Department I - C Plus Plus

Modern and Lucid C++ for Professional Programmers

Part 3 – Streams, Iterators and Algorithms

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Recap Week 2

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Working with std::string


```
#include <iostream>
#include <string>

void askForName(std::ostream & out) {
  out << "What is your name? ";
}

std::string inputName(std::istream & in) {
  std::string name{};
  in >> name;
  return name;
}

void sayGreeting(std::ostream & out, std::string name) {
  out << "Hello " << name << ", how are you?\n";
}

int main() {
  askForName(std::cout);
  sayGreeting(std::cout, inputName(std::cin));
}
```

```
void askForName(std::ostream & out)
```

- **`std::string` and built-in types represent values**
  - Can be copied and passed-by-value
  - No need to allocate memory explicitly for storing the chars
- **Some objects aren't values, because they can not be copied:**
  - Streams representing the program's I/O
- **Functions taking a stream object must take it as a reference, because they provide a side-effect to the stream (i.e., output characters)**
- **Reference parameters are marked with `'&'` (ampersand)**
- **In Java all objects are passed as references! (not the same kind of references as in C++!)**
  - Same name, different concept

Caution: Call Sequence

- **Statements are sequenced by ; (semicolon)**
- **Within a single expression, such as a function call, sequence of evaluation is undefined! (except for the comma operator ,)**

```
void sayGreeting(std::ostream & out,
                 std::string name1,
                 std::string name2){
  out << "Hello " << name1 << ", do you love " << name2 << "?\n";
}

int main() {
  askForName(std::cout);
  sayGreeting(std::cout,
              inputName(std::cin),
              inputName(std::cin));
}
```

Formatted I/O

Goals:

- You know how to read and write from and to streams
- You know about the possible states of an `std::istream`
- You can read input from an `std::istream` safely

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- **Stream objects provide C++'s I/O mechanism**
  - Pre-defined globals: `std::cin std::cout` 😟
- **Use them ONLY in the `main()` function!**
- **"shift" operators read into variables or write values**
  - `std::cin >> x; std::cout << x;`
- **Multiple values can be streamed at once**
  - `std::cout << "the value is " << x << '\n';`
- **Streams have a state that denotes if I/O was successful or not**
  - Only `.good()` streams actually do I/O
  - You need to `.clear()` the state in case of an error

Reading a `std::string` Value


```
#include <iostream>
#include <string>

std::string inputName(std::istream & in) {
  std::string name{};
  in >> name;
  return name;
}
```

- **Reading a `std::string` can not go wrong, unless the stream is already `!good()`**
  - The content of the `std::string` is replaced
  - Maybe the `std::string` is empty after reading

Reading an int Value


```
int inputAge(std::istream& in) {
  int age{-1};
  if (in >> age) {
    return age;
  }
  return -1;
}
```

- **No error recovery**
- **One wrong input puts the stream into status fail**
- **Characters remain in input**

```cpp
#include <iostream>

int main() {
  size_t count{0};
  char c{};
  while (std::cin >> c) ++count;
  std::cout << count << "\n";
}
```

```
$ mycharcount < input.txt
42
$ mycharcount
12345
<CTRL-D>
6
$
```

- **If you write programs to read all of the input you need to terminate the input:**
  - Ctrl-D (Linux/Mac) and Ctrl-Z (Windows)
  - You might need to (re)set the focus to the Cevelop console
- **Press <Enter> to send the current line to the input**
  - You may edit the line before sending, e.g. delete characters

Robust Reading an `int` Value

```
int inputAge(std::istream & in) {
  while (in.good()) {
    std::string line{};
    getline(in, line);
    std::istringstream is{line};
    int age{-1};
    if (is >> age) {
      return age;
    }
  }
  return -1;
}
```

- **Read a line and parse it as an integer until `OK` or `EOF`**
- **Use an `std::istringstream` as intermediate stream**

An `std::istream`'s States

```
int readFrom(std::istream & is) {
  //...
}
```

State Bit Set	Query	Entered
<none>	`is.good()`	initial `is.clear()`
`failbit`	`is.fail()`	formatted input failed
`eofbit`	`is.eof()`	trying to read at end of input
`badbit`	`is.bad()`	unrecoverable I/O error

- **Formatted input on stream `is` must check for `is.fail()`**
  - If failed, `is.clear()` the stream and consume invalid input characters before continue

Dealing With Invalid Input

```
int inputAge(std::istream& in) {
  while (in.good()) {
    int age{-1};
    if (in >> age) {
      return age;
    }
    in.clear();  // remove fail flag
    in.ignore(); // one char
    // alt: in.ignore(std::numeric_limits<std::streamsize>::max(), '\n');
    // ignores whole line
  }
  return -1;
}
```

```
#include <iostream>
#include <iomanip>
```

I/O Manipulators:
setw(n), setprecision(n)

```
int main() {
  std::cout << 42 << '\t'
            << std::oct << 42 << '\t'
            << std::hex << 42 << '\n';
  std::cout << 42 << '\t' // std::hex is sticky
            << std::dec << 42 << '\n';
  std::cout << std::setw(10) << 42
            << std::left<< std::setw(5)<< 43 << "*\n";
  std::cout << std::setw(10) << "hallo"<<"*\n";

  double const pi{std::acos(0.5) * 3};
  std::cout << std::setprecision(4) << pi << '\n';
  std::cout << std::scientific << pi <<  '\n';
  std::cout << std::fixed << pi * 1e6 <<  '\n';
}
```

Reading and Modifying

```
#include <iostream>
#include <cctype>
int main() {
  char c{};
  while(std::cin.get(c)) {
    std::cout.put(std::tolower(c));
  }
}
```

- **A very simple program transforming its input to lower case**
  - `<cctype>` contains character conversion and character kind query functions (`std::tolower(c)`, `std::isupper(c)`)
- **`get()` and `put()` are unformatted I/O functions**
  - What happens when we use `>>` and `<<` ?
- **More in the exercises for you to experiment with!**

Summary

- Output can be done using `ostream`, i.e., `std::cout` and `<<`
- Input uses `istream`, i.e., `std::cin` and `>>` to an lvalue
- Streams have a state for `eof` and format errors on input

`std::vector<T>` and its Iterators

Goals:

- You can use an `std::vector` in your code
- You know how to get and use iterators of an `std::vector`

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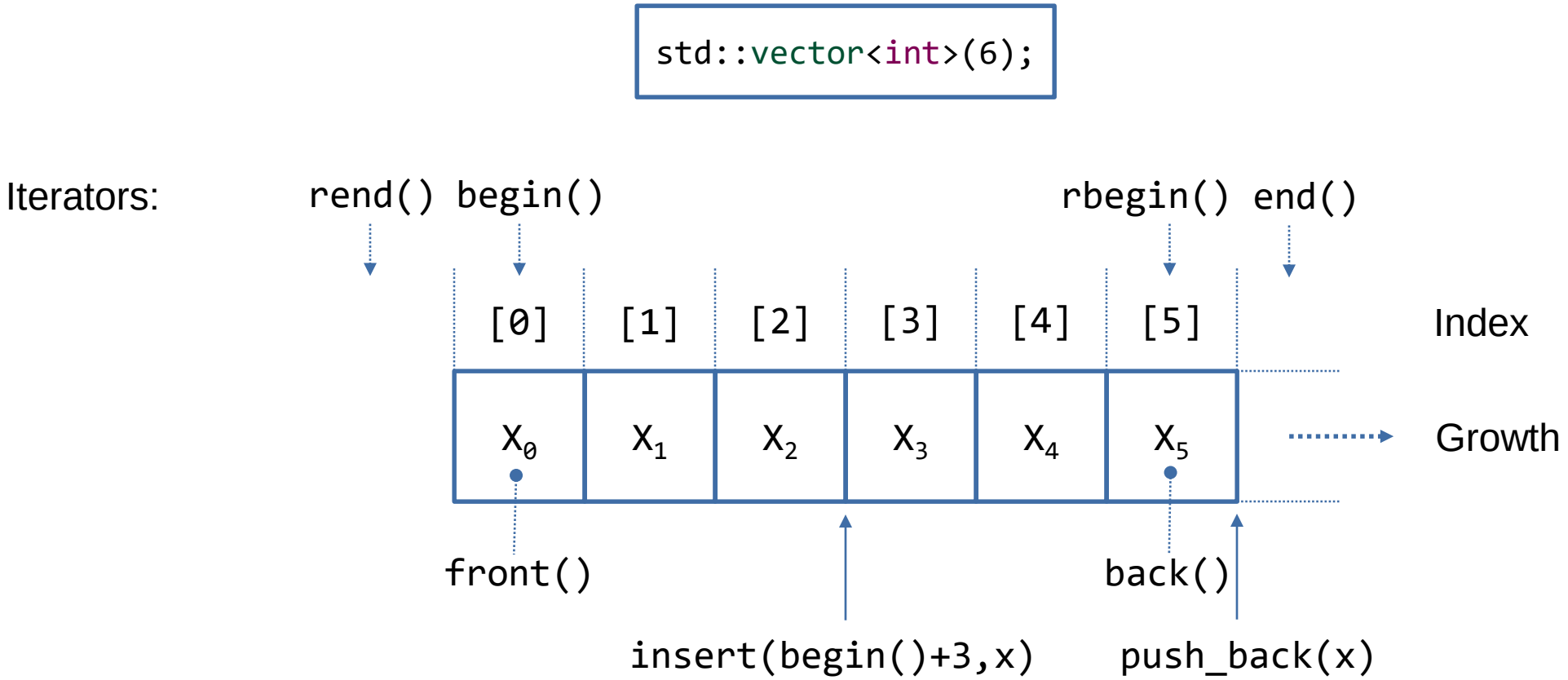
Introduction to std::vector<T>

```
std::vector<int>{1, 2, 3, 4, 5};
```

- **C++'s std::vector<T> is a Container = contains its elements of type T (no need to allocate them)**
  - java.util.ArrayList<T> is a collection = keeps references to T objects (must be “new”ed)
  - T is a *template type parameter* (= placeholder for type)
- **std::vector can be initialized with a list of elements**
  - Otherwise it is empty: `std::vector<double> vd{};`
  - Other construction means might need parentheses (legacy)
- **Future: In C++17 the template type argument can be deduced from the initializer**



- **Parenthesis at definition allow providing initial size, when type of elements is a number**
  - `std::vector<std::string> words{6};` works

Bad Style Iteration

```
for (size_t i = 0; i < v.size(); ++i) {
  std::cout << "v[" << i << "] = " << v[i] << '\n';
}
```

- **You can index a vector like an array**
  - CAUTION: No bounds check!
  - Accessing an element outside the valid range is Undefined Behavior

- **Index variable type is "unsigned"**
  - `size_t` or std::vector<T>::size_type
- **Accessing elements with `at()` checks bounds**
  - std::out_of_range exception is thrown when accessing an invalid index

```
for (size_t i = 0; i < v.size(); ++i) {
  std::cout << v.at(i) << '\n';
}
```

Element Iteration (Ranged-Based for)

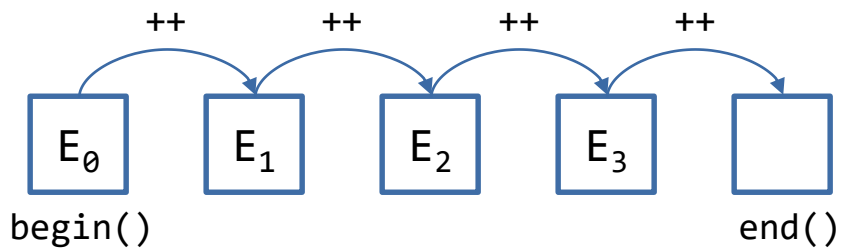
- **Advantage: No index error possible**
- **Works with all containers, even value lists {1, 2, 3}**

	const: • element cannot be changed	**non-const:** • element can be changed

reference:
• element in vector is accessed
	`for (auto const & cref : v) {`
	`  std::cout << cref << '\n';`
	`}`
		`for (auto & ref : v) {`
		`  ref *= 2;`
		`}`

copy:
• loop has own copy of the element
	`for (auto const ccopy : v) {`
	`  std::cout << ccopy << '\n';`
	`}`
		`for (auto copy : v) {`
		`  copy *= 2;`
		`  std::cout << copy << '\n';`
		`}`

```
#include <iterator>
```

- **Each container provides iterators**
- **There is always a pair of iterators denoting begin and end of an iteration**
  - `std::begin(v)` and `std::end(v)`
  - `v.begin()` and `v.end()`
- **C++ iterators don't know the end of an iteration (no `hasNext()` member)**
- **Operations:**
  - Comparison: You have to compare the current iterator to end

```
iterator != std::end(v)
```

  - Accessing the current element: `*` operator

```
*iterator
```

  - Step to the next element: `++` operator

```
++iterator
```

```
for (auto it = std::begin(v); it != std::end(v); ++it) {
  std::cout << (*it)++ << ", ";
}
```

- **Start with std::begin(v)**
- **Compare against std::end(v)**
- **Access element with *iterator**
  - Changing the element in a non-const container is possible in this way
- **Guarantee to just have read-only access with `std::cbegin()` and `std::cend()`**

```
for (auto it = std::cbegin(v); it != std::cend(v); ++it) {
  std::cout << *it << ", ";
}
```

Using Iterators with Algorithms

Goals:

- You know some basic algorithms of the standard library
- You can apply the algorithms to an `std::vector` with its iterators
- You should want to avoid writing hand-written loops

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```
#include <iterator>
```


- **Each algorithm takes iterator arguments**
  - The range(s) of elements to apply an algorithm to is specified by iterators
- **The does what its name tells us**
- **Example: Counting values**
  - Algorithm std::count returns the number of occurrences of a value in range
  - Works with all ranges denoted by a pair of iterators

```
size_t count_blanks(std::string s) {
  size_t count{0};
  for (size_t i = 0; i < s.size(); ++i) {
    if (s[i] == ' ') {
      ++count;
    }
  }
  return count;
}
```

```
//The implementation is so simple it
//is not even necessary to create
//a separate function

size_t count_blanks(std::string s) {
  return std::count(s.begin(), s.end(), ' ');
}
```

Algorithm Examples: `std::accumulate` and `std::distance`

- **Summing up all values in a vector (with `std::accumulate`)**
  - Applies + operator to elements
  - Requires the initial value

```
std::vector<int> v{5, 4, 3, 2, 1};
std::cout << std::accumulate(std::begin(v), std::end(v), 0)<< " = sum\n";
```

- **Number of elements in range (with `std::distance`)**
  - Containers provide a `size()` member function
  - Useful if you only have iterators

```
void printDistanceAndLength(std::string s) {
  std::cout << "distance: "<< std::distance(s.begin(), s.end()) <<'\n';
  std::cout << "in a string of length: "<< s.size()<<'\n';
}
```

Algorithm Example: for_each

```
void print(int x) {
  std::cout << "print: "<< x << '\n';
}
void printAll(std::vector<int> v) {
  std::for_each(std::crbegin(v), std::crend(v), print);
}
```

- **Like `for` statement: Executes an action for each element in a range**
- **Last argument is a function ("first class value" in C++) that takes one parameter of the element type**
- **Using `std::cout` outside `main` is discouraged**
  - What can we do if we want to print to a given `std::ostream`?

```
void print(int x, std::ostream & out) {
  out << "print: "<< x << '\n';
}
void printAll(std::vector<int> v, std::ostream & out) {
  std::for_each(std::crbegin(v), std::crend(v), print(?, out));
}
```

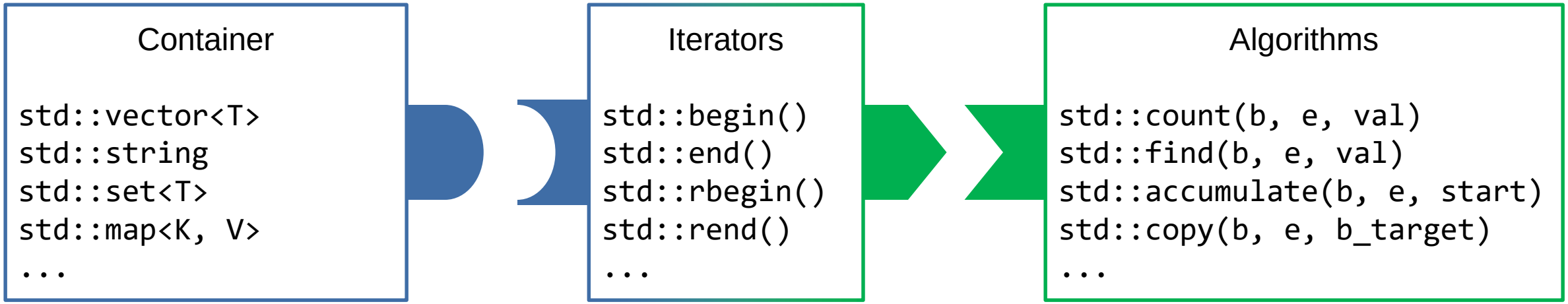
```
void printAll(std::vector<int> v, std::ostream & out) {
  std::for_each(std::crbegin(v), std::crend(v), [&out](auto x) {
    out << "print: "<< x << '\n';
  });
}
```

Lambda structure:

```
[<capture>](<parameters>) -> <return-type> {
  <statements>
}
```

- A lambda expression creates a function object on the fly that can be passed to an algorithm
  - The created function is called from within the algorithm
  - Capture names variables taken from the surrounding scope, or define new ones (= copy, & -> reference, rename possible, type deduced)
- Parameters are like function parameters, if any, but you can use auto
- The return_type can be omitted if void or consistent return statements in the body (-> compiler knows)

Iterators Connect Containers and Algorithms



- **Containers cannot be used with algorithms directly**
  - Iterators connect containers and algorithms

Appending Elements to an std::vector<T>

- **Inserting elements into an std::vector<T>**
  - Append: `v.push_back(<value>);`
  - Insert anywhere: `v.insert(<iterator-position>, <value>);`
- **When using the std::copy algorithm the target has to be an iterator too**

```
std::copy(<input-begin-iterator>, <input-end-iterator>, <output-begin-iterator>);
```

- **Can we do the following?**

```
std::vector<int> source{1, 2, 3}, target{};
std::copy(source.begin(), source.end(), target.end());
```

- **We need an std::back_inserter or an std::inserter**

```
std::vector<int> concat(std::vector<int> first, std::vector<int> second) {
  std::copy(second.begin(), second.end(), std::back_inserter(first));
  return first;
}
```

Filling an std::vector<T> With Values

```
#include <iterator>
```


- **Filling a vector with std::fill requires a vector with existing elements to be overwritten**

```
std::vector<int> v{};
v.resize(10);
std::fill(std::begin(v), std::end(v), 2);
```

```
std::vector<int> v(10);
std::fill(std::begin(v), std::end(v), 2);
```

Caution: Requires round parentheses in case of a vector with numeric elements, otherwise it would get 1 element whose value is 10

- **Or create a vector directly filled with 10 2s**

```
std::vector<int> v(10, 2);
```

Filling an std::vector<T> With Different Values

```
#include <iterator>
```


- **The algorithms std::generate() and std::generate_n() fill a range with computed values**
  - Either use std::back_inserter or a non-empty container

```
std::vector<double> powerOfTwos{};
double x{1.0};
std::generate_n(std::back_inserter(powerOfTwos),
                5,
                [&x] {return x *= 2.0;}
);
```

```
std::vector<double> powerOfTwos(5);
double x{1.0};
std::generate(powerOfTwos.begin(),
              powerOfTwos.end(),
              [&x] {return x *= 2.0;}
);
```

- **The std::iota() algorithm fills a range with subsequent values (1, 2, 3, ...)**

```
#include <numeric>
```

```
std::vector<int> v(100);
std:iota(std::begin(v), std::end(v), 1);
```

- **`std::find()` and `std::find_if()` return an iterator to the first element that matches the value or condition**
  - If no match exists the end of the range is returned

```
auto zero_it = std::find(std::begin(v), std::end(v), 0);
if (zero_it == std::end(v)){
  std::cout << "no zero found \n";
}
```

- **Similarly std::count() and std::count_if() return the number of matching elements in a range**

```
std::cout << std::count(v.begin(), v.end(), 42) << " times 42\n";
std::cout << std::count_if(begin(v), end(v), [](int x) {
  return isEven(x);
}) << " even numbers\n";
```

Avoid Programming Your Own Loops (if possible)

- **Writing readable code is about expressing intentions**
  - For many intentions there is matching iterator-based algorithm in the standard library
- **It is superior to use the corresponding algorithm (function call) instead of coding your own loop**
  - Correctness
  - Readability
  - Performance

```
bool find_with_loop(std::vector<int> const & values, int const v) {
  auto const end = std::end(values);
  for (auto it = std::begin(values); it != end; ++it) {
    if (*it == v) {
      return true;
    }
  }
  return false;
}
```

```
bool find_with_algorithm(std::vector<int> const & values, int const v) {
  auto const pos = std::find(std::begin(values), std::end(values), v);
  return pos != std::end(values);
}
```

Iterators for I/O

Goals:

- You know how to create iterators for `std::istreams` and `std::ostreams`
- You can specify ranges on streams with stream iterators

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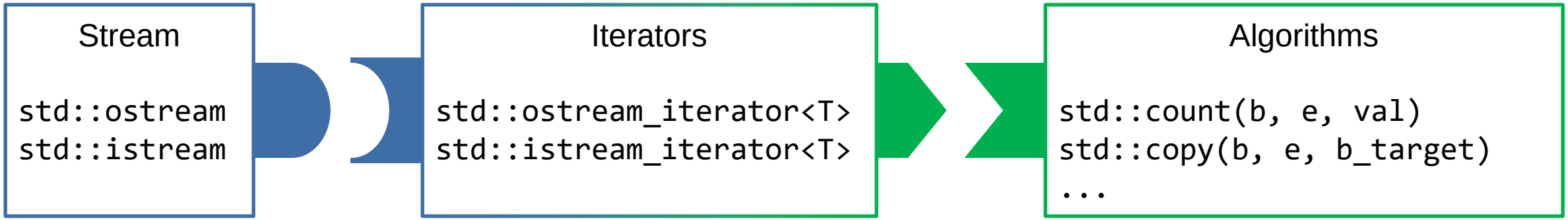

- **Streams (std::istream and std::ostream) cannot be used with algorithms directly**

```
std::copy(std::begin(v), std::end(v), std::ostream_iterator<int>{std::cout, ", "});
```

- **`std::ostream_iterator<T>` outputs values of type `T` to the given `std::ostream`**
  - No `end()` marker needed for ouput, it ends when the input range ends
- **`std::istream_iterator<T>` reads values of type `T` from the given `std::istream`**
  - End iterator is the default constructed `std::istream_iterator<T>{}`
  - It ends when the stream is no longer `good()`

Shorter Type Names With Using Alias Declarations

- The (stream) iterators have a very unpleasant name length, even with auto-completion
- A type alias can help to abbreviate that

```
using <alias-name> = <type>;
```

- Useful if long type names occur more than once
- Example
  - Copy strings from standard input to standard ouput

```
using input = std::istream_iterator<std::string>;
input eof{};
input in{std::cin};
std::ostream_iterator<std::string> out{std::cout, " "};
std::copy(in, eof, out);
```

- **`std::istream_iterator` uses operator `>>` for input**
  - Disadvantage: It skips white space
- **For an exact copy, we also need the rest**
- **`std::istreambuf_iterator<char>` uses `std::istream::get()` to get every character**
  - This only works with `char`-like types

```
using input = std::istreambuf_iterator<char>;
input eof{};
input in{std::cin};
std::ostream_iterator<char> out{std::cout, " "};
std::copy(in, eof, out);
```

Filling an std::vector<T> from Standard Input

- **To fill a vector from a stream you can either use copy with std::back_inserter(v)**
  - It uses v.push_back() internally

```
using input = std::istream_iterator<int>;
input eof{};
std::vector<int> v{};
std::copy(input{std::cin}, eof, std::back_inserter(v));
```

- **Or, construct the std::vector<T> directly from two iterators**

```
using input = std::istream_iterator<int>;
input eof{};
std::vector<int> const v{input{std::cin}, eof};
```

- Output can be done using `ostream`, i.e., `std::cout` and `<<`
- Input uses `istream`, i.e., `std::cin` and `>>` to an lvalue
- Streams have a state for `eof` and format errors on input
- Use algorithms over hand-written loops whenever possible
- Iterators specify ranges in C++ and connect streams/containers with algorithms