ASSEMBLY
UNDER THE HOOD

MODERN x64 PROGRAMMING FOR WINDOWS

FROM FUNDAMENTALS TO ADVANCED TECHNIQUES

- ARCHITECTURE & CPU
- WINDOWS INTERNALS
- OPTIMIZATION & SIMD
- REVERSE ENGINEERING
- DEBUGGING & SECURITY
- MULTITHREADING & SYNCHRONIZATION

```
; Windows x64
; function sum(int* a, int n)
; RDI = a, RSI = n
xor     eax, eax
test    rsi, rsi
jle     .done
.loop:
mov     ecx, dword ptr [rdi]
add     eax, ecx
add     rdi, 4
dec     rsi
jnz     .loop
.done:
ret
```

STEVE T.

Assembly Under the Hood: Modern x64 Programming for Windows

From Fundamentals to Advanced Techniques

Steve T. Team Publications

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From Fundamentals to Advanced Techniques

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Introduction: Why Assembly Still Matters

In an era of managed runtimes, garbage collection, and just-in-time compilation, you might wonder whether learning assembly language is still worth the effort. The short answer is yes, but not for the reasons you might think. You will rarely write large programs in assembly today, and the days of hand-tuning every hot loop are long gone. What assembly gives you instead is something far more valuable: a deep, intuitive understanding of how your code actually executes on the hardware.

Consider this scenario. A production server is experiencing intermittent crashes under heavy load. The stack traces point to a third-party library, and the application team has no source code for it. Understanding the x64 calling convention, stack frame layout, and structured exception handling allows you to analyze the crash dump, identify a corrupted return address, and trace the problem back through the call chain. Without that low-level knowledge, you are stuck.

Or consider a different scenario: a game engine needs to process millions of pixels per frame. The C++ compiler generates reasonable code, but profiling reveals the bottleneck is in a vectorized image processing routine. Knowing SIMD instructions, data alignment requirements, and how the CPU's execution pipeline works lets you rewrite the critical path to achieve the performance the hardware is capable of delivering.

This book assumes you can read and write C or C++ comfortably. You understand pointers, structs, function calls, and basic data structures. What you may lack is an understanding of what those constructs look like when compiled down to machine instructions and executed by the CPU. That gap is exactly what this book fills.

We focus specifically on x64 assembly under Windows because that combination dominates the desktop and server computing world. The x64 architecture, originally designed by AMD as "AMD64" and later adopted by Intel as "Intel 64," provides 16 general-purpose registers (up from 8 in x86), a flat

memory model with an 8-terabyte user address space, and mandatory SIMD support through SSE2. Windows enforces a single calling convention for x64, which simplifies things considerably compared to the multiple conventions that existed in the 32-bit era.

The toolchain we use throughout this book is the Microsoft Macro Assembler (MASM), specifically ml64.exe, which ships with Visual Studio and the Windows SDK [1,2]. MASM uses Intel syntax, which is the most widely documented and understood assembly syntax. We will also reference NASM and GCC/Clang where relevant, but our primary examples use MASM.

The journey ahead takes us from the very basics: what are registers, how does a function call work, what is a stack frame? to advanced topics like AVX-512 vectorization, reverse engineering compiled binaries, and writing secure code that resists modern attack techniques. Each chapter stands on its own but also builds on the foundations laid in earlier chapters.

Let us begin our journey into the heart of x64 Windows programming.

[1] Microsoft Macro Assembler (MASM) documentation, Microsoft Learn, https://learn.microsoft.com/en-us/cpp/assembler/masm/microsoft-macro-assembler-reference?view=msvc-170 [2] MASM for x64 (ml64.exe), Microsoft Learn, https://learn.microsoft.com/en-us/cpp/assembler/masm/masm-for-x64-ml64-exe?view=msvc-170

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