

Modern C++

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Agenda

1. Language history
2. Language core novelties
3. New modifiers
4. New constructions
5. Standard library

Introduction to new C++ standards

C++ standardization history

1998 – first ISO C++ standard

2003 – TC1 (“Technical Corrigendum 1”) published as (“C++03”).

Bug fixes for C++98

2005 – “Technical Report 1” published

2011 – ratified C++0x --> C++11

2013 – full version of C++14 draft

2014 – C++14 published (minor revision)

2017 – C++17

2020 – C++20 published

2023 – C++23 (Work In Progress...)

Introduction to new C++ standards

Compilers support

C++11 support

Full support - gcc4.8.1, clang3.3

Compiler flag:

-std=c++0x

-std=c++11

C++14 support

Full support – gcc5, clang3.4

Compiler flag:

-std=c++1y

-std=c++14

C++17 support

Full support - gcc7, clang6

Compiler flag:

-std=c++1z

-std=c++17

C++20 support

Partial support ongoing on master branches

Compiler flag:

-std=c++2a

-std=c++20

More details:

https://en.cppreference.com/w/cpp/compiler_support

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1. Language history
2. Language core novelties
 - *nullptr*
 - *using* aliases
 - nested namespaces
 - scoped enums
 - structured bindings
 - automatic type deduction
3. New modifiers
4. New constructions
5. Standard library

nullptr

New keyword - *nullptr*:

- value for pointers which point to nothing,
- more expressive and safer than NULL/0 constant,
- has defined type - `std::nullptr_t`,
- solves the problem with overloaded functions taking pointer or integer as an argument.

nullptr

Examples

```
int* p1 = nullptr;  
int* p2 = NULL;  
int* p3 = 0;  
  
p2 == p1; // true  
p3 == p1; // true  
  
int* p {}; // p is set to nullptr
```

nullptr

Examples

```
void foo(int);

foo(0);      // calls foo(int)
foo(NULL);   // calls foo(int)
foo(nullptr); // compile-time error
```

```
void bar(int);
void bar(void*);
void bar(nullptr_t);

bar(0);      // calls bar(int)
bar(NULL);   // calls bar(int) if NULL is 0, ambiguous if NULL is 0L
bar(nullptr); // calls bar(void*) or bar(nullptr_t) if provided
```


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Using alias

Type alias is a name that refers to a previously defined type (similar to typedef)

```
using flags = std::ios_base::fmtflags; // equal to typedef std::ios_base::fmtflags flags;

using SocketContainer = std::vector<std::shared_ptr<Socket>>;
typedef std::vector<std::shared_ptr<Socket>> SocketContainer;
std::vector<std::shared_ptr<Socket>> typedef SocketContainer;

template<typename T>
using V = std::vector<T>;

V<int> v;
```

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Nested namespaces

Simple syntax sugar, useful with deep hierarchy of namespaces.

```
//before
namespace outer {
    namespace middle {
        namespace inner {
            // code...
        }
    }
}

//after
namespace outer::middle::inner {
    // code...
}
```

Task 1 & 2

- Change all NULL to nullptr
- Change typedef to using alias

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Scoped enums

enum class, enum struct

C++11 enumeration type was extended by a definition of scoped enum type. This type restricts range of defined constants only to defined in enum type and does not allow implicit conversions to integers.

```
enum Colors
{
    RED = 10,
    BLUE,
    GREEN
};
```

```
Colors a = RED;
int c = BLUE;
```

```
enum class Languages
{
    ENGLISH,
    GERMAN,
    POLISH
};
```

```
Languages d = Languages::ENGLISH;
//int e = Languages::ENGLISH; // Not possible
int e = static_cast<int>(Languages::ENGLISH);
```

Scoped enums

enum-base

In C++11 it is allowed to provide a type specification of enum base type.

```
enum Colors
{
    RED = 10,
    BLUE,
    GREEN
};

std::cout << sizeof(Colors) << std::endl; // size(int) but may be different if GREEN is defined
// as value higher than int can hold

enum Colors : unsigned char
{
    RED = 10,
    BLUE,
    GREEN
};

std::cout << sizeof(Colors) << std::endl; // size(unsigned char)
```


Scoped enums

forward declaration

It is possible to provide a forward declaration for enumeration, which needs to have a base type.

```
enum Colors : unsigned int;  
  
enum struct Languages : unsigned char;
```

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Structured bindings

Allows 'unpacking'/binding of subobjects directly into named initializers.
Previously `std::tie()` provided similar, but inferior behaviour.

```
std::set<int> s = {1, 3, 5, 7, 11};

//before
auto result = s.insert(9);
//result is std::pair<iterator, bool>
if (result.second)
    *result.first;

//after
auto [iter, success] = s.insert(9);
if (success)
    *iter;
```

```
struct Quaternion {
    int x;
    int y;
    int z;
    int w;
};

Quaternion fun();

auto [a, b, c, d] = fun();
```

Structured bindings

Allows 'unpacking'/binding of subobjects directly into named initializers.
Previously `std::tie()` provided similar, but inferior behaviour.

```
std::set<int> s = {1, 3, 5, 7, 11};  
  
bool success{false};  
std::set<int>::iterator iter;  
  
std::tie(iter, success) = s.insert(9);  
if (success)  
    *iter;
```

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Auto keyword

Type declaration with *auto*

Variable declaration with keyword *auto* allows to automatically deduce a type by compiler.

In previous versions *auto* was used to create automatic variable (created on stack) – noone was using it.

Const and *volatile* modifiers can be used when defining an automatic variable, as well as references and pointers.

Typical and convenient usage of *auto* is to allow a compiler to automatically deduce a type of iterator.

To get `const_iterator` you need to use methods `cbegin()` or `cend()` from the interface of standard containers.

Auto keyword

Examples

```
auto i = 42;           // i : int
const auto *ptr_i = &i; // ptr_i : const int*

double f();
auto r1 = f();         // r1 : double
const auto& r2 = f();   // r2: const double&

std::set<std::string> someStringSet;
auto it = someStringSet.begin();           // it : std::set<std::string>::iterator
const auto& ref_someStringSet = someStringSet; // ref_someStringSet :
                                              //      const std::set<std::string>&
```

Auto keyword

Examples

```
void do_something(int& x);  
void print(const int& x);  
  
std::vector<int> vec = { 1, 2, 3, 4, 5 };  
  
for(auto it = vec.begin(); it != vec.end(); ++it)  
{  
    do_something(*it);        // it : vector<int>::iterator  
}  
  
for(const auto& item : vec) // ok - range-based for  
{  
    print(item);             // item : const int &  
}
```


Auto keyword

Examples

```
const vector<int> values;
auto v1 = values; // v1 : vector<int>
auto& v2 = values; // v2 : const vector<int>&

volatile long clock = 0L;
auto c = clock; // c : long

Gadget items[10];
auto g1 = items; // g1 : Gadget*
auto& g2 = items; // g2 : Gadget(&)[10] - reference to an array

int func(double) { return 10; }
auto f1 = func; // f1 : int (*)(double)
auto& f2 = func; // f2: int(&)(double)
```

Decltype keyword

Type declaration with *decltype*

decltype keyword allows a compiler to deduce a declared type of an object or an expression given as its argument.

```
std::map<std::string, float> coll;  
  
decltype(coll) coll2;           // coll2 has type of coll  
decltype(coll)::key_type val;   // val has type std::string
```

New syntax of function declaration

Function declaration with returned type ->

New, alternative syntax of function declaration allows to declare returned type after the arguments list. It allows to specify returned type inside function of using function arguments. In combination with decltype, returned type can be provided as an expression using function arguments.

```
int sum(int a, int b);  
auto sum(int a, int b) -> int;  
  
template <typename T1, typename T2>  
auto add(T1 a, T2 b) -> decltype(a + b)  
{  
    return a + b;  
}
```

Automatic deduction of returned type (C++14)

Deduction with *auto*

In C++14 returned type can be automatically deduced from function implementation.

Deduction mechanism is the same as for automatic deduction of variable types.

If function has many *return* instructions, all of them must return values of the same type.

Recursion for functions with auto return types is possible, only if recursive function call occurs after at least one return statement returning non-recursive value.

Automatic deduction of returned type (C++14)

Examples

```
auto multiply(int x, int y)
{
    return x * y;
}

auto get_name(int id)
{
    if (id == 1)
        return string("Gadget");
    else if (id == 2)
        return string("SuperGadget");
    return string("Unknown");
}
```

```
auto factorial(int n)
{
    if (n == 1)
        return 1;
    return factorial(n-1) * n;
}
```

Task 3 & 4 & 5

- Write a new scoped enum named `Color` and define in it 3 colors of your choice. Inherit from unsigned char.
- Add a new field: `Color color`` in the `Shape`` class, so that every shape has it's own defined color.
- Use `auto``, wherever you should.
- Use range-based for loops, wherever possible.

It's quiz time!

- <https://b.socrative.com/login/student/>
- Room name: NOKIAPARO
- (multiple choice test)

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 - attributes
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Default, delete, override, final keywords

default

default declaration enforces a compiler to generate default implementation for marked functions (eg. default constructor when other constructors were defined).

You can mark as default only special member functions like: default constructor, copy constructor, copy assignment operator, move constructor (C++11), move assignment operator (C++11), destructor

```
class Gadget
{
public:
    Gadget(const Gadget&); // copy constructor will prevent
                          // generating implicitly declared
                          // default ctor and move operations

    Gadget() = default;
    Gadget(Gadget&&) noexcept = default;
};
```

Default, delete, override, final keywords

delete

delete declaration deletes marked function from the class interface. No code is generated for this function. Calling it, getting its address or usage in *sizeof* causes compilation error.

```
class NoCopyable
{
protected:
    NoCopyable() = default;

public:
    NoCopyable(const NoCopyable&) = delete;
    NoCopyable& operator=(const NoCopyable&) = delete;
};

class NoMoveable
{
    NoMoveable(NoMoveable&&) = delete;
    NoMoveable& operator=(NoMoveable&&) = delete;
};
```

Default, delete, override, final keywords

Prohibiting implicit conversions with *delete*

Marking as delete some of a function overloaded versions helps to avoid implicit conversions.

```
void integral_only(int a)
{
    cout << "integral_only: " << a << endl;
}

void integral_only(double d) = delete;

// ...

integral_only(10); // OK

short s = 3;
integral_only(s); // OK - implicit conversion from short

integral_only(3.0); // error - use of deleted function
```

Default, delete, override, final keywords

override

override declaration enforces a compiler to check, if given function overrides virtual function from a base class.

```
struct A
{
    virtual void foo() = 0;
    void dd() {}
};

struct B : A
{
    void foo() override {}    // OK, method overrides in base class
    void bar() override {}    // error, there is no virtual method in struct A
    void dd() override {}     // error, only virtual methods can be overridden
};
```

Default, delete, override, final keywords

Prohibiting inheritance with *final*

final declaration used after a class name does not allow to create a derived class, inheriting from a marked class.

```
struct A final
{};

struct B : A           // error, cannot derive from class marked as final
{};
```

Default, delete, override, final keywords

Prohibiting overriding with *final*

final used after virtual function declaration prohibits its override in a derived class.

```
struct A
{
    virtual void foo() const final
    {}

    void bar() const final           // error, only virtual functions can be marked as final
    {}
};

struct B : A
{
    void foo() const override       // error, cannot override function marked as final
    {}
};
```

Task 6 & 7.

- Mark copy constructors as `default`.
- Delete `getY()` method in `Square` and all default constructors of shapes
- Mark `Circle` class as `final`
- Mark `getX()` in `Rectangle` as `final`. What is the problem?
- Mark all overridden virtual methods. Can you spot the problem?

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Attributes

Attributes provide the unified standard syntax for implementation-defined language extensions, such as the GNU and IBM language extensions `__attribute__((...))`, Microsoft extension `__declspec()`, etc.

Standard attributes:

`[[noreturn]]` (C++11) - function does not return, like `std::terminate`. If it does, we have UB

`[[deprecated]]` (C++14) - function is deprecated

`[[deprecated("reason")]]` (C++14) - as above, but compiler will emit the reason

`[[fallthrough]]` (C++17) - in switch, indicates that fall through between cases is intentional, silences compiler warning on missing 'break;'

`[[nodiscard]]` (C++17) - issues warning if result of function is unused

`[[nodiscard("reason")]]` (C++20) - as above, but with the reason

`[[likely]]`, `[[unlikely]]` (C++20) - hints for optimization of branching

Attributes

[[noreturn]], [[deprecated]]

```
[[ noreturn ]] void f() {  
    throw "error";  
}  
// OK  
  
[[ noreturn ]] void q(int i) {  
if (i > 0)  
    throw "positive";  
}  
// behavior is undefined if called with an argument <= 0  
  
[[deprecated("Please use f2 instead")]] int f1()  
{ /* do something */ }
```

Attributes

[[fallthrough]]

```
//before
switch (int i) {
    case 0: //intentional fallthrough
    case 2: process(i); break;
    default: print_warning(); break;
}
```

```
//after
switch (int i) {
    case 0: [[fallthrough]];
    case 2: process(i); break;
    default: print_warning(); break;
}
```

Attributes

[[nodiscard]]

```
struct [[nodiscard]] VeryImportant { ... };  
// every place which uses VeryImportant as return type will issue warning if discarded  
  
[[nodiscard]] bool launch() { ... }  
void f() {  
    launch(); // warning on discarded return value  
}  
  
void g() {  
    std::vector<int> vec = {1, 2, 3, 4, 5};  
    vec.empty(); // it's not making vector empty! warning will be issued  
    bool isEmpty = vec.empty(); // OK  
}
```

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Noexcept keyword

- 1) Specifies whether a function will throw exceptions or not.
- 2) The *noexcept* operator performs a compile-time check that returns true if an expression is declared to not throw any exceptions. Returns bool.

```
void bar() noexcept(true) {}  
void baz() noexcept { throw 42; }  
// noexcept is the same as noexcept(true)  
  
int main()  
{  
    bar(); // fine  
    baz(); // compiles, but calls std::terminate  
}
```

```
void may_throw();  
void no_throw() noexcept;  
  
int main()  
{  
    std::cout << std::boolalpha  
               << "Is may_throw() noexcept? "  
               << noexcept(may_throw()) << '\n' //false  
               << "Is no_throw() noexcept? "  
               << noexcept(no_throw()) << '\n'; //true  
}
```

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Constexpr

C++11 introduces two meanings of constants:

- `constexpr` - constant evaluated during compile time
- `const` - constant, which value can not change

Constant expression (*constexpr*) is evaluated by compiler during compilation.

It can not have values which are not known during compilation and can not have any side effects.

If constant expression can not be computed during compilation, compiler will raise an error.

In C++11 `constexpr` variables must be initialized with constant expression.

Important: `const` does not need to be initialized with constant expression.

```
int x1 = 7;
constexpr int x2 = 7;

constexpr int x3 = x1; // error: initializer is not a constant expression
constexpr int x4 = x2; // OK
constexpr int n_x = factorial(x);
```


Constexpr functions

Examples in C++11

```
constexpr int factorial(int n)
{
    return (n == 0) ? 1 : n * factorial(n-1);
}
```

```
template <typename T, size_t N>
constexpr size_t size_of_array(T (&)[N])
{
    return N;
}
```

```
// ...
```

```
const int SIZE = 2;
int arr1[factorial(1)];
int arr2[factorial(SIZE)];
int arr3[factorial(3)];
int arr4[factorial(size_of_array(arr3))];
```

Constexpr functions

constexpr in C++14

In C++14 constexpr restrictions were relaxed. Every function can be marked as constexpr, unless it:

- uses static or thread_local variables,
- uses variable declarations without initializations,
- is virtual,
- calls non-constexpr functions,
- uses non-literal types (values unknown during compilation),
- uses ASM code block,
- has try-catch blocks or throws exceptions

Constexpr functions

Examples

```
constexpr int foo(int bar)
{
    if(bar < 20)
    {
        return 4;
    }

    int k = 5;
    for(int i = 0; i < 54; ++i)
    {
        bar++;
    }

    if(bar > 51)
    {
        return bar + k;
    }

    return 1;
}
```

Constexpr functions

Examples

```
struct Point
{
constexpr Point(int x_, int y_)
    : x(foo(x_)), y(y_)
{}

int x, y;
};

constexpr Point a = { 1, 2 };
```

Constexpr functions

constexpr in C++17

Two new features added:

- compile-time if constexpr
- constexpr lambda

Constexpr in C++17

Examples

```
template<class T> struct dependent_false : std::false_type  
{};
```

```
template <typename T>  
constexpr bool is_integral()  
{  
    if constexpr (std::is_integral<T>::value)  
        return true;  
    else  
        static_assert(dependent_false<T>::value);  
}
```

```
static_assert(is_integral<int>());
```

Task 8.

Write a function that calculates n-th Fibonacci's number. Do not mark it `constexpr`.

In the first line of `main()` add computing 45-th Fibonacci's number. Measure the time of program execution (time ./modern_cpp)

Mark fibonacci function as `constexpr`, compile the program and measure the time of execution once again.

If you can't see a big difference assign the result to the `constexpr` variable.

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 - move semantics
 - smart pointers
 - delegating constructors
 - lambda expressions
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Variable initialization in modern C++



Source: [.gif](#)

Uniform variable initialization

Use of {} braces to initialize variables

C++11 introduced possibility to initialize variable with {} braces.

It allows to avoid many problems known from C++98 such as:

- most vexing parse,

- no possibility to initialize containers with list of values,

- different methods for initializing variables of simple types, complex types, structures and arrays.

All methods for initialization of variables from C++98 are correct excluding type narrowing implicit conversion in initialization list.

Uniform variable initialization

Examples

```
int i;           // undefined value

int va(5);       // c++98: "direct initialization", v = 5
int vb = 10;     // c++98: "copy initialization", v = 10
int vc();        // c++98: "function declaration", common error named
                // "most-vexing-parse", compiles normally, but generally
                // this behaviour is not expected

int vd{};        // c++11: brace initialization - default value
int ve{5};       // c++11: brace initialization

int values[] = { 1, 2, 3, 4 }; // c++98: brace initialization

struct P { int a, b; };
P p = { 20, 40 };           // c++98: brace initialization
```

Uniform variable initialization

Examples

```
std::complex<float> ca(12.0f, 54.0f); // c++98: initialization of classes
                                     // using constructor
std::complex<float> cb{12.0f, 54.0f}; // c++11: brace initialization, using
                                     // the same constructor as above

std::vector<std::string> colors;      // c++98: no brace initialization like with
colors.push_back("yellow");          // simple arrays/structs
colors.push_back("blue");

std::vector<std::string> names = {    // c++11: brace initialization with
    "John",                          // std::initializer_list
    "Mary"
};

std::vector<std::string> names{       // c++11: brace initialization with
    "John",                          // std::initializer_list
    "Mary"
};

int array[] = { 1, 2, 5.5 };         // C++98: OK,
                                     // C++11: error - implicit type narrowing
```

Intializing non-static variables in class brace-or-equal initializer

In C++98 class variables could be initialized only on initializer list of constructor or in its body. The exception existed only for static, integer constants.

Since C++14 it is possible to initialize all variables and constants in class body. Such initialization defined default values for class fields but they can be overwritten in initializer list of constructor or in its body.

Intializing non-static variables in class

Example

```
class Foo
{
public:
    Foo()
    {}

    Foo(std::string a) :
        m_a(a)
    {}

    void print()
    {
        std::cout << m_a << std::endl;
    }

private:
    std::string m_a = "Fooooo";           // C++98: error, C++11: OK
    static const unsigned VALUE = 20u;    // C++98: OK, C++11: OK
};

Foo().print();           // Fooooo
Foo("Baar").print();     // Baar
```

Initialization with use of initialization list

`std::initializer_list`

In C++98 initialization with use of initialization list was possible only for arrays and POD structures (Plain Old Data).

In C++11 this syntax was extended also for class object with use of special class template - `std::initializer_list`.

`std::initializer_list` utilizes copy semantics so once value is put on such list it cannot be moved from there somewhere else (e.g. `std::unique_ptr` cannot moved from such list).

`std::initializer_list` has some auxiliary functions: `size()`, `begin()/end()`.

Constructors that has `std::initialize_list` as parameter has higher priority over others.

Initialization with use of initialization list

Example

```
template<class Type>
class Bar
{
public:
    Bar(std::initializer_list<Type> values)
    {
        for(auto a : values)           // only example, can be much better
        {
            m_values.push_back(value);
        }
    }

    Bar(Type a, Type b) :
        m_values{a, b}
    {}

private:
    std::vector<Type> m_values;
};

Bar<int> b = { 1, 2 };                // OK, first constructor is used
Bar<int> b = { 1, 2, 5, 51 };          // OK, first constructor is used
Bar<std::unique_ptr<int>> c = { new int{1}, new int{2} }; // error - std::unique_ptr is non-copyable
```

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Move semantics

Advantages and novelties

Better performance from recognition of temporary objects and ability to move variables from them instead making copies (mostly deep copies).

New syntax by introducing *r-value* references (**auto && value**).

New class methods:

move constructor

move assignment operator

```
Class(Class && src),  
Class& operator=(Class && src).
```

New auxiliary functions:

`std::move()` – forces the use of move constructor or move assignment operator,

`std::forward()` – transfer of value forward as is.

Move semantics

Examples

```
struct A
{
    int a, b;
};

A foo()
{
    return {1, 2};
}

A a;                // l-value
A& ra = a;          // l-value reference to l-value, OK
A& rb = foo();       // l-value reference to r-value, ERROR
A const& rc = foo(); // const l-value reference to r-value, OK (exception in rules)

A&& rra = a;         // r-value reference to l-value, ERROR
A&& rrb = foo();      // r-value reference to r-value, OK

A const ca{20, 40};
A const&& rrc = ca;  // const r-value reference to const l-value, ERROR
```

Move semantics

Example of std::move usage

```
struct A
{
    A(A&& src) :
        m_value(std::move(src.m_value))
    {}

    A& operator=(A&& src)
    {
        m_value = std::move(src.m_value);
        return *this;
    }

    std::shared_ptr<int> m_value;
};
```

Move semantics

Example of std::forward usage

```
template<class Type>
class Bar
{
public:
    template<class... Args>
    Bar(Args&&... args) :
        m_values(std::forward<Args>(args)...)    // much better
    {}

private:
    std::vector<Type> m_values;
};

Bar<int> b = { 1, 2, 5, 51 };
```

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 - move semantics
 - **smart pointers**
 - delegating constructors
 - lambda expressions
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 - designated initializers
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Smart pointers

Application

std::unique_ptr class should be used when:

- exception may be thrown while managing pointers,
- function has many paths of execution and many return points,
- there is only one object that controls life-time of allocated object,
- resistance to exceptions is important.

std::shared_ptr can be used when:

- there are many users of an object but no explicit owner,
- there is no way to implicitly transfer an ownership from and to external library.

std::weak_ptr can be used to:

- break cycles in shared_ptrs
- observe resources

Uniform variable initialization

Task 9.

- Use ``initializer_list`` to initialize the collection.
- Add a new constructor to Shape - ``Shape(Color c)``. What happens?
- Use constructor inheritance to allow initialization of all shapes providing only a ``Color`` as a parameter. Create some shapes providing ``Color`` only param.
- Add in-class field initialization for all shapes to safely use inherited constructor.

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Delegating constructors

Since C++11 you can provide another constructor on constructor's initialization list. This allows to remove code duplications.

```
class Foo {  
public:  
    Foo() {  
        // code to do A  
    }  
    Foo(int nValue): Foo() { // use Foo() default constructor to do A  
        // code to B  
    }  
};
```

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Lambda expressions

Basic lambda expressions

Lambda expression is defined directly in-place of its usage. Usually it is used as a parameter of another function that expects pointer to function or functor – in general a callable object.

Every lambda expression causes the compiler to create unique closure class that implements function operator with code from the expression.

Closure is an object of a closure class. According to way of capture type this object keeps references or copies to local variables.

```
[](){}; // empty lambda

[] { std::cout << "hello world" << std::endl; } // unnamed lambda

auto l = [] (int x, int y) { return x + y; };

auto result = l(2, 3); // result = 5
```

Lambda expressions

Basic lambda expressions

If implementation of lambda doesn't contain return statement, the returned type is void.

If implementation of lambda has return statement(s), the returned type is a type of used expression(s).

It is much better to use lambda expressions to create predicates and functors required by algorithms in standard library (e.g. for `std::sort`).

```
[](bool condition) -> int
{
    if (condition)
        return 1;
    else
        return 2;
};
```

```
std::array<double, 6> values = { 5.0, 4.0, -1.4, 7.9, -8.22, 0.4 };

std::sort(values.begin(), values.end(), [](double a, double b)
{
    return std::abs(a) < std::abs(b); // sorting values using
                                     // absolute values
});
```

Lambda expressions

Scope of variables

Inside brackets `[]` we can include elements that the lambda should capture from the scope in which it is create. Also the way how they are captured can be specified.

`[]` empty brackets means that inside the lambda no variable from outer scope can be used.

`[&]` means that every variable from outer scope is captured by reference, including *this* pointer. Functor created by lambda expression can read and write to any captured variable and all of them are kept inside lambda by reference.

`[=]` means that every variable from outer scope is captured by value, including *this* pointer. All variables from outer scope are copied to lambda expression and can be read and written to but with no effect on those captured variable, except for *this* pointer. *this* pointer when copied allows lambda to modify all variables it points to.

`[capture-list]` allows to explicitly capture variable from outer scope by mentioning their names on the list. By default all elements are captured by value. If variable should be captured by reference it should be preceded by `&` which means capturing by reference.

Lambda expressions

Scope of variables

```
int a {5};
auto add5 = [=](int x) { return x + a; };
cout << add5(1); // 6

int counter {};
auto inc = [&counter] { counter++; };
inc(); // counter = 1

int even_count = 0;
vector<int> v = {1, 2, 3, 4, 5};
for_each(v.begin(), v.end(), [&even_count] (int n)
{
    if (n % 2 == 0)
        ++even_count;
});
cout << "There are " << even_count // = 2
<< " even numbers in the vector." << endl;
```


Lambda expressions

Generic lambdas (C++14)

In C++11 parameters of lambda expression must be declared with use of specific type.

C++14 allows to declare parameter as *auto* (*generic lambda*).

This allows compiler to deduce the type of lambda parameter in the same way parameters of templates are deduced. In result compiler generates code equivalent to closure class given below.

```
auto lambda = [](auto x, auto y) { return x + y; }
```

```
struct UnnamedClosureClass
{
    template <typename T1, typename T2>
    auto operator()(T1 x, T2 y) const
    {
        return x + y;
    }
};
```

```
auto lambda = UnnamedClosureClass();
```

Lambda expressions

Lambda capture expressions (C++14)

C++11 lambda functions capture variables declared in their outer scope by value -copy or by reference. This means that value members of a lambda cannot be move-only types.

C++14 allows captured members to be initialized with arbitrary expressions. This allows both capture by value -move and declaring arbitrary members of the lambda, without having a correspondingly named variable in an outer scope.

```
auto lambda = [value = 1]{ return value; };

std::unique_ptr<int> ptr(new int(10));
auto anotherLambda = [value = std::move(ptr)] {return *value;};
```

Lambda expressions (C++17)

C++17 introduce:

- Constexpr lambda
- Lambda capture of `*this`

```
constexpr int inc(int n)
{
    return [n] { return n + 1; }();
}
```

```
auto inc2 = [](int n) constexpr
{ return n + 1; };
```

```
static_assert(inc(1) == 2);
static_assert(inc2(1) == 2);
```

```
struct S2 { void f(int i); };
void S2::f(int i)
{
    [=]{};           // OK: by-copy capture default
    [=, &i]{};       // OK: by-copy, except i by reference
    [*this]{};       // until C++17: Error: invalid syntax
                    // since c++17: OK: S2 by copy
    [=, this] {};    // until C++20: Error: this when = is default
                    // since C++20: OK, same as [=]
}
```

Task 10.

- Change functions from `main.cpp` into lambdas (`sortByArea`, `perimeterBiggerThan20`, `areaLessThan10`)
- Change lambda `areaLessThan10` into lambda `areaLessThanX`, which takes `x = 10` on a capture list. What is the problem?
- Use `std::function` to solve the problem.

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Variadic templates

Syntax

Templates with variable number of arguments (*variadic template*) use new syntax of parameter pack, that represents many or zero parameters of template.

```
template<class... Types>
class variadic_class
{
    /*...*/
};

template<class... Types>
void variadic_foo(Types&&... args)
{
    /*...*/
}

variadic_class<float, int, std::string> v;

variadic_foo(1, "", 2u);
```

Variadic templates

Unpacking function parameters

Unpacking group parameters uses new syntax of elipsis operator (...).

In case of function arguments it unpacks them in order given in template function call.

It is possible to call a function on a parameter pack. In such case given function will be called on every argument from a function call.

It is also possible to use recursion to unpack every single argument.

It requires the variadic template Head/Tail and non-template function to be defined.

Variadic templates

Example

```
template<class... Types>
void variadic_foo(Types&&... args)
{
    callable(args...);
}

template<class... Types>
void variadic_perfect_forwarding(Types&&... args)
{
    callable(std::forward<Types>(args)...);
}

void variadic_foo() {}

template<class Head, class... Tail>
void variadic_foo(Head const& head, Tail const&... tail)
{
    /*action on head*/
    variadic_foo(tail...);
}
```


Variadic templates

Unpacking template class parameters

Unpacking template class parameters looks the same as unpacking template function arguments but with use of template classes.

It is possible to unpack all types at once (e.g. in case of base class that is variadic template class) or using partial and full specializations.

Variadic templates

Example

```
template<class... Types>
struct Base
{};

template<class... Types>
struct Derived : Base<Types...>
{};

template<int... Number>
struct Sum;

template<int Head, int... Tail>
struct Sum<Head, Tail...>
{
    const static int RESULT = Head + Sum<Tail...>::RESULT;
};

template<>
struct Sum<>
{
    const static int RESULT = 0;
}

Sum<1, 2, 3, 4, 5>::RESULT; // = 15
```

Variadic templates

sizeof... operator

sizeof... returns the number of parameters in parameter pack.

```
template<class... Types>
struct NumOfArguments
{
    const static unsigned NUMBER_OF_PARAMETERS = sizeof...(Types);
};
```

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Designated initializers

Officially from C++20, since almost ever via compiler non-standard extensions

Similar to the way it works in C99 (but with more restrictions), when constructing an *aggregate*, one can specify name of data member being initialized, instead of relying only on number and order of members.

```
struct A { int x, y; };
struct B { struct A a; };
struct A a = {1, 3}; // C++98 brace initialization
struct A a = {.x = 1, .y = 3}; // C++20 designated initializers

struct A a = {.x = 1, .y = 2.5f}; // compile-time error (narrowing conversion)
struct A a = {.y = 1, .x = 2}; // valid C, invalid C++ (out of order)
int arr[3] = {[1] = 5}; // valid C, invalid C++ (array)
struct B b = {.a.x = 0}; // valid C, invalid C++ (nested)
struct B b = {.a = {.x = 0}}; // can be nested with additional braces
struct A a = {.x = 1, 2}; // valid C, invalid C++ (mixed)
```

Designated initializers

Example usage

```
void addMarkerOnMap(double latitude, double longitude);

addMarkerOnMap(51.1, 17.03); // center of Wrocław, Poland
addMarkerOnMap(17.03, 51.1); // center of desert, Yemen

struct Coordinates { double latitude, longitude; };
void addMarkerOnMap(Coordinates coords);

// unambiguous, safer expression of intent
addMarkerOnMap({.latitude = 51.1, .longitude = 17.03});
```

It's quiz time!

- <https://b.socrative.com/login/student/>
- Room name: NOKIAPARO
- (multiple choice test)

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 - new things in standard library in short

New elements in standard library

C++11

With addition to already mentioned improvements in language, following new elements were introduced into C++ standard library:

- `<array>`, `<unordered_map>`, `<unordered_set>`,
- `<chrono>` (clocks, durations)
- `<tuple>`,
- `<regex>`,
- `<thread>`, `<mutex>`, `<condition_variable>`, `<future>`, `<atomic>`
- `<functional>` (major changes),
- `<random>`
- `<type_traits>`

New elements in standard library

C++17

With addition to already mentioned improvements in language, following new elements were introduced into C++ standard library:

- `<optional>`, `<variant>`, `<any>`
- `<filesystem>`
- `<string_view>`
- `<execution>`
- `<charconv>`

New elements in standard library

C++20

With addition to already mentioned improvements in language, following new elements were introduced into C++ standard library:

- `<chrono>` (dates, calendars, time zones)
- `<concepts>`
- `<compare>` (operator `<=>`)
- `<format>`
- `<ranges>`
- `<bit>`

References

- Version with features from cppreference.com ([c++11](http://cppreference.com/c++11), [c++14](http://cppreference.com/c++14), [c++17](http://cppreference.com/c++17), [c++20](http://cppreference.com/c++20))
- Modern cpp features with examples (nice collection [here](#))
- "*Effective Modern C++*" by Scott Meyers (c++11 & 14)
- godbolt.org - great online compiler and more

NOKIA