

ABI comparison with reflection

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Abstract

This paper describes a usage of the reflection API introduced in P2996, for comparing equality of ABI of a type / layout of data between two processes, communicating either over a network or across different modules (perhaps built separately) within the same process (eg: two python extension modules in a single python run).

We propose two approaches:

1. Creating a recursive hash of the ABI by hashing all information whose equality may be relevant when communicating across a boundary where ABI comes into play. We go into the depths of this in this paper. We also discuss a config struct which can be used to compute the hash for different usages.
2. Creating a full description of the data being shared and communicating that across process boundaries. This is slower and requires more bytes of data.

We also discuss how standardization of such a system as a library may benefit the ecosystem.

Introduction

This paper is meant to demonstrate how reflection in the most general sense can be used to solve the age-old problem of ABI compatibility of messages and objects passed across various modules communicating with each other. The communication may be across language boundaries (C++ => Python => C++) or over network. Historically a lot of source-generation based tools (think protobuf) have attempted to provide third-party solutions for this, but we will demonstrate how reflection (in particular, value based reflection as explored in P2996) can solve a pertinent problem in this domain.

We also propose a ABI representation type that has considerable forward and backwards compatibility concepts in it, and can be a candidate for standardization. Discussion on this is unavoidable because any discussion of comparing ABI across processes has to involve a discussion on how to serialize the aforementioned ABI or ABI hash.

Motivation and Scope

The aim of this paper is to develop a helpful set of meta functions we can use to assert ABI compatibility across modules which are communicating with some data objects. We will be using value based reflection as demonstrated in [P2996R1 - Reflection for C++26](#).

We will constrain ourselves to systems where one process / module (we shall call it **publisher**) is creating a memory layout to be passed to another process / module (we shall call it **subscriber**). The subscriber wants to know if the **data** sent over by the publisher can be used in the form that the subscriber's code expects to use it.

Two common occurrences of this set of problems are

- Inter-process communication over network / shared memory. A subscriber may care if the fields they want are present and of the same type or not. It may also care about the size of the message.
- Python bindings where one python extension module (written in C++) may create a struct which is passed to a different python extension module. Ostensibly compiled by a different person at an entirely different time with nothing shared except perhaps a header.

- An example may be the [numpy](#) library. A user may write their own python extension library that operates on a numpy array created by an entirely different system. Both these C++ modules are glued / connected via a Python process.
- Since the two C++ modules may be in the same process, it is possible to call function pointers of functions in module 1 from module 2. Does this mean we can do virtual functions across modules? Is this safe?

The topic of serialization / deserialization / ABI of meta::info objects is discussed, but this paper does not aim to propose a path forward for that. Merely to discuss how that can be useful in some contexts.

Decision tree - tasks to solutions

This section serves as the guide rail for the following sections, and covers a number of common tasks that people often have to do that may be assisted with reflection.

1. Inter-process communication (limited to POD data)
 - a. **Receiver of data knows the ABI, just wants to validate**
 - i. Solution: ABI hashing
 1. **Receiver can handshake with sender to convey what all elements to hash**
(member names? member types certainly)
 - Solution: Sender sends the ABI hash computed in the manner the receiver wants.
 2. No handshake is possible, data flow is one-way
 - Solution: Sender sends N different ABI hashes, one each for each kind of hashing technique
 - b. **Receiver of data is unaware of the ABI, wants to know how to parse the incoming data**
 - i. Solution: Sender sends over a fully specified description of the ABI in a premeditated format. We could call this premeditated format the ABI of the ABI, but only for a limited subset of the language.
2. Intra-process communication
 - a. **Sharing POD structs across different shared modules in the same process**
 - i. Same decision tree as under point (1)
 1. Libraries that facilitate this can use ABI hashing automatically to allow implicit object type conversions.
 - b. **Sharing non-POD objects across shared modules**
 - i. Sharing function pointers via capsules is already achievable in Python, but verbose.
 - ii. Solution: ABI hashing schemes can include a methodology of hashing virtual functions in order.

Proposals

We propose various methods that can help in standardizing ABIs and their communication. All this is implemented and compiling here: <https://godbolt.org/z/sndxcK5qj>

ABIHashingConfig

We propose two standard structs with room for future expansion:

```
C/C++
// Common usecase optimized with future extensibility
struct ABIHashingConfig {
    static constexpr int MINIMUM_SUPPORTED_VERSION = 0; // To allow future rollover
    static constexpr int MAXIMUM_SUPPORTED_VERSION = 0; // To gracefully error out
    uint8_t version : 4 = 0;
    bool include_nsdm_names : 1 = true;
    bool include_indirections : 1 = false; // Only relevant in intra-process comparison
} __attribute__((packed));

// Virtual ABI hashing use-case kept as an optional extension
enum class VTableHashingMode : uint8_t {
    NONE, SIGNATURE, SIGNATURE_AND_NAMES, NUM_VTABLE_HASHING_MODES
};
enum class VirtualABI : uint8_t { ITANIUM, MSVC };
struct IndirectionABIHashingConfig {
    uint8_t version : 4 = 0;
    VTableHashingMode virtual_hashing_mode : 4 = VTableHashingMode::NONE;
    VirtualABI abi_mode : 2 = VirtualABI::ITANIUM; // Architecture dependent default
} __attribute__((packed));
```

Serialized representation of ABIHashingConfig can be of this form:

- If **include_indirections** is false:
 - If **version** is up to a certain number in the future:
 - Serialized representation is 1 byte.
 - Else for future extensibility
 - We can introduce an extension struct which can be assumed to be present if version is greater than a certain number in the future
- If **include_indirections** is true:

- At the end of the ABI hash, we can expect a `IndirectionABIHashingConfig` struct as well. It has similar semantics for the "version" field as the earlier struct.
- This struct is not optimized for size since it would never be serialized across process boundaries.

We can bump versions if we have to change the hashing methods in the future, or if we change the input to the hashing methods.

The publisher may choose to serialize multiple ABIHashes sequentially in its messages if it is concerned about backwards compatibility with older subscribers. It can keep hashing with old versions as well for some time. Each such version will basically add an overhead of 1 byte for the config struct, and 8 bytes for the hash (or more, if later versions revise this).

We also provide a `"MINIMUM_SUPPORTED_VERSION"` constant, which can be bumped in the future to deprecate old versions.

Recursive ABI hashing

This is the simplest technique for asserting some confidence on two modules having a compatible ABI. It is very powerful and simple to use, and solves a large number of common problems, without requiring any fancy new features. On the flip side, it is also not 100% accurate due to the presence of hash collisions and must be utilized with that kept in mind.

The idea is simple, each data type that is communicated across a boundary where ABI comes into question, has an ordered list of members which may be of the following different types:

- Primitive data type members (may come through inheritance or not)
- Non-primitive data type members (may come through inheritance or not)
- Bitfield members (need to hash their offsets and sizes correctly)
- Virtual methods in this class (may be hashed optionally, depends on the use case)
- Members which are pointers or references to other data type objects

We posit that the following algorithm can output a hash value that is generally useful to the wide C++ community for a wide variety of problems.

Implementation experience

I was able to implement the proposed ideas in the following manner. Note that albeit the final implementation must formalize the hashing methodology, at present the paper does not aim to optimize things like reduction of the number of unique (and some potentially redundant) hash operations.

C/C++

```
template <typename T, ABIHashingConfig config = ABIHashingConfig{},
         IndirectionABIHashingConfig indirection_cfg = IndirectionABIHashingConfig{}>
constexpr size_t get_abi_hash() {
    // TODO: Handle recursive cycles.
    size_t hash = 0;
    // Need to keep a local lambda else it does not recognize it is constexpr.
    auto hash_combine = [](size_t seed, size_t v) -> size_t {
        return seed ^ (v + 0x9e3779b9 + (seed << 6) + (seed >> 2));
    };
    [ : expand(nonstatic_data_members_of(^T)) : ] >> [&] <auto e> {
        constexpr auto elem_type = meta::type_of(e);
        constexpr auto is_indirect_ref = (
            meta::test_type(^std::is_pointer_v, elem_type) ||
            meta::test_type(^std::is_reference_v, elem_type)
        );
        if constexpr (!config.include_indirections && is_indirect_ref) {
            return;
        }

        if constexpr (config.include_nsdm_names) {
            auto name = std::string(meta::name_of(e));
            hash = hash_combine(hash, HASH_STR(name.c_str()));
        }
        if constexpr (meta::is_bit_field(e)) {
            hash = hash_combine(hash, std::meta::offset_of(e));
            hash = hash_combine(hash, std::meta::bit_offset_of(e));
            hash = hash_combine(hash, std::meta::bit_size_of(e));
        } else {
            hash = hash_combine(hash, std::meta::offset_of(e));
            hash = hash_combine(hash, std::meta::size_of(e));
        }
        if constexpr (meta::test_type(^std::is_class_v, elem_type)) {
            using T2 = typename[:meta::type_of(e):];
            hash = hash_combine(hash, get_abi_hash<T2, config, indirection_cfg>());
        } else {
            if constexpr (meta::test_type(^std::is_pointer_v, elem_type)) {
                if constexpr (config.include_indirections) {
                    // Hash the underlying type's ABI recursively.
                }
            }
        }
    };
}
```

```

        constexpr auto ctype = std::meta::substitute(
            ^std::remove_pointer, {elem_type});
        using T2 = typename[:ctype:];
        hash = hash_combine(hash, get_abi_hash<T2, config, indirection_cfg>());
    }
} else if constexpr (meta::test_type(^std::is_reference_v, elem_type)) {
    if constexpr (config.include_indirections) {
        // Hash the underlying type's ABI recursively.
        constexpr auto ctype = std::meta::substitute(
            ^std::remove_reference, {elem_type});
        using T2 = typename[:ctype:];
        hash = hash_combine(hash, get_abi_hash<T2, config, indirection_cfg>());
    }
} else {
    // Returns empty string as of right now, perhaps there is a better way?
    // Debate if this is even useful? Since we hashed the size and name earlier.
    auto name = std::string(meta::name_of(meta::type_of(e)));
    hash = hash_combine(hash, HASH_STR(name.c_str()));
}
}
};
if constexpr (config.include_indirections) {
    if constexpr (indirection_cfg.virtual_hashing_mode != VTableHashingMode::NONE) {
        // TODO
    }
}
// Attributes like `packed` may change the size of the struct.
// Not everyone would be concerned with padding at the end though.
// Can consider making this optional via a config param.
hash = hash_combine(hash, sizeof(T));
return hash;
}

```

As for implementation of the HASH_STR function, a constexpr version of that will work for our use-cases.

```

C/C++
// See https://stackoverflow.com/a/9842857 for implementation
// Better implementations are possible

```

```
// Full implementation can be found here: https://godbolt.org/z/sndxcK5qj  
#define HASH_STR(x) (crc32<sizeof(x) - 2>(x) ^ 0xFFFFFFFF)
```

cvref / pointers

One could argue that recursing into types which are referred to via pointers or references are irrelevant when hashing the ABI. "constness" is certainly irrelevant. But pointers / references might still deserve a recursion if the object is being shared within the same process (two python extension modules communicating).

A question that may come up is, in cases like pointers, indirections of memory layout, and such, what is the software contract between the two modules sharing this object? And can reflection have anything to do with that? My view is that such ideas must be conveyed through the function names / API names that pass these objects between the two modules. For instance, if an object wants to transfer ownership of a dynamically allocated memory to a different module, it must convey this through the function name, and this should not be included in the ABI of the modules, and thus is ignored from the hash.

vtable internals

The code to hash the virtual function ordering has been left out in the above implementation, but it can be implemented in a relatively easy manner.

- Iterate all base classes of type T in order, and recursively do the following:
 - Iterate all members in order to find virtual methods via `is_virtual` (pure or not).
 - For each virtual method, first hash the name of the method.
 - Then, for each type in the virtual method's signature, hash it recursively using this algorithm.

Cycles in hashing

Once `include_indirections` is enabled, thanks to forward declarations we could easily have cycles in the algorithm. To avoid this, the `get_abi_hash` method must keep a stack of all types that are being hashed right now, to avoid an infinite loop. This is not yet implemented in the linked implementation.

Recursive ABI description

As opposed to hashing, a fully serializable ABI definition can be widely useful too, because not only is it more descriptive, it is also flexible since it allows various applications to adapt to changing ABI of their underlying data. It also makes ABI a non-monolithic concept, allowing small ABI breakages to only impact libraries which actually depended on the part that was broken. It can also allow so-motivated developers to write applications

which are flexible to ABI changes (they may write their code in a manner which can read the offset of a given field by accessing the ABI description, and then access that member from that memory location).

This is a really controversial topic since defining this can easily be made to encompass an ABI for meta::info objects, so we will discuss how this idea can solve some use-cases that ABI hashing cannot, without proposing a final ABI in this paper.

Further discussion on this is in the [Parse the data format to interpret incoming messages](#) section.

Enums

Computing the hash of enums can be widely useful, and is pretty simple to accomplish without much effort. It does not allow forwards or backwards compatibility though in its most basic form. In most cases users would want to publish the enum's full map as a JSON or equivalent format across processes and validate the required values only. Constructing that representation is simple with the examples from P2996R1 and is omitted here.

One interesting topic pending further thought is, if a type that we are hashing contains an element that is an enum, perhaps we should include the hash of the enum in that? That may indicate that the `get_abi_hash` method might be augmented to include the enum class' hash as well.

Use-cases

Check if all the members are in the right place / right type

The subscriber may have hard-coded assumptions about the layout of data in the struct sent over (both of them may have been compiled with the same header). Such a codebase has two advantages:

- It is easy to write the subscriber code. It just has to include the same header as the publisher.
- The subscriber code can be efficient since it can have hardcoded member offsets in the struct.

There is a disadvantage of writing such code though:

- Subscriber code is dependent on the ABI of the publisher's data and is inflexible / has to be recompiled with the new header whenever there is any *significant* (discussed later) change to the header's members.
- Even if all the fields the subscriber cares about are present, it must also assert the size of the message is fixed, because inadvertently the subscriber code might have some implicit assumptions about the size of the message. This can only happen if the API between the subscriber and publisher has some method which returns an array of the *data* objects.

Parse the data format to interpret incoming messages

This is a more flexible style of writing the subscriber code, where it can contain code to parse a ABI textual description so it can better decide how to fetch various fields that it is interested in. This would require the ABI description to have a standard textual.

In particular, if there is a way to communicate the full descriptive textual definition of a class in a parsed form from a publisher to a subscriber, the subscriber can choose to adjust their deserialization code in order to efficiently unpack the received fields and pack them into its own internal format. This provides a lot of flexibility in softwares that communicate with each other, since this makes them only loosely coupled. New changes to the underlying data format can be easily kept backwards compatible. Some of these ideas are explored in [protobuf](#) already, and it does something similar using sourcegen approaches.

For communicating between languages, as long as the description of this textual format is well documented, any language can implement a method to unpack the received information.

Call virtual functions on objects owned by another module

This is only applicable in situations like inter-language bindings where the modules communicating are running in the same process. In particular, if I have a python extension written in C++ that exposes an object of this sort:

```
C/C++
class MyStateInterface {
public:
    virtual void mutate() = 0;
    virtual int get() = 0;
};
```

Passing this object to python can be made possible by adding python bindings for this interface class. That will mean all methods in the class are now contained in a python binding. See [P2911R1](#).

Now say we have another python extension module in the same process and it would like to be able to accept objects of this type in its interface methods:

```
C/C++
void process_state(MyStateInterface* state);
```

In this situation, if python was able to deduce that the ABIHash of the MyStateInterface type matches across both modules, it could allow passing this type safely from one extension module to another (of course, intermediated by the binding library's syntax).

Performance implications and example use-cases

ABI hashes can often just be replaced by a human-written “version” field, which obviously is error-prone. Once that is out of the picture, ABI hashes have a few potential value propositions, for example:

- Networked systems that communicate over a UDP network may not have a handshake step available to communicate the full object description before communicating. Using a few bytes per message to communicate an ABI should be a good solution that solves most common cases.
- Python extension module libraries like pybind11 and boost::python may want to introduce an unconditional assertion that compares the relatively small ABI hash of a given type between two extension modules, before it allows a type-cast from “extension_module1::MyClass1” to “extension_module2::MyClass2”. Using a larger comparison object here (example: a full class description) may introduce performance penalties, but to be fair it would ideally only have to do that once and later just remember which type-casts are allowed.
- When serializing data, ABI hashes may be useful in reducing the amount of bytes that have to be dumped. For large data structures this may reduce the overhead of the serialization format. This point is closely related to the UDP point from before.

Standardization

The techniques we propose here can be implemented plainly on top of value based reflection by any user. As such, this does not present any obstacles to the standardization of reflection (P2996) in any manner. That said, there is a case to be made for standardizing these techniques.

Benefits of standardization

If the programmatic description of the ABI of a data type can be standardized, open source software authors can start to depend on it safely, massively reducing software code that has to check validity of various information received from a publisher. In the long run this can be a very valuable addition to the open source ecosystem.

Discussion on potential downsides of standardization

The simplest argument to be made against standardization is that a lot of these use-cases have already been solved by technologies like [protobuf](#) and [Apache Avro](#), among others. These systems have been around for a

long time, offering source-generation based solutions for inter process safe sharing of data. Unfortunately, these solutions fall short on a few fronts:

- There is no way to share virtual functions for instance, so they are limited to data objects.
- They introduce a build system dependency which deters various users / developers from using them.
- They may have their own overheads and make it harder for a C++ user to have their code function in a native manner (perhaps they want to pack their members in a certain way, for instance).

A more relevant argument against standardization is that the ABI hash or the ABI textual description will itself become a part of the ABI or API of the language itself. So if in the future one of these has to evolve, it will cause an ABI break of a different manner. This can be addressed in a different form:

- ABI breakages ought to only happen with new language standards, since that is when it is most likely for the structure of a struct or class to change. Many C++ modules already use standard library objects as a part of their API, which means such modules are already subject to ABI breakage on new standards releases. Thus it follows that they must already tag the standard in their release / deployment process, making this concern slightly less concerning.
- Changes to hash functions / textual representation must be rolled out in a backwards compatible manner. If we ever need to make such changes, the language must offer a way to continue to compute the older version of the hash / textual description, such that library authors can bundle both old and new versions of the hash / textual description in their library's API.

Our discussion in the section on ABIHashingConfig mentions an approach where the ABIHashingConfig itself is bundled with the ABIHash, allowing most applications to remain forwards and backwards compatible. For applications where the message size is important, they may have to accept an ABI break if versions of this ABI hashing technique mismatch.

std::hash integration

One potential API to integrate hashing of this form into the library without introducing a new top level function, might be to overload std::hash (and alike) with a form like:

```
C/C++
namespace std {
namespace abi::meta {
template <typename T, ABIHashingConfig config = ABIHashingConfig{ },
        IndirectionABIHashingConfig indirection_config = IndirectionABIHashingConfig{ }>
struct ABIHash { };
} // namespace meta::abi

template <typename T, meta::abi::ABIHashingConfig config>
```

```
struct hash<meta::abi::ABIHash<T, config>> {
    size_t operator()() const {
        return meta::abi::get_abi_hash<T, config>();
    }
};
} // namespace std
```

Cross language support

Modules written in other languages may wish to compute the expected hash of a struct on their end as well. To that point, C++ may benefit from keeping in mind that exposing an API for the `get_abi_hash` function in different languages (with a different form of input, even if it is runtime) would be beneficial. This can be implemented by the community once a standard hashing scheme is decided upon, for each version of the hashing config.

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