Modern C++ Programming

11. Code Conventions

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C++ Project Organization

Project Organization

Project Root

bin **build** **doc**

submodules **third_party** **data**

tests **examples** **utils**

include **src**

LICENSE **README.md**

CMakeLists.txt **Doxyfile** **.gitignore**

.clang-tidy **.clang-format**

Project Directories 1/2

Fundamental directories

`include`	Project (public) header files
`src`	Project source files and private headers
`tests`	Source files for testing the project

Empty directories

`bin`	Output executables
`build`	All intermediate files
`doc`	Project documentation

Project Directories 1/2

Optional directories

`submodules` Project submodules

`third_party` (less often `deps/external/extern`) dependencies or external libraries

`data` Files used by the executables or for testing

`examples` Source files for showing project features

`utils` (or `script`) Scripts and utilities related to the project

`cmake` CMake submodules (.cmake)

Project Files

`LICENSE` Describes how this project can be used and distributed[★]

`README.md` General information about the project in `Markdown` format, [*,†]

`CMakeLists.txt` Describes how to compile the project

`Doxyfile` Configuration file used by `doxygen` to generate the documentation (see next lecture)

others `.gitignore`, `.clang-format`, `.clang-tidy`, etc.

[*] `Markdown` is a language with a syntax corresponding to a subset of HTML tags `github.com/adam-p/markdown-here/wiki/Markdown-Cheatsheet`

[†] See `embedded-artistry-readme-template` for guidelines

[★] Choose an open source license `choosealicense.com`

File extensions

Common C++ file extensions:

- **header** `.h` `.hh` `.hpp` `.hxx`
- **header implementation**
  - `.i.h`, .i.hpp, `-inl.h`, `.inl.hpp`
  - separate implementation in standard header
  - inline implementation in standard header (Google)
- **src** `.c` `.cc` `.cpp` `.cxx`

Common conventions:

- `.h` `.c` `.cc` Google
- `.hh` `.cc`
- `.hpp` `.cpp`
- `.hxx` `.cxx`

`src/include` directories

`src/include` directories should present exactly the same directory structure

Every directory included in **`include`** should be also present in **`src`**

Organization:

- Public **headers** in **`include`**
- **source files**, **private headers**, **header implementations** in **`src`**
- The **main** file (if present) can be placed in **`src`** and called **`main.*`** or placed in the project root directory with an arbitrary name

Common Rules

The file should have the same name of the class/namespace that they implement

- `class MyClass`
  my_class.hpp (MyClass.hpp)
  my_class.i.hpp (MyClass.i.hpp)
  my_class.cpp (MyClass.cpp)

- `namespace my_np`
  my_np.hpp (MyNP.hpp)
  my_np.i.hpp (MyNP.i.hpp)
  my_np.cpp (MyNP.cpp)

Code Organization Example

- **include**
  - my_class1.hpp
  - my_templ_class.hpp
  - **subdir1**
    - my_lib.hpp
- **src**
  - my_class1.cpp
  - my_templ_class.i.hpp
  - my_templ_class.cpp (specialization)
  - **subdir1**
    - my_lib.i.hpp (template/inline functions)
    - my_lib.cpp

- main.cpp (if necessary)
- README.md
- CMakeLists.txt
- Doxyfile
- LICENSE
- **build** (empty)
- **bin** (empty)
- **doc** (empty)
- **test**
  - test1.cpp
  - test2.cpp

Coding Styles and Conventions

Overview

> *“one thing people should remember is there is what you can do in a language and what you should do”*

Bjarne Stroustrup

Most important rule:

BE CONSISTENT!!

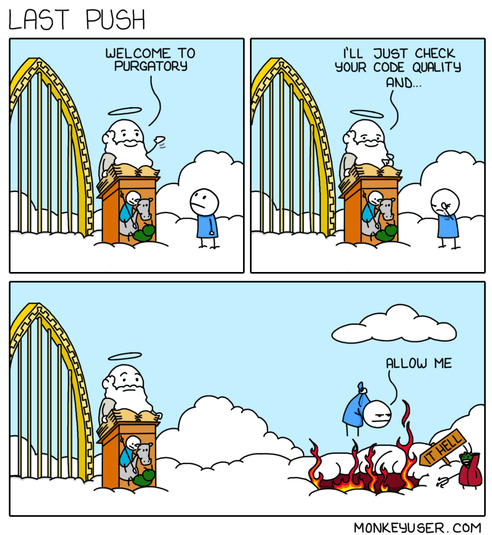
“The best code explains itself”

Google

Code Quality

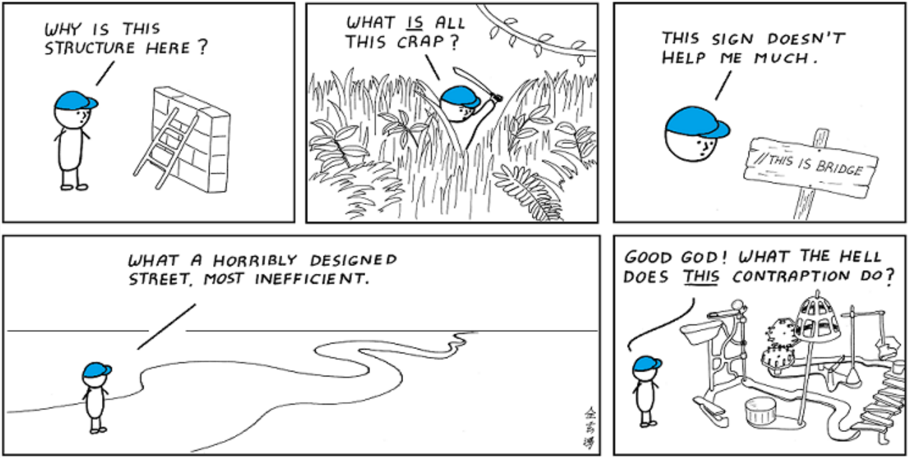
“The worst thing that can happen to a code base is size”

— *Steve Yegge*



Bad Code

How *my* code looks like for other people?


WHY IS THIS STRUCTURE HERE ?
WHAT IS ALL THIS CRAP ?
THIS SIGN DOESN'T HELP ME MUCH.
//THIS IS BRIDGE
WHAT A HORRIBLY DESIGNED STREET. MOST INEFFICIENT.
GOOD GOD! WHAT THE HELL DOES THIS CONTRAPTION DO?

abstrusegoose.com/432

Coding Styles

Coding styles are common guidelines to improve the *readability*, *maintainability*, prevent *common errors*, and make the code more *uniform*

Most popular coding styles:

- ***LLVM Coding Standards***
  `llvm.org/docs/CodingStandards.html`
- ***Google C++ Style Guide***
  `google.github.io/styleguide/cppguide.html`

Coding Styles 2/2

- ***Webkit Coding Style***
  `webkit.org/code-style-guidelines`
- ***Mozilla Coding Style***
  `developer.mozilla.org`
- ***Chromium Coding Style***
  `chromium.googlesource.com`
  `c++-dos-and-donts.md`
- ***Unreal Engine***
  `docs.unrealengine.com/en-us/Programming`
- *μ**OS++***
  `micro-os-plus.github.io/develop/coding-style`
  `micro-os-plus.github.io/develop/naming-conventions`

Legend

※ → **Important!**
Highlight potential code issues such as bugs, inefficiency, and can compromise readability. Should not be ignored

∗ → **Useful**
It is not fundamental but it emphasizes good practices. Should be followed if possible

▪ → **Minor / Obvious**
Style choice or not very common issue

#include and namespace

#include 1/3

- ※ **Every includes must be self-contained**
  - the project must compile with any include order
  - do not rely on recursive `#include`

- ∗ **Include as less as possible, especially in header files**
  - do not include unneeded headers
  - it is not in contrast with the previous rule

LLVM, GOOGLE, CHROMIUM, UNREAL

- **`include guard`** vs. `#pragma once`
  - Use **`include guard`** if portability is a strong requirement GOOGLE, CHROMIUM
  - `#pragma once` otherwise for performance WEBKIT, UNREAL

- **`#include`** preprocessor should be placed immediately **after** the *header comment* and *include guard* LLVM

Order of #include LLVM, Google

(1) Main Module Header (it is only one)

(2) Local project includes (in alphetical order)

(3) System includes (in alphetical order)

System includes are self-contained, local includes might not

Project includes LLVM, Google

* Use `""` syntax
* Should be absolute paths from the project include root
  e.g. `#include "directory1/header.hpp"`

System includes LLVM, Google

* Use `<>` syntax
  e.g. `#include <iostream>`

#include 3/3

- **Use C++ headers instead of C headers:**

  <cassert> instead of <assert.h>

  <cmath> instead of <math.h>, etc.

- **Report at least one function used for each include**

  ```
  <iostream>   // std::cout, std::cin
  ```

Example:

```
#include "MyClass.hpp"               // MyClass
                                    [ blank line ]
#include "my_dir/my_headerA.hpp"     // npA::ClassA, npB::f2()
#include "my_dir/my_headerB.hpp"     // np::g()
                                    [ blank line ]
#include <iostream>                  // std::cout
#include <cmath>                     // std::fabs()
#include <vector>                    // std::vector
```

Namespaces 1/2

- ※ Avoid `using namespace`-directives at global scope LLVM, Google, WebKit, Unreal, Hic

- ∗ Limit `using namespace`-directives at local scope and prefer explicit namespace specification Google, WebKit

- ※ Always place code in a namespace to avoid *global namespace pollution* Google, WebKit

- ∗ Avoid *anonymous* namespaces in headers Google

- ▪ Prefer *anonymous* namespaces instead of `static` variables Google

Namespaces 2/2

Style guidelines:

- The content of namespaces is not indented

  GOOGLE, WEBKIT

- Close namespace declarations

  `} // namespace <namespace_identifier>` LLVM

  `} // namespace` (for anonymous namespaces) GOOGLE

Unnamed namespaces:

- Items local to a source file (e.g. .cpp) file should be wrapped in an unnamed namespace. While some such items are already file-scope by default in C++, not all are; also, shared objects on Linux builds export all symbols, so unnamed namespaces (which restrict these symbols to the compilation unit) improve function call cost and reduce the size of entry point tables CHROMIUM

Variables and Prepossessing

Variables 1/2

※ Place a variables in the narrowest scope possible, and *always* initialize variables in the declaration
Google, Isocpp, Mozilla, Hic

- Use assignment syntax `=` when performing ”simple“ initialization or for constructors Chromium

- Avoid static global variables LLVM, Google

- Declaration of pointer/reference variables or arguments may be placed with the asterisk/ampersand *adjacent* to either the *type* or to the variable *name* for all in the same way Google
  - `char* c;` WebKit, Mozilla, Chromium, Unreal
  - `char *c;`
  - `char * c;`

Variables 2/2

- ※ Use fixed-width integer type (e.g. `int64_t`, `int8_t`, etc.).
  Exception: `int` and `unsigned` Google, Unreal

- * Use `size_t` for object and allocation sizes, object counts, array and pointer offsets, vector indices, and so on. (integer overflow behavior for signed types is undefined) Chromium

- * Use `int64_t` instead of `size_t` for object counts and loop indices Google

- ▪ Use brace initialization to convert arithmetic types (narrowing) e.g. `int64_t{x}` Google

- * Use `true`, `false` for boolean variables instead numeric values `0, 1` WebKit

Variables 2/2

- ※ Do not shift `≪` signed operands HIC
- ※ Do not directly compare floating point `==`, `<`, etc. HIC
- Do not use `auto` to deduce a raw pointer/reference. Use `auto*` / `auto&` instead

Style:

- Use floating-point literals to highlight floating-point data types, e.g. `30.0f` WEBKIT (opposite)
- Avoid redundant type, e.g. `unsigned int`, `signed int` WEBKIT

Macro and Preprocessing 1/2

Code guidelines:

- Avoid defining macros, especially in headers GOOGLE
- `#undef` macros wherever possible
- Prefer `const` values and `inline` functions to `#define` WEBKIT
- Do not use macro for enumerator, constant, and functions
- Always use curly brackets for multilines macro

```
#define MACRO       \
{                   \
    line1;          \
    line2;          \
}
```

Macro and Preprocessing 2/2

Style:

- Close `#endif` with the respective condition of the first `#if`

```
#if defined(MACRO)
    ...
#endif // defined(MACRO)
```

- The hash mark that starts a preprocessor directive should always be at the beginning of the line GOOGLE

```
#if defined(MACRO)
#   define MACRO2
#endif
```

- Place the `\` rightmost for multilines macro

```
#define MACRO2                 \
    macro_def...
```

- Prefer `#if defined(MACRO)` instead of `#ifdef MACRO`

Functions and Classes

Functions

※ Default arguments are allowed only on *non*-virtual functions GOOGLE

- Prefer return values rather than output parameters GOOGLE

- Limit overloaded functions GOOGLE

- Do not declare functions with an excessive number of parameters. Use a wrapper structure instead HIC

Functions

∗ Passing function arguments by `const` *pointer* or *reference* if those arguments are not intended to be modified by the function UNREAL

▪ Do not pass **`by-const value`** for built-in types, especially in the declaration (same signature of `by-value`)

※ Prefer pass **`by-reference`** instead **`by-value`** except for raw arrays and built-in types WEBKIT

Functions 3/4

※ Never return pointers for new objects. Use `std::unique_ptr` instead — Chromium

```
int*                 f() { return new int[10]; } // wrong!!
std::unique_ptr<int> f() { return new int[10]; } // correct
```

Style guidelines:

- All parameters should be aligned if they do not fit in a single line (especially in the declaration) — Google

```
void f(int        a,
       const int* b);
```

- Parameter names should be the same for declaration and definition — Clang-Tidy

- Do not use `inline` when declaring a function (only in the definition) — LLVM

Functions 4/4

Forward declarations vs. #includes

- *Prefer forward declaration*: reduce compile time, less dependency CHROMIUM
- *Prefer* `#include`: *safer* GOOGLE

Structs and Classes 1/4

Code guidelines:

※ Objects are fully initialized by constructor call GOOGLE, WEBKIT

- Use a `struct` only for passive objects that carry data; everything else is a `class` GOOGLE

Minors:

- Use braced initializer lists for aggregate types `A{1, 2};` LLVM, GOOGLE
- Do not use braced initializer lists `{}` for constructors. It can be confused with `std::initializer_list` object LLVM
- Do not define implicit conversions. Use the `explicit` keyword for conversion operators and constructors GOOGLE

Structs and Classes 2/4

Style guidelines:

- ※ Declare class data members in special way*. Examples:
  - Trailing underscore (e.g. `member_var_`) GOOGLE, μOS
  - Leading underscore (e.g. `_member_var`) EDALAB, .NET
  - Public members (e.g. `m_member_var`) WEBKIT

- Class inheritance declarations order: `public`, `protected`, `private` GOOGLE

- First data members, then function members

- If possible, **avoid** `this->` keyword

*
- It helps to keep track of class variables and local function variables
- The first character is helpful in filtering through the list of available variables

Structs and Classes 3/4

```
struct A {        // passive data structure
    int   x;
    float y;
};

class B {
public:
    B();
    void public_function();

protected:
    int   _a;                   // in general, it is not public in
                                // derived classes
    void _protected_function(); // "protected_function()" is not wrong
                                // it may be public in derived classes
private:
    int   _x;
    float _y;

    void _private_function();
};
```

Structs and Classes 4/4

- In the constructor, each member should be indented on a separate line, e.g. WebKit, Mozilla

```
A::A(int x1, int y1, int z1) :
    x(x1),
    y(y1),
    z(z1) {
```

- *Multiple inheritance* and *virtual inheritance* are discouraged Google, Chromium

- Prefer **composition** over *inheritance*

Modern C++ Features

Modern C++ Features 1/3

Use modern C++ features wherever possible

- `static_cast` `reiterpreter_cast` instead of *old style cast* `(type)` Google, μOS, Hic
- Use `explicit` constructors / conversion operators

Use C++11/C++14/C++17 features wherever possible

- Use `constexpr` instead of *macro* Google
- Use `using` instead `typedef`
- Prefer `enum class` instead of plain `enum` Unreal, μOS
- `static_assert` compile-time assertion Unreal, Hic
- `lambda` expression Unreal
- `move` semantic Unreal

Modern C++ Features 2/3

※ `nullptr` instead of `0` or `NULL` LLVM, Google, Unreal
WebKit, Mozilla, Hic

※ Use *range-for* loops whatever possible
LLVM, WebKit, Unreal

※ Use `auto` to avoid type names that are noisy, obvious, or unimportant

```
auto array = new int[10];
auto var   = static_cast<int>(var);
```

LLVM, Google

lambda, iterators, template expression Unreal (only)

- Use `[[deprecated]]` / `[[noreturn]]` to indicate deprecated functions / that do not return

- Avoid `throw()` expression. Use `noexpect` instead Hic

Modern C++ Features 3/3

Use C++11/C++14/C++17 features for classes

※ Use always `override/final` function member keyword
WebKit, Mozilla, Unreal, Chromium

∗ Use braced *direct-list-initialization* or *copy-initialization* for setting default data member value. Avoid initialization in constructors if possible
Unreal

```
struct A {
    int x = 3;   // copy-initialization
    int x { 3 }; // direct-list-initialization (best option)
};
```

- Prefer *defaulted* default constructor `= default`
Mozilla, Chromium

- Use `= delete` to mark deleted functions

Control Flow

Control Flow 1/4

※ The `if` and `else` keywords belong on separate lines

※ Each statement should get its own line

```
if (c1) <statement1>; else <statement2> // wrong!!
```

Google, WebKit

- Multi-lines statements and complex conditions require curly braces Google

- Curly braces are not required for single-line statements (but allowed) (`for, while, if`) Google

```
if (c1) {  // not mandatory
    <statement>
}
```

Control Flow 2/4

※ Tests for `null/non-null`, and `zero/non-zero` should all be done without equality comparisons WEBKIT, MOZILLA

```
if (!ptr)         // wrong!!
    return;
if (!count)       // wrong!!
    return;
```

```
if (ptr == nullptr)     // correct
    return;
if (count == 0)         // correct
    return;
```

※ Prefer `(ptr == nullptr)` and `x > 0` over `(nullptr == ptr)` and `0 < x` CHROMIUM

- Boolean expression longer than the standard line length requires to be consistent in how you break up the lines GOOGLE

- Prefer `empty()` method over `size()` to check if a container has no items MOZILLA

Control Flow 3/4

- Avoid redundant control flow (see next slide)
  - Do not use `else` after a `return` / `break`

    LLVM, Mozilla, Chromium
  - Avoid `return true/return false` pattern
  - Merge multiple conditional statements
- Do not use `goto` μOS

Control Flow 3/4

```
if (condition) {    // wrong!!
    < code1 >
    return;
}
else // <-- redundant
    < code2 >
//---------------------------
if (condition) {    // Corret
   < code1 >
   return;
}
< code2 >
```

```
if (condition)    // wrong!!
    return true;
else
    return false;
//-------------------------
return condition; // Corret
```

Control Flow

- Use *early exits* (`continue` , `break` , `return`) to simplify the code

LLVM

```
for (<condition1>) {    // wrong!!
    if (<condition3>)
        ...
}
//-----------------------------
for (<condition1>) {    // Correct
    if (!<condition3>)
        continue;
     ...
}
```

- Turn predicate loops into predicate functions

LLVM

```
for (<loop_condition1>) { // should be
   if (<condition2>) {    // an external
       var = ...          // function
       break;             //
   }                      //
}                         //
```

Naming and Formatting

Spacing

※ Use always the same indentation style:

- tab → 2 spaces — Google, Mozilla
- tab → 4 spaces — LLVM, Webkit
- tab = 4 spaces — Unreal

※ Separate commands, operators, etc., by a space
LLVM, Google, WebKit

```
if(a*b<10&&c)          // wrong!!
if (a * c < 10 && c)   // correct
```

※ Line length (width) should be at most **80 characters** long (or 120) → help code view on a terminal
LLVM, Google, Mozilla

▪ Never put trailing white space or tabs at the end of a line
Google, Mozilla

Naming Conventions

General rule:

- ※ Use full words, except in the rare case where an abbreviation would be more canonical and easier to understand WebKit

- Avoid short and very long names

Style Conventions

Camel style Uppercase first word letter (sometimes called *Pascal style* or *Capital case*) (less readable, shorter names)

```
CamelStyle
```

Snake style Lower case words separated by single underscore (good readability, longer names)

```
snake_style
```

Macro style Upper case words separated by single underscore (sometimes called *Screaming style*) (good readability, longer names)

```
MACRO_STYLE
```

Entity Names 1/2

Variable Variable names should be nouns

- Camel style e.g. `MyVar` LLVM, UNREAL
- Snake style e.g. `my_var` GOOGLE, μOS

Constant

- Camel style + `k` prefix,
  e.g. `kConstantVar` GOOGLE, MOZILLA
- Macro style e.g. `CONSTANT_VAR` WEBKIT, OPENSTACK

Enum

- Camel style + `k`
  e.g. `enum MyEnum { kEnumVar1, kEnumVar2 }`
  GOOGLE
- Camel style
  e.g. `enum MyEnum { EnumVar1, EnumVar2 }`
  LLVM, WEBKIT

Entity Names 2/2

Namespace

- Snake style, e.g. `my_namespace` Google, LLVM
- Camel style, e.g. `MyNamespace` WebKit

Typename

- Camel style (including `classes`, `structs`, `enums`, `typedefs`, etc.)
  e.g. `HelloWorldClass` LLVM, Google, WebKit
- Snake style μOS (class)

Entity Names 3/3

Function ※ Should be descriptive verb (as they represent actions) WebKit

- Use `set` prefix for modifier methods WebKit
- Do not use `get` for observer (`const`) methods without parameters WebKit
- Style:
  - Lowercase Camel style, e.g. `myFunc()` LLVM
  - Uppercase Camel style for standard functions e.g. `MyFunc()` Google, Mozilla, Unreal
  - Snake style for cheap functions e.g. `my_func()` Google, Std

Macro and Files

Macro Macro style

e.g. `MY_MACRO` GOOGLE

File

- Snake style (`my_file`) GOOGLE
- Camel style (`MyFile`) LLVM

Naming and Formatting Issues

※ **Reserved names** (do not use):

  - double underscore followed by any character `__var`
  - single underscore followed by uppercase `_VAR`

- Use common loop variable names
  - `i, j, k, l` used in order
  - `it` for iterators

- Prefer consecutive alignment

```
int           var1 = ...
long long int var2 = ...
```

Naming and Formatting Issues

※ Use the same line ending (e.g. `'\n'`) for all files
Mozilla, Chromium

※ Use always the same style for braces

- Same line — WebKit (others), Mozilla
- Its own line — Unreal, WebKit (function)
  Mozilla (Class)

∗ Do not use UTF characters for portability

∗ Use `UTF-8` encoding for portability — Chromium

- Close files with a blank line — Mozilla, Unreal

```
int main() {
    code
}
```

```
int main
{
    code
}
```

Maintainability and Code Documentation

Maintainability

- ※ Avoid complicated template programming GOOGLE

- ※ Use the `assert` to document preconditions and assumptions LLVM

- Prefer `sizeof(variable/value)` instead of `sizeof(type)` GOOGLE

- Avoid if possible *RTTI* (`dynamic_cast`) or *exceptions* LLVM, GOOGLE

- Only one space between statement and comment WEBKIT

- Address compiler warnings. Compiler warning messages mean something is wrong UNREAL

Code Documentation 1/2

- ∗ Any file start with a license LLVM, Unreal

- ∗ Each file should include
  - `@author` name, surname, affiliation, email
  - `@version`
  - `@date` e.g. year and month
  - `@file` the purpose of the file

  in both header and source files

- Document methods/classes/namespaces only in header files

- ※ Include `@param[in]` , `@param[out]` , `@param[in,out]` , `@return` tags

- The first sentence (beginning with `@brief`) is used as an abstract

Code Documentation 2/2

- Use always the same style of comment

- Be aware of the comment style, e.g.
  - Multiple lines

    ```
    /**
     * comment1
     * comment2
     */
    ```

  - single line

    ```
    /// comment
    ```

- Prefer `//` comment instead of `/* */` → allow string-search tools like `grep` to identify valid code lines

C++ Guidelines

C++ Guidelines 1/5

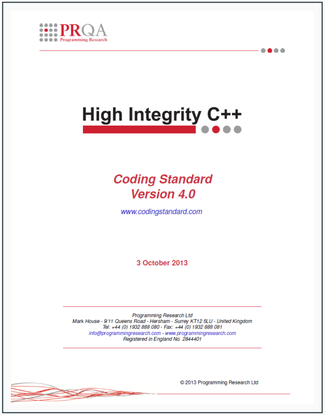
C++ Core Guidelines

`Authors:` Bjarne Stroustrup, Herb Sutter

CORE GUIDELINES

The guidelines are focused on relatively high-level issues, such as interfaces, resource management, memory management, and concurrency. Such rules affect application architecture and library design. Following the rules will lead to code that is statically type safe, has no resource leaks, and catches many more programming logic errors than is common in code today

High Integrity C++ Coding Standard (HIC++)



PRQA Programming Research

High Integrity C++

Coding Standard
Version 4.0

www.codingstandard.com

3 October 2013

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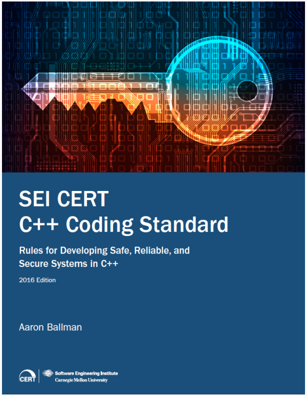
This document defines a set of rules for the production of high quality C++ code.
The guiding principles of this standard are maintenance, portability, readability and robustness

C++ Guidelines 3/5

CERT C++ Secure Coding

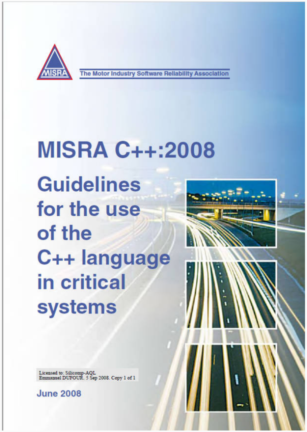
`Author:` Aaron Ballman


SEI CERT
C++ Coding Standard
Rules for Developing Safe, Reliable, and Secure Systems in C++
2016 Edition
Aaron Ballman
CERT
Software Engineering Institute
Carnegie Mellon University

This standard provides rules for secure coding in the C++ programming language.
The goal of these rules is to develop safe, reliable, and secure systems, for example by eliminating undefined behaviors that can lead to undefined program behaviors and exploitable vulnerabilities

C++ Guidelines 4/5

MISRA C++ Coding Standard



MISRA

The Motor Industry Software Reliability Association

MISRA C++:2008

Guidelines for the use of the C++ language in critical systems

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Emmanuel DUFOUR. 5 Sep 2008. Copy 1 of 1

June 2008

`MISRA C++` provides coding standards for developing safety-critical systems.

The standard has been accepted worldwide across all safety sectors where safety, quality or reliability are issues of concern including Automotive, Industrial, Medical devices, Railways, Nuclear energy, and Embedded systems

C++ Guidelines 5/5

AUTOSAR C++ Coding Standard

AUTOSAR C++ was designed as an addendum to MISRA C++:2008 for the usage of the C++14 language.
The main application sector is automotive, but it can be used in other embedded application sectors