

# 1.

## Optimizing software in C++

### An optimization guide for Windows, Linux, and Mac platforms

By Agner Fog. Technical University of Denmark.  
Copyright © 2004 - 2023. Last updated 2023-07-01.

#### Contents

|      |   |    |
|------|---|----|
| 1    | Introduction .....                                  | 3  |
| 1.1  | Why software is often slow .....                    | 4  |
| 1.2  | The costs of optimizing .....                       | 4  |
| 2    | Choosing the optimal platform .....                 | 5  |
| 2.1  | Choice of hardware platform .....                   | 5  |
| 2.2  | Choice of microprocessor .....                      | 6  |
| 2.3  | Choice of operating system .....                    | 7  |
| 2.4  | Choice of programming language .....                | 8  |
| 2.5  | Choice of compiler .....                            | 10 |
| 2.6  | Choice of function libraries .....                  | 11 |
| 2.7  | Choice of user interface framework .....            | 13 |
| 2.8  | Overcoming the drawbacks of the C++ language .....  | 14 |
| 3    | Finding the biggest time consumers .....            | 15 |
| 3.1  | How much is a clock cycle? .....                    | 15 |
| 3.2  | Use a profiler to find hot spots .....              | 16 |
| 3.3  | Program installation .....                          | 18 |
| 3.4  | Automatic updates .....                             | 18 |
| 3.5  | Program loading .....                               | 18 |
| 3.6  | Dynamic linking and position-independent code ..... | 19 |
| 3.7  | File access .....                                   | 19 |
| 3.8  | System database .....                               | 20 |
| 3.9  | Other databases .....                               | 20 |
| 3.10 | Graphics .....                                      | 20 |
| 3.11 | Other system resources .....                        | 20 |
| 3.12 | Network access .....                                | 20 |
| 3.13 | Memory access .....                                 | 21 |
| 3.14 | Context switches .....                              | 21 |
| 3.15 | Dependency chains .....                             | 21 |
| 3.16 | Execution unit throughput .....                     | 21 |
| 4    | Performance and usability .....                     | 22 |
| 5    | Choosing the optimal algorithm .....                | 24 |
| 6    | Development process .....                           | 24 |
| 7    | The efficiency of different C++ constructs .....    | 25 |
| 7.1  | Different kinds of variable storage .....           | 25 |
| 7.2  | Integers variables and operators .....              | 29 |
| 7.3  | Floating point variables and operators .....        | 31 |
| 7.4  | Enums .....   | 33 |
| 7.5  | Booleans .....                                      | 33 |
| 7.6  | Pointers and references .....                       | 35 |
| 7.7  | Function pointers .....                             | 37 |
| 7.8  | Member pointers .....                               | 37 |
| 7.9  | Smart pointers .....                                | 37 |
| 7.10 | Arrays .....  | 38 |
| 7.11 | Type conversions .....                              | 40 |
| 7.12 | Branches and switch statements .....                | 43 |

|       |  |     |
|-------|--|-----|
| 7.13  | Loops.....   | 45  |
| 7.14  | Functions .....  | 47  |
| 7.15  | Function parameters .....  | 50  |
| 7.16  | Function return types .....                                      | 50  |
| 7.17  | Function tail calls .....  | 51  |
| 7.18  | Recursive functions.....   | 51  |
| 7.19  | Structures and classes.....                                      | 52  |
| 7.20  | Class data members (instance variables) .....                    | 53  |
| 7.21  | Class member functions (methods).....                            | 54  |
| 7.22  | Virtual member functions .....                                   | 55  |
| 7.23  | Runtime type identification (RTTI).....                          | 55  |
| 7.24  | Inheritance .....  | 55  |
| 7.25  | Constructors and destructors .....                               | 56  |
| 7.26  | Unions .....   | 57  |
| 7.27  | Bitfields .....  | 57  |
| 7.28  | Overloaded functions .....                                       | 58  |
| 7.29  | Overloaded operators .....                                       | 58  |
| 7.30  | Templates .....  | 58  |
| 7.31  | Threads .....  | 61  |
| 7.32  | Exceptions and error handling .....                              | 62  |
| 7.33  | Other cases of stack unwinding .....                             | 66  |
| 7.34  | Propagation of NAN and INF .....                                 | 66  |
| 7.35  | Preprocessing directives .....                                   | 67  |
| 7.36  | Namespaces.....  | 67  |
| 8     | Optimizations in the compiler .....                              | 67  |
| 8.1   | How compilers optimize .....                                     | 67  |
| 8.2   | Comparison of different compilers.....                           | 76  |
| 8.3   | Obstacles to optimization by compiler.....                       | 80  |
| 8.4   | Obstacles to optimization by CPU.....                            | 85  |
| 8.5   | Compiler optimization options .....                              | 85  |
| 8.6   | Optimization directives.....                                     | 87  |
| 8.7   | Checking what the compiler does .....                            | 88  |
| 9     | Optimizing memory access .....                                   | 91  |
| 9.1   | Caching of code and data .....                                   | 91  |
| 9.2   | Cache organization .....   | 91  |
| 9.3   | Functions that are used together should be stored together.....  | 92  |
| 9.4   | Variables that are used together should be stored together ..... | 93  |
| 9.5   | Alignment of data.....   | 94  |
| 9.6   | Dynamic memory allocation .....                                  | 95  |
| 9.7   | Data structures and container classes .....                      | 97  |
| 9.8   | Strings .....  | 105 |
| 9.9   | Access data sequentially .....                                   | 105 |
| 9.10  | Cache contentions in large data structures .....                 | 106 |
| 9.11  | Explicit cache control .....                                     | 108 |
| 10    | Multithreading.....  | 110 |
| 10.1  | Simultaneous multithreading.....                                 | 112 |
| 11    | Out of order execution .....                                     | 113 |
| 12    | Using vector operations.....                                     | 115 |
| 12.1  | AVX instruction set and YMM registers .....                      | 117 |
| 12.2  | AVX512 instruction set and ZMM registers .....                   | 117 |
| 12.3  | Automatic vectorization .....                                    | 118 |
| 12.4  | Using intrinsic functions .....                                  | 121 |
| 12.5  | Using vector classes .....                                       | 125 |
| 12.6  | Transforming serial code for vectorization.....                  | 129 |
| 12.7  | Mathematical functions for vectors.....                          | 131 |
| 12.8  | Aligning dynamically allocated memory.....                       | 133 |
| 12.9  | Aligning RGB video or 3-dimensional vectors .....                | 133 |
| 12.10 | Conclusion.....  | 133 |