四川大學
SICHUAN UNIVERSITY

Object Oriented Programming—C++
Lecture3 Initialization & References

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Course Overview

周次	日期	理论课主题	上机课（4-13周）	内容
1（校历第2周）	2月28日	Introduction		
2（校历第3周）	3月7日	Types and Structs Initialization and References Streams Containers Iterators and Pointers	To be announced at Week 4	Features of C++
3（校历第4周）	3月14日			
4（校历第5周）	3月21日			
5（校历第6周）	3月28日			
6（校历第7周）	4月4日	Quiz I & Mid-Term Review		
7（校历第8周）	4月11日	Classes Template Classes Template Functions Functions and Algorithms Operator Overloading Special Member Functions		Object Oriented Programming (OOP)
8（校历第9周）	4月18日			
9（校历第10周）	4月25日			
10（校历第11周）	5月2日			
11（校历第12周）	5月9日			
12（校历第13周）	5月16日	Quiz II		
13（校历第14周）	5月23日	Move Semantics		Advanced Features of C++
14（校历第15周）	5月30日	Type Safety		
15（校历第16周）	6月6日	Final Review		

Acknowledgement: Materials of this course are mainly adapted from CS106L / 106B @ Stanford.

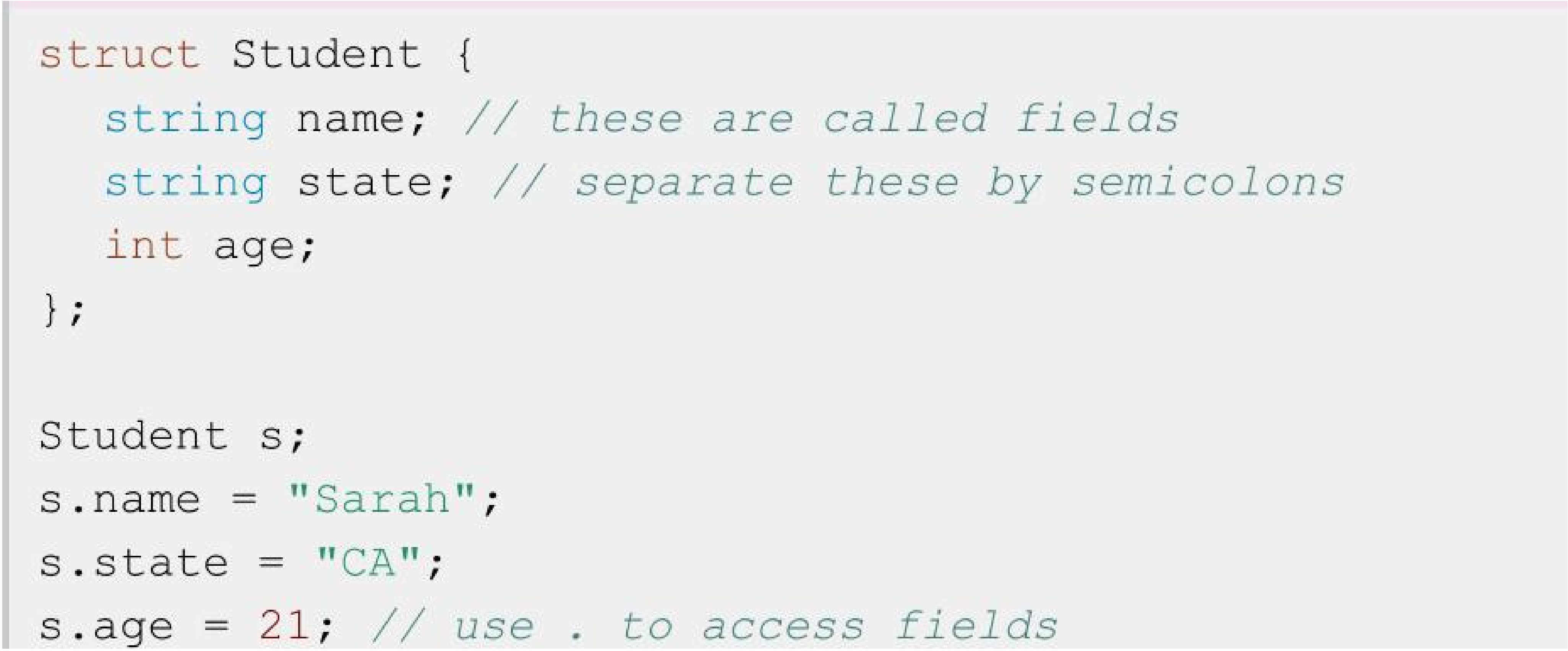
Today

- **Initialization**
- Using auto
- References
- If time: Const

Definition

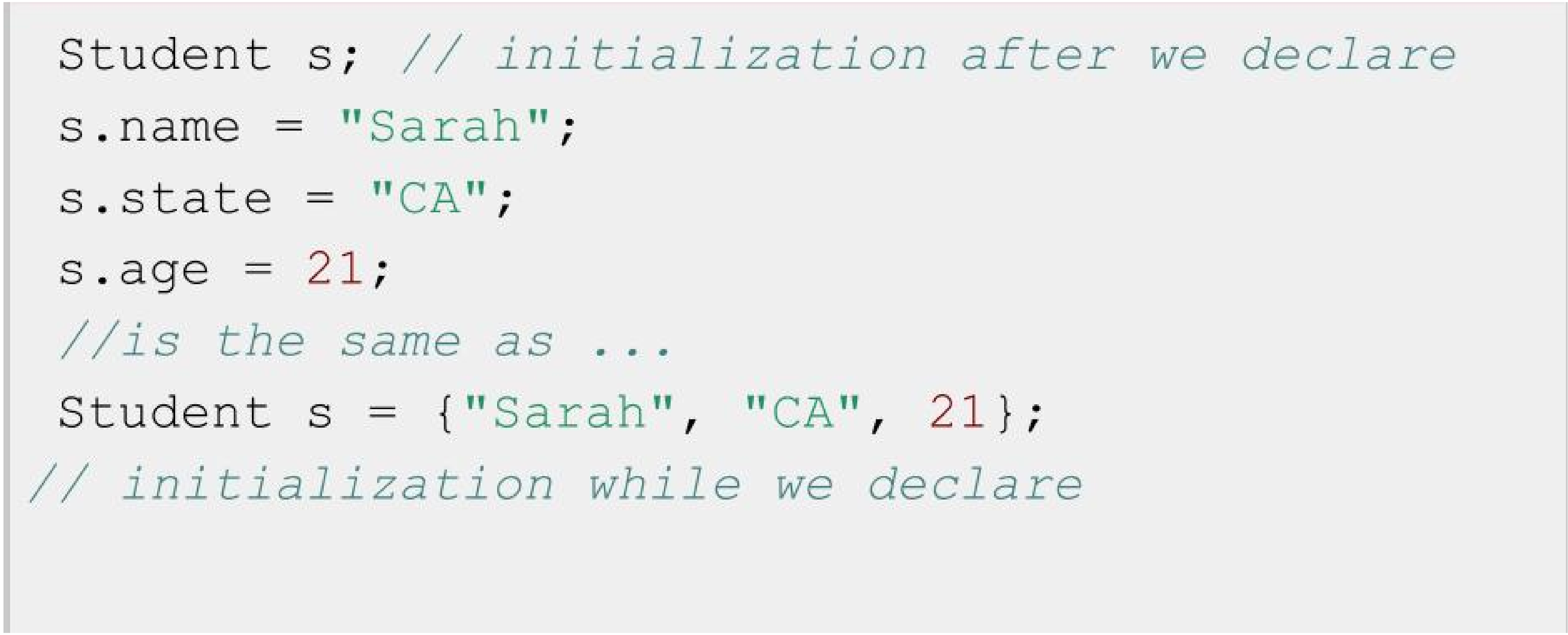
Initialization: How we provide initial values to variables

Reminder: Structs in Code



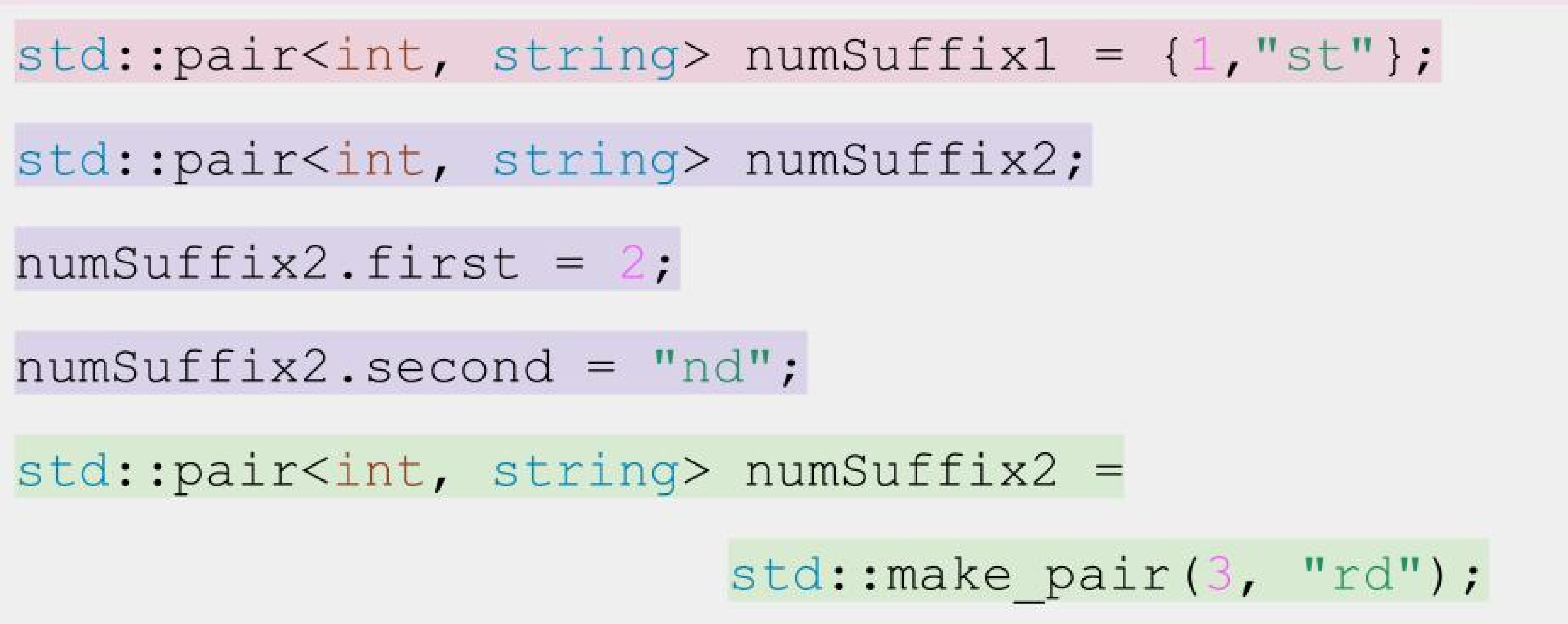
```
struct Student {
  string name; // these are called fields
  string state; // separate these by semicolons
  int age;
};

Student s;
s.name = "Sarah";
s.state = "CA";
s.age = 21; // use . to access fields
```

Recall: Two ways to initialize a struct



```
 Student s; // initialization after we declare
 s.name = "Sarah";
 s.state = "CA";
 s.age = 21;
 //is the same as ...
 Student s = {"Sarah", "CA", 21};
// initialization while we declare
```

Multiple ways to initialize a pair...

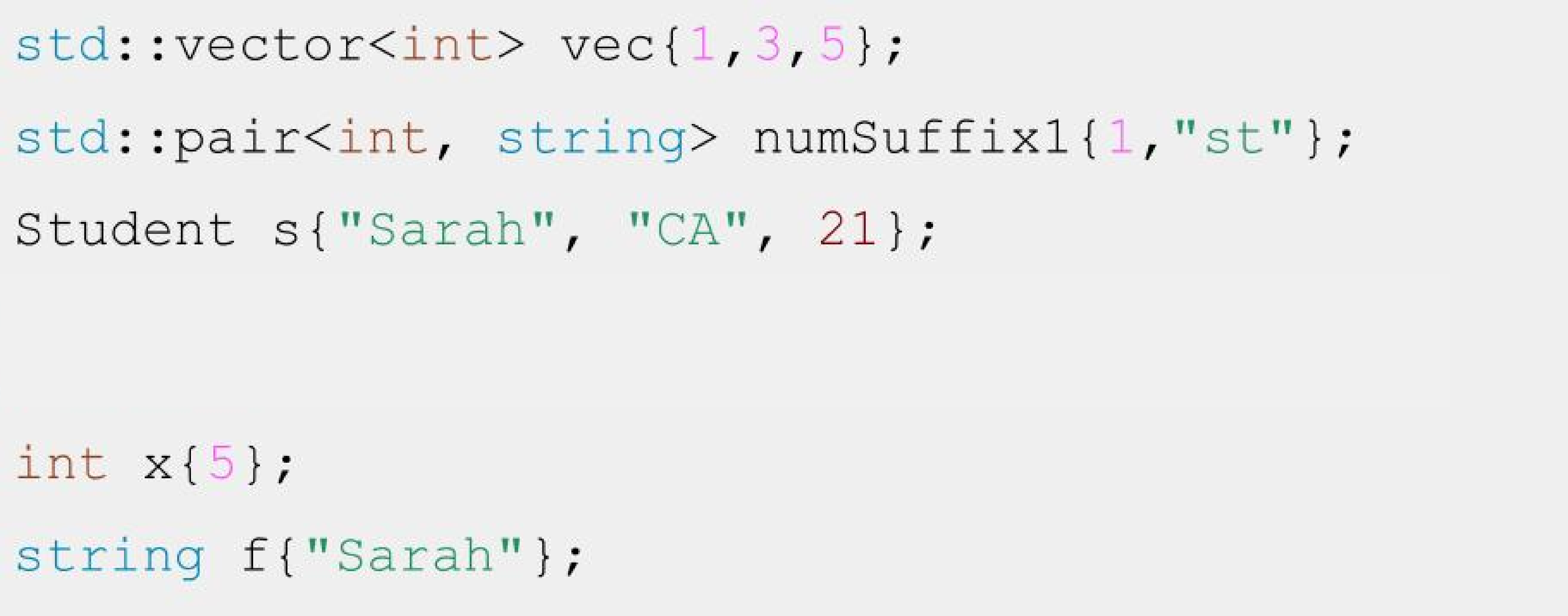


```
std::pair<int, string> numSuffix1 = {1,"st"};

std::pair<int, string> numSuffix2;

numSuffix2.first = 2;

numSuffix2.second = "nd";

std::pair<int, string> numSuffix2 =

                       std::make_pair(3, "rd");
```

Definition

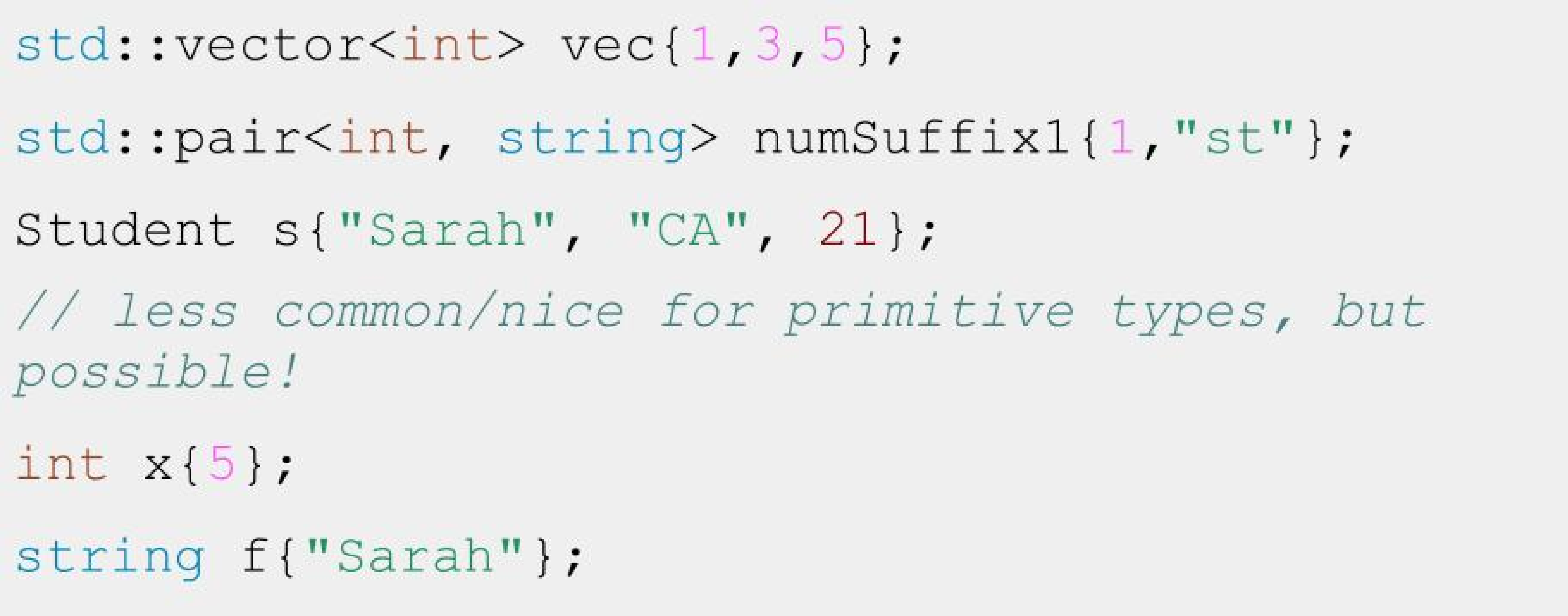
Uniform initialization: curly bracket {...} initialization. Available for all types, immediate initialization on declaration!

Uniform Initialization



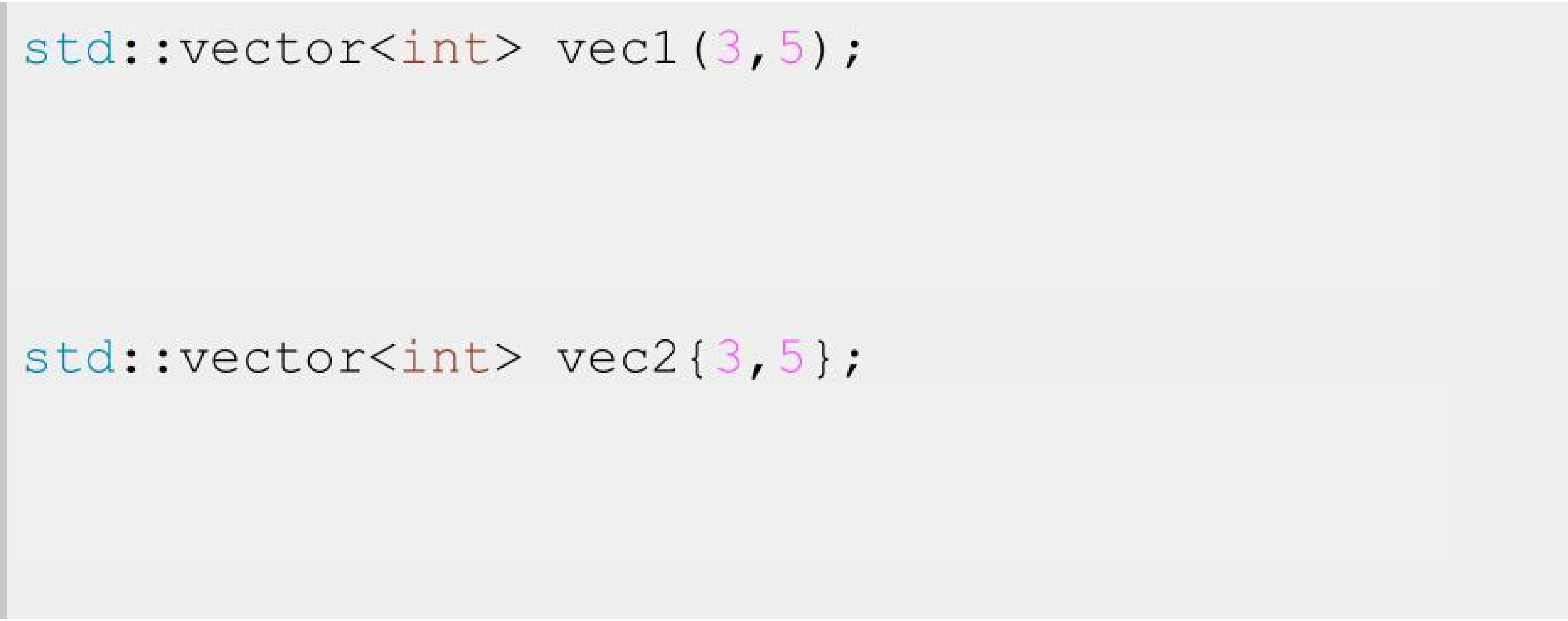
```
std::vector<int> vec{1,3,5};
std::pair<int, string> numSuffix1{1,"st"};
Student s{"Sarah", "CA", 21};


int x{5};
string f{"Sarah"};
```

Uniform Initialization



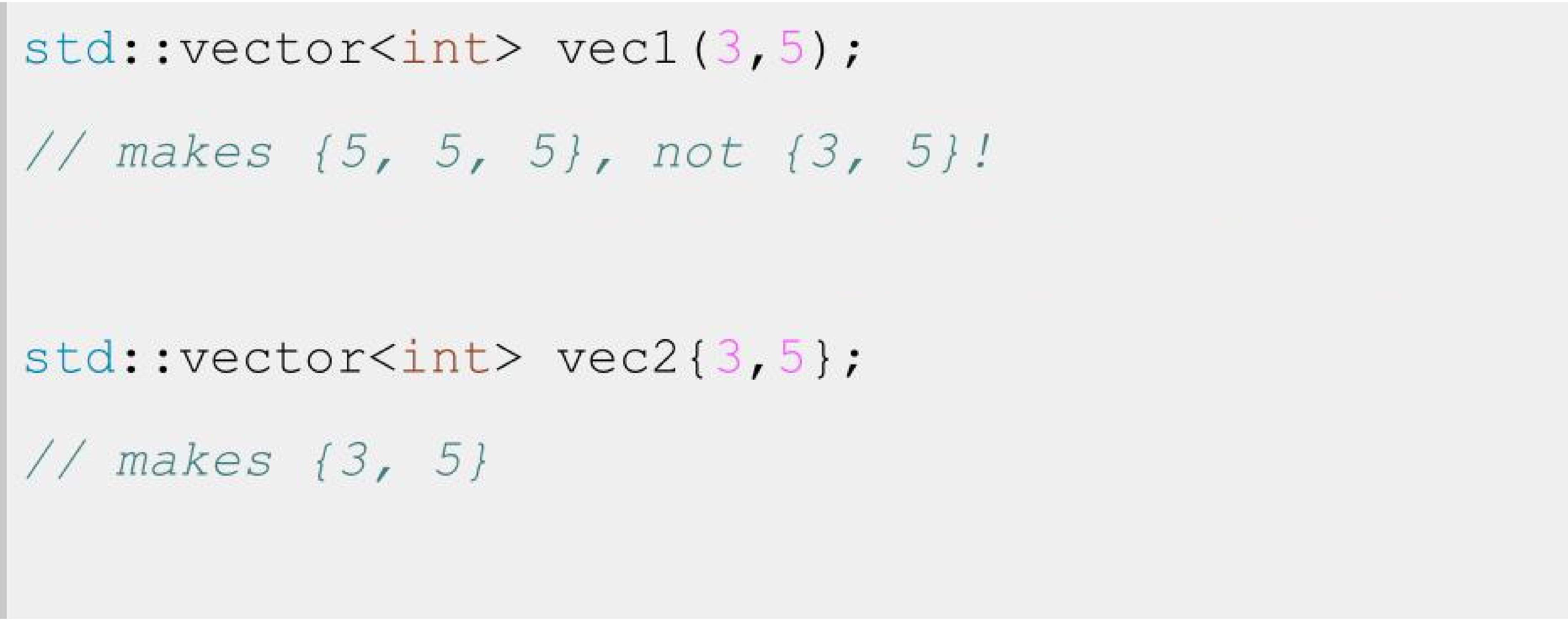
```
std::vector<int> vec{1,3,5};

std::pair<int, string> numSuffix1{1,"st"};

Student s{"Sarah", "CA", 21};

// less common/nice for primitive types, but
possible!

int x{5};

string f{"Sarah"};
```

Careful with Vector initialization!



```
std::vector<int> vec1(3,5);



std::vector<int> vec2{3,5};
```

Careful with Vector initialization!



```
std::vector<int> vec1(3,5);
// makes {5, 5, 5}, not {3, 5}!


std::vector<int> vec2{3,5};
// makes {3, 5}
```

TLDR: use uniform initialization to initialize **every field** of your non-primitive typed variables

- but be careful not to use vec(n, k)!

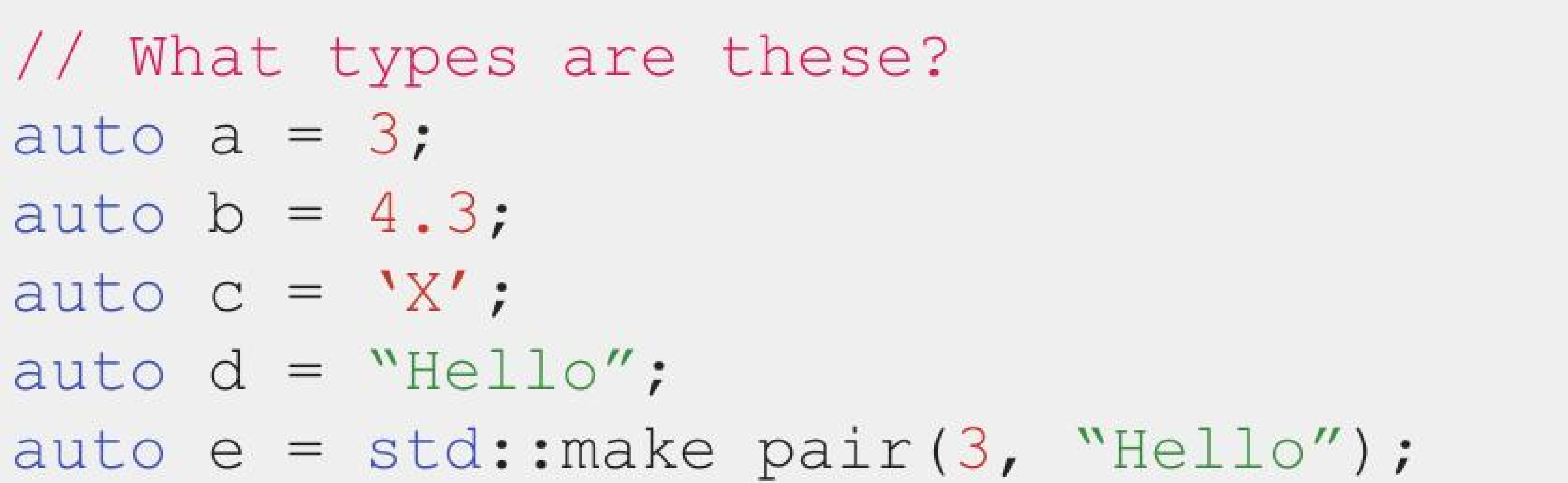
Today

- Initialization
- **Using auto**
- References
- If time: Const

Recap: Type Deduction with auto

auto: Keyword used in lieu of type when declaring a variable, tells the compiler to deduce the type.

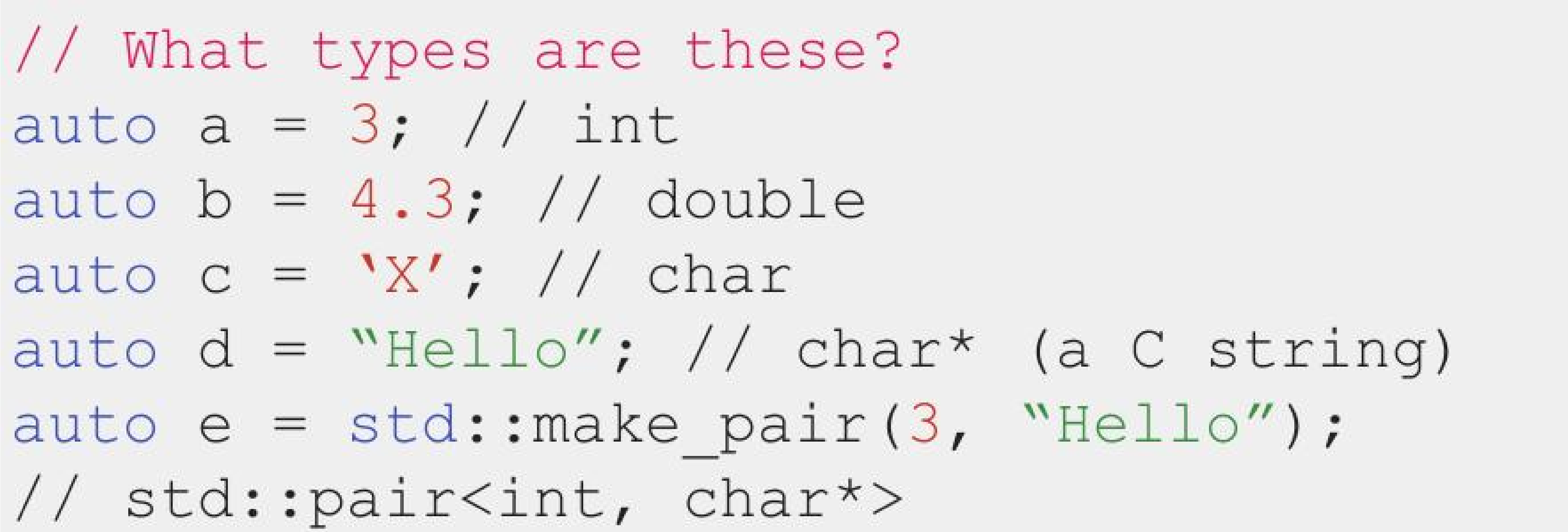
Type Deduction using auto



```
// What types are these?
auto a = 3;
auto b = 4.3;
auto c = ‘X’;
auto d = “Hello”;
auto e = std::make pair(3, “Hello”);
```

� **auto does not mean that the variable doesn’t have a type.**
It means that the type is **deduced** by the compiler.

Type Deduction using auto



```
// What types are these?
auto a = 3; // int
auto b = 4.3; // double
auto c = ‘X’; // char
auto d = “Hello”; // char* (a C string)
auto e = std::make_pair(3, “Hello”);
// std::pair<int, char*>
```

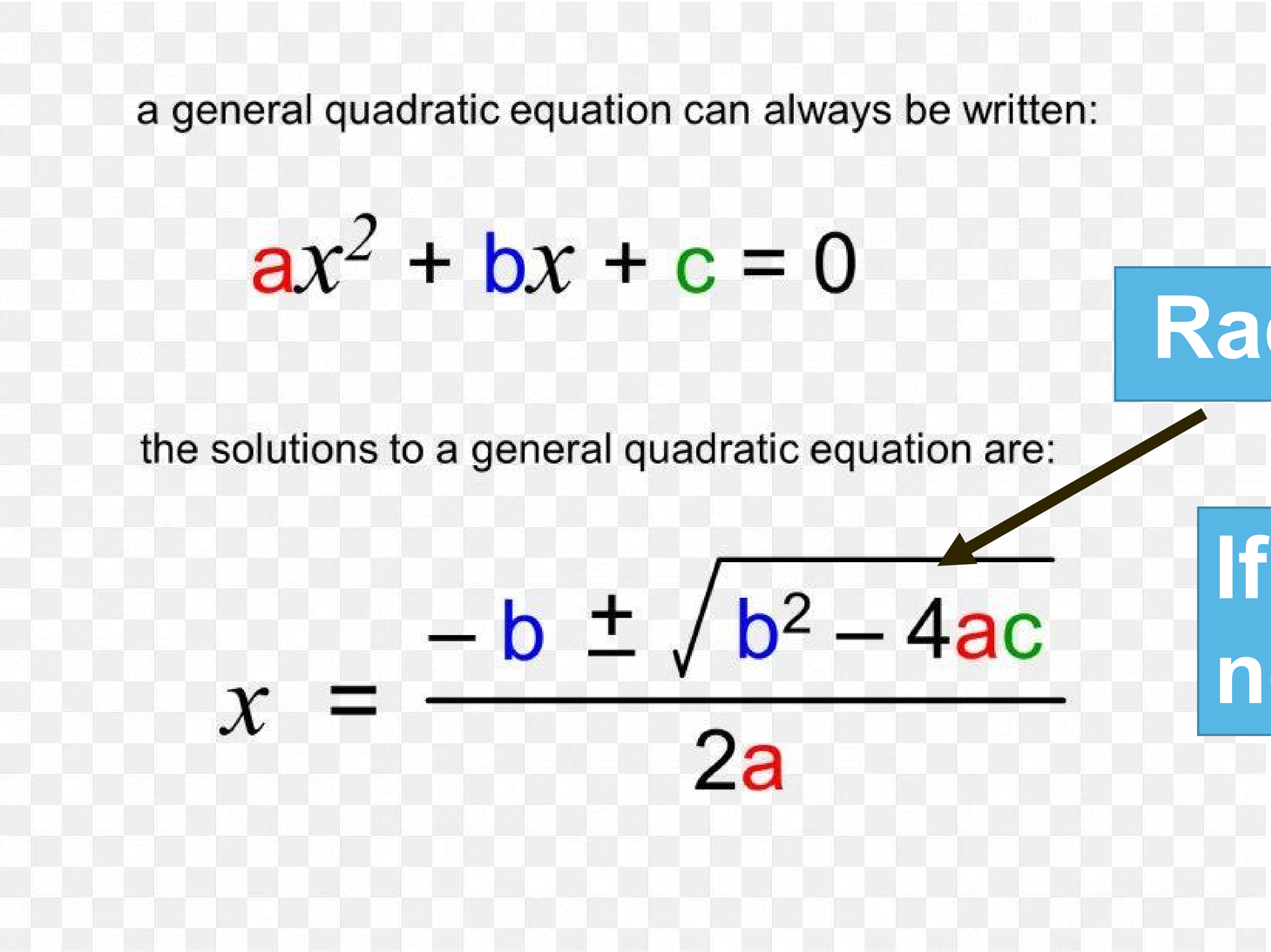
� **auto does not mean that the variable doesn’t have a type.**
It means that the type is **deduced** by the compiler.

! auto does not mean that the variable doesn’t have a type.

It means that the type is **deduced** by the compiler.

Code Demo!

quadratic.cpp



a general quadratic equation can always be written:

$$ax^2 + bx + c = 0$$

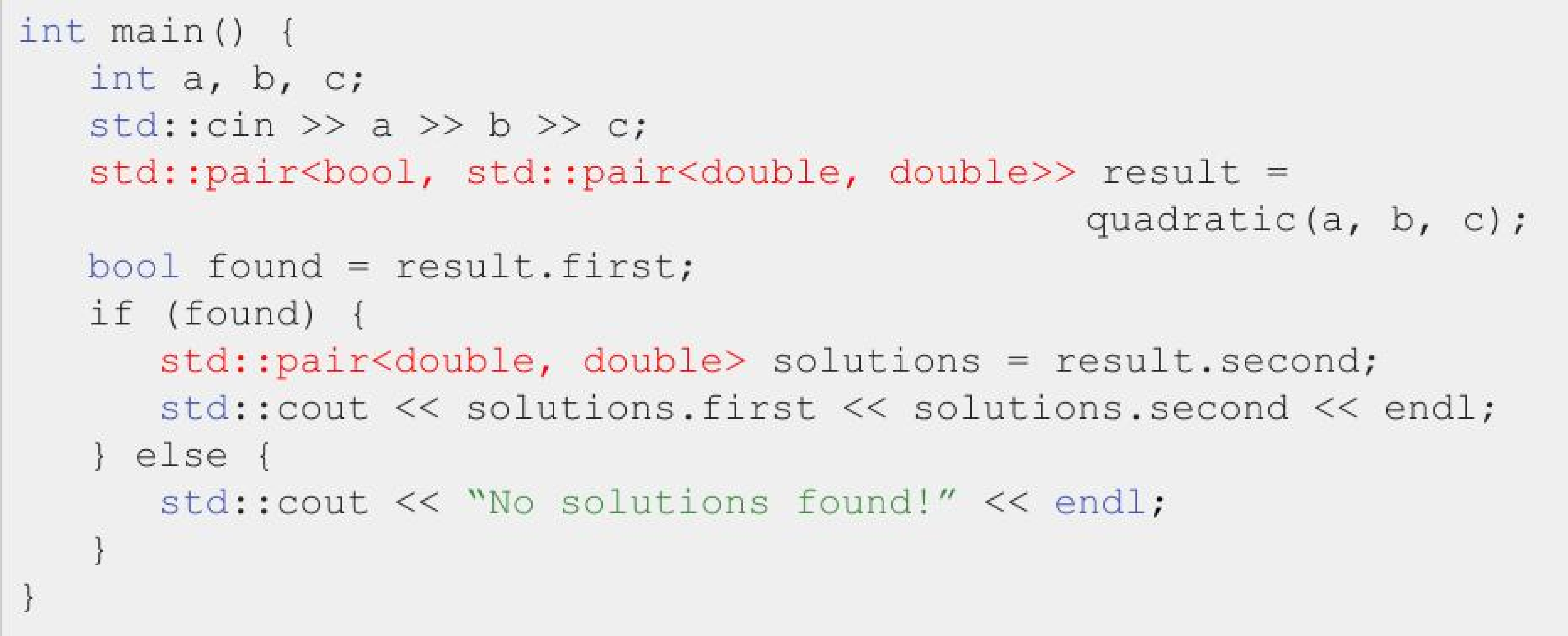
the solutions to a general quadratic equation are:

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

Radical

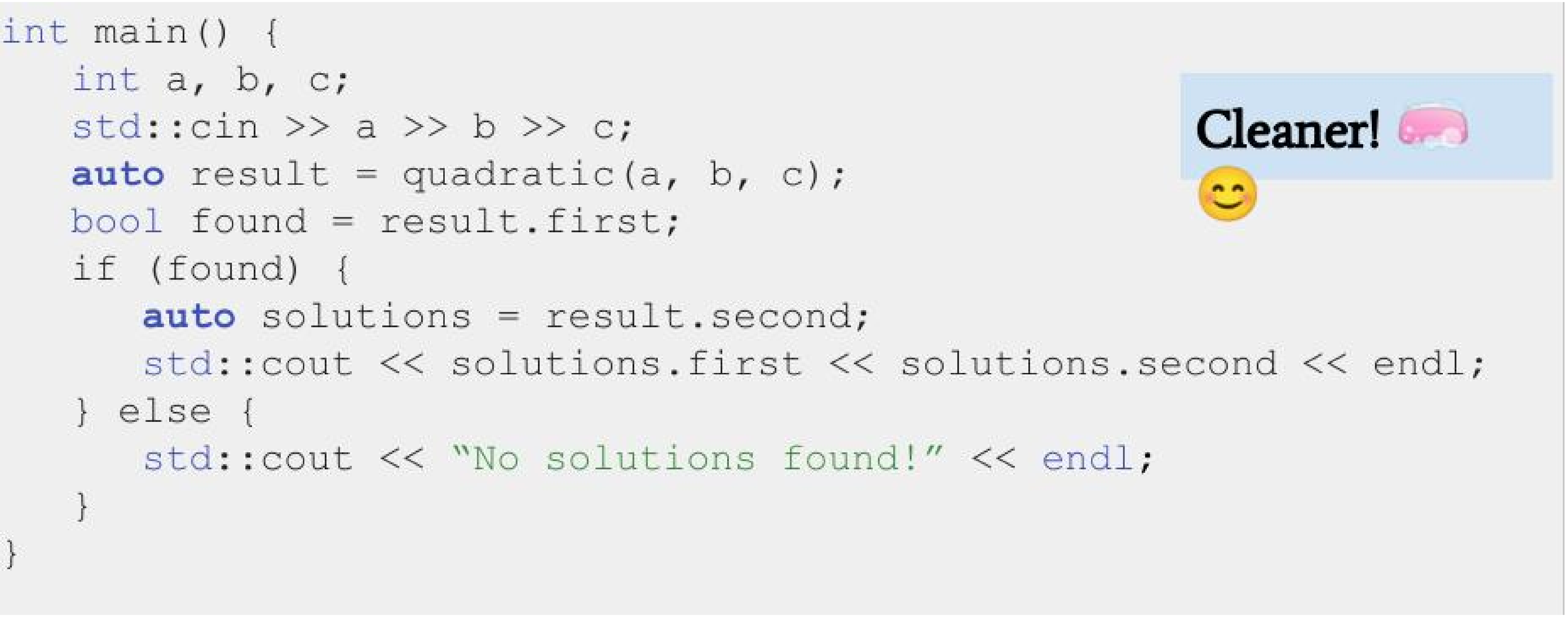
If Radical < 0, no real roots

Quadratic: Typing these types out is a pain…



```
int main() {
   int a, b, c;
   std::cin >> a >> b >> c;
   std::pair<bool, std::pair<double, double>> result =
                                             quadratic(a, b, c);
   bool found = result.first;
   if (found) {
      std::pair<double, double> solutions = result.second;
      std::cout << solutions.first << solutions.second << endl;
   } else {
      std::cout << “No solutions found!” << endl;
   }
}
```

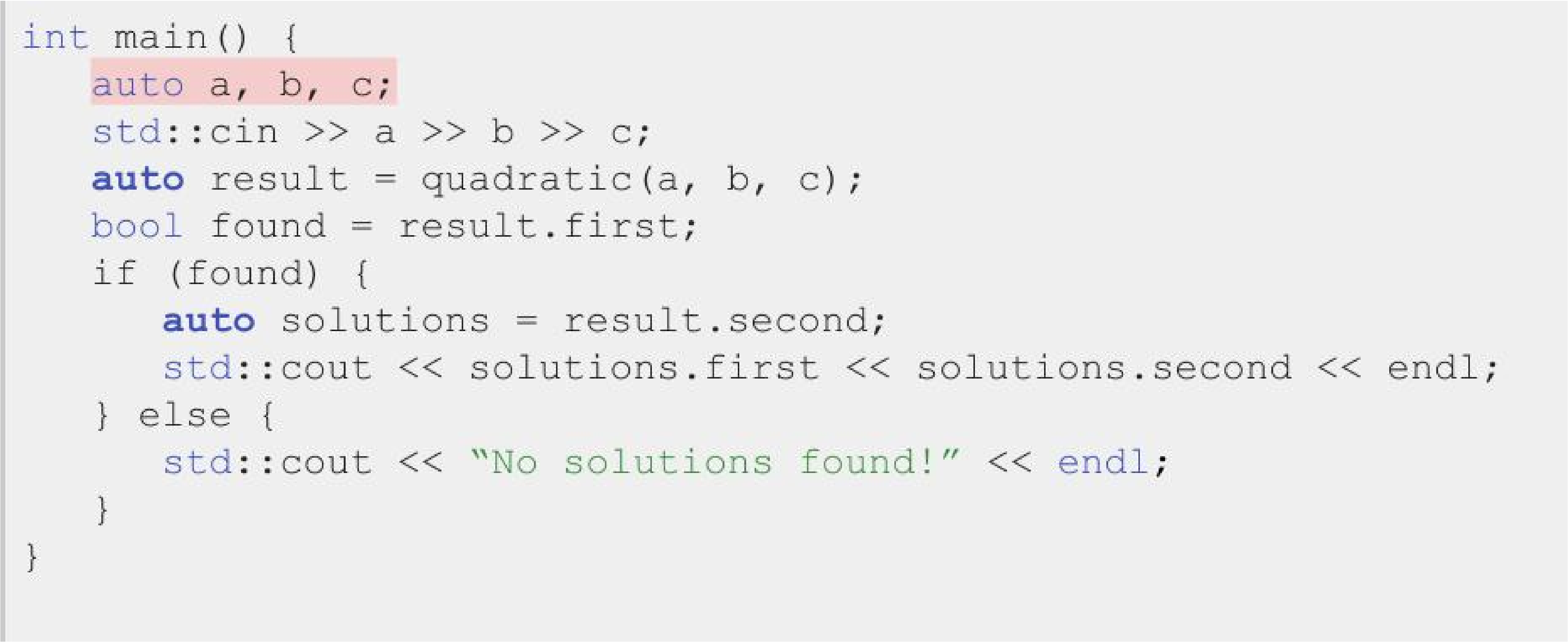
Quadratic: Typing these types out is a pain...



```cpp
int main() {
    int a, b, c;
    std::cin >> a >> b >> c;
    auto result = quadratic(a, b, c);
    bool found = result.first;
    if (found) {
        auto solutions = result.second;
        std::cout << solutions.first << solutions.second << endl;
    } else {
        std::cout << "No solutions found!" << endl;
    }
}
```

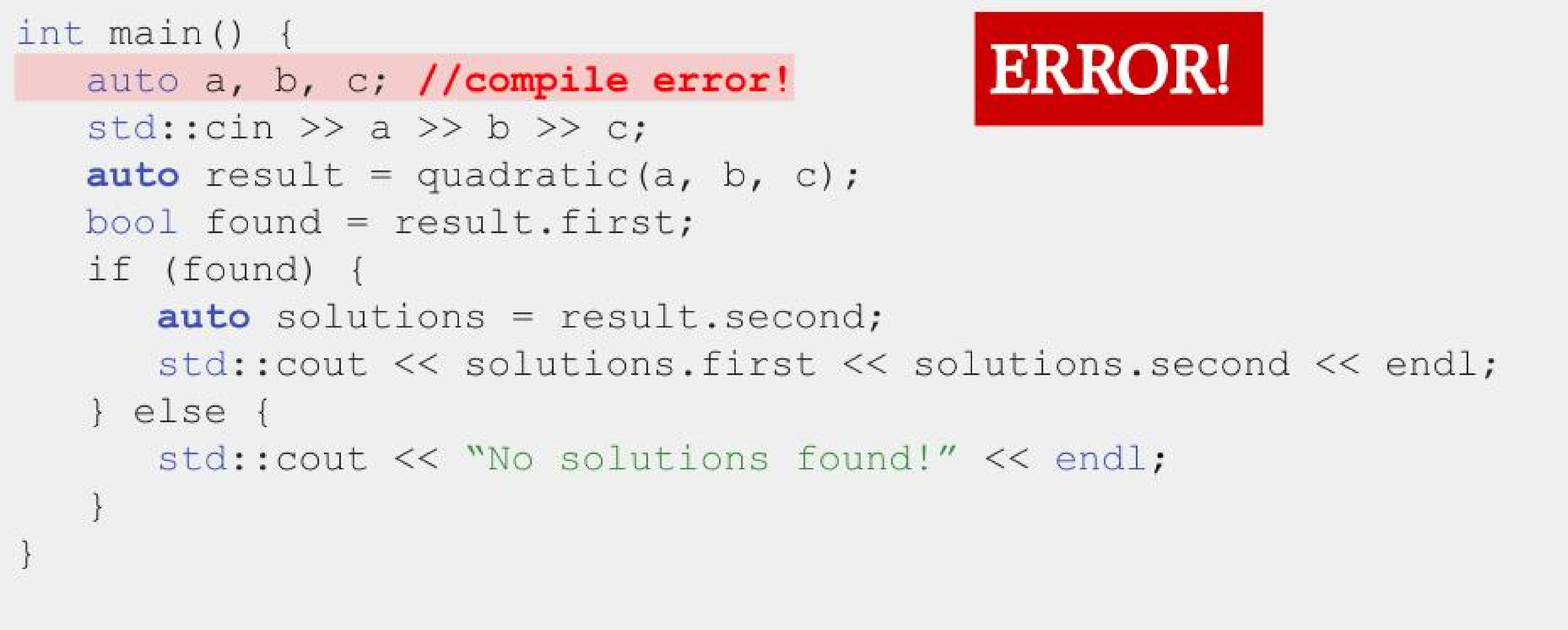
Cleaner! 🧼 😊

Don’t overuse auto!



```
int main() {
    auto a, b, c;
    std::cin >> a >> b >> c;
    auto result = quadratic(a, b, c);
    bool found = result.first;
    if (found) {
        auto solutions = result.second;
        std::cout << solutions.first << solutions.second << endl;
    } else {
        std::cout << “No solutions found!” << endl;
    }
}
```

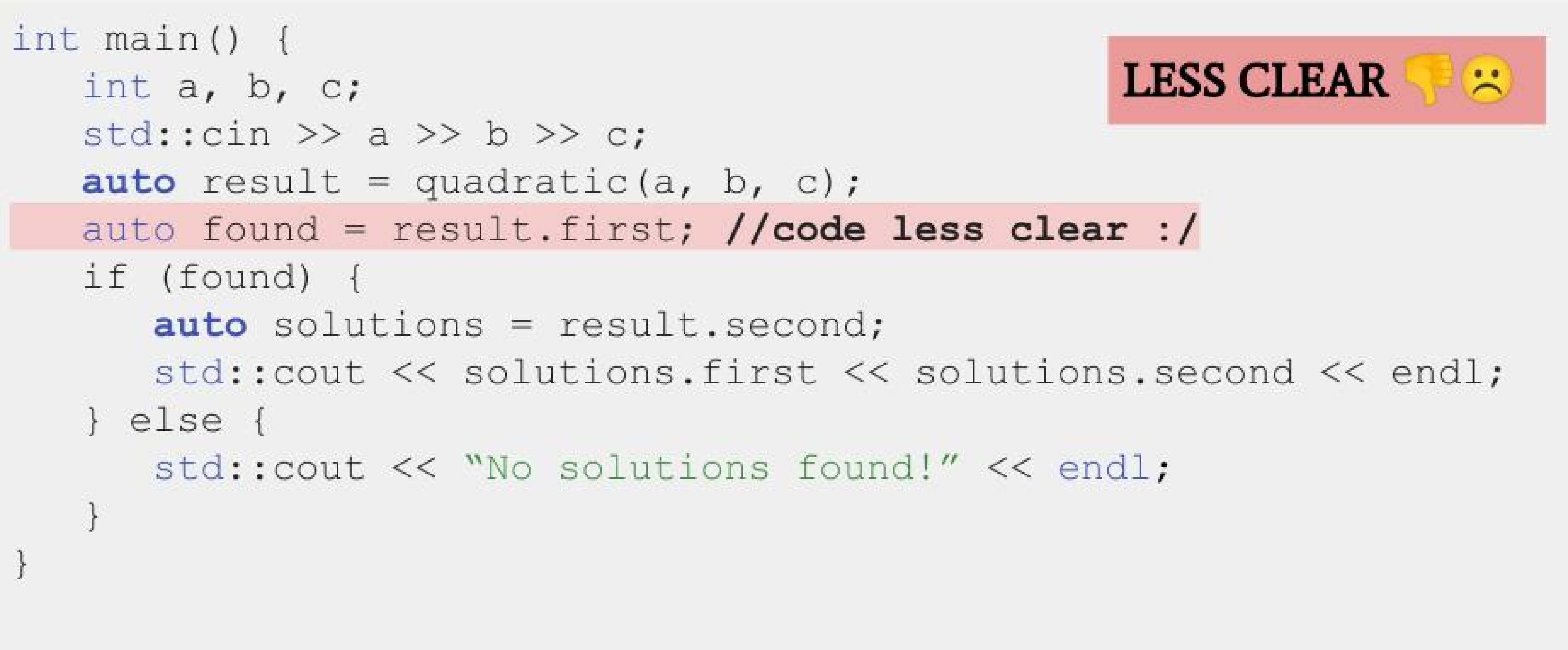
Can’t deduce the type b/c no value provided



ERROR!

```
int main() {
    auto a, b, c; //compile error!
    std::cin >> a >> b >> c;
    auto result = quadratic(a, b, c);
    bool found = result.first;
    if (found) {
        auto solutions = result.second;
        std::cout << solutions.first << solutions.second << endl;
    } else {
        std::cout << “No solutions found!” << endl;
    }
}
```

For simple types (like bool) type it out



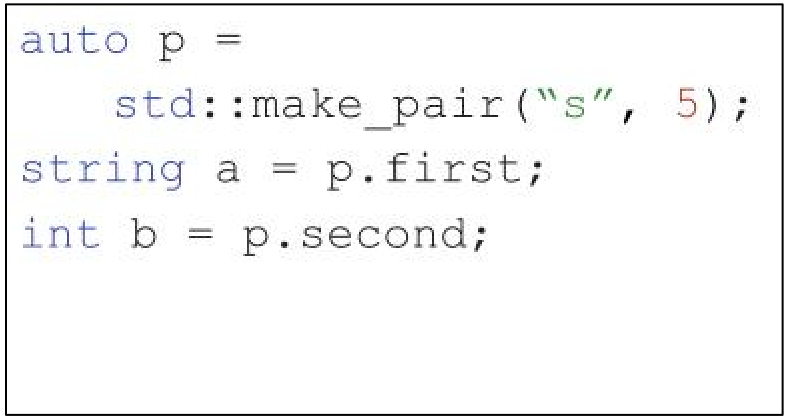
LESS CLEAR 👎☹

```
int main() {
   int a, b, c;
   std::cin >> a >> b >> c;
   auto result = quadratic(a, b, c);
   auto found = result.first; //code less clear :/
   if (found) {
      auto solutions = result.second;
      std::cout << solutions.first << solutions.second << endl;
   } else {
      std::cout << “No solutions found!” << endl;
   }
}
```

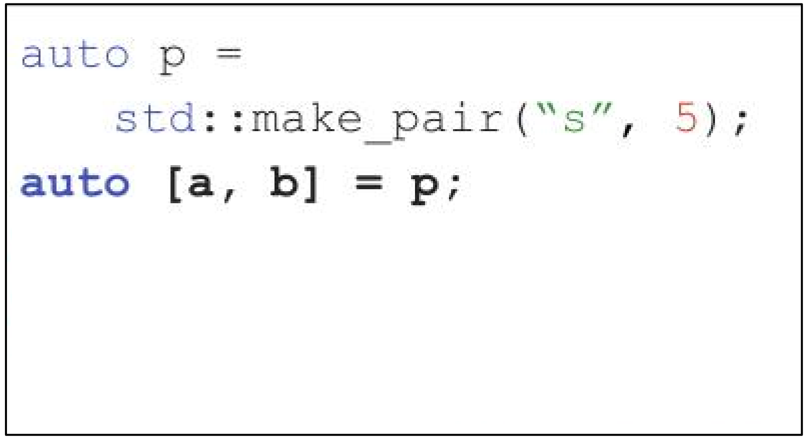
Don’t overuse auto

…but use it to reduce long type names

Structured Binding



```
auto p =
    std::make_pair(“s”, 5);
string a = p.first;
int b = p.second;
```

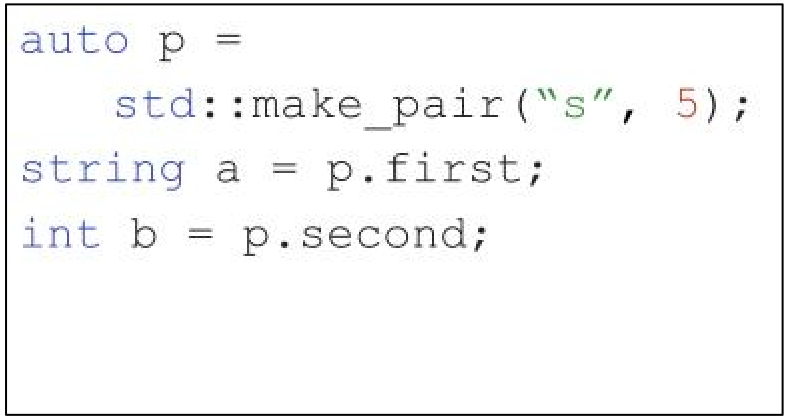


```
auto p =
    std::make_pair(“s”, 5);
auto [a, b] = p;
```

Structured Binding

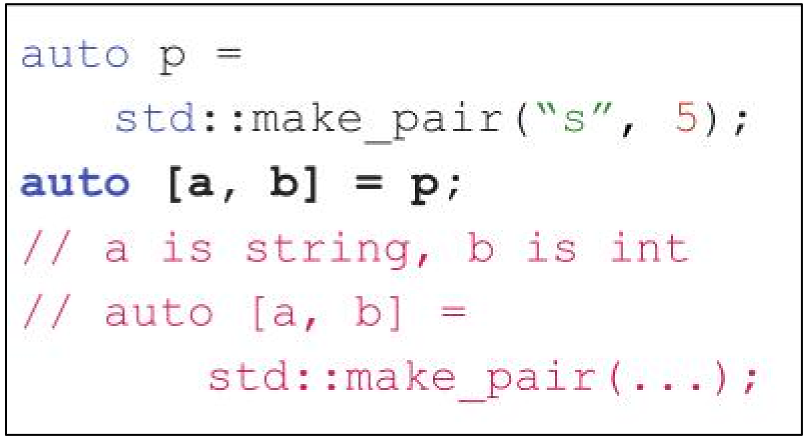
Structured binding lets you initialize directly from the contents of a struct

Before



```
auto p =
    std::make_pair("s", 5);
string a = p.first;
int b = p.second;
```

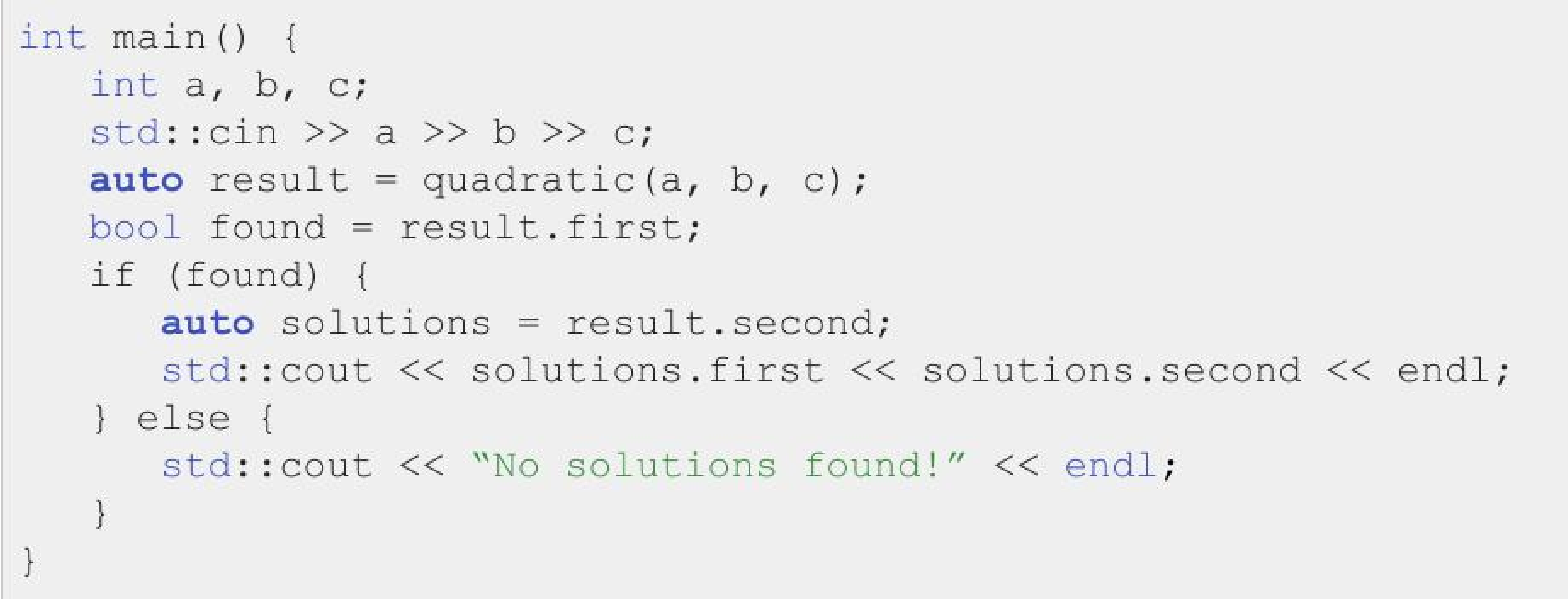
After



```
auto p =
    std::make_pair("s", 5);
auto [a, b] = p;
// a is string, b is int
// auto [a, b] =
        std::make_pair(...);
```

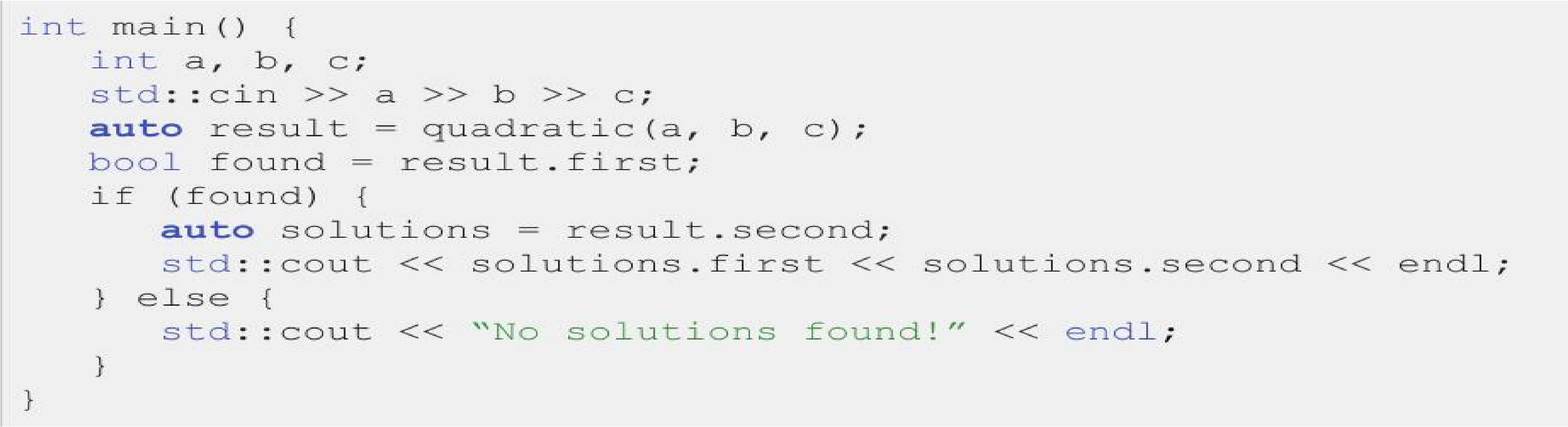
� This works for regular structs, too. Also, no nested structured binding.

A better way to use quadratic…

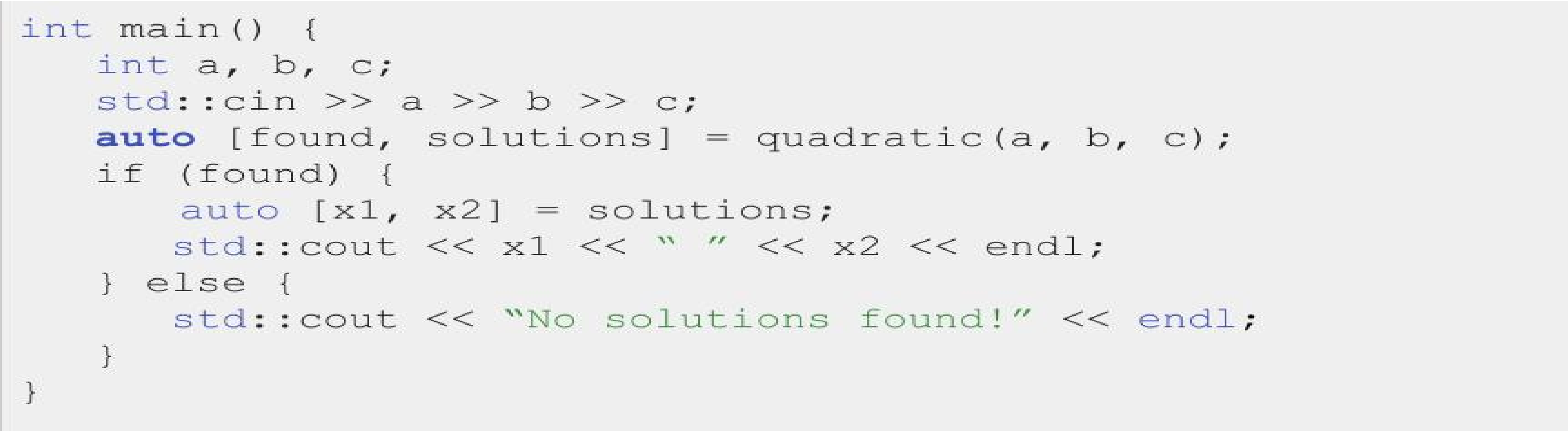


```cpp
int main() {
    int a, b, c;
    std::cin >> a >> b >> c;
    auto result = quadratic(a, b, c);
    bool found = result.first;
    if (found) {
        auto solutions = result.second;
        std::cout << solutions.first << solutions.second << endl;
    } else {
        std::cout << “No solutions found!” << endl;
    }
}
```

A better way to use quadratic…

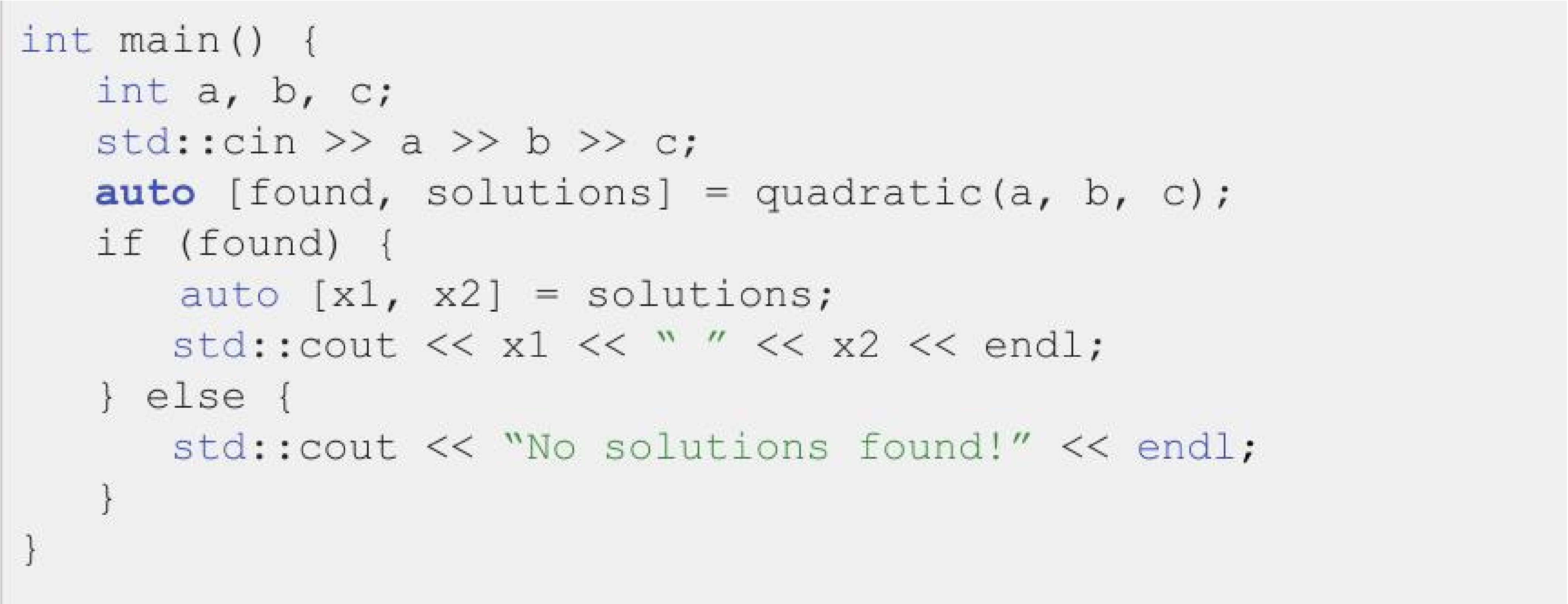


```cpp
int main() {
    int a, b, c;
    std::cin >> a >> b >> c;
    auto result = quadratic(a, b, c);
    bool found = result.first;
    if (found) {
        auto solutions = result.second;
        std::cout << solutions.first << solutions.second << endl;
    } else {
        std::cout << “No solutions found!” << endl;
    }
}
```



```cpp
int main() {
    int a, b, c;
    std::cin >> a >> b >> c;
    auto [found, solutions] = quadratic(a, b, c);
    if (found) {
        auto [x1, x2] = solutions;
        std::cout << x1 << “ ” << x2 << endl;
    } else {
        std::cout << “No solutions found!” << endl;
    }
}
```

Using Structured Binding



```
int main() {
    int a, b, c;
    std::cin >> a >> b >> c;
    auto [found, solutions] = quadratic(a, b, c);
    if (found) {
        auto [x1, x2] = solutions;
        std::cout << x1 << “ ” << x2 << endl;
    } else {
        std::cout << “No solutions found!” << endl;
    }
}
```

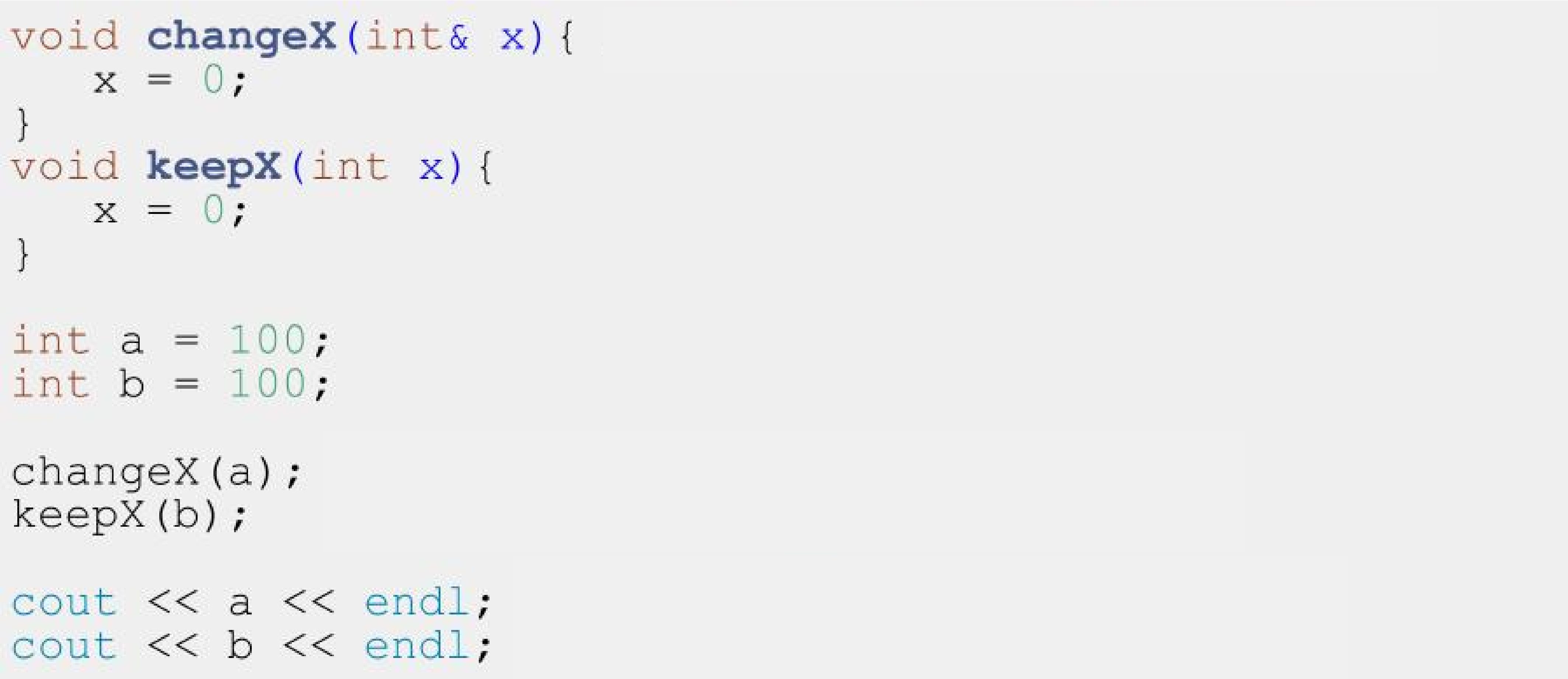
- This is better because it’s *semantically clearer*: variables have clear names.

Today

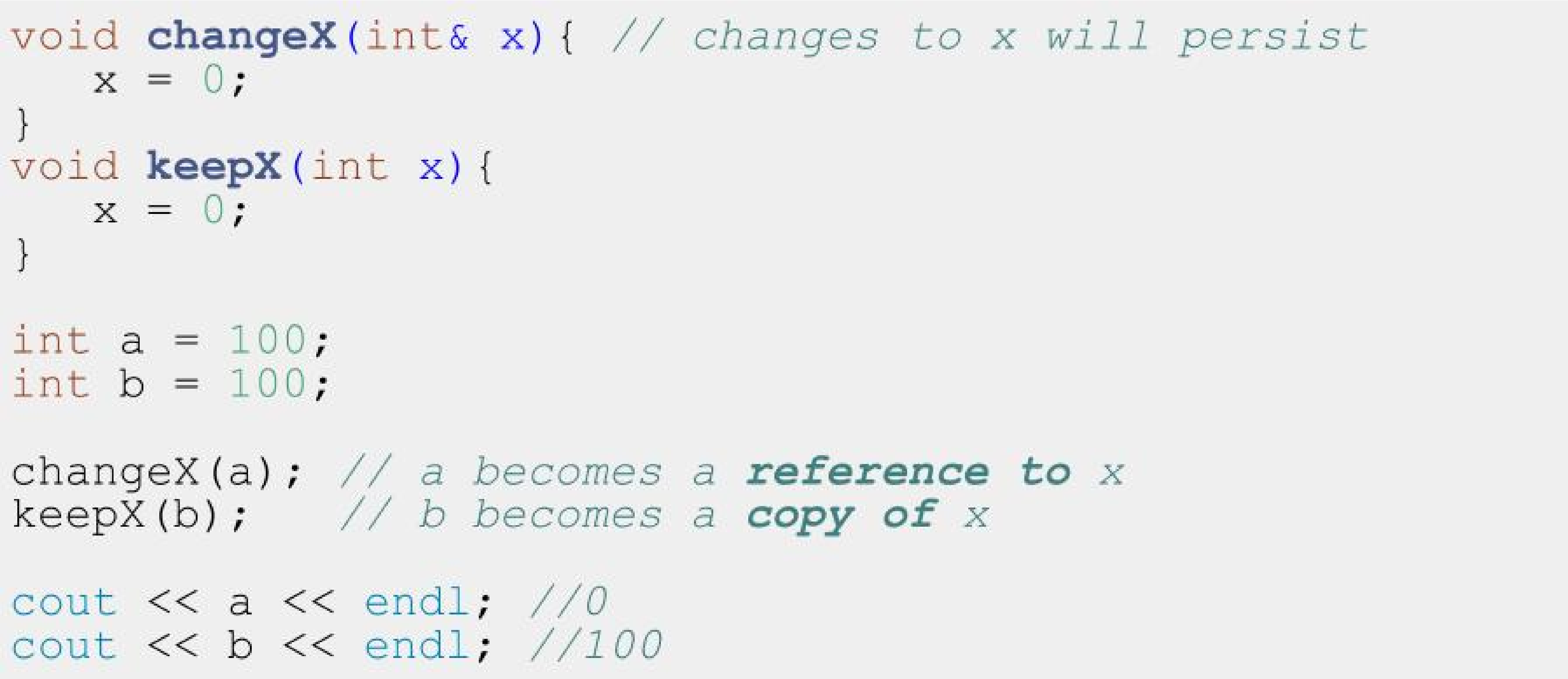
- Initialization
- Using auto
- **References**
- If time: Const

Definition

Reference: An alias (another name) for a named variable



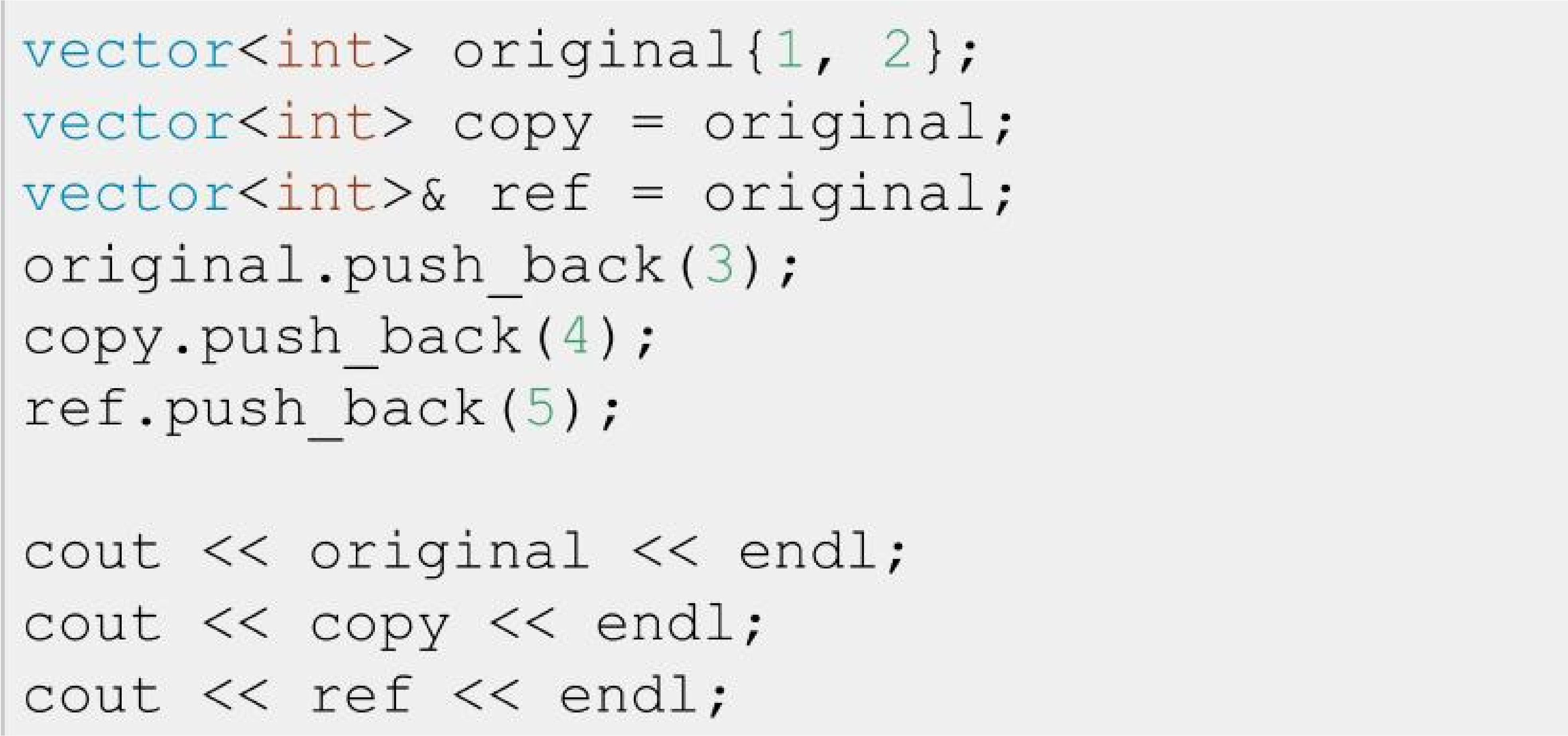
```
void changeX(int& x){
   x = 0;
}
void keepX(int x){
   x = 0;
}

int a = 100;
int b = 100;

changeX(a);
keepX(b);

cout << a << endl;
cout << b << endl;
```



```
void changeX(int& x){ // changes to x will persist
    x = 0;
}
void keepX(int x){
    x = 0;
}

int a = 100;
int b = 100;

changeX(a); // a becomes a reference to x
keepX(b);   // b becomes a copy of x

cout << a << endl; //0
cout << b << endl; //100
```

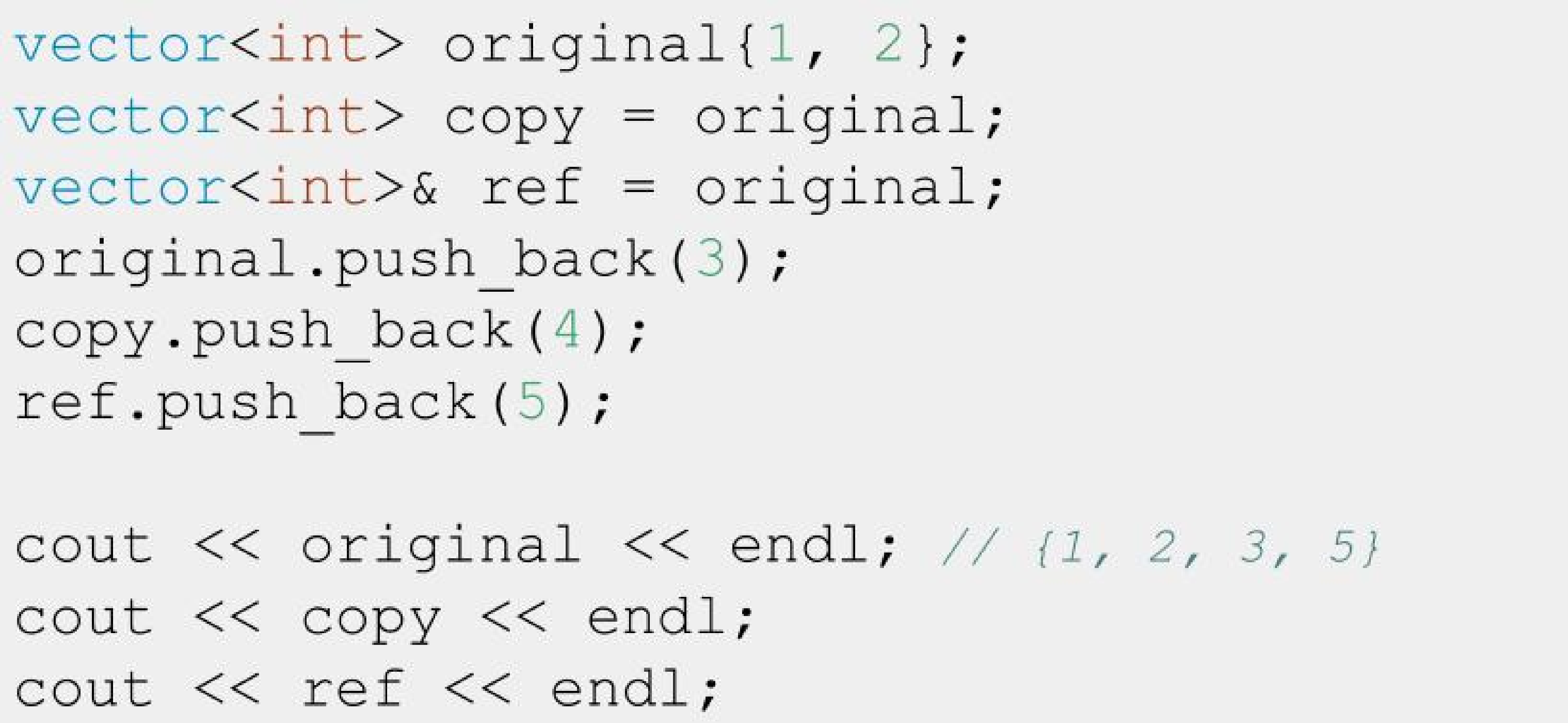
Standard C++ vector (intro)

References to variables



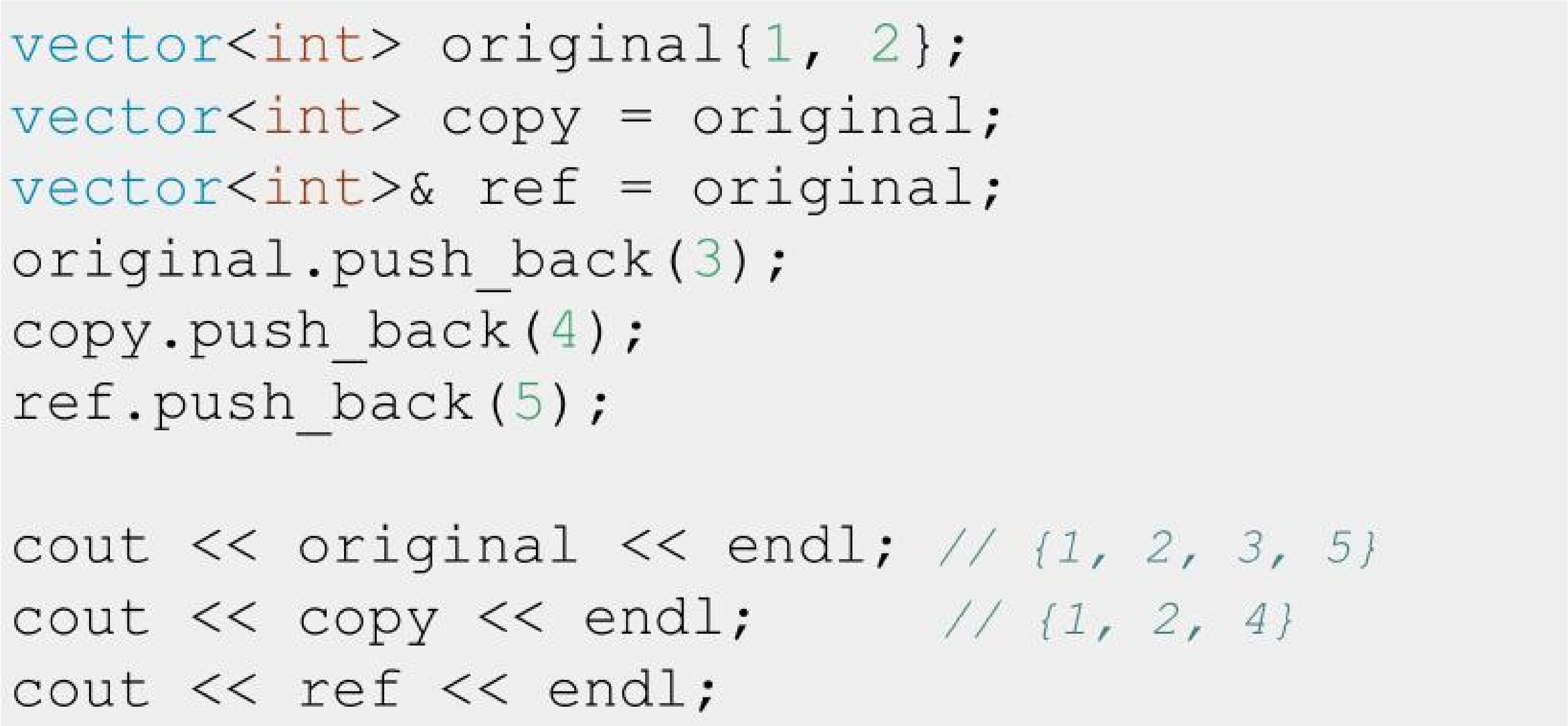
```
vector<int> original{1, 2};
vector<int> copy = original;
vector<int>& ref = original;
original.push_back(3);
copy.push_back(4);
ref.push_back(5);

cout << original << endl;
cout << copy << endl;
cout << ref << endl;
```

References to variables



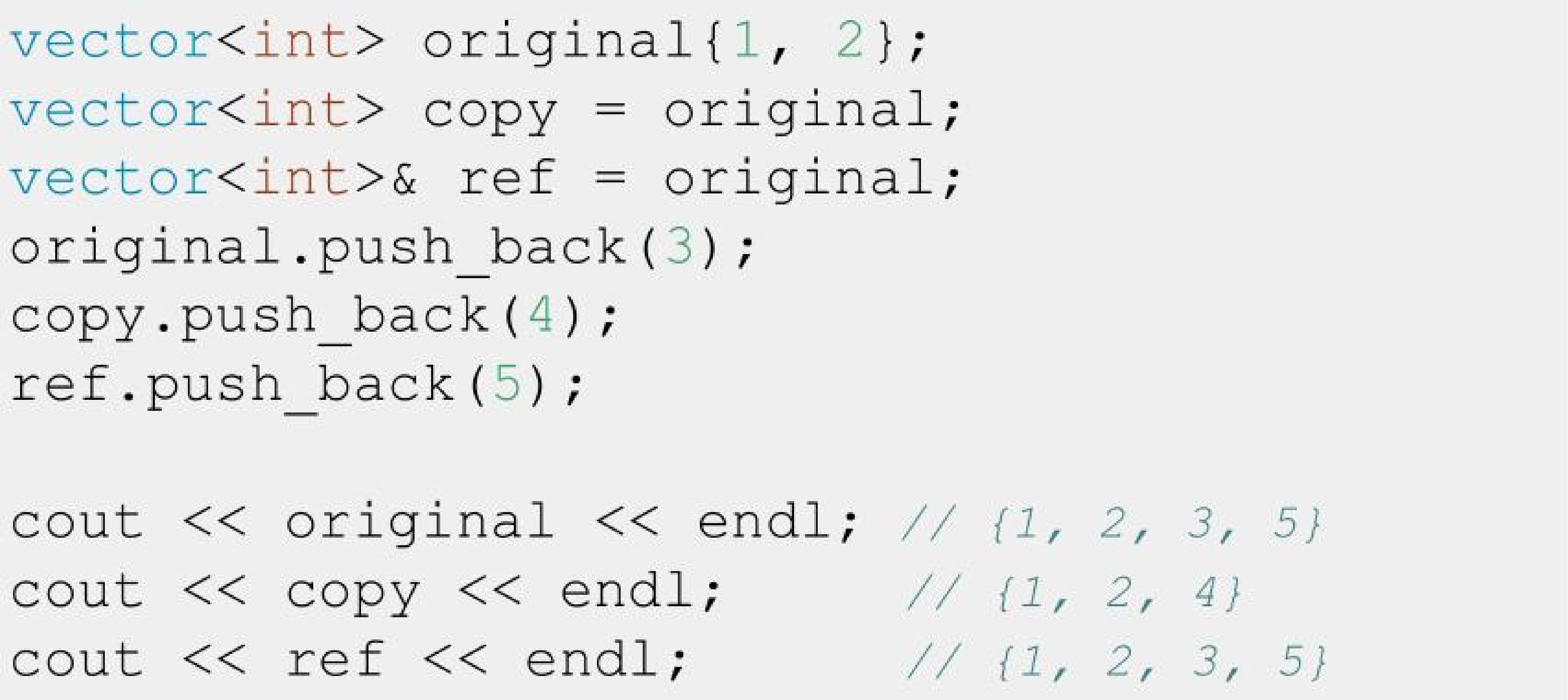
```
vector<int> original{1, 2};
vector<int> copy = original;
vector<int>& ref = original;
original.push_back(3);
copy.push_back(4);
ref.push_back(5);

cout << original << endl; // {1, 2, 3, 5}
cout << copy << endl;
cout << ref << endl;
```

References to variables



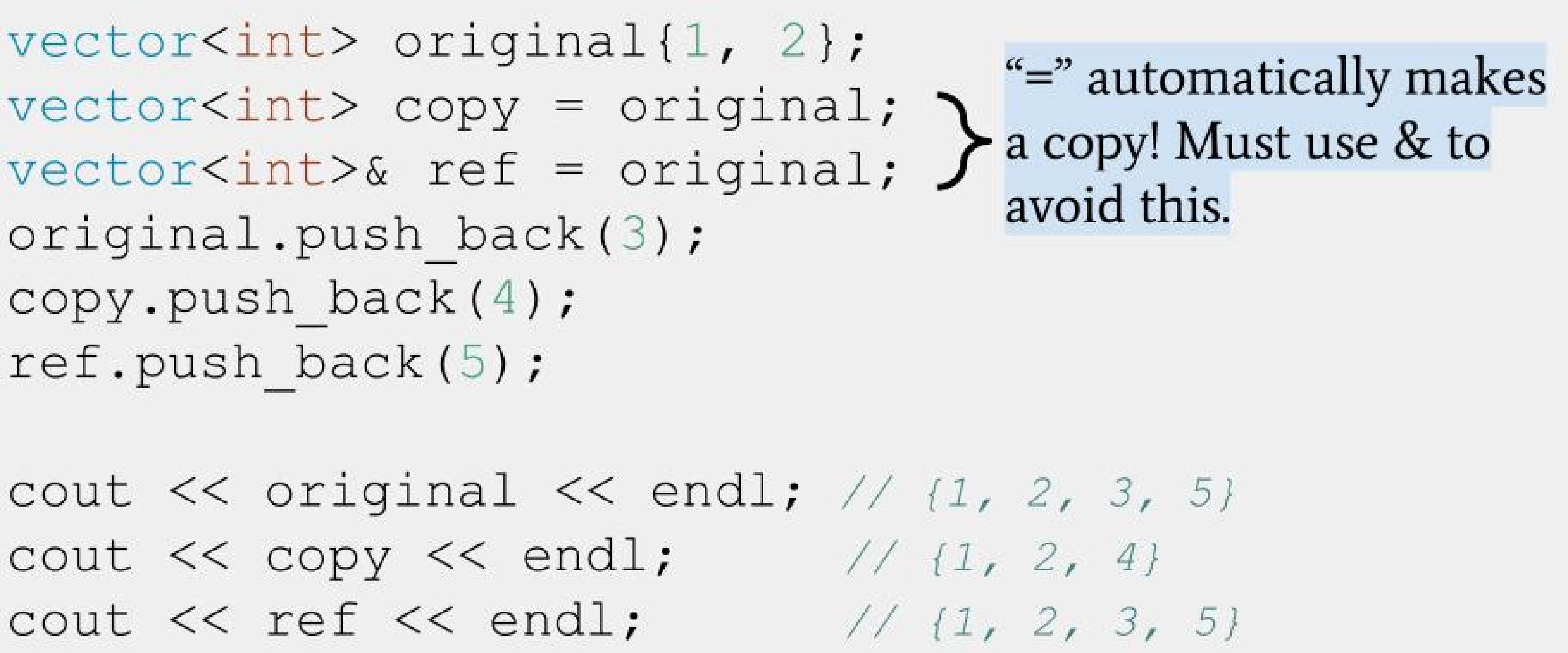
```
vector<int> original{1, 2};
vector<int> copy = original;
vector<int>& ref = original;
original.push_back(3);
copy.push_back(4);
ref.push_back(5);

cout << original << endl; // {1, 2, 3, 5}
cout << copy << endl;      // {1, 2, 4}
cout << ref << endl;
```

References to variables



```
vector<int> original{1, 2};
vector<int> copy = original;
vector<int>& ref = original;
original.push_back(3);
copy.push_back(4);
ref.push_back(5);

cout << original << endl; // {1, 2, 3, 5}
cout << copy << endl;     // {1, 2, 4}
cout << ref << endl;      // {1, 2, 3, 5}
```

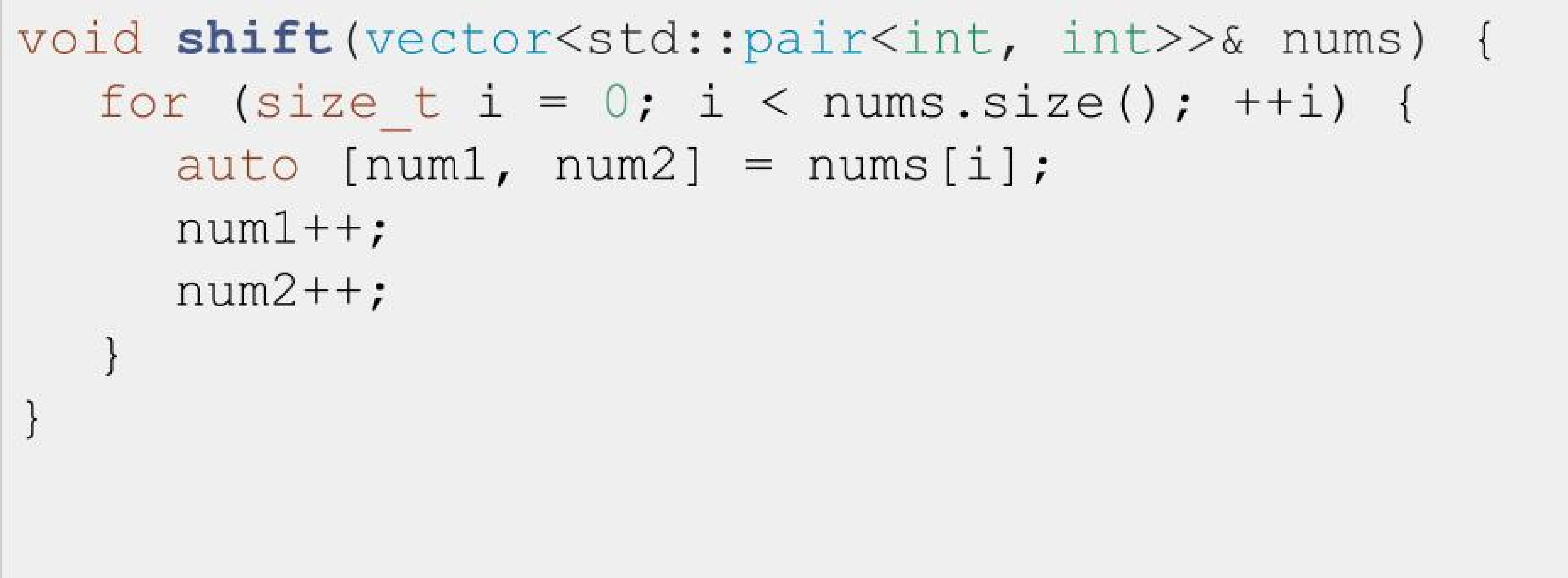
References to variables



```
vector<int> original{1, 2};
vector<int> copy = original;
vector<int>& ref = original;
original.push_back(3);
copy.push_back(4);
ref.push_back(5);

cout << original << endl; // {1, 2, 3, 5}
cout << copy << endl;     // {1, 2, 4}
cout << ref << endl;      // {1, 2, 3, 5}
```

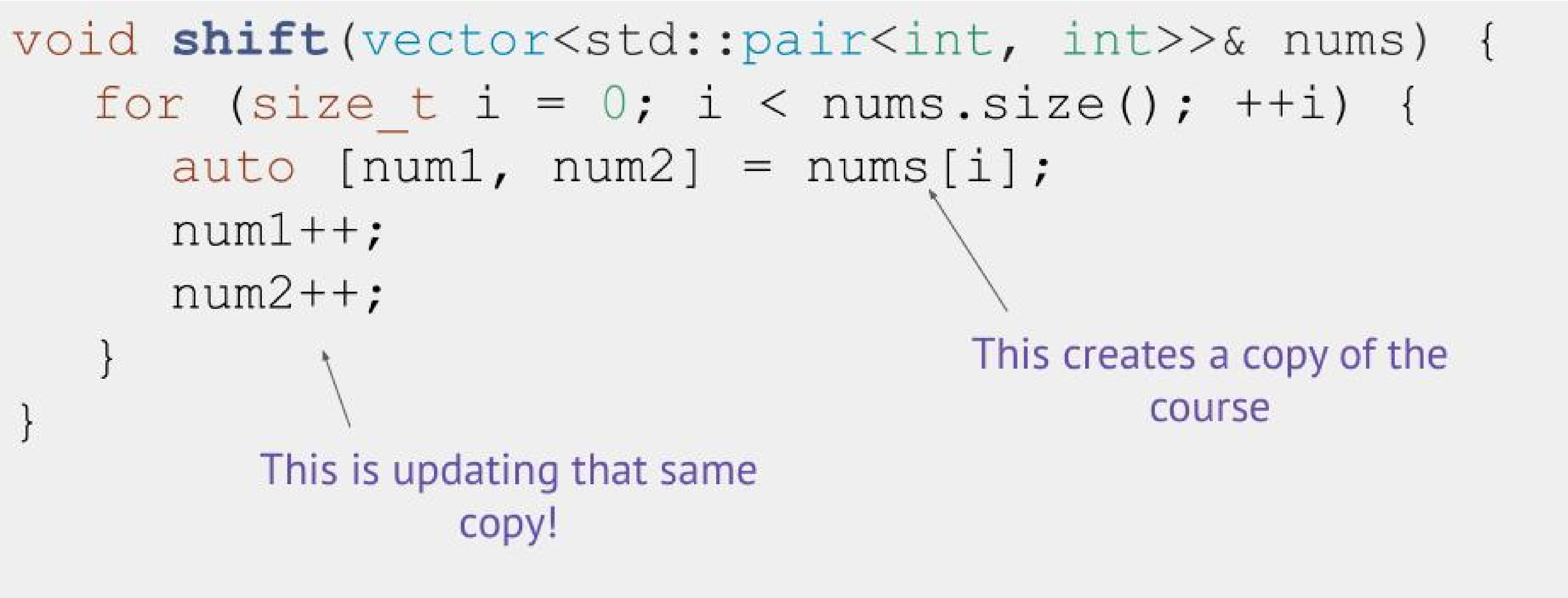
“=” automatically makes a copy! Must use & to avoid this.

The classic reference-copy bug 1.0:



```
void shift(vector<std::pair<int, int>>& nums) {
  for (size_t i = 0; i < nums.size(); ++i) {
    auto [num1, num2] = nums[i];
    num1++;
    num2++;
  }
}
```

The classic reference-copy bug 1.0:

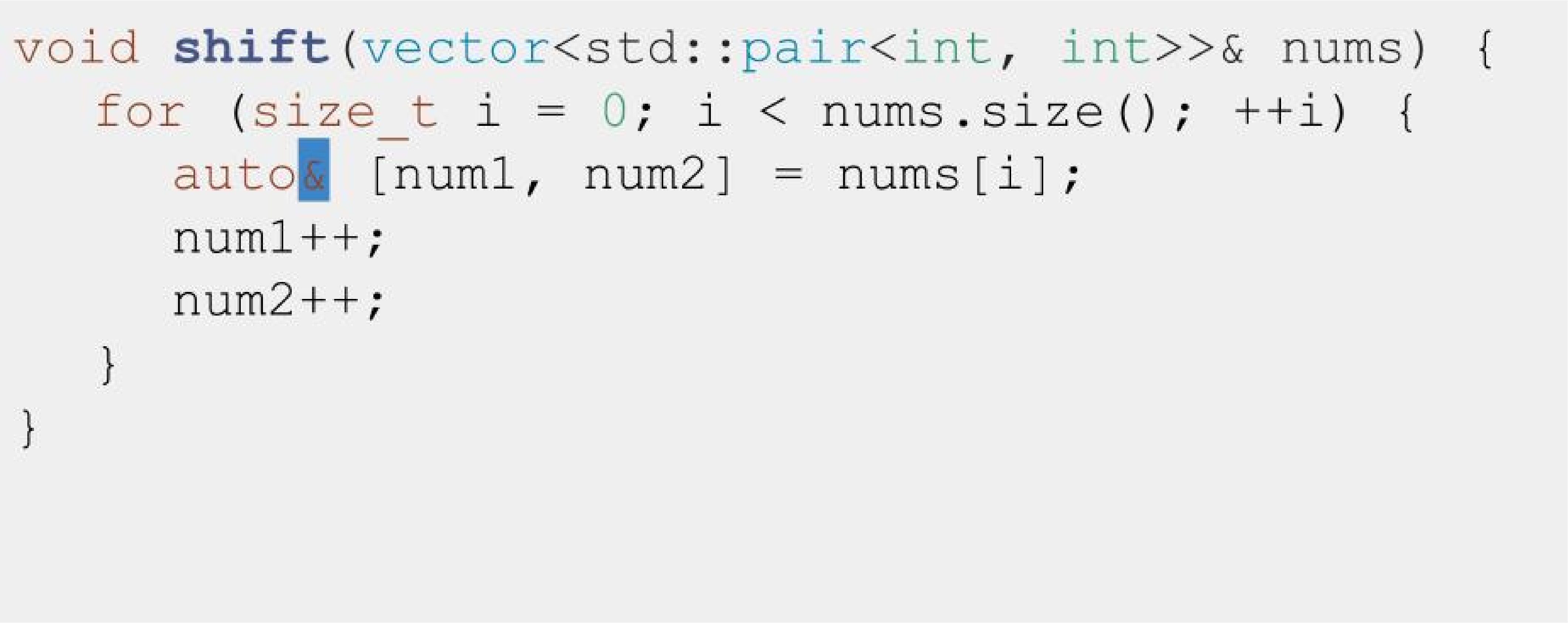


```
void shift(vector<std::pair<int, int>>& nums) {
   for (size_t i = 0; i < nums.size(); ++i) {
      auto [num1, num2] = nums[i];
      num1++;
      num2++;
   }
}
```

This creates a copy of the course

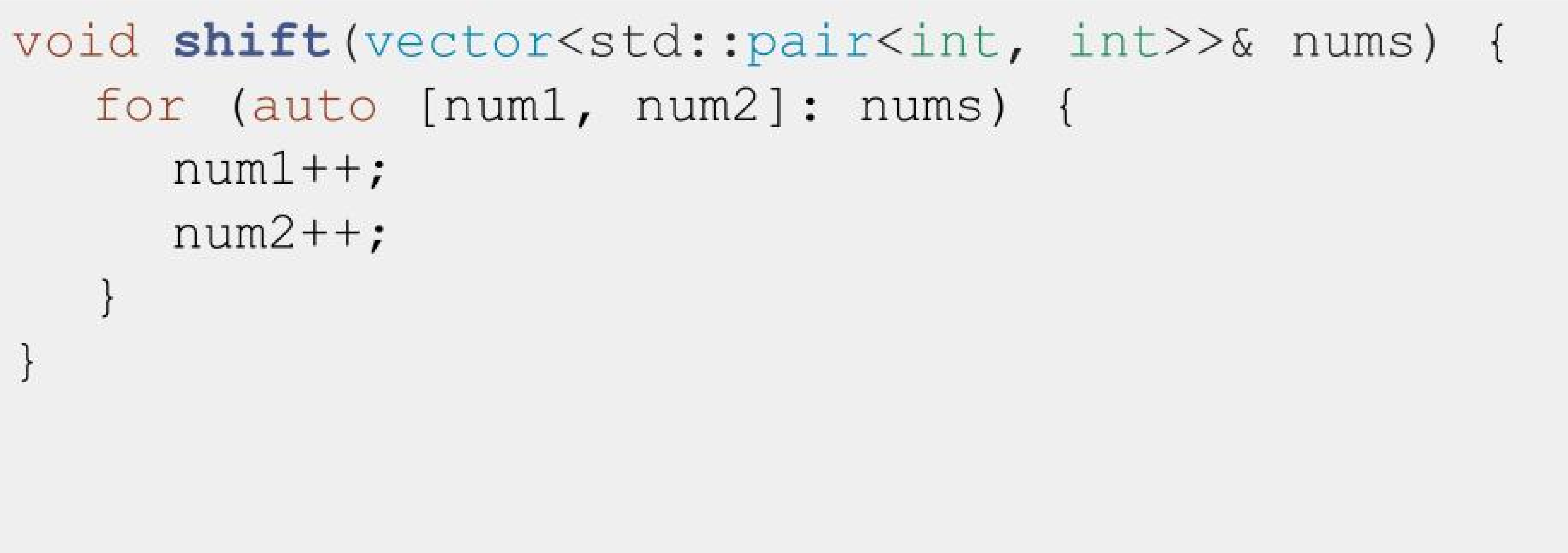
This is updating that same copy!

The classic reference-copy bug 1.0: Fixed



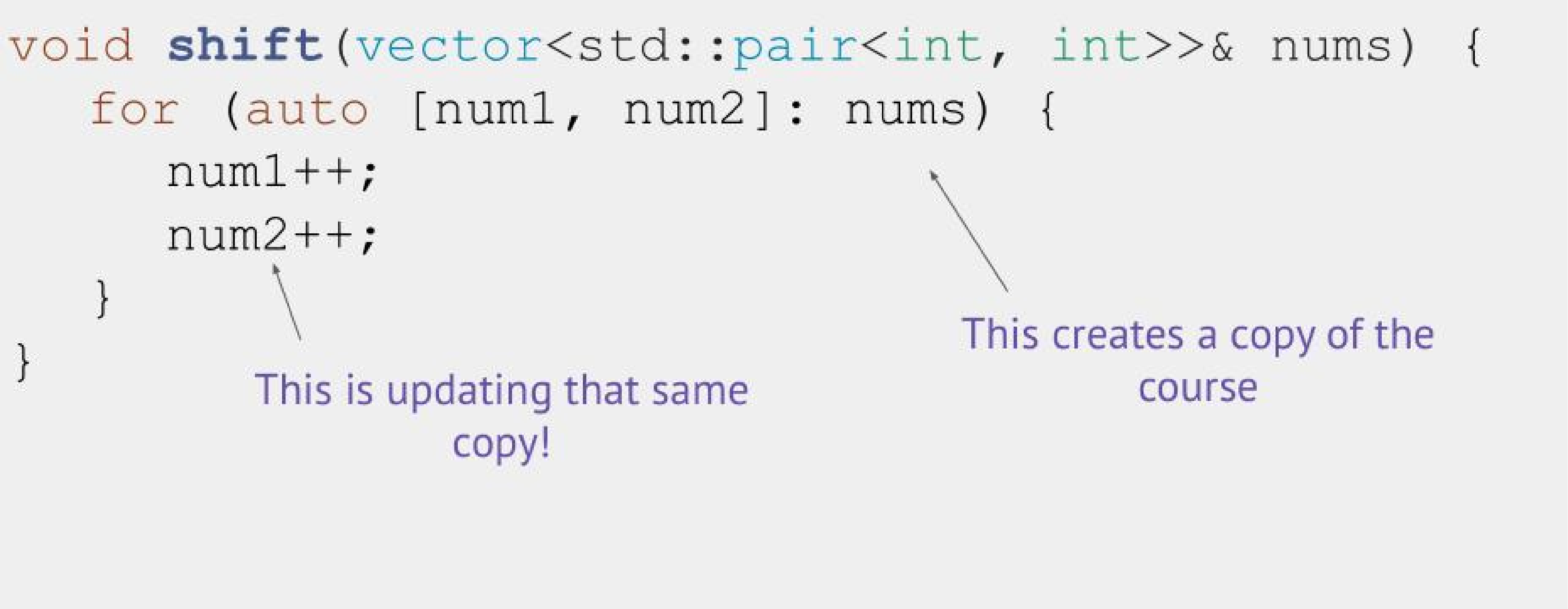
```
void shift(vector<std::pair<int, int>>& nums) {
   for (size_t i = 0; i < nums.size(); ++i) {
      auto& [num1, num2] = nums[i];
      num1++;
      num2++;
   }
}
```

The classic reference-copy bug 2.0:



```
void shift(vector<std::pair<int, int>>& nums) {
   for (auto [num1, num2]: nums) {
      num1++;
      num2++;
   }
}
```

The classic reference-copy bug 2.0:

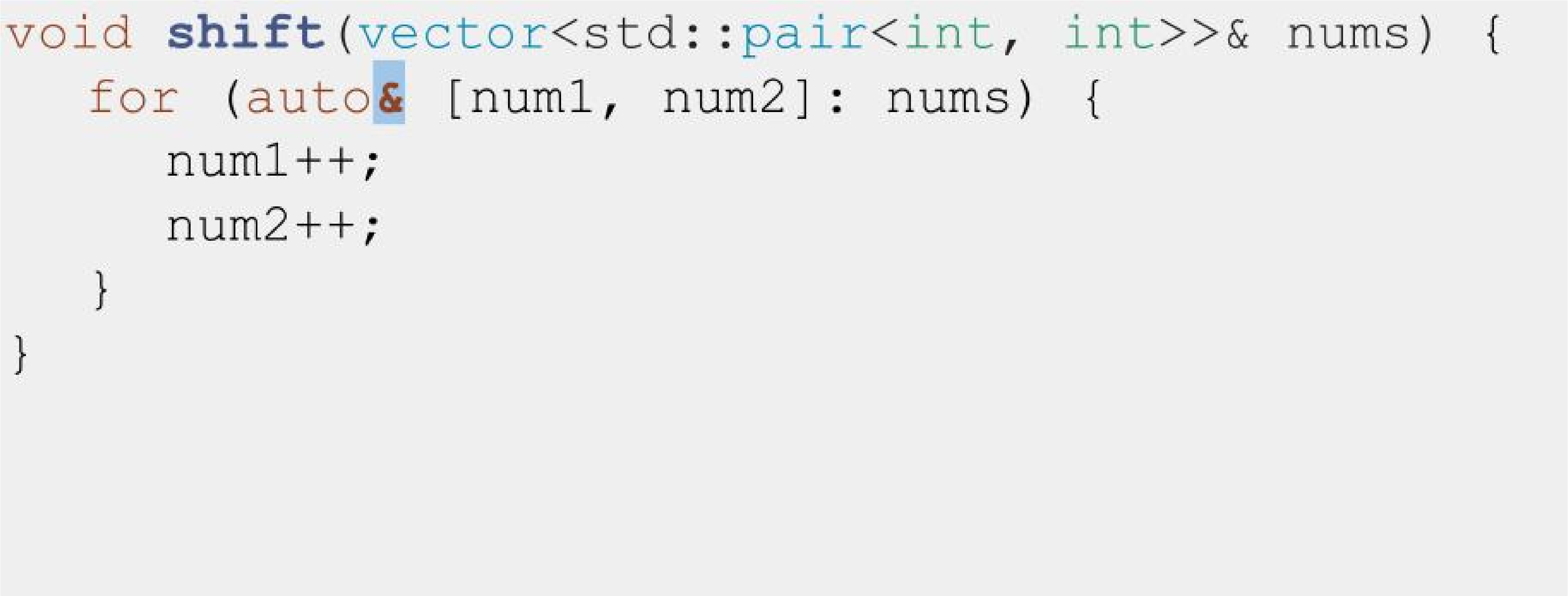


```
void shift(vector<std::pair<int, int>>& nums) {
    for (auto [num1, num2]: nums) {
        num1++;
        num2++;
    }
}
```

This is updating that same copy!

This creates a copy of the course

The classic reference-copy bug 2.0, fixed:



```cpp
void shift(vector<std::pair<int, int>>& nums) {
    for (auto& [num1, num2]: nums) {
        num1++;
        num2++;
    }
}
```

Definition: l-values vs r-values

- **l-values** can appear on the **left** or **right** of an =
- x is an l-value

```
int x = 3;
int y = x;
```

l-values have names

l-values are **not temporary**

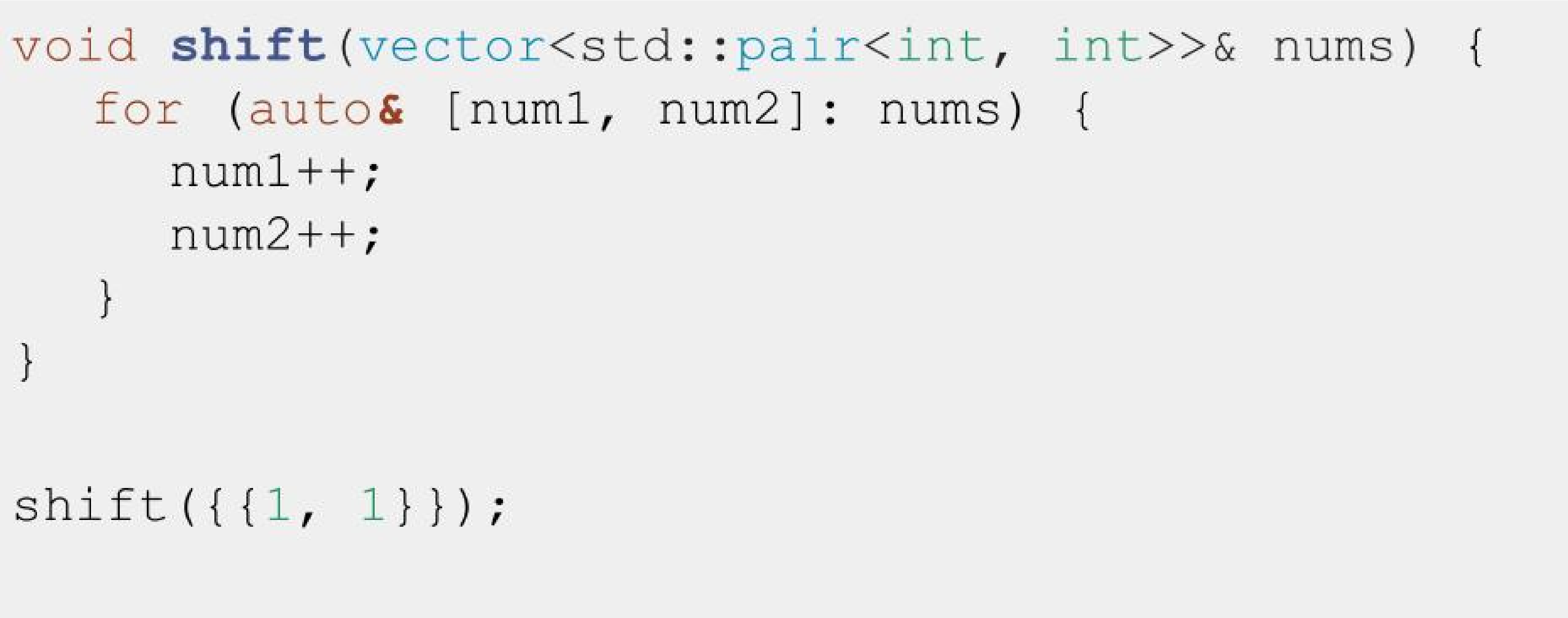
- **r-values** can ONLY appear on the **right** of an =
- 3 is an **r-value**

```
int x = 3;
int y = x;
```

r-values don’t have names

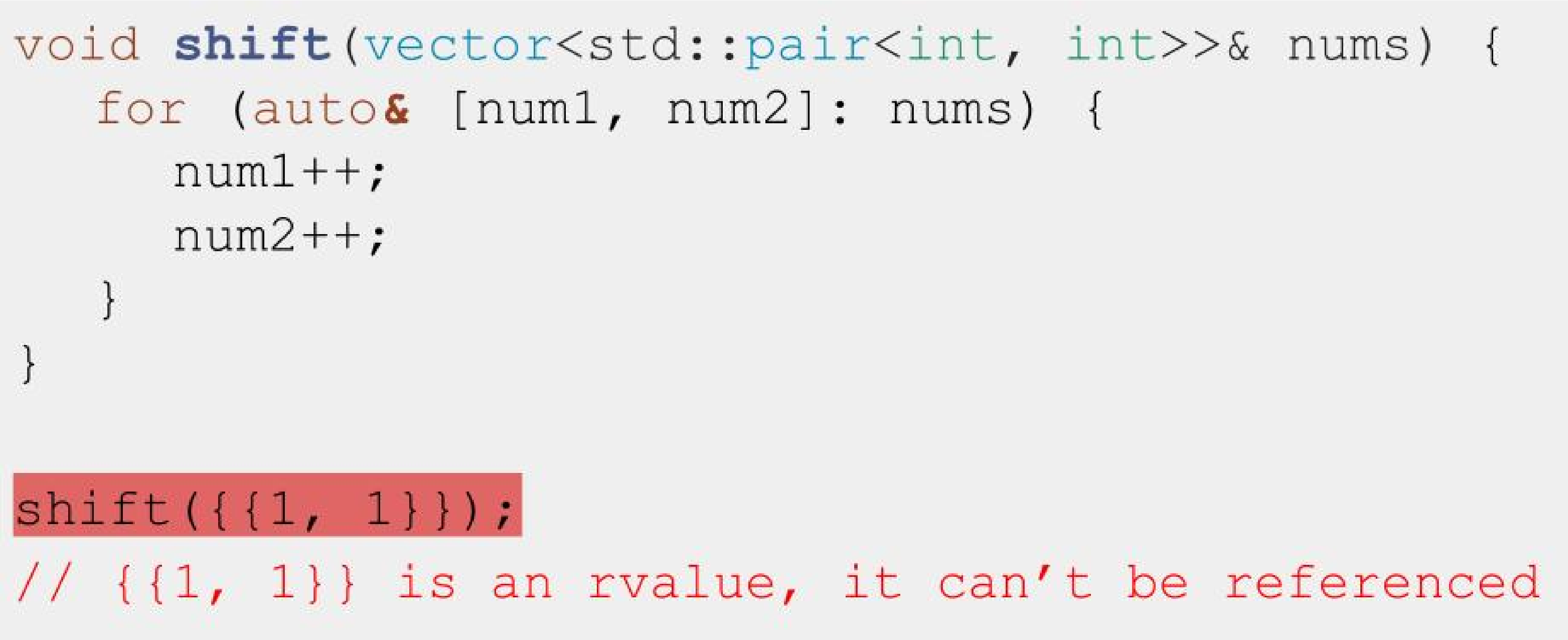
r-values are **temporary**

The classic reference-rvalue error



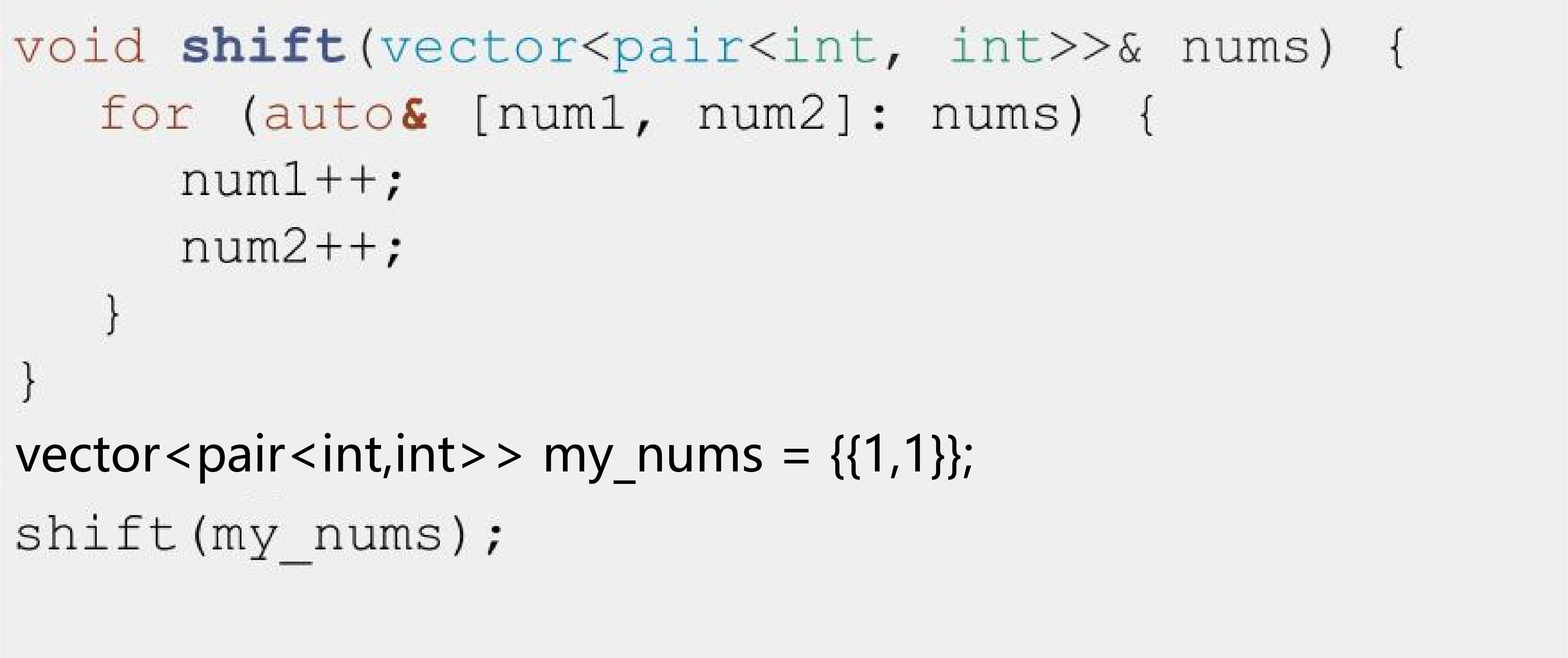
```
void shift(vector<std::pair<int, int>>& nums) {
    for (auto& [num1, num2]: nums) {
        num1++;
        num2++;
    }
}

shift({{1, 1}});
```

The classic reference-rvalue error



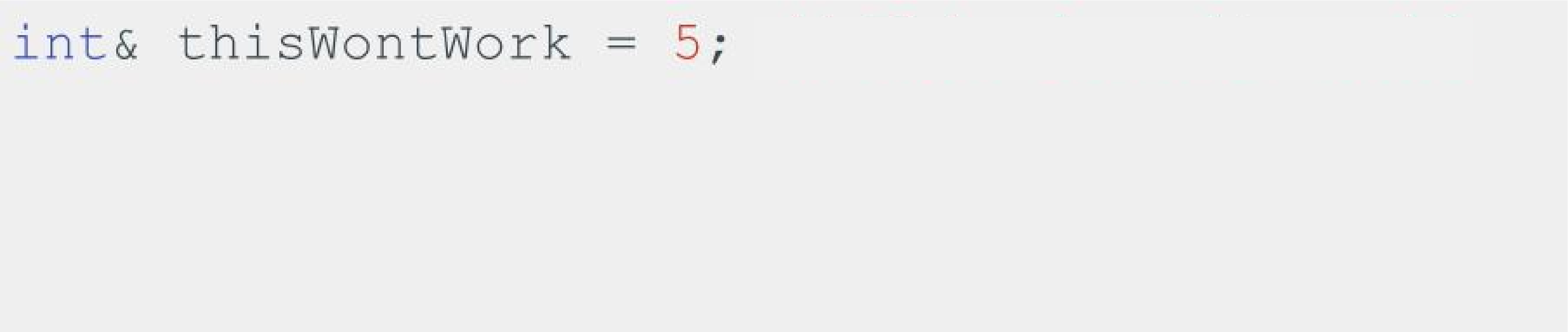
```
void shift(vector<std::pair<int, int>>& nums) {
   for (auto& [num1, num2]: nums) {
      num1++;
      num2++;
   }
}

shift({{1, 1}});
// {{1, 1}} is an rvalue, it can’t be referenced
```

The classic reference-rvalue error, fixed



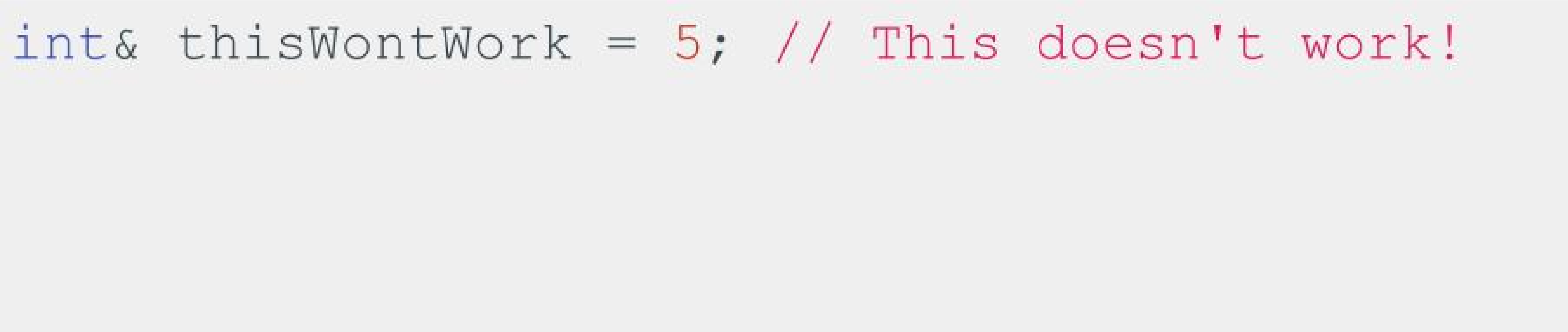
```
void shift(vector<pair<int, int>>& nums) {
   for (auto& [num1, num2]: nums) {
      num1++;
      num2++;
   }
}
vector<pair<int,int>> my_nums = {{1,1}};
shift(my_nums);
```

Note: You can only create references to variables



```
int& thisWontWork = 5;
```

Note: You can only create references to variables



```
int& thisWontWork = 5; // This doesn't work!
```

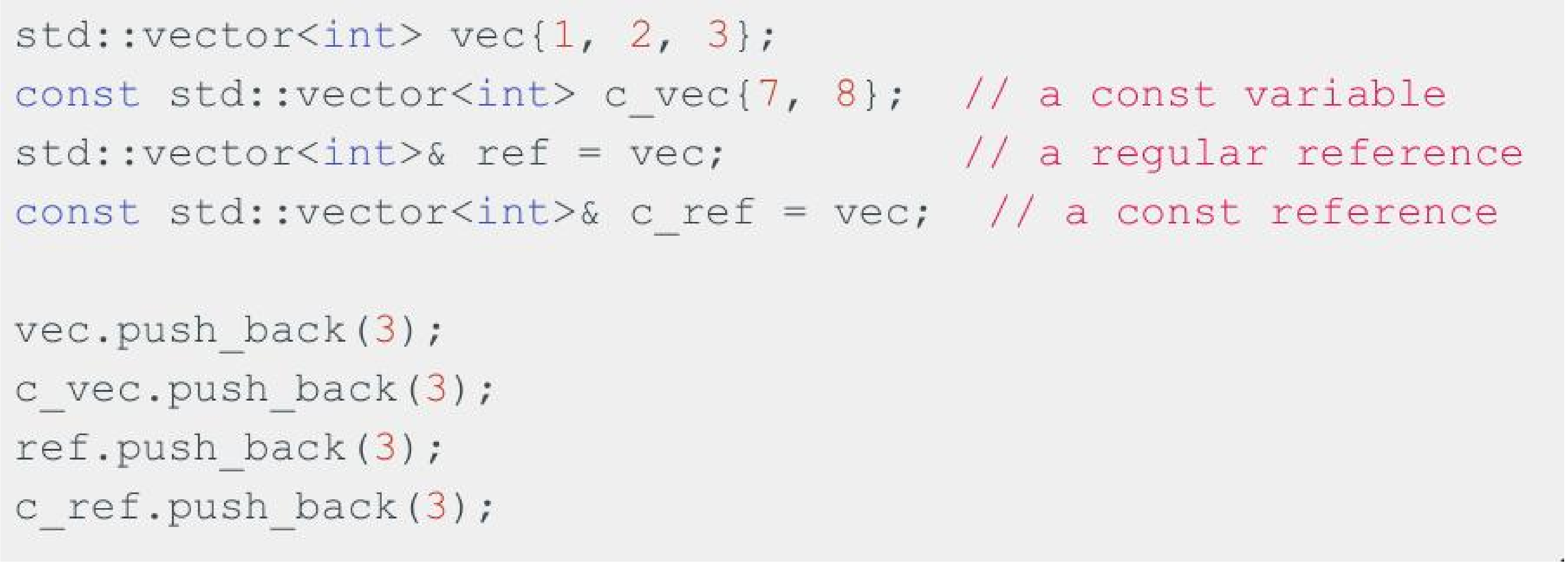
Today

- Initialization
- Using auto
- References
- **If time: Const**

BONUS: Const and Const References

const indicates a variable can’t be modified!

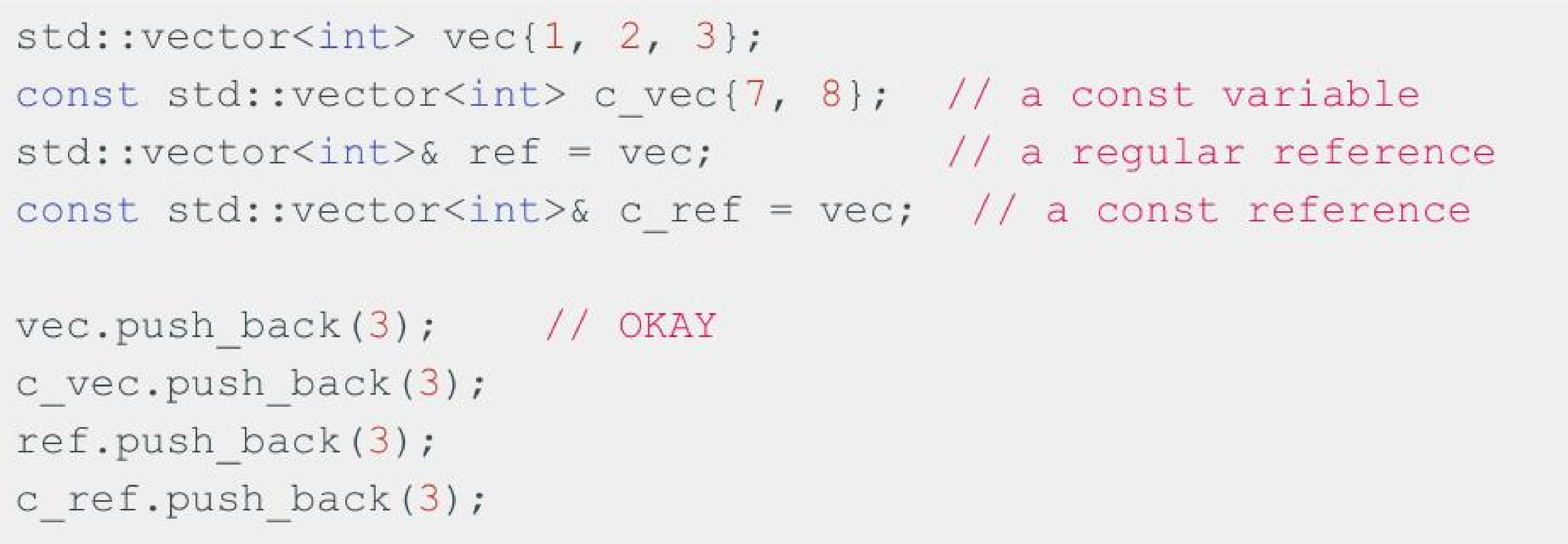
const variables can be references or not!



```
std::vector<int> vec{1, 2, 3};
const std::vector<int> c_vec{7, 8};  // a const variable
std::vector<int>& ref = vec;         // a regular reference
const std::vector<int>& c_ref = vec;  // a const reference

vec.push_back(3);
c_vec.push_back(3);
ref.push_back(3);
c_ref.push_back(3);
```

const indicates a variable can’t be modified!

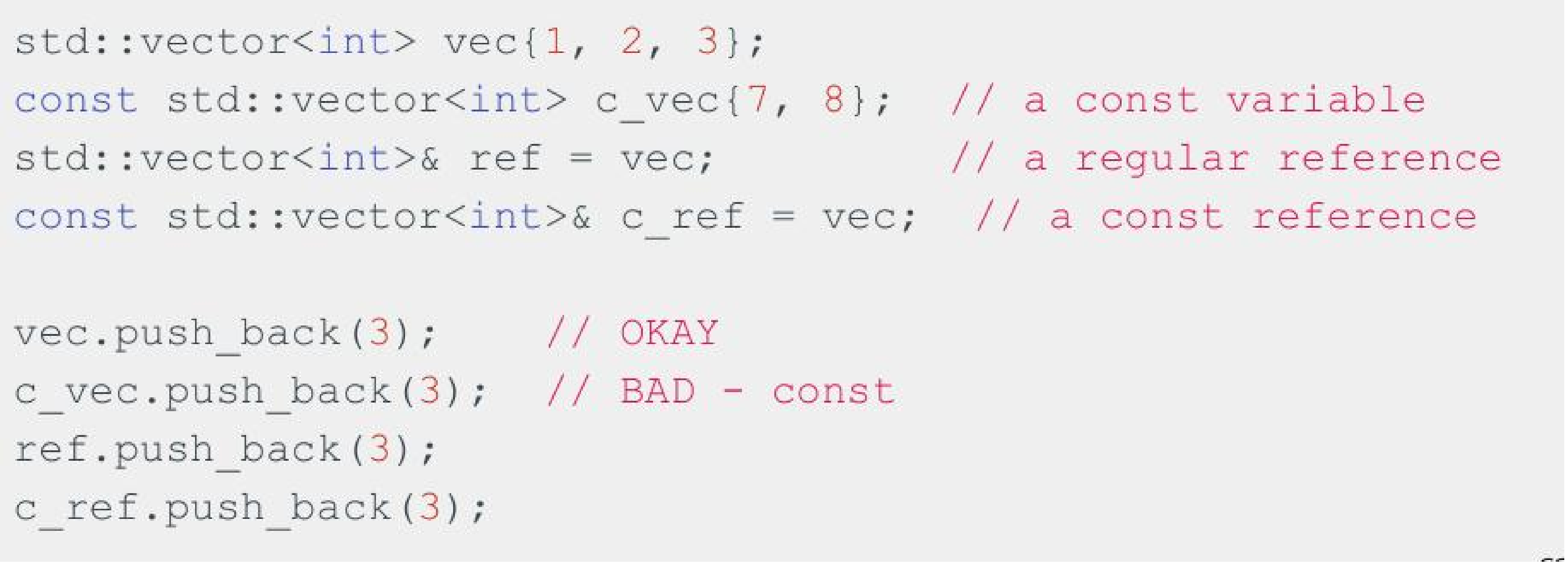
const variables can be references or not!



```
std::vector<int> vec{1, 2, 3};
const std::vector<int> c_vec{7, 8};  // a const variable
std::vector<int>& ref = vec;         // a regular reference
const std::vector<int>& c_ref = vec;  // a const reference

vec.push_back(3);    // OKAY
c_vec.push_back(3);
ref.push_back(3);
c_ref.push_back(3);
```

const indicates a variable can’t be modified!

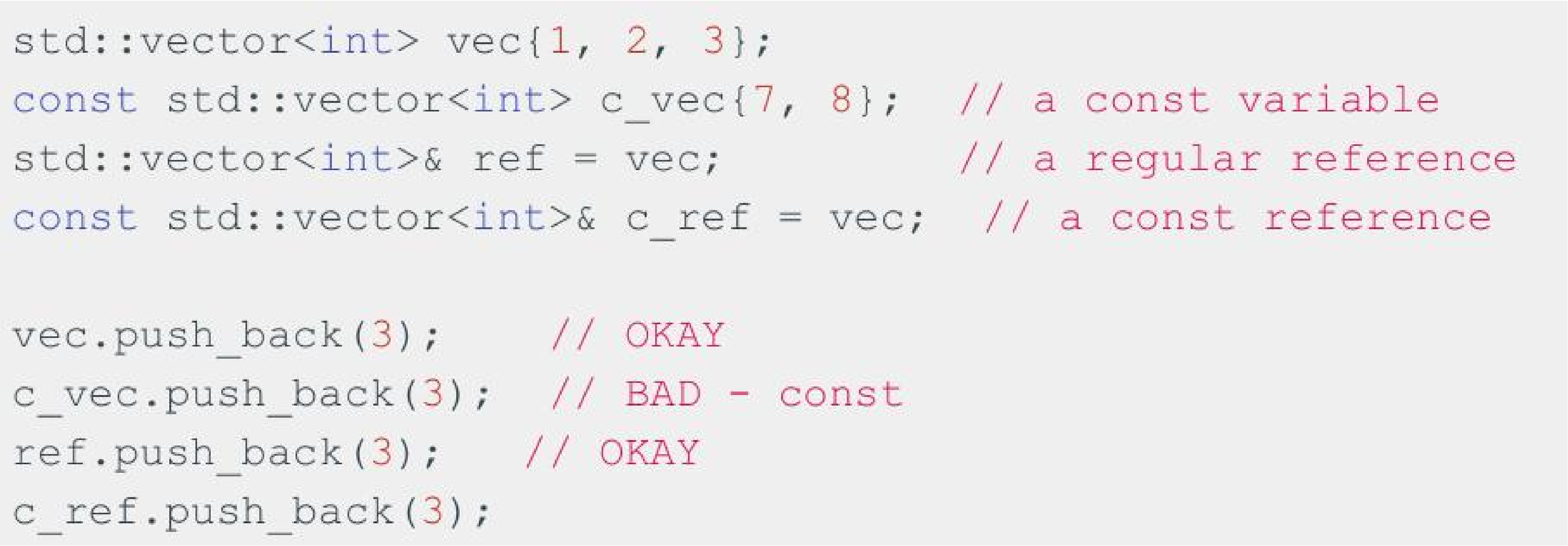
const variables can be references or not!



```
std::vector<int> vec{1, 2, 3};
const std::vector<int> c_vec{7, 8};  // a const variable
std::vector<int>& ref = vec;         // a regular reference
const std::vector<int>& c_ref = vec;  // a const reference

vec.push_back(3);     // OKAY
c_vec.push_back(3);   // BAD - const
ref.push_back(3);
c_ref.push_back(3);
```

const indicates a variable can’t be modified!

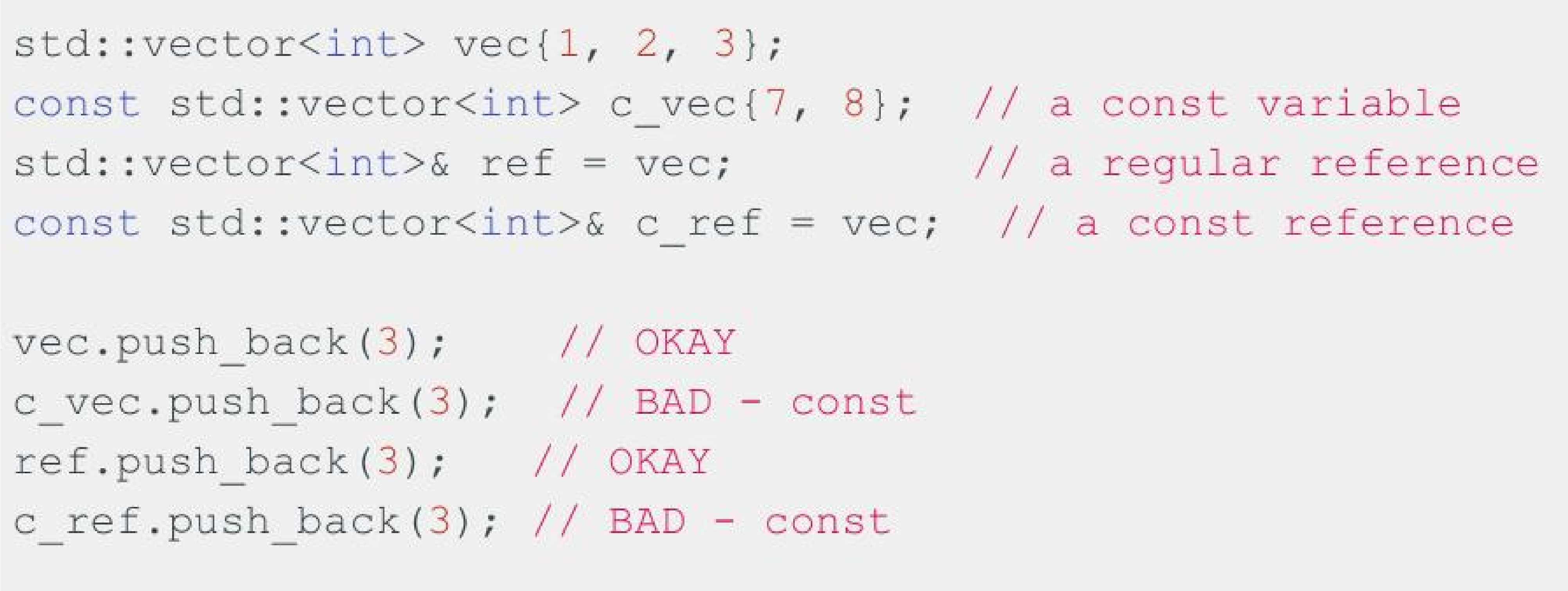
const variables can be references or not!



```
std::vector<int> vec{1, 2, 3};
const std::vector<int> c_vec{7, 8};  // a const variable
std::vector<int>& ref = vec;         // a regular reference
const std::vector<int>& c_ref = vec;  // a const reference

vec.push_back(3);     // OKAY
c_vec.push_back(3);   // BAD - const
ref.push_back(3);    // OKAY
c_ref.push_back(3);
```

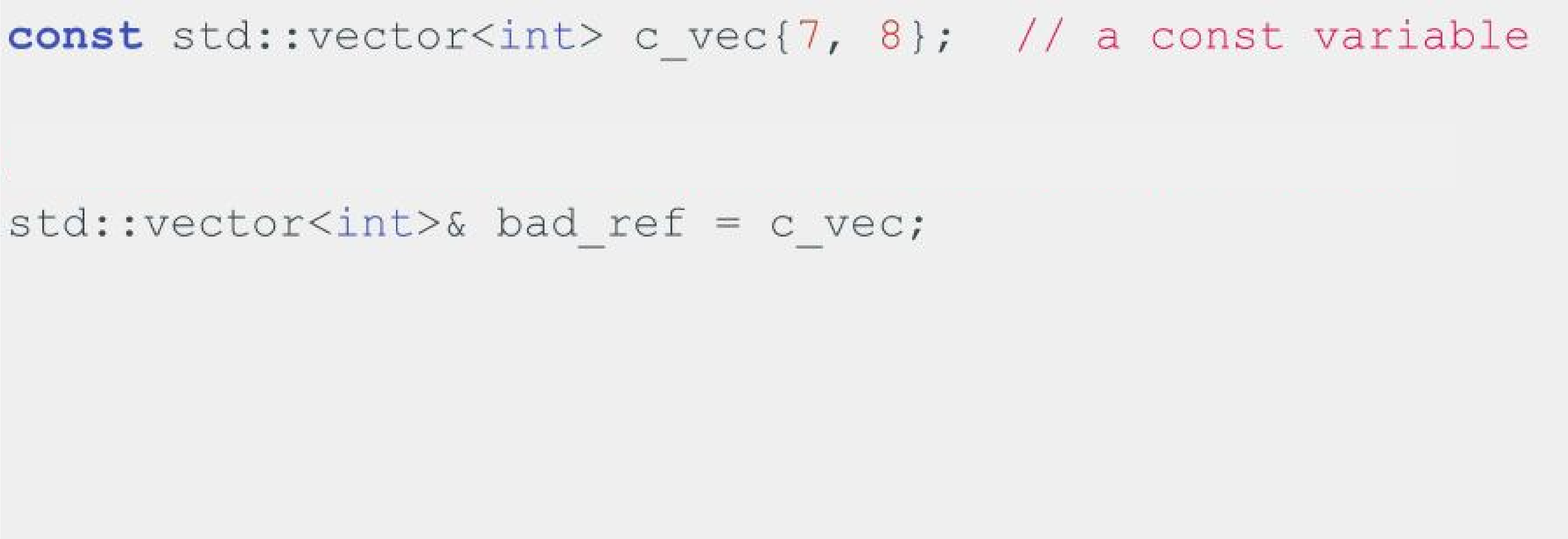
const indicates a variable can’t be modified!

const variables can be references or not!



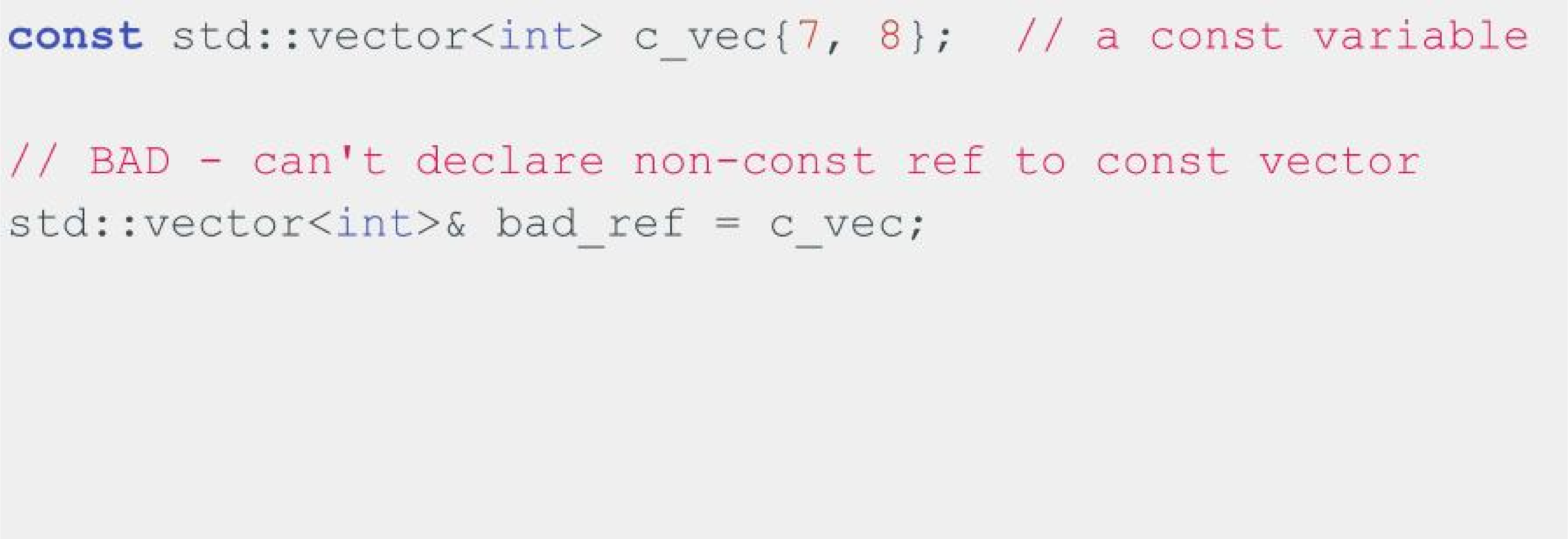
```
std::vector<int> vec{1, 2, 3};
const std::vector<int> c_vec{7, 8};  // a const variable
std::vector<int>& ref = vec;         // a regular reference
const std::vector<int>& c_ref = vec;  // a const reference

vec.push_back(3);    // OKAY
c_vec.push_back(3);  // BAD - const
ref.push_back(3);   // OKAY
c_ref.push_back(3); // BAD - const
```

Can’t declare non-const reference to const variable!



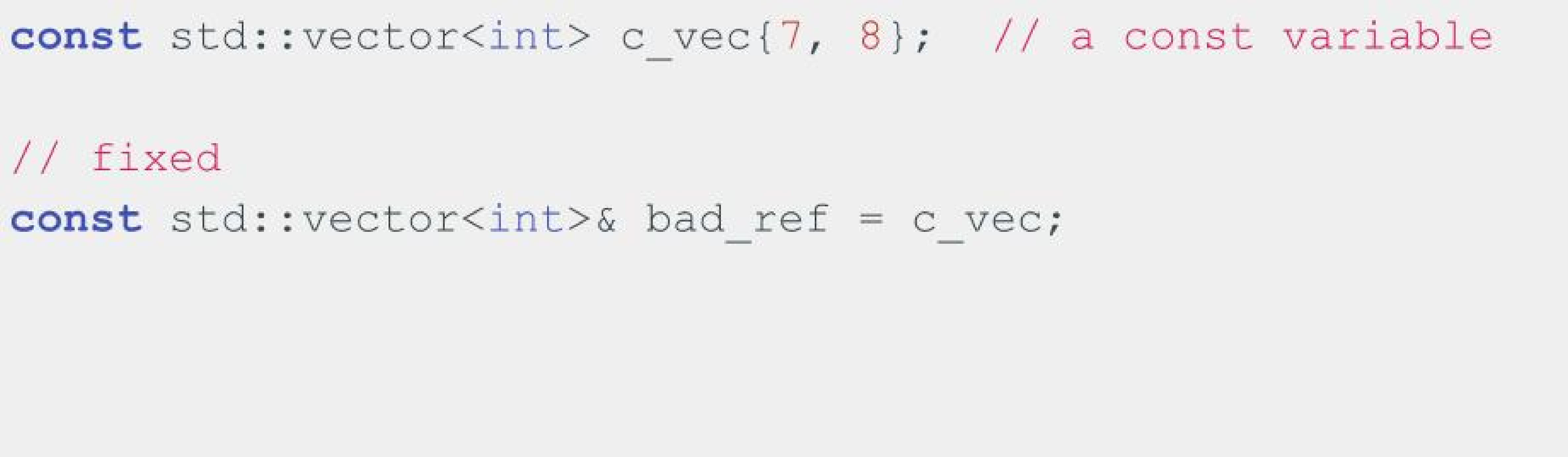
```
const std::vector<int> c_vec{7, 8};  // a const variable


std::vector<int>& bad_ref = c_vec;
```

Can’t declare non-const reference to const variable!



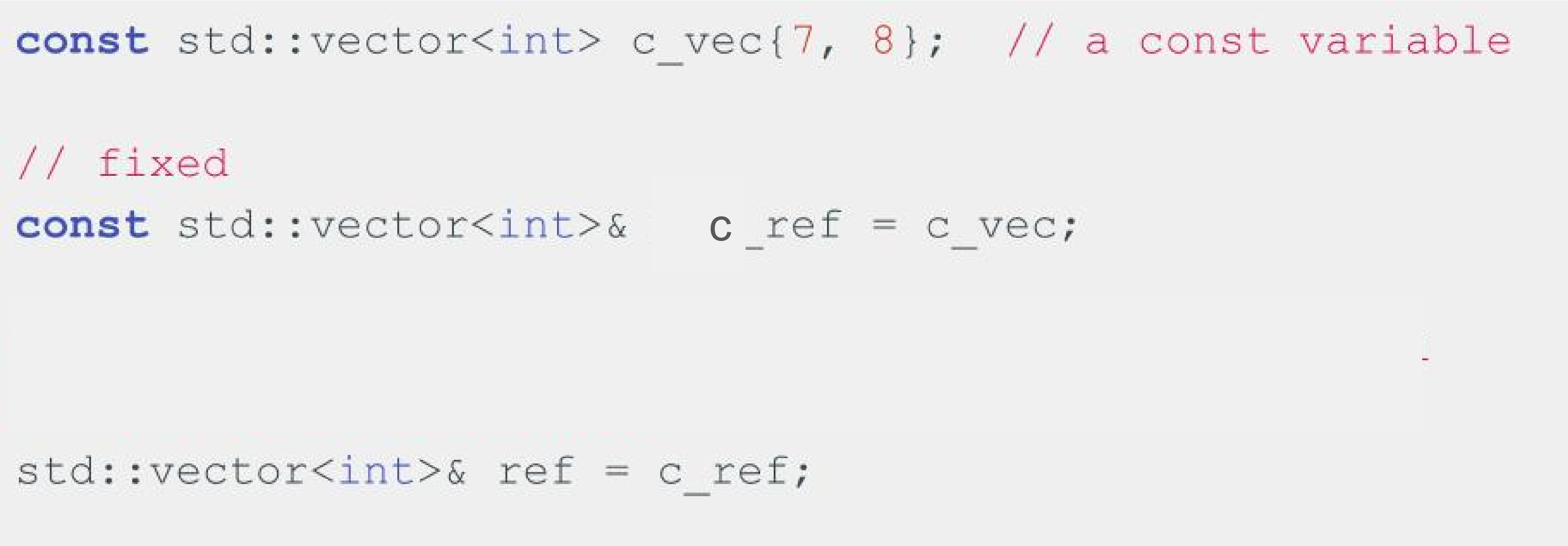
```
const std::vector<int> c_vec{7, 8};  // a const variable

// BAD - can't declare non-const ref to const vector
std::vector<int>& bad_ref = c_vec;
```

Can’t declare non-const reference to const variable!



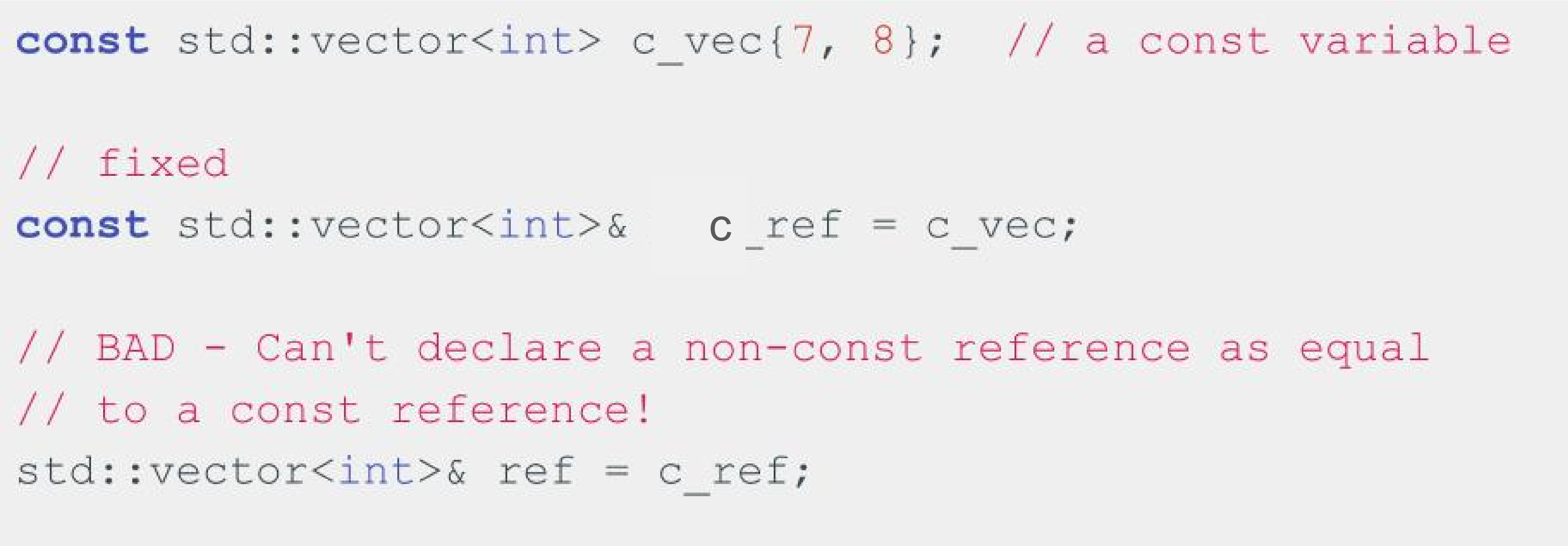
```
const std::vector<int> c_vec{7, 8};  // a const variable

// fixed
const std::vector<int>& bad_ref = c_vec;
```

Can’t declare non-const reference to const variable!



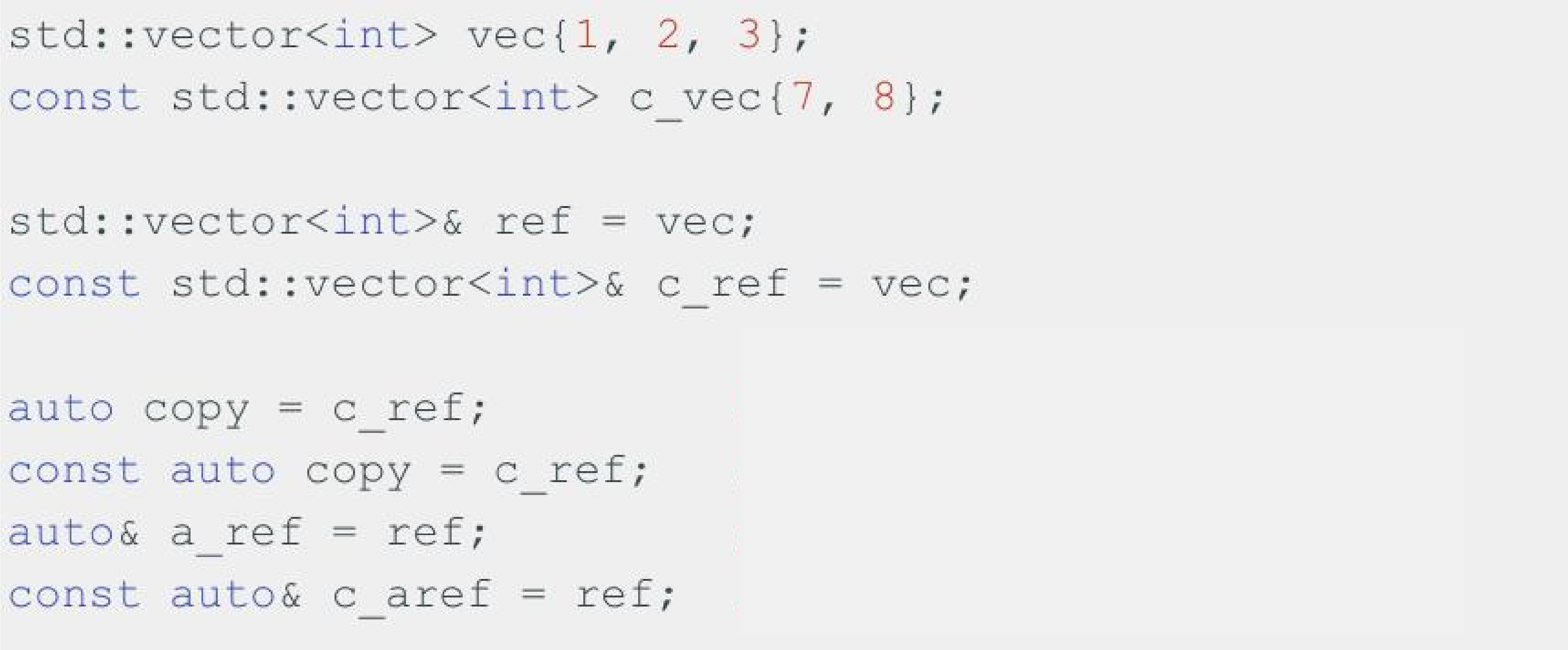
```
const std::vector<int> c_vec{7, 8};  // a const variable

// fixed
const std::vector<int>&   c _ref = c_vec;



std::vector<int>& ref = c_ref;
```

Can’t declare non-const reference to const variable!



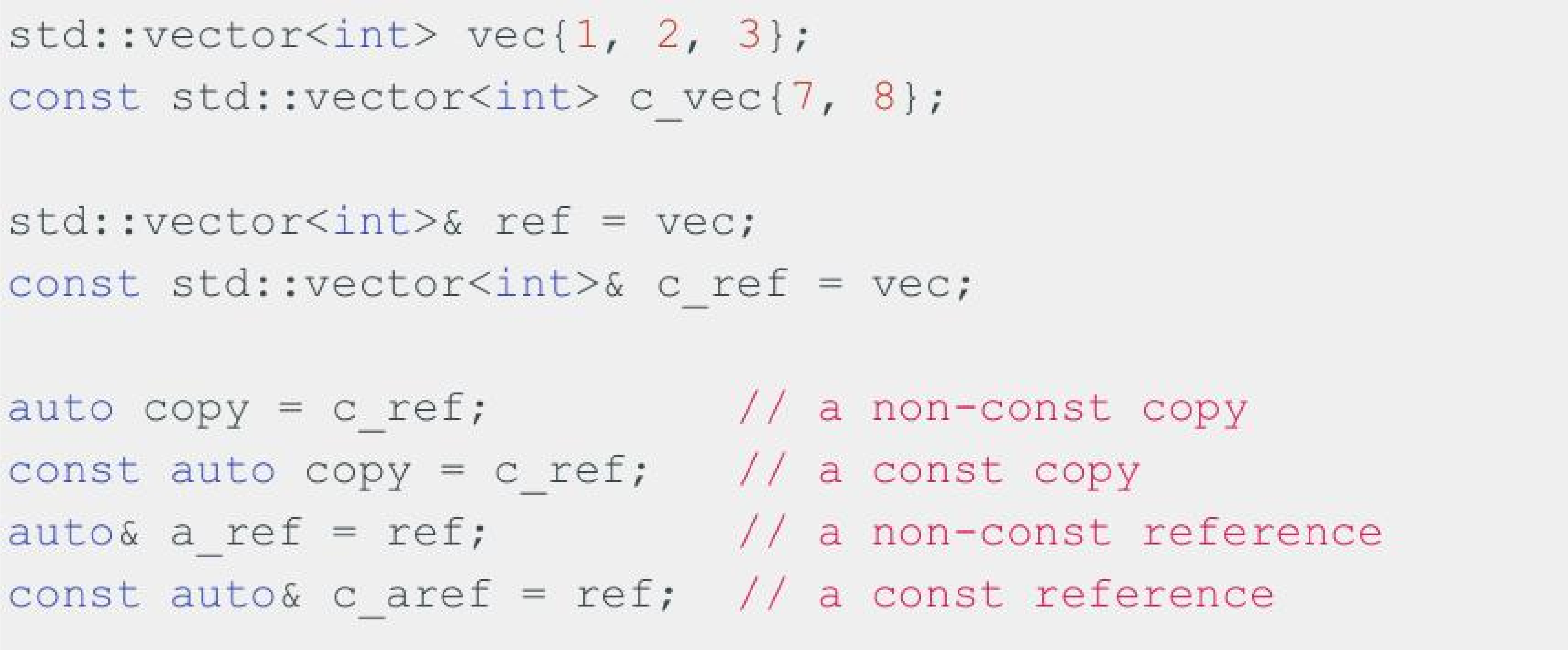
```
const std::vector<int> c_vec{7, 8};  // a const variable

// fixed
const std::vector<int>&   c_ref = c_vec;

// BAD - Can't declare a non-const reference as equal
// to a const reference!
std::vector<int>& ref = c_ref;
```

const & subtleties



```cpp
std::vector<int> vec{1, 2, 3};
const std::vector<int> c_vec{7, 8};

std::vector<int>& ref = vec;
const std::vector<int>& c_ref = vec;

auto copy = c_ref;
const auto copy = c_ref;
auto& a_ref = ref;
const auto& c_aref = ref;
```

const & subtleties



```
std::vector<int> vec{1, 2, 3};
const std::vector<int> c_vec{7, 8};

std::vector<int>& ref = vec;
const std::vector<int>& c_ref = vec;

auto copy = c_ref;                // a non-const copy
const auto copy = c_ref;          // a const copy
auto& a_ref = ref;                // a non-const reference
const auto& c_aref = ref;         // a const reference
```

Remember: C++, by default, makes copies when we do variable assignment! We need to use & if we need references instead.

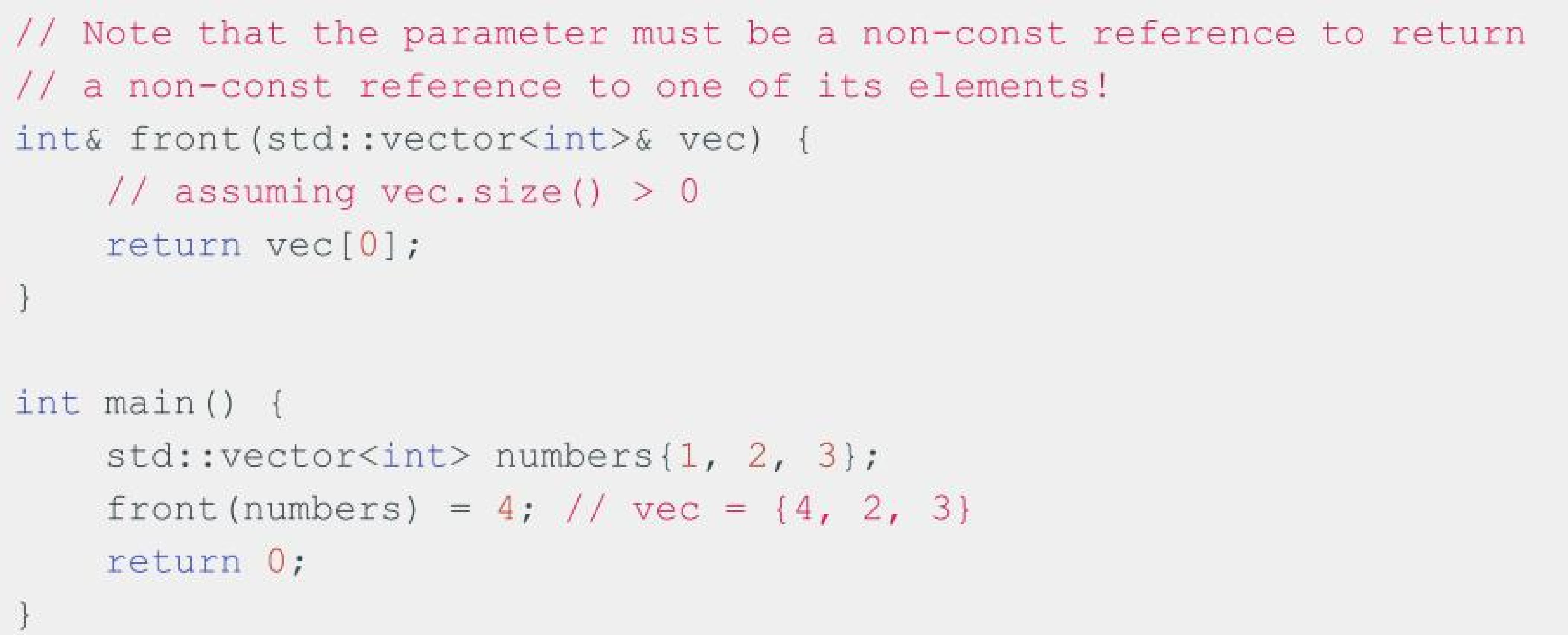
When do we use references/const references?

- If we’re working with a variable that takes up little space in memory (e.g. int, double), we don’t need to use a reference and can just copy the variable

- If we need to alias the variable to modify it, we can use references

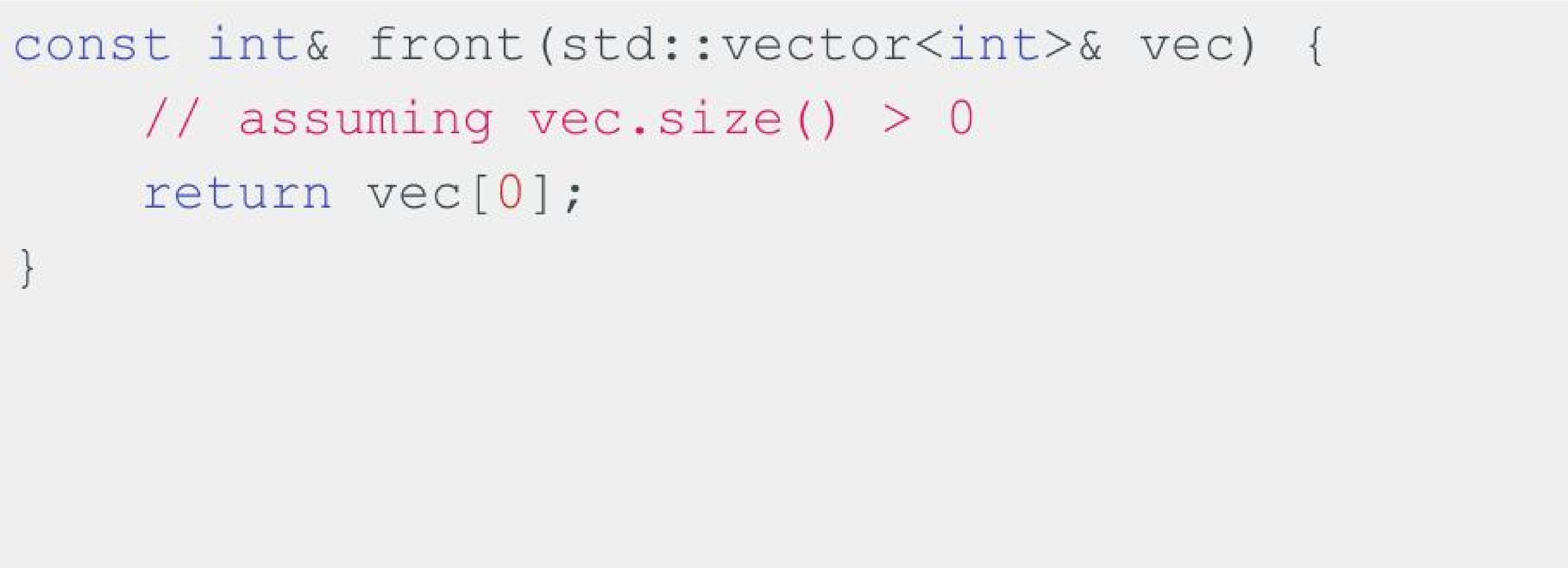
- If we don’t need to modify the variable, but it’s a big variable (e.g. std::vector), we can use const references

You can return references as well!



```cpp
// Note that the parameter must be a non-const reference to return
// a non-const reference to one of its elements!
int& front(std::vector<int>& vec) {
    // assuming vec.size() > 0
    return vec[0];
}

int main() {
    std::vector<int> numbers{1, 2, 3};
    front(numbers) = 4; // vec = {4, 2, 3}
    return 0;
}
```

Can also return const references



```
const int& front(std::vector<int>& vec) {
    // assuming vec.size() > 0
    return vec[0];
}
```

Recap

- **Uniform Initialization**
    - A “uniform” way to initialize variables of different types!
- **References**
    - Allow us to alias variables
- **Const**
    - Allow us to specify that a variable can’t be modified

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Coding for the world

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