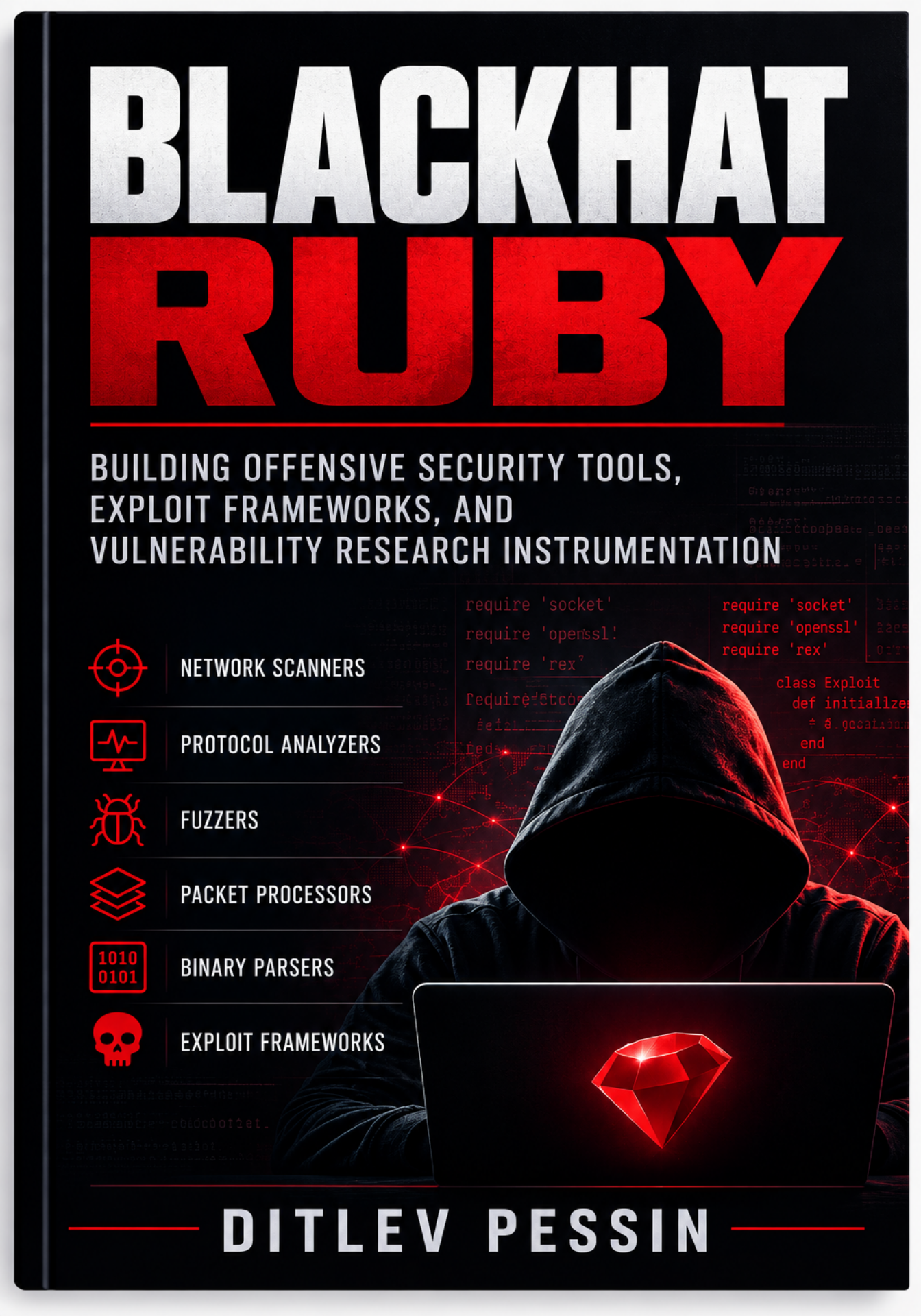
BLACKHAT RUBY

BUILDING OFFENSIVE SECURITY TOOLS, EXPLOIT FRAMEWORKS, AND VULNERABILITY RESEARCH INSTRUMENTATION

- NETWORK SCANNERS
- PROTOCOL ANALYZERS
- FUZZERS
- PACKET PROCESSORS
- BINARY PARSERS
- EXPLOIT FRAMEWORKS



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BlackHat Ruby

Building Offensive Security Tools, Exploit Frameworks, and Vulnerability Research Instrumentation

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Building Offensive Security Tools, Exploit Frameworks, and Vulnerability Research Instrumentation

About This Book

This book teaches intermediate to advanced developers and security practitioners how to use Ruby for offensive cybersecurity work. You will learn to build professional-grade penetration testing tools, network scanners, protocol

analyzers, fuzzers, packet processors, binary parsers, and exploit frameworks in controlled laboratory environments. Every chapter provides production-quality, fully functional code that runs in isolated labs, with thorough explanations of mechanisms, tradeoffs, and real-world applicability. Ethical considerations and legal boundaries are woven throughout. By the end, you will understand not only how to build offensive security tooling in Ruby, but also how defenders detect and mitigate these techniques, making you a more effective security professional regardless of which side of the keyboard you sit on.

Preface

Security professionals spend most of their careers using tools built by others. Nmap for scanning. Metasploit for exploitation. Burp Suite for web application testing. Wireshark for packet analysis. These tools are excellent, but relying solely on them creates a dangerous gap in understanding. When you cannot see inside the tool, you cannot fully trust its output, adapt it to unusual situations, or recognize when its assumptions no longer hold.

This book exists to close that gap. It teaches you to build security tools from scratch in Ruby, giving you the deep understanding that comes from writing the code yourself rather than merely invoking commands. You will learn how network scanners actually work at the socket level, how protocol parsers interpret binary data, how fuzzers systematically explore input spaces, and how exploit frameworks organize complex attack chains. This knowledge transfers regardless of language: once you understand the underlying mechanisms, you can implement them in Python, Go, Rust, or any other toolchain.

Ruby is an unusual choice for this purpose. It does not dominate security tooling the way Python does. It lacks the raw performance of systems languages like C, Rust, or Go. Yet Ruby has quietly powered some of the most influential security projects in the industry, most notably Metasploit, which was rewritten in Ruby in 2007 and remains one of the world's most widely used penetration testing platforms. Ruby brings specific strengths to security development: an expressive standard library with robust networking and binary data handling, dynamic metaprogramming that enables flexible frameworks, readable code that teams can maintain and extend, and a mature gem ecosystem with ready-made building blocks for protocol implementations and system interaction.

The target reader knows how to program. You understand variables, loops, conditionals, and basic object-oriented concepts. You may have used security tools professionally or in personal study, but you want to go deeper than command-line invocation. You want to understand what happens when you run a scan, how an exploit payload is constructed and delivered, how fuzzers discover unknown bugs, and how defenders detect these techniques. This book assumes that foundation and builds on it with progressively advanced material.

The structure follows a deliberate progression. Early chapters establish Ruby language features and tooling patterns specifically relevant to security development. Middle chapters cover core offensive techniques: network scanning, protocol analysis, packet processing, vulnerability assessment, fuzzing, reverse engineering, and exploit development. Later chapters address detection engineering, secure coding practices, deployment considerations, and professional responsibilities. Each chapter builds on previous material, so reading order matters.

Every code example in this book is designed to run in an isolated laboratory environment. These are not toy snippets meant only to illustrate a concept; they are complete, functional implementations with proper error handling, logging, configuration options, and documentation. You can use them as starting points for your own tools, modify them to fit specific needs, or study them to understand patterns and techniques applicable across the security domain. The examples prioritize correctness and clarity over cleverness. A tool that works reliably in a real engagement is more valuable than one that demonstrates a cool trick but fails under adversarial conditions.

The ethical framework is not an afterthought. Every technique described is intended for authorized security testing, research, and education in controlled environments. Testing systems without permission is illegal in most jurisdictions and harmful regardless of intent. The legal and ethical boundaries are foundational to everything covered here, not a disclaimer appended at the end. If you are reading this book to learn how to hack systems you do not own, put it down now. If you are reading it to understand how security tools work so you can build better defenses, find vulnerabilities responsibly, or conduct authorized assessments, welcome.

A note on performance: Ruby is not the fastest language. For high-throughput packet processing, you might prefer Go or Rust. For kernel-level work, C remains essential. For machine learning integration, Python has stronger ecosystem support. But for the broad category of security tooling

involving network communication, protocol analysis, vulnerability research automation, and exploit development, Ruby is more than adequate. Development speed and code clarity often matter more than marginal execution time differences. A scanner that takes three minutes instead of two is acceptable if it took half as long to build and is easier to maintain. Moreover, modern Ruby implementations with YJIT (integrated into CRuby since version 3.1) deliver meaningful performance improvements without requiring code changes or sacrificing compatibility.

I am grateful to the many researchers, developers, and security professionals who have contributed open-source tools, written documentation, shared knowledge publicly, and built the ecosystem that makes this book possible. Special thanks to the Metasploit Project contributors, the Ruby core team, Trail of Bits for Ruzzy, and the countless authors of security research papers and vulnerability disclosures that informed this work.

If you find errors, have suggestions for improvements, or discover new techniques worth including, please contribute. Security is a collaborative endeavor, and this book should evolve alongside the field it describes.

Now let's get started.

Introduction: Why Ruby for Offensive Security

In 2003, a security researcher named H.D. Moore wrote a portable network tool in Perl to test the security of computers and networks. That tool became Metasploit, and by 2007 the entire framework had been rewritten in Ruby over an eighteen-month effort that produced more than 150,000 lines of new code [1]. Today Metasploit hosts over two thousand exploits and nearly six hundred payloads, remains one of the most widely used penetration testing platforms in the world, and continues to be developed in Ruby. That single project demonstrates something important: Ruby is not just capable of powering serious security tooling, it is already doing so at the highest levels of the profession.

Yet if you browse security conference talks, read writeups on HackerOne, or check GitHub for new penetration testing projects, Ruby rarely appears in the spotlight. Python dominates the conversation. Go is gaining ground for performance-critical tools. Rust enthusiasts promise memory safety without sacrificing speed. Ruby, by comparison, seems almost invisible in offensive security circles.

This invisibility is unfortunate and largely undeserved.

Ruby brings a unique combination of strengths to security development that other languages struggle to match. Its expressive standard library includes robust networking primitives, binary data handling, system process control, and cryptographic functions without requiring external dependencies. The language dynamic nature makes it ideal for rapid prototyping of exploit code, protocol implementations, and proof-of-concept research where iteration speed matters more than raw performance. Ruby readability means security tools written in it are easier to audit, modify, and extend, which is critical when you need to adapt quickly during an engagement or debug a complex exploit chain at two in the morning. And the gem ecosystem provides ready-made building blocks for everything from HTTP manipulation and DNS resolution to PCAP parsing and Active Directory protocol implementations.

None of this means Ruby is the right choice for every security task. For high-performance packet processing, you might prefer Go or Rust. For deep kernel-level work, C is still king. For machine learning integration, Python has an edge. But for the broad category of security tooling that involves network communication, protocol analysis, vulnerability research automation, and exploit development, Ruby deserves serious consideration.

What This Book Will Teach You

This book takes you from Ruby fundamentals relevant to security through progressively advanced topics in offensive security development. Each chapter builds on previous material, so the structure matters: early chapters establish the language skills and tooling foundations you need, middle chapters cover the core offensive techniques and tool-building patterns, and later chapters address detection, secure coding, deployment, and professional practice.

You will learn to build network scanners from scratch using low-level socket programming, implementing TCP connect scans, SYN scans, and UDP scanning techniques with proper parallelization and rate control. You will write protocol analyzers that parse HTTP, DNS, SMB, and other protocols at the binary level, giving you the skills to understand how these protocols work and how to exploit their quirks. You will implement packet capture and processing tools that read PCAP files, analyze live traffic, and detect anomalies in network communications.

You will build fuzzers that systematically test applications and services for bugs, crashes, and potential vulnerabilities using both mutation-based and generation-based approaches. You will parse binary file formats including PE executables and ELF binaries, extracting headers, sections, symbols, and other artifacts useful in reverse engineering workflows. You will explore exploit development concepts from stack mechanics and buffer overflows through return-oriented programming chains and shellcode encoding, all demonstrated in safe laboratory environments with clear explanations of underlying mechanisms.

You will develop post-exploitation tooling that simulates privilege escalation enumeration, credential access, lateral movement, and command-and-control communication patterns, mapped to MITRE ATT&CK techniques so you understand how real adversaries operate. You will flip perspective to understand how defenders detect these techniques through EDR, IDS signatures,

behavioral analysis, and network monitoring. And you will learn secure coding practices specific to Ruby, ensuring your own tools are robust against bugs and supply chain vulnerabilities.

Throughout, you will find production-quality code examples designed to run in isolated laboratory environments. These are not toy snippets or conceptual sketches; they are complete, functional implementations with proper error handling, logging, configuration options, and documentation. You can use them as starting points for your own tools, modify them to fit specific needs, or study them to understand patterns and techniques applicable across the security domain.

What This Book Will Not Teach You

This book is not a general introduction to Ruby programming. If you need to learn variables, loops, conditionals, and basic object-oriented concepts from scratch, start with a dedicated Ruby tutorial first. The target reader knows how to write programs and now wants to apply those skills to offensive security.

This book is not a comprehensive guide to every penetration testing technique, exploit class, or red team tactic that exists. Some topics, like web application vulnerability classes or advanced Active Directory exploitation, could each fill their own books. Instead, the focus is on using Ruby as a tool for security research and development, with specific techniques chosen to illustrate broader concepts and patterns.

This book does not teach illegal hacking. Every technique described is intended for authorized security testing, research, and education in controlled environments. The legal and ethical boundaries are not an afterthought; they are foundational to everything covered here.

Ethical Foundations and Legal Boundaries

Before writing a single line of offensive security code, you must understand the rules that govern its use. These rules exist for good reasons: to protect individuals, organizations, and infrastructure from harm, and to maintain the professional integrity of the security community.

The fundamental principle is consent. You may only test systems you own or have explicit, written authorization to test. This means penetration

testing engagements with signed contracts, bug bounty programs with clearly defined scopes, capture-the-flag competitions designed for security practice, and isolated laboratory environments you control entirely. Testing without permission is not just unethical; in most jurisdictions it is illegal, potentially violating computer misuse laws, unauthorized access statutes, and data protection regulations.

Authorization must be specific and documented. Vague verbal agreements are insufficient. A proper authorization document should define the scope (which systems, networks, or applications may be tested), the methods allowed (what techniques are in scope), the timing (when testing may occur), and the reporting requirements (how findings will be communicated). Never exceed the scope of your authorization, even if you discover interesting targets along the way.

Responsible disclosure is equally important. When you discover vulnerabilities through legitimate research, you have ethical obligations to report them to affected parties and allow reasonable time for remediation before public disclosure. The coordinated vulnerability disclosure process, documented in frameworks like OWASP guidelines and RFC 9116, provides a structured approach that balances the interests of researchers, vendors, and users.

This book emphasizes responsible practice throughout. Code examples include safety mechanisms, logging, and configuration options designed to minimize unintended impact. Techniques are explained in the context of authorized testing and research, with clear warnings about legal requirements and potential consequences of misuse.

Setting Up Your Isolated Laboratory Environment

Offensive security development requires a safe, controlled environment where you can experiment freely without affecting production systems or violating laws. The following setup provides a solid foundation for all the exercises and examples in this book.

The recommended approach uses virtualization to create isolated networks and target systems. VirtualBox (free) or VMware Workstation Player (free for personal use) are suitable choices. Create a host-only network adapter that allows your workstation to communicate with guest VMs while remaining isolated from external networks.

For your attacking workstation, Kali Linux is the standard choice, providing pre-installed security tools and Ruby support. Install Ruby using the system package manager or, preferably, a version manager like rbenv or rvm to maintain multiple Ruby versions and keep your security tools separate from system Ruby. Ruby 3.2 or later is recommended for this book, as it includes performance improvements and security enhancements over earlier versions.

For target systems, use intentionally vulnerable images designed for security training: Metasploitable (both version 2 and 3), DVWA (Damn Vulnerable Web Application), OWASP Juice Shop, or VulnHub machines. These provide realistic targets without risking production infrastructure. Always run these in isolated networks; several are known to have critical vulnerabilities that could be exploited if connected to the internet.

Additional tools worth installing include Wireshark for packet analysis, Nmap for comparison and validation of your custom scanners, Burp Suite Community Edition for web application testing, and Ghidra or radare2 for reverse engineering exercises. These tools complement the Ruby-based tools you will build and provide reference implementations to study.

With this foundation in place, you are ready to begin. The next chapter covers the Ruby language fundamentals specifically relevant to security development, establishing the skills you need for everything that follows.

Introduction: Why Ruby for Offensive Security

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Chapter 1: Ruby Fundamentals for Security Development

Security tooling places specific demands on a programming language that general-purpose applications do not. You need precise control over binary data, reliable system interaction, robust error handling under adversarial conditions, and the ability to structure projects so they remain maintainable as complexity grows. This chapter covers the Ruby features that matter most for security development, with examples drawn from real tooling patterns rather than abstract exercises.

Core Language Features That Matter for Security Code

Ruby dynamic nature is both a strength and a consideration in security contexts. The language provides metaprogramming capabilities that can generate code at runtime, introspect objects, and modify behavior on the fly. These features are powerful for building flexible security frameworks but require careful use to avoid introducing vulnerabilities into your own tools.

Blocks, procs, and lambdas are fundamental to Ruby concurrency patterns used extensively in security tooling. A port scanner that processes thousands of ports in parallel, a fuzzer that tests multiple inputs simultaneously, or a protocol analyzer that handles concurrent connections all rely on these constructs. Understanding the difference between them matters for performance and correctness.

A block is the most common construct, passed to methods using either curly braces or do-end syntax. Procs are objects that wrap blocks and can be stored, passed around, and called independently. Lambdas are stricter variants that enforce arity checking and return behavior. For security tools, procs are particularly useful for registering callbacks in event-driven architectures like packet analyzers or exploit frameworks.

Module mixins provide Ruby approach to code reuse without deep inheritance hierarchies. Security tooling often shares common functionality across

different modules: logging, configuration handling, network utilities, output formatting. Modules let you compose these capabilities cleanly. A scanner module might mix in logging, a rate-limiting mixin, and an output formatter without creating rigid class hierarchies.

The Enumerable module is worth special mention. Almost every security tool processes collections of data: IP addresses to scan, ports to check, packets to analyze, vulnerabilities to report. Enumerable provides map, select, reject, group_by, reduce, and dozens of other methods that make collection processing concise and readable. Mastering Enumerable patterns will make your security code more maintainable than equivalent imperative loops.

Working with Raw Bytes, Encodings, and Binary Data

Security work involves binary data constantly. Network packets have headers defined as specific byte sequences. Protocol messages use structured formats with fields packed into fixed sizes. Exploit payloads consist of raw machine instructions encoded as bytes. File formats like PE executables or ELF binaries define their structures in terms of byte offsets and field sizes.

Ruby handles all of this through its String class and the pack/unpack methods, which provide a template-based system for converting between Ruby values and binary representations. This is one of the most important APIs you will use.

Strings in Ruby hold bytes, not characters, despite the historical terminology. Every String has an encoding attribute that determines how those bytes are interpreted as text, but the underlying bytes remain accessible regardless. When working with binary data, you typically set the encoding to ASCII-8BIT (also known as BINARY) to signal that the string contains raw bytes rather than text.

The pack method converts arrays of values into binary strings according to a template. The unpack method does the reverse, parsing binary strings back into Ruby values. The template directives control types, sizes, and byte ordering. For network protocols, you need to understand these thoroughly because protocol specifications define exact binary layouts that must be reproduced precisely.

Here is a practical example showing how to construct a simple TCP SYN packet header using pack:

```ruby
# Constructing a minimal IPv4 + TCP SYN header
def build_syn_packet(src_ip, dst_ip, src_port, dst_port)
  # IPv4 header fields
  version_ihl = 0x45          # Version 4, IHL 5 (20 bytes)
  dscp_ecn = 0x00             # No QoS
  total_length = 40           # 20 byte IP + 20 byte TCP
  identification = rand(0xFFFF)
  flags_fragment = 0x4000     # Don't fragment
  ttl = 64
  protocol = 6                # TCP
  header_checksum = 0        # Calculated later

  # Pack IPv4 header (20 bytes)
  ip_src = src_ip.split('.').pack('C*')
  ip_dst = dst_ip.split('.').pack('C*')

  ip_header = [
    version_ihl, dscp_ecn, total_length,
    identification, flags_fragment, ttl,
    protocol, header_checksum,
    ip_src, ip_dst
  ].pack('nnnnnnnn a4a4')

  # TCP header fields
  seq_number = rand(0xFFFFFFFF)
  ack_number = 0
  data_offset_flags = 0x5002   # Data offset 5, SYN flag set
  window_size = 65535
  tcp_checksum = 0
  urgent_pointer = 0

  tcp_header = [
    src_port, dst_port,
    seq_number, ack_number,
    data_offset_flags, window_size,
    tcp_checksum, urgent_pointer
  ].pack('nnnnnnnn')

  # Calculate checksums (simplified)
  ip_header[10, 2] = calculate_checksum(ip_header).pack('n')

  "#{ip_header}#{tcp_header}"
end

def calculate_checksum(data)
  sum = data.each_slice(2).map { |pair|
    pair.pack('C*').unpack('n')[0]
  }.reduce(0, :+)

  while sum > 0xFFFF
```

```
    sum = (sum & 0xFFFF) + (sum >> 16)
  end

  (~sum) & 0xFFFF
end
```

This demonstrates several patterns you will see repeatedly. The pack directives 'nnnnnnnn' create eight 16-bit big-endian unsigned integers. The 'a4a4' directive creates two four-byte strings for the IP addresses. The calculate_checksum method shows how to iterate over bytes in pairs, a common pattern in network protocol implementations.

Unpack works in the reverse direction. When parsing incoming packets, you use unpack with matching directives to extract fields:

```
def parse_ipv4_header(data)
  return nil unless data.bytesize >= 20
  return nil unless data[0] == "\x45"

  version_ihl, dscp_ecn, total_length,
    identification, flags_fragment, ttl,
    protocol, checksum,
    src_ip, dst_ip = data[0, 20].unpack('CCnnnnnnn CCCC')

  {
    version: (version_ihl >> 4),
    ihl: (version_ihl & 0x0F) * 4,
    total_length: total_length,
    protocol: protocol,
    ttl: ttl,
    src_ip: "#{src_ip[0]}.#{src_ip[1]}.#{src_ip[2]}.#{src_ip[3]}",
    dst_ip: "#{dst_ip[0]}.#{dst_ip[1]}.#{dst_ip[2]}.#{dst_ip[3]}"
  }
end
```

Key pack directives for security work include:

- 'C' for unsigned 8-bit, 'S' for unsigned 16-bit native order, 'L' for unsigned 32-bit native order
- 'n' for 16-bit big-endian (network byte order), 'N' for 32-bit big-endian
- 'v' for 16-bit little-endian, 'V' for 32-bit little-endian
- 'a' for space-padded string, 'A' for space-trimmed string, 'Z' for null-terminated
- 'h*' for hex string (low nibble first), 'H*' for hex string (high nibble first)

- Modifiers: '>' forces big-endian, '<' forces little-endian, '!' uses native size types

Understanding byte ordering is critical. Network protocols almost always use big-endian (network byte order). Windows binary formats like PE use little-endian. Confusing these will produce malformed packets or incorrect parsing results that are difficult to debug.

System Interaction: Processes, Files, and Environment Control

Security tools frequently need to spawn processes, manipulate files, read environment variables, and interact with the operating system at a low level. Ruby provides comprehensive APIs for all of these tasks, but security considerations apply both to how you use them and how attackers might exploit improper use in your own code.

Process spawning is essential for many security tools. A vulnerability scanner might spawn Nmap or other external tools for specialized checks. An exploit framework might launch shellcode in a child process for testing. A post-exploitation tool might execute commands on compromised systems. Ruby offers multiple methods with different behaviors and security implications.

The system method runs a command and returns true if it succeeds, false otherwise. It blocks until the command completes and inherits standard I/O by default. The backtick operator captures stdout as a string. Both pass commands through the shell, which introduces injection risks if you include user-controlled input in the command string.

For security tools, the safer approach uses exec, spawn, or Open3 with argument arrays instead of shell strings. This avoids shell interpretation and prevents injection:

```ruby
require 'open3'

def run_command_safely(executable, *args)
  stdout, stderr, status = Open3.capture3(executable, *args)

  {
    stdout: stdout,
    stderr: stderr,
    success: status.success?,
    exit_code: status.exitstatus
  }
end

# Safe usage - no shell injection possible
result = run_command_safely('nmap', '-sn', '192.168.1.0/24')

# Dangerous usage to avoid
user_input = "target; rm -rf /"
system("nmap #{user_input}")  # Shell injection vulnerability
```

File operations require careful handling of permissions and paths. Security tools often read configuration files, write logs, process PCAP captures, or handle binary payloads. Use absolute paths where possible to avoid confusion about working directories. Validate file extensions and magic numbers when reading untrusted files. Never trust filenames from external sources without sanitization to prevent path traversal attacks.

Environment variable handling matters for both functionality and security. Some tools depend on environment variables for configuration (proxy settings, SSL certificates, logging levels). Your tools should document required environment variables and provide sensible defaults. When spawning child processes, consider whether they need the full parent environment or a minimal, controlled one to reduce attack surface.

Error Handling, Logging, and Observability in Security Tools

Security tools operate in unpredictable environments. Networks are unreliable, targets may be misconfigured or unresponsive, firewalls drop packets silently, services crash under unusual input, and permissions may be insufficient for certain operations. Robust error handling is not optional; it is fundamental to building tools that professionals can rely on during engagements.

Ruby exception hierarchy provides the foundation. StandardError is the parent of most exceptions you should catch. Never rescue Exception broadly, as this catches SystemExit, Interrupt, and other critical exceptions that should propagate. Define custom exception classes for tool-specific errors to enable precise handling:

```
module SecurityTool
  class Error < StandardError; end
  class ConnectionError < Error; end
  class ParseError < Error; end
  class TimeoutError < Error < Timeout::Error; end
  class AuthenticationError < Error; end
end

def connect_to_target(host, port, timeout = 5)
  socket = TCPSocket.new(host, port, nil, nil, connect_timeout: timeout)
rescue Errno::ECONNREFUSED
  raise SecurityTool::ConnectionError, "Connection refused by #{host}:#{port}"
rescue Errno::ETIMEDOUT
  raise SecurityTool::TimeoutError, "Connection timed out to #{host}:#{port}"
rescue Errno::EHOSTUNREACH
  raise SecurityTool::ConnectionError, "Host unreachable: #{host}"
ensure
  socket&.close
end
```

Logging deserves serious attention in security tooling. During an engagement, you need visibility into what your tools are doing, what they found, and where problems occurred. Implement structured logging that records timestamps, severity levels, component names, and contextual information. Log enough detail for debugging but respect operational constraints like log volume and sensitive data handling.

Ruby Logger is adequate for basic needs, but consider more sophisticated solutions for production tools. The log4r gem provides flexible configuration with multiple appenders and filters. Structured JSON logging integrates well with SIEM systems and security operations workflows. At minimum, implement levels (DEBUG, INFO, WARN, ERROR) and ensure logs are written to both stdout/stderr for interactive use and files for later analysis.

Observability extends beyond logging. Security tools should report progress during long-running operations, provide clear status indicators, and communicate results in structured formats that can be parsed by other tools or integrated into reporting workflows. Command-line flags for verbosity

control, output format selection (text, JSON, CSV), and result filtering make your tools more useful in professional settings.

Project Structure, Testing, and Packaging Conventions

As security tools grow beyond single scripts, organization matters. A well-structured project is easier to maintain, extend, test, and share with teammates or the broader community. Follow established Ruby conventions while adapting for security-specific needs.

A typical security tool project structure includes:

```
my_security_tool/
  bin/
    my_tool          # Executable entry point
  lib/
    my_tool.rb       # Main module file
    my_tool/
      version.rb     # Version constant
      scanner.rb     # Core scanning logic
      parser.rb      # Protocol/data parsing
      output.rb      # Report generation
      utils.rb       # Shared utilities
  config/
    default.yml      # Default configuration
    wordlists/       # Dictionaries and lists
  test/
    test_scanner.rb  # Unit tests
    fixtures/        # Test data (sample packets, responses)
  spec/              # RSpec tests (alternative to minitest)
  Gemfile            # Dependencies
  README.md          # Documentation
  LICENSE            # License file
```

The bin directory contains executable scripts that set up the environment and invoke the library code. The lib directory holds the core implementation organized into modules and classes. Configuration files separate settings from code, enabling different profiles for different engagement types. Test directories contain automated tests that verify correctness and catch regressions.

Use Bundler to manage dependencies. A Gemfile declares required gems with version constraints, and bundle install creates a reproducible environment. For security tools, pin dependency versions in Gemfile.lock to ensure

consistent behavior across environments. Run bundle audit regularly to check for known vulnerabilities in your dependencies.

Testing is essential for security tools because incorrect behavior can lead to false positives (wasting analyst time), false negatives (missing real vulnerabilities), or worse, unintended impact on targets. Write unit tests for parsing logic, protocol implementations, and utility functions. Use integration tests that verify end-to-end behavior against controlled test targets. Include edge cases: malformed input, unexpected responses, network errors, permission issues.

For packaging, consider how your tool will be distributed. A Ruby gem works well for library-style tools used by other developers. For standalone command-line tools, options include distributing source with a Gemfile, creating platform packages with fpm, or building self-contained executables with ruby-packer or similar tools. Document installation requirements clearly, including Ruby version, system dependencies, and any prerequisites like libpcap for packet capture functionality.

Building a Production-Quality Logging Module

The logging patterns described above are important enough to warrant a complete implementation. Production security tools need structured, configurable logging that works consistently across all modules. The following implementation provides a reusable logging foundation suitable for any Ruby security tool.

```
require 'logger'
require 'json'
require 'time'
require 'forwardable'

module SecurityTool
  # Structured logger supporting multiple output formats and destinations
  class Logger
    extend Forwardable
    def_delegators :@core, :debug, :info, :warn, :error, :fatal

    LEVELS = {
      debug: Logger::DEBUG,
      info: Logger::INFO,
      warn: Logger::WARN,
```

```ruby
      error: Logger::ERROR,
      fatal: Logger::FATAL
    }.freeze

    def initialize(options = {})
      @component = options[:component] || 'main'
      @format = (options[:format] || :text).to_sym
      @level = LEVELS.fetch((options[:level] || :info).to_sym, Logger::INFO)
      @output = options[:output] || $stdout
      @file_path = options[:file_path]
      @include_timestamps = options.fetch(:include_timestamps, true)
      @include_component = options.fetch(:include_component, true)

      @core = ::Logger.new(@output)
      @core.level = @level

      # Add file output if specified
      if @file_path
        FileUtils.mkdir_p(File.dirname(@file_path))
        file_logger = ::Logger.new(@file_path)
        file_logger.level = @level
        @file_output = file_logger
      end

      # Configure formatter based on selected format
      @core.formatter = formatter
    end

    def log(level, message, context = {})
      level_sym = level.to_sym
      return unless LEVELS[level_sym] >= @level

      entry = build_entry(level_sym, message, context)

      @core.add(LEVELS[level_sym]) { format_output(entry) }
      @file_output&.add(LEVELS[level_sym]) { format_output(entry) }
    end

    def debug(message, context = {})
      log(:debug, message, context)
    end

    def info(message, context = {})
      log(:info, message, context)
    end

    def warn(message, context = {})
      log(:warn, message, context)
    end

```

```ruby
    def error(message, context = {})
      log(:error, message, context)
    end

    def with_context(context)
      ContextualLogger.new(self, context)
    end

    private

    def formatter
      proc do |severity, timestamp, progname, msg|
        "#{msg}\n"
      end
    end

    def build_entry(level, message, context)
      entry = {
        level: level.to_s.upcase,
        message: message.to_s,
        component: @component
      }

      entry[:timestamp] = Time.now.utc.iso8601(3) if @include_timestamps
      entry.merge!(context.compact) unless context.empty?

      entry
    end

    def format_output(entry)
      case @format
      when :json
        JSON.fast_generate(entry)
      when :text
        parts = []
        parts << "[#{entry[:timestamp]}]" if entry[:timestamp]
        parts << "[#{entry[:component]}]" if entry[:component] &&
        ↪  @include_component
        parts << "[#{entry[:level]}]"
        parts << entry[:message]

        # Append context as key=value pairs
        extra = entry.reject { |k, _| %w[level message component
        ↪  timestamp].include?(k.to_s) }
        parts << " #{extra.map { |k, v| "#{k}=#{v}" }.join(' ')}" unless
        ↪  extra.empty?

        parts.join(' ')
      when :csv
        # CSV format for SIEM integration
```

```ruby
        values = %w[timestamp level component message].map do |field|
          entry[field.to_sym].to_s.gsub('"', '""')
        end
        values.map { |v| "\"#{v}\"" }.join(',')
      else
        entry[:message].to_s
      end
    end
  end

  # Logger that automatically includes context in every log entry
  class ContextualLogger
    def initialize(base_logger, context)
      @logger = base_logger
      @context = context
    end

    def debug(message)
      @logger.debug(message, @context.dup)
    end

    def info(message)
      @logger.info(message, @context.dup)
    end

    def warn(message)
      @logger.warn(message, @context.dup)
    end

    def error(message)
      @logger.error(message, @context.dup)
    end
  end
end

# Usage example in a scanner module
class MyScanner
  include SecurityTool::Logging if defined?(SecurityTool::Logging)

  def initialize(options = {})
    @logger = SecurityTool::Logger.new(
      component: 'scanner',
      level: (options[:verbose] ? :debug : :info),
      format: options[:log_format] || :text,
      file_path: options[:log_file]
    )
  end

  def scan(target)
    logger = @logger.with_context(target: target)
```

```
    logger.info("Starting scan")

    begin
      # Scanning logic here
      logger.debug("Probing port", port: 80)
      logger.info("Scan complete", duration: elapsed_time)
    rescue => e
      logger.error("Scan failed", error: e.message, class: e.class.name)
      raise
    end
  end
end
```

This logging module demonstrates several production-quality patterns. It supports multiple output formats (text, JSON, CSV) for different consumption scenarios. The contextual logger pattern allows modules to attach persistent metadata to all their log entries without repeating it. File and console output can operate simultaneously. Severity filtering ensures verbose debug output does not clutter normal operation.

Configuration Management Pattern

Security tools need flexible configuration that supports command-line arguments, configuration files, environment variables, and sensible defaults. A robust configuration system validates inputs, documents expected values, and provides clear error messages when configuration is invalid.

```
require 'yaml'
require 'ostruct'

module SecurityTool
  class ConfigurationError < StandardError; end

  # Hierarchical configuration loader with validation
  class Config
    def initialize(defaults = {})
      @defaults = defaults
      @overrides = {}
      @sources = []
    end

    def load_file(path)
      return self unless File.exist?(path)

```

```
        data = YAML.safe_load(File.read(path), permitted_classes: [Symbol, Date,
        ↪  Time])
        raise ConfigurationError, "Invalid YAML in #{path}" unless
        ↪  data.is_a?(Hash)

        @overrides.deep_merge!(data)
        @sources << { type: :file, path: path }
        self
      end

      def load_env(prefix)
        ENV.each do |key, value|
          next unless key.start_with?(prefix)
          config_key = key.sub(/^#{prefix}/, '').downcase.to_sym
          @overrides[config_key] = parse_value(value)
        end
        @sources << { type: :environment, prefix: prefix }
        self
      end

      def load_cli(options)
        @overrides.deep_merge!(options)
        @sources << { type: :cli }
        self
      end

      def [](key)
        value = resolved_value(key)
        return value if !value.nil? || @defaults.key?(key)

        raise ConfigurationError, "Missing required configuration: #{key}"
      end

      def fetch(key, default = nil)
        resolved_value(key) || default
      end

      def to_h
        resolve_all
      end

      def to_struct
        OpenStruct.new(to_h)
      end

      def sources
        @sources.dup
      end

      private
```

```ruby

    def resolved_value(key)
      parts = key.to_s.split('.').map(&:to_sym)
      value = nil

      # Check overrides first (CLI > env > file > defaults)
      current = @overrides
      parts.each do |part|
        return nil unless current.is_a?(Hash) && current.key?(part)
        value = current[part]
        current = value
      end
      return value unless value.nil?

      # Fall back to defaults
      current = @defaults
      parts.each do |part|
        return nil unless current.is_a?(Hash) && current.key?(part)
        value = current[part]
        current = value
      end
      value
    end

    def resolve_all
      result = @defaults.dup
      deep_merge!(result, @overrides)
      result
    end

    def deep_merge!(hash1, hash2)
      hash2.each do |key, value|
        if hash1[key].is_a?(Hash) && value.is_a?(Hash)
          deep_merge!(hash1[key], value)
        else
          hash1[key] = value
        end
      end
      hash1
    end

    def parse_value(value)
      case value.downcase
      when 'true', 'yes', '1' then true
      when 'false', 'no', '0' then false
      when /^\d+$/ then Integer(value)
      when /^\d+\.\d+$/ then Float(value)
      else value
      end
    end
```

```ruby
  end
end

# Usage example showing full configuration hierarchy
def setup_configuration(cli_options)
  # Default configuration
  defaults = {
    scanning: {
      timeout: 5,
      max_threads: 100,
      rate_limit: 0,
      retry_count: 2
    },
    output: {
      format: :text,
      verbose: false,
      log_file: nil
    },
    network: {
      proxy: nil,
      user_agent: 'SecurityTool/1.0'
    }
  }

  config = SecurityTool::Config.new(defaults)

  # Load from file (if specified or default exists)
  config_file = cli_options[:config] || ENV['SECURITY_TOOL_CONFIG'] ||
  ↪  '~/.security_tool.yml'
  config.load_file(File.expand_path(config_file)) if config_file

  # Load environment variables with prefix
  config.load_env('SECURITY_TOOL_')

  # Apply CLI overrides (highest priority)
  config.load_cli(cli_options.transform_keys(&:to_sym))

  config
end
```

This configuration system implements a clear precedence hierarchy: command-line options override environment variables, which override configuration files, which override defaults. The hierarchical key structure (e.g., scanning.timeout) keeps related settings organized. Type coercion for environment variables handles the string-only nature of ENV automatically. Validation occurs at access time, providing immediate feedback when required values are missing.

Metaprogramming Patterns for Security Frameworks

Ruby metaprogramming enables dynamic code generation and runtime modification that is particularly valuable for security frameworks. Exploit frameworks need to dynamically load modules, register capabilities, generate payloads, and adapt behavior based on target characteristics. The following patterns demonstrate how to use metaprogramming responsibly in security tooling.

Dynamic module registration allows frameworks like Metasploit to discover and load exploit modules automatically:

```
module ExploitFramework
  class << self
    attr_reader :modules
  end
  @modules = {}

  # Register a module dynamically
  def self.register_module(name, module_class)
    @modules[name] = {
      class: module_class,
      info: module_class.module_info,
      loaded_at: Time.now
    }
  end

  # Find modules matching criteria
  def self.find_modules(criteria = {})
    @modules.select do |_, mod|
      criteria.all? do |key, value|
        case value
        when Proc
          value.call(mod[:info])
        when Regexp
          mod[:info][key]&.to_s =~ value
        else
          mod[:info][key] == value
        end
      end
    end
  end

  # Instantiate a module by name with options
  def self.instantiate(name, options = {})
    mod = @modules[name]
    raise ArgumentError, "Unknown module: #{name}" unless mod

```

```
    instance = mod[:class].new(options)
    instance.validate!
    instance
  end
end

# Module base class with dynamic registration
module ExploitFramework
  class ModuleBase
    class << self
      attr_accessor :module_info

      def register_as(name)
        ExploitFramework.register_module(name, self)
      end

      def option(name, required: false, default: nil, description: '')
        (@options ||= []) << {
          name: name,
          required: required,
          default: default,
          description: description
        }
      end

      def options
        @options || []
      end
    end

    def initialize(options = {})
      @options = {}
      self.class.options.each do |opt|
        @options[opt[:name]] = options[opt[:name]] || opt[:default]
      end
    end

    def [](key)
      @options[key]
    end

    def []=(key, value)
      @options[key] = value
    end

    def validate!
      missing = self.class.options.select { |o| o[:required] &&
      ↪  @options[o[:name]].nil? }.map { |o| o[:name] }
      raise ArgumentError, "Missing required options: #{missing.join(', ')}"
      ↪  unless missing.empty?
```

```ruby
    end

    def run
      raise NotImplementedError
    end
  end
end

# Example exploit module using the framework
class VulnerableServiceExploit < ExploitFramework::ModuleBase
  self.module_info = {
    name: 'vulnerable_service_overflow',
    description: 'Stack buffer overflow in vulnerable service',
    author: 'Security Researcher',
    platform: ['linux'],
    architecture: ['x86'],
    session_type: 'shell',
    targets: [
      { name: 'Automatic', auto: true },
      { name: 'Custom Build', offset: 112, ret_addr: 0xbffff7d0 }
    ]
  }

  option :RHOST, required: true, description: 'Target host'
  option :RPORT, required: false, default: 9999, description: 'Target port'
  option :LHOST, required: true, description: 'Listener address'
  option :LPORT, required: false, default: 4444, description: 'Listener port'

  register_as('exploits/linux/misc/vulnerable_service')

  def run
    # Exploit implementation
    puts "Exploiting #{@options[:RHOST]}:#{@options[:RPORT]}"
  end
end

# Usage
modules = ExploitFramework.find_modules(platform: 'linux')
exploit =
↪  ExploitFramework.instantiate('exploits/linux/misc/vulnerable_service',
  RHOST: '192.168.1.100', LHOST: '192.168.1.50')
exploit.run
```

This pattern demonstrates dynamic module registration, metadata-driven discovery, and configuration validation that underlies professional exploit frameworks. Modules declare their capabilities declaratively, the framework handles loading and lifecycle management, and users interact through a consistent interface regardless of the underlying implementation.

Dynamic method generation can create specialized handlers at runtime:

```ruby
module ProtocolHandlers
  # Generate parsing methods from a protocol specification
  def self.define_parser(module_name, fields)
    mod = Module.new
    module_name.to_s.split('::').reduce(Object) { |parent, name|
      parent.const_set(name, mod) unless parent.const_defined?(name)
      parent.const_get(name)
    }

    fields.each do |field|
      name = field[:name]
      offset = field[:offset]
      type = field[:type]
      size = field[:size]

      # Generate a reader method for this field
      mod.define_method("read_#{name}") do |data|
        raise ArgumentError, "Insufficient data" unless data.bytesize >= offset + size

        case type
        when :uint8 then data[offset].ord
        when :uint16_be then data[offset, 2].unpack1('n')
        when :uint16_le then data[offset, 2].unpack1('v')
        when :uint32_be then data[offset, 4].unpack1('N')
        when :uint32_le then data[offset, 4].unpack1('V')
        when :string then data[offset, size].gsub(/\x00/, '')
        when :bytes then data[offset, size]
        end
      end
    end

    # Generate a builder method
    mod.define_method(:build) do |field_values|
      buffer = ''.b
      fields.each do |field|
        value = field_values[field[:name]]
        case field[:type]
        when :uint8 then buffer << [value].pack('C')
        when :uint16_be then buffer << [value].pack('n')
        when :uint16_le then buffer << [value].pack('v')
        when :uint32_be then buffer << [value].pack('N')
        when :uint32_le then buffer << [value].pack('V')
        when :string, :bytes then buffer << value.ljust(field[:size], "\x00")[0, field[:size]]
        end
      end
      buffer
```

```
    end

    mod
  end
end

# Define a parser from specification
CustomProtocol = ProtocolHandlers.define_parser('CustomProtocol', [
  { name: :magic, offset: 0, type: :uint16_be, size: 2 },
  { name: :version, offset: 2, type: :uint8, size: 1 },
  { name: :type, offset: 3, type: :uint8, size: 1 },
  { name: :length, offset: 4, type: :uint16_be, size: 2 },
  { name: :payload, offset: 6, type: :bytes, size: 256 }
])

# Use generated methods
parser = CustomProtocol.new
data = "\xAB\xCD\x01\x03\x00\x08hello!"
puts parser.read_magic(data)      # => 43981 (0xABCD)
puts parser.read_type(data)       # => 3
puts parser.read_payload(data)    # => "hello!"
```

This pattern generates parsing and building methods from a declarative protocol specification, eliminating boilerplate code and ensuring consistency between field definitions and accessors. It is particularly valuable when working with many different binary protocols.

Testing Patterns for Security Tools

Security tools require rigorous testing because incorrect behavior can lead to false positives that waste analyst time, false negatives that miss real vulnerabilities, or unintended impact on target systems. The following patterns demonstrate testing approaches specific to security tooling.

Unit tests for parsing logic should cover valid inputs, edge cases, and malformed data:

```ruby
require 'minitest/autorun'
require_relative '../lib/packet_parser'

class TestIpv4Parser < Minitest::Test
  def test_parse_valid_header
    # Valid IPv4 header with known values
    header = [
      0x45,           # Version 4, IHL 5
      0x00,           # DSCP/ECN
      0x003C,         # Total length 60
      0x1234,         # Identification
      0x4000,         # Don't fragment
      0x40,           # TTL 64
      0x06,           # Protocol TCP
      0x0000,         # Checksum (to be calculated)
      192, 168, 1, 1, # Source IP
      10, 0, 0, 1     # Destination IP
    ].pack('CCnnnnCC CCCC')

    result = PacketParsers::Ipv4Packet.parse(header)

    assert_equal(4, result[:version])
    assert_equal(60, result[:total_length])
    assert_equal('192.168.1.1', result[:src_ip])
    assert_equal('10.0.0.1', result[:dst_ip])
  end

  def test_reject_invalid_version
    header = "\x05" + ("\x00" * 19)   # Version 5 is invalid
    assert_nil(PacketParsers::Ipv4Packet.parse(header))
  end

  def test_reject_short_data
    header = "\x45\x00"               # Too short for valid header
    assert_nil(PacketParsers::Ipv4Packet.parse(header))
  end

  def test_parse_with_options
    # Header with options (IHL > 5)
    header = [
      0x48,           # Version 4, IHL 8 (32 bytes)
      0x00,
      0x0020,
      0x1234,
      0x4000,
      0x40,
      0x06,
      0x0000,
      192, 168, 1, 1,
      10, 0, 0, 1
```

```
    ].pack('CCnnnnnCC CCCC') + ("\x00" * 12)   # Options padding

    result = PacketParsers::Ipv4Packet.parse(header)
    assert_equal(32, result[:ihl])
  end
end
```

Integration tests should verify end-to-end behavior against controlled targets:

```
require 'minitest/autorun'
require 'socket'
require_relative '../lib/scanner'

class TestTcpScanner < Minitest::Test
  def setup
    # Start a test TCP server on a random port
    @server = TCPServer.new('127.0.0.1', 0)
    @port = @server.addr[1]
    @thread = Thread.new do
      loop do
        begin
          client = @server.accept
          client.close
        rescue IOError
          break
        end
      end
    end
    sleep 0.1   # Allow server to start
  end

  def teardown
    @server.close rescue nil
    @thread.kill rescue nil
    @thread.join rescue nil
  end

  def test_detects_open_port
    scanner = TcpScanner.new('127.0.0.1', timeout: 2)
    result = scanner.check_port(@port)
    assert_equal(:open, result)
  end

  def test_detects_closed_port
    # Use a port unlikely to be in use
    scanner = TcpScanner.new('127.0.0.1', timeout: 1)
    result = scanner.check_port(59999)
    assert_equal(:closed, result)
```

```
  end

  def test_handles_timeout
    # Use an unreachable address that will timeout
    scanner = TcpScanner.new('10.255.255.1', timeout: 1)
    result = scanner.check_port(80)
    assert_includes([:filtered, :unknown], result)
  end
end
```

Fuzzing the tool itself ensures it handles malformed input gracefully:

```
require 'minitest/autorun'
require_relative '../lib/parser'

class TestParserRobustness < Minitest::Test
  def test_handles_random_binary_input
    # Parser should not crash on random data
    100.times do
      random_data = SecureRandom.bytes(rand(1..4096))
      begin
        result = MyProtocolParser.parse(random_data)
        # Result may be nil for invalid data, but should not raise
      rescue => e
        flunk "Crashed on random input: #{e.class} - #{e.message}"
      end
    end
  end

  def test_handles_edge_case_lengths
    # Test boundary conditions
    [0, 1, 7, 8, 9, 255, 256, 257, 65535, 65536].each do |length|
      data = "\x41" * length
      begin
        MyProtocolParser.parse(data)
      rescue ArgumentError => e
        # Expected for invalid data
      rescue => e
        flunk "Unexpected error with length #{length}: #{e.class}"
      end
    end
  end

  def test_handles_null_bytes_everywhere
    data = "\x00" * 1024
    result = MyProtocolParser.parse(data)
    # Should handle gracefully, not crash or hang
    assert(result.nil? || result.is_a?(Hash))
  end
end
```

These testing patterns ensure security tools are robust against the unpredictable inputs they encounter in real engagements: malformed packets, unexpected responses, network errors, and adversarial data designed to crash or confuse parsers.

With these fundamentals established, you have the foundation to build serious security tooling in Ruby. The next chapter applies these skills to network scanning, implementing discovery tools that form the basis of almost every penetration testing engagement.

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