`std::launder`, `std::start_lifetime_as`, and UB in `reinterpret_cast`

OR…type punning done right

Javier López-Gómez

`using std::cpp`, 2025-03-19

About me

Javier Lopez-Gomez

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Summary of the last 5+ years (compilers-wise)...

- 2017–2020: PhD in Computer Science and Technology (ARCOS-UC3M)
  - Prototype implementation of C++ contracts (clang)
  - Research internship at CERN in 2019: Definition shadowing in the Cling C++ interpreter
- 2020–2023: Senior Fellow (SFT, CERN)
  - More Cling – but also RNTuple and general contributions to the ROOT project
- **2024–(currently): Senior Compiler Engineer (Zimperium, Inc.)**
  - Binary-to-binary obfuscation solution

C++ trivia (1)

Let's assume this type definition for `MyType`.

```
struct MyType {
  uint32_t i;
  float f;
};
static_assert(sizeof(MyType) == 8 && alignof(MyType) == 4);
```

Is this well-defined C++ or UB?

```
unsigned char b[]{0x00, 0x11, 0x22, 0x33, 0xff, 0x00, 0xff, 0x00};
auto *p = reinterpret_cast<MyType *>(&b);
some_fn_taking_int(p->i);
```

C++ trivia (1)

Let’s assume this type definition for `MyType`.

```
struct MyType {
```

UNDEFINED BEHAVIOR 🤦 due to

- Violates strict aliasing
- Storage may not be suitably aligned for `MyType`
- `p` accesses `MyType` object out of its lifetime

Is th

```
some_fn_taking_int(p->i);
```

C++ trivia (2)

Given the previous definition for `MyType`, again

Is this well-defined C++ or UB?

```
MyType foo{123, 42.0f};
auto *p = reinterpret_cast<unsigned char *>(&foo);
fn_doing_something_on_char_array(p, sizeof(MyType));
```

Give

Is th

(MOSTLY) UNDEFINED BEHAVIOR

- See P1839R7; a defect in ISO CPP standard?

Given the previous definition for `MyType`, again

Is this well-defined C++ or UB?

```
alignas(MyType) unsigned char b[]{0x00, 0x11, 0x22, 0x33, 0xff, 0x00,
    0xff, 0x00};
auto o = std::bit_cast<MyType>(b);
some_fn_taking_int(p->i);
```

C++ trivia (3)

Given the previous definition for `MyType`, again

Is th

WELL-DEFINED

- Note, however, that result may vary depending on arch endianness

Contents

Introduction

Definitions: Undefined Behavior (UB)

Undefined behavior (UB) [defns.undefined]

3.65 **[defns.undefined]**

undefined behavior

behavior for which this document imposes no requirements

[*Note 1 to entry*: Undefined behavior may be expected when this document omits any explicit definition of behavior or when a program uses an incorrect construct or invalid data. Permissible undefined behavior ranges from ignoring the situation completely with unpredictable results, to behaving during translation or program execution in a documented manner characteristic of the environment (with or without the issuance of a *diagnostic message* (3.18)), to terminating a translation or execution (with the issuance of a diagnostic message). Many incorrect program constructs do not engender undefined behavior; they are required to be diagnosed. Evaluation of a constant expression (7.7) never exhibits behavior explicitly specified as undefined in Clause 4 through Clause 15. — *end note*]

Definitions: ill-formed

Ill-formed [defns.ill.formed] [defns.well.formed]

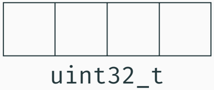
3.26 [defns.ill.formed]
ill-formed program
program that is not well-formed (3.68)

3.68 [defns.well.formed]
well-formed program
C++ program constructed according to the syntax and semantic rules

Ill-formed, no diagnostic required: program is ill-formed, but no compiler diagnostic is required, e.g. different definitions for an inlined function.

Definitions: Type punning

- From Wikipedia[1]: *"In computer science, a type punning is any programming technique that subverts of circumvents the type system of a programming language in order to achieve an effect that would be difficult or impossible to achieve within the bounds of the formal language."*
  - I.e., accessing **underlying in-memory representation** of an object of type `Foo` as a different type, `Bar`, e.g.



...and accessing as `unsigned char[]`

- Why? Useful for (de-)serialization, networking code, or calling legacy (C) library code.

[1] Source: `https://en.wikipedia.org/wiki/Type_punning`.

reinterpret_cast and UB

As we saw, some **reinterpret_cast**s result in UB...

Q: Why, C++, why? 😟

A: TL;DR[2]: Can two pointers of **different types** really point to the **same object**?

Compiler may optimize based on that!

[2] There are more causes; but this is a nice summary.

`reinterpret_cast` and UB

As we saw, some `reinterpret_cast`s result in UB...

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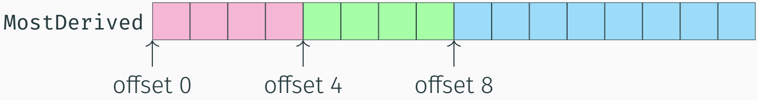
[2] There are more causes; but this is a nice summary.

Types, layout, and lifetime

A quick reminder

- C++ has fundamental + compound types (arrays, pointers, classes…)
  - **Class** types have **base subobjects** and **member subobjects**




```cpp
struct  Base { int i; }
struct  Derived : Base { float f; }
struct  MostDerived : Derived { double d; }
```

  - Types have size and **alignment**!

A quick reminder

- C++ has fundamental + compound types (arrays, pointers, classes...)

- Standard-layout *[class.prop]*: TL;DR
  - All non-static members defined in same class
  - All non-static members are also standard-layout
  - No `virtual`
- POD: standard-layout + trivial

- Types have size and **alignment**!

Storage Duration vs. Lifetime (1)

- *Storage Duration* $\neq$ *Lifetime*!
- Storage Duration: `static`, `thread_local`, automatic, dynamic

Lifetime starts... *[intro.object], par. 1*

6.7.2 Object model **[intro.object]**

1 The constructs in a C++ program create, destroy, refer to, access, and manipulate objects. An *object* is created by a definition (6.2), by a *new-expression* (7.6.2.8), by an operation that implicitly creates objects (see below), when implicitly changing the active member of a union (11.5), or when a temporary object is created (7.3.5, 6.7.7). An object occupies a region of storage in its period of construction (11.9.5), throughout its lifetime (6.7.4), and in its period of destruction (11.9.5).

Storage Duration vs. Lifetime (1)

- *Storage Duration $\neq$ Lifetime*!
- Storage Duration: `static`, `thread_local`, automatic, dynamic

Lifetime ends... *[basic.life], par. 2.3–2.5*

as described in 20.2.10.2. The lifetime of an object o of type `T` ends when:

- if `T` is a non-class type, the object is destroyed, or
- if `T` is a class type, the destructor call starts, or
- the storage which the object occupies is released, or is reused by an object that is not nested within o (6.7.2).

Storage Duration vs. Lifetime (2)

```
using T = std::vector<int>;

void *p = ::aligned_alloc(alignof(T), sizeof(T));
static_cast<T*>(p)->push_back(101); // UB!

auto v1 = new (p) T(); //     -\
v1->push_back(42);     //      |- v1 vector lifetime
v1->~T();              //     _/
v1->push_back(102);    // UB!
auto v2 = new (p) T(); //     -\
v2->push_back(123);    //      |- v2 vector lifetime
v2->~T();              //     _/
v2->push_back(103);    // UB!
::free(p);
```

Storage Duration vs. Lifetime (2)

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Storage Duration vs. Lifetime (2)

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v2->~T();              //     _/
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::free(p);
```

Storage Duration vs. Lifetime (2)

```
using T = std::vector<int>;

void *p = ::aligned_alloc(alignof(T), sizeof(T));
```

Accessing an object out of its lifetime is UB…

…even for trivial types!

```
v2->push_back(103);     // UB!
::free(p);
```

Implicit Lifetime (C++20)

Per C++20, objects may be created implicitly if it avoids UB...

Listing 1: UB before C++20 (taken from P0593R6)

```
struct X { int a, b; };
X *make_x() {
  X *p = (X*)malloc(sizeof(struct X)); // C++20: implicitly create X
  p->a = 1;
  p->b = 2;
  return p;
}
```

Per C++20, objects may be created implicitly if it avoids UB...

Listing 2: UB before C++20 (taken from P0593R6)

```
struct X { int a, b; };
X *make_x() {
  X *p = (X*)malloc(sizeo    ru    )    C++20: implicitly create X
  p->a = 1;
  p->b = 2;
  return p;
}
```

Implicit Lifetime (C++20)

Per C++20, objects may be created implicitly if it avoids UB...

Happens in many places; remarkably:

- Memory allocation functions, incl. `malloc()`
- `memcpy()` and `memmove()`
- `std::bit_cast()`

X

Alignment Requirements

Alignment determines which base addresses are legal for a data type.

E.g. assuming `sizeof(int) == 4` and `alignof(int) == 4`

- An `int` may be at offset 0, 4, 8, etc.
- But not at offset 3

Alignment Requirements

Alig

E.g.

Important; underlying HW may be unable to do unaligned accesses.

Padding / Packing

In order to ensure alignment, compiler may insert padding bytes

```
struct X {
  unsigned char c;
  int i; /// <<<< Padding inserted before 'i'
};
```

- Value of padding bytes is unspecified...
- **Packed structure:** do not include padding. Compiler-specific ❌

Strict Aliasing

Strict Aliasing rule

- **Aliasing:** more than one name (pointer / reference) refers to same address.
- **Strict Aliasing:** only pointers of the **same type** can point to the same object.

[basic.lval], par. 11

11 An object of dynamic type T_{obj} is *type-accessible* through a glvalue of type T_{ref} if T_{ref} is similar (7.3.6) to:

(11.1) — T_{obj},

(11.2) — a type that is the signed or unsigned type corresponding to T_{obj}, or

(11.3) — a `char`, `unsigned char`, or `std::byte` type.

If a program attempts to access (3.1) the stored value of an object through a glvalue through which it is not type-accessible, the behavior is undefined.[42] If a program invokes a defaulted copy/move constructor or

A very obvious example

```
int fn(int *i, float *f) {
  (*i)++;
  *f = 3.1415f;
  return *i;
}
// Optimizer assumes value of '*i' can't be changed by assigning '*f'

int main(int argc, char *argv[]) {
  int a = 1;
  return fn(&a, reinterpret_cast<float *>(&a));
}
```

A very obvious example

```
int
  (
  *
  r
}
//

int
  i
  r
}
```

▷ See in Godbolt

```
fn(int*, float*):
        push    rbp
        mov     rbp, rsp
        mov     qword ptr [rbp - 8], rdi
        mov     qword ptr [rbp - 16], rsi
        mov     rax, qword ptr [rbp - 8]
        mov     ecx, dword ptr [rax]
        add     ecx, 1
        mov     dword ptr [rax], ecx
        mov     rax, qword ptr [rbp - 16]
        movss   xmm0, dword ptr [rip + .LCPI0_0]
        movss   dword ptr [rax], xmm0
        mov     rax, qword ptr [rbp - 8]
        mov     eax, dword ptr [rax]
        pop     rbp
        ret
```

(-O0)

```
fn(int*, float*):
        mov     eax, dword ptr [rdi]
        inc     eax
        mov     dword ptr [rdi], eax
        mov     dword ptr [rsi], 1078529622
        ret
```

(-O2)

A not-so-obvious example

BSD sockets: `sockaddr` vs. `sockaddr_in`

Q: Strict aliasing violation (Y/N)? 🤦

```
struct sockaddr_in addr_in;

addr_in.sin_addr.s_addr = INADDR_ANY;
addr_in.sin_port = htons(8080);
// Violates strict aliasing ??
bind(sockfd, reinterpret_cast<struct sockaddr *>(&addr_in), sizeof(
    addr_in));
```

Type Punning done right

Possible (or not) approaches for type punning

People that type-pun, usually take one of the following approaches:

- Based on `union`
- Using `reinterpret_cast` (sometimes combined w/ `std::launder`)
- Use of `memcpy()`
- `std::bit_cast`
- `std::start_lifetime_as`

Some of them lead to **UB in C++** (but otherwise correct in C)

Possible (or not) approaches for type punning

People that type-pun, usually take one of the following approaches:

You should also be aware of...

- `sizeof(char)`, `sizeof(int)`, etc., are platform-dependent.
  - Use fixed-width integer types (e.g. `uint32_t`) if appropriate
- ISO C++ requires `CHAR_BIT` to be ≥ 8; POSIX requires it to be $== 8$

Some of them lead to **UB in C++** (but otherwise correct in C)

union-based

From *[class.union.general]*: at most **one non-static member is active**; accessing non-active members of a `union` is **UB**![3]. [4]

```
union {
  unsigned char c[sizeof(int)];
  int i;
} u{ 0xff00ff00 }; // active member is 'i'


u.c[0]; // UB!
```

IN GENERAL: DON'T! – It's legal in C, though.

[3] Accesses object whose lifetime has not begun.

[4] Exception on next slide.

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[4] Exception on next slide.

BUT THERE'S ONE EXCEPTION!

[class.union.general], p. 2, Note 1 says...

[*Note 1*: One special guarantee is made in order to simplify the use of unions: If a standard-layout union contains several standard-layout structs that share a common initial sequence (11.4), and if a non-static data member of an object of this standard-layout union type is active and is one of the standard-layout structs, the common initial sequence of any of the standard-layout struct members can be inspected; see 11.4. — *end note*]

union-based: THE ONLY EXCEPTION

BUT

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seq

Again BSD sockets: `sockaddr` and `sockaddr_in` have a common prefix

```
union {
  struct sockaddr addr;
  struct sockaddr_in addr_in;
};

addr_in.sin_addr.s_addr = INADDR_ANY;
addr_in.sin_port = htons(8080);
// See also [class.mem.general], p. 29.
bind(sockfd, &addr, sizeof(addr_in));
```

`reinterpret_cast`-based

`reinterpret_cast<T>(obj)` is guaranteed to be safe if

- Pointer $\leftrightarrow$ integral type (e.g. `uintptr_t`)
- Pointer-interconvertible *[basic.compound], p. 5*:

5 Two objects a and b are *pointer-interconvertible* if

(5.1) — they are the same object, or

(5.2) — one is a union object and the other is a non-static data member of that object (11.5), or

(5.3) — one is a standard-layout class object and the other is the first non-static data member of that object or any base class subobject of that object (11.4), or

(5.4) — there exists an object c such that a and c are pointer-interconvertible, and c and b are pointer-interconvertible.

- Cast-to type is one of
  - `char`, `unsigend char` or `std::byte`
  - `decltype(obj)` (or its signed / unsigned type)

`reinterpret_cast`-based

`reinterpret_cast<T>(obj)` is guaranteed to be safe if

- Don't do `reinterpret_cast<float *>(&an_int)` (violates strict aliasing)
- But even `reinterpret_cast<unsigned char *>(&something)` is not totally right
  - A `unsigned char []` object is not within its lifetime![a]
  - P1839R7 is supposed to fix that
  - What about `std::as_bytes` / `std::as_writable_bytes` then? 🤦

Key idea: pay attention to your `reinterpret_cast`s; they are most likely UB (strict aliasing)!

[a] Most compilers will do the right thing, but it's still UB!

object or

pointer-

`std::launder`: w00t?

`std::launder` is…

- According to cppreference.com:

  Devirtualization fence with respect to `p`. Returns a pointer to an object at the same address that `p` represents, while the object can be a new base class subobject whose most derived class is different from that of the original `*p` object.

  Formally, given

- According to ISO C++ wording: a pointer optimization barrier

  17.6.5 Pointer optimization barrier **[ptr.launder]**

  ```
  template<class T> constexpr T* launder(T* p) noexcept;
  ```

  1 *Mandates*: `!is_function_v<T> && !is_void_v<T>` is `true`.

  2 *Preconditions*: `p` represents the address *A* of a byte in memory. An object *X* that is within its lifetime (6.7.4) and whose type is similar (7.3.6) to `T` is located at the address *A*. All bytes of storage that would be reachable through (6.8.4) the result are reachable through `p`.

`std::launder`: w00t?

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  17.6.5 Pointer optimization🤦rie🤦 🤦 **[ptr.launder]**

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  2 *Preconditions*: `p` represents the address A of a byte in memory. An object X that is within its lifetime (6.7.4) and whose type is similar (7.3.6) to `T` is located at the address A. All bytes of storage that would be reachable through (6.8.4) the result are reachable through `p`.

`std::launder`: pointer provenance

- *Pointer* $\neq$ *MemoryAddress*; an **address** is just the **value of a pointer**.
- In C++, **a pointer points to an object**. The compiler can make assumptions on the pointee.

Instead, think of a pointer as a pair

$$\langle \mathit{address}, \mathit{provenance} \rangle$$

where *provenance* determines which values can be reached through the pointer.

- **Money laundering:** concealing the origin of money
- **Pointer laundering:** update the provenance of a pointer, i.e. remove any assumptions on the pointee

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`std::launder`: pointer provenance

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Inst

- **Pre-conditions:**

  17.6.5 Pointer optimization barrier **[ptr.launder]**

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whe

- Useful when replacing an object (reusing storage) that had `const` members or references
- **Pointer laundering:** update the provenance of a pointer, i.e. remove any assumptions on the pointee

std::launder: Example 1

```
uint32_t i = 42;
float *fp = reinterpret_cast<float *>(&i);

new (static_cast<void *>(&i)) float(12.34f);

// std::cout << *fp << std::endl; // UB! 'fp' doesn't point to a '
    float' object
std::cout << *std::launder(fp) << std::endl; // OK;
```

std::launder: Example 2

```
  struct MyStruct {
    const float f;
  };

  MyStruct obj{12.34f};

  MyStruct *p = &obj;
  std::cout << "f=" << p->f << std::endl;

  new (static_cast<void*>(p)) MyStruct{3.1415f};

  std::cout << p->f << std::endl; // ????
  std::cout << std::launder(p)->f << std::endl; // OK
}
```

memcpy( ) over (representation of) different object

```
uint32_t i = 42;

float f;
memcpy(&f, &i, sizeof(uint32_t)); // OK

unsigned char c[sizeof(uint32_t)];
memcpy(c, &i, sizeof(uint32_t)); // Also OK
```

Strict-aliasing [✅] Alignment reqs. [✅] Lifetime [✅]

memcpy( ) over (representation of) different object

```
uint32_t i = 42;
```

- memcpy( ) is optimized out where possible by major compilers

  ▷ See in Godbolt

std::bit_cast

std::bit_cast *[bit.cast], p. 1-2*

22.11.3 Function template bit_cast [bit.cast]

```
template<class To, class From>
  constexpr To bit_cast(const From& from) noexcept;
```

Constraints:

- `sizeof(To) == sizeof(From)` is `true`;
- `is_trivially_copyable_v<To>` is `true`; and
- `is_trivially_copyable_v<From>` is `true`.

Returns: An object of type `To`. Implicitly creates objects nested within the result (6.7.2). Each bit of the value representation of the result is equal to the corresponding bit in the object representation of `from`. Padding bits of the result are unspecified. For the result and each object created within

std::bit_cast: Example

```cpp
float f = 42.0f;

auto c = std::bit_cast<std::array<unsigned char, sizeof(float)>>(f);
// Use the 'c' array
```

Strict-aliasing [✅] Alignment reqs. [✅] Lifetime [✅]

std::bit_cast: Example

- (Very) roughly speaking: ISO-CPP-blessed for the previous `memcpy()`
- It's `constexpr`; optimized out where possible ▷ See in Godbolt
- Note: `std::bit_cast<SomeType *>()` is simply WRONG! (P0476R1)

std::start_lifetime_as (C++23)

- Explicit lifetime management (C++23)
- Starts lifetime of an object of the given type at the given address
  - Underlying object representation is preserved

```
uint32_t i = 42;
float *f = std::start_lifetime_as<float>(&i);

std::cout << *f << std::endl; // OK
```

std::start_lifetime_as (C++23)

- Recall the strict aliasing rule! No pair of objects of different type can be at same address!
  - Thus, accessing `i` becomes UB!

```
uint32_t i = 42;
float *f = std::start_lifetime_as<float>(&i);

std::cout << *f << std::endl; // OK
std::cout << i << std::endl; // UB!
std::start_lifetime_as<int>(&i);

std::cout << i << std::endl; // Still UB!
std::cout << *std::launder(&i) << std::endl; // OK
```

std::start_lifetime_as (C++23)

- Recall the strict aliasing rule! No pair of objects of different type can be at same address!
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std::start_lifetime_as<int>(&i);

std::cout << i << std::endl; // Still UB!
std::cout << *std::launder(&i) << std::endl; // OK
```

In brief...

Punning via ... is ...

- Based on `union` ❌(note the exception)
- Using `reinterpret_cast`
  - Pointer ↔ integral type: ✅
  - Pointer-interconvertible: ✅
  - To `char`-like type: [Cast ✅] [Deref ❓]
  - Rest: ❌
- Using `std::as_bytes` / `std::as_writable_bytes` (C++20) ✅ ❓
- Use of `memcpy()` ✅
- `std::bit_cast` ✅
- `std::start_lifetime_as` ✅

What if $C++ \leq xx$

If $C++ \leq 23$...

- Taking into account ▷ P0593R6, it may be implemented by using the special properties of `memmove()`
- The compiler infers the type of the object whose lifetime starts

If $C++ \leq 20$...

- For `std::bit_cast`: consider possible impl. described in ▷ cppreference.com
- Or...just use `memcpy()`

Practical Case: (de-)serialization

Introduction to serialization (1)

Serialize: lay out an in-memory **data structure** as a **sequence of bytes**.

Note that...

- A type can have nested pointers / references
- `sizeof(int)` , `sizeof(long)` , etc. can vary depending on target[a]

```
static_cast(sizeof(char) == 1); // ??
static_cast(sizeof(int) == 4); // ??
```

- Differences in machine endianness
- Types require alignment (+ maybe padding)

[a] See, e.g. ILP32, LLP64 models.

Introduction to serialization (2)

Can be just `memcpy()` if...

- Data structure is trivially copiable
- No pointers / references to other data structures
- Uses fixed-width types, e.g. `uint32_t`
- Machine boundary is never crossed (e.g. IPC)
- Alignment is satisfied on de-serialization

Introduction to serialization (2)

Can be just `memcpy( )` if...

Else, implement proper data serialization!

- Encode numbers using a common endianness, e.g. big-endian
- Flatten data structure to byte buffer → follow pointers / references

Example

Let’s consider this simple data structure

```
struct Foobar {
  uint64_t l64;
  uint32_t i32;

  static size_t Serialize(const Foorbar& obj, unsigned char *buf);
  static Foobar Deserialize(const unsigned char *buf);
};
```

Example: machine boundary NOT crossed: ’(de-)serialize’

```
size_t Foobar::Serialize(const Foorbar& obj, unsigned char *buf) {
  memcpy(buf, &obj, sizeof(Foobar));
}

Foobar Foobar::Deserialize(const unsigned char *buf) {
  Foobar ret;
  memcpy(&ret, buf, sizeof(Foobar));
  return ret;
}
```

Example: machine boundary NOT crossed: '(de-)serialize'

Padding bytes are **unspecified**. If you care, avoid this!.

Example: machine boundary crossed: (de-)serialize

```cpp
size_t Foobar::Serialize(const Foorbar& obj, unsigned char *buf) {
  buf += SerializeUInt64(obj.l64, buf);
  buf += SerializeUInt32(obj.i32, buf);
}

Foobar Foobar::Deserialize(const unsigned char *buf) {
  Foobar ret;
  buf += DeserializeUInt64(buf, obj.l64);
  buf += DeserializeUInt32(buf, obj.i32);
  return ret;
}
```

Example: machine boundary crossed: (de-)serialize

Example of UInt32 little-endian (de-)serialization

```
size_t SerializeUInt32(uint32_t i, unsigned char *buf) {
  bytes[0] = (i & 0x000000ff);
  bytes[1] = (i & 0x0000ff00) >> 8;
  bytes[2] = (i & 0x00ff0000) >> 16;
  bytes[3] = (i & 0xff000000) >> 24;
  return 4;
}

size_t DeserializeUInt32(unsigned char *buf, uint32_t& i) {
  i = std::uint32_t(buf[0]) + (std::uint32_t(buf[1]) << 8)
    + (std::uint32_t(buf[2]) << 16) + (std::uint32_t(buf[3]) <<
       24);
  return 4;
}
```

Summary

As a rule of thumb

- *standard-layout* / *POD* + machine boundary not crossed (ever) $\rightarrow$ copy + start lifetime on receiving end
- Rest: implement proper serialization!

See also: ▷ Boost Serialization

Conclusion

Ideas to take home

About reinterpret_cast

- Most of its uses are UB; don't do it unless you are absolutely sure!
- Even `reinterpret_cast<char *>` is not well-defined, but it works in practice
- Use `std::bit_cast` or `std::start_lifetime_as` if available

Type punning is only okay if...

- It doesn't break the strict aliasing rule
- Only accesses bytes reachable through the original pointer
- Complies to the alignment requirements of the type
- The accessed object is within its lifetime
- NO `union`s, please!

- Implement proper serialization where appropriate!

Other Resources

1. The ISO C++ standard (working draft): `https://github.com/cplusplus/draft`
2. JTC1/SC22/WG21 P0593R6:
   `https://www.open-std.org/jtc1/sc22/wg21/docs/papers/2020/p0593r6.html`
3. JTC1/SC22/WG21 P0476R1:
   `https://www.open-std.org/jtc1/sc22/wg21/docs/papers/2016/p0476r1.html`
4. JTC1/SC22/WG21 P3292R0:
   `https://www.open-std.org/jtc1/sc22/wg21/docs/papers/2024/p3292r0.html`
5. JTC1/SC22/WG21 P1839R7:
   `https://www.open-std.org/jtc1/sc22/wg21/docs/papers/2025/p1839r7.html`
6. `https://en.cppreference.com/w/cpp/numeric/bit_cast`
7. `https://en.wikipedia.org/wiki/64-bit_computing#64-bit_data_models`
8. `https://www.kernel.org/doc/html/latest/core-api/unaligned-memory-access.html`

Thank you!

[Link to slides used in this presentation]

1. Paragraphs from the ISO C++ standard have been cited verbatim from the working draft.

Backup

A very obvious example

```
int fn(int *i, float *f) {
  (
  *
  r
}
//

int
  i
  r
}
```

I did not say this – but it's here just for completeness

- `-fno-strict-aliasing` option (GCC / clang) may help
- Useful for legacy codebases or when you **really (really!)** know what you are doing
  - Linux kernel uses it, e.g. in ▷ arch/arm64/kernel/vdso32/Makefile

Type-based Alias Analysis (TBAA)

Alias analysis based on the type system of a high level language.

LLVM-specific, from ▷ llvm/lib/Analysis/TypeBasedAliasAnalysis.cpp:

- **Scalar TBAA:** alias analysis on fundamental datatype, **regardless of where it appears**.
- **Struct-path aware TBAA:** analysis takes into account **base type** (struct), **access type** (leaf, fundamental type), and its **offset**.

If you are interested, read the very clear 100+ code comment in there!