

Boost.SafeNumbers: A Proposal

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Introduction

Much recent effort in improving the safety of C++ has revolved around memory safety and library hardening [1][2][4]. These are incredibly important undertakings in light of the US Government's recommendations to move to memory safe languages [5]. Another source of errors in C++ come from the behavior of arithmetic. It is legal to compare a signed integer to an unsigned integer yet the resulting behavior can be unexpected. Take for example: `-99 < 340282366920938463463374607431768211408`. This should obviously evaluate to `true`, but it is in fact `false` because these values are bitwise equal (as unsigned 128-bit integers). The goal is to avoid this situation entirely by offering compile-time as well as runtime type safety guarantees much like the primitive types in Rust [10] do.

Boost.SafeNumbers

I do not want to see any longer a bool became an int.

— u/RoyBellingan[3]

The aim of Boost.SafeNumbers is to be used as a complete replacement for the builtin numeric types of C++. We have several goals that align with this desire.

Goals

Provide Concrete Types

The concrete types the library will provide are:

1. Unsigned Integers: u8, u16, u32, u64, and u128
2. Signed Integers: i8, i16, i32, i64, and i128
3. Floating Point: f32 and f64
4. Bool: boolean

Each of these types will have the following properties:

1. No implicit conversions (to include to boolean values)
2. No mixed sign operations
3. No operators defined between Boost.SafeNumbers and builtin numeric types except for explicit, and non-narrowing construction
4. Any numerical error such as overflow will `throw` on error by default.

These types offer alternatives to all the standard numerical types in C++ as well as the often requested 128-bit integer types.

Provide Options for Runtime Behavior

The first option is to allow for `-fno-exceptions` environments. To do this we will internally use `boost.throw_exception` which already has well-defined results depending on the mode of operations

Second the types will have a number of different operators much like they do in Rust[8]:

```
class u32
{
    // Throws/terminates on overflow
    friend constexpr u32 operator+(u32 lhs, u32 rhs);

    // Saturates to std::numeric_limits<u32>::max()
    friend constexpr u32 saturating_add(u32 lhs, u32 rhs) noexcept;

    // Allows well defined wrapping behavior
    friend constexpr u32 wrapping_add(u32 lhs, u32 rhs) noexcept;

    ...
};
```

Complete Standard Library Support

Since our goal is to provide a complete replacement for the built-in numeric types we need to provide a complete standard library including support for: `<charconv>`, `<format>`, `<iostream>`, `<cmath>`, `{fmt}`, etc.

Acceptable Runtime Penalty

Experimentation with Boost.Unordered with shows that Fil-C come with an ~2.5x runtime [9]. By leveraging existing compiler intrinsics to detect overflow (e.g. `_builtin_add_overflow`) the goal is to have a runtime penalty of less than 2x. If the runtime penalty is too great the additional safety offered by this library may not be sufficiently convincing for use.

Human-Readable Error Messages

In many cases such as mixed sign operations we intend to emit a compiler error. To make these compiler errors useful they must be trivially human-readable instead of emitting the template spaghetti that C++ and Boost are known for.

Analysis of Alternatives

Boost.Safe_Numerics

Boost.safe_numerics [7] offers a users the ability to wrap types before an operation at runtime, with policy based results on error.

Example 1. This example shows how to use Boost.safe_numerics

```
try
{
    using namespace boost::safe_numerics;
    safe<std::int8_t> x = INT_MAX;
    safe<std::int8_t> y = 2;
    safe<std::int8_t> z;
    // rather than producing an invalid result an exception is thrown
    z = x + y;
}
catch(const std::exception & e)
{
    // which we can catch here
    std::cout << "error detected:" << e.what() << std::endl;
}
```

This example when using our proposal would instead look something like:

Example 2. An annotated version of the Example 1 except using Boost.SafeNumbers instead

```
try
{
    using namespace boost::safetypes;
    i8 x = INT_MAX; // Compile error: implicit narrowing is not allowed
    i8 y = 2;        // Compile error: implicit narrowing is not allowed
    i8 z = x + y;   // Good since x and y are both of type i8
}
catch(const std::exception & e)
{
    std::cout << "error detected:" << e.what() << std::endl;
}
```

Moving the errors from run time to compile time should be far easier to debug, and lead to fewer instances where exceptions are possible.

Intel Safe Arithmetic

Boost.SafeNumbers offers to provide a smaller set of features (e.g. no arbitrary precision arithmetic) with greater interoperability with the STL. This library [11] is also in active development.

Existing Compiler Flags and Sanitizers

GCC, Clang, and other offer "-Wsign-conversion", "-Wconversion", and "-Wfloat-equal" can be used today to avoid large classes of bugs, and we highly recommend their use. These flags along with UBSan will catch large classes of bugs. Boost.SafeNumbers aims to take this a step further in rigidity of rules. For example, UBSan will allow rollover of an unsigned integer, whereas by default Boost.SafeNumbers will throw.

Conclusion

In conclusion, Boost.SafeNumbers aims to offer a library level solution to issues of arithmetic safety in C++. By offering solid performance, an expansive standard library, and readable compiler errors it should be viewed as an acceptable alternative to the built-in types and STL.

Sources

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