Department I - C Plus Plus

Modern and Lucid C++ for Professional Programmers

Part 6 – ADL & Enums

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Warmup – Classes & Output Operator

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- **Class definition in header file**
- **Member implementaiton in source file**

Date.h

```
#ifndef DATE_H_
#define DATE_H_

class Date {
  int year, month, day;
public:
  Date(int year, int month, int day);

  static bool isLeapYear(int year);

private:
  bool isValidDate() const;
};

#endif /* DATE_H_ */
```

Date.cpp

```
#include "Date.h"

Date::Date(int year, int month, int day)
  : year{year}, month{month}, day{day} {
  /*...*/
}

bool Date::isLeapYear(int year) {
  /*...*/
}

bool Date::isValidDate() const {
  /*...*/
}
```

- **The default constructor is available implicity**
  - Unless another constructor is implemented
- **You usually don't need to implement**
  - Copy/Move Constructors
  - Destructor
- **Use the member initializer list!**
- **Constructors with one parameter should be declared `explicit`**

Date.h

```
#ifndef DATE_H_
#define DATE_H_

class Date {
  int year, month, day;
public:
  Date(int year, int month, int day)
  : year{year}, month{month}, day{day} {/*...*/}

  static bool isLeapYear(int year) {/*...*/}

private:
  bool isValidDate() const {/*...*/}
};

#endif /* DATE_H_ */
```

- **Input (>>) and Output (<<) always as free operator!**
  - With `read`/`print` helper member function

Date.h

```
class Date {
  int year, month, day;
public:
  std::istream & read(std::istream & is);
  std::ostream & print(std::ostream & os) const ;
};
std::istream & operator>>(std::istream & is, Date & date);
std::ostream & operator<<(std::ostream & os, Date const & date);
```

Date.cpp

```
#include "Date.h"

std::istream & operator>>(std::istream & is, Date & date) {
  return date.read(is);
}
std::ostream & operator<<(std::ostream & os, Date const & date) {
  return date.print(os);
}
```

Namespaces

Goals:

- You know to group and structure names into namespaces
- You know how Argument Dependent Lookup works

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Scoping with Namespaces

- **Namespaces are scopes for grouping and preventing name clashes**
  - Same name in different scopes possible
  - Example `boost::optional` and `std::optional` can coexist
- **Global namespace has the `::` prefix**
  - Can be omitted if unique
  - `::std::cout` is usually equal to `std::cout`
- **Nesting of namespaces is possible**
  - Example: `std::literals::chrono_literals`
- **Nesting of scopes allows hiding of names**
  - Hidden names can only be accessed when they belong to a named scope

Namespace Example

- **Namespaces can only be defined outside of classes and functions**
- **The same namespace can be opened and closed multiple times to gather definitions and declarations (header files)**
- **Qualified names are used to access names in a namespace**
  - `demo::subdemo::foo()`
- **A name with a leading :: is called a fully qualified name**
  - `::std::cout`

```
namespace demo {
void foo(); //1
namespace subdemo {
void foo() {/*2*/}
} // subdemo
} // demo

namespace demo {
void bar() {
  foo(); //1
  subdemo::foo(); //2
}
}

void demo::foo() { /*1*/ } // definition

int main() {
  using demo::subdemo::foo;
  foo(); //2
  demo::foo(); //1
  demo::bar();
}
```

- **Import a name from a namespace into the current scope**
  - That name can be used without a namespace prefix
  - Useful if the name is used very often

```
using std::string;
string s{"no std::"};
```

- **Alternative: Using alias for types if a name is long**

```
using input = std::istream_iterator<int>;
input eof{};
```

- **There are also using directives, which import ALL names of a namespace into the current scope**
  - Use them only in local scope to avoid "pollution" of your namespace

```
int main() {
  using namespace std;
  cout << "Hello John";
  //many more uses of std names
}
```

Anonymous Namespaces

- **Special case: omit name after namespace**
  - The compiler choses a unique internal identifier
- **Implicit using directive for the chosen name**
- **Hides module internals**
  - Helper functions and types
  - Constants
- **Use them only in source files (*.cpp)**

```cpp
#include <iostream>
namespace {   // anonymous
void doit() { // can not be called
              // outside this file
  std::cout << "doit called\n";
}
} // anonymous namespace ends

void print() { // callable from other
               // parts if declared
  doit();
  std::cout << "print called\n";
}
```

```cpp
void caller() { // in a different file
  void print(); // declare print
  print();
  void doit();  // declare doit
  doit();       // linker error
}
```

Defining Date in a Namespace

- **Class `Date` can/should be put in a namespace to group it with its operators and functions**

Date.h

```
namepace date {
class Date {
  int year, month, day;
public:
  std::ostream & print(std::ostream & os) const;
};

inline std::ostream & operator<<(std::ostream & os, Date const & date) {
  return date.print(os);
}
}
```

- **Using names from a namespace requires qualification**

```
date::Date d{};
```

Defining Members for Date in a Namespace

- **Member implementations need to be qualified with that namespace too**
  - Example: `date::Date::read`

Date.h

```
namepace date {
class Date {
  int year, month, day;
public:
  std::istream & read(std::istream & is);
};
}
```

Date.cpp

```
#include "Date.h"

std::istream & date::Date::read(std::istream & is) {
  //...
  return is;
}
```

Name Resolution for Namespace Members

- **Types and (non-member) functions belonging to that type should be placed in a common namespace**

```
namespace date { ... }
```

- **Advantage: Argument Dependent Lookup!**
  - When the compiler encounters an unqualified function or operator call with an argument of a user-defined type it looks into the namespace in which that type is defined to resolve the function/operator
  - E.g. it is not necessary to write **`std::`** in front of **`for_each`** when `std::vector::begin()` is an argument of the function

date.h

```
namespace date {

class Date {
  //...
};

bool is_holiday(Date const &);

}
```

calendar.cpp

```
#include "date.h"

using Dates = std::vector<date::Date>;

void mark_holidays(Dates const & dates) {
  for_each(begin(dates), end(dates),
    [](date::Date const & d) {
      if (is_holiday(d)) //date::is_holiday
        //...
    });
}
```

Operators in Namespace – Argument Dependent Lookup

- **Unqualified operator calls don't allow explicit namespace qualification**
  - NOT: `std::cout date::<< birthday;`
- **Functions and operators are looked up in the namespace of the type of their arguments first**
  - E.g. namespaces `std` and `date` for `std::cout << birthday;`

Any.cpp

```
#include "Date.h"

void foo() {
  date::Date birthday{2011, 8, 2};
  //date::operator<< (std::cout, d);
  std::cout << birthday;
}
```

Date.h

```
namepace date {
class Date {
  //...
};
inline std::ostream & operator<<(std::ostream & os, Date const & date) {
  return date.print(os);
}
}
```

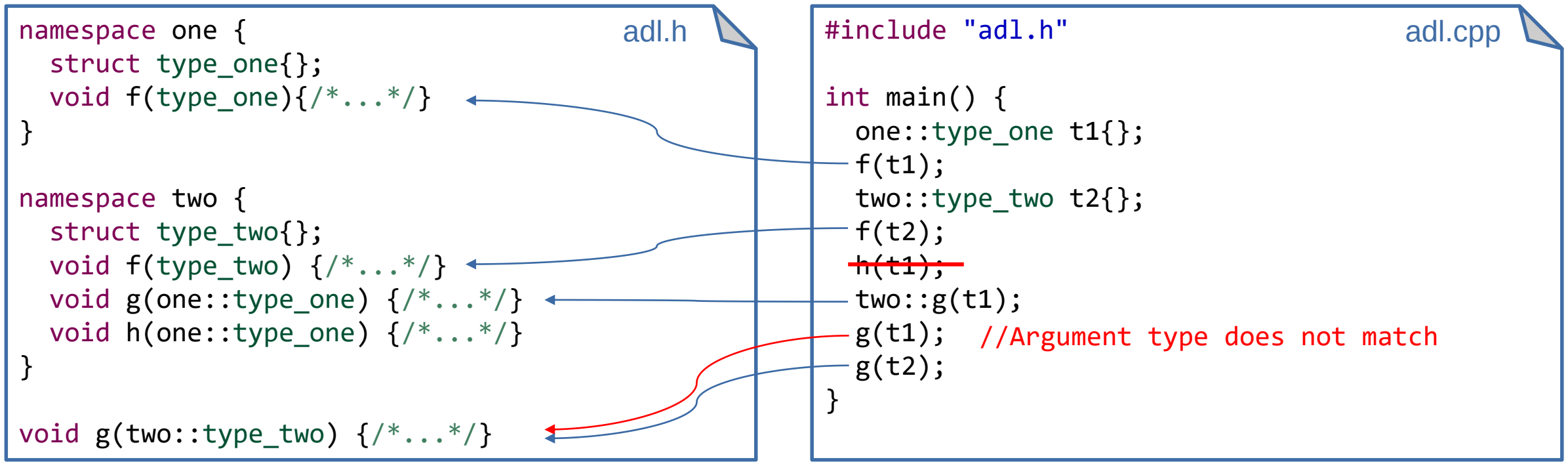
ADL Examples

adl.h

```
namespace one {
  struct type_one{};
  void f(type_one){/*...*/}
}

namespace two {
  struct type_two{};
  void f(type_two) {/*...*/}
  void g(one::type_one) {/*...*/}
  void h(one::type_one) {/*...*/}
}

void g(two::type_two) {/*...*/}
```

adl.cpp

```
#include "adl.h"

int main() {
  one::type_one t1{};
  f(t1);
  two::type_two t2{};
  f(t2);
  h(t1);
  two::g(t1);
  g(t1);  //Argument type does not match
  g(t2);
}
```



ADL Issues (Where Intuition Fails)

- **Generic code (Templates) might not pick up a global `operator<<` in an algorithm call using `ostream_iterator` if the value output is from namespace `std` too**
  - E.g. `std::vector<int>`
- **This example only works when the `operator<<(ostream &, vec const &)` is put in namespace `std`, because both arguments are in `std`**
  - This is not allowed by the standard!

intuition.cpp

```
using std::vector;
using std::ostream;
using vec = vector<int>;
using outv = std::ostream_iterator<vec>;
using out = std::ostream_iterator<int>;

namespace std {
ostream & operator<<(ostream & os, vec const & v) {
  copy(begin(v), end(v), out{os, ","});
  return os;
}
}

void work_only_with_shift_in_ns_std(ostream & os) {
  vector<vec> vv{{1, 2, 3}, {4, 5, 6}};
  copy(begin(vv), end(vv), outv{os, "\n"});
}
```

Workaround for std::-Resolution Problem

- **Create a new type by inheriting from `std::vector<int>`**
  - Requires support for inheriting constructors

```
struct Sub : Base {
  using Base::Base;
};
```

- **Alias would not be sufficient**

```
using vec = vector<int>;
```

- **Not recommended to derive from standard containers in general**
- **Does not help with `std::map`/`std::pair`**

workaround.cpp

```
using std::ostream;
using std::vector;
using out = std::ostream_iterator<int>;

namespace X {
struct vec : vector<int> { // vec is a new type
  using vector<int>::vector; // inherit ctors
};
ostream & operator<<(ostream & os, vec const & v) {
  copy(begin(v), end(v), out{os, ","});
  return os;
}
}

void works_with_inheriting_ctors(ostream & os) {
  using outv = std::ostream_iterator<X::vec>;
  vector<X::vec> vv{{1, 2, 3},{4, 5, 6}};
  copy(begin(vv), end(vv), outv{os, "\n"});
}
```

Enums

Goals:

- You know how to create enumerations as simple types with few values
- You know the difference between soped and unscoped enumerations
- You know how to specify the values of enumerators

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Enumeration Types

- **Enumerations are useful to represent types with only a few values**

```
enum <name> {
  <enumerators>
};
```

```
enum class <name> {
  <enumerators>
};
```

- **An enumeration creates a new type that can easily be converted to an integral type (for unscoped enumeration)**
  - Conversion from an integral type to an enumeration is not possible implicitly
- **The individual values (enumerators) are specified in the type**
- **Unless specified explicitly the values start with 0 and increase by 1**
- **Unscoped enumeration (no class keyword)**

```
enum day_of_week {
  Mon, Tue, Wed, Thu, Fri, Sat, Sun
}; 0   1   2   3   4   5   6
```

  - Enumerators leak into surrounding scope
  - Best used as member of a class
- **Scoped enumeration (class keyword)**

```
enum class day_of_week {
  Mon, Tue, Wed, Thu, Fri, Sat, Sun
}; 0   1   2   3   4   5   6
```

  - Enumerators do not leak into surrounding scope
  - Underlying type can be specified

Scopes of Enumerators

- **Unscoped enumeration (no class keyword)**
  - Enumerators leak into surrounding scope

```
namespace date {

enum day_of_week {
  Mon, Tue, Wed, Thu, Fri, Sat, Sun
};
  //Enumerators are visible here
}

bool is_weekend(date::day_of_week day) {
  return day == date::Sat ||
         day == date::Sun;
}
```

- **Scoped enumeration (class keyword)**
  - Enumerators do not leak into surrounding scope

```
namespace date {

enum class day_of_week {
  Mon, Tue, Wed, Thu, Fri, Sat, Sun
};

}

bool is_weekend(date::day_of_week day) {
  return day == date::day_of_week::Sat ||
         day == date::day_of_week::Sun;
}
```

Enumeration Conversion

- **Operators can be overloaded for `enum`s**
- **Examples**
  - Prefix increment

```
dayOfWeek operator++(dayOfWeek &)
```

  - Postfix increment

```
dayOfWeek operator++(dayOfWeek &, int)
```

- **Implicit conversion from `enum` to `int` (Only for unscoped enums)**

```
int day = Sun;
```

- **Explicit conversion from `int` to `enum`**

```
dayOfWeek tuesday = static_cast<dayOfWeek>(1);
```

```
enum dayOfWeek {
  Mon, Tue, Wed, Thu, Fri, Sat, Sun
};

dayOfWeek operator++(dayOfWeek & aday) {
  int day = (aday + 1) % (Sun + 1);
  aday = static_cast<dayOfWeek>(day);
  return aday;
}

dayOfWeek operator++(dayOfWeek & aday, int) {
  dayOfWeek ret{aday};
  if (aday == Sun)
    aday = Mon;
  else
    aday = static_cast<dayOfWeek>(aday + 1);
  return ret;
}
```

Defining Values of Enumerators

- **With = values can be specified for enumerators**
  - Subsequent enumerators get value incremented (+1)
- **Different enumerators can have the same value**
- **In some cases enumerations are used to create bit masks**
  - Values are a power of 2 (x^2)

```
enum month {
  jan = 1, feb, mar, apr, may,
  jun, jul, aug, sep, oct, nov, dec,
  january = jan, february, march,
  april, june = jun, july, august,
  september, october, november,
  december
};
```

```
enum file_permissions {
  readable = 1,
  writeable = 2,
  executable = 4
};
```

- **Enumerator names are not mapped automatically to their original name**
  - Might become a feature in a future C++ standard (2020?)
- **You can provide a lookup table and overload the output operator (<<)**

```
std::ostream & operator<<(std::ostream & out, month m) {
  static std::array<std::string, 12> const month_names {
    "Jan", "Feb", "Mar", "Apr", "May", "Jun",
    "Jul", "Aug", "Sep", "Oct", "Nov", "Dec" };
  out << month_names[m - 1]; //m - 1 if Jan has value 1
  return out;
}
```

Specifying the Underlying Type

- **Enumeration classes can specify the underlying type by inheritance**
- **The underlying type can be any integral type**
- **This allows forward-declaring enumerations**
  - Can be used to hide implementation details if defined as a class member

```
enum class launch_policy
 : unsigned char
{
  sync = 1,
  async = 2,
  gpu = 4,
  process = 8,
  none = 0
};
```

Enumeration Example


```
#ifndef STATEMACHINE_H_
#define STATEMACHINE_H_

struct Statemachine {
  Statemachine();
  void processInput(char c);
  bool isDone() const;
private:
  enum class State : unsigned short;
  State theState;
};

#endif /* STATEMACHINE_H_ */
```

```
#include "Statemachine.h"
#include <cctype>
enum class Statemachine::State : unsigned short {
  begin, middle, end
};
Statemachine::Statemachine()
  : theState {State::begin} {}
void Statemachine::processInput(char c) {
  switch (theState) {
    case State::begin:
      if (!isspace(c)) theState = State::middle;
      break;
    case State::middle:
      if (isspace(c)) theState = State::end;
      break;
    case State::end:
      break; // ignore input
  }
}
bool Statemachine::isDone() const {
  return theState == State::end;
}
```

Arithmetic Types (Ring5)

Goal:

- You know how to implement your own arithmetic type
- You know the possible ambiguities that might arise from implicit conversion

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- **Disclaimer: You usually do not want to implement your own arithmetic types!**
  - Future C++ standards will provide additional arithmetic types, like unbounded large integer and rational
- **Here are the basics if you ever need them anyway**
- **Example: Modulo arithmetic**
  - Rings / Finite fields
  - Used in Cryptography

- **Ring5: Arithmetic Modulo 5**

```
struct Ring5 {
  explicit Ring5(unsigned x = 0u)
    : val{x % 5}{}
  unsigned value() const {
    return val;
  }
private:
  unsigned val;
};
```

- **Invariant:**
  - Member variable is in range `0..4`
- **Accessor to value**
- **Constructor explicit?**

- **Arithmetic types must be equality comparable**
  - `operator ==`
  - CUTE requires this operator in `ASSERT_EQUAL`

```
void testValueCtorWithLargeInput() {
  Ring5 four{19};
  ASSERT_EQUAL(Ring5{4}, four);
}
```

- **Boost can be used to get `!=` easily**
  - Use `boost::equality_comparable`

```
struct Ring5 :
    boost::equality_comparable<Ring5> {
  bool operator==(Ring5 const & r) const {
    return val == r.val;
  }
  //...
};
```

Output Operator for Ring5

- **It might be convenient to have the output operator (<<) to print a Ring5**
  - As always: Output operator NOT as a class member!
- **CUTE requires the output operator for nice failure messages**

```
std::ostream & operator<<(std::ostream & out, Ring5 const & r) {
  out << "Ring5{" << r.value() << '}';
  return out;
}
```

```
void testOutputOperator() {
  std::ostringstream out{};
  out << Ring5{4};
  ASSERT_EQUAL("Ring5{4}", out.str());
}
```

Plus Operation for Ring5

- **Result must be in the range `0..4`**
  - E.g. `(4 + 4) = 8 % 5 = 3`
- **Implement both operators yourself**
  - `operator+`
  - `operator+=`
- **(Or) Use boost**
  - Implement `operator+=`
  - Derive from `boost::addable<Ring5>`

```
struct Ring5 :
    boost::equality_comparable<Ring5>,
    boost::addable<Ring5> {
  Ring5 operator+=(Ring5 const & r) {
    val = (val + r. val) % 5;
    return *this;
  }
  //...
};
```

```
void testAdditionWrap() {
  Ring5 four{4};
  Ring5 three = four + four;
  ASSERT_EQUAL(Ring5{3}, three);
}
```

Multiplication Operation for Ring5

- **Example for self implemented multiplication**
  - Operator *= as member function
  - Operator * as free (inline) function
    - Pass left-hand operand by value
- **Modulo only needed in *= Operator**
  - Avoids code duplication

```
struct Ring5 :
    boost::equality_comparable<Ring5>,
    boost::addable<Ring5> {
  Ring5 operator*=(Ring5 const & r) {
    val = (val * r. val) % 5;
    return *this;
  }
  //...
};
```

```
inline Ring5 operator*(Ring5 l,
                       Ring5 const & r) {
  l *= r;
  return l;
}
```

Mixed Arithmetic with Ring5

- **What if we want to add `Ring5` and `int`?**
- **Either implement all combinations of parameters for `operator+`**
  - `operator+(Ring5, unsigned)`
  - `operator+(unsigned, Ring5)`
- **Or make constructor non-explicit**
- **The latter might become a problem when we want to have automatic conversion to `unsigned` as well**
  - Ambiguity or wrong conversion happens

- **`four` should have the value `4`**
- **`four` should have the type `Ring5`**

```
void test_AdditionWithInt_ValueIsFour() {
  Ring5 two{2};
  auto four = two + 2u;
  ASSERT_EQUAL(Ring5{4}, four);
}

void test_AdditionWithInt_TypeIsRing5() {
  Ring5 two{2};
  auto four = two + 2u;
    ASSERT_EQUAL(typeid(Ring5).name(),
      typeid(decltype(four)).name());
}
```

Mixed Arithmetic: Multiple Overloads and Automatic Conversion

- **Overhead with code, duplication, danger of wrong implementation**
  - Test cases help
  - Overload could be forgotten

```
inline Ring5 operator+(Ring5 const & l, unsigned r) {
  return Ring5{l.value() + r};
}

inline Ring5 operator+(unsigned l, Ring5 const & r) {
  return Ring5{l + r.value()};
}
```

- **Non-explicit constructor provides automatic inward conversion**
  - Type conversion operator
    - `operator <type>() const` member function
    - `explicit` preferred but requires `static_cast`
- **Danger: Ambiguities and unexpected conversions are lurking**

```
struct Ring5 {
  Ring5(unsigned x) : val{ x % 5 } {}
  operator unsigned() const {
    return val;
  }
  //...
};
```

- **C++ allows to mark functions and constructors as `constexpr`**
- **Guarantees compiler to evaluate function**
- **Provides support for literals type that can be initialized at compile-time**
- **Functions must be "pure" functions**
  - no external side-effects
  - no memory
  - no exceptions
- **Faster program execution**

```
struct Ring5 {
  explicit constexpr Ring5(unsigned x)
    : val{ x % 5 } {
  }
  constexpr Ring5 operator+(Ring5 const & r) const {
    return Ring5{val + r.val};
  }
  //...
};
```

- **Writing `Ring5{4}` to create a value of type `Ring5` is a bit annoying when many such values are needed**
- **`4_R5` would be shorter**
- **User-defined literals allow to defined suffixes to constants to change their type or value**

```
constexpr <type> operator"" <suffix>(<parameter>);
```

- **Must be put in a (separate) namespace**

```
namespace R5 {
  constexpr Ring5 operator"" _R5(unsigned long long v) {
    return Ring5{static_cast<unsigned>(v % 5)};
  }
}
```

  - Requires using namespace directive

```
using namespace R5;
static_assert(Ring5{2} == 7_R5, "UDL operator");
```