

# **Reversing: Secrets of Reverse Engineering**

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Eldad Eilam



Wiley Publishing, Inc.



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# **Foreword**

It is amazing, and rather disconcerting, to realize how much software we run without knowing for sure what it does. We buy software off the shelf in shrink-wrapped packages. We run setup utilities that install numerous files, change system settings, delete or disable older versions and superceded utilities, and modify critical registry files. Every time we access a Web site, we may invoke or interact with dozens of programs and code segments that are necessary to give us the intended look, feel, and behavior. We purchase CDs with hundreds of games and utilities or download them as shareware. We exchange useful programs with colleagues and friends when we have tried only a fraction of each program's features.

Then, we download updates and install patches, trusting that the vendors are sure that the changes are correct and complete. We blindly hope that the latest change to each program keeps it compatible with all of the rest of the programs on our system. We rely on much software that we do not understand and do not know very well at all.

I refer to a lot more than our desktop or laptop personal computers. The concept of ubiquitous computing, or "software everywhere," is rapidly putting software control and interconnection in devices throughout our environment. The average automobile now has more lines of software code in its engine controls than were required to land the Apollo astronauts on the Moon.

Today's software has become so complex and interconnected that the developer often does not know all the features and repercussions of what has been created in an application. It is frequently too expensive and time-consuming to test all control paths of a program and all groupings of user options. Now, with multiple architecture layers and an explosion of networked platforms that the software will run on or interact with, it has become literally impossible for all

combinations to be examined and tested. Like the problems of detecting drug interactions in advance, many software systems are fielded with issues unknown and unpredictable.

Reverse engineering is a critical set of techniques and tools for understanding what software is really all about. Formally, it is “the process of analyzing a subject system to identify the system’s components and their interrelationships and to create representations of the system in another form or at a higher level of abstraction”(IEEE 1990). This allows us to visualize the software’s structure, its ways of operation, and the features that drive its behavior. The techniques of analysis, and the application of automated tools for software examination, give us a reasonable way to comprehend the complexity of the software and to uncover its truth.

Reverse engineering has been with us a long time. The conceptual Reversing process occurs every time someone looks at someone else’s code. But, it also occurs when a developer looks at his or her own code several days after it was written. Reverse engineering is a discovery process. When we take a fresh look at code, whether developed by ourselves or others, we examine and we learn and we see things we may not expect.

While it had been the topic of some sessions at conferences and computer user groups, reverse engineering of software came of age in 1990. Recognition in the engineering community came through the publication of a taxonomy on reverse engineering and design recovery concepts in *IEEE Software* magazine. Since then, there has been a broad and growing body of research on Reversing techniques, software visualization, program understanding, data reverse engineering, software analysis, and related tools and approaches. Research forums, such as the annual international Working Conference on Reverse Engineering (WCRE), explore, amplify, and expand the value of available techniques. There is now increasing interest in binary Reversing, the principal focus of this book, to support platform migration, interoperability, malware detection, and problem determination.

As a management and information technology consultant, I have often been asked: “How can you possibly condone reverse engineering?” This is soon followed by: “You’ve developed and sold software. Don’t you want others to respect and protect your copyrights and intellectual property?” This discussion usually starts from the negative connotation of the term reverse engineering, particularly in software license agreements. However, reverse engineering technologies are of value in many ways to producers and consumers of software along the supply chain.

A stethoscope could be used by a burglar to listen to the lock mechanism of a safe as the tumblers fall in place. But the same stethoscope could be used by your family doctor to detect breathing or heart problems. Or, it could be used by a computer technician to listen closely to the operating sounds of a sealed disk drive to diagnose a problem without exposing the drive to

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potentially-damaging dust and pollen. The tool is not inherently good or bad. The issue is the use to which the tool is put.

In the early 1980s, IBM decided that it would no longer release to its customers the source code for its mainframe computer operating systems. Mainframe customers had always relied on the source code for reference in problem solving and to tailor, modify, and extend the IBM operating system products. I still have my button from the IBM user group Share that reads: “If SOURCE is outlawed, only outlaws will have SOURCE,” a word play on a famous argument by opponents of gun-control laws. Applied to current software, this points out that hackers and developers of malicious code know many techniques for deciphering others’ software. It is useful for the good guys to know these techniques, too.

Reverse engineering is particularly useful in modern software analysis for a wide variety of purposes:

- Finding malicious code. Many virus and malware detection techniques use reverse engineering to understand how abhorrent code is structured and functions. Through Reversing, recognizable patterns emerge that can be used as signatures to drive economical detectors and code scanners.
- Discovering unexpected flaws and faults. Even the most well-designed system can have holes that result from the nature of our “forward engineering” development techniques. Reverse engineering can help identify flaws and faults before they become mission-critical software failures.
- Finding the use of others’ code. In supporting the cognizant use of intellectual property, it is important to understand where protected code or techniques are used in applications. Reverse engineering techniques can be used to detect the presence or absence of software elements of concern.
- Finding the use of shareware and open source code where it was not intended to be used. In the opposite of the infringing code concern, if a product is intended for security or proprietary use, the presence of publicly available code can be of concern. Reverse engineering enables the detection of code replication issues.
- Learning from others’ products of a different domain or purpose. Reverse engineering techniques can enable the study of advanced software approaches and allow new students to explore the products of masters. This can be a very useful way to learn and to build on a growing body of code knowledge. Many Web sites have been built by seeing what other Web sites have done. Many Web developers learned HTML and Web programming techniques by viewing the source of other sites.

- Discovering features or opportunities that the original developers did not realize. Code complexity can foster new innovation. Existing techniques can be reused in new contexts. Reverse engineering can lead to new discoveries about software and new opportunities for innovation.

In the application of computer-aided software engineering (CASE) approaches and automated code generation, in both new system development and software maintenance, I have long contended that any system we build should be immediately run through a suite of reverse engineering tools. The holes and issues that are uncovered would save users, customers, and support staff many hours of effort in problem detection and solution. The savings industry-wide from better code understanding could be enormous.

I've been involved in research and applications of software reverse engineering for 30 years, on mainframes, mid-range systems and PCs, from program language statements, binary modules, data files, and job control streams. In that time, I have heard many approaches explained and seen many techniques tried. Even with that background, I have learned much from this book and its perspective on reversing techniques. I am sure that you will too.

Elliot Chikofsky  
Engineering Management and Integration (Herndon, VA)  
Chair, Reengineering Forum  
Executive Secretary, IEEE Technical Council on Software Engineering

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This book would probably never exist if it wasn’t for Avner (“Sabi”) Zangvil, who originally suggested the idea of writing a book about reverse engineering and encouraged me to actually write it.

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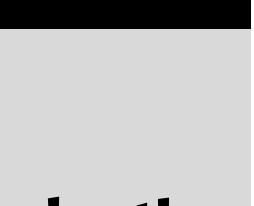
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# Introduction

Welcome to *Reversing: Secrets of Reverse Engineering*. This book was written after years of working on software development projects that repeatedly required reverse engineering of third party code, for a variety of reasons. At first this was a fairly tedious process that was only performed when there was simply no alternative means of getting information. Then all of a sudden, a certain mental barrier was broken and I found myself rapidly sifting through undocumented machine code, quickly deciphering its meaning and getting the answers I wanted regarding the code's function and purpose. At that point it dawned on me that this was a remarkably powerful skill, because it meant that I could fairly easily get answers to any questions I had regarding software I was working with, even when I had no access to the relevant documentation or to the source code of the program in question. This book is about providing knowledge and techniques to allow anyone with a decent understanding of software to do just that.

The idea is simple: we should develop a solid understanding of low-level software, and learn techniques that will allow us to easily dig into any program's binaries and retrieve information. Not sure why a system behaves the way it does and no one else has the answers? No problem—dig into it on your own and find out. Sounds scary and unrealistic? It's not, and this is the very purpose of this book, to teach and demonstrate reverse engineering techniques that can be applied daily, for solving a wide variety of problems.

But I'm getting ahead of myself. For those of you that haven't been exposed to the concept of software reverse engineering, a little introduction is in order.

## Reverse Engineering and Low-Level Software

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Before we get into the various topics discussed throughout this book, we should formally introduce its primary subject: reverse engineering. Reverse engineering is a process where an engineered artifact (such as a car, a jet engine, or a software program) is deconstructed in a way that reveals its innermost details, such as its design and architecture. This is similar to scientific research that studies natural phenomena, with the difference that no one commonly refers to scientific research as reverse engineering, simply because no one knows for sure whether or not nature was ever engineered.

In the software world reverse engineering boils down to taking an existing program for which source-code or proper documentation is not available and attempting to recover details regarding its' design and implementation. In some cases source code is available but the original developers who created it are unavailable. This book deals specifically with what is commonly referred to as binary reverse engineering. Binary reverse engineering techniques aim at extracting valuable information from programs for which source code is unavailable. In some cases it is possible to recover the actual source-code (or a similar high-level representation) from the program binaries, which greatly simplifies the task because reading code presented in a high-level language is far easier than reading low-level assembly language code. In other cases we end up with a fairly cryptic assembly language listing that describes the program. This book explains this process and *why* things work this way, while describing in detail how to decipher the program's code in a variety of different environments.

**I've decided to name this book "Reversing", which is the term used by many online communities to describe reverse engineering. Because the term *reversing* can be seen as a nickname for *reverse engineering* I will be using the two terms interchangeably throughout this book.**

Most people get a bit anxious when they try to imagine trying to extract meaningful information from an executable binary, and I've made it the primary goal of this book to prove that this fear is not justified. Binary reverse engineering works, it can solve problems that are often *incredibly* difficult to solve in any other way, and it is not as difficult as you might think once you approach it in the right way.

This book focuses on reverse engineering, but it actually teaches a great deal more than that. Reverse engineering is frequently used in a variety of environments in the software industry, and one of the primary goals of this book is to explore many of these fields while teaching reverse engineering.

Here is a brief listing of some of the topics discussed throughout this book:

- Assembly language for IA-32 compatible processors and how to read compiler-generated assembly language code.
- Operating systems internals and how to reverse engineer an operating system.
- Reverse engineering on the .NET platform, including an introduction to the .NET development platform and its assembly language: MSIL.
- Data reverse engineering: how to decipher an undocumented file-format or network protocol.
- The legal aspects of reverse engineering: when is it legal and when is it not?
- Copy protection and digital rights management technologies.
- How reverse engineering is applied by crackers to defeat copy protection technologies.
- Techniques for preventing people from reverse engineering code and a sober attempt at evaluating their effectiveness.
- The general principles behind modern-day malicious programs and how reverse engineering is applied to study and neutralize such programs.
- A live session where a real-world malicious program is dissected and revealed, also revealing how an attacker can communicate with the program to gain control of infected systems.
- The theory and principles behind decompilers, and their effectiveness on the various low-level languages.

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## How This Book Is Organized

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This book is divided into four parts. The first part provides basics that will be required in order to follow the rest of the text, and the other three present different reverse engineering scenarios and demonstrates real-world case studies. The following is a detailed description of each of the four parts.

**Part I – Reversing 101:** The book opens with a discussion of all the basics required in order to understand low-level software. As you would expect, these chapters couldn't possibly cover *everything*, and should only be seen as a refreshing survey of materials you've studied before. If all or most of the topics discussed in the first three chapters of this book are completely new to you, then this book is probably not for you. The

primary topics studied in these chapters are: an introduction to reverse engineering and its various applications (chapter 1), low-level software concepts (chapter 2), and operating systems internals, with an emphasis on Microsoft Windows (chapter 3). If you are highly experienced with these topics and with low-level software in general, you can probably skip these chapters. Chapter 4 discusses the various types of reverse engineering tools used and recommends specific tools that are suitable for a variety of situations. Many of these tools are used in the reverse engineering sessions demonstrated throughout this book.

**Part II – Applied Reversing:** The second part of the book demonstrates real reverse engineering projects performed on real software. Each chapter focuses on a different kind of reverse engineering application. Chapter 5 discusses the highly-popular scenario where an operating-system or third party library is reverse engineered in order to make better use of its internal services and APIs. Chapter 6 demonstrates how to decipher an undocumented, proprietary file-format by applying data reverse engineering techniques. Chapter 7 demonstrates how vulnerability researchers can look for vulnerabilities in binary executables using reverse engineering techniques. Finally, chapter 8 discusses malicious software such as viruses and worms and provides an introduction to this topic. This chapter also demonstrates a real reverse engineering session on a real-world malicious program, which is exactly what malware researchers must often go through in order to study malicious programs, evaluate the risks they pose, and learn how to eliminate them.

**Part III – Piracy and Copy Protection:** This part focuses on the reverse engineering of certain types of security-related code such as copy protection and Digital Rights Management (DRM) technologies. Chapter 9 introduces the subject and discusses the general principals behind copy protection technologies. Chapter 10 describes anti-reverse-engineering techniques such as those typically employed in copy-protection and DRM technologies and evaluates their effectiveness. Chapter 11 demonstrates how reverse engineering is applied by “crackers” to defeat copy protection mechanisms and steal copy-protected content.

**Part IV – Beyond Disassembly:** The final part of this book contains materials that go beyond simple disassembly of executable programs. Chapter 12 discusses the reverse engineering process for virtual-machine based programs written under the Microsoft .NET development platform. The chapter provides an introduction to the .NET platform and its low-level assembly language, MSIL (Microsoft Intermediate Language). Chapter 13 discusses the more theoretical topic of decompilation, and explains how decompilers work and why decompiling native assembly-language code can be so challenging.

**Appendices:** The book has three appendixes that serve as a powerful reference when attempting to decipher programs written in Intel IA-32 assembly language. Far beyond a mere assembly language reference guide, these appendixes describe the common code fragments and compiler idioms emitted by popular compilers in response to typical code sequences, and how to identify and decipher them.

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## Who Should Read this Book

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This book exposes techniques that can benefit people from a variety of fields. Software developers interested in improving their understanding of various low-level aspects of software: operating systems, assembly language, compilation, etc. would certainly benefit. More importantly, anyone interested in developing techniques that would enable them to quickly and effectively research and investigate existing code, whether it's an operating system, a software library, or any software component. Beyond the techniques taught, this book also provides a fascinating journey through many subjects such as security, copyright control, and others. Even if you're not specifically interested in reverse engineering but find one or more of the sub-topics interesting, you're likely to benefit from this book.

In terms of pre-requisites, this book deals with some fairly advanced technical materials, and I've tried to make it as self-contained as possible. Most of the required basics are explained in the first part of the book. Still, a certain amount of software development knowledge and experience would be essential in order to truly benefit from this book. If you don't have any professional software development experience but are currently in the process of studying the topic, you'll probably get by. Conversely, if you've never officially studied computers but have been programming for a couple of years, you'll probably be able to benefit from this book.

Finally, this book is probably going to be helpful for more advanced readers who are already experienced with low-level software and reverse engineering who would like to learn some interesting advanced techniques and how to extract remarkably detailed information from existing code.

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## Tools and Platforms

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Reverse engineering revolves around a variety of tools which are required in order to get the job done. Many of these tools are introduced and discussed throughout this book, and I've intentionally based most of my examples on free tools, so that readers can follow along without having to shell out thousands of

dollars on tools. Still, in some cases massive reverse engineering projects can greatly benefit from some of these expensive products. I have tried to provide as much information as possible on every relevant tool and to demonstrate the effect it has on the process. Eventually it will be up to the reader to decide whether or not the project justifies the expense.

Reverse engineering is often platform-specific. It is affected by the specific operating system and hardware platform used. The primary operating system used throughout this book is Microsoft Windows, and for a good reason. Windows is the most popular reverse engineering environment, and not only because it is the most popular operating system in general. Its lovely open-source alternative Linux, for example, is far less relevant from a reversing standpoint precisely because the operating system and most of the software that runs on top of it are open-source. There's no point in reversing open-source products—just read the source-code, or better yet, ask the original developer for answers. There are no secrets.

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## What's on the Web Site

The book's website can be visited at <http://www.wiley.com/go/eeilam>, and contains the sample programs investigated throughout the book. I've also added links to various papers, products, and online resources discussed throughout the book.

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## Where to Go from Here?

This book was designed to be read continuously, from start to finish. Of course, some people would benefit more from reading only select chapters of interest. In terms of where to start, regardless of your background, I would recommend that you visit Chapter 1 to make sure you have all the basic reverse engineering related materials covered. If you haven't had any significant reverse engineering or low-level software experience I would strongly recommend that you read this book in its "natural" order, at least the first two parts of it.

If you are highly experienced and feel like you are sufficiently familiar with software development and operating systems, you should probably skip to Chapter 4 and go over the reverse engineering tools.