C++: Be type-safe

The journey of determining the number of elements in an array

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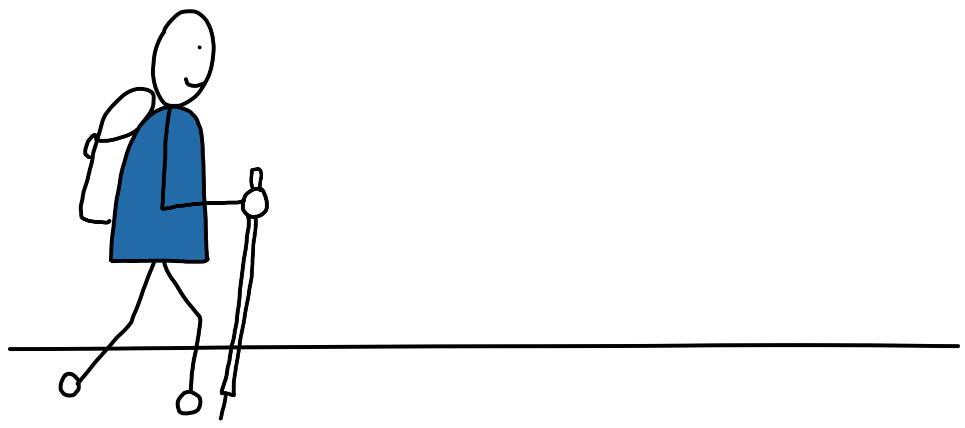
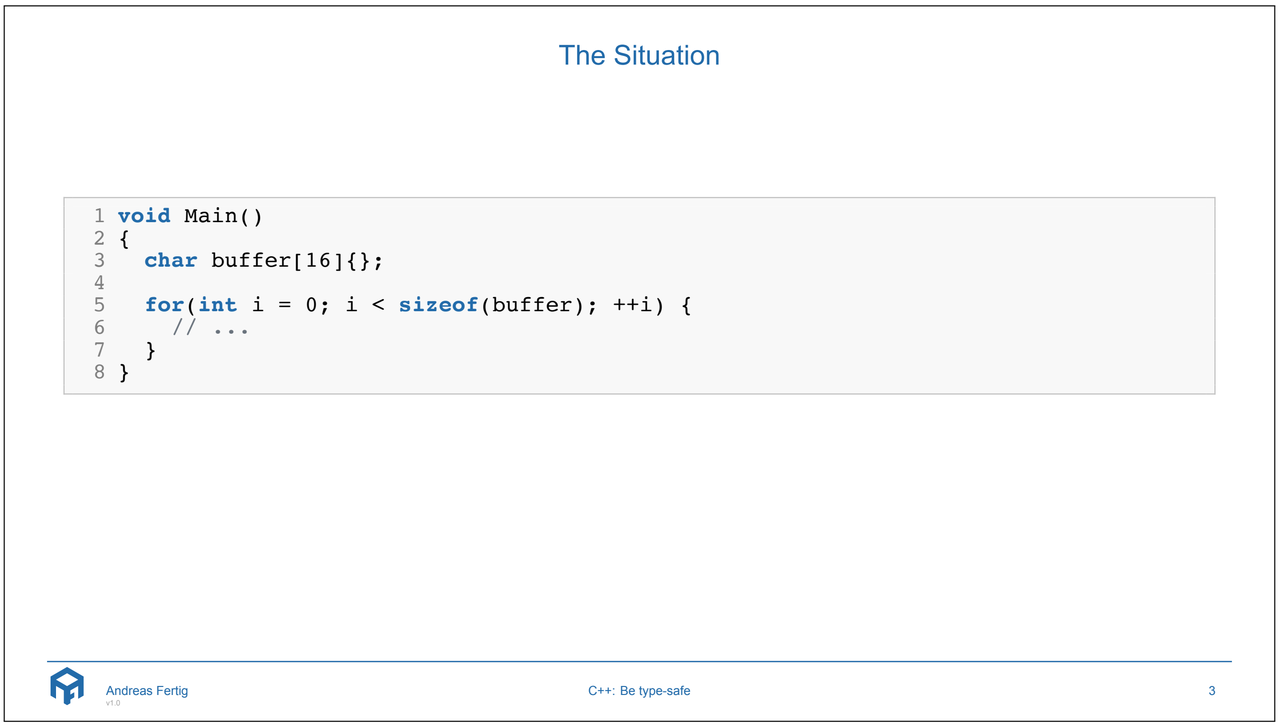
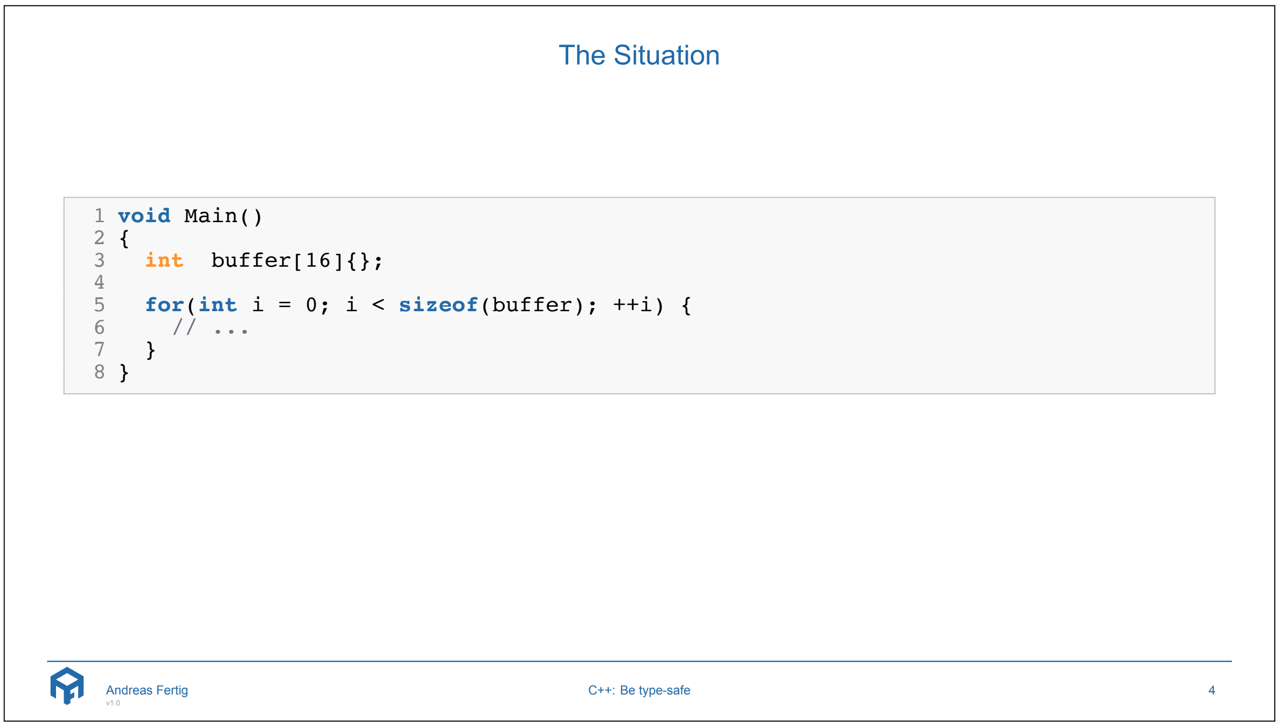




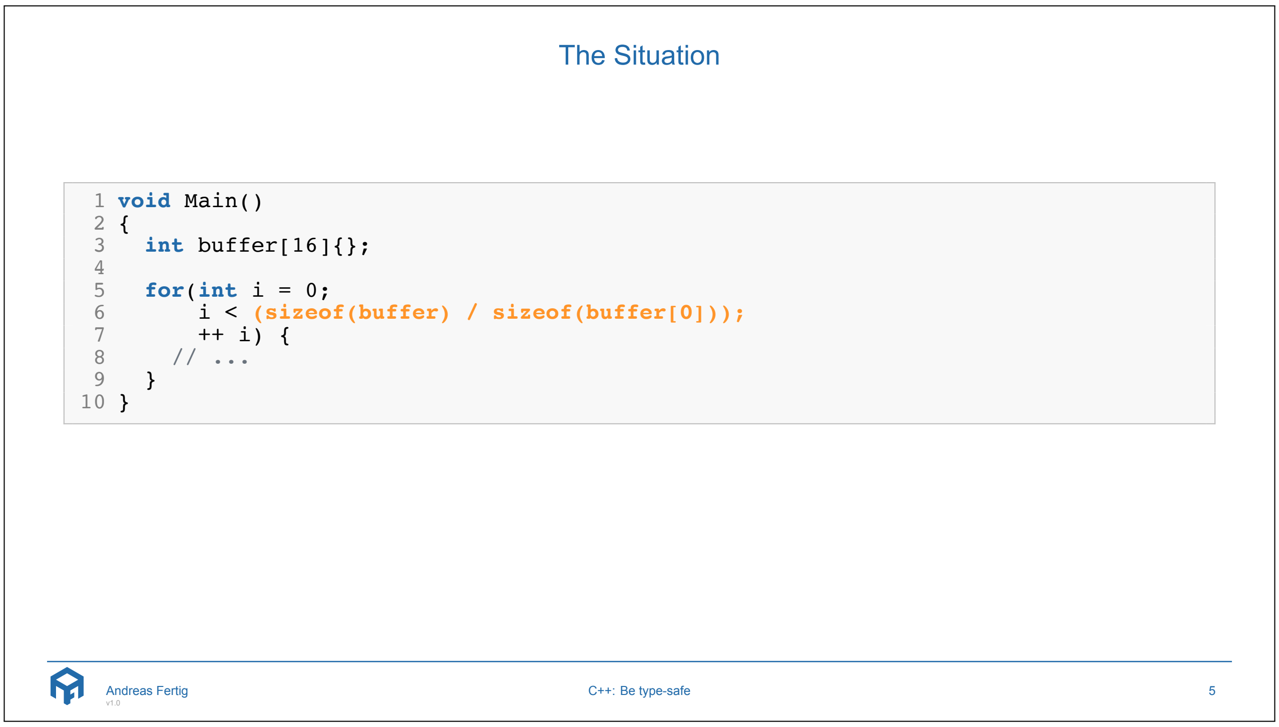
The Situation

```cpp
void Main()
{
  char buffer[16]{};

  for(int i = 0; i < sizeof(buffer); ++i) {
    // ...
  }
}
```



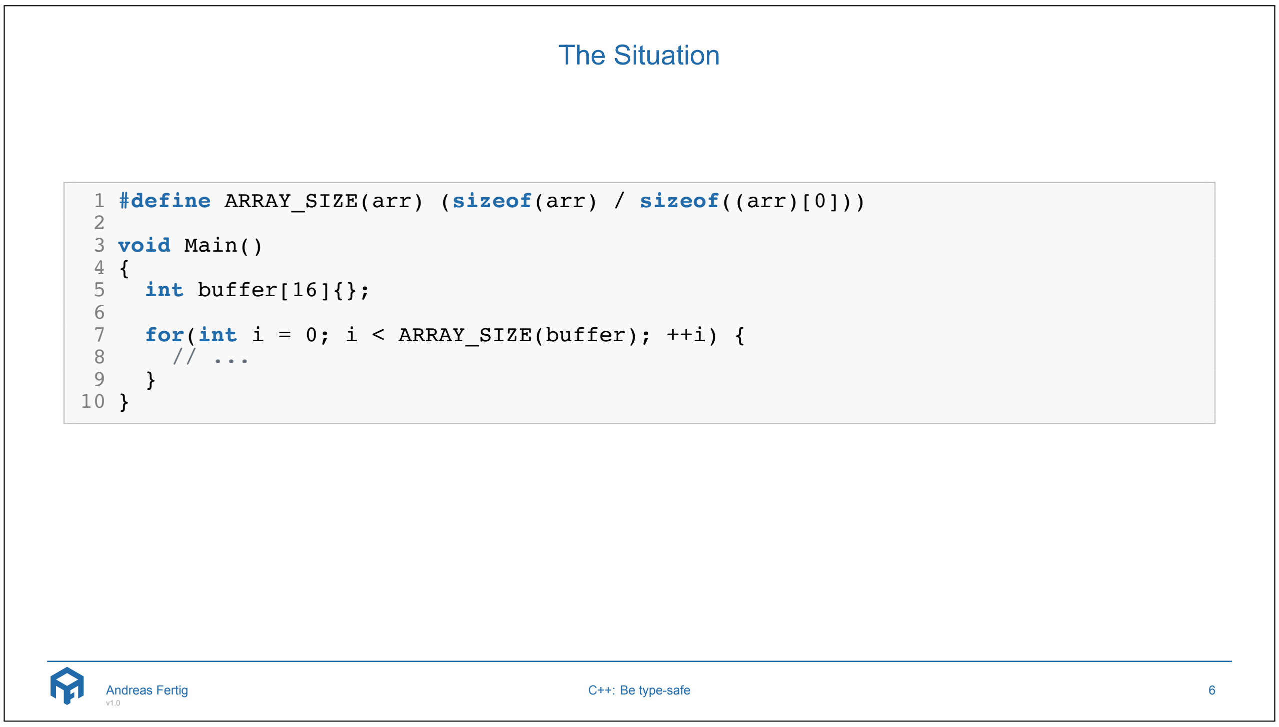
The Situation

```cpp
void Main()
{
  int  buffer[16]{};

  for(int i = 0; i < sizeof(buffer); ++i) {
    // ...
  }
}
```



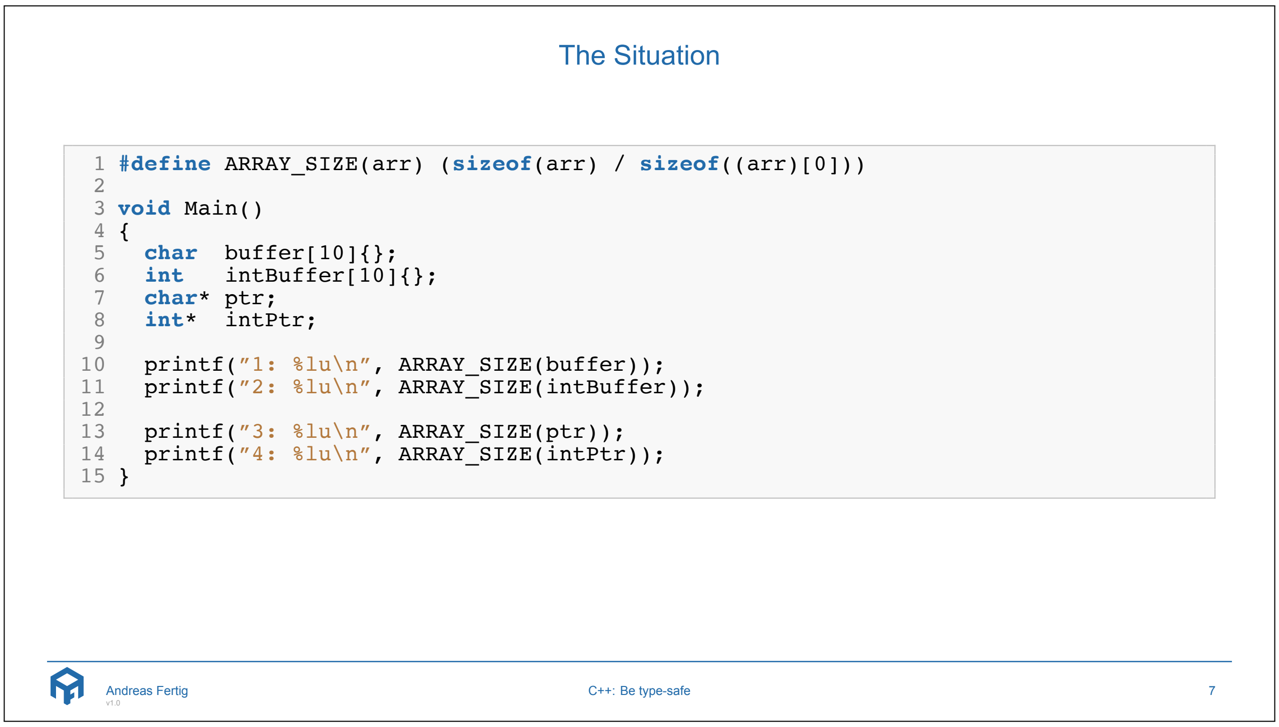
The Situation

```cpp
void Main()
{
  int buffer[16]{};

  for(int i = 0;
      i < (sizeof(buffer) / sizeof(buffer[0]));
      ++ i) {
    // ...
  }
}
```



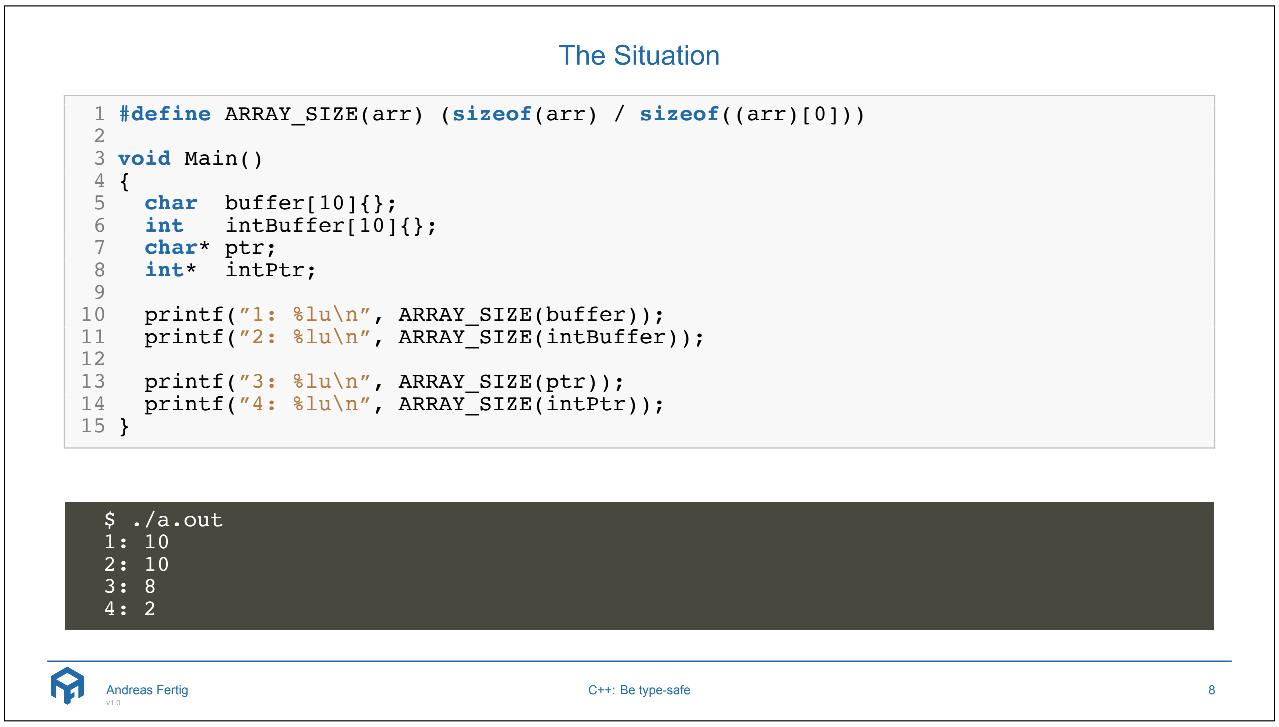
The Situation

```cpp
#define ARRAY_SIZE(arr) (sizeof(arr) / sizeof((arr)[0]))

void Main()
{
  int buffer[16]{};

  for(int i = 0; i < ARRAY_SIZE(buffer); ++i) {
    // ...
  }
}
```



The Situation

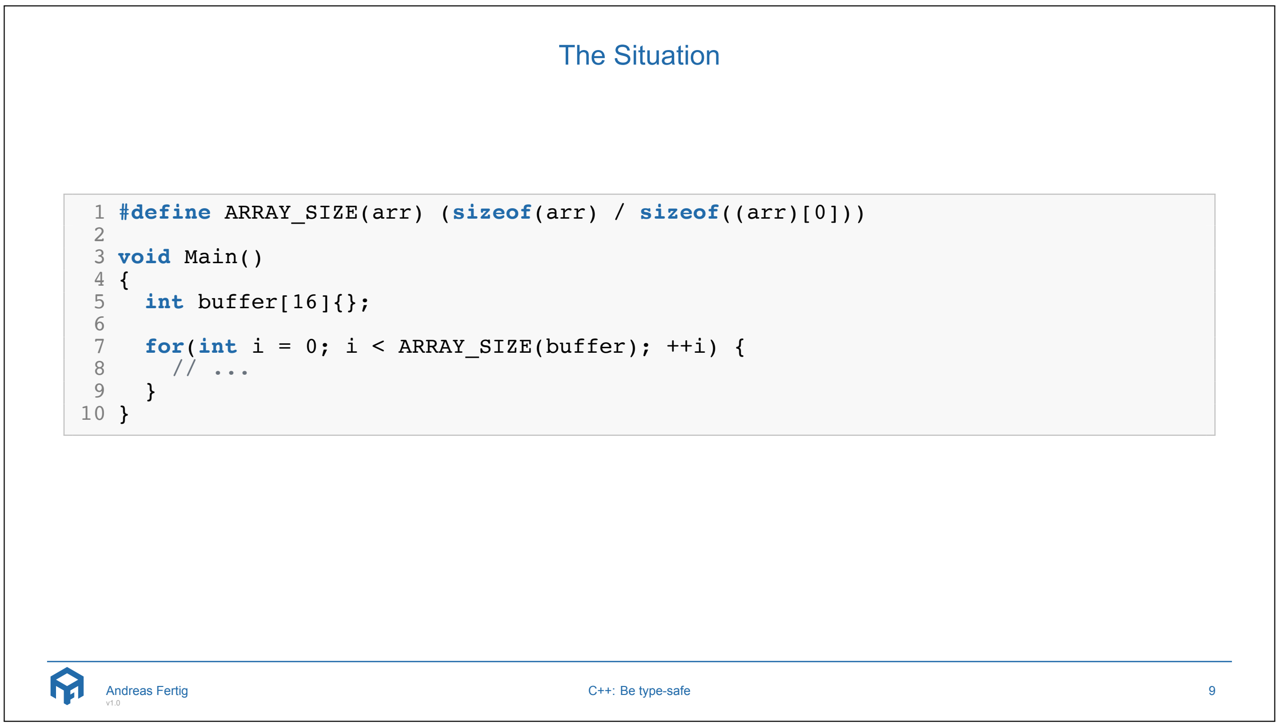
```cpp
#define ARRAY_SIZE(arr) (sizeof(arr) / sizeof((arr)[0]))

void Main()
{
  char  buffer[10]{};
  int   intBuffer[10]{};
  char* ptr;
  int*  intPtr;

  printf("1: %lu\n", ARRAY_SIZE(buffer));
  printf("2: %lu\n", ARRAY_SIZE(intBuffer));

  printf("3: %lu\n", ARRAY_SIZE(ptr));
  printf("4: %lu\n", ARRAY_SIZE(intPtr));
}
```



The Situation

```cpp
#define ARRAY_SIZE(arr) (sizeof(arr) / sizeof((arr)[0]))

void Main()
{
  char  buffer[10]{};
  int   intBuffer[10]{};
  char* ptr;
  int*  intPtr;

  printf("1: %lu\n", ARRAY_SIZE(buffer));
  printf("2: %lu\n", ARRAY_SIZE(intBuffer));

  printf("3: %lu\n", ARRAY_SIZE(ptr));
  printf("4: %lu\n", ARRAY_SIZE(intPtr));
}
```

```
$ ./a.out
1: 10
2: 10
3: 8
4: 2
```



The Situation

```cpp
#define ARRAY_SIZE(arr) (sizeof(arr) / sizeof((arr)[0]))

void Main()
{
  int buffer[16]{};

  for(int i = 0; i < ARRAY_SIZE(buffer); ++i) {
    // ...
  }
}
```

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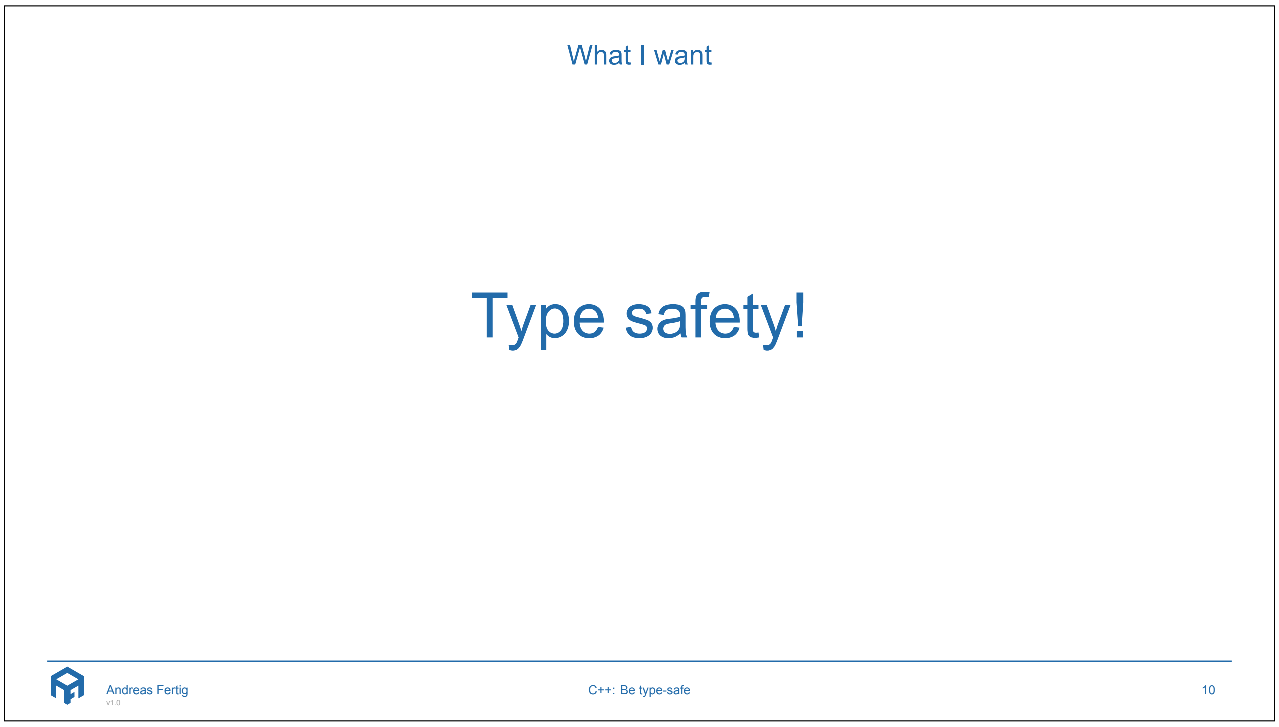

What I want

Type safety!

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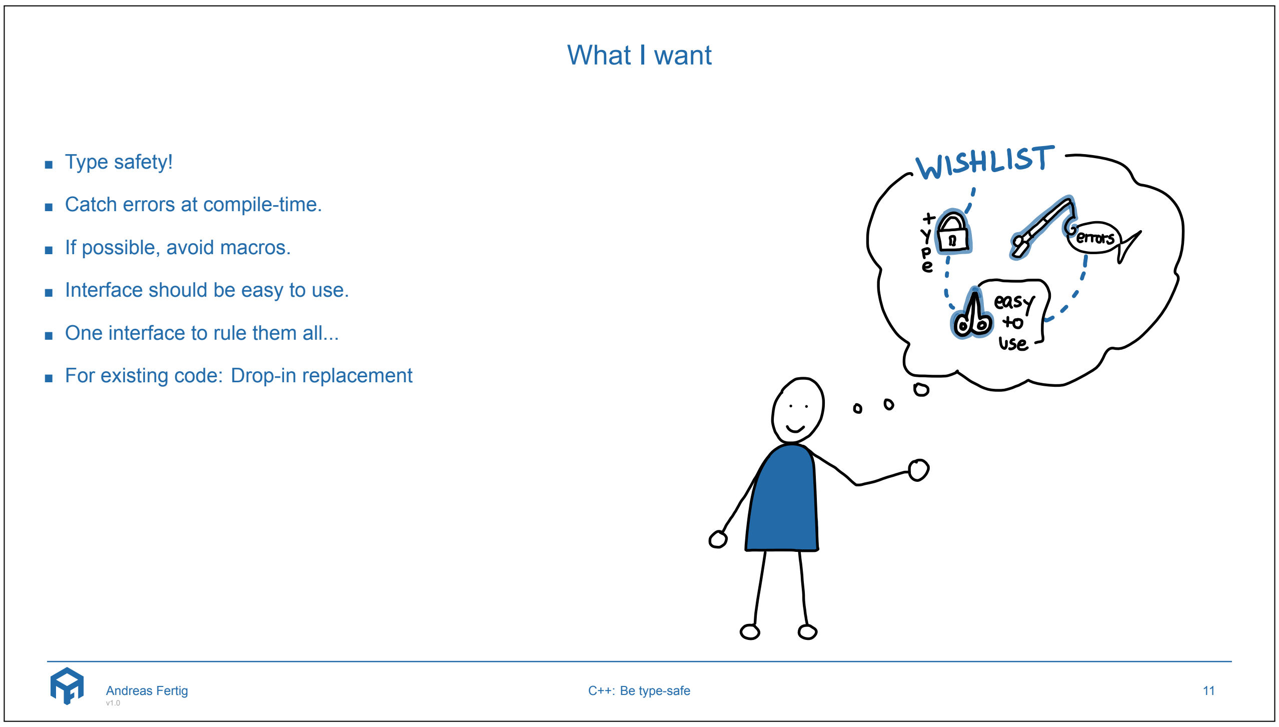

What I want

- Type safety!
- Catch errors at compile-time.
- If possible, avoid macros.
- Interface should be easy to use.
- One interface to rule them all...
- For existing code: Drop-in replacement

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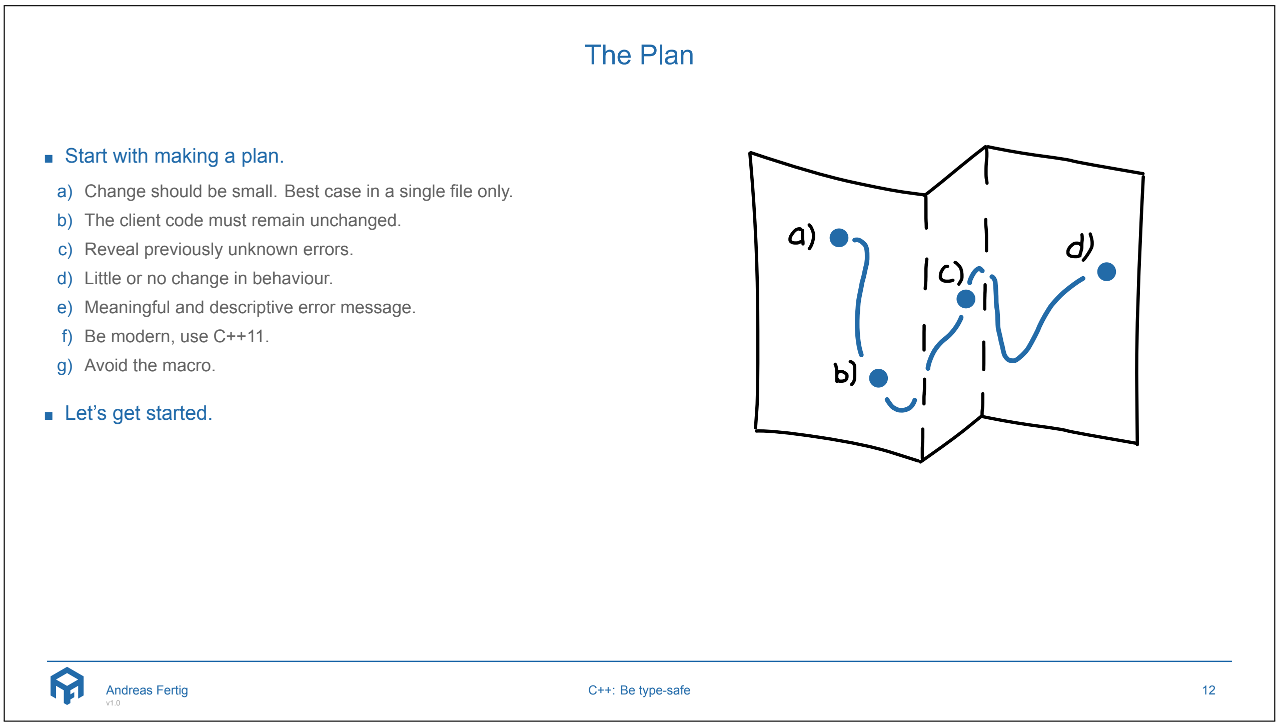
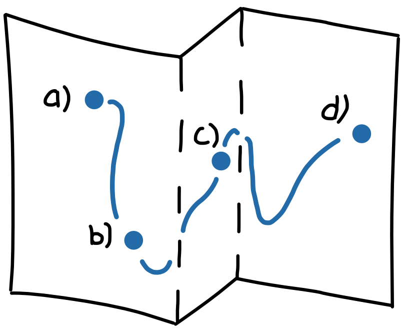


The Plan

- Start with making a plan.
  a) Change should be small. Best case in a single file only.
  b) The client code must remain unchanged.
  c) Reveal previously unknown errors.
  d) Little or no change in behaviour.
  e) Meaningful and descriptive error message.
  f) Be modern, use C++11.
  g) Avoid the macro.
- Let's get started.



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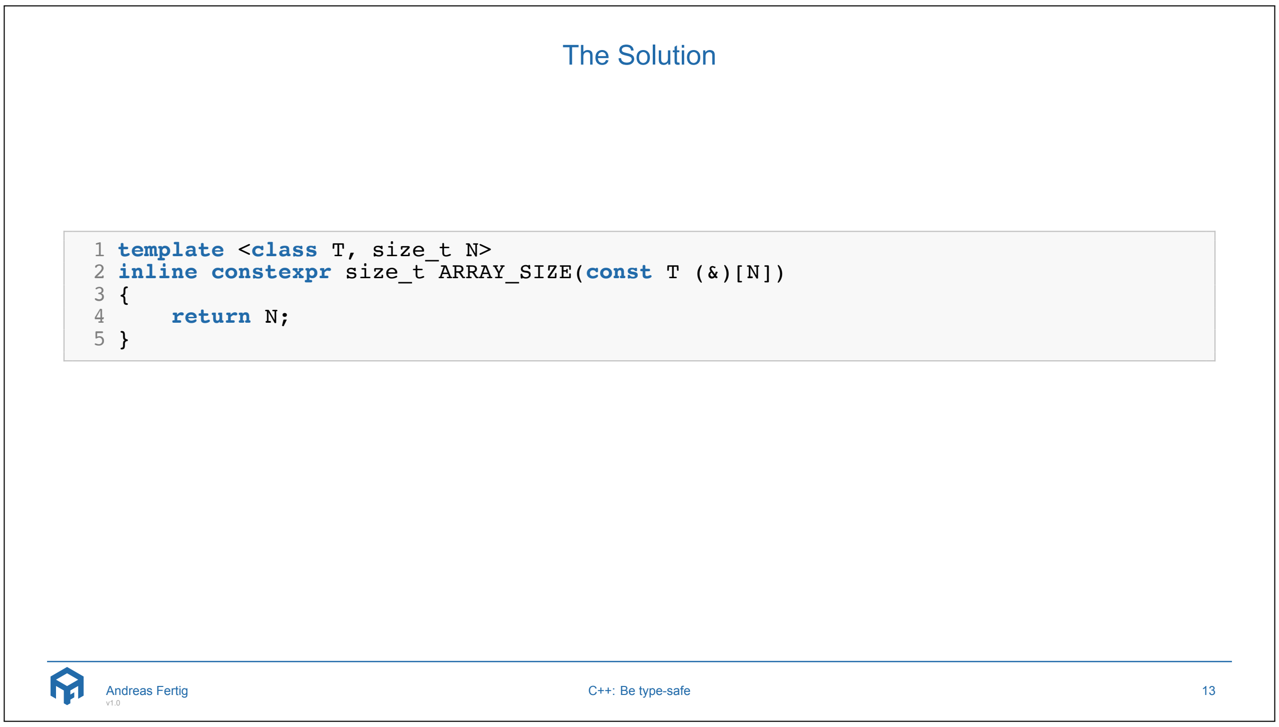
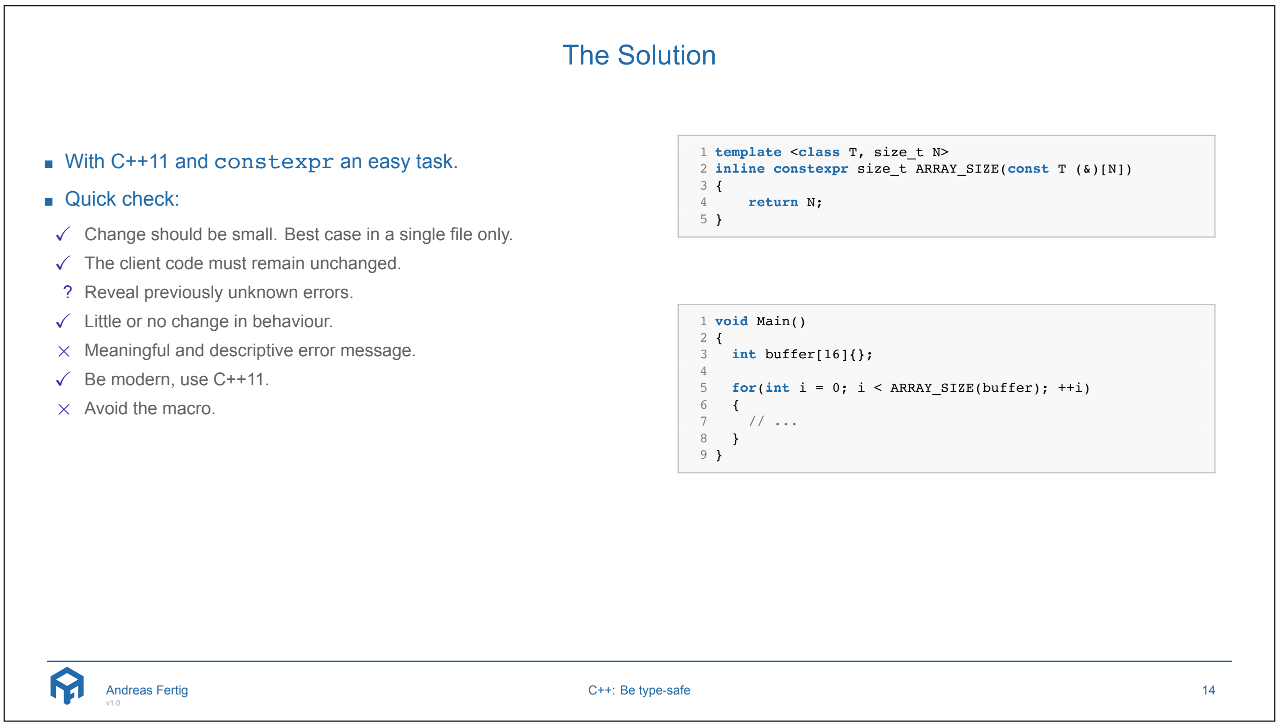


The Solution

```cpp
template <class T, size_t N>
inline constexpr size_t ARRAY_SIZE(const T (&)[N])
{
    return N;
}
```



The Solution

- With C++11 and `constexpr` an easy task.
- Quick check:
  - ✓ Change should be small. Best case in a single file only.
  - ✓ The client code must remain unchanged.
  - ? Reveal previously unknown errors.
  - ✓ Little or no change in behaviour.
  - × Meaningful and descriptive error message.
  - ✓ Be modern, use C++11.
  - × Avoid the macro.

```cpp
template <class T, size_t N>
inline constexpr size_t ARRAY_SIZE(const T (&)[N])
{
    return N;
}
```

```cpp
void Main()
{
  int buffer[16]{};

  for(int i = 0; i < ARRAY_SIZE(buffer); ++i)
  {
    // ...
  }
}
```

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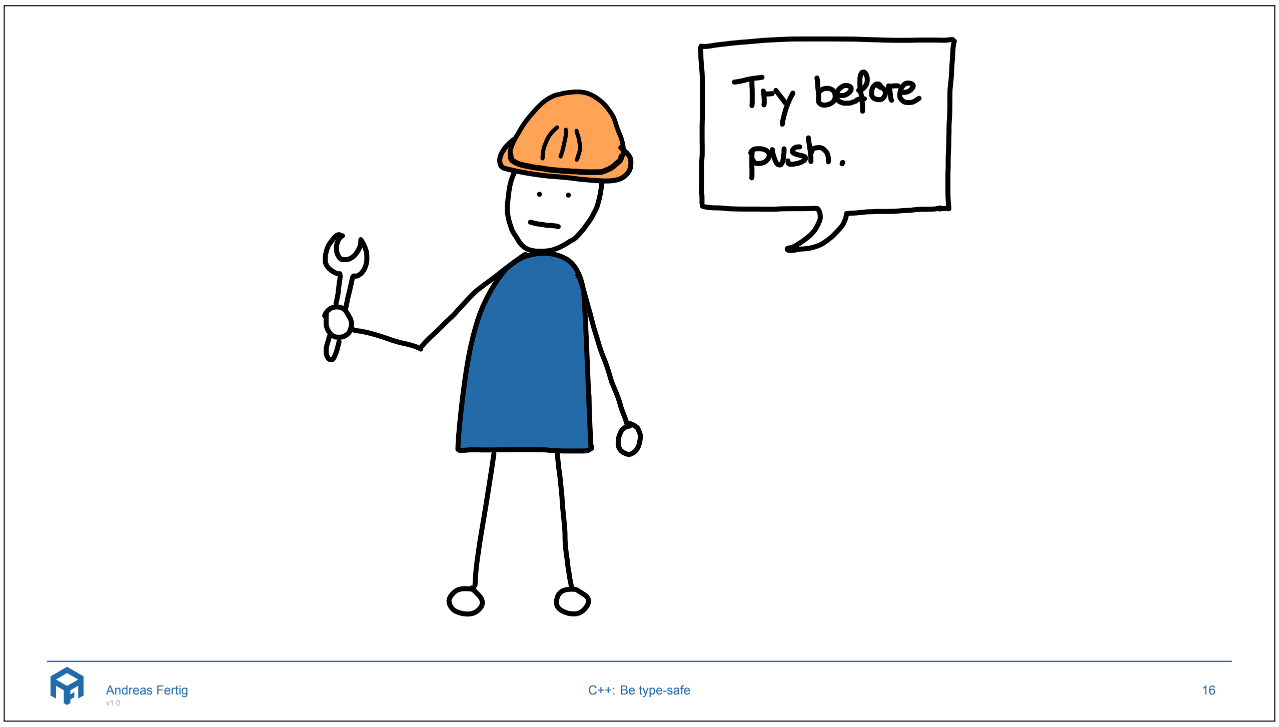

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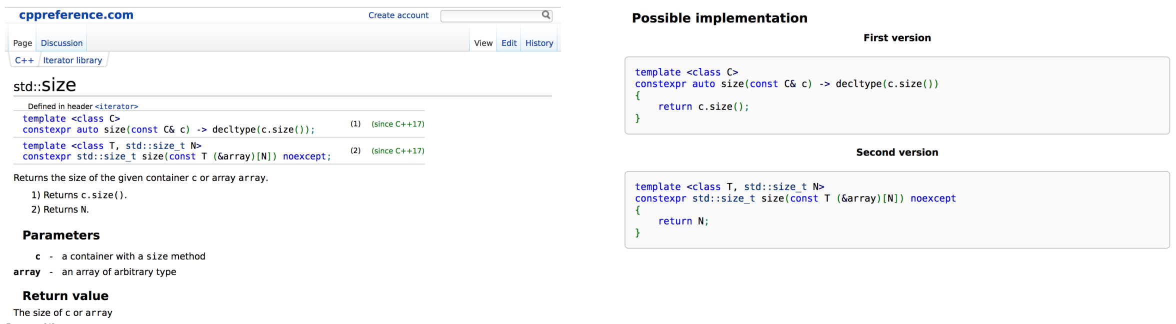
```cpp
template <class T, size_t N>
inline constexpr size_t ARRAY_SIZE(const T (&)[N])
{
    return N;
}
```

std::size



std::size

Defined in header `<iterator>`

```cpp
template <class C>
constexpr auto size(const C& c) -> decltype(c.size());              (1)  (since C++17)
template <class T, std::size_t N>
constexpr std::size_t size(const T (&array)[N]) noexcept;           (2)  (since C++17)
```

Returns the size of the given container c or array `array`.

1) Returns `c.size()`.
2) Returns N.

Parameters

c	-	a container with a `size` method
array	-	an array of arbitrary type

Return value

The size of c or `array`

Possible implementation

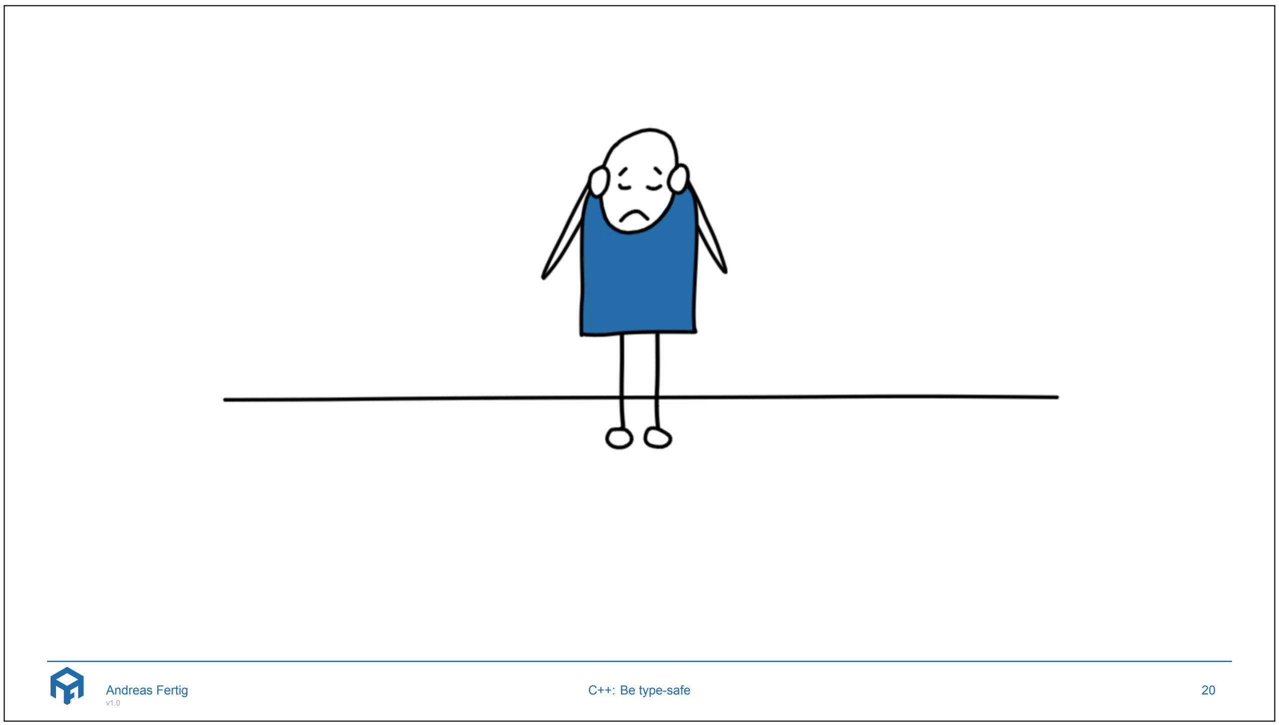
First version

```cpp
template <class C>
constexpr auto size(const C& c) -> decltype(c.size())
{
    return c.size();
}
```

Second version

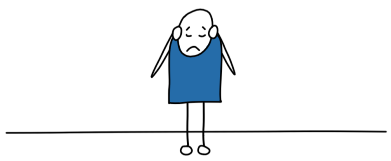
```cpp
template <class T, std::size_t N>
constexpr std::size_t size(const T (&array)[N]) noexcept
{
    return N;
}
```

Source: [1]



Arg

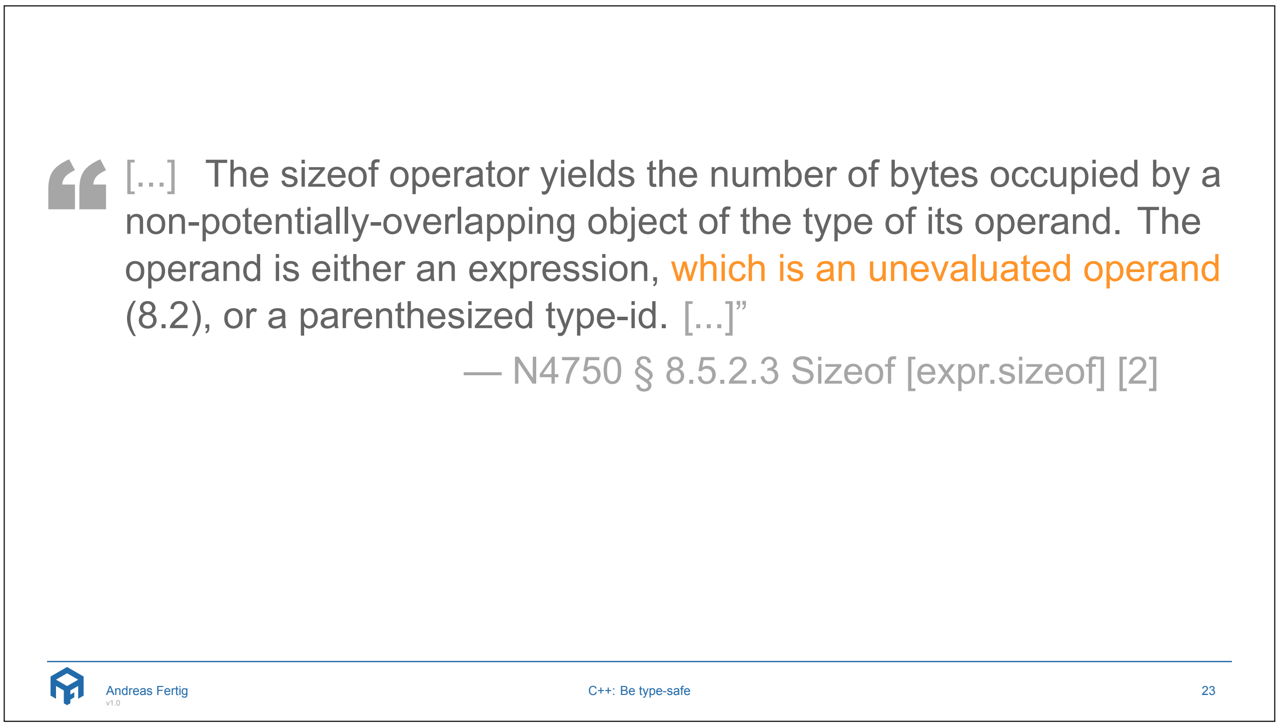
```
x.cpp:16:4: error: cannot form pointer to deduced class template specialization /
    type
  X* x;
   ^
x.cpp:16:6: error: declaration of variable 'x' with deduced type 'X *' requires /
    an initializer
  X* x;
     ^
2 errors generated.
```



Arg

```cpp
struct X
{
  char v[12];
};

void Main()
{
  X* x;
  static_assert(ARRAY_SIZE(x->v) == 12, "Wrong array length");
}
```



“[...] The sizeof operator yields the number of bytes occupied by a non-potentially-overlapping object of the type of its operand. The operand is either an expression, which is an unevaluated operand (8.2), or a parenthesized type-id. [...]”

— N4750 § 8.5.2.3 Sizeof [expr.sizeof] [2]

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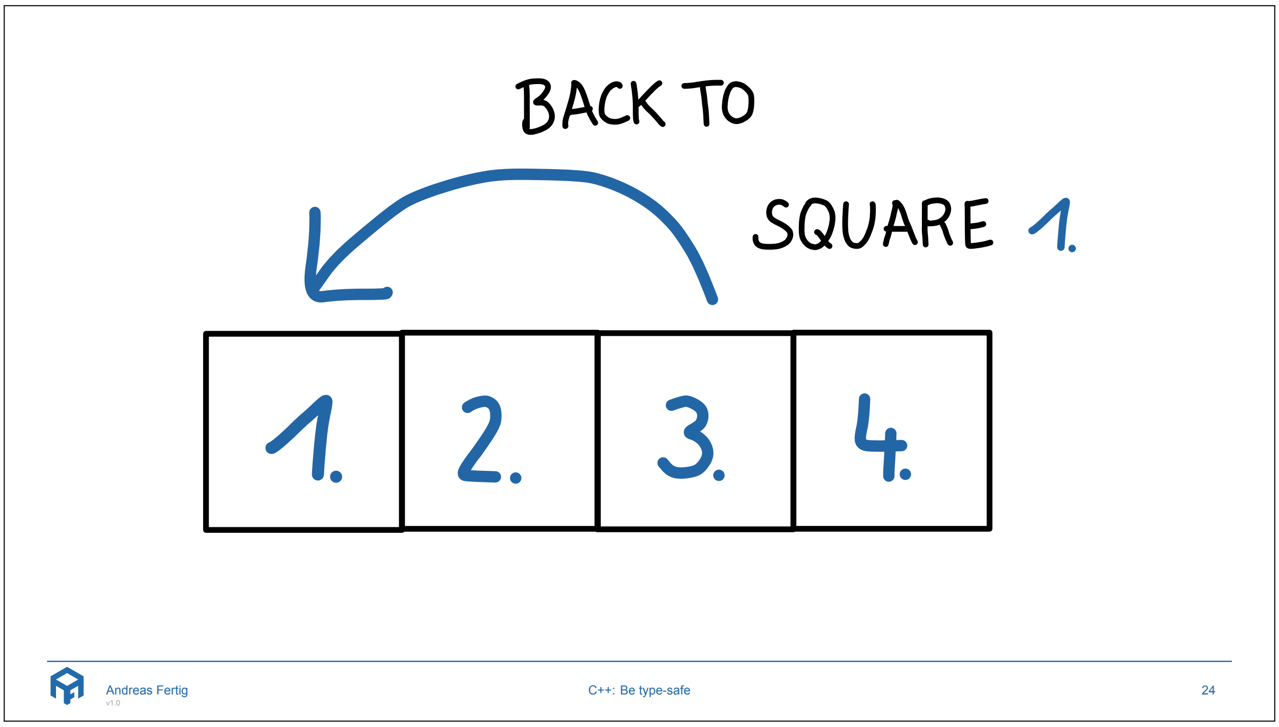

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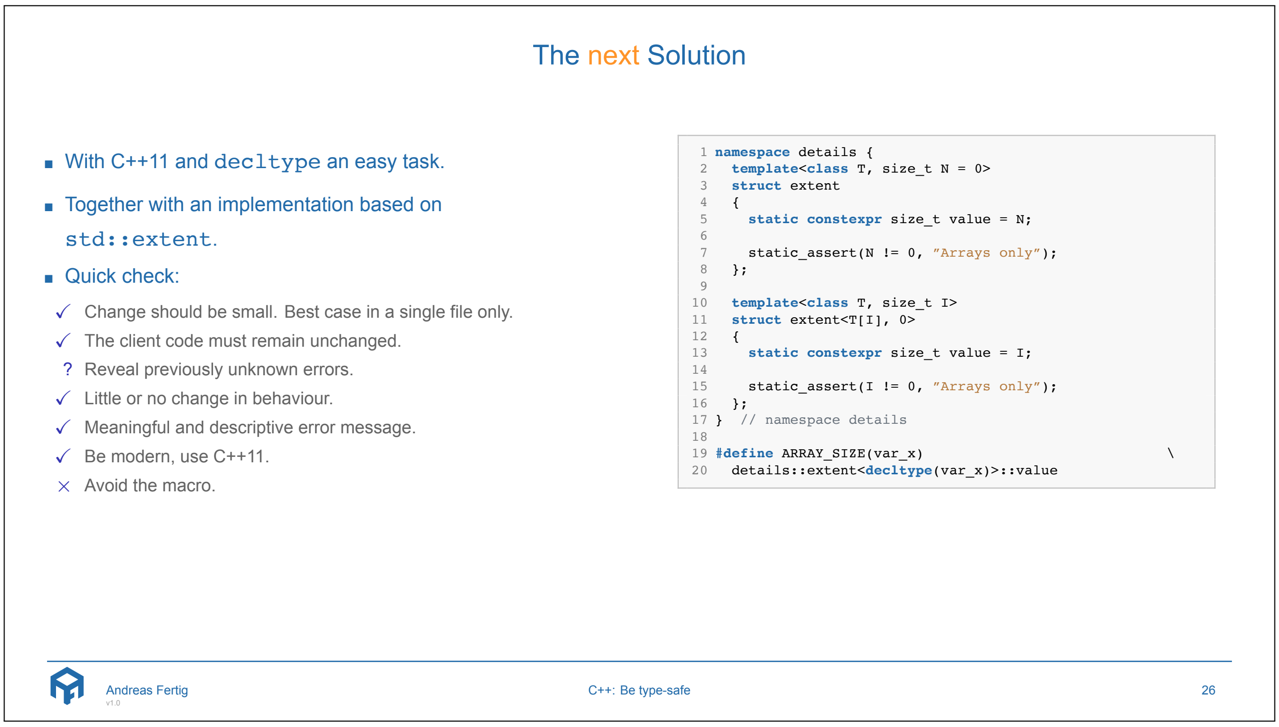
The next Solution



The next Solution

- With C++11 and `decltype` an easy task.
- Together with an implementation based on `std::extent`.
- Quick check:

✓ Change should be small. Best case in a single file only.
✓ The client code must remain unchanged.
? Reveal previously unknown errors.
✓ Little or no change in behaviour.
✓ Meaningful and descriptive error message.
✓ Be modern, use C++11.
× Avoid the macro.

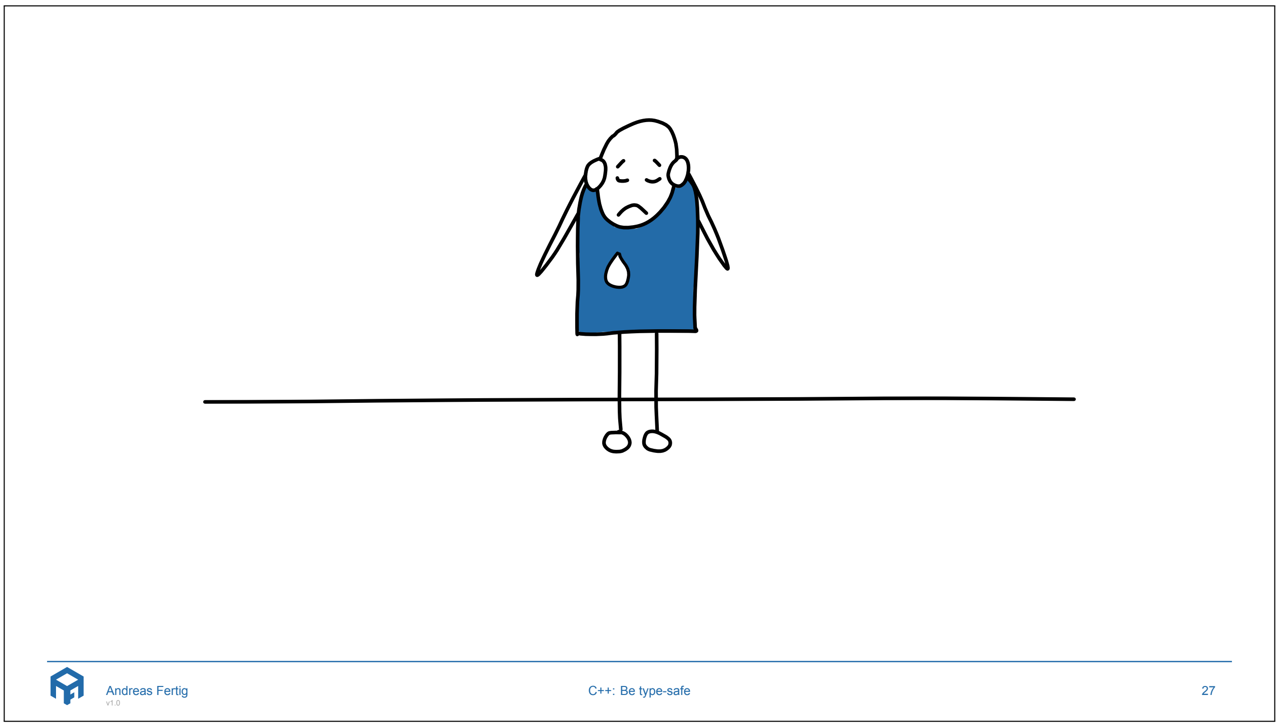
```cpp
namespace details {
  template<class T, size_t N = 0>
  struct extent
  {
    static constexpr size_t value = N;

    static_assert(N != 0, "Arrays only");
  };

  template<class T, size_t I>
  struct extent<T[I], 0>
  {
    static constexpr size_t value = I;

    static_assert(I != 0, "Arrays only");
  };
}  // namespace details

#define ARRAY_SIZE(var_x)                           \
  details::extent<decltype(var_x)>::value
```



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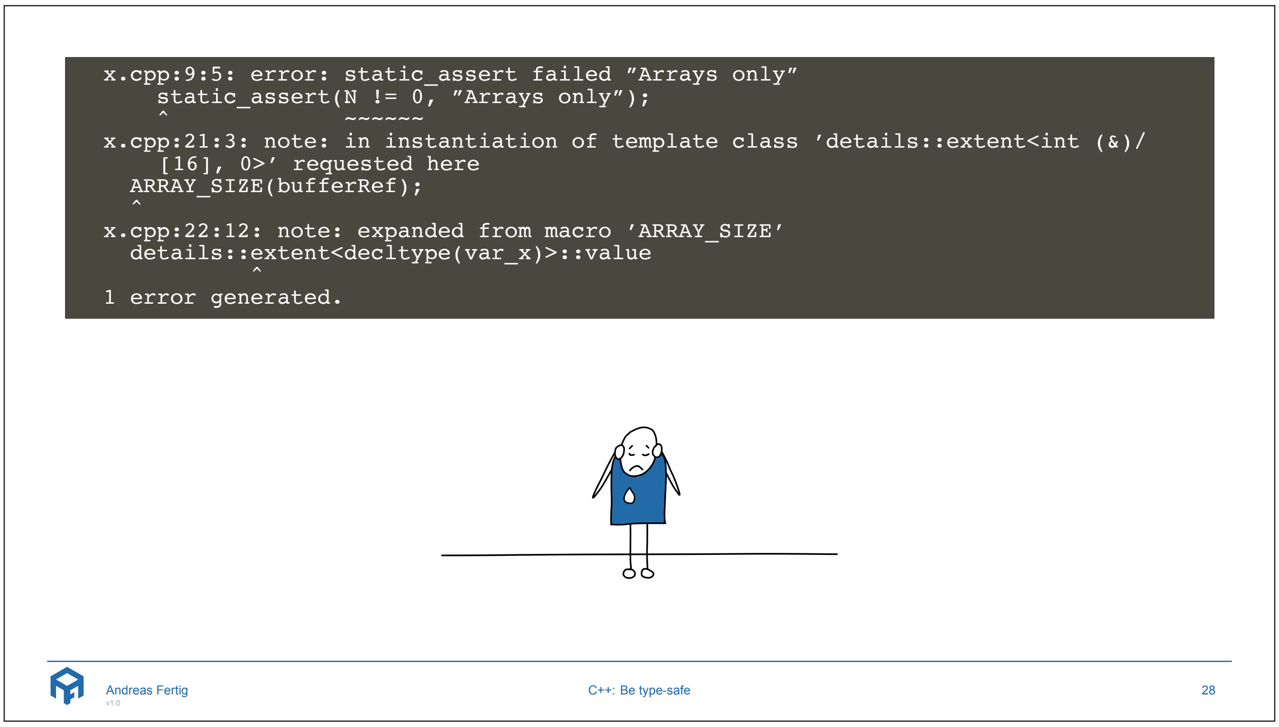

```
x.cpp:9:5: error: static_assert failed ”Arrays only”
    static_assert(N != 0, ”Arrays only”);
    ^             ~~~~~~
x.cpp:21:3: note: in instantiation of template class ’details::extent<int (&)/
    [16], 0>’ requested here
  ARRAY_SIZE(bufferRef);
  ^
x.cpp:22:12: note: expanded from macro ’ARRAY_SIZE’
  details::extent<decltype(var_x)>::value
           ^
1 error generated.
```

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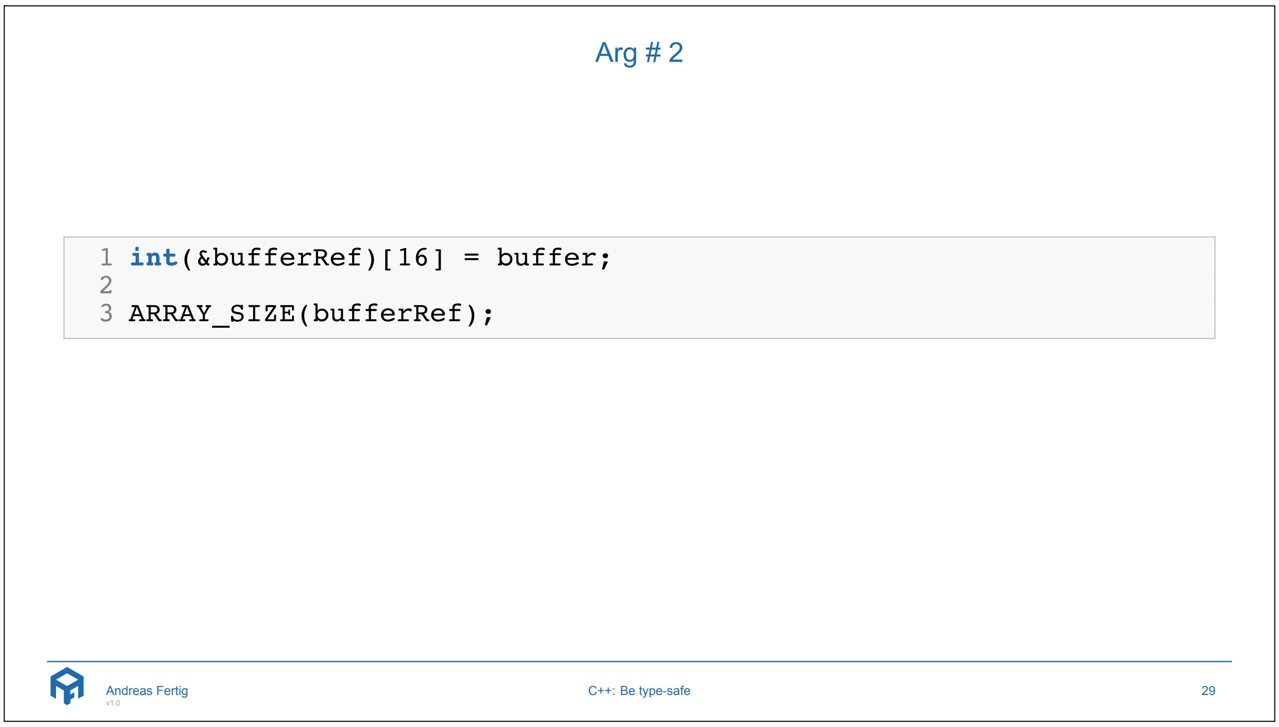
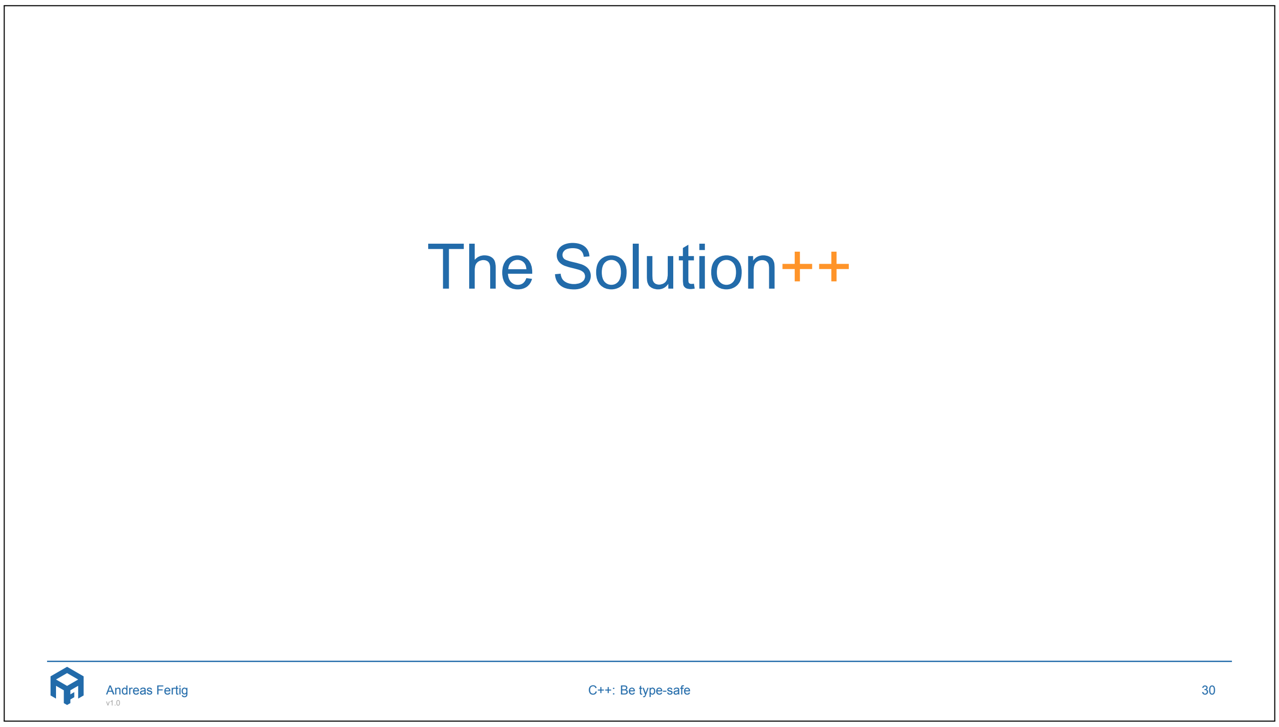


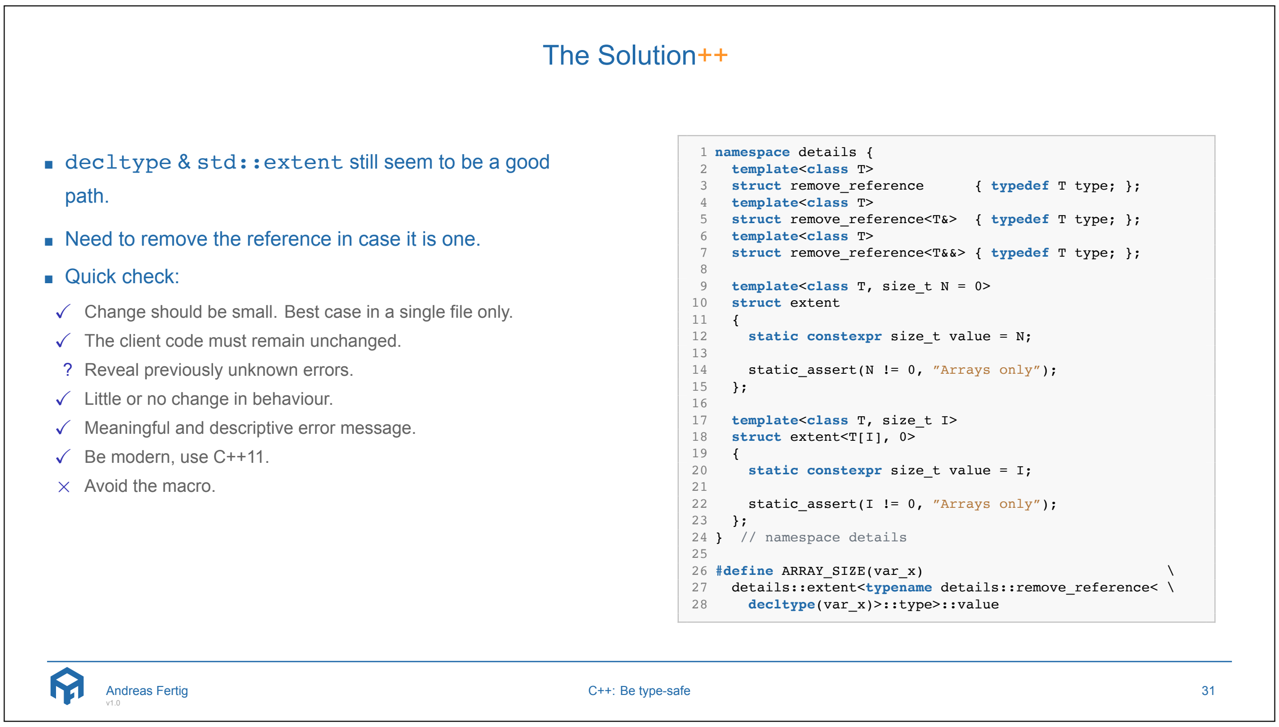
Arg # 2

```cpp
int(&bufferRef)[16] = buffer;

ARRAY_SIZE(bufferRef);
```



The Solution++



The Solution++

- `decltype` & `std::extent` still seem to be a good path.
- Need to remove the reference in case it is one.
- Quick check:
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  - ✓ Little or no change in behaviour.
  - ✓ Meaningful and descriptive error message.
  - ✓ Be modern, use C++11.
  - × Avoid the macro.

```cpp
namespace details {
  template<class T>
  struct remove_reference      { typedef T type; };
  template<class T>
  struct remove_reference<T&>  { typedef T type; };
  template<class T>
  struct remove_reference<T&&> { typedef T type; };

  template<class T, size_t N = 0>
  struct extent
  {
    static constexpr size_t value = N;

    static_assert(N != 0, "Arrays only");
  };

  template<class T, size_t I>
  struct extent<T[I], 0>
  {
    static constexpr size_t value = I;

    static_assert(I != 0, "Arrays only");
  };
}  // namespace details

#define ARRAY_SIZE(var_x)                                  \
  details::extent<typename details::remove_reference< \
    decltype(var_x)>::type>::value
```

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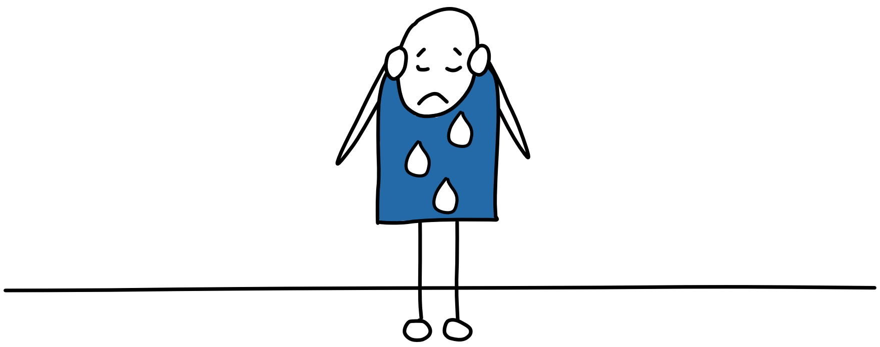

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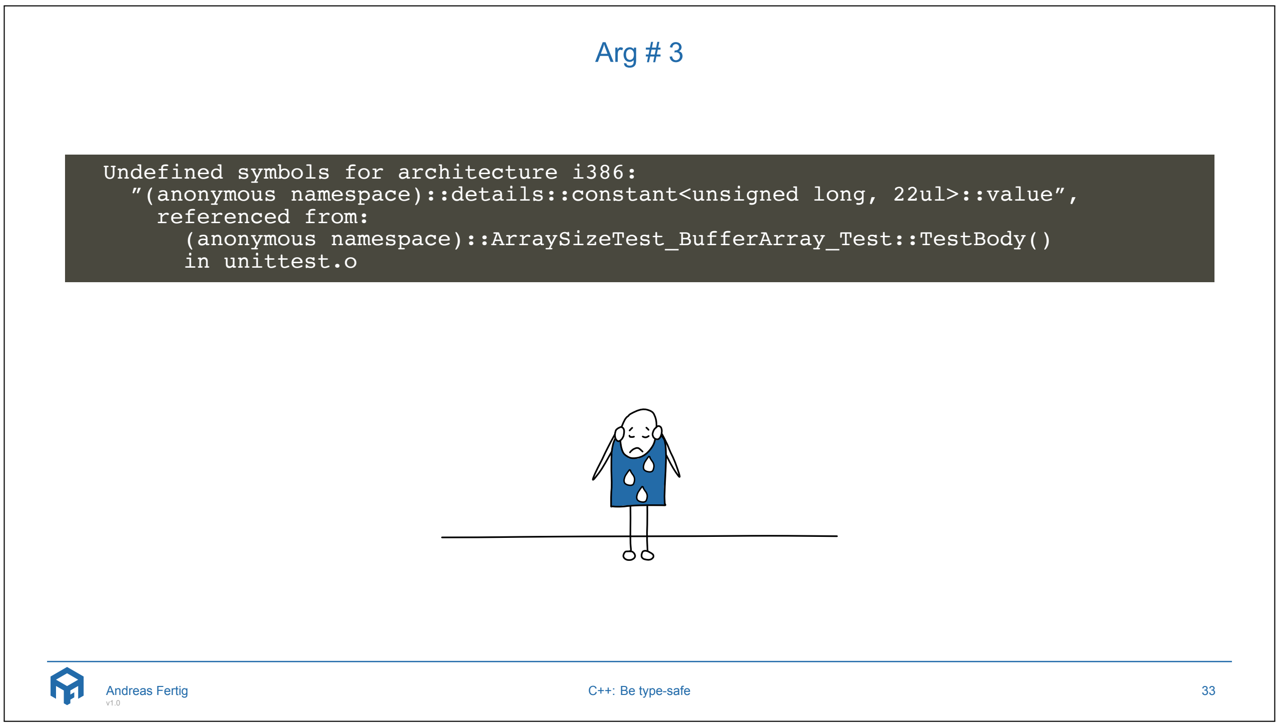
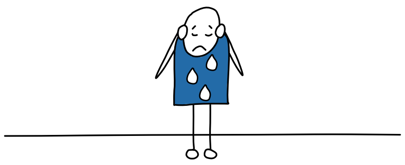


Arg # 3

```
Undefined symbols for architecture i386:
  "(anonymous namespace)::details::constant<unsigned long, 22ul>::value",
    referenced from:
      (anonymous namespace)::ArraySizeTest_BufferArray_Test::TestBody()
      in unittest.o
```



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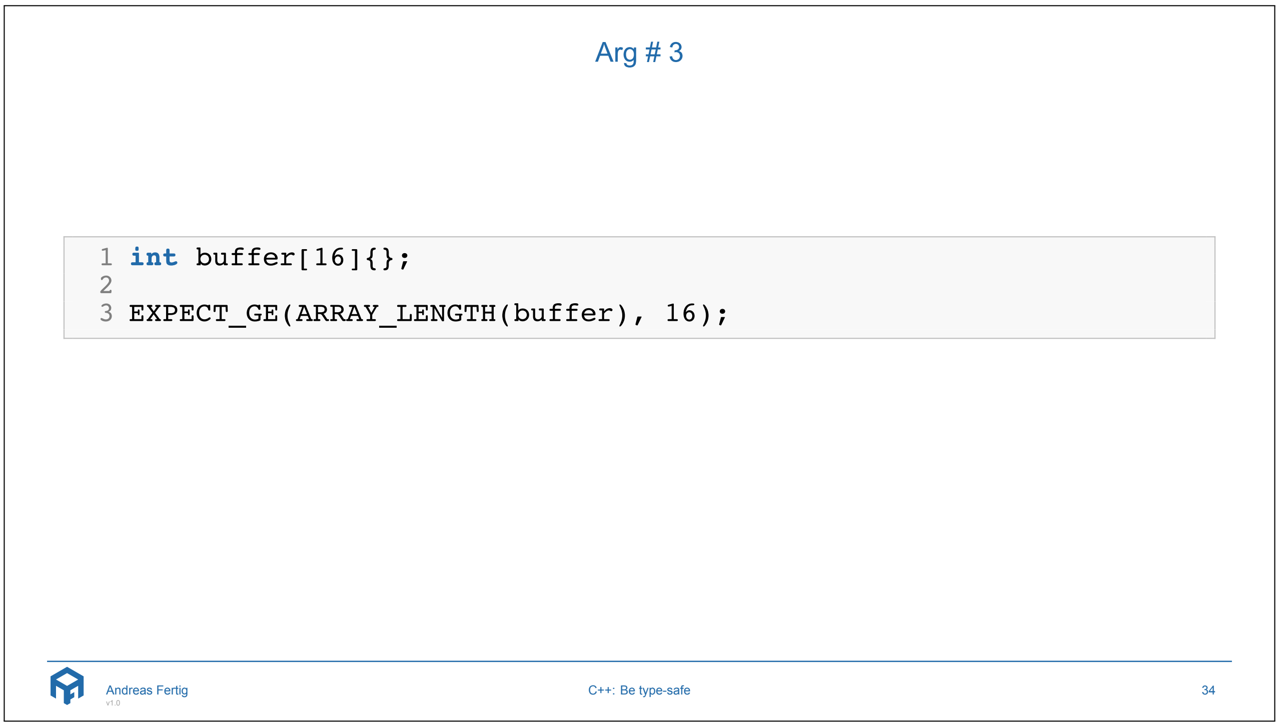

Arg # 3

```cpp
int buffer[16]{};

EXPECT_GE(ARRAY_LENGTH(buffer), 16);
```

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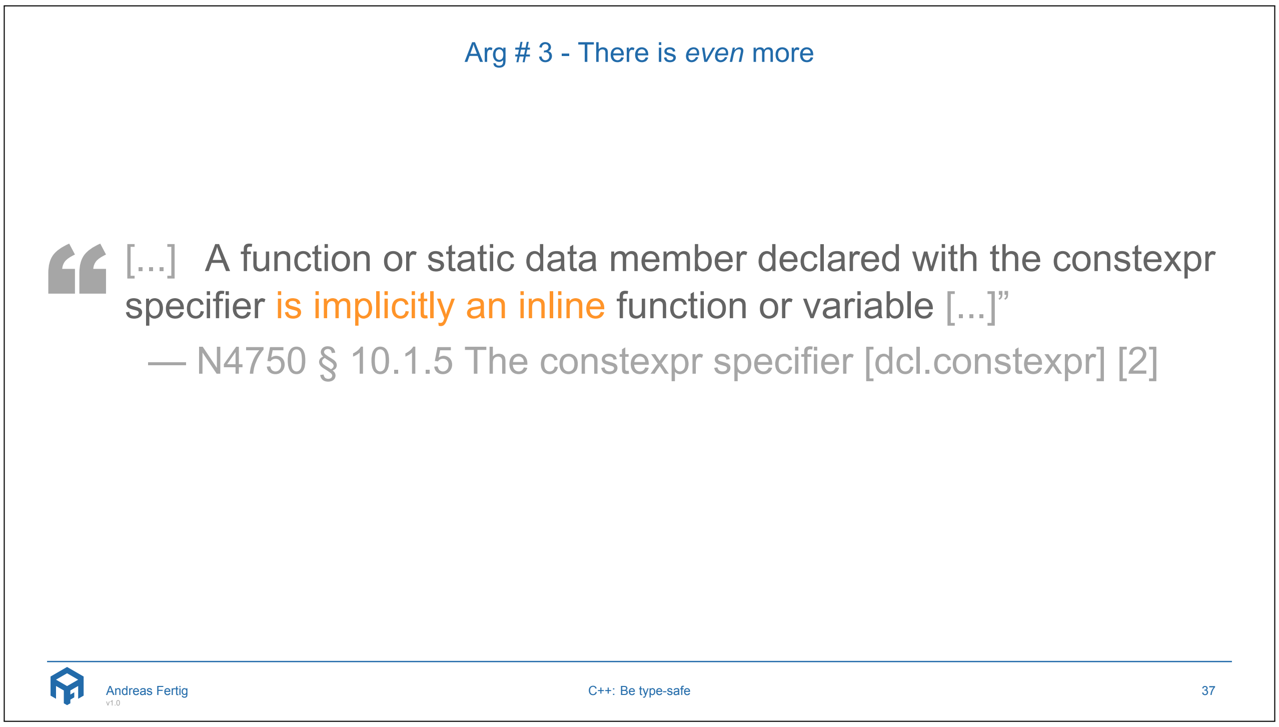
Arg # 3

```
int buffer[16]{};

const auto& ref = ARRAY_LENGTH(buffer);
```

Arg # 3 - There is more

`-pedantic`



Arg # 3 - There is *even* more

“[...] A function or static data member declared with the constexpr specifier is implicitly an inline function or variable [...]”

— N4750 § 10.1.5 The constexpr specifier [dcl.constexpr] [2]

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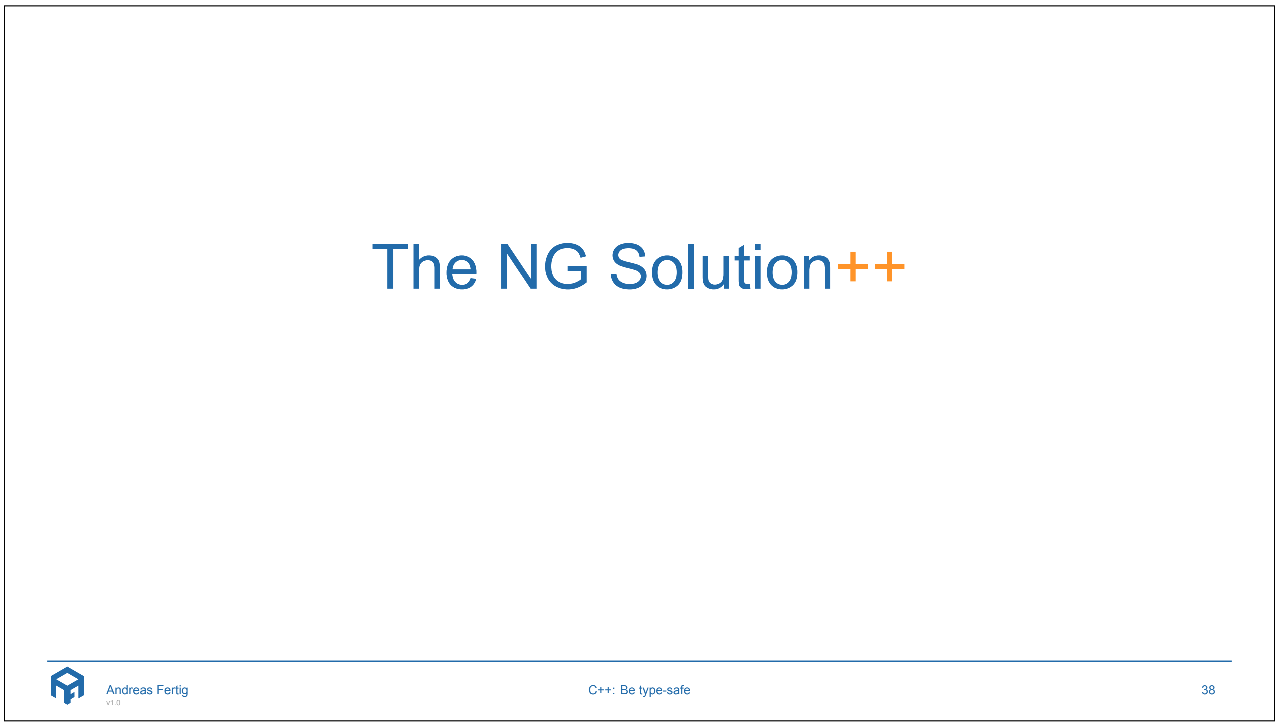

The NG Solution++

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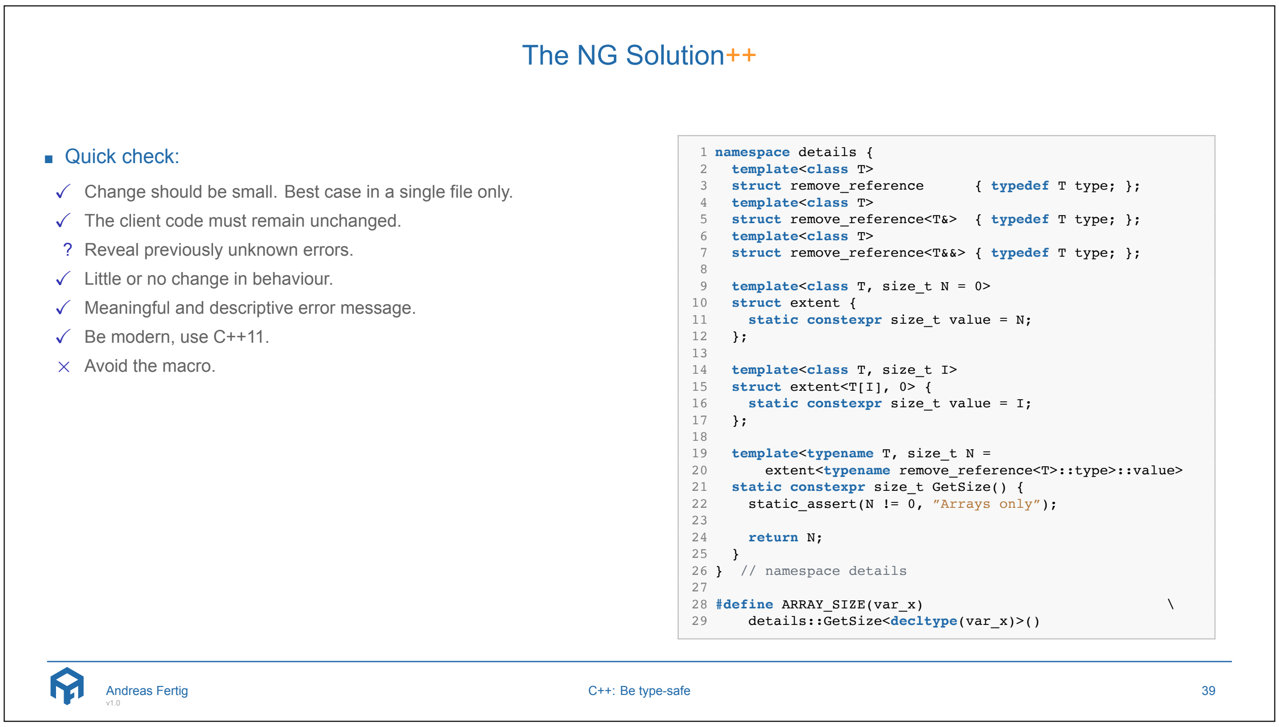

The NG Solution++

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  - ✓ The client code must remain unchanged.
  - ? Reveal previously unknown errors.
  - ✓ Little or no change in behaviour.
  - ✓ Meaningful and descriptive error message.
  - ✓ Be modern, use C++11.
  - × Avoid the macro.

```cpp
namespace details {
  template<class T>
  struct remove_reference      { typedef T type; };
  template<class T>
  struct remove_reference<T&>  { typedef T type; };
  template<class T>
  struct remove_reference<T&&> { typedef T type; };

  template<class T, size_t N = 0>
  struct extent {
    static constexpr size_t value = N;
  };

  template<class T, size_t I>
  struct extent<T[I], 0> {
    static constexpr size_t value = I;
  };

  template<typename T, size_t N =
      extent<typename remove_reference<T>::type>::value>
  static constexpr size_t GetSize() {
    static_assert(N != 0, "Arrays only");

    return N;
  }
}  // namespace details

#define ARRAY_SIZE(var_x)                                       \
    details::GetSize<decltype(var_x)>()
```

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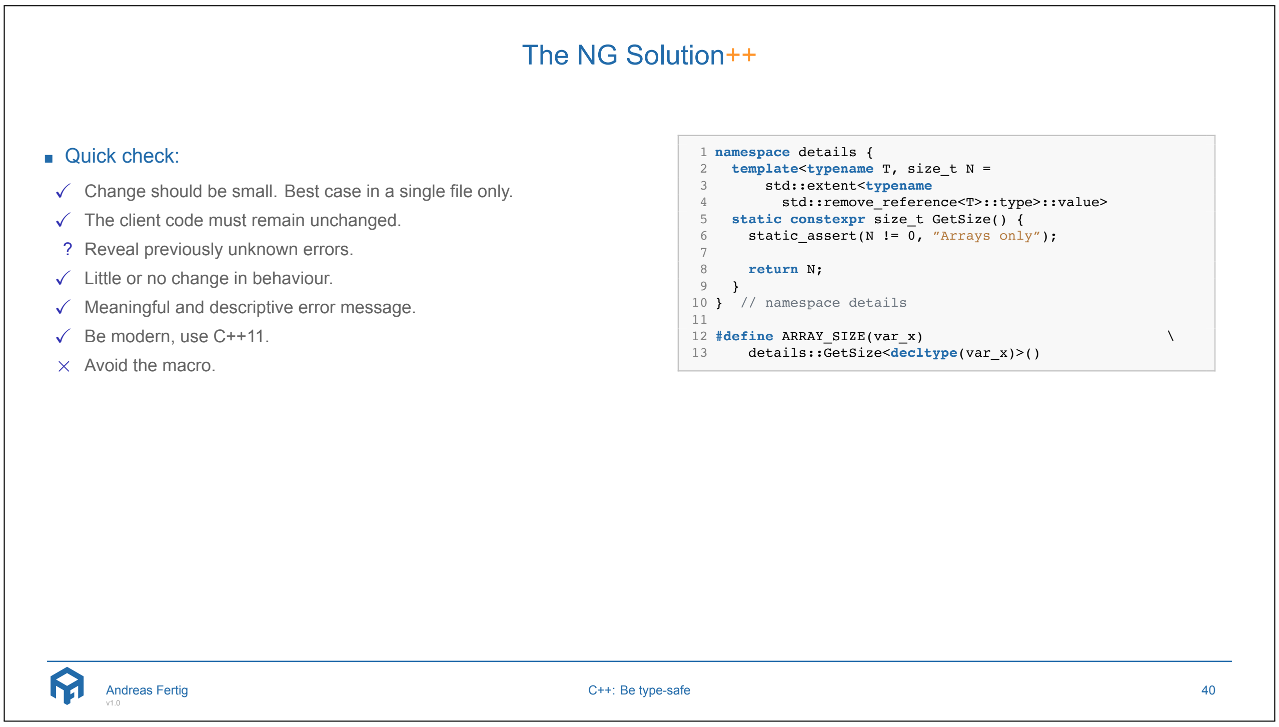

The NG Solution++

- Quick check:
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  - ? Reveal previously unknown errors.
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  - ✓ Meaningful and descriptive error message.
  - ✓ Be modern, use C++11.
  - × Avoid the macro.

```cpp
namespace details {
  template<typename T, size_t N =
      std::extent<typename
        std::remove_reference<T>::type>::value>
  static constexpr size_t GetSize() {
    static_assert(N != 0, "Arrays only");

    return N;
  }
}  // namespace details

#define ARRAY_SIZE(var_x)                                       \
    details::GetSize<decltype(var_x)>()
```

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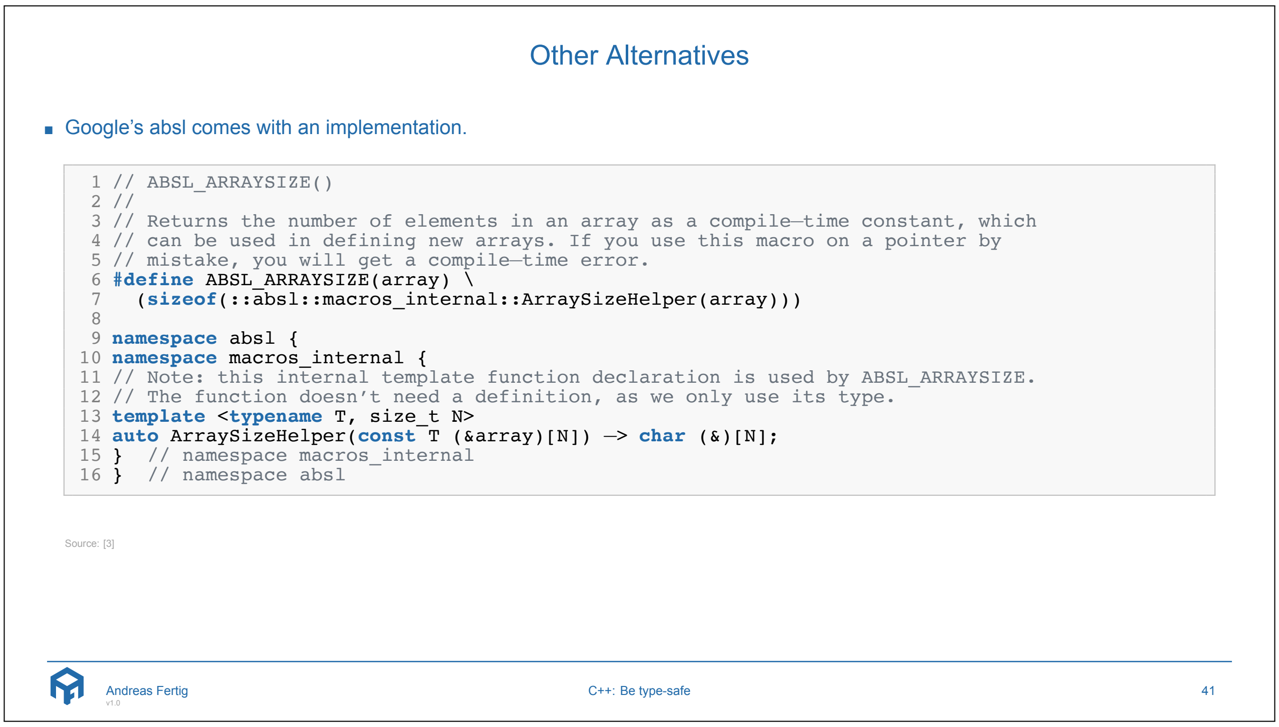

Other Alternatives

- Google's absl comes with an implementation.

```cpp
// ABSL_ARRAYSIZE()
//
// Returns the number of elements in an array as a compile–time constant, which
// can be used in defining new arrays. If you use this macro on a pointer by
// mistake, you will get a compile–time error.
#define ABSL_ARRAYSIZE(array) \
  (sizeof(::absl::macros_internal::ArraySizeHelper(array)))

namespace absl {
namespace macros_internal {
// Note: this internal template function declaration is used by ABSL_ARRAYSIZE.
// The function doesn't need a definition, as we only use its type.
template <typename T, size_t N>
auto ArraySizeHelper(const T (&array)[N]) –> char (&)[N];
}  // namespace macros_internal
}  // namespace absl
```

Source: [3]

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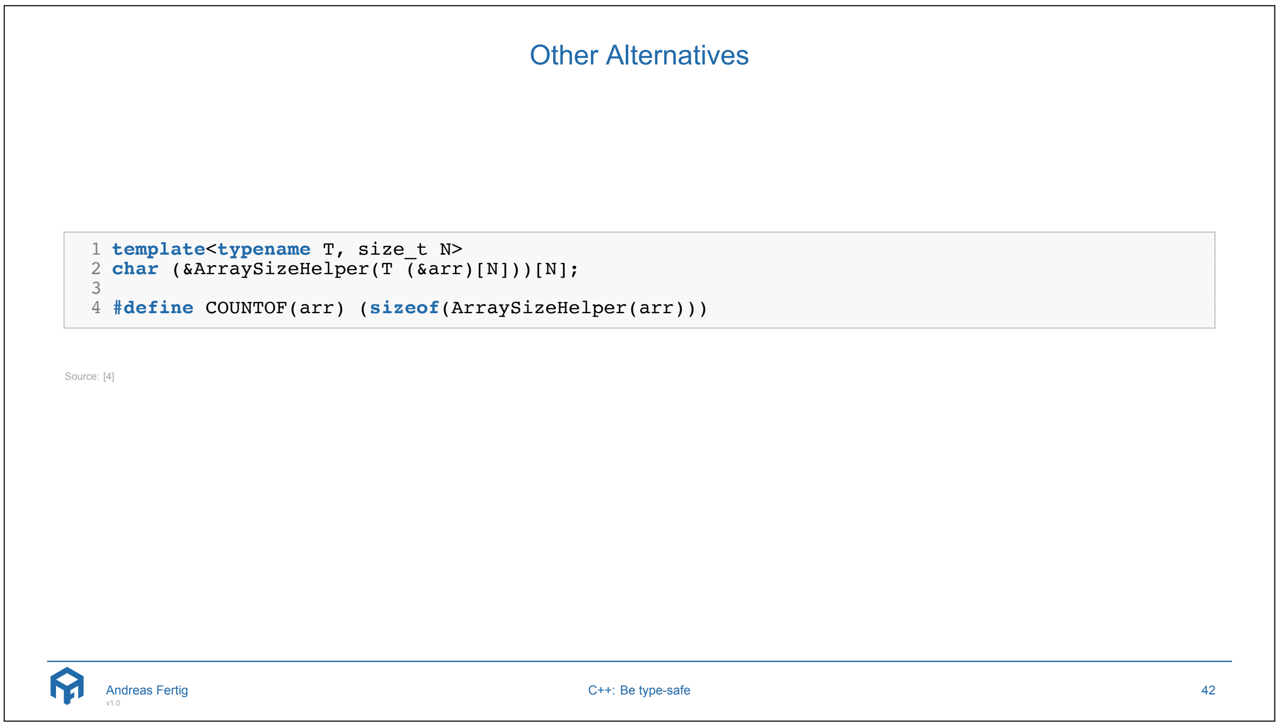

Other Alternatives

```cpp
template<typename T, size_t N>
char (&ArraySizeHelper(T (&arr)[N]))[N];

#define COUNTOF(arr) (sizeof(ArraySizeHelper(arr)))
```

Source: [4]

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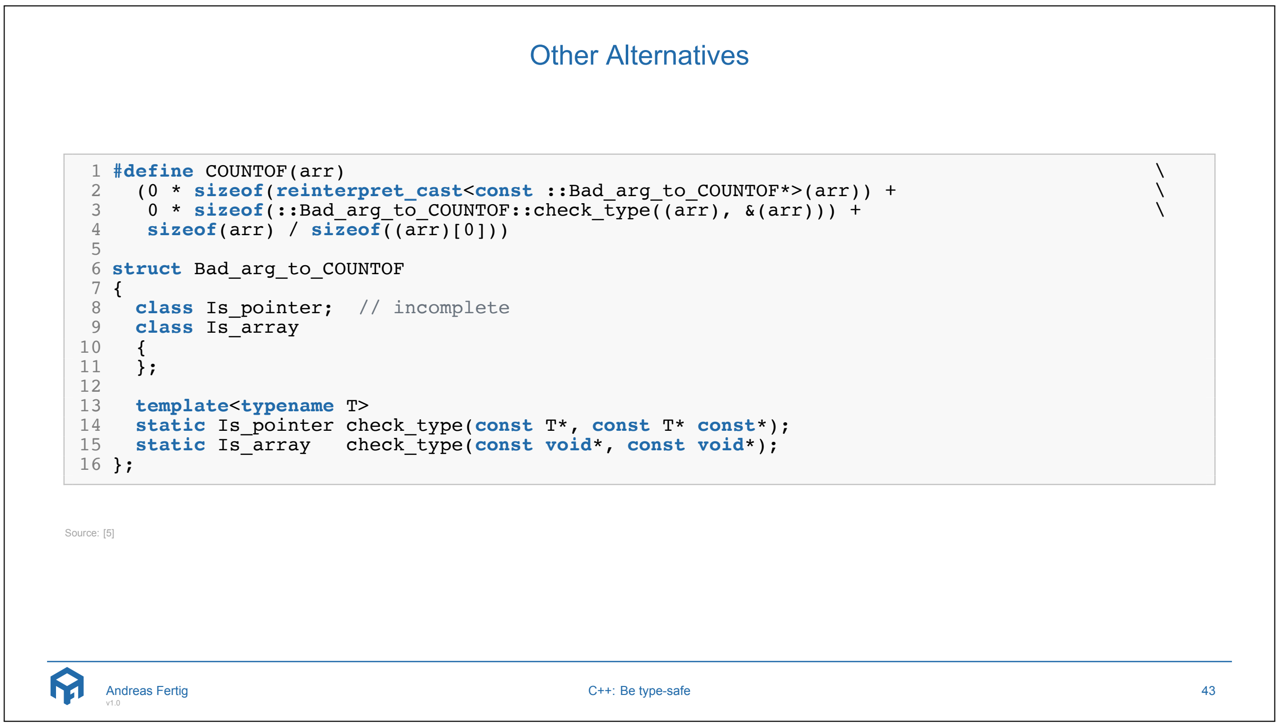

Other Alternatives

```cpp
#define COUNTOF(arr)                                                      \
  (0 * sizeof(reinterpret_cast<const ::Bad_arg_to_COUNTOF*>(arr)) +      \
   0 * sizeof(::Bad_arg_to_COUNTOF::check_type((arr), &(arr))) +         \
   sizeof(arr) / sizeof((arr)[0]))

struct Bad_arg_to_COUNTOF
{
  class Is_pointer;  // incomplete
  class Is_array
  {
  };

  template<typename T>
  static Is_pointer check_type(const T*, const T* const*);
  static Is_array   check_type(const void*, const void*);
};
```

Source: [5]

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C++: Be type-safe

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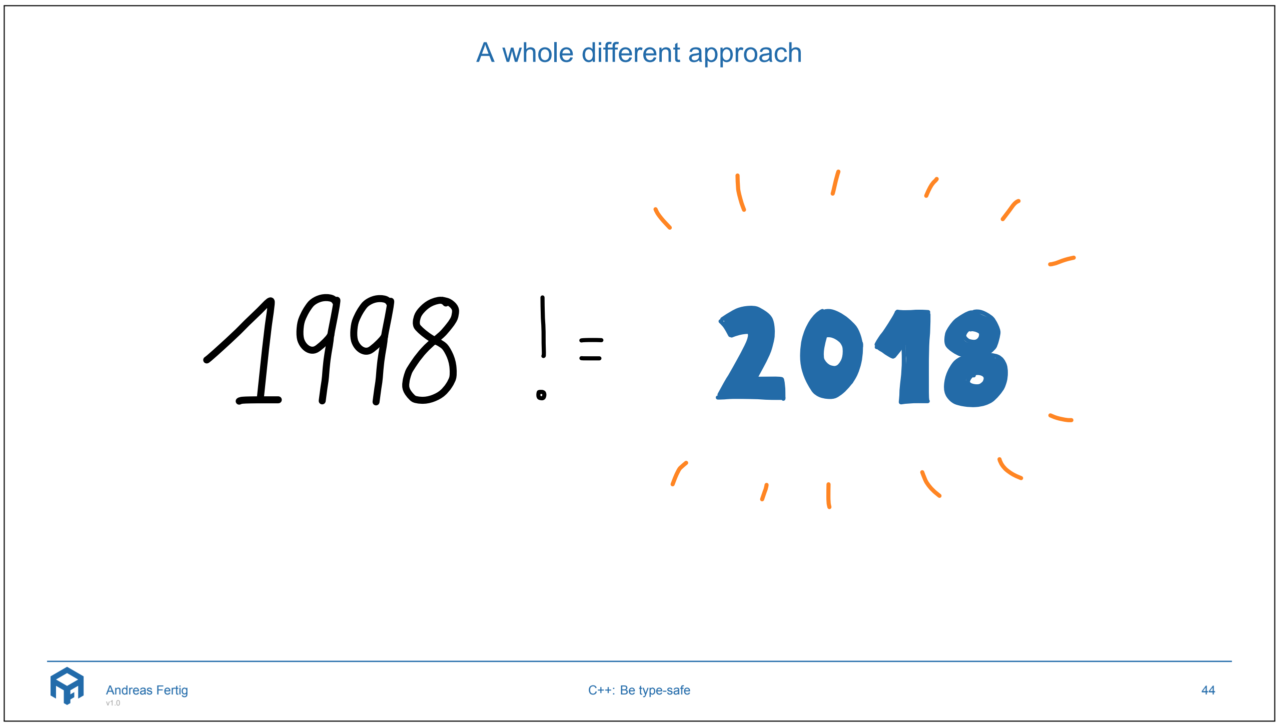

A whole different approach

1998 != 2018

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C++: Be type-safe

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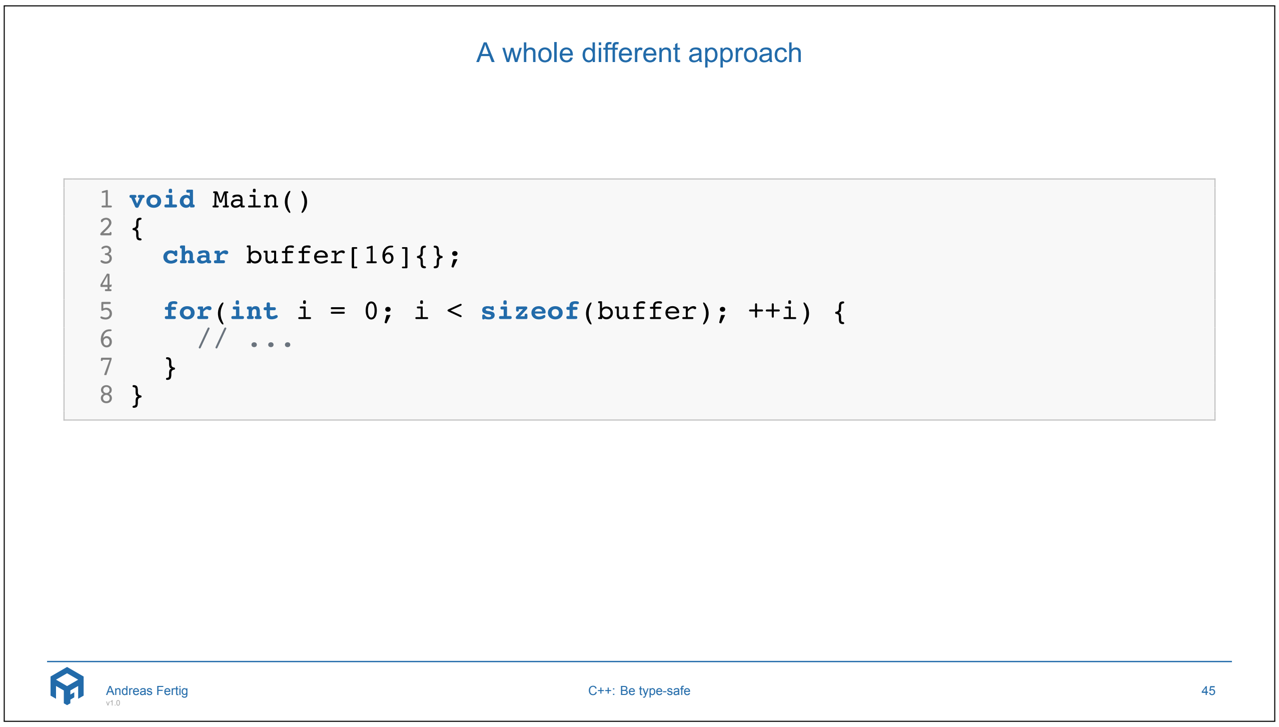
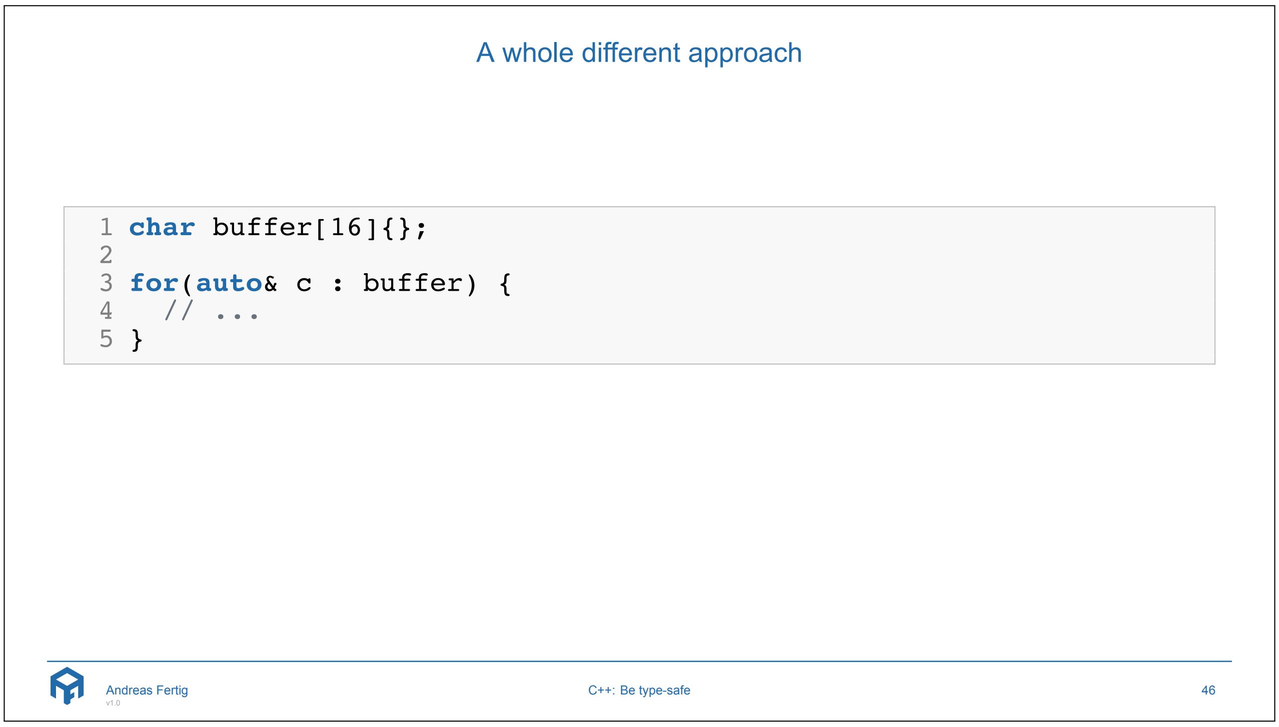


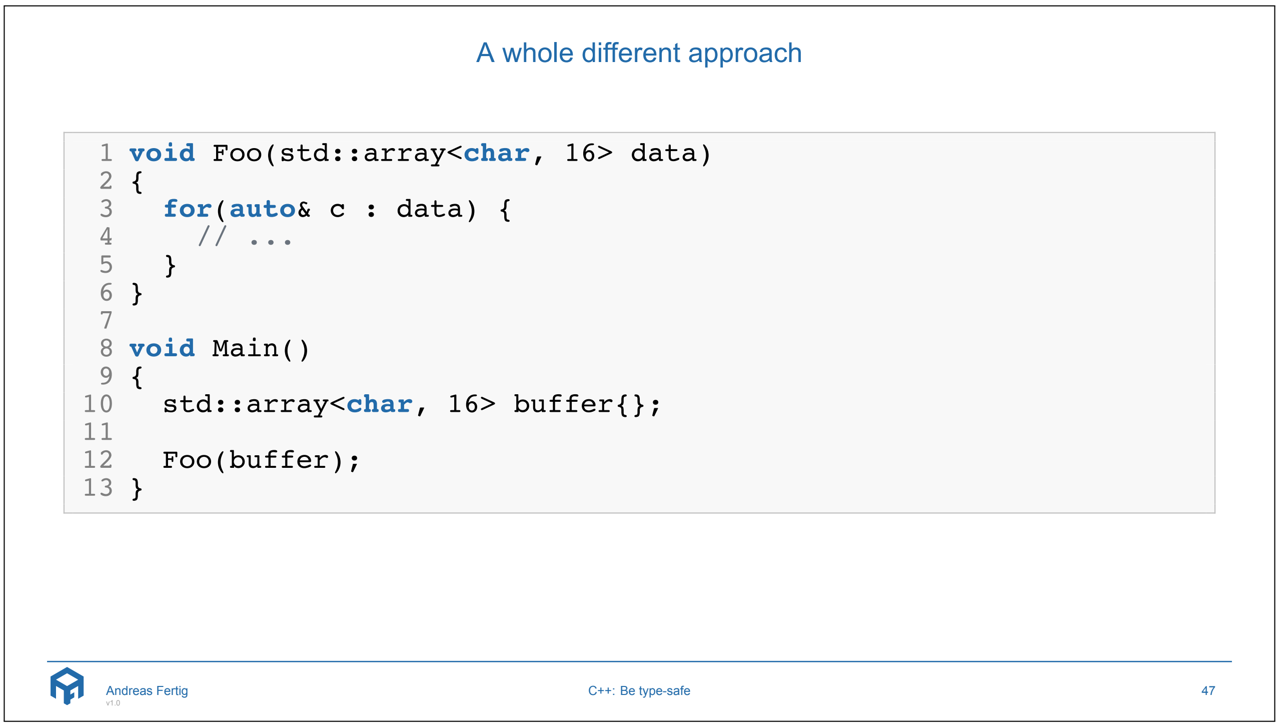
A whole different approach

```cpp
void Main()
{
  char buffer[16]{};

  for(int i = 0; i < sizeof(buffer); ++i) {
    // ...
  }
}
```



A whole different approach

```cpp
char buffer[16]{};

for(auto& c : buffer) {
  // ...
}
```



A whole different approach

```cpp
void Foo(std::array<char, 16> data)
{
  for(auto& c : data) {
    // ...
  }
}

void Main()
{
  std::array<char, 16> buffer{};

  Foo(buffer);
}
```

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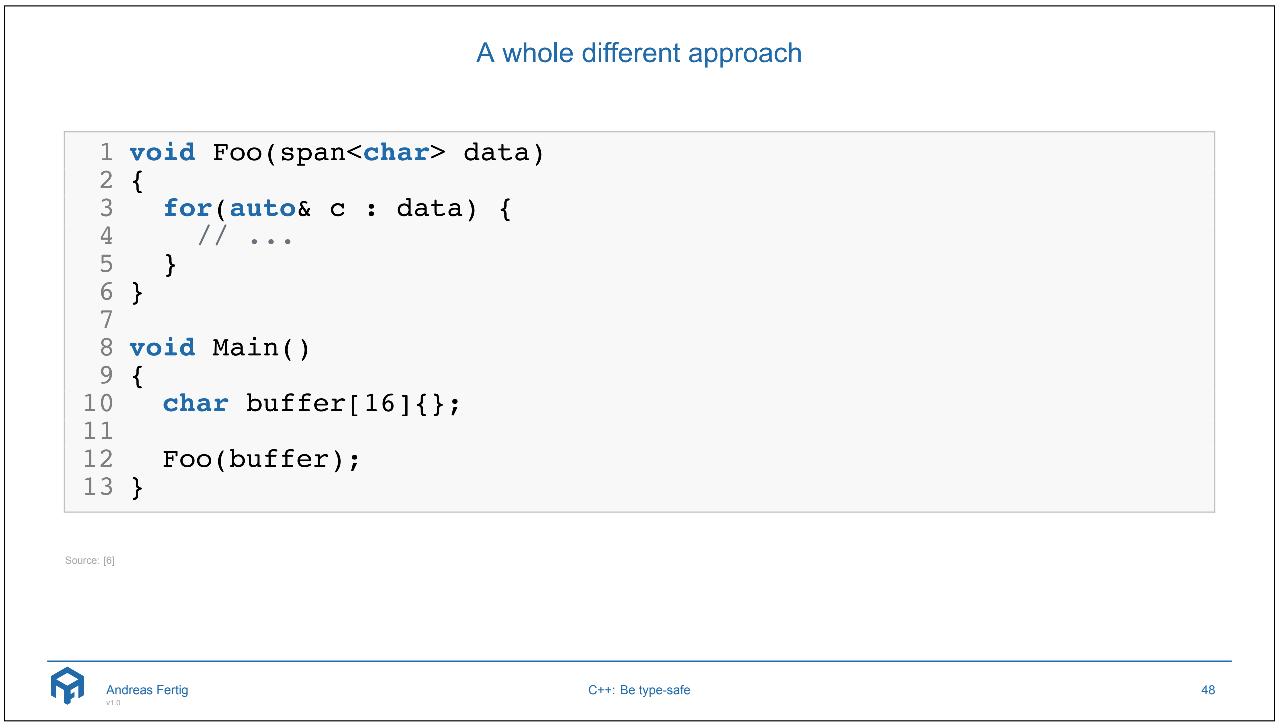

A whole different approach

```cpp
void Foo(span<char> data)
{
  for(auto& c : data) {
    // ...
  }
}

void Main()
{
  char buffer[16]{};

  Foo(buffer);
}
```

Source: [6]

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Be

MODERN!

}

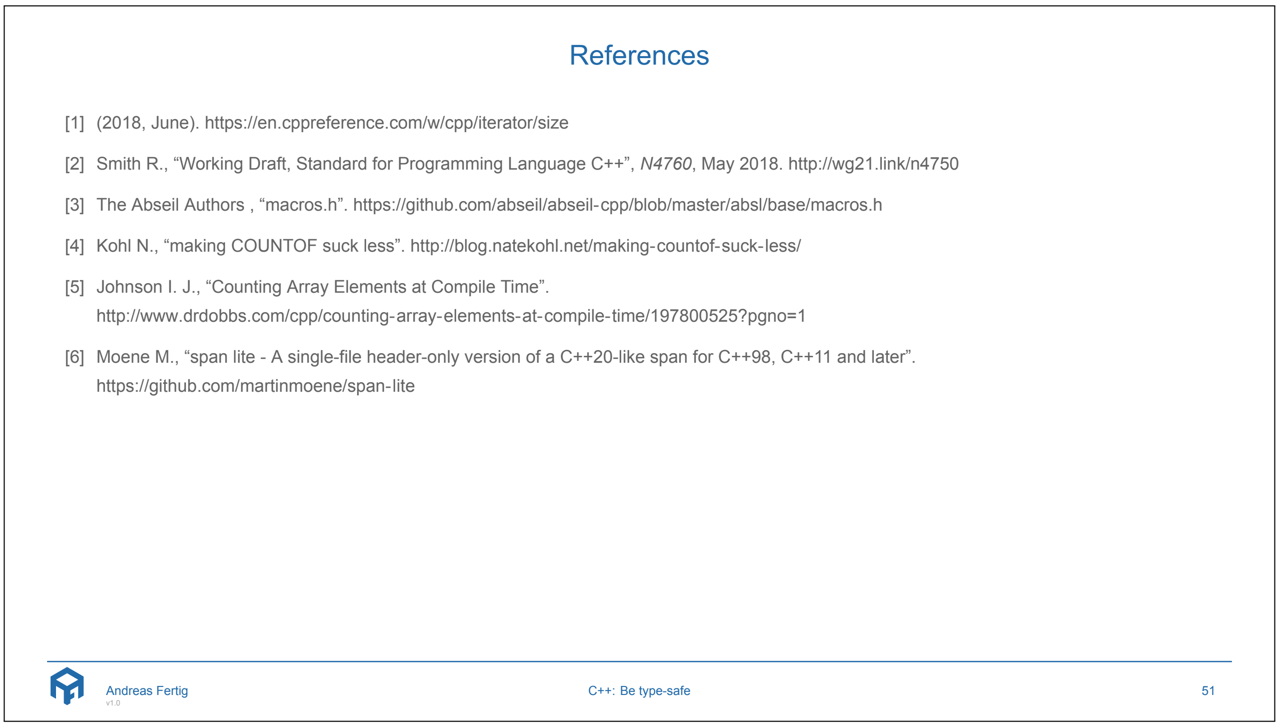
Ich bin Fertig.

Available online:

https://www.AndreasFertig.Info

Images by Franziska Panter:

https://panther-concepts.de



References

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[3] The Abseil Authors , “macros.h”. https://github.com/abseil/abseil-cpp/blob/master/absl/base/macros.h

[4] Kohl N., “making COUNTOF suck less”. http://blog.natekohl.net/making-countof-suck-less/

[5] Johnson I. J., “Counting Array Elements at Compile Time”. http://www.drdobbs.com/cpp/counting-array-elements-at-compile-time/197800525?pgno=1

[6] Moene M., “span lite - A single-file header-only version of a C++20-like span for C++98, C++11 and later”. https://github.com/martinmoene/span-lite

References

Images:

2: Franziska Panter
11: Franziska Panter
12: Franziska Panter
15: Franziska Panter
16: Franziska Panter
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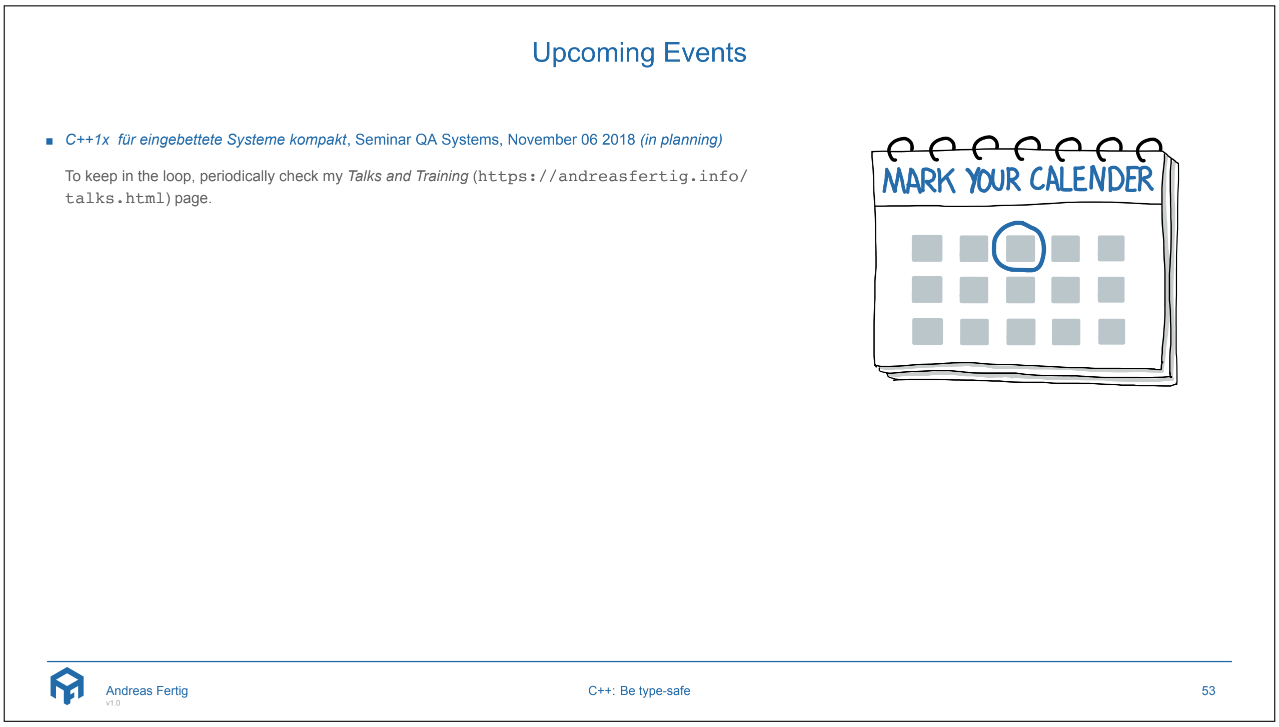
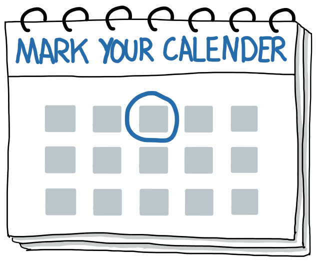
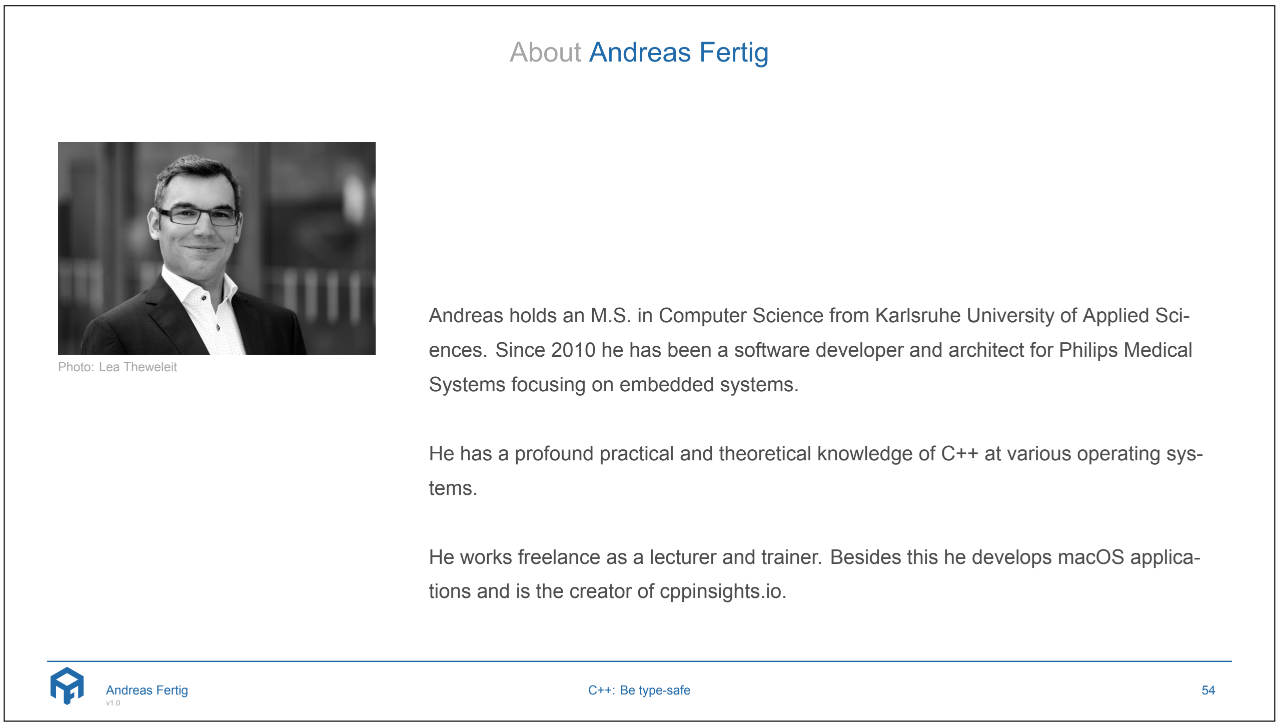


Upcoming Events

- *C++1x für eingebettete Systeme kompakt*, Seminar QA Systems, November 06 2018 *(in planning)*

To keep in the loop, periodically check my *Talks and Training* (`https://andreasfertig.info/talks.html`) page.





About Andreas Fertig

Photo: Lea Theweleit

Andreas holds an M.S. in Computer Science from Karlsruhe University of Applied Sciences. Since 2010 he has been a software developer and architect for Philips Medical Systems focusing on embedded systems.

He has a profound practical and theoretical knowledge of C++ at various operating systems.

He works freelance as a lecturer and trainer. Besides this he develops macOS applications and is the creator of cppinsights.io.