Writing good C++14

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The big question

- **“What is good modern C++?”**
  - ***Many*** people want to write ”Modern C++”
- Guidelines project
  - Produce a useful answer
  - Enable ***many*** people to use that answer
    - For most programmers, not just language experts
  - Please help!

The problem and the opportunity

- We have a great modern language
    - C++11 (good)
        - -> C++14 (better)
            - -> C++17 (much better still, I hope)
    - Technical specifications
    - Shipping
        - in wide-spread production work
            - and more facilities well in the works
    - C++1*
        - is easier to write and maintain
        - runs faster
        - can express more than older C++
            - with less code

The problem and the opportunity

- Many people
  - Use C++ in archaic or foreign styles
  - Get lost in details
  - Are obsessed with language-technical details

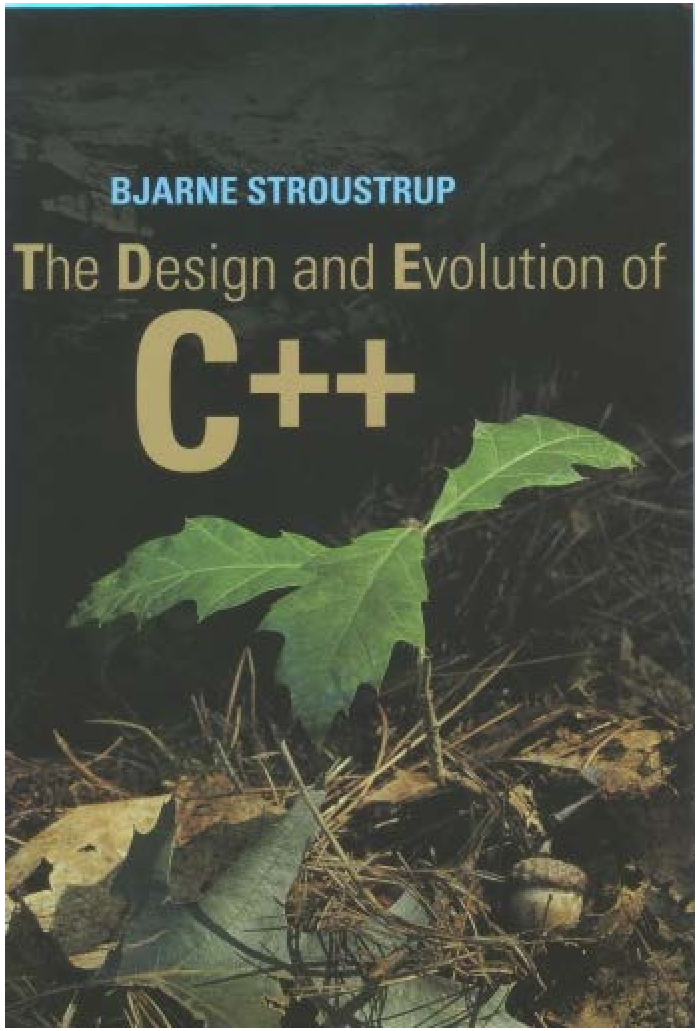
Doctor, doctor, it hurts when I do X!!!

So don’t do X

- “Within C++ is a smaller, simpler, safer language struggling to get out”
  - Code can be simpler
  - as efficient as ever
  - as expressive as ever

A smaller, simpler C++

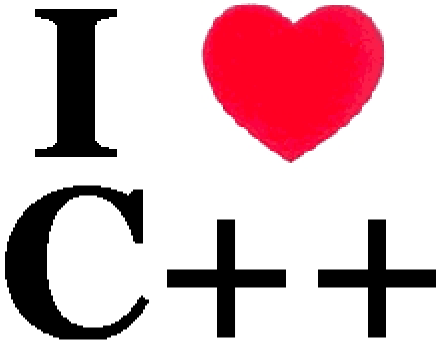
- Let’s get it out
  - ***Now!***
  - Without inventing a new language
  - 100% compatibility – compile with current compilers
- Coding guidelines
  - Supported by a “guidelines support library” (GSL)
  - Supported by analysis tools
- Don’t sacrifice
  - Generality
  - Performance
  - Simplicity
  - Portability across platforms



A smaller, simpler C++

- I think ***we*** can do it
    - I can’t do it alone
    - No individual can
    - No single company can

- Please help!



Initial work (still incomplete)

- I describe significant initial work
  - Microsoft (Herb Sutter and friends)
  - Morgan Stanley (Bjarne Stroustrup and friends)
  - CERN (Axel Naumann and friends)
- Available
  - Core guidelines (now)
  - Guidelines support library (now; Microsoft, GCC, Clang; Windows, Linux, Mac)
  - Analysis tool (Microsoft in October; ports later (November?))
  - MIT License
- Related CppCon talks
  - Herb Sutter: ***Writing Good C++14 By Default*** (Tuesday)
  - Gabriel Dos Reis: ***Modules*** (Tuesday)
  - Gabriel Dos Reis: ***Contracts*** (Wednesday)
  - Neil MacIntosh: ***Static analysis (***Wednesday)
  - Neil MacIntosh: ***array_view, string_view, etc.*** (Wednesday)

We all hate coding rules*†

- Rules are (usually)
  - Written to prevent misuse by poor programmers
    - “don’t do this and don’t do that”
  - Written by people with weak experience with C++
    - At the start of an organization’s use of C++
- Rules (usually) focus on
  - “layout and naming”
  - Restrictions on language feature use
  - Not on programming principles
- Rules (usually) are full of bad advice
  - Write “pseudo-Java” (as some people thought was cool in 1990s)
  - Write “C with Classes” (as we did in 1986)
  - Write C (as we did in 1978)
  - …

*Usual caveats

†and thanks

Coding rules*

*Usual caveats

- Are outdated
  - Become a drag of their users
- Are specialized
  - but used outside their intended domain
- Are not understood by their users
  - Enforced by dictate: Do this or else!
  - Require detailed language-lawyer knowledge to follow
- Are not well supported by tools
  - Platform dependencies
  - Compiler dependencies
  - Expensive
- Do not provide guidance
  - Telling what not to do is not enough

Coding guidelines

- Let’s build a ***good*** set!
  - Comprehensive
  - Browsable
  - Supported by tools (from many sources)
  - Suitable for gradual adoption
- For modern C++
  - Compatibility and legacy code be damned! (initially)
- Prescriptive
  - Not punitive
- Teachable
  - Rationales and examples
- Flexible
  - Adaptable to ***many*** communities and tasks
- Non-proprietary
  - But assembled with taste and responsiveness

- We aim to offer guidance
  - What is good modern C++?
  - Confused, backwards-looking teaching is a big problem

High-level rules

- Provide a conceptual framework
  - Primarily for humans
- Many can’t be checked completely or consistently
  - *P.1: Express ideas directly in code*
  - *P.2: Write in ISO Standard C++*
  - *P.3: Express intent*
  - *P.4: Ideally, a program should be statically type safe*
  - *P.5: Prefer compile-time checking to run-time checking*
  - *P.6: What cannot be checked at compile time should be checkable at run time*
  - *P.7: Catch run-time errors early*
  - *P.8: Don't leak any resource*
  - *P.9: Don't waste time or space*

Lower-level rules

- Provide enforcement
    - Some complete
    - Some heuristics
    - Many rely on static analysis
    - Some beyond our current tools
    - Often easy to check “mechanically”
- Primarily for tools
    - To allow specific feedback to programmer
- Help to unify style
- Not minimal or orthogonal

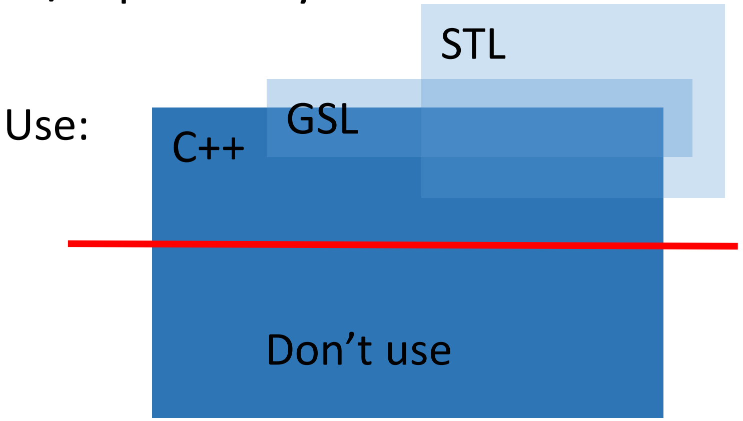
- *F.16: Use **T*** or **owner<T*>** to designate a single object*
- *C.49: Prefer initialization to assignment in constructors*
- *ES.20: Always initialize an object*

The structure of a rule

- The rule itself - e.g., ***no naked `new`***
- **Reference number** - e.g., ***C.7*** (the 7th rule related to classes).
- **Reason** (rationale) - because programmers find it hard to follow rules they don’t understand
- **Example** - because rules are hard to understand in the abstract; can be positive or negative
- **Alternative** - for "don’t do this" rules
- **Exception** - we prefer simple general rules. However, many rules apply widely, but not universally
- **Enforcement** - ideas about how the rule might be checked "mechanically"
- **See also** - references to related rules and/or further discussion (in this document or elsewhere)
- **Note** (comments) - something that needs saying that doesn't fit the other classifications
- **Discussion** - references to more extensive rationale and/or examples placed outside the main lists of rules

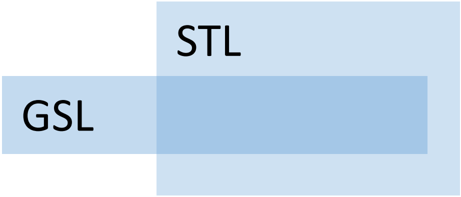
Subset of superset

- Simple sub-setting doesn't work
  - We need the low-level/tricky/close-to-the-hardware/error-prone/expert-only features
    - For implementing higher-level facilities efficiently
    - Many low-level features can be used well
  - We need the standard library
- Extend language with a few abstractions
  - ***Use*** the STL
  - ***Add*** a small library (the GSL)
    - ***No*** new language features
    - Messy/dangerous/low-level features can be used to implement the GSL
  - ***Then*** subset
- What we want is "***C++ on steroids***"
  - Simple, safe, flexible, and fast
  - Not a neutered subset



Some rules rely on libraries

- The ISO C++ standard library
  - E.g., **vector<T>** and **unique_ptr<T>**
- The Guideline Support Library
  - E.g., **array_view<T>** and **not_null<T>**



- Some rules using the GSL
  - *I.11: Never transfer ownership by a raw pointer (**T***)*
    - Use an ownership pointer (e.g. **unique_ptr<T>**) or **owner<T*>**
  - *I.12: Declare a pointer that may not be the **nullptr** as **not_null***
    - E.g., **not_null<int*>**
  - *I.13 Do not pass an array as a single pointer*
    - Use a handle type, e.g., **vector<T>** or **array_view<T>**

Double our productivity

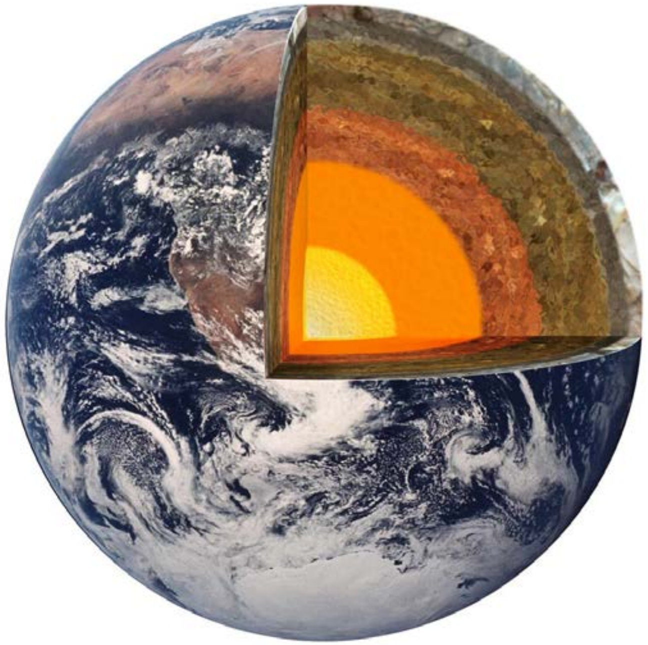
- “Imitate experienced programmers”
    - Most programmer don’t know what “everybody knows”
- Eliminate whole classes of errors
    - Fewer crashes and security violations
- Simplify
    - Simplicity aids maintenance
    - Consistent style speeds up learning
    - Guide people away from obscure corners and exotic technique
    - Emphasis on avoiding waste improves performance
    - Separate rules for exceptional needs
- Do not compromise performance

Duramax Diesel 6.6L V8 Turbo

Have you gone mad? (no)

- We attack the most common and the most serious sources of errors
  - I hate debugging
- We eliminate whole classes of errors
  - Eliminate resource leaks
    - Without loss of performance
  - Eliminate dangling pointers
    - Without loss of performance
  - Eliminate out-of-range access
    - With minimal cost
- Tool support is essential
  - Static analysis
  - Support library (tiny)
  - Reinforce the type system

Core Rules



- Some people will not be able to apply all rules
  - At least initially
  - Gradual adoption will be very common
- Many people will need additional rules
  - For specific needs
- We initially focus on the core rules
  - The ones we hope that everyone eventually could benefit from
- The core of the core
  - No leaks
  - No dangling pointers
  - No type violations through pointers

No resource leaks

- We know how
  - Root every object in a scope
    - **vector<T>**
    - **string**
    - **ifstream**
    - **unique_ptr<T>**
    - **shared_ptr<T>**
  - RAII
    - "No naked **new**"
    - "No naked **delete**"

Dangling pointers – the problem

- One nasty variant of the problem

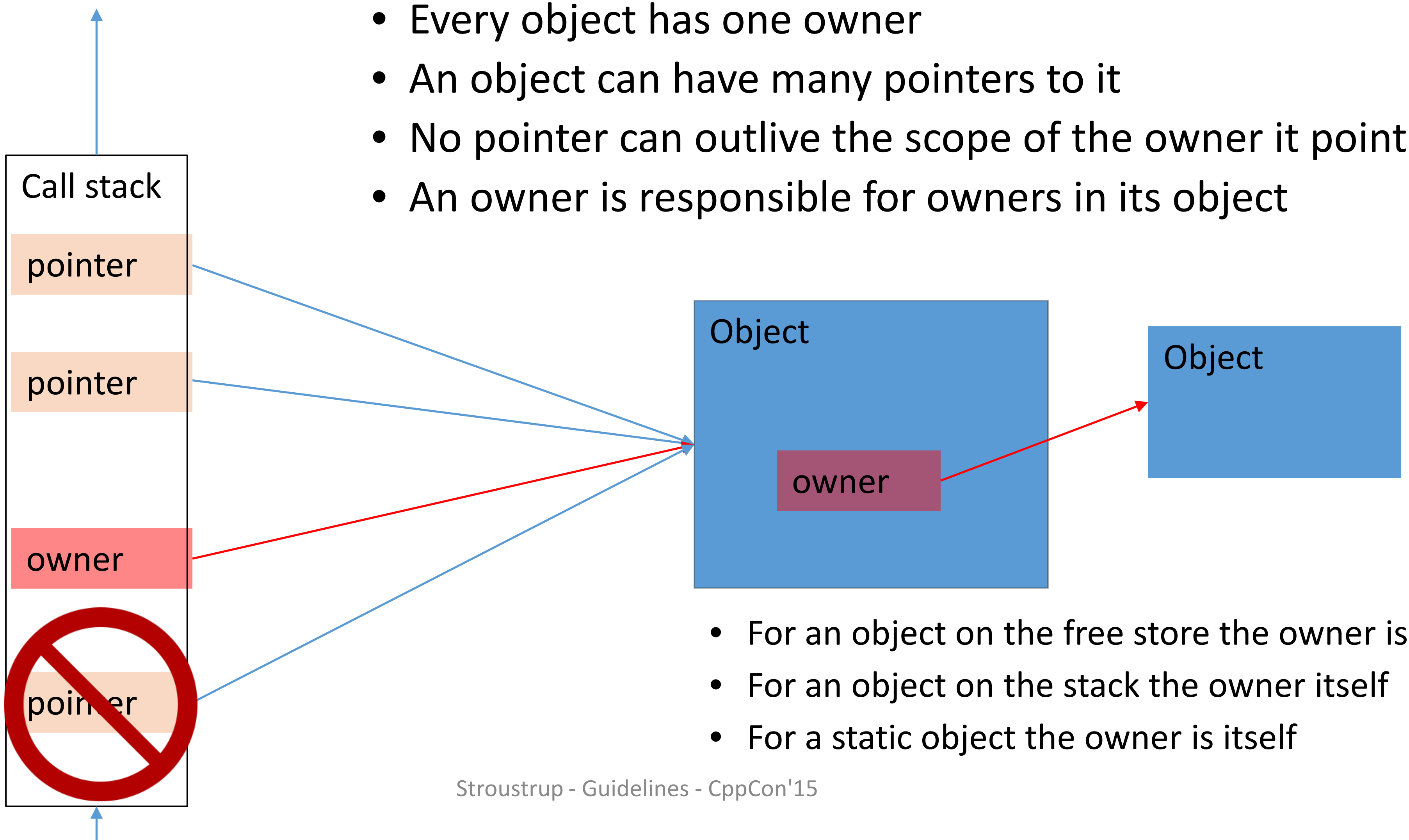
```
void f(X* p)
{
        // …
        delete p;           // looks innocent enough
}

void g()
{
        X* q = new X;       // looks innocent enough
        f(q);
        // … do a lot of work here …
        q->use();           // Ouch! Read/scramble random memory
}
```

Dangling pointers

- We ***must*** eliminate dangling pointers
  - Or type safety is compromised
  - Or memory safety is compromised
  - Or resource safety is compromised
- Eliminated by a combination of rules
  - Distinguish owners from non-owners
  - Assume raw pointers to be non-owners
  - Catch all attempts for a pointer to “escape” into a scope enclosing its owner’s scope
    - **return**, **throw**, out-parameters, long-lived containers, …
  - Something that holds an owner is an owner
    - E.g. **vector<owner<int*>>**, **owner<int*>[]**, …

Owners and pointers

- Every object has one owner
- An object can have many pointers to it
- No pointer can outlive the scope of the owner it points to
- An owner is responsible for owners in its object



- For an object on the free store the owner is a pointer
- For an object on the stack the owner itself
- For a static object the owner is itself

Dangling pointers

- Ensure that no pointer outlives the object it points to

```
void f(X* p)
{
        // …
        delete p;               // bad: delete non-owner
}

void g()
{
        X* q = new X;       // bad: assign object to non-owner
        f(q);
        // … do a lot of work here …
        q->use();               // Make sure we never get here
}
```

How do we represent ownership?

- High-level: Use an ownership abstraction
- Low-level: mark owning pointers **owner**
    - An **owner** must be **delete**d or passed to another **owner**
    - A non-**owner** may not be **delete**d

- Note
    - I talk about pointers
    - What I say applies to anything that refers to an object
        - References
        - Containers of pointers
        - Smart pointers
        - ..

How do we represent ownership

- Mark an owning **T***: **owner<T*>**
  - Initial idea
    - **owner<T*>** would hold a **T*** and an “owner bit”
    - Costly: bit manipulation
    - Not ABI compatible
    - Not C compatible
  - So our GSL **owner** is
    - A handle for static analysis
    - Documentation
    - Not a type with it’s own operations
    - Cost free: No run-time cost (time or space)
    - ABI compatible
    - **template<typename T> owner = T;**

GSL: owner<T>

- How do we implement ownership abstractions?

```
template<SemiRegular T>
class vector {
        owner<T*> elem;         // the anchors the allocated memory
        T* space;               // just a position indicator
        T* end;                 // just a position indicator
        // …
};
```

- **owner<T*>** is just an alias for **T***

GSL: owner<T>

- How about code we cannot change?

```
void foo(owner<int*>);            // foo requires an owner

void f(owner<int*> p, int* q, owner<int*> p2, int* q2)
{
      foo(p);                     // OK: transfer ownership
      foo(q);                     // bad: q is not an owner
      delete p2;                  // necessary
      delete q2;                  // bad: not an owner
}
```

- A static analysis tool can tell us where our code mishandles ownership

owner is a low-level mechanism

- Use proper ownership abstractions
  - E.g., **unique_ptr** and **vector**
    - Implemented using **owner**
- **owner** is intended to simplify static analysis
  - **owner**s in application code is a sign of a problem
    - Usually, C-style interfaces

How to avoid/catch dangling pointers

- Rules (giving pointer safety):
  - Don’t transfer to pointer to a local to where it could be accessed by a caller
  - A pointer passed as an argument can be passed back as a result
  - A pointer obtained from new can be passed back as a result as an owner

```
int*  f(int* p)
{
        int x = 4;
        return &x;                  // No! would point to destroyed stack frame
        return new int{7};          // OK (sort of: doesn’t dangle, but returns an owner as an int*)
        return p;                   // OK: came from caller
}
```

How to avoid/catch dangling pointers

- It’s not just pointers
  - All ways of “escaping”
    - **return**, **throw**, place in long-lived container, …
  - Same for containers of pointers
    - E.g. **vector<int*>**, **unique_ptr<int>**, iterators, built-in arrays, …
  - Same for references
- Never let a “pointer” point to an out-of-scope object

How to avoid/catch dangling pointers

- Classify pointers according to ownership

```
vector<int*> f(int* p)
{
        int x = 4;
        int* q = new int{7};
        vector<int*> res = {p, &x, q};          // Bad: { unknown, pointer to local, owner }
        return res;
}
```

- Don’t mix different ownerships in an array
- Don’t let different return statements of a function mix ownership

How to avoid/catch dangling pointers

- Try to be explicit about ownership

```
vector<int*> f(int* p)
{
        int x = 4;
        owner<int*> q = new int{7};
        vector<int*> res = {p, &x, q};              // Bad: { unknown, pointer to local, owner }
        vector<owner<int*>> r2 = {p, &x, q};        // Bad: { unknown, pointer to local, owner }
        return res;
}
```

- Some convoluted code cannot be represented in a statically type-safe manner
  - Avoid such code
  - If you really need it, encapsulate it in an expression that include run-time representation of ownership (pointer, ownership bit)

Other problems

- Other ways of misusing pointers
  - Range errors: **array_view<T>**
  - **nullptr** dereferencing: **not_null<T>**
- Wasteful ways of addressing pointer problems
  - Misuse of smart pointers
- Other ways of breaking the type system (beyond the scope of this talk)
  - Unions
  - Casts
- "Just test everywhere at run time" is ***not*** an acceptable answer
  - Hygiene rules
  - Static analysis
  - Run-time checks

GSL - array_view<T>

- Common style

```
void f(int* p, int n)                // what is n? (How would a tool know?)
{
        p[7] = 9;                            // OK?
        for (int i=0; i<n; ++i) p[i] = 7;    // OK?
}
```

- Better

```
void f(array_view<int> a)
{
        a[7] = 9;                            // OK? Checkable against a.size()
        for (int& x : a) x = 7;              // OK
}
```

GSL - array_view<T>

- Common style

```
void f(int* p, int n);
int a[100];
// …
f(a,100);
f(a,1000);     // likely disaster
```

- Better

```
void f(array_view<int> a)
int a[100];
// …
f(array_view<int>{a});
f(a);
f({a,1000});   // easily checkable
```

- “Make simple things simple”
  - Simpler than “old style”
  - Shorter
  - At least as fast
  - Sometimes using the GSL
  - Sometimes using the STL

nullptr problems

- Mixing **nullptr** and pointers to objects
  - Causes confusion
  - Requires (systematic) checking
- Caller

```
void f(char*);

f(nullptr);                    // OK?
```

- Implementer

```
void f(char* p)
{
        if (p==nullptr)        // necessary?
        // …
}
```

- Can you trust the documentation?
- Compilers don’t read manuals, or comments
- Complexity, errors, and/or run-time cost

GSL - not_null<T>

- Caller

```
void f(not_null<char*>);

f(nullptr);     // Obvious error: caught be static analysis
char* p = nullptr;
f(p);           // Constructor for not_null can catch the error
```

- Implementer

```
void f(not_null<char*> p)
{
        // if (p==nullptr) // not necessary
        // …
}
```

GSL - not_null<T>

- **not_null<T>**
  - A simple, small class
  - **not_null<T*>** is **T*** except that it cannot hold **nullptr**
  - Can be used as input to analyzers
    - Minimize run-time checking
  - Checking can be “debug only”
  - For any **T** that can be compared to **nullptr**
    - E.g. **not_null<array_view<T>>**

To summarize

- Type and resource safety:
    - RAII (scoped objects with constructors and destructors)
    - No dangling pointers
    - No leaks (track ownership pointers)
    - Eliminate range errors
    - Eliminate nullptr dereference
- That done we attack other sources of problems
    - Logic errors
    - Performance bugs
    - Maintenance hazards
    - Verbosity
    - …

(Mis)uses of smart pointers

- “Smart pointers” are popular
  - To represent ownership
  - To avoid dangling pointers
- “Smart pointers” are overused
  - Can be expensive
    - E.g., **shared_ptr**
  - Can mess up interfaces fore otherwise simple functions
    - E.g. **unique_ptr** and **shared_ptr**
  - Often, we don’t need a pointer
    - Scoped objects
    - We need pointers
      - For OO interfaces
      - When we need to change the object referred to

But ordinary pointers don’t dangle any more

(Mis)uses of smart pointers

- Consider
    - **void f(T*);** **//** *use; no ownership transfer or sharing*
    - **void f(unique_ptr<T>);** **//** *transfer unique ownership and use*
    - **void f(shared_ptr<T*>);** **//** *share ownership and use*
- Taking a raw pointer (**T***)
    - Is familiar
    - Is simple, general, and common
    - Is cheaper than passing a smart pointer (usually)
    - Doesn’t lead to dangling pointers
    - Doesn’t lead to replicated versions of a function for different shared pointers
- In terms of tradeoffs with smart pointers, other simple “object designators” are equivalent to **T***
    - iterators, references, **array_view**, etc.

(Mis)uses of smart pointers

- Don’t use ownership pointers unless you change ownership

```
void f(X*);                       // just uses X; no ownership transfer or sharing – good
void g(shared_ptr<X>);                    // just uses X – bad
unique_ptr<X> h(unique_ptr<X>);           // just uses X – bad (give pointer back to prevent destruction)

void use()
{
        auto p = make_shared<X>{};
        f(p.get());                               // extract raw pointer (note: pointers do not dangle)
        g(p);                                     // mess with use count (probably a mistake)
        auto q = h(make_unique<X>(p.get()));      // transfer ownership to just use (a mistake)
                                                  // extract raw pointer, then wrap it and copy
        q.release();                              // prevent destruction
}
```

Rules, standards, and libraries

- Could the rules be enforced by the compiler?
    - Some could, but we want to use the rules ***now***
        - Some compiler support would be very nice; let’s talk
    - Many could not
    - Rules will change over time
    - Compilers have to be more careful about false positives
    - Compilers cannot ban legal code
- Could the GSL be part of the standard?
    - Maybe, but we want to use it ***now***
    - The GSL is tiny and written in portable C++11
    - The GSL does not depend on other libraries
    - The GSL is similar to, but not identical to **boost::** and **experimental::** components
        - So they may become standard
- We rely on the standard library

Too many rules

- For
  - Novices, experts, infrastructure, ordinary large applications, low-latency, high-reliability, security targets, hard-real time
- You can’t remember all of those rules!
- You don’t need all of those rules
- You couldn’t learn all of those rules before writing code
- You’d hate to even look through all of those rules
- The rule set must be extensible
  - you’ll never know them all
- The tools know the rules
  - And will point you to the relevant ones

Rule classification

- P: Philosophy
- I: Interfaces
- F: Functions
- C: Classes and class hierarchies
- Enum: Enumerations
- ES: Expressions and statements
- E: Error handling
- R: Resource management
- T: Templates and generic programming
- CP: Concurrency
- The Standard library
- SF: Source files
- CPL: C-style programming
- GSL: Guideline support library

Supporting sections

- NL: Naming and layout
- PER: Performance
- N: Non-Rules and myths
- RF: References
- Appendix A: Libraries
- Appendix B: Modernizing code
- Appendix C: Discussion
- To-do: Unclassified proto-rules

We are not unambitious

- Type and resource safety
  - No leaks
  - No dangling pointers
    - No bad accesses
  - No range errors
  - No use of uninitialized objects
  - No misuse of
    - Casts
    - Unions
- We think we can do it
  - At scale
    - 4+ million C++ Programmers, N billion lines of code
  - Zero-overhead principle

We aim to change the way we write code

- That means ***you***
- What would you like your code to look like in 5 years?
  - Once we know, we can aim to achieve that
  - Modernizing a large code base is not easy
  - The answer is not “just like my code today”
  - Think “gradual adoption” (except for brand-new code)
- Not everybody will agree what the code should look like
  - Not all code should look the same
  - We think there can be a common core
  - We need discussion, feedback, and a variety of tools
- Help wanted!
  - Rules, tools, reviews, comments
  - Editors

Current status

- Available
  - About 350 Rules (https://github.com/isocpp/CppCoreGuidelines)
  - GSL for Clang, GCC, and Microsoft (https://github.com/microsoft/gsl)
  - First tools: October for Microsoft; ports later (November?)
  - MIT License
- We need help
  - Review of rules
    - More examples and refinements for existing rules
  - Specialized rule sets
    - For particular application areas, projects, …
    - For concurrency
    - For libraries
    - …
- Continuous development
  - "forever"

The basic C++ model is now complete

- C++ (using the guidelines) is type safe and resource safe
  - Which other language can claim that?
  - Eliminate dangling pointers
  - Eliminate resource leaks
  - Check for range errors (optionally and cheaply)
  - Check for **nullptr** (optionally and cheaply)
  - Have concepts
- Why not a new C++-like language?
  - Competing with C++ is hard
    - Most attempts fail, C++ constantly improves
  - It would take 10 years (at least)
    - And we would still have lots of C and C++
  - A new C++-like language might damage the C++ community
    - Dilute support, divert resources, distract

Microsoft Visual C++

GCC

Edison Design Group

Questions

- P: Philosophy
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Coding guidelines

- Boost Library Requirements and Guidelines
- Bloomberg: BDE C++ Coding
- Facebook: ???
- GCC Coding Conventions
- Google C++ Style Guide
- JSF++: JOINT STRIKE FIGHTER AIR VEHICLE C++ CODING STANDARDS
- Mozilla Portability Guide.
- Geosoft.no: C++ Programming Style Guidelines
- Possibility.com: C++ Coding Standard
- SEI CERT: Secure C++ Coding Standard
- High Integrity C++ Coding Standard
- llvm.org/docs/CodingStandards.html

Non-aims

- Create “the one true C++ subset”
  - There can be no such marvel
  - Core guidelines + guidelines for specific needs
- Making a totally flexible set of rules to please everybody
  - Our rules are ***not*** value neutral
    - Total freedom is chaos
  - We want “modern C++”
    - ***not*** “everything anyone ever thought was cool and/or necessary”
- Turning C++ into Java, Haskell, C, or whatever
  - “If you want Smalltalk you know where to find it”

- What we want is “***C++ on steroids***”
  - Simple, safe, flexible, and fast
  - Not a neutered subset

Philosophy

- Attack hard problems
  - Resources, interfaces, bounds, …
- Be prescriptive
  - “don’t do that” is not very helpful
- Give rationale
  - “because I say so” is not very helpful
- Offer machine-checkable rules
  - Machines are systematic, fast, and don’t get bored
- Don’t limit generality
  - For most of us most of the time
- Don’t compromise performance
  - Of course
- Subset of superset
  - Don’t fiddle with subtle language rules