CS241 Principles and Practice of Problem Solving

Lecture 8: Containers and Algorithms

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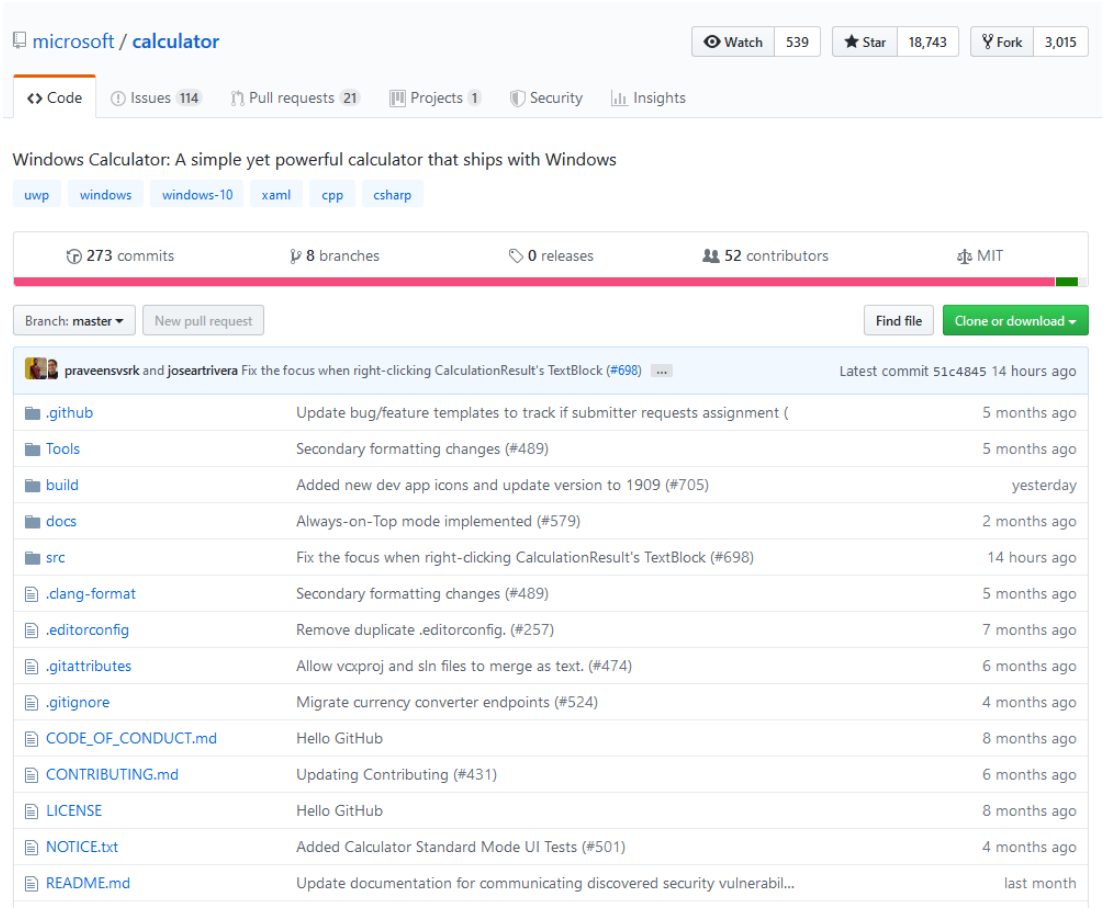
A large portion of the contents in the following pages come from Prof. Bjarne Stroustrup's slides.
The original contents could be found here.

Lingering issues from Lecture 6

```
1  Token Token_stream::get()  // read a Token from the Token_stream
2  {
3      if (full) { full=false; return buffer; }  // check if we already have a
        Token ready
4      char ch;
5      cin >> ch; // note that >> skips whitespace (space, newline, tab, etc.)
6      switch (ch) {
7      case '(': case ')': case ';': case 'q': case '+': case '-': case '*': case '
        /':
8          return Token{ch}; // let each character represent itself
9      case '.':
10     case '0': case '1': case '2': case '3': case '4': case '5': case '6': case '
        7': case '8': case '9':
11         { cin.putback(ch); // put digit back into the input stream
12         double val;
13         cin >> val; // read a floating-point number
14         return Token{number ,val};
15         }
16     default:
17         error("Bad token");
18     }
19 }
20
```

How is Windows Calculator implemented?



microsoft / calculator

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Code | Issues 114 | Pull requests 21 | Projects 1 | Security | Insights

Windows Calculator: A simple yet powerful calculator that ships with Windows

uwp windows windows-10 xaml cpp csharp

273 commits | 8 branches | 0 releases | 52 contributors | MIT

Branch: master | New pull request | Find file | Clone or download

praveensvsrk and joseartrivera Fix the focus when right-clicking CalculationResult's TextBlock (#698) ... Latest commit 51c4845 14 hours ago

.github	Update bug/feature templates to track if submitter requests assignment (	5 months ago
Tools	Secondary formatting changes (#489)	5 months ago
build	Added new dev app icons and update version to 1909 (#705)	yesterday
docs	Always-on-Top mode implemented (#579)	2 months ago
src	Fix the focus when right-clicking CalculationResult's TextBlock (#698)	14 hours ago
.clang-format	Secondary formatting changes (#489)	5 months ago
.editorconfig	Remove duplicate .editorconfig. (#257)	7 months ago
.gitattributes	Allow vcxproj and sln files to merge as text. (#474)	6 months ago
.gitignore	Migrate currency converter endpoints (#524)	4 months ago
CODE_OF_CONDUCT.md	Hello GitHub	8 months ago
CONTRIBUTING.md	Updating Contributing (#431)	6 months ago
LICENSE	Hello GitHub	8 months ago
NOTICE.txt	Added Calculator Standard Mode UI Tests (#501)	4 months ago
README.md	Update documentation for communicating discovered security vulnerabil...	last month

A quick recap after the break

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- Lecture 5 & 6: Write a simple program

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- Now what?

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- Lecture 1: Error handling
- Lecture 2: C++ in 4 slides
- Lecture 5 & 6: Write a simple program
- Now what?
- Generic programming in this lecture

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- Classes
- Inheritance
- Parameterized types

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Question: Let's think about OOP and GP. Are they compatible?

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  - Better performance (?)
- In C++, this is technically implemented by using `template`

Example: summation

Summation over a double array

```
1 double sum(double array[], int n)
2 {
3     double s = 0;
4     for (int i = 0; i < n; ++i ) s = s + array[i];
5     return s;
6 }
7
```

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Summation over an integer list

```
1  struct Node { Node* next; int data; };
2  int sum(Node* first)
3  {
4      int s = 0;
5      while (first) {
6          s += first->data;
7          first = first->next;
8      }
9      return s;
10 }
11
```

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int sum(data)
// somehow parameterize with the data structure
{
    int s = 0; // initialize
    while (not at end) { // loop through all elements
        s = s + get value; // compute sum
        get next data element;
    }
    return s; // return result
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This is called algorithm.

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```
1  template<class Iter, class T>   // Iter should be an Input_iterator
2                                  // T should be something we can + and =
3  T sum(Iter first, Iter last, T s)   // T is the accumulator type
4  {
5      while (first!=last) {
6          s = s + *first;
7          ++first;
8      }
9      return s;
10 }
11
```

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- STL is a *software library*.
- It is part of the ISO C++ Standard Library
- Specifically, STL provides an extensible framework dealing with data in a C++ program.
  - Include ∼10 containers and ∼60 algorithms
  - Other organizations provide more containers and algorithms in the style of the STL (e.g. boost, SGI, microsoft)

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- array (primitive)
- Why do we dislike array?
- We have to reinvent the wheel all the time

STL Containers

- Sequence containers
  - Array
  - Vector
  - Deque (Double-ended queue)
  - List
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Container class templates

Sequence containers:

array	Array class (class template)
vector	Vector (class template)
deque	Double ended queue (class template)
forward_list	Forward list (class template)
list	List (class template)

Container adaptors:

stack	LIFO stack (class template)
queue	FIFO queue (class template)
priority_queue	Priority queue (class template)

Associative containers:

set	Set (class template)
multiset	Multiple-key set (class template)
map	Map (class template)
multimap	Multiple-key map (class template)

Unordered associative containers: http://www.cplusplus.com/reference/stl/

unordered_set	Unordered Set (class template)
unordered_multiset	Unordered Multiset (class template)
unordered_map	Unordered Map (class template)
unordered_multimap	Unordered Multimap (class template)

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- Collect
- Organize
- Retrieve
- Add
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- ...

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There are some universal algorithms that are used to process the data
Basic operations for those containers are identical

Design ideals

Separation of concerns

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- Containers store data, but don't know about algorithms
- Algorithms and containers interact through iterators

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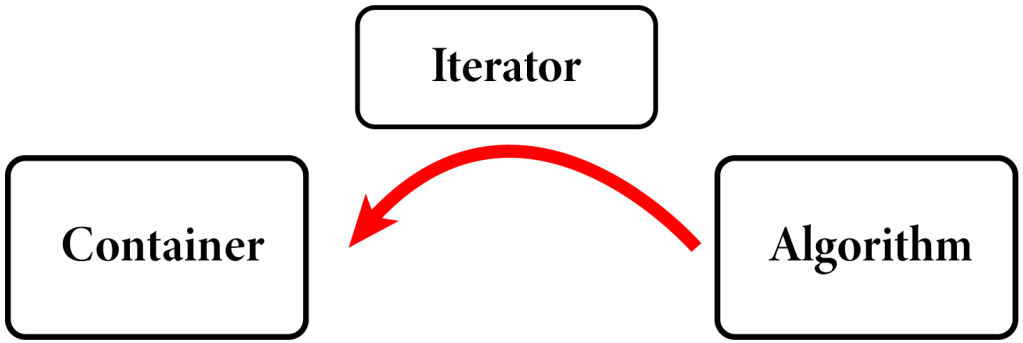
  - Two levels of abstraction/lifting/generalization: algorithm→iterator; iterator(data structure)→ data
  - Different from pointer

Basic model of STL

- Container
- Iterator
- Algorithm



Complete model of STL

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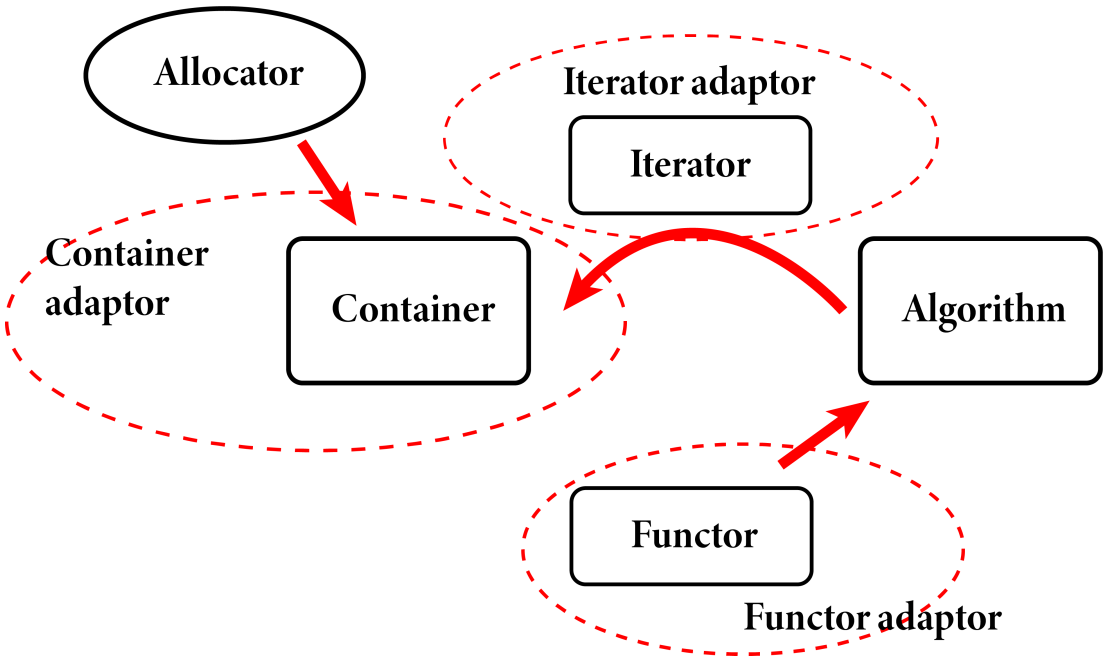
- Functor



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  - Container adaptor: pile, stack, etc
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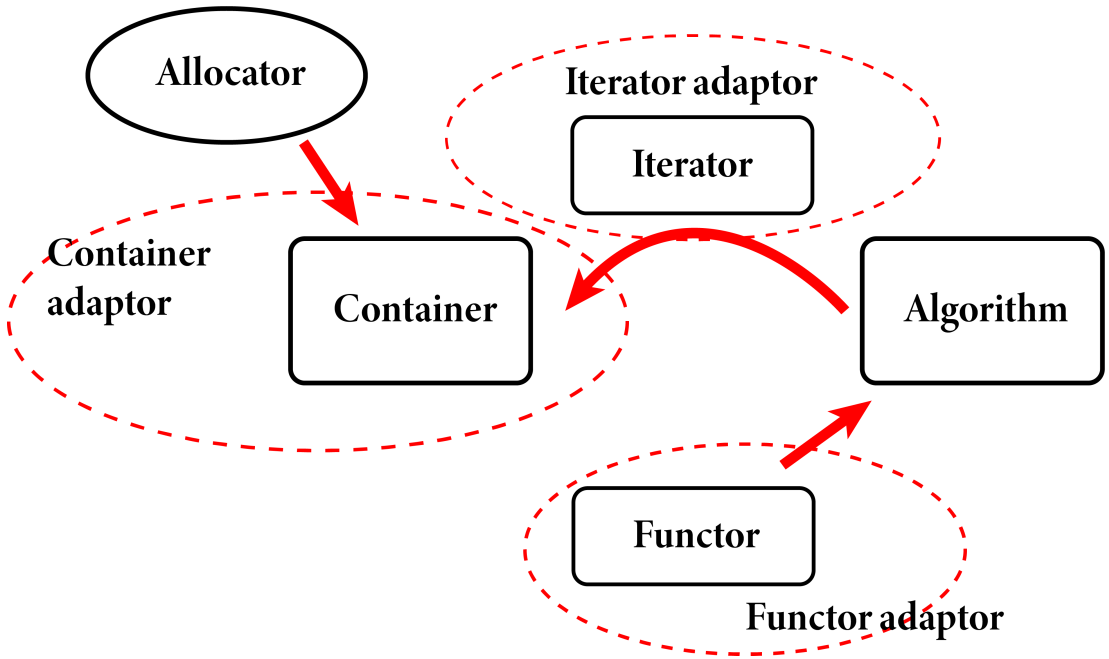

Complete model of STL

- Container
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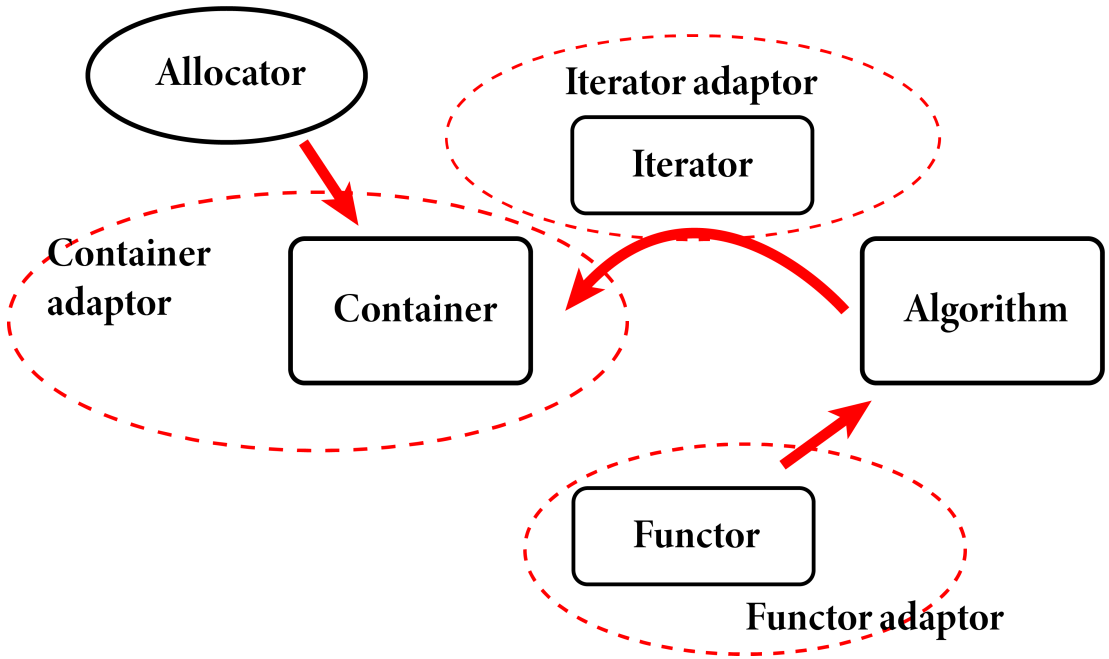
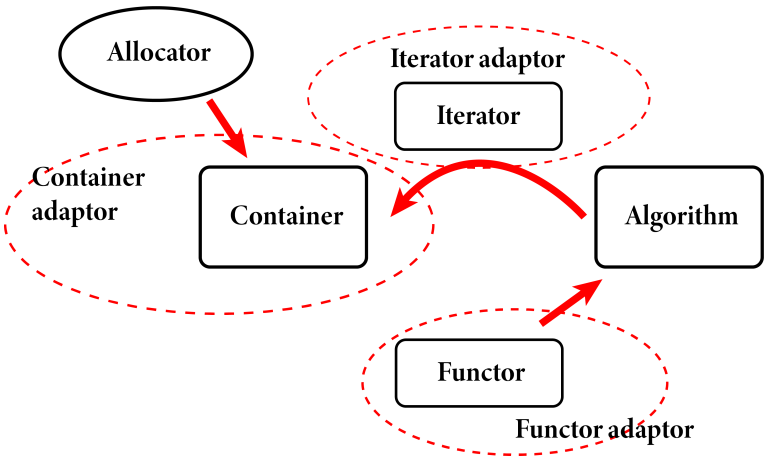
- Allocator
- Adaptor
  - Container adaptor: pile, stack, etc
  - Does not support iterator
- Functor



Example

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5  using namespace std;
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7  int main()
8  {
9      int ia[6] = {27, 210, 12, 47, 109, 83};
10     vector<int, allocator<int>> vi(va, ia +
        6);
11     cout << count_if(vi.begin(), vi.end(),
        not1(bind2nd(less<int>(), 40)));
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Example (Cont'd)

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- Allocator:
- Algorithm:
- Iterator:
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- Adaptors:

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Iterators

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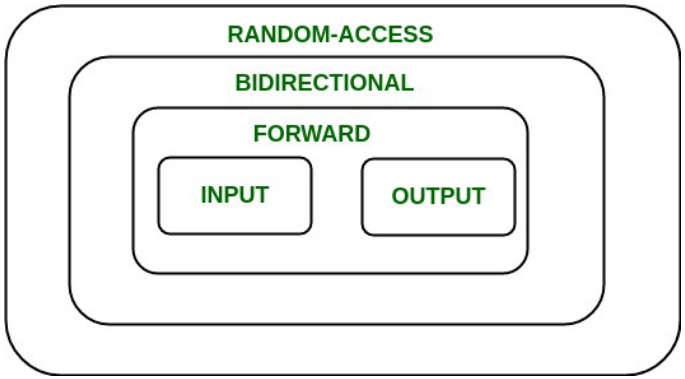
An iterator is an object (like a pointer) that points to an element inside the container.
It can:

- Point to elements
- Iterate through container (via ++)
- But, not all iterators are born equal

Types of iterators

Iterators are classified into five categories depending on the functionality they implement:



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  1. "++" has to be supported

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- Input: from the program's perspective
- Sequential:
  1. "++" has to be supported
  2. Each element could only be dereferenced once

Input and output iterators

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Output

Output iterators are ...

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- Direction: only "++" are supported

Example: forward_list

Bidirectional iterators

Bidirectional iterators are iterators that can be used to access the sequence of elements in a range in both directions (towards the end and towards the beginning).

Random-access iterators

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Question:

- Is a pointer an iterator?
- What type of iterator is most resemblant to a pointer?

Quick summary

category				properties	valid expressions
all categories				*copy-constructible*, *copy-assignable* and *destructible*	`X b(a);` `b = a;`
				Can be incremented	`++a` `a++`
Random Access	Bidirectional	Forward	Input	Supports equality/inequality comparisons	`a == b` `a != b`
				Can be dereferenced as an *rvalue*	`*a` `a->m`
			Output	Can be dereferenced as an *lvalue* (only for *mutable iterator types*)	`*a = t` `*a++ = t`
				default-constructible	`X a;` `X()`
				Multi-pass: neither dereferencing nor incrementing affects dereferenceability	`{ b=a; *a++; *b; }`

				Can be decremented	`--a`
					`a--`
					`*a--`

				Supports arithmetic operators + and -	`a + n`
					`n + a`
					`a - n`
					`a - b`

				Supports inequality comparisons (<, >, <= and >=) between iterators	`a < b`
					`a > b`
					`a <= b`
					`a >= b`

				Supports compound assignment operations += and -=	`a += n` `a -= n`
				Supports offset dereference operator ([])	`a[n]`

Functors

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What's the difference?

Why we prefer functors?

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  1. Statefulness: it can save current state (or data)
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  3. Parameterization

```
1  cout << count_if(vi.begin(), vi.end(), not1(bind2nd(less<int>(), 40)));
2
```

std::less

C++11 version

```
1 template <class T> struct less {
2     bool operator() (const T& x, const T& y) const {return x<y;}
3     typedef T first_argument_type;
4     typedef T second_argument_type;
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For this specific case, `less` is also known as a predicate.

- A predicate is a function or a function object that takes arguments and returns a bool

Back to the example

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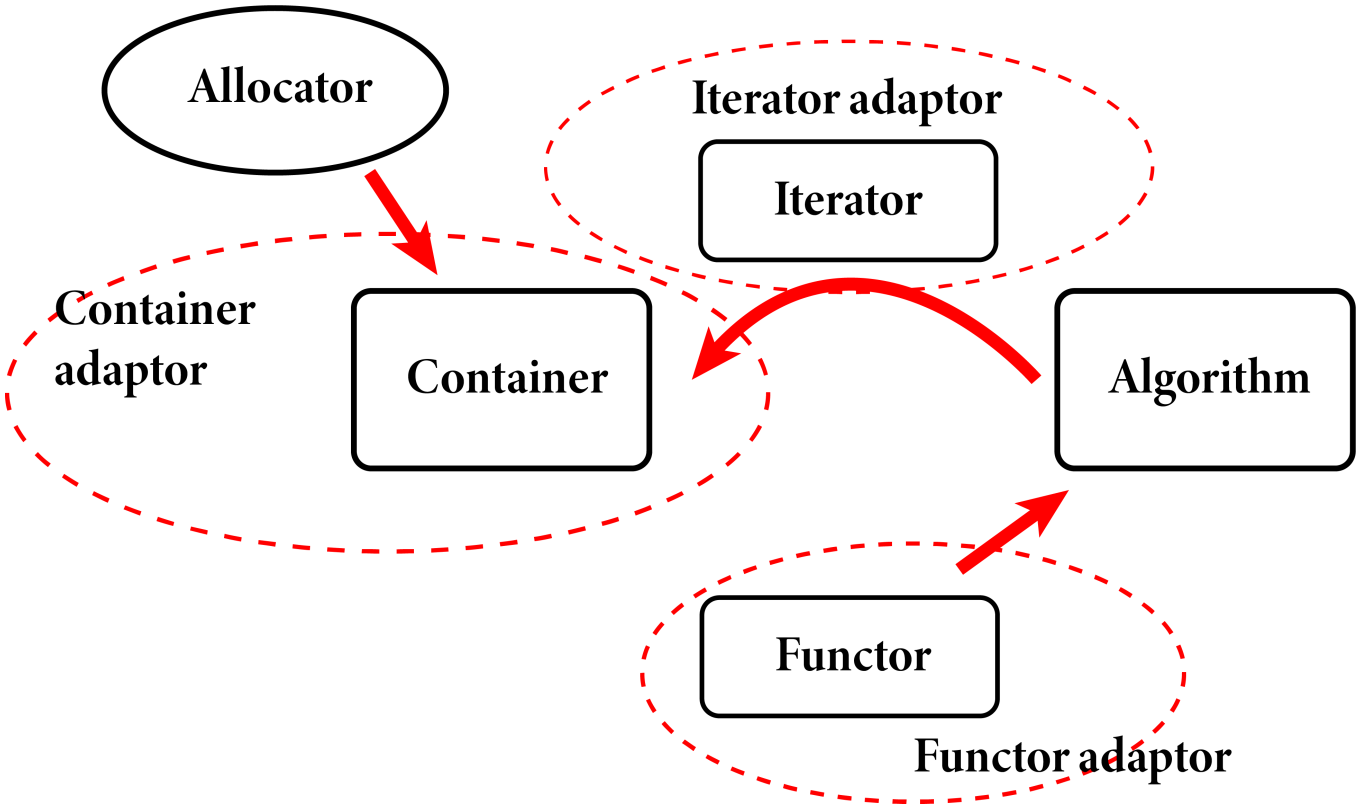
Now we know that functors provide us with a lot of flexibilities. But how is this connected to the bigger picture?


Allocator
Iterator adaptor
Iterator
Container
adaptor
Container
Algorithm
Functor
Functor adaptor

Policy parameterization

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For example, we need to parameterize `sort` by the comparison criteria

```
1  struct Record {
2      string name; // standard string for ease of use
3      char addr[24]; // old C-style string to match database layout
4      // ...
5  };
6
7  vector<Record> vr;
8  // ...
9  sort(vr.begin(), vr.end(), Cmp_by_name()); // sort by name
10 sort(vr.begin(), vr.end(), Cmp_by_addr()); // sort by addr
11
```

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- Core ideal: separation of concerns
- Back to the question raised at the beginning: does GP conflict with OOP?
- Yes and No
- Stroustrup: "C++ is a general-purpose programming language with a bias towards systems programming that:"
  1. is a better C
  2. supports data abstraction
  3. supports object-oriented programming
  4. supports generic programming.