

# Modern C++ Programming

## 9. CODE ORGANIZATION AND CONVENTIONS

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# Agenda

- **Basic Concepts**

- Translation Unit
- Linkage
- Global and local scope

- **Variables Storage**

- Storage class specifiers
- Storage duration

- **Dealing with Multiple Files**

- One definition rule
- Limit template instantiations

- **Namespace**

- One definition rule
- Namespace alias
- Inline namespace
- Anonymous namespace

- **C++ Project Organization**

- Project Files
- Include and library

- **Coding Style and Conventions**

- File names and spacing
- `#include`
- Namespace
- Variables
- Functions
- Structs and Classes
- C++11/C++14 features
- Control Flow
- Entity names
- Issues

# Basic Concepts

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# Translation Unit

## Header File and Source File

**Header files** allow to define interfaces (.h, .hpp, ...), while keeping the implementation in separated **source files** (.c, .cpp, ...).

## Translation Unit

A **translation unit** (or compilation unit) is the basic unit of compilation in C++. It consists of the contents of a single source file, plus the contents of any header files directly or indirectly included by it. A single translation unit can be compiled into an object file, library, or executable program

# Linkage

## Linkage

**Linkage** refers to the visibility of symbols to the linker when processing files

## Internal Linkage

**Internal linkage** refers to everything only in scope of a translation unit

## External Linkage

**External linkage** refers to entities that exist beyond a single translation unit. They are accessible through the whole program, which is the combination of all translation units

# Local and Global Scopes

## Local Scope

Variables that are declared inside a function or a block are called local variables (**local scope**)

## Global Scope

Variables that are defined outside of all the functions and hold their value throughout the life-time of the program are global variables (**global scope**)

# Variables Storage

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# Storage Class Specifiers

## Storage Class

A **storage class** for a variable declarations is a type specifier that governs the lifetime, the linkage, and memory location of objects

- A given object can have only one storage class
- Variables defined within a block have automatic storage unless otherwise specified

Storage Class	Keyword	Lifetime	Visibility	Init value
Automatic	auto/no keyword	Code Block	Local	Not defined
Register	register	Code Block	Local	Not defined
Static	static	Whole Program	Local	Zero-initialized
External	extern	Whole Program	Global	Zero-initialized
Thread Local*	thread_local	Thread Execution	Thread	Zero-initialized



# Storage Duration Specifiers

**Automatic storage duration.** Scope variables (local variable). register or stack (depending on compiler, architecture, etc.).

`register` hints to the compiler to place the object in the processor registers (deprecated in C++11)

**Static storage duration.** The storage for the object is allocated when the program begins and deallocated when the program ends ( `static` keyword at local or global scope)

**Thread storage duration** C++11. The object is allocated when the thread begins and deallocated when the thread ends. Each thread has its own instance of the object. ( `thread_local` can appear together with `static` or `extern`)

**Dynamic storage duration.** The object is allocated and deallocated per request by using dynamic memory allocation functions

# Storage Class Examples

```
int      x;    // global scope*
static int y;  // static global scope*
extern int z;  // extern global scope*

thread_local int a;    // global* (each thread has its own value)
thread_local static int a; // static global* (each thread has
                        // its own value)

int main() {
    int      b;    // automatic
    auto     c = b; // automatic
    static int d;   // local scope and whole program lifetime
    register int e;  // automatic (deprecated)
    thread_local int t; // automatic (each thread has its own value)

    auto array = new int[10]; // automatic and dynamic storage duration
}
```

## static Variable Example

```
#include <iostream>

void f() {
    static bool val = false;  // static
    if (val) {
        std::cout << "b";
        return;
    }
    val = true;
    std::cout << "a";
}

int main() {
    f(); // print a
    f(); // print b
}
```

# Dealing with Multiple Translation Units

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## One Definition Rule (ODR):

- (1) In any **translation unit**, a template, type, function, or object can have *no more than* one definition
  - Any number of declarations are allowed
- (2) In the **entire program**, an object or non-inline function cannot have more than one definition
- (3) Types, templates, and extern inline functions, can be defined in more than one translation unit. For a given entity, each definition must be the same
  - Non-extern objects and functions in different translation units are different entities, even if their names and types are the same

## static and extern keywords

`static` *global variable or functions* are visible only within the file (internal linkage)

- **Non-static** global variables or functions with the same name in different translation units produce name collision (or name conflict)

`extern` keyword is used to declare the existence of *global variables or functions* in another translation unit (external linkage)

- the variable or function must be defined in a one and only one translation unit

If, within a translation unit, the same identifier appears with both *internal* and *external* linkage, the behavior is undefined

# One Definition Rule (Example, points (1), (2))

header.hpp:

```
void f();
```

main.cpp:

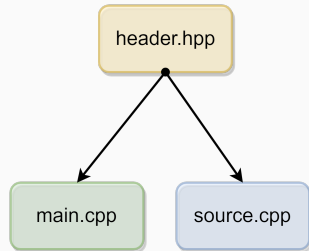
```
#include "header.hpp"
#include <iostream>
int      a = 1;
static int b = 2; // internal linkage
extern int c;      // external linkage

int main() {
    std::cout << b; // print 2
    std::cout << c; // print 4
    f();           // print 5
}
```

source.cpp:

```
#include "header.hpp"
// int      a = 2; // linking error !! (multiple definitions)
static int b = 5; // ok
int      c = 4;   // ok

void f() { std::cout << b; } // print 5
```



# One Definition Rule (Example, point (3))

header.hpp:

```
inline void f() {} // the function is inline (no linking error)

template<typename T = void>
void g() {}        // the function is a template (no linking error)

using var_t = int; // types can be defined multiple times (no linking error)
```

main.cpp:

```
#include "header.hpp" // included two times in the program!!
                        // (main.cpp and source.cpp)

int main() {
    f();
    g();
}
```

source.cpp:

```
#include "header.hpp"

void h() {
    f();
    g();
}
```



# One Definition Rule (Classes)

header.hpp:

```
struct A {  
    void f() {}; // declaration and definition (correct)  
    void g();  
};  
void A::g() {} // definition (wrong)!! multiple definitions  
  
struct B {  
    void f(); // declaration (correct) : definition is in source.cpp  
};
```

main.cpp:

```
#include "header.hpp" // linking error !!  
                        // (multiple definitions of A.g())  
  
int main() {  
}
```

source.cpp:

```
#include "header.hpp" // linking error !!  
                        // (multiple definitions of A.g())  
  
void B::f() {} // ok  
  
void g() {}
```

header.hpp:

```
template<typename T>
void f();
```

```
template<>           // linking error (multiple definitions) included twice
void f<int>() {}      // full specializations are standard functions
```

main.cpp:

```
#include "header.hpp"
```

```
int main() {
// f<int>();      // linking error, f<int>() is not defined here
}
```

source.cpp:

```
#include "header.hpp"
```

```
template<typename T>
void f() {}          // valid only here
```

```
void g() {
    f<int>();         // ok
}
```

Good practice: declare full specializations in header

header.hpp:

```
template<typename T>
void f();

void f<int>(); // informs the user that f<int>() has been specialized

template<typename T>
struct A {
    void f();
};
template<>
void A<int>::f(); // informs the user that A<int>::f() has been specialized
```

source.cpp:

```
#include "header.hpp"
template<>
void f<int>() {}

template<>
void A<int>::f() {}
```

**Forward declaration** is a declaration of an identifier for which a complete definition has not yet given

“*forward*” means that an entity is declared before it is used

**Functions** and **Classes** have external linkage by default

main.cpp:

```
void f(); // forward declaration
class A;  // forward declaration

class B {
    friend A; // ok, A is declared
};
int main() {
    f();
    // A a; // compiler error!! no definition (incomplete type)
}
```

source.cpp:

```
void f() {} // definition of f()
class A {}; // definition of A()
```

## Advantages:

- Forward declarations can save compile time, as `#include` force the compiler to open more files and process more input
- Forward declarations can save on unnecessary recompilation.  
`#include` can force your code to be recompiled more often, due to unrelated changes in the header

## Disadvantages:

- Forward declarations can hide a dependency, allowing user code to skip necessary recompilation when headers change
- A forward declaration may be broken by subsequent changes to the library
- Forward declaring multiple symbols from a header can be more verbose than simply `#including` the header

Full Story:

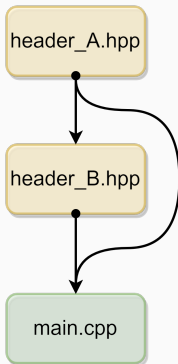
[google.github.io/styleguide/cppguide.html#Forward\\_Declarations](https://google.github.io/styleguide/cppguide.html#Forward_Declarations)

The **include guard** avoids the problem of multiple inclusions of a header file in a translation unit

`#pragma once` (C++11, C++14) preprocessor directive force the current file to be included only once in a translation unit

`#pragma once` should be used in every header files

Common case:



header\_A.hpp:

```
#pragma once    // it is required to prevent "multiple definitions"
                // linking error

struct A {
};
```

header\_B.hpp:

```
#include "header_A.hpp" // included here

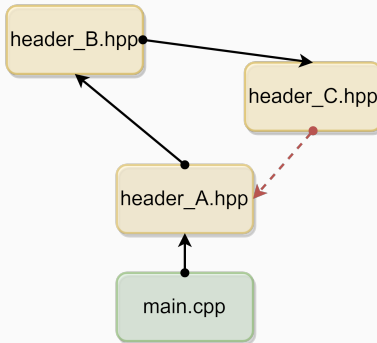
struct B {
    A a;
};
```

main.cpp:

```
#include "header_A.hpp" // .. and included here
#include "header_B.hpp"

int main() {
    A a;
    B b;
}
```

A **circular dependency** is a relation between two or more modules which either directly or indirectly depend on each other to function properly



Circular dependencies can be solved by using forward declaration, or better, by rethinking the project organization



header\_A.hpp:

```
#pragma once
#include "header_B.hpp"

class A {
    B b;
};
```

header\_B.hpp:

```
#pragma once
#include "header_C.hpp"

class B {
    C c;
};
```

header\_C.hpp:

```
#pragma once
#include "header_A.hpp"

class C { // compile error!! header_A already included by main.cpp
    A a;   // the compiler cannot view the class C
};
```

header\_A.hpp:

```
#pragma once  
class B;    // forward declaration  
  
class A {  
    B b;  
};
```

header\_B.hpp:

```
#pragma once  
class C;    // forward declaration  
  
class B {  
    C c;  
};
```

header\_C.hpp:

```
#pragma once  
class A;    // forward declaration  
  
class C {  
    A a;  
};
```

header.hpp:

```
template<typename T>
void f();

template<typename T>
class A {
    void g();
    void h();
};

template<typename T>
class B {
    void g();
    void h();
};
```

source.cpp: (templates in a source file)

```
#include "header.hpp"

template<typename T>
void f() {}

template<typename T>
void A<T>::g() {}

template<typename T>
void A<T>::h() {}

template<typename T>
void B<T>::g() {}

template<typename T>
void B<T>::h() {}

template void f<int>();
template void f<char>();
template class A<int>;
template void B<int>::f();
```

main.cpp:

```
#include "header.hpp"

int main() {
    f<int>();    // ok
    f<char>();   // ok
    // f<short>(); // compile error !!

    A<int> a1; // ok
    a1.f();    // ok
    a1.g();    // ok
    // A<short> a2; // compile error !!

    B<int> b1; // ok
    b1.f();    // ok
    b1.g();    // compile error !!
}
```

# Summary

- **header:** declaration of
  - structs/classes
  - functions, inline functions
  - template function/classes
  - extern global variables/functions
- **header implementation:** definition of (see next slides)
  - inline functions
  - template functions/classes
- **source file:** definition of
  - functions
  - templates full specialization
  - limited template instantiations
  - static global variables
  - extern variables/functions definition

# Common Linking Errors

Very common linking errors:

- **undefined reference**

Solutions:

- Check if the right headers are included
- Break circular dependencies with forward declarations

- **multiple definitions**

Solutions:

- `inline` function definition
- Add `#pragma once` to header files
- Use `extern` declaration for global variables
- Place template definition in header file and full specialization in source files

# Namespace

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The problem: Named entities, such as variables, functions, and compound types declared outside any block has *global scope*, meaning that its name is valid anywhere in the code

***Namespaces*** allow to group named entities that otherwise would have global scope into narrower scopes, giving them ***namespace scope*** (where *std* stands for “standard”)

Namespaces provide a method for preventing name conflicts in large projects. Symbols declared inside a namespace block are placed in a named scope that prevents them from being mistaken for identically-named symbols in other scopes.



# Defining a Namespace

```
#include <iostream>
using namespace std;

namespace my_namespace1 {
    void f() {
        cout << "my_namespace1" << endl;
    }
}

namespace my_namespace2 {
    void f() {
        cout << "my_namespace2" << endl;
    }
}

int main () {
    my_namespace1::f(); // print my_namespace1
    my_namespace2::f(); // print my_namespace2
    // f(); // compile error!! f() is not visible
}
```

# Namespace Conflits

```
#include <iostream>
using namespace std;

void f() {
    cout << "global" << endl;
}

namespace ns1 {
    void f() { cout << "ns1::f()" << endl; }
    void g() { cout << "ns1::g()" << endl; }
}

int main () {
    f();          // ok, print "global"
    // g();       // compile error!! g() is not visible
    using namespace ns1;
    // f();       // compile error!! ambiguous function name
    ::f();        // ok, print "global"
    ns1::f();     // ok, print "ns1::f()"
    g();          // ok, print "ns1::g()"
}
```

# Nested Namespaces and Multiple files

header.hpp:

```
#include <iostream>

namespace ns1 {
    void f() { cout << "ns1::f()" << endl; }
    namespace ns2 {
        void f() { cout << "ns1::ns2::f()" << endl; }
        void g() { cout << "ns1::ns2::g()" << endl; }
    }
}
```

main.cpp:

```
#include "header.hpp"

namespace ns1 {    // the same namespace can be declared multiple times
    void g() {}    // ok
    // void f() {} // compile error!! function name conflict
}

int main() {
    ns1::f();        // ok, print "ns1::f()"
    ns1::ns2::f();   // ok, print "ns1::ns2::f()"
    using namespace ns1::ns2;
    g();             // ok, print "ns1::ns2::g()"
}
```

# Namespace Alias

**Namespace alias** allows declaring an alternate name for an existing namespace

```
namespace ns1 {  
    void g() {}  
}  
  
namespace ns_alias = ns1; // namespace alias  
  
int main() {  
    using namespace ns_alias;  
    g();  
}
```

## inline Namespace

**inline namespaces** is a concept similar to library versioning. It is a mechanism that makes a nested namespace look and act as if all its declarations were in the surrounding namespace

```
namespace ns1 {  
    inline namespace V99 {  
        void f(int) {}    // most recent version  
    }  
    namespace V98 {  
        void f(int) {}  
    }  
}  
  
using namespace ns1;  
  
int main() {  
    V98::f(1);    // call V98  
    V99::f(1);    // call V99  
    f(1);         // call default version (V99)  
}
```

# Anonymous Namespace

A namespace with no identifier before an opening brace produces an **unnamed/anonymous namespace**

Entities inside an anonymous namespace are used for declaring unique identifiers, visible in the same source file

## Anonymous namespaces vs. static global entities

Anonymous namespaces allow type declarations and they are less verbose

main.cpp

```
#include <iostream>
namespace { // anonymous
    void f() { std::cout << "main"; }
}

int main() {
    f();    // ok, print "main"
}
```

source.cpp

```
#include <iostream>
namespace { // anonymous
    void f() { std::cout << "source"; }
}

int g() {
    f();    // ok, print "source"
}
```

# C++ Project Organization

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# Project Organization

Project  
Root



bin



build



test



submodules/  
externals/  
dependencies



lib



doc



include



src



CMakeLists.txt



doxygen.cfg



LICENSE



README.md



# Project Directories

**bin** Output executables

**build** All object (intermediate) file

**data** Files used by the executables

**doc** Project documentation

**includes** Project header files

**src** Project source files

**test** Source files for tests

**lib** External libraries or third party

**submodules** (also “externals” or “dependencies”)  
External dependencies or submodules

## 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 (see next lecture)

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

\*: Markdown is a language to generate text file with a syntax corresponding to a very small subset of HTML tags

[github.com/adam-p/markdown-here/wiki/Markdown-Cheatsheet](https://github.com/adam-p/markdown-here/wiki/Markdown-Cheatsheet) 36/56

# File extensions

## Common C++ file extensions:

- **header** `.h` `.hh` `.hpp` `.hxx`
- **header implementation** `.i.h` `.i.hpp` [EDALAB](#)
- **src** `.c` `.cc` `.cpp` `.cxx`
- **textually included at specific points** `.inc` [GOOGLE](#)

## Common conventions:

- `.h` `.c` `.cc` [GOOGLE](#)
- `.hpp` `.cpp`
- `.hxx` `.cxx`

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

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

Organization:

- **headers** and **header implementations** in `include`
- **source files** in `src`

## Compiler includes and libraries flags

Specify the **include path** to the compiler:

```
g++ -std=c++14 -Iinclude main.cpp -o main
```

-I can be used multiple times

Specify the **library path** (path where search for static/dynamic libraries) to the compiler:

```
g++ -std=c++14 -L<library_path> main.cpp -o main
```

-L can be used multiple times

Specify the **library name** (e.g. liblibrary.a) to the compiler:

```
g++ -std=c++14 -llibrary main.cpp -o main
```

The predefined environmental variable in Linux/Unix for linking dynamic libraries/shared libraries is `LD_LIBRARY_PATH`

A **library** is a package of code that is meant to be reused by many programs

A **static library** (.a) consists of routines that are compiled and linked directly into your program. If a program is compiled with a static library, all the functionality of the static library becomes part of your executable

A **dynamic library**, also called a **shared library** (.so), consists of routines that are loaded into your application at run-time. If a program is compiled with a dynamic library, the library does not become part of your executable. It remains as a separate unit

# Coding Styles and Conventions

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Most important rule:

**BE CONSISTENT!!**

“The best code explains itself”

GOOGLE



**Coding styles** are common guidelines to improve the readability, 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`

# File names and Spacing

## File names:

- Lowercase Underscore
- Camel UpperCase

GOOGLE  
LLVM

## Spacing:

- ※ Never use tab
- tab → 2 spaces
- tab → 4 spaces
- ※ Separate commands, operators, etc., by a space (Google, LLVM)

LLVM, GOOGLE,  
GOOGLE  
LLVM

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

- ※ Line length (width) should be at most 80 characters long (help code view on a terminal)

LLVM, GOOGLE

# #include

## Order of #include

LLVM, GOOGLE

- (1) Class header (it is only one)
- (2) Local project includes (in alphabetical order)
- (3) System includes (in alphabetical order)

## Project includes

LLVM, GOOGLE

- should be indicated with "" syntax
  - should be absolute paths from the project include root
- e.g. `#include "directory1/header.hpp"`

## System includes

LLVM, GOOGLE

- should be indicated with <> syntax
- e.g. `#include <iostream>`

## Use C++ header instead of C header:

`<cassert>` instead of `<assert.h>`  
`<cmath>` instead of `<math.h>`, etc.

# Namespaces

## Code guidelines:

- Avoid `using`-directives at global scope LLVM, GOOGLE
- Limit `using`-directives at local scope and prefer explicit namespace specification GOOGLE
- Always place code in a namespace GOOGLE
- Avoid *anonymous* namespaces in headers

## Style guidelines:

- The contents of namespaces are not indented GOOGLE
- Close the namespace declaration with  

```
} // namespace <namespace_identifier>
```

 LLVM

# Variables

- Avoid static and global variables LLVM, GOOGLE
- Prefer iterator/variable preincrement LLVM, GOOGLE
- Place a variables in the narrowest scope possible, and initialize variables in the declaration GOOGLE, ISOCPP
- Declaration of pointer variables or arguments may be placed with the asterisk *adjacent* to either the *type* or to the variable *name* for all in the same way  

```
char* c; char *c;
```

 GOOGLE
- Use fixed-width integer type GOOGLE
- Use brace initialization to convert arithmetic types (e.g. `int64{x}`) GOOGLE

# Functions

## Code guidelines:

- Prefer using return values rather than output parameters
- Limit overloaded functions
- Default arguments are allowed only on *non*-virtual functions

GOOGLE

GOOGLE

GOOGLE

## Style guidelines:

- All parameters should be aligned if possible
- Parameter names should be the same for declaration and definition
- Don't use `inline` when declaring a function [in a class definition]

GOOGLE

LLVM

## Code guidelines:

- Use a struct only for passive objects that carry data; everything else is a class LLVM, GOOGLE
- Use braced initializer lists LLVM, GOOGLE
- Do not use braced initializer lists for constructors LLVM
- Avoid multiple inheritance GOOGLE
- Objects that are fully initialized by constructor call GOOGLE
- Do not define implicit conversions. Use the `explicit` keyword for conversion operators and single-argument constructors GOOGLE

## Style guidelines:

- Class inheritance declarations order:  
public, protected, private GOOGLE
- First data members, then function members
- Declare class data members in special way\*. Examples:
  - Trailing underscore (e.g. `member_var_`) GOOGLE
  - Leading underscore (e.g. `_member_var`) EDALAB, .NET
  - Public members (e.g. `m_member_var`)

\*

- 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 49/56



## Use C++11/C++14 features where possible

- Use *constant expressions* instead *macros* GOOGLE
- `static_cast` `reinterpret_cast` instead *old style cast*  
`(type)` GOOGLE
- Use *range-for* loops wherever possible LLVM
- Use `auto` type deduction to make the code more readable  
`auto array = new int[10];`  
`auto var = static_cast<int>(var);` LLVM, GOOGLE
- `nullptr` instead `0` or `NULL` LLVM
- Use `[[deprecated]]` to indicate deprecated functions
- Use `using` instead `typedef`

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

- Use `explicit` constructors
- Use *defaulted* default constructor
- Use `override` keyword
- Use `final` keyword

- Multi-lines statements and complex conditions require curly braces [GOOGLE](#)
- Boolean expression longer than the standard line length requires to be consistent in how you break up the lines [GOOGLE](#)
- Curly braces are not required for single-line statements (but allowed) [GOOGLE](#)
- The `if` and `else` keywords belong on separate lines [GOOGLE](#)

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

```
if (c2) { // required
    <statement1>
    <statement2>
}
```

```
if (complex_condition1 &&
    complex_condition2) { // required
    <statement1>
}

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

- Do not use else after a return
- Use *early exits* and continue to simplify code
- Turn predicate loops into predicate functions
- Merge multiple conditional statements

LLVM

LLVM

LLVM

```
void f() {
    if (c1) {
        <statement1>
        return/break/continue;
    } // error!!
    else
        <statement2>
}

void f() {
    if (c1) {
        <statement1>
        return/break/continue;
    } // correct
    <statement2>
}
```

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

if (<condition1>) { // error!!
    if (<condition2>)
        <statement>
}

// correct
if (<condition1> && <condition2>)
    <statement>
```

**General rule:** *avoid abbreviation and very long names*

**variable** Variable names should be nouns

- Uppercase Camel style e.g. MyVar LLVM
- Lowercase separated by underscore e.g. my\_var GOOGLE

**constant**

- k prefix, e.g. kConstantVar GOOGLE
- Upper case separated by underscore CONSTANT\_VAR

**function** Should be verb phrases (as they represent actions)

- Lowercase camel style, e.g. myFunc() LLVM
- Uppercase camel style for standard functions  
e.g. MyFunc() GOOGLE
- Lowercase separated by underscore for cheap functions  
e.g. my\_func() GOOGLE, STD

**namespace** Lowercase separated by underscore

e.g. my\_namespace GOOGLE, LLVM<sub>54/56</sub>

**typename** Uppercase camel style (including classes, structs, enums, typedefs, etc.)

e.g. HelloWorldClass

LLVM, GOOGLE

**enum name** - k prefix

e.g. enum MyEnum { kEnumVar1, kEnumVar2 } GOOGLE

- Uppercase camel style

e.g. enum MyEnum { EnumVar1, EnumVar2 } LLVM

**macro** Uppercase separated by underscore

e.g. MY\_MACRO

GOOGLE

do not use macro for enumerator, constant, and functions

## Other Issues

Do not use *RTTI* (`dynamic_cast`) or *exceptions* [LLVM](#), [GOOGLE](#)

### Code style

- Use common loop variable names
  - `i,j,k,l` used in order
  - `it` for iterators
- Use `true`, `false` for boolean variables
- Prefer consecutive alignment

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

### Code commenting

- Each file should start with a license
- Each file should include `@author`, `@version`, `@date`
- Use always the same style for commenting
  - `/** comment */`
  - `/// comment`

[LLVM](#)

[GOOGLE](#)  
[LLVM](#) 56/56