Assembly Language for x86 Processors

Eighth Edition

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To Jack and Candy Irvine

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Preface

Assembly Language for x86 Processors, Eighth Edition, teaches assembly language programming and architecture for x86 and Intel64 processors. It is an appropriate text for the following types of college courses:

- Assembly Language Programming
- Fundamentals of Computer Systems
- Fundamentals of Computer Architecture

Students use Intel or AMD processors and program with **Microsoft Macro Assembler (MASM)**, running on recent versions of Microsoft Windows. Although this book was originally designed as a programming textbook for college students, it serves as an effective supplement to computer architecture courses. As a testament to its popularity, previous editions have been translated into numerous languages.

Emphasis of Topics This edition includes topics that lead naturally into subsequent courses in computer architecture, operating systems, and compiler writing:

- Virtual machine concept
- Instruction set architecture
- Elementary Boolean operations
- Instruction execution cycle
- Memory access and handshaking
- Interrupts and polling
- Hardware-based I/O
- Floating-point binary representation

Other topics relate specially to x86 and Intel64 architecture:

- Protected memory and paging
- Memory segmentation in real-address mode
- 16-Bit interrupt handling
- MS-DOS and BIOS system calls (interrupts)
- Floating-point unit architecture and programming
- Instruction encoding

Certain examples presented in the book lend themselves to courses that occur later in a computer science curriculum:

- Searching and sorting algorithms
- High-level language structures
- Finite-state machines
- Code optimization examples

What's New in the Eighth Edition

This edition represents this book's transition into the world of interactive electronic textbooks. We're very excited about this innovative concept, because for the first time readers will be able to experiment and interact with review questions, code animations, tutorial videos, and multiple-input exercises.

- **All section reviews** in the chapters have been rewritten as interactive questions, giving the reader immediate feedback on their answers. New questions were added, others removed, and many revised.
- **Code animations** allow the reader to step through program code and view both variable values and comments about the code. Readers no longer have to visually jump back and forth between program code and text explanations on the next page.
- **Links to timely tutorial videos** have been inserted in the text, so readers can receive tutoring on topics as they encounter them in the text. Previously, readers would need to purchase a separate subscription to gain access to the entire set of videos, presented as a list. In this edition, videos are free.
- **Multiple-input exercises** allow readers to browse a program listing and insert variable values into boxes next to the code. They receive immediate colorized feedback, giving them the opportunity to experiment until all input values are correct.
- **Hypertexted definitions of key terms** are placed throughout the text, connected to an online glossary.

In short, we have taken the successful content of this book (refined through many editions) and brought it into the interactive electronic textbook world.

This book is still focused on its primary goal, to teach students how to write and debug programs at the machine level. It will never replace a complete book on computer architecture, but it does give students the first-hand experience of writing software in an environment that teaches them how a computer works. Our premise is that students retain knowledge better when theory is combined with experience. In an engineering course, students construct prototypes; in a computer architecture course, students should write machine-level programs. In both cases, they have a memorable experience that gives them confidence to work in any OS/machine-oriented environment.

Protected mode programming is entirely the focus of chapters 1 through 13. As such, students can create 32-bit and 64-bit programs that run under the most recent versions of Microsoft Windows. The remaining three legacy chapters cover 16-bit programming. These chapters cover BIOS programming, MS-DOS services, keyboard and mouse input, dist storage fundamentals, video programming, and graphics.

Subroutine Libraries We supply three versions of the subroutine library that students use for basic input/output, simulations, timing, and other useful tasks. The Irvine32 and Irvine64 libraries run in protected mode. The 16-bit version (Irvine16.lib) runs in real-address mode and is used only by Chapter 14 through Chapter 16. Full source code for the libraries is supplied on the companion website. The link libraries are available only for convenience, not to prevent students from learning how to program input–output themselves. Students are encouraged to create their own libraries.

Included Software and Examples All the example programs were tested with Microsoft Macro Assembler, running in a recent version of Microsoft Visual Studio. In addition, batch files are supplied that permit students to assemble and run applications from the Windows command prompt. Information

Updates and corrections to this book may be found at the Companion website, including additional programming projects for instructors to assign at the ends of chapters.

Overall Goals

The following goals of this book are designed to broaden the student's interest and knowledge in topics related to assembly language:

- Intel and AMD processor architecture and programming
- Real-address mode and protected mode programming
- Assembly language directives, macros, operators, and program structure
- Programming methodology, showing how to use assembly language to create system-level software tools and application programs
- Computer hardware manipulation
- Interaction between assembly language programs, the operating system, and other application programs

One of our goals is to help students approach programming problems with a machine-level mind set. It is important to think of the CPU as an interactive tool, and to learn to monitor its operation as directly as possible. A debugger is a programmer's best friend, not only for catching errors, but as an educational tool that teaches about the CPU and operating system. We encourage students to look beneath the surface of high-level languages and to realize that most programming languages are designed to be portable and, therefore, independent of their host machines. In addition to the short examples, this book contains hundreds of ready-to-run programs that demonstrate instructions or ideas as they are presented in the text. Reference materials, such as guides to MS-DOS interrupts and instruction mnemonics, are available at the end of the book.

Required Background The reader should already be able to program confidently in at least one high-level programming language such as Python, Java, C, or C++. One chapter covers C++ interfacing, so it is very helpful to have a compiler on hand. I have used this book in the classroom with majors in both computer science and management information systems, and it has been used elsewhere in engineering courses.

Features

Complete Program Listings The author's website contains supplemental learning materials, study guides, and all the source code from the book's examples. Two link libraries (32-bit and 64-bit) are supplied with the book, containing more than 40 procedures that simplify user input–output, numeric processing, disk and file handling, and string handling. In the beginning stages of the course, students can use this library to enhance their programs. Later, they can create their own procedures and add them to the library.

Programming Logic Two chapters emphasize Boolean logic and bit-level manipulation. A conscious attempt is made to relate high-level programming logic to the low-level details of the machine. This approach helps students to create more efficient implementations and to better understand how compilers generate object code.

Hardware and Operating System Concepts The first two chapters introduce basic hardware and data representation concepts, including binary numbers, CPU architecture, status flags, and memory mapping. A survey of the computer's hardware and a historical perspective of the Intel processor family helps students to better understand their target computer system.

Structured Programming Approach Beginning with Chapter 5, procedures and functional decomposition are emphasized. Students are given more complex programming exercises, requiring them to focus on design before starting to write code.

Java Bytecodes and the Java Virtual Machine In Chapters 8 and 9, the author explains the basic operation of Java bytecodes with short illustrative examples. Numerous short examples are shown in disassembled bytecode format, followed by detailed step-by-step explanations.

Creating Link Libraries Students are free to add their own procedures to the book's link library and create new libraries. They learn to use a toolbox approach to programming and to write code that is useful in more than one program.

Macros and Structures A chapter is devoted to creating structures, unions, and macros, which are essential in assembly language and systems programming. Conditional macros with advanced operators serve to make the macros more professional.

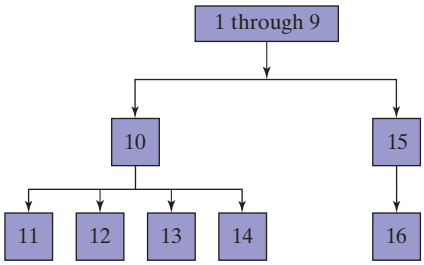
Interfacing to High-Level Languages A chapter is devoted to interfacing assembly language to C and C++. This is an important job skill for students who are likely to find jobs programming in high-level languages. They can learn to optimize their code and see examples of how C++ compilers optimize code.

Instructional Aids All the program listings are available on the Web. Instructors are provided a test bank, answers to review questions, solutions to programming exercises, and a Microsoft PowerPoint slide presentation for each chapter. More details can be found on Page xxvi.

VideoNotes VideoNotes are Pearson's visual tool designed to teach students key programming concepts and techniques. These short step-by-step videos demonstrate basic assembly language concepts. VideoNotes allow for self-paced instruction with easy navigation including the ability to select, play, rewind, fast-forward, and stop within each VideoNote exercise. Details below.

Chapter Descriptions

Chapters 1 to 8 contain core concepts of assembly language and should be covered in sequence. After that, you have a fair amount of freedom. The following chapter dependency graph shows how later chapters depend on knowledge gained from other chapters.



1. **Basic Concepts:** Applications of assembly language, basic concepts, machine language, and data representation.
2. **x86 Processor Architecture:** Basic microcomputer design, instruction execution cycle, x86 processor architecture, Intel64 architecture, x86 memory management, components of a microcomputer, and the input–output system.
3. **Assembly Language Fundamentals:** Introduction to assembly language, linking and debugging, and defining constants and variables.
4. **Data Transfers, Addressing, and Arithmetic:** Simple data transfer and arithmetic instructions, assemble-link-execute cycle, operators, directives, expressions, JMP and LOOP instructions, and indirect addressing.
5. **Procedures:** Linking to an external library, description of the book's link library, stack operations, defining and using procedures, flowcharts, and top-down structured design.
6. **Conditional Processing:** Boolean and comparison instructions, conditional jumps and loops, high-level logic structures, and finite-state machines.
7. **Integer Arithmetic:** Shift and rotate instructions with useful applications, multiplication and division, extended addition and subtraction, and ASCII and packed decimal arithmetic.
8. **Advanced Procedures:** Stack parameters, local variables, advanced PROC and INVOKE directives, and recursion.
9. **Strings and Arrays:** String primitives, manipulating arrays of characters and integers, two-dimensional arrays, sorting, and searching.
10. **Structures and Macros:** Structures, macros, conditional assembly directives, and defining repeat blocks.
11. **MS-Windows Programming:** Protected mode memory management concepts, using the Microsoft-Windows API to display text and colors, and dynamic memory allocation.
12. **Floating-Point Processing and Instruction Encoding:** Floating-point binary representation and floating-point arithmetic. Learning to program the 32-bit floating-point unit. Understanding the encoding of 32-bit machine instructions.
13. **High-Level Language Interface:** Parameter passing conventions, inline assembly code, and linking assembly language modules to C and C++ programs.
14. **16-Bit MS-DOS Programming:** Memory organization, interrupts, function calls, and standard MS-DOS file I/O services.

15. **Disk Fundamentals:** Disk storage systems, sectors, clusters, directories, file allocation tables, handling MS-DOS error codes, and drive and directory manipulation.
16. **BIOS-Level Programming:** Keyboard input, video text, graphics, and mouse programming.

- *Appendix A:* MASM Reference
- *Appendix B:* The x86 Instruction Set
- *Appendix C:* BIOS and MS-DOS Interrupts
- *Appendix D:* Answers to Review Questions (Chapters 14–16)

Instructor and Student Resources

Instructor Resource Materials

The following protected instructor material is available on pearson.com
For username and password information, please contact your Pearson Representative.

- Lecture PowerPoint Slides
- Instructor Solutions Manual

Student Resource Materials

The following useful materials are located at *www.asmirvine.com*:

- *Getting Started*, a comprehensive step-by-step tutorial that helps students customize Visual Studio for assembly language programming.
- Corrections to errors found in the book.
- Supplementary articles on assembly language programming topics.
- Required support files for assembling and linking your programs, complete source code for all example programs in the book, and complete source code for the author's supplementary library.
- *Assembly Language Workbook*, an interactive workbook covering number conversions, addressing modes, register usage, debug programming, and floating-point binary numbers.
- Debugging Tools: Tutorials on using the Microsoft Visual Studio debugger.

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Previous Editions

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About the Author

Kip Irvine has written five computer programming textbooks, for Intel Assembly Language, C++. Visual Basic (beginning and advanced), and COBOL. His book *Assembly Language for Intel-Based Computers* has been translated into six languages. His first college degrees (B.M., M.M., and doctorate) were in Music Composition, at University of Hawaii and University of Miami. He began programming computers for music synthesis around 1982 and taught programming at Miami-Dade Community College for 17 years. He earned an M.S. degree in Computer Science from the University of Miami, and taught computer programming in the School of Computing and Information Sciences at Florida International University for 18 years.