Software Engineering

Moscow Institute of Physics and Technology

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01. Introduction and Brief Overview

General Introduction

- 01.01 – Software engineering. The C++ programming language. Programming paradigms. Instruments. References.

Environment and Compiler

- 01.02 – Environment Visual Studio Code. Terminal. Compiler g++ from GCC. Minimal program. Function `main`.

Standard Library

- 01.03 – Standard library overview. Comments. Documenting code. Utility Doxygen.
- 01.04 – Standard library header files.

Version Control System

- 01.05 – Version control system Git. Project hosting system GitHub. Git graphical client SmartGit.

02. Basics of Programming

Fundamental Data Types

- 02.01 – Type `bool`. Objects. Variables. Literals `false` and `true`. Operator `sizeof`. Attribute `maybe_unused`.
- 02.02 – Type `char`. Escape sequences. Portability problem.
- 02.03 – Type `int`. Modifiers `short` and `long`. Literal suffixes. Two's complement. Overflow problem.
- 02.04 – Types `float`, `double` and `long double`. Floating point formats. Precision problem.
- 02.05 – Type signness. Modifiers `signed` and `unsigned`.
- 02.06 – Constants. Qualifier `const`.
- 02.07 – Type aliases. Declaration `using`. Specifier `typedef`. Alias `std::size_t`. Fixed-width integer types.

Objects and Variables

- 02.08 – Declarations. Definitions. Default, value, direct, copy and list initialization. Undefined behavior.
- 02.09 – Type inference. Placeholder `auto`.
- 02.10 – Implicit, explicit, narrowing and C-style type conversions. Operator `static_cast`.

Operators and Expressions

- 02.11 – Logical operators. Alternative representations. Short-circuit evaluations.
- 02.12 – Expressions. Arithmetic and comparison operators. Operator arity. Operator precedence.
- 02.13 – Operator exclusive or.
- 02.14 – Assignment operators. Arithmetic swap algorithm. Function `std::swap`.
- 02.15 – Operator division. Operator remainder.
- 02.16 – Evaluation order. Unspecified behavior. Operator associativity. Operator comma.

Selection Statements

- 02.17 – Statement `if`.
- 02.18 – Statement `switch`. Labels `case` and `default`. Attributes `fallthrough`, `likely` and `unlikely`.
- 02.19 – Ternary operator.

Loops and Jump Statements

- 02.20 – Statement `for`.
- 02.21 – Statement `continue`.
- 02.22 – Statement `break`. Infinite loops.
- 02.23 – Statement `goto`. Labels.
- 02.24 – Statement `while`.
- 02.25 – Statement `while-do`.

Memory Management

- 02.26 – Pointers. Operator address of. Operator dereference. Literal `nullptr`.
- 02.27 – Constant pointers. Pointers to constants.

Collections and Containers

- 02.28 – Static arrays. Aggregate initialization. Non-standard compiler extensions.
- 02.29 – Function `std::size`. Index access operator. Pointer arithmetic.
- 02.30 – Dynamic objects. Operators `new` and `delete`. Dynamic arrays. Operators `new[]` and `delete[]`.
- 02.31 – Container `std::vector` overview.

Lvalue References

- 02.32 – Lvalue references.
- 02.33 – Constant lvalue references.
- 02.34 – Lvalue reference type inference. Placeholder `decltype(auto)`. Specifier `decltype`.
- 02.35 – Utility `std::reference_wrapper`.

Functional Programming

- 02.36 – Functions. Statement `return`. Attribute `nodiscard`. Object `std::ignore`.
- 02.37 – Calling conventions. Attributes `cdecl`, `stdcall` and `fastcall`.
- 02.38 – Type `void`. Default arguments. Function overloading.
- 02.39 – Passing arguments. Container `std::span`.
- 02.40 – Storage durations. Dangling pointers and references. Automatic and static objects. Specifier `static`.
- 02.41 – Inline functions. Specifier `inline`. Special memory. Qualifier `volatile`.
- 02.42 – Recursion. Factorial. Binomial coefficients. Catalan numbers.
- 02.43 – Insertion, merge and hybrid sort algorithms. Timsort algorithm. Function `std::midpoint`.
- 02.44 – Binary search algorithm.

03. Object-Oriented Programming

User-defined Data Types

- 03.01 – Structures. Declaration `struct`. Data members. Instances. Designated initialization.
- 03.02 – Operator point. Operator arrow.
- 03.03 – Classes. Declaration `class`. Encapsulation. Specifiers `public` and `private`. Constructors. Destructors.
- 03.04 – Member functions. Constant member functions.
- 03.05 – Nested classes. Pointer `this`. Logical and bitwise constancy. Specifier `mutable`.
- 03.06 – Static members.

Interclass Relations

- 03.07 – Composition, aggregation, association and dependency relations.
- 03.08 – Friend functions and classes. Specifier `friend`.
- 03.09 – Pattern PassKey.
- 03.10 – Pattern Attorney-Client.

Inheritance and Hierarchies

- 03.11 – Class hierarchies. Base and derived classes. Public inheritance. Protected members. Specifier `protected`.
- 03.12 – Private inheritance. Composition.
- 03.13 – Multiple inheritance. Virtual inheritance. Diamond problem.
- 03.14 – Appendix: scheme.
- 03.15 – Empty classes. Empty base optimization. Attribute `no_unique_address`.

Dynamic Polymorphism

- 03.16 – Virtual functions. Specifiers `virtual`, `override` and `final`. Virtual destructors. Abstract base classes.
- 03.17 – Virtual pointers. Virtual tables.
- 03.18 – Appendix: scheme.
- 03.19 – Covariant return types.

Runtime Type Identification

- 03.20 – Downcasting type conversions. Operator `dynamic_cast`.
- 03.21 – Operator `typeid`.
- 03.22 – Library Boost.TypeIndex.
- 03.23 – Utility `std::any`. Function `std::make_any`. Pointers to raw memory.

Rvalue References

- 03.24 – Lvalue, glvalue, xvalue, rvalue and prvalue expressions.
- 03.25 – Rvalue references.
- 03.26 – Temporary objects. Extending lifetime.
- 03.27 – Copy and move semantics. Function `std::move`.
- 03.28 – Member functions reference qualifiers.
- 03.29 – Container `Vector`. Special member functions. Deep and shallow copy. Copy and swap. Rules of 0, 3 and 5.
- 03.30 – Copy elision. Return value optimization. Named return value optimization.

Operator Overloading

- 03.31 – Rational arithmetic. Type `Rational`. User-defined type conversions. Specifier `explicit`.
- 03.32 – Library Boost.Rational.
- 03.33 – Three-way comparison operator. Strong ordering. Equivalence. Equality.
- 03.34 – Weak ordering.
- 03.35 – Unordered objects. Partial ordering.
- 03.36 – Input and output operators.
- 03.37 – Constant and non-constant index access operators. Constancy type conversions. Operator `const_cast`.

04. Generic Programming

Function Templates

- 04.01 – Function templates. Declaration `template`. Type template parameters. Specifier `typename`. Instantiating.
- 04.02 – Full specializations. Function template overloading.
- 04.03 – Dimov - Abrahams example.
- 04.04 – Non - type template parameters. Passing static arrays by lvalue reference.
- 04.05 – Variadic templates. Template and function parameter packs. Ellipsis. Operator `sizeof...`
- 04.06 – Variadic expressions. Fold expressions. Arithmetic reduce algorithm.
- 04.07 – Tree traverse algorithm. Pointers to members.

Class Templates

- 04.08 – Class templates. Container `Stack`. Default types. Instantiating member functions.
- 04.09 – Class template argument deduction. Template template parameters.
- 04.10 – Full and partial specializations.
- 04.11 – Instantiating friend functions and operators.

Forwarding References

- 04.12 – Forwarding references. Perfect forwarding. Function `std::forward`.
- 04.13 – Template type inference. Reference collapsing rules.
- 04.14 – Special member function templates. Substitution failure is not an error. Metafunction `std::enable_if`.

Special Templates

- 04.15 – Type alias templates. Container `Array`.
- 04.16 – Variable and constant templates.

Constant Expressions

- 04.17 – Template metaprogramming. Compile - time factorial.
- 04.18 – Compile - time prime number test algorithm.
- 04.19 – Constant expressions. Immediate functions. Specifiers `constexpr`, `consteval` and `constinit`.
- 04.20 – Statement `if constexpr`.
- 04.21 – Hybrid template metaprogramming. Compile - time rational arithmetic.
- 04.22 – Utility `Tuple`. Dependent names. Ambiguity problem.
- 04.23 – Utility `std::tuple`. Functions `std::make_tuple`, `std::get` and `std::tie`. Structured bindings.

Trait Templates

- 04.24 – Metafunctions `is_same`. Base classes `std::false_type` and `std::true_type`.
- 04.25 – Metafunctions `is_any_of` and `is_all_of`.
- 04.26 – Integral arithmetic types. Metafunctions `is_integral`. Base class `std::integral_constant`.
- 04.27 – Metafunctions `is_array`.
- 04.28 – Metafunctions `add_lvalue_reference` and `add_rvalue_reference`.
- 04.29 – Metafunctions `remove_reference`.
- 04.30 – Metafunctions `is_base_of`. Variadic functions.
- 04.31 – Unevaluated contexts. Function `declval`.
- 04.32 – Metafunctions `is_polymorphic`.
- 04.33 – Metafunctions `is_convertible`.
- 04.34 – Compile - time conditions. Metafunctions `enable_if`.

Concepts and Constraints

- 04.35 – Concepts. Declaration `concept`. Constraints. Concepts `same_as`.
- 04.36 – Simple, type and compound requirements. Expression `requires`. Concepts `totally_ordered`.
- 04.37 – Requires clauses. Concept `std::integral`.

Variadic Type Lists

- 04.38 – Compile - time type collections. Container `Deque`.

05. Software Architecture Patterns

Generative Patterns

- 05.01 – Pattern Builder.
- 05.02 – Pattern Factory method.
- 05.03 – Pattern Abstract factory.
- 05.04 – Pattern Prototype. Virtual constructors.
- 05.05 – Pattern Singleton. Default and deleted special member functions. Specifiers `default` and `delete`.
- 05.06 – Pattern Noncopyable. Library Boost.Noncopyable.

Structural Patterns

- 05.07 – Pattern Adapter.
- 05.08 – Pattern Bridge.
- 05.09 – Pattern Composite.
- 05.10 – Pattern Decorator.
- 05.11 – Pattern Facade.

Behavioral Patterns

- 05.12 – Pattern Memento.
- 05.13 – Pattern Observer.
- 05.14 – Pattern State. Finite-state machines. Forward declarations.
- 05.15 – Pattern Strategy.
- 05.16 – Pattern Template method. Non-virtual interfaces.

Template Patterns

- 05.17 – Static polymorphism. Eliminating virtuality.
- 05.18 – Curiously recurring template pattern.
- 05.19 – Mixin based pattern Singleton.
- 05.20 – Pattern Controller.
- 05.21 – Extending functionality. Barton-Nackman trick. Restricted template expansion.
- 05.22 – Library Boost.Operators.
- 05.23 – Mixin based pattern Memento. Inverted inheritance.
- 05.24 – Variadic base classes.

06. Projects and Libraries

Preprocessing Stage

- 06.01 – Multi-file projects. Build stages. Source and header files. Translation units. Object and executable files.
- 06.02 – Preprocessor. Directives `include`, `define`, `undef`, `if`, `else`, `endif` and `pragma`. Macros.
- 06.03 – Macros `FILE`, `LINE`, `DATE`, `TIME` and others. Identifier `func`.
- 06.04 – Utility `std::source_location`.

Compilation and Linkage

- 06.05 – Conditional compilation. Include guards. One definition rule. Specifier `extern`. Inline variables.
- 06.06 – Precompiled header files.
- 06.07 – Global variables and constants. Anonymous namespaces.
- 06.08 – Internal and external linkage. Multiply defined and unresolved external symbols.
- 06.09 – Reducing compile-time dependencies. Pointers to implementations.
- 06.10 – Class implementation details.
- 06.11 – Appendix: main.
- 06.12 – Namespaces. Declaration `namespace`. Scope operator. Argument dependent lookup. Namespace aliases.

Module Support

- 06.13 – Modules. Declaration `module`. Global module fragments. Exporting symbols. Declaration `export`.
- 06.14 – Interface and implementation units. Standard library modules.
- 06.15 – Submodules.
- 06.16 – Importing modules. Declaration `import`.

Build Automation System

- 06.17 – Builder CMake. File CMakeLists. Packages. Targets. Libraries. Scripts.

Custom Libraries

- 06.18 – Importing symbols and aliases. Library Boost.DLL.
- 06.19 – Static libraries.
- 06.20 – Library implementation details.
- 06.21 – Dynamic libraries. C-style linkage. Declaration `extern "C"`. Implicit and explicit library linkage.

07. Handling Errors and Debugging

Code Interruptions

- 07.01 – Compile-time and runtime assertions. Declaration `static_assert`. Macro `assert`.
- 07.02 – Normal and abnormal exits. Functions `std::atexit`, `std::exit`, `std::abort` and `std::terminate`.

Return Code Handling

- 07.03 – Return codes. Macro `errno`. Function `std::strerror`.
- 07.04 – Scoped and unscoped enumerations. Declaration `enum`. Underlying types.
- 07.05 – Unions. Declaration `union`.
- 07.06 – Hybrid return codes. Utility `Alternative`. Anonymous unions.
- 07.07 – Utility `std::variant`. Type `std::monostate`. Functions `std::get`, `std::visit` and others.
- 07.08 – Ternary logic. Library Boost.Tribool.
- 07.09 – Utility `std::optional`. Object `std::nullopt`. Function `std::make_optional`.
- 07.10 – Utility `std::expected`. Type `std::unexpected`.

Exception Handling

- 07.11 – Statements `throw`, `try` and `catch`. Stack unwinding. User-defined exceptions. Attribute `noreturn`.
- 07.12 – Exception safety guarantees. Specifier and operator `noexcept`. Zero-overhead principle.
- 07.13 – Exception safe container `Stack` interface.
- 07.14 – Backtracing. Call stack. Container `std::stacktrace`.

Debugging and Profiling

- 07.15 – Debugger GDB. Commands run, break, next, step, continue, print and backtrace.
- 07.16 – Memory leaks. Profiler Valgrind. Processor load. Profiler Callgrind. Visualizer KCachegrind. Utility htop.
- 07.17 – Logging. Tracing. Library Boost.Log.
- 07.18 – Library Google.Log.
- 07.19 – Testing. Unit tests. Test suites and cases. Datasets. Fixtures. Library Boost.Test.
- 07.20 – Assertions. Expectations. Library Google.Test.
- 07.21 – Benchmarks. Algorithmic complexity. Library Google.Benchmark.

08. Instruments of Calculus

Bitwise Processing

- 08.01 – Number systems. Binary, octal, decimal and hexadecimal literals.
- 08.02 – Bitwise logical operators. Bitwise swap algorithm.
- 08.03 – Reflected binary Gray code. Gray code encode and decode algorithms.
- 08.04 – Encoder implementation.
- 08.05 – Bit fields. Utility `Timestamp`.
- 08.06 – Benchmarks for bit fields.
- 08.07 – Fixed-size sequences of bits. Utility `std::bitset`.
- 08.08 – Enumeration `std::byte`.
- 08.09 – Endianess. Big and little endian byte orders. Enumeration `std::endian`. Function `std::to_integer`.
- 08.10 – Reinterpreting bits. Operator `reinterpret_cast`. Type punning. Function `std::bit_cast`.

Long Arithmetic

- 08.11 – Indian exponentiation algorithm.
- 08.12 – Factorial for type `int`. Utility `std::numeric_limits`.
- 08.13 – Long arithmetic. Type `Integer`. Long arithmetic and comparison operators. Square root algorithm.
- 08.14 – Karatsuba fast multiplication algorithm.
- 08.15 – Appendix: main.
- 08.16 – Factorial for type `Integer`.
- 08.17 – Extended checked and unchecked integer types. Library Boost.Multiprecision.
- 08.18 – Factorial for type `boost::multiprecision::cpp_int`.
- 08.19 – Embedding Python. Python C/C++ API. Global interpreter locker. Library Boost.Python.
- 08.20 – Factorial for type `boost::python::api::object`. Module `math`.

Floating Point Types

- 08.21 – Precision. Exponent. Infinity. Quiet and signaling NaNs. Standard IEEE-754.
- 08.22 – Floating point numbers compare algorithms. Absolute and relative epsilon constants. Function `std::abs`.
- 08.23 – Extended floating point types.
- 08.24 – Numerical methods. Derivatives. Special math functions. Library Boost.Math.
- 08.25 – Complex numbers. Type `std::complex`. Functions `std::real`, `std::imag` and others.
- 08.26 – Discrete Fourier transform algorithm.

Random Numbers

- 08.27 – Non-deterministic generators. Entropy sources. Seeds. Engines. Distributions.
- 08.28 – Appendix: scheme.
- 08.29 – Monte-Carlo methods. Pi constant estimation.
- 08.30 – Appendix: scheme.
- 08.31 – W. L. Putnam mathematical competition problem. Probability estimation. Barycentric coordinate method.
- 08.32 – Statistics. Weighted mean and variance. Library Boost.Accumulators.

Chrono Management

- 08.33 – Namespace `std::chrono`. System, steady and high-resolution clocks. Time points. Unix epoch.
- 08.34 – Durations. Duration type conversions.
- 08.35 – Durations since epoch. C-style time. Type `std::time_t`. Function `std::time`.
- 08.36 – Utility `Timer`.
- 08.37 – Library Boost.Timer.
- 08.38 – Calendars. Years. Months. Days. Hours. Minutes. Seconds.
- 08.39 – Time zones.
- 08.40 – Namespace `std::literals`. User-defined literals. Literal operators.

09. Detailed Memory Management

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