Modern C++

Function objects: Lambda, Bind, Function

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CQG

Структура лекции

- Создание функциональных объектов в C++17
  - λ (lambda)
  - std::bind
  - std::bind vs lambda
- std::function
  - Способы передачи callback функций
  - Обзор std::function
  - std::function vs template
- Идиомы использования

А ты используешь auto?

```
auto x = 4;
auto y = 3.37;
auto ptr = &x;
cout << typeid(x).name(); // i
cout << typeid(y).name(); // d
cout << typeid(ptr).name(); // Pi


set<int> container;
const auto it = container.find(5); // long type name
```

Задача “18 ≤ x < 27”

```
count_if(ages.begin(), ages.end(), ???);
```

Задача “18 ≤ x < 27”

```
struct Between18And27
{
    bool operator() (int value)
    {
        return 18 <= value && value < 27;
    }
};

count_if(ages.begin(), ages.end(), Between18And27());
```

Инструменты C++11

λ

Задача “18 ≤ x < 27”

```
class Between18And27
{
public:
    bool operator() (int value)
    {
        return 18 <= value && value < 27;
    }
};

count_if(ages.begin(), ages.end(), Between18And27());
```

Lambda. Задача “18 ≤ x < 27”

```
class Between18And27
{
public:
    bool operator() (int value)
    {
        return 18 <= value && value < 27;
    }
};
```

```
count_if(ages.begin(), ages.end(),
    [](int value) -> bool
    {
        return 18 <= value && value < 27;
    });
```

Синтаксис lambda

```
[](){}
```

```
[] (int value) -> bool
{
    return 18 <= value && value < 27;
}
```

```
[capture]
  (arguments)
    -> return_type
      {body}
```

Capture

```
int x = 0;
int y = 0;

cin >> x >> y;

count_if(ages.begin(), ages.end(),
    [] (int value)
    {
        return ??? <= value && value < ???;
    });
```

Capture

```
int x = 0;
int y = 0;

cin >> x >> y;

count_if(ages.begin(), ages.end(),
    [] (int value)
    {
        return x <= value && value < y;
    });
```

```
error C3493: 'x' cannot be implicitly captured
because no default capture mode has been specified
```

Capture по значению

```
int x = 0;
int y = 0;

cin >> x >> y;

count_if(ages.begin(), ages.end(),
    [x, y] (int value)
    {
        return x <= value && value < y;
    });
```

Capture по значению

```
int x = 1;

for_each(ages.begin(), ages.end(),
    [x] (int value)
    {
        x *= value;
    });
```

```
error C3491: 'x': a by-value capture cannot be
modified in a non-mutable lambda
```

Capture по значению

```
int x = 1;

for_each(ages.begin(), ages.end(),
    [x] (int value) mutable
    {
        x *= value;
    });

cout << x; // 1
```

Capture по ссылке

```
int x = 1;

for_each(ages.begin(), ages.end(),
    [&x] (int value) mutable
    {
        x *= value;
    });

cout << x; // 42
```

Capture по ссылке

```
int x = 1;

for_each(ages.begin(), ages.end(),
    [&x] (int value)
    {
        x *= value;
    });

cout << x; // 42
```

Опасность передачи по ссылке

```
auto MakeLambda()
{
    int x = 0;
    int y = 0;
    cin >> x >> y;

    return [&x, &y] (int value)
           {
               return x <= value && value < y;
           };
}
```

Висячий указатель

```
auto MakeLambda()
{
    int x = 0;
    int y = 0;
    cin >> x >> y;

    return [&x, &y] (int value)
           {
               return x <= value && value < y;
           };
}

count_if(ages.begin(), ages.end(), MakeLambda());
// Incorrect. Possible crash!!!
```

Capture “this”

```
class MyClass
{
public:
   void ProcessInt(int a) { … }

   void ProcessVectorOfInts(const vector<int>& va)
   {
      for_each(va.begin(), va.end(),
         [] (int a)
         {
            ProcessInt(a);
         });
   }
};
```

error C2352: 'MyClass::ProcessInt' : illegal call of non-static member function

CQG

Capture “this”

```
class MyClass
{
public:
    void ProcessInt(int a) { … }

    void ProcessVectorOfInts(const vector<int>& va)
    {
        …
        ProcessInt(777);
        …

    }
};
```

Capture “this”

```
class MyClass
{
public:
    void ProcessInt(int a) { … }

    void ProcessVectorOfInts(const vector<int>& va)
    {
        …
        this->ProcessInt(777);
        …


    }
};
```

Capture “this”

```
class MyClass
{
public:
   void ProcessInt(int a) { … }

   void ProcessVectorOfInts(const vector<int>& va)
   {
      for_each(va.begin(), va.end(),
         [] (int a)
         {
            ProcessInt(a);
         });
   }
};
```

Capture “this”

```
class MyClass
{
public:
   void ProcessInt(int a) { … }

   void ProcessVectorOfInts(const vector<int>& va)
   {
      for_each(va.begin(), va.end(),
         [this] (int a)
         {
            ProcessInt(a);
         });
   }
};
```

Много параметров в capture

```
int firstCoolParam = 1;


for_each(va.begin(), va.end(),
         [firstCoolParam] (int& i_value)
         {
            i_value += firstCoolParam;
         });
```

Много параметров в capture

```
int firstCoolParam = 1;
int secondCoolParam = 1;

for_each(va.begin(), va.end(),
         [firstCoolParam, secondCoolParam]
            (int& i_value)
         {
            i_value +=
               firstCoolParam * secondCoolParam;
         });
```

Default capture

```
int firstCoolParam = 1;
int secondCoolParam = 1;

for_each(va.begin(), va.end(),
         [=] (int& i_value)
         {
            i_value +=
               firstCoolParam * secondCoolParam;
         });
```

Не рекомендуется!

Default capture

```
int firstCoolParam = 1;
int secondCoolParam = 1;

for_each(va.begin(), va.end(),
         [&] (int& i_value)
         {
            firstCoolParam += i_value;
            secondCoolParam *= i_value;
         });
```

Не рекомендуется (есть исключения)!

Lambda type

```
??? lambda = [] (int i_value) { cout << i_value };

auto lambda = [] (int i_value) { cout << i_value };
```

Generic lambdas (C++14)

```
auto print1 = [](auto a) { cout << a; };

print1("aaa");
print2(15);


auto printN = [print1](auto... args)
    {
        (print1(args), ...);
    };

printN("args", 42, 20.19)
```

Capture initializer (C++14)

```
auto lambda = [x = GetValue()] (auto a)
    {
        return a < x;
    };


std::set<int> cont = GetHugeContainer();
auto isInContainer =
    [c = std::move(cont)](int i)
    {
        return c.contains(i); // contains is from C++20
    };
```

std::bind

Использование std::bind

```
#include <functional>

using namespace std;
using namespace std::placeholders;
```

Использование std::bind

```
void f(int a, int b, int c, int d)
{
    cout << a << b << c << d << endl;
}
```

Мы хотим получить **g(int x)**, такую что:

```
void g(int x)
{
    f(7, 6, 5, x);
}

auto g = bind(f,  7,  6,  5, _1);
g(4); // 7654
```

Использование std::bind

```
void f(int a, int b, int c, int d);

auto g2 = bind(f, _1, _2,  5,  6);
g2(3, 4);
// 3456

auto g0 = bind(f,  1,  2,  3,  4);
g0();
// 1234

auto g3 = bind(f, _2, _1, _1, _3);
g3(7, 8, 9);
// 8779
```

std::bind. Задача “x < 27”

```
template<class T = void>
struct less; // STL: Functional objects


count_if(ages.begin(), ages.end(),
    bind(less<int>(), _1, 27))
```

std::bind. Задача “18 ≤ x < 27”

```
count_if(ages.begin(), ages.end(),
    bind(logical_and<bool>(),
        bind(greater_equal<int>(), _1, 18),
        bind(less<int>(), _1, 27)));

// Note: inner bind expressions
// are invoked eagerly and
// returned value is passed to outer one
```

std::bind. Задача “18 ≤ x < 27”

```
int x = 0;
int y = 0;

cin >> x >> y;

count_if(ages.begin(), ages.end(),
   bind(logical_and<bool>(),
      bind(greater_equal<int>(), _1, x),
      bind(less<int>(), _1, y)));
```

std::bind. Методы класса

```
struct Multiplier
{
   Multiplier (int multiplier) :
      m_multiplier(multiplier)
   {}

   void CountValue(int value) const
   {
      cout << value * m_multiplier << endl;
   }

   int m_multiplier;
};
```

std::bind. Методы класса

```
Multiplier ml_5(5);
Multiplier ml_20(20);

auto g1 = bind(&Multiplier::CountValue, ml_5, _1)
g1(7);
// 35

auto g2 = bind(&Multiplier::CountValue, _1, _2)
g2(ml_20, 7);
// 140

auto g0 = bind(&Multiplier::CountValue, ml_5, 10)
g0();
// 50
```

std::bind. Методы класса

```
vector<int> collInt;
Multiplier ml_5(5);

for_each(collInt.begin(), collInt.end(),
   bind(&Multiplier::CountValue, ml_5, _1));

vector<Multiplier> collMul;

for_each(collMul.begin(), collMul.end(),
   bind(&Multiplier::CountValue, _1, 10));
```

std::bind. Методы класса

```
vector<Multiplier*> coll;

for_each(coll.begin(), coll.end(),
   bind(&Multiplier::CountValue, _1, 10));
```

```
vector<shared_ptr<Multiplier>> coll;

for_each(coll.begin(), coll.end(),
   bind(&Multiplier::CountValue, _1, 10));
```

std::bind. Передача параметров

```
struct Accumulator
{
    void AddValue(int i_val) { m_summ += i_val; }

    int GetSumm() const { return m_summ; }

private:
    int m_summ = 0;
};
```

std::bind. Передача параметров

```
Accumulator acc;

for_each( ages.begin(), ages.end(),
  bind(
    &Accumulator::AddValue, acc, _1));

cout << acc.GetSumm() << endl; // 0
```

std::bind. Передача параметров

```
Accumulator acc;

for_each( ages.begin(), ages.end(),
  bind(
    &Accumulator::AddValue, acc, _1));

cout << acc.GetSumm() << endl;
```

```
constructor
copy constructor
copy constructor
destructor
destructor
0
destructor
```

std::bind. Передача параметров

```
Accumulator acc;

for_each( ages.begin(), ages.end(),
  bind(
    &Accumulator::AddValue, ref(acc), _1) );

cout << acc.getValue() << endl; // 197
```

```
constructor
197
destructor
```

“To bind or not to bind”. Сложность

```
void print(ostream& os, size_t i)
{
   os << i << endl;
}

map<string, vector<float>> m;

for_each(m.begin(), m.end(),
 bind(print, cout,
  bind(&vector<int>::size,
   bind(
    &map<string, vector<int>>::value_type::second,_1))));
```

“To bind or not to bind”. Сложность

```
void print(ostream& os, size_t i)
{
   os << i << endl;
}

map<string, vector<float>> m;

for_each(m.begin(), m.end(),
   [] (const auto& x)
   {
      print(cout, x.second.size());
   });
```

“To bind or not to bind”. Перегрузка

```
void process(int a) { /*do int processing*/ }
void process(double a) { /*do double processing*/ }

auto l = []() { process(1); };

auto b = bind(process, 1);
```

error C2672: 'std::bind': no matching overloaded function found

“To bind or not to bind”. Перегрузка

```
void process(int a) { /*do int processing*/ }
void process(double a) { /*do double processing*/ }

auto l = []() { process(1); };

auto b = bind(
   static_cast<void(*)(int)>(process), 1);
```

“To bind or not to bind”. Аргумент за?

```
struct B
{
    int f(int a, int b, int c)
    {
        return a + b + c;
    }
} b;

auto f = bind(&B::f, ref(b), 1, -1, _1);

auto f1 = [&b](int c)
    {
        return b.f(1, -1, c);
    };
```

“To bind or not to bind”. Аргумент за?

std::bind:

```
return f(0);

B::f(int, int, int):
add esi, edx
lea eax, [rsi+rcx]
ret
main:
sub rsp, 24
xor ecx, ecx
mov edx, -1
mov esi, 1
lea rdi, [rsp+15]
call B::f(int, int, int)
add rsp, 24
ret
```

Lambda:

```
return f1(0);

main:
xor eax, eax
ret
```

https://gcc.godbolt.org/z/99VwiV

std::function

Callback

```
void Alarm(int i_time, ??? i_callback)
{
    ::Sleep(i_time);
    i_callback ???;
}
```

Callback (function pointer)

```
void DoBeep()
{
    // make beep-beep-beep
}

void DoBlink()
{
    // make blink-blink-blink
};
```

Callback (function pointer)

```
void Alarm(int i_time, void(*i_callback)(void) )
{
    ::Sleep(i_time);
    if (i_callback)
    {
        (*i_callback)();
    }
}

Alarm(3, DoBeep);
Alarm(3, DoBlink);
```

Callback (interface)

```
struct IAlarmObserver
{
   virtual void OnAlarm() = 0;
};
```

```
struct Beeper :
   IAlarmObserver
{
   void OnAlarm() override
   {
      // make beep-beep
   }
};
```

```
struct Blinker :
   IAlarmObserver
{
   void OnAlarm() override
   {
      // make blink-blink
   }
};
```

Callback (interface)

```
void Alarm(int i_time, IAlarmObserver& i_callback)
{
   ::Sleep(i_time);
   i_callback.OnAlarm();
}

Beeper beeper;
Alarm(3, beeper);

Blinker blinker;
Alarm(3, blinker);
```

Callback

Functional object?

Bind?

Lambda?

~~`std::function<...>`~~

`template`

Callback (template)

```
template<typename TCallback>
void Alarm(int i_time, const TCallback& i_callback)
{
    ::Sleep(i_time);
    i_callback();
}

CBeeper beeper;
Alarm(3, beeper);

Alarm(3, []() { /*do stuff*/ });
```

std::function

```
bool SomeFunc (int first, int second);

function<bool (int, int)> f1 = SomeFunc;
f1(25, 27);

function<bool (int, int)> f2 = less<int>();
f2(25, 27);

function<bool (int)> f3 = bind(less<int>(), _1, 27);
f3(25);
```

std::function

```
function< bool (int, int) > f = SomeFunc;
f(12, 15);

function< bool (int, int) > f2;
f2(12, 15); // bad_function_call exception

if (f2)
{
   //...
}

f2 = f;
f2 = nullptr;
```

Callback

```
void Alarm(int i_time,
    const function<void (void)>& i_callback)
{
    ::Sleep(i_time);
    if (i_callback)
    {
        i_callback();
    }
}

Alarm(3, DoBeep);

Blinker blinker;
Alarm(3, bind(&Blinker::OnAlarm, blinker));
```

std::function. Передача параметров

```
class CAccumulator
{
public:
   void AddValue(int i_val) { m_summ += i_val; }

   int GetSumm() const { return m_summ; }

private:
   int m_summ = 0;
};
```

std::function. Передача параметров

```
class Accumulator
{
public:
    void operator()(int i_val) { m_summ += i_val; }

    int GetSumm() const { return m_summ; }

private:
    int m_summ = 0;
};
```

function

```
Accumulator acc;

function< void (int) > f1 = acc;
function< void (int) > f2 = acc;

f1(10);
f2(10);

cout << acc.GetSumm() << endl;
// 0
```

function

```
Accumulator acc;

function< void (int) > f1 = ref(acc);
function< void (int) > f2 = ref(acc);

f1(10);
f2(10);

cout << acc.GetSumm() << endl;
// 20
```

Недостатки function

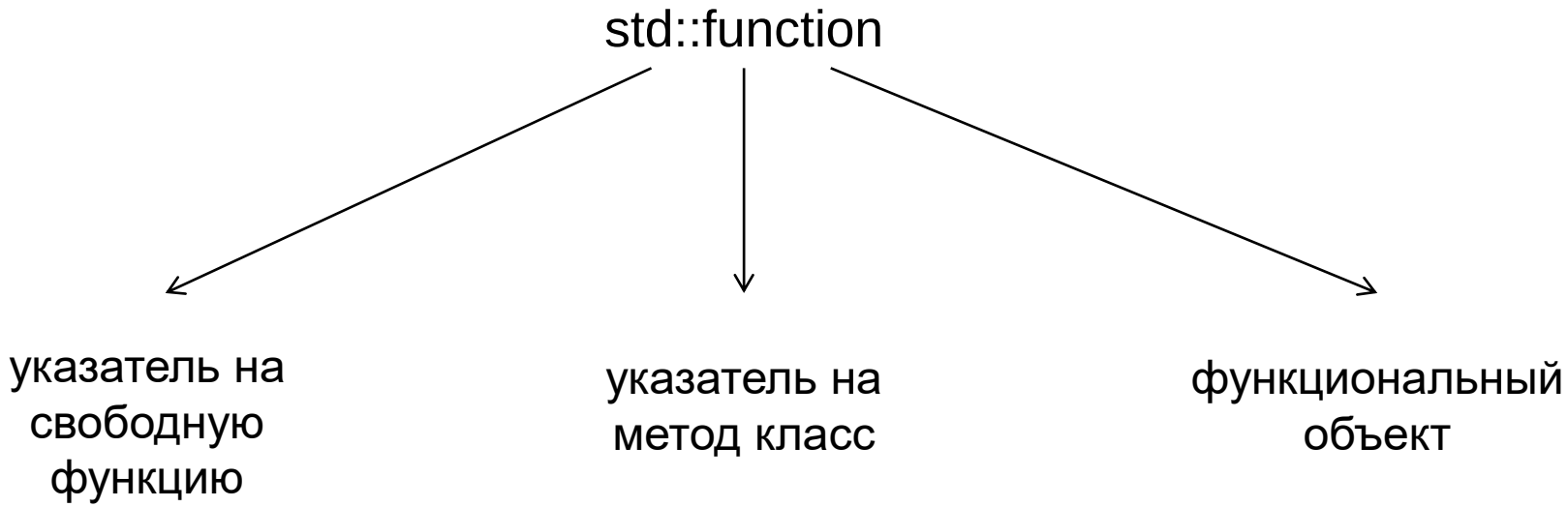
1) **Размер объекта function в восемь раз больше указателя на функцию.**

   совет: используете const function& для передачи:

```
void Alarm(int i_time,
    const function<void (void)>& i_pCallback)
{
    ...
}
```

2) **Для выполнения требуется несколько вложенных вызовов, в отличие от одного у указателя на функцию.**

Достоинства std::function



std::function vs template

```
class Base
{
   virtual process(const
      std::function<void()>& i_callback)
   {}
};
```

```
// function_ref maybe C++2x? https://youtu.be/HYENjkZvsrM
```

std::function vs template

```
void beep(){ /*do beep*/ }

vector<function<void()>> actions;

actions.push_back(beep);
actions.push_back([](){/*do stuff*/});
actions.push_back(bind(plus<int>(), 1, 2));

for (const auto& f : actions) { f(); }
```

Практическое правило

```
class A
{
    std::function<void()> m_callback;
};

template<typename T>
void foo(const T& i_callback);
```

Неверные типы!

```
auto l = [](int x) -> int
    {
        return x * 0.5;
    };
cout << l(3); // 1

function<void()> f = [](){} // performance
auto f = [](){}
```

Неверные типы!

```
// dangling reference
function<const int&(int&)> f =
    [](int& x){ return x; };

int x = 1;
cout << f(x) // 2947400

function<const int&(int&)> f =
    [](int& x) -> const int& { return x; };
```

Идиомы использования

STL algorithms

```
transform(points.begin(), points.end(),
          points.begin(),
          [](const Point& p)
          { return Point(p.x + 10, p.y + 10); });

all_of(points.begin(), points.end(),
       [&circle](const Point& p)
       { return circle.Contains(p); });

students.erase(
 remove_if(students.begin(), students.end(),
  [](const Student& x){ return !x.isListening(); }),
students.end());
```

Callback (async)

```
struct Query
{
   Query(function<void(std::vector<int>)> callback);
   function<void(std::vector<int>)> callback;
};


Query query(
   [](std::vector<int> data)
   {
      cout << “data arrived!!!”;
      /* do something with data */
   });
```

IIILE (immediately invoked lambda expression)

```
string str;
if (...)
    str = “beep”;
else
    str = “blink”;

foo(str);
```

IIILE (immediately invoked lambda expression)

```
string str;
if (...)
    str = “beep”;
else
    str = “blink”;

foo(str);
```

```
foo([&]{
    if (...)
        return “beep”;
    else
        return “blink”;
}());
```

IIILE (immediately invoked lambda expression)

```
string str;
if (...)
    str = “beep”;
else
    str = “blink”;

/* do something
    with str */
```

```
const string str = [&]{
    if (...)
        return “beep”;
    else
        return “blink”;
}()

/* do something
    with str */
```

Отложенные вычисления

```
const auto calcBigObject = [](){ ... };
if (...)
{
    auto o = calcBigObject();
    ...
}
else if (...) { ... }
else
{
    auto o = calcBigObject();
    ...
}
```

Легкая замена других абстракций

Иногда разные абстракции решают одинаковые задачи.

Функции высшего порядка иногда могут заменить:

- RAII guards
- Iterators
- …

See https://youtu.be/HYENjkZvsrM?t=1486

Дополнительные ресурсы

- Book: Effective Modern C++, Scott Meyers
- Useful resources:
  - https://gcc.godbolt.org/
  - https://cppinsights.io/
- Jason Turner YouTube channel:
  - C++ Weekly
  - C++ Lambdas
- Conference talks:
  - Higher-order functions and function_ref by Vittorio Romeo https://youtu.be/HYENjkZvsrM
  - Functional C++ for Fun and Profit by Phil Nash https://youtu.be/YgcUuYCCV14
  - Повседневный C++: алгоритмы и итераторы by Михаил Матросов https://youtu.be/LuaNbkRPGRo


Buy
100
8119
LMT DAY
Sell 100
8119
STP DAY
Sell 100
8119
LMT DAY
Buy 100@8119 LMT DAY

Q&A

Лабораторная работа (ООП)

```
class Account
{
public:
void Tweet(const std::string&);
void ReTweet(int, const std::string&);
void AddFollower(
   const std::function<void(int, const std::string&)>&);
void SetAutoReTweet(Account&);
const std::vector<std::string>& GetAllTweets() const;

private:
int m_id;
std::vector<std::string> m_tweets;
std::vector<
   std::function<void(int, const std::string&)>>
      m_followers;
};
```

Лабораторная работа (Func)

```
template<class T>
struct Stream
{
    T current;
    std::function<Stream<T>()> next;
};

for (int i = 0; i < 10; ++i)
{
  cout << stream.current << endl;
  stream = stream.next();
}
```

Лабораторная работа (Func)

```
template<class T>
struct Stream
{
    T current;
    std::function<Stream<T>()> next;
};

template<class T, class TFn>
Stream<T> CreateStream(T init, TFn fn)
{
    return Stream<T>(init,
        [=] { return CreateStream(fn(init), fn); });
}
```