The C++ Core Guidelines Project

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The big question

- **“What is good modern C++?”**
  - ***Many*** people want to write ”Modern C++”
- What would you like your code to look like in 5 years time?
  - “Just like what I write today” is a poor answer
- The C++ Core Guidelines project
  - https://github.com/isocpp/CppCoreGuidelines
  - Produce a ***useful*** answer
    - Implies tool support and enforcement
  - Enable ***many*** people to use that answer
    - For most programmers, not just language experts
  - Please help

C++ Core Guidelines

- We offer complete type- and resource-safety
  - No memory corruption
  - No resource leaks
  - No garbage collector (because there is no garbage to collect)
  - No runtime overheads (Except where you need range checks)
  - No new limits on expressibility
  - ISO C++ (no language extensions required)
  - Simpler code
  - Tool enforced
- “C++ on steroids”
  - Not some neutered subset

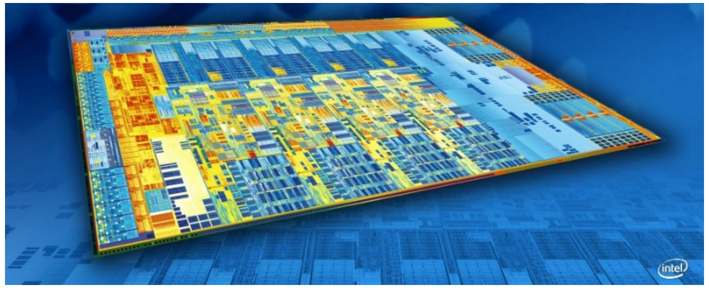
Caveat: work in progress

Work in progress

- General approach
  - Guidelines
  - Library
  - Static analysis
- Not all production ready
  - Some experimental
  - Some conjectures
- Many parts in use
  - Not Science Fiction

Why not just “fix” C++?

- C++ is too big and complicated
  - Obviously
  - With many features dating back to the 1970s and 1980s
- Everybody wants “just two more features”
  - And not the same two features
- Don’t break my code!!!
  - Nobody wants their code broken, however ugly
  - There are hundreds of billions of lines of C++ code “out there”
  - There are millions of C++ programmers
- Stability/compatibility is a feature
  - We can’t simplify C++, but we can simplify the use of C++



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C++ use

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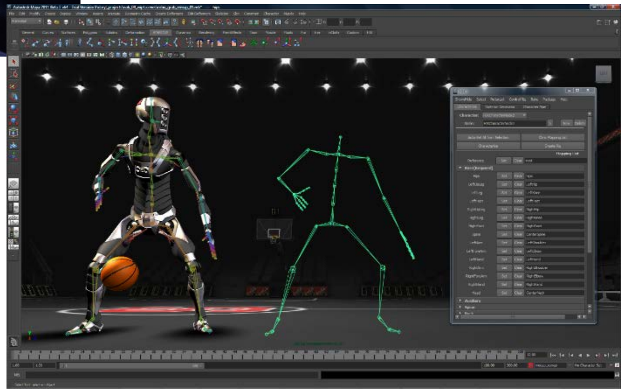
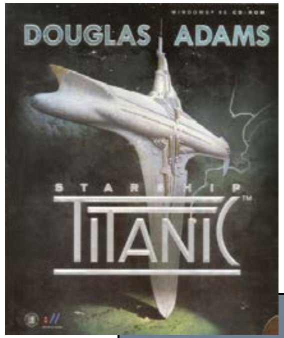
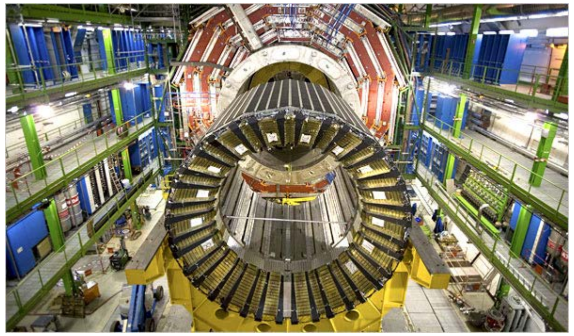


- About 4.5M C++ developers
- 2007-17: increase of about 100,000 developers/year
- www.stroustrup.com/applications.html



Java



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Coding guidelines

- We need guidelines for writing good modern C++
  - Static type safe
  - No resource leaks
  - No dangling pointers
  - No range errors
  - No nullptr references
  - No misuse of unions
  - No casts
  - No bloat
  - No messy error-prone low-level code
  - No known inefficiencies
  - Good use of the standard library
  - …

How?

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 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

Current (Partial) Solutions

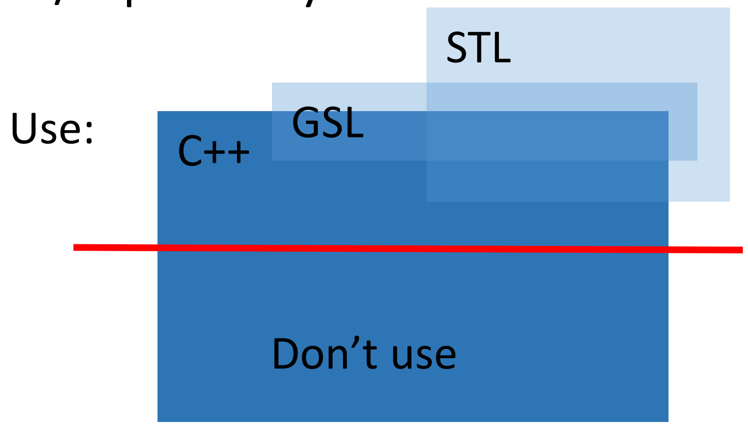
- These are old problems and old solutions
  - 40+ years
- Manual resource management doesn’t scale
- Smart pointers add complexity and cost
- Garbage collection is at best a partial solution
  - Doesn’t handle non-memory solutions (“finalizers are evil”)
  - Is expensive at run time
  - Is non-local (systems are often distributed)
  - Introduces non-predictability
- Static analysis doesn’t scale
  - Gives false positives (warning of a construct that does not lead to an error)
  - Doesn’t handle dynamic linking and other dynamic phenomena
  - Is expensive at compile time

Our solution: A cocktail of techniques

- Not a single neat miracle cure
  - Rules (from the “Core C++ Guidelines”)
    - Statically enforced
  - Libraries (STL, GSL)
    - So that we don’t have to directly use the messy parts of C++
  - Reliance on the type system
    - The compiler is your friend
  - Static analysis
    - To extend the type system
- None of those techniques is sufficient by itself
- Enforces basic ISO C++ language rules
- Not just for C++
  - But the “cocktail” relies on much of C++

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



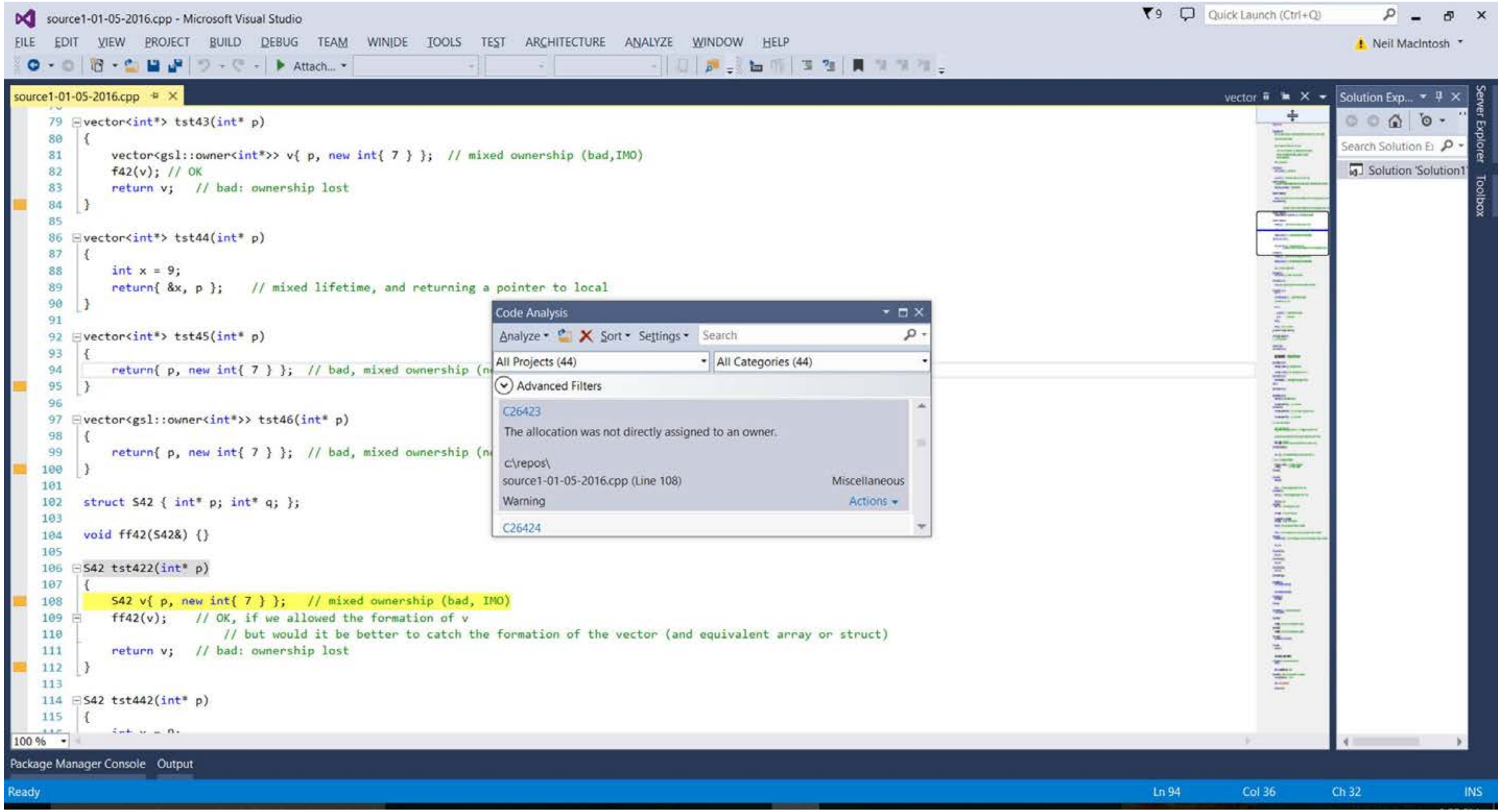
Guidelines: High-level rules

- 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*

Guidelines: Lower-level rules

- Provide enforcement
  - Some complete
  - Some heuristics
  - Often easy to check “mechanically”
- Primarily for tools
  - To allow specific feedback to programmer
- Help to unify style
  - *R.1: Manage resources automatically using resource handles and RAII*
  - *R.2: In interfaces, use raw pointers to denote individual objects (only)*
  - *R.3: A raw pointer (a T*) is non-owning*
  - *R.4: A raw reference (a T&) is non-owning*
  - *R.5: Prefer scoped objects, don't heap-allocate unnecessarily*
  - *R.6: Avoid non-const global variables*
- Not minimal or orthogonal

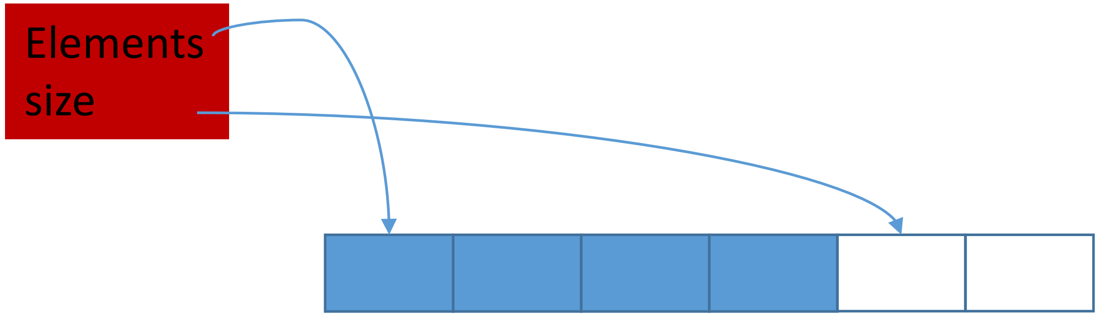
Static analyzer (currently integrated)



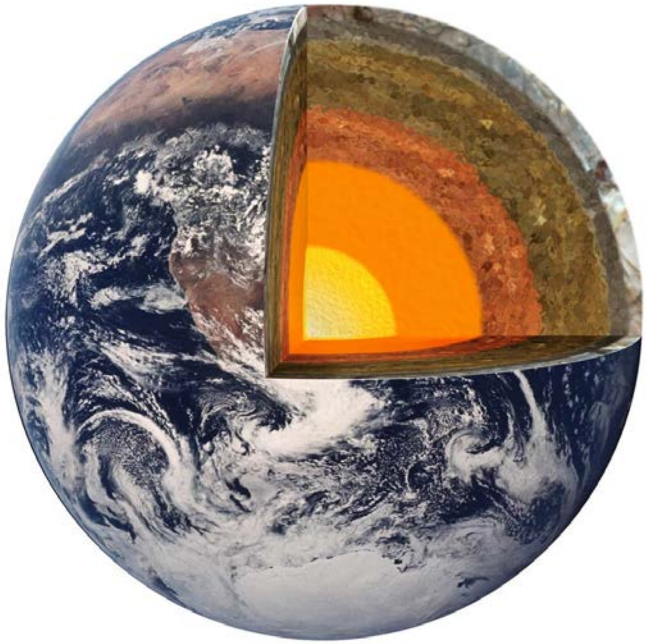
GSL – Guidelines support Library

- Minimal, to be absorbed into ISO C++
- **not_null**, **owner**, **Expects**, **Ensures**, …
- **span**
  - Non-owning potentially run-time checked reference to a continuous sequence
    - Implemented as a pointer, integer pair

```
int a[100];
span s {a};             // note: template argument deduction
for (auto x : s)        // note: no range error, not nullptr check
        cout << x << '\n';
```



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

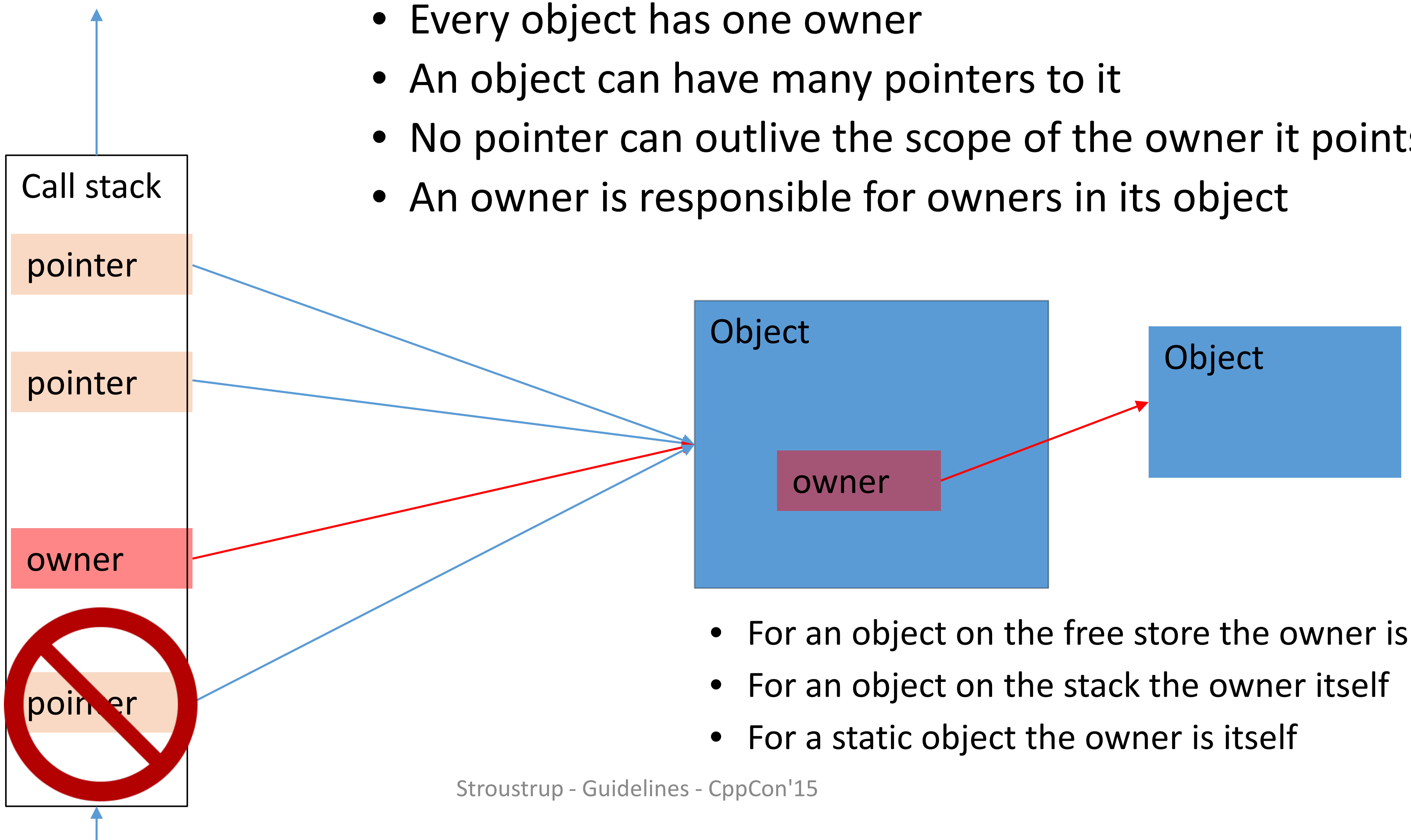
```
void f(X* p)
{
      // …
      delete p;              // looks innocent enough
}

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

How do we represent ownership?

- 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
- High-level: Use an ownership abstraction
  - Low-level owner annotations don't scale
  - Use them only for
    - C-style pointer interfaces
    - In ownership abstraction implementations
- Note
  - I talk about pointers
  - What I say applies to anything that refers to an object
    - References, Containers of pointers, Smart pointers, ...

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***

```
template<typename T> using owner = T;
```

How to avoid/catch dangling pointers

- Classify pointers according to ownership

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

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

Dangling pointer summary

- Simple:
  - We never let a “pointer” point to an out-of-scope object
- 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

Other problems

- Other ways of misusing pointers
  - Range errors: use **std::span<T>**
  - **nullptr** dereferencing: use **gsl::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: use **std::variant**
  - Casts: don't except for hardware quantities (e.g., device registers)

- "Just test everywhere at run time" is ***not*** an acceptable answer
  - Hygiene rules
  - Static analysis
  - Run-time checks

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- In: Introduction
- P: Philosophy
- I: Interfaces
- F: Functions
- C: Classes and class hierarchies
- Enum: Enumerations
- R: Resource management
- ES: Expressions and statements
- Per: Performance
- CP: Concurrency and parallelism
- E: Error handling
- Con: Constants and immutability
- T: Templates and generic programming
- CPL: C-style programming
- SF: Source files
- SL: The Standard Library

Supporting sections

- A: Architectural ideas
- NR: Non-Rules and myths
- RF: References
- Pro: Profiles
- GSL: Guidelines support library
- NL: Naming and layout rules
- FAQ: Answers to frequently asked questions
- Appendix A: Libraries
- Appendix B: Modernizing code
- Appendix C: Discussion
- Appendix D: Supporting tools
- Glossary
- To-do: Unclassified proto-rules

Expression rules

- ES.40: Avoid complicated expressions
- ES.41: If in doubt about operator precedence, parenthesize
- ES.42: Keep use of pointers simple and straightforward
- ES.43: Avoid expressions with undefined order of evaluation
- ES.44: Don't depend on order of evaluation of function arguments
- ES.45: Avoid "magic constants"; use symbolic constants
- ES.46: Avoid narrowing conversions
- ES.47: Use nullptr rather than 0 or NULL
- ES.48: Avoid casts
- ES.49: If you must use a cast, use a named cast
- ES.50: Don't cast away const
- ES.55: Avoid the need for range checking
- ES.56: Write std::move() only when you need to explicitly move an object to another scope
- ES.60: Avoid new and delete outside resource management functions
- ES.61: Delete arrays using delete[] and non-arrays using delete
- ES.62: Don't compare pointers into different arrays
- ES.63: Don't slice
- ES.64: Use the T{e} notation for construction
- ES.65: Don't dereference an invalid pointer

Arithmetic rules

- ES.100: Don't mix signed and unsigned arithmetic
- ES.101: Use unsigned types for bit manipulation
- ES.102: Use signed types for arithmetic
- ES.103: Don't overflow
- ES.104: Don't underflow
- ES.105: Don't divide by zero
- ES.106: Don't try to avoid negative values by using unsigned
- ES.107: Don't use unsigned for subscripts, prefer gsl::index

Parameter passing semantic rules:

- F.22: Use T* or owner<T*> to designate a single object
- F.23: Use a not_null<T> to indicate that "null" is not a valid value
- F.24: Use a span<T> or a span_p<T> to designate a half-open sequence
- F.25: Use a zstring or a not_null<zstring> to designate a C-style string
- F.26: Use a unique_ptr<T> to transfer ownership where a pointer is needed
- F.27: Use a shared_ptr<T> to share ownership

Value return semantic rules:

- F.42: Return a T* to indicate a position (only)
- F.43: Never (directly or indirectly) return a pointer or a reference to a local object
- F.44: Return a T& when copy is undesirable and "returning no object" isn't needed
- F.45: Don't return a T&&
- F.46: int is the return type for main()
- F.47: Return T& from assignment operators
- F.48: Don't return std::move(local)

Overview

- Maintain static type safety
  - Avoid cast and un-tagged unions
- Be precise about ownership
  - Don’t litter
  - Use ownership abstractions
- Eliminate dangling pointers
- Make general resource management implicit
  - Hide every explicit delete/destroy/close/release
  - “lots of explicit annotations” doesn’t scale
- Static guarantees (run-time is too late)
- Test for **nullptr** and range
  - Minimize run-time checking
  - Use checked library types