C++ Coding Standards

101 Rules, Guidelines, and Best Practices

Herb Sutter
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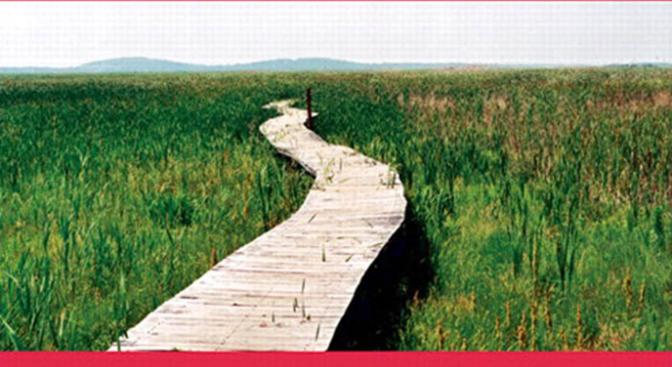

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Preface

Get into a rut early: Do the same process the same way. Accumulate idioms. ***Standardize.*** *The only difference(!) between Shakespeare and you was the size of his idiom list—not the size of his vocabulary.*

— Alan Perlis [emphasis ours]

The best thing about standards is that there are so many to choose from.

— Variously attributed

We want to provide this book as a basis for your team's coding standards for two principal reasons:

- *A coding standard should reflect the community's best tried-and-true experience:* It should contain proven idioms based on experience and solid understanding of the language. In particular, a coding standard should be based firmly on the extensive and rich software development literature, bringing together rules, guidelines, and best practices that would otherwise be left scattered throughout many sources.
- *Nature abhors a vacuum:* If you don't consciously set out reasonable rules, usually someone else will try to push their own set of pet rules instead. A coding standard made that way usually has all of the least desirable properties of a coding standard; for example, many such standards try to enforce a minimalistic C-style use of C++.

Many bad coding standards have been set by people who don't understand the language well, don't understand software development well, or try to legislate too much. A bad coding standard quickly loses credibility and at best even its valid guidelines are liable to be ignored by disenchanted programmers who dislike or disagree with its poorer guidelines. That's "at best"—at worst, a bad standard might actually be enforced.

How to Use This Book

Think. Do follow good guidelines conscientiously; but don't follow them blindly. In this book's Items, note the Exceptions clarifying the less common situations where the guidance may not apply. No set of guidelines, however good (and we think these ones are), should try to be a substitute for thinking.

Each development team is responsible for setting its own standards, and for setting them responsibly. That includes your team. If you are a team lead, involve your team members in setting the team's standards; people are more likely to follow standards they view as their own than they are to follow a bunch of rules they feel are being thrust upon them.

This book is designed to be used as a basis for, and to be included by reference in, your team's coding standards. It is not intended to be the Last Word in coding standards, because your team will have additional guidelines appropriate to your particular group or task, and you should feel free to add those to these Items. But we hope that this book will save you some of the work of (re)developing your own, by documenting and referencing widely-accepted and authoritative practices that apply nearly universally (with Exceptions as noted), and so help increase the quality and consistency of the coding standards you use.

Have your team read these guidelines with their rationales (i.e., the whole book, and selected Items' References to other books and papers as needed), and decide if there are any that your team simply can't live with (e.g., because of some situation unique to your project). Then commit to the rest. Once adopted, the team's coding standards should not be violated except after consulting with the whole team.

Finally, periodically review your guidelines as a team to include practical experience and feedback from real use.

Coding Standards and You

Good coding standards can offer many interrelated advantages:

- *Improved code quality:* Encouraging developers to do the right things in a consistent way directly works to improve software quality and maintainability.
- *Improved development speed:* Developers don't need to always make decisions starting from first principles.
- *Better teamwork:* They help reduce needless debates on inconsequential issues and make it easier for teammates to read and maintain each other's code.
- *Uniformity in the right dimension:* This frees developers to be creative in directions that matter.

Under stress and time pressure, people do what they've been trained to do. They fall back on habit. That's why ER units in hospitals employ experienced, trained personnel; even knowledgeable beginners would panic.

As software developers, we routinely face enormous pressure to deliver tomorrow's software yesterday. Under schedule pressure, we do what we are trained to do and are used to doing. Sloppy programmers who in normal times don't know good practices of software engineering (or aren't used to applying them) will write even sloppier and buggier code when pressure is on. Conversely, programmers who form good habits and practice them regularly will keep themselves organized and deliver quality code, fast.

The coding standards introduced by this book are a collection of guidelines for writing high-quality C++ code. They are the distilled conclusions of a rich collective experience of the C++ community. Much of this body of knowledge has only been available in bits and pieces spread throughout books, or as word-of-mouth wisdom. This book's intent is to collect that knowledge into a collection of rules that is terse, justified, and easy to understand and follow.

Of course, one can write bad code even with the best coding standards. The same is true of any language, process, or methodology. A good set of coding standards fosters good habits and discipline that transcend mere rules. That foundation, once acquired, opens the door to higher levels. There's no shortcut; you have to develop vocabulary and grammar before writing poetry. We just hope to make that easier.

We address this book to C++ programmers of all levels:

If you are an apprentice programmer, we hope you will find the rules and their rationale helpful in understanding what styles and idioms C++ supports most naturally. We provide a concise rationale and discussion for each rule and guideline to encourage you to rely on understanding, not just rote memorization.

For the intermediate or advanced programmer, we have worked hard to provide a detailed list of precise references for each rule. This way, you can do further research into the rule's roots in C++'s type system, grammar, and object model.

At any rate, it is very likely that you work in a team on a complex project. Here is where coding standards really pay off—you can use them to bring the team to a common level and provide a basis for code reviews.

About This Book

We have set out the following design goals for this book:

- *Short is better than long:* Huge coding standards tend to be ignored; short ones get read and used. Long Items tend to be skimmed; short ones get read and used.

- *Each Item must be noncontroversial:* This book exists to document widely agreed-upon standards, not to invent them. If a guideline is not appropriate in all cases, it will be presented that way (e.g., "Consider X…" instead of "Do X…") and we will note commonly accepted exceptions.
- *Each Item must be authoritative:* The guidelines in this book are backed up by references to existing published works. This book is intended to also provide an index into the C++ literature.
- *Each Item must need saying:* We chose not to define new guidelines for things that you'll do anyway, that are already enforced or detected by the compiler, or that are already covered under other Items.

  Example: "Don't return a pointer/reference to an automatic variable" is a good guideline, but we chose not to include it in this book because all of the compilers we tried already emit a warning for this, and so the issue is already covered under the broader Item 1, "Compile cleanly at high warning levels."

  Example: "Use an editor (or compiler, or debugger)" is a good guideline, but of course you'll use those tools anyway without being told; instead, we spend two of our first four Items on "Use an automated build system" and "Use a version control system."

  Example: "Don't abuse `goto`" is a great Item, but in our experience programmers universally know this, and it doesn't need saying any more.

Each Item is laid out as follows:

- *Item title:* The simplest meaningful sound bite we could come up with as a mnemonic for the rule.
- *Summary:* The most essential points, briefly stated.
- *Discussion:* An extended explanation of the guideline. This often includes brief rationale, but remember that the bulk of the rationale is intentionally left in the References.
- *Examples (if applicable):* Examples that demonstrate a rule or make it memorable.
- *Exceptions (if applicable):* Any (and usually rare) cases when a rule doesn't apply. But beware the trap of being too quick to think: "Oh, I'm special; this doesn't apply in my situation"—that rationalization is common, and commonly wrong.
- *References:* See these parts of the C++ literature for the full details and analysis.

In each section, we chose to nominate a "most valuable Item." Often, it's the first Item in a section, because we tried to put important Items up front in each part; but other times an important Item couldn't be put up front, for flow or readability reasons, and we felt the need to call it out for special attention in this way.

Acknowledgments

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Inspiration for some of the "sound bites" came from many sources, including the playful style of [Cline99], the classic **import this** of [Peters99], and the legendary and eminently quotable Alan Perlis.

We especially want to thank the people whose technical feedback has helped to make many parts of this book better than they would otherwise have been. Series editor Bjarne Stroustrup's incisive comments from concept all the way through to the final draft were heavily influential and led to many improvements. We want to give special thanks to Dave Abrahams, Marshall Cline, Kevlin Henney, Howard Hinnant, Jim Hyslop, Nicolai Josuttis, Jon Kalb, Max Khesin, Stan Lippman, Scott Meyers, and Daveed Vandevoorde for their active participation in review cycles and detailed comments on several drafts of this material. Other valuable comments and feedback were contributed by Chuck Allison, Samir Bajaj, Marc Barbour, Travis Brown, Neal Coombes, Damian Dechev, Steve Dewhurst, Peter Dimov, Attila Feher, Alan Griffiths, Michi Henning, James Kanze, Mat Marcus, Petru Marginean, Robert C. "Uncle Bob" Martin, Bartosz Milewski, Balog Pal, Jeff Peil, Peter Pirkelbauer, Vladimir Prus, Dan Saks, Luke Wagner, Matthew Wilson, and Leor Zolman.

As usual, the remaining errors, omissions, and shameless puns are ours, not theirs.

Herb Sutter
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Seattle, September 2004

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1. Compile cleanly at high warning levels.

Summary

Take warnings to heart: Use your compiler's highest warning level. Require clean (warning-free) builds. Understand all warnings. Eliminate warnings by changing your code, not by reducing the warning level.

Discussion

Your compiler is your friend. If it issues a warning for a certain construct, often there's a potential problem in your code.

Successful builds should be silent (warning-free). If they aren't, you'll quickly get into the habit of skimming the output, and you *will* miss real problems. (See Item 2.)

To get rid of a warning: a) understand it; and then b) rephrase your code to eliminate the warning and make it clearer to both humans and compilers that the code does what you intended.

Do this even when the program seemed to run correctly in the first place. Do this even when you are positive that the warning is benign. Even benign warnings can obscure later warnings pointing to real dangers.

Examples

Example 1: A third-party header file. A library header file that you cannot change could contain a construct that causes (probably benign) warnings. Then wrap the file with your own version that **#include**s the original header and selectively turns off the noisy warnings for that scope only, and then **#include** your wrapper throughout the rest of your project. Example (note that the warning control syntax will vary from compiler to compiler):

```
// File: myproj/my_lambda.h -- wraps Boost's lambda.hpp
//   Always include this file; don't use lambda.hpp directly.
//   NOTE: Our build now automatically checks "grep lambda.hpp <srcfile>".
// Boost.Lambda produces noisy compiler warnings that we know are innocuous.
// When they fix it we'll remove the pragmas below, but this header will still exist.
//
#pragma warning(push)        // disable for this header only
  #pragma warning(disable:4512)
  #pragma warning(disable:4180)
  #include <boost/lambda/lambda.hpp>
#pragma warning(pop)         // restore original warning level
```

Example 2: "Unused function parameter." Check to make sure you really didn't mean to use the function parameter (e.g., it might be a placeholder for future expansion, or a required part of a standardized signature that your code has no use for). If it's not needed, simply delete the name of a function parameter:

```
// ... inside a user-defined allocator that has no use for the hint ...

// warning: "unused parameter 'localityHint'"
pointer allocate( size_type numObjects, const void *localityHint = 0 ) {
  return static_cast<pointer>( mallocShared( numObjects * sizeof(T) ) );
}

// new version: eliminates warning
pointer allocate( size_type numObjects, const void * /* localityHint */ = 0 ) {
  return static_cast<pointer>( mallocShared( numObjects * sizeof(T) )   );
}
```

Example 3: "Variable defined but never used." Check to make sure you really didn't mean to reference the variable. (An RAII stack-based object often causes this warning spuriously; see Item 13.) If it's not needed, often you can silence the compiler by inserting an evaluation of the variable itself as an expression (this evaluation won't impact run-time speed):

```
// warning: "variable 'lock' is defined but never used"
void Fun() {
  Lock lock;

  // ...

}

// new version: probably eliminates warning
void Fun() {
  Lock lock;
  lock;

  // ...

}
```

Example 4: "Variable may be used without being initialized." Initialize the variable (see Item 19).

Example 5: "Missing **return***."* Sometimes the compiler asks for a **return** statement even though your control flow can never reach the end of the function (e.g., infinite loop, **throw** statements, other **return**s). This can be a good thing, because sometimes you only *think* that control can't run off the end. For example, **switch** statements that do not have a **default** are not resilient to change and should have a **default** case that does **assert(false)** (see also Items 68 and 90):

```
// warning: missing "return"
int Fun( Color c ) {
  switch( c ) {
  case Red:     return 2;
  case Green:   return 0;
  case Blue:
  case Black:   return 1;
  }
}

// new version: eliminates warning
int Fun( Color c ) {
  switch( c ) {
  case Red:     return 2;
  case Green:   return 0;
  case Blue:
  case Black:   return 1;
  default:      assert( !"should never get here!" );    // !"string" evaluates to false
                return -1;
  }
}
```

Example 6: "Signed/unsigned mismatch." It is usually not necessary to compare or assign integers with different signedness. Change the types of the variables being compared so that the types agree. In the worst case, insert an explicit cast. (The compiler inserts that cast for you anyway, and warns you about doing it, so you're better off putting it out in the open.)

Exceptions

Sometimes, a compiler may emit a tedious or even spurious warning (i.e., one that is mere noise) but offer no way to turn it off, and it might be infeasible or unproductive busywork to rephrase the code to silence the warning. In these rare cases, as a team decision, avoid tediously working around a warning that is merely tedious: Disable that specific warning only, disable it as locally as possible, and write a clear comment documenting why it was necessary.

References

[Meyers97] §48 • [Stroustrup94] §2.6.2

25. Take parameters appropriately by value, (smart) pointer, or reference.

Summary

Parameterize well: Distinguish among input, output, and input/output parameters, and between value and reference parameters. Take them appropriately.

Discussion

Choosing well among values, references, and pointers for parameters is good habit that maximizes both safety and efficiency.

Although efficiency should not be our primary up-front concern (see Item 8), neither should we write needlessly inefficient code when all other things, including clarity, are equal (see Item 9).

Prefer to follow these guidelines for choosing how to take parameters. For input-only parameters:

- Always **const**-qualify all pointers or references to input-only parameters.
- Prefer taking inputs of primitive types (e.g., **char**, **float**) and value objects that are cheap to copy (e.g., **Point**, **complex<float>**) by value.
- Prefer taking inputs of other user-defined types by reference to **const**.
- Consider pass-by-value instead of reference if the function requires a copy of its argument. This is conceptually identical to taking a reference to **const** plus doing a copy, and it can help compiler to better optimize away temporaries.

For output or input/output parameters:

- Prefer passing by (smart) pointer if the argument is optional (so callers can pass null as a “not available” or “don’t care” value) or if the function stores a copy of the pointer or otherwise manipulates ownership of the argument.
- Prefer passing by reference if the argument is required and the function won’t store a pointer to it or otherwise affect its ownership. This states that the argument is required and makes the caller responsible for providing a valid object.

Don’t use C-style varargs (see Item 98).

References

[Alexandrescu03a] • [Cline99] §2.10-11, 14.02-12, 32.08 • [Dewhurst03] §57 • [Koenig97] §4 • [Lakos96] §9.1.11-12 • [McConnell93] §5.7 • [Meyers97] §21-22 • [Stroustrup94] §11.4.4 • [Stroustrup00] §5.5, §11.6, §16.3.4 • [Sutter00] §6, §46

73. Throw by value, catch by reference.

Summary

Learn to **catch** properly: Throw exceptions by value (not pointer) and catch them by reference (usually to **const**). This is the combination that meshes best with exception semantics. When rethrowing the same exception, prefer just **throw;** to **throw e;**.

Discussion

When throwing an exception, throw an object by value. Avoid throwing a pointer, because if you throw a pointer, you need to deal with memory management issues: You can't throw a pointer to a stack-allocated value because the stack will be unwound before the pointer reaches the call site. You could throw a pointer to dynamically allocated memory (if the error you're reporting isn't "out of memory" to begin with), but you've put the burden on the catch site to deallocate the memory. If you feel you really must throw a pointer, consider throwing a value-like smart pointer such as a **shared_ptr<T>** instead of a plain **T***.

Throwing by value enjoys the best of all worlds because the compiler itself takes responsibility for the intricate process of managing memory for the exception object. All you need to take care of is ensuring that you implement a non-throwing copy constructor for your exception classes (see Item 32).

Unless you are throwing a smart pointer, which already adds an indirection that preserves polymorphism, catching by reference is the only good way to go. Catching a plain value by value results in slicing at the catch site (see Item 54), which violently strips away the normally-vital polymorphic qualities of the exception object. Catching by reference preserves the polymorphism of the exception object.

When rethrowing an exception **e**, prefer writing just **throw;** instead of **throw e;** because the first form always preserves polymorphism of the rethrown object.

Examples

Example: Rethrowing a modified exception. Prefer to rethrow using **throw;**:

```
catch( MyException& e ) {                      // catch by reference to non-const
  e.AppendContext("Passed through here");     // modify
  throw;                                       // rethrow modified object
}
```

References

[Dewhurst03] §64-65 • [Meyers96] §13 • [Stroustrup00] §14.3 • [Vandevoorde03] §20

74. Report, handle, and translate errors appropriately.

Summary

Know when to say when: Report errors at the point they are detected and identified as errors. Handle or translate each error at the nearest level that can do it correctly.

Discussion

Report an error (e.g., write **throw**) wherever a function detects an error that it cannot resolve itself and that makes it impossible for the function to continue execution. (See Item 70.)

Handle an error (e.g., write a **catch** that doesn't rethrow the same or another exception or emit another kind of error code) in the places that have sufficient knowledge to handle the error, including to enforce boundaries defined in the error policy (e.g., on **main** and thread mainlines; see Item 62) and to absorb errors in the bodies of destructors and deallocation operations.

Translate an error (e.g., write a **catch** that does rethrow a different exception or emits another kind of error code) in these circumstances:

- *To add higher-level semantic meaning:* For example, in a word processing application, **Document::Open** could accept a low-level unexpected-end-of-file error and translate it to a document-invalid-or-corrupt error, adding semantic information.
- *To change the error handling mechanism:* For example, in a module that uses exceptions internally but whose C API public boundary reports error codes, a boundary API would catch an exception and emit a corresponding error code that fulfills the module's contract and that the caller can understand.

Code should not accept an error if it doesn't have the context to do something useful about that error. If a function isn't going to handle (or translate, or deliberately absorb) an error itself, it should allow or enable the error to propagate up to a caller who can handle it.

Exceptions

It can occasionally be useful to accept and re-emit (e.g., **catch** and rethrow) the same error in order to add instrumentation, even though the error is not actually being handled.

References

[Stroustrup00] §3.7.2, §14.7, §14.9 • [Sutter00] §8 • [Sutter04] §11 • [Sutter04b]

83. Use a checked STL implementation.

Summary

Safety first (see Item 6): Use a checked STL implementation, even if it's only available for one of your compiler platforms, and even if it's only used during pre-release testing.

Discussion

Just like pointer mistakes, iterator mistakes are far too easy to make and will usually silently compile but then crash (at best) or appear to work (at worst). Even though your compiler doesn't catch the mistakes, you don't have to rely on "correction by visual inspection," and shouldn't: Tools exist. Use them.

Some STL mistakes are distressingly common even for experienced programmers:

- *Using an invalidated or uninitialized iterator:* The former in particular is easy to do.
- *Passing an out-of-bounds index:* For example, accessing element 113 of a 100-element container.
- *Using an iterator "range" that isn't really a range:* Passing two iterators where the first doesn't precede the second, or that don't both refer into the same container.
- *Passing an invalid iterator position:* Calling a container member function that takes an iterator position, such as the position passed to **insert**, but passing an iterator that refers into a different container.
- *Using an invalid ordering:* Providing an invalid ordering rule for ordering an associative container or as a comparison criterion with the sorting algorithms. (See [Meyers01] §21 for examples.) Without a checked STL, these would typically manifest at run time as erratic behavior or infinite loops, not as hard errors.

Most checked STL implementations detect these errors automatically, by adding extra debugging and housekeeping information to containers and iterators. For example, an iterator can remember the container it refers into, and a container can remember all outstanding iterators into itself so that it can mark the appropriate iterators as invalid as they become invalidated. Of course, this makes for fatter iterators, containers with extra state, and some extra work every time you modify the container. But it's worth it—at least during testing, and perhaps even during release (remember Item 8; don't disable valuable checks for performance reasons unless and until you know performance is an issue in the affected cases).

Even if you don't ship with checking turned on, and even if you only have a checked STL on one of your target platforms, at minimum ensure that you routinely run your full complement of tests against a version of your application built with a checked STL. You'll be glad you did.

Examples

Example 1: Using an invalid iterator. It's easy to forget when iterators are invalidated and use an invalid iterator (see Item 99). Consider this example adapted from [Meyers01] that inserts elements at the front of a **deque**:

```
deque<double>::iterator current = d.begin();

for( size_t i = 0; i < max; ++i )
  d.insert( current++, data[i] + 41 );          // do you see the bug?
```

Quick: Do you see the bug? You have three seconds.—Ding! If you didn't get it in time, don't worry; it's a subtle and understandable mistake. A checked STL implementation will detect this error for you on the second loop iteration so that you don't need to rely on your unaided visual acuity. (For a fixed version of this code, and superior alternatives to such a naked loop, see Item 84.)

Example 2: Using an iterator range that isn't really a range. An iterator range is a pair of iterators **first** and **last** that refer to the first element and the one-past-the-end-th element of the range, respectively. It is required that **last** be reachable from **first** by repeated increments of **first**. There are two common ways to accidentally try to use an iterator range that isn't actually a range: The first way arises when the two iterators that delimit the range point into the same container, but the first iterator doesn't actually precede the second:

```
for_each( c.end(), c.begin(), Something );     // not always this obvious
```

On each iteration of its internal loop, **for_each** will compare the first iterator with the second for equality, and as long as they are not equal it will continue to increment the first iterator. Of course, no matter how many times you increment the first iterator, it will never equal the second, so the loop is essentially endless. In practice, this will, at best, fall off the end of the container **c** and crash immediately with a memory protection fault. At worst, it will just fall off the end into uncharted memory and possibly read or change values that aren't part of the container. It's not that much different in principle from our infamous and eminently attackable friend the buffer overrun.

The second common case arises when the iterators point into different containers:

```
for_each( c.begin(), d.end(), Something );     // not always this obvious
```

The results are similar. Because checked STL iterators remember the containers that they refer into, they can detect such run-time errors.

References

[Dinkumware-Safe] • [Horstmann95] • [Josuttis99] §5.11.1 • [Metrowerks] • [Meyers01] §21, §50 • [STLport-Debug] • [Stroustrup00] §18.3.1, §19.3.1

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