;
    __m512i bcstq_h = _mm512_set1_epi64(n_15_08);
    __m512i bcstq_l = _mm512_set1_epi64(n_07_00);
    __m512i zmmzero = _mm512_castsi128_si512(_mm_cvtsi64_si128(0x1A1A400));
    __m512i zmmTen = _mm512_set1_epi64(10);
    __m512i asciiZero = _mm512_set1_epi64('0');
    __m512i ifma_const = _mm512_setr_epi64(0x0000000000002af31dc, ...);
    __m512i permb_const = _mm512_castsi128_si512(_mm_set_epi8(0x78, ...));
    __m512i lowbits_h = _mm512_madd52lo_epu64(zmmzero, bcstq_h, ifma_const);
    __m512i lowbits_l = _mm512_madd52lo_epu64(zmmzero, bcstq_l, ifma_const);
    __m512i highbits_h = _mm512_madd52hi_epu64(asciiZero, zmmTen, lowbits_h);
    __m512i highbits_l = _mm512_madd52hi_epu64(asciiZero, zmmTen, lowbits_l);
    __m512i perm = _mm512_permutex2var_epi8(highbits_h, permb_const, highbits_l);
    __m128i digits_15_0 = _mm512_castsi512_si128(perm);
    return digits_15_0;
}
```

# Does fast integer processing matter?

- Replace fast digit count by naive approach based on `std::to_string`

```
std::to_string(value).length();
```

- Only 34% worse in one dataset.

## What about compilation time?

We've observed a 6% slow-down when compiling simdjson with static reflection enabled. (clang p2996 experimental branch).

# Key Technical Insights

## 1. With reflection and concepts

- your code becomes shorter
- your code becomes more general

## 2. Compilation time not much slower

## 3. Compile-Time optimizations can be awesome

- Consteval: 2-2.6x speedup alone

## 4. **SIMD** String operations benefit

## 5. Every Optimization Matters

- Small gains compound into huge improvements

# Thank You!

## **C++ Reflection Paper Authors**

- The authors of P2996 for making compile-time reflection a reality

## **Compiler Implementation Teams**

- Everyone that implemented P2996 and made it publicly available.
- Early adopters testing and providing feedback

## **Compiler Explorer Team**

- Matt Godbolt and contributors

## **simdjson Community**

- All contributors and users (John Keiser, Geoff Langdale, Paul Dreik...)

# Questions?

Daniel Lemire and Francisco Geiman Thiesen

GitHub: [github.com/simdjson/simdjson](https://github.com/simdjson/simdjson)

Thank you!

