Investigating the Ecosystem of Offensive Information Security Tools

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Abstract—The internet landscape is growing and at the same time becoming more heterogeneous. Services are performed via computers and networks, critical data is stored digitally. This enables freedom for the user, and flexibility for operators. Data is easier to manage and distribute. However, every device connected to a network is potentially susceptible to cyber attacks. Security solutions, such as antivirus software or firewalls, are widely established. However, certain types of attacks cannot be prevented with defensive measures alone. Offensive security describes the practice of security professionals using methods and tools of cyber criminals. This allows them to find vulnerabilities before they become the point of entry in a real attack. Furthermore, following the methods of cyber criminals enables security professionals to adapt to a criminal’s point of view and potentially discover attack angles formerly ignored. As cyber criminals often employ freely available security tools, having knowledge about these provides additional insight for professionals. This work categorises and compares tools regarding metrics concerning maintainability, usability and technical details. Generally, several well-established tools are available for the first phases, while phases after the initial breach lack a variety of tools.

Index Terms—Security Assessment, Penetration Testing, Security Tools, Information Security, Survey

I. INTRODUCTION

The Internet of Things (IoT) provides a number of benefits, to consumers as well as business organisations. Flexibility and ease of use, coupled with low management overhead and cost make it a desirable concept. Smart cities, for example, can benefit from IoT solutions [1], as well as cloud applications [2]. For business organisations, logistics and asset management can be aided by the IoT [3]. The IoT is characterised by its heterogeneity, as an abundance of different devices can constitute an IoT. Communication as well as embedded computation capabilities mark the common denominator on which IoT devices and networks depend. While these features are a given in the age of constant mobile connectivity and open Wireless Local Area Networks (WLANs), they also constitute the vulnerabilities of IoT networks. Being connected to networks leads to an increased attack surface. Furthermore, IoT devices are often cheap and manufactured in large numbers for short periods of time, until they become obsolete. After that, newer versions are produced, often for small prices. Consequently, re-use of hard- and software as well as low effort in programming contribute to insecure operating conditions [4]. The IoT is but a part of the development towards increased connectivity that inherently carries higher risks of cyber attacks. Botnets targeting IoT devices, such as Mirai [5], industrial environments falling prey to attackers, such as the power grid in the Ukraine in December 2015 [6], and ransomware attacks on healthcare infrastructure [7] and consumers [8] alike show the need for increased automated security in this brave new digital world. As the networking paradigms are shifting from classic home and office networks to heterogeneous ad hoc networks, security solutions have to adapt as well [9]. Offensive security measures become an administrators friend to discover vulnerabilities along the attack phases. By preemptive security, such as vulnerability checking, threats can be mitigated before an attacker can exploit them. These capabilities are more relevant in the heterogeneous environments presented today. Furthermore, an insight regarding methods as well as tools of cyber criminals is becoming crucial for Information Technology (IT) security professionals. Since criminals often rely on publicly available tools, an understanding of those allows security professionals to gain insight about the threat potential and possible attack vectors. Furthermore, if IT security professionals adapt to the methodology of a cyber criminal, they obtain a new understanding of attacking a system, potentially allowing for a more suited defense against attacks. Additionally, any vulnerability
found by methods and tools of attackers is a vulnerability that can be mitigated before a real attack occurs. The contribution of this work is

- the identification and collection of the most well-known and used open source security assessment tools and
- the mapping of these tools to well-established attack models and
- the analysis, comparison and discussion of the capabilities of these tools.

The remainder of this work is structured as follows. The state of the art is presented in Section II. The methodology underlying this paper is introduced in Section III. The tools are introduced and evaluated in Section IV. A conclusion is drawn in Section V.

II. STATE OF THE ART

There is an abundance in literature regarding tools for offensive security purposes, in numerous blogs, but also in specialist books. However, an objective indication why the tools were chosen to be presented is not provided. Either they are used and recommended by the author, who usually is a security professional that has built a tool-box for themselves. Or the tools are contained in a suite, such as Kali Linux [10]. VeLü presents the usage of Kali Linux for penetration testing in his book, discussing the tools he deems most relevant [11]. Oakley introduces red teeming in his book, where tools are introduced in the respective stages based on experience of the author [12]. Kim presents practical penetration testing with the tools chosen in a similar fashion [13]. Forshaw reduces the focus to tools for attacking network protocols, thus setting a scope [14]. However, the tools chosen are derived from his long experience. In general, it is beneficial to have tools introduced by professionals with a long experience in the fields, as they took a long time to chose the right tool-box and become acquainted with it. In this work, however, the focus is on creating tangible, objective criteria for rating offensive security tools.

III. METHODOLOGY

This section presents the methodology on which this work is founded. First, definitions of the terms are presented, after that, the sources from which the tools are collected. Furthermore, the scope of tools and applications is discussed, a metric for attack stages is presented as well as the feature criteria of the tools.

A. Definitions

This paragraph presents the definitions of terms used in this work that are underlying to the evaluation.

Offensive information security: Often called red teeming or penetration testing. It is a concept that describes using tools and methods of an attacker to detect security vulnerabilities which then can be fixed before an attacker can exploit them.

Tool: Finding a definition of the term tool in the context of software is exceedingly difficult. For this work, a tool is defined as a software program that can be used as such without further software, except for operating system and corresponding environment. A tool can consist of related parts that could be used in a stand-alone fashion, but are distributed and commonly used together as they follow purposes along the path of a security assessment.

Freeware: In the context of this work, this term describes tools which can be obtained by private persons and professionals alike free of charge. The free usage is not limited regarding the time of usage, so trial versions of commercial software are not considered. They are not specific to organisations.

Enterprise networks: Consisting of IT infrastructures, such as computers and servers. Specifically excluded are Operation Technology (OT) environments as found in industrial environments.

B. Data Sources

As the collection of exhaustive, consistent lists of security tools with their attribution to a specific attack phase is difficult, several sources were considered when identifying tools to evaluate in this work. First, the literature presented in Section II was used to extract the tools the authors used. Second, comprehensive lists that can be found online were employed. The nmap project [15] provides a list of security tools, called sectools [16]. Furthermore, r0lan provides an overview of tools that is attributed to the phases they are used in [17]. From these sources, the most relevant tools were extracted. Third, well-known security distributions such as Kali [10] and Parrot [18] Linux contain the tools that are most established in the security community.

C. Scope

The scope of this work are enterprise networks as discussed in Section III-A, consisting of computers, servers and auxiliary devices. Furthermore, the scope regarding the tools is limited on tools with a security focus. Since there is a trend in security research as well as cyber criminals to use tools that are already installed on the target machine for exploitation purposes, many tasks in security assessment can be performed without security-specific tools. This technique is called living off the land. An example is the use of Microsoft PowerShell for enumerating users and directories.

D. Attack Metrics: MITRE ATT&CK

The MITRE ATT&CK matrix [19] was developed based on the well-established Lockheed Martin Cyber Kill Chain [20]. Both aim at splitting a cyber attack into distinct phases during which an attacker follows a certain goal. This is used to aid in comprehending the objectives of an attack and ultimately mitigating it. The structure of the MITRE ATT&CK model is shown in Figure 1. Each of these phases requires a different set of tools, so the aim of this work is mapping tools to these phases as discussed in Section IV. The phases used in the MITRE ATT&CK Enterprise matrix are as follows, with the description according to the MITRE-homepage [19].

Reconnaissance: The phase during which an adversary collects information about the target. Generally, reconnaissance
techniques are categorised in active, i.e. with the adversary interacting with the target system in an unexpected way, and passive, i.e. the adversary not directly interacting with the target system.

Resource Development: The adversary is obtaining resources that can aid in attacking the system, such as accounts, systems, and other capabilities. The resources might be used in later phases, such as Command and Control (C&C).

Initial Access: The adversary attempts to gain an initial foothold on the target system. This is the first phase with direct adversarial action on the target.

Execution: The adversary executes malicious code on the target system. This code execution usually follows an underlying goal. Often, on-board capabilities of the target system, such as compilers and interpreters, aid in the execution of malicious code.

Persistence: The phase in which the adversary aims to secure the foothold. Persistence allows re-entry and access to the system after the adversary logged out or the system rebooted.

Privilege Escalation: In this phase, the adversary aims at obtaining higher privileges. Often, certain users are restricted from performing security-critical tasks, and the first foothold was performed with such restricted accounts. Elevating privileges allows the adversary to perform a wider variety of actions.

Defense Evasion: After gaining access and elevating the privileges, the adversary actively evades detection by Intrusion Detection System (IDS). Obfuscation of the tools as well as deactivation of security measures are performed in this phase.

Credential Access: The adversary aims at stealing account credentials for further use and to aid in following phases.

Discovery: In this phase, the adversary is gaining information about the environment in which the target system is located. This includes machines and services, accounts and users.

Lateral Movement: In this phase, the adversary is moving through the target environment and infecting new systems. Often, the foothold with which entry to the network was gained does not contain the desired target, so lateral movement is necessary to reach devices that are not directly reachable from the outside.

Collection: In this phase, the adversary gathers the desired information from the target machine.

Command and Control (C&C): In this phase, the adversary executes control over the targeted systems and communicates with them.

Exfiltration: The phase in which the adversary attempts to steal and obtain data without the owner of the target system noticing. The data has to be sent in a fashion that does not cause suspicion.

Impact: In this phase, the adversary maliciously impacts the target system by destroying or restricting its functionality. This activity can easily be detected by the owner of the system.

E. Tool Features

In order to evaluate and rate the tools, a metric needs to be defined. This metric should contain tangible, verifiable features. The features used in this work are listed as follows:

- Actively maintained: This feature is evaluated according to the latest release and the average number of releases per year. Actively maintained tools provide bug fixes and the integration of new features and protocols as well as more active support.
- Usage: This feature discusses the licence a tool is published under, the support a user can expect and whether or not a paid version of the tool is available.
- Technical: This feature describes the interface of the tool for a user as well as the programming language the tool is programmed in. This is important as the way of interaction can make a tool more difficult or easier to apply, while the programming language in open source

### Fig. 1. MITRE ATT&CK Model

| Pre-attack       | Enterprise Attack                  | Post-attack                   |
|------------------|------------------------------------|------------------------------|
| 1. Reconnaissance| 3. Initial Access                  | 11. Collection               |
| 2. Resource Devel.| 4. Execution                       | 12. Command and Control (C&C)|
|                  | 5. Persistence                     | 13. Exfiltration             |
|                  | 6. Privilege Escalation            | 14. Impact                   |
|                  | 7. Defense Evasion                 |                              |
|                  | 8. Credential Access               |                              |
|                  | 9. Discovery                       |                              |
|                  | 10. Lateral Movement               |                              |
|                  |                                    |                              |
tools describes whether or not a user could adapt and extend the tool. These features allow an assessment of the tools according to several dimensions. It can be derived if the tool is actively developed and likely to be adapted to new technologies. Furthermore, the capabilities for extending and embedding the tool into a toolchain can be obtained from these features.

IV. Analysis

In this section the relevant tools are identified and the metric is applied for comparison. Then, the results for the comparison are discussed.

A. Identification

For the evaluation, well-established, commonly used security tools tailored for each of the phases as presented in Section III-D were identified, collected and compared. As it is not trivial to find an exhaustive overview of security tools, several sources were used to obtain information. Apart from books presented in Section II, web resources were considered as well. The nmap network scanner [15] hosts a list of security tools [16]. Every tool that fits the scope of this work in the top 50 tools of the sectools-list is evaluated in this work. Thus, a good coverage of relevant tools is expected. Furthermore, r0lan provides an overview of tools commonly used for the individual phases [17]. Among links to tools, r0lan provides an abundance of sources that describe methods rather than tools, and information how to employ tools without a first focus on security, such as PowerShell, to perform security-relevant tasks. From these sources, the most used tools were extracted. They are listed in Table I categorised according to the phases of the MITRE ATT&CK metric.

B. Comparison

The tools identified in the previous subsection are listed in Table I with the criteria alongside which they are evaluated. It can be seen that the first stage has the most extensive number of tools available. Most tools are still actively maintained, meaning new releases are provided at the time of this work. However, a few tools, empire [42] and Responder [35], are indicated to be deprecated. Furthermore, several tools, Veil-Evasion [32], Veil-Pillage [41], shellter [33], windows-privesc-check [38], and Cloakify-Facory [44] have their latest releases older than a year, which indicates limited maintenance of these tools. Since most versions are free, do not have a paid version and are developed by members of the community, most support is provided in terms of forums or mailing lists. Every tool provides a Command Line Interface (CLI), some tools additionally provide a Graphical User Interface (GUI) or Web-based User Interface (WUI). The CLI-capabilities allow for the tool to be integrated into toolchains, with the output being piped into other applications. Furthermore, since a number of tools is written in Python, integration of the source code into user tools is easily possible. All tools, except for Maltego [22] and shelter [33], provide their code for a user to extend and adapt.

C. Discussion

The features based on which the tools are evaluated are intended to provide information for a user to pick a tool that fits her need. Furthermore, the quality and suitability of tools, as well as their versatility is evaluated. For example, mst [27] can be used in nine of 14 phases, making it the most versatile and powerful tool in this comparison. This is due to the toolbox-approach that allows mst to load different modules for specific tasks. Furthermore, research underlying this work shows that some phases have significantly more tools created for them than others. For example, the execution phase does not have a singular tool dedicated to it. Instead, board measures of the target system are used, or tools that are not security-specific, such as web servers or communication tools. Furthermore, the variety of tools, especially in the reconnaissance-phase, is an indicator of knowledge and experience an IT security professional should have.

V. Conclusion

This work highlights a few insights. First, there is a plethora of IT security assessment tools available that can be used by professionals as well as cyber criminals. Being aware of these tools and gaining familiarity is therefore crucial for security experts. The majority is freely available and actively maintained, with examples and help readily available. Second, some phases have more tools dedicated to them than others. Reconnaissance has an abundance of publicly available tools solely for the purpose of gathering information that can be used to exploit a target. The initial access phase has several tools as well, as attacks can be aimed at different types of targets. For example, there is a number of tools to attack websites, a different set of tools for attacking databases and further tools for other attack vectors. Understanding these as a professional is crucial for hardening any potential attack vector and preventing attacks from happening in the first place. Other phases rely on tools already available on the target systems, such as programming compilers and interpreters, PowerShell, netcat and other tools. These can be misused to perform malicious activity, a fact of which IT security professionals need to be aware of as well. This living off the land can be discussed in a future work, as there is an abundance of tools that can be misused under the right circumstances. Furthermore, tools for cracking passwords and for monitoring and exploiting wireless devices were not considered in this work, as they would exceed the scope. An exhaustive overview of such tools can be discussed in a future work as well. This work shows that gaining insight about attacks is crucial for defense. A method commonly used to obtain information about attackers, their tools and aims is honeypots [45], [46]. Attributing attackers and attacks is similarly important in order to implement counter measures suitable for the attacks which are identified as most likely or having most impact [47]. In general, detecting attacks is becoming increasingly difficult due to the changes in

1These tools are indicated to be no longer actively maintained.
IT infrastructure. Using context information, employing novel machine learning approaches and creating and providing data to train IDSs on are required to secure IT network against current and future attacks.

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| Tools                      | Releases          | Usage aspects          | Technical aspects          |
|---------------------------|-------------------|------------------------|---------------------------|
|                           | First | p.a. | Latest | Licence | Supp. | Paid | Interf. | Lang. |
| Reconnaissance            |       |      |        |         |       |      |         |       |
| nmap 15                   | 1997  | 10   | 2020   | Nmap Publ. Src. | Forum | no   | GUL, CLI | Lua, C, C++, Python, Shell |
| OpenVAS 21                | 2006  | 9    | 2020   | GNU GPLv2 2.0   | Forum | no   | GUL, CLI | C, NASL, Yacc, Shell, C++ |
| Maltego 22                | 2007  | 11   | 2020   | Proprietary     | Forum | yes  | GUI     | Java |
| Shodan 23                 | 2009  | n/a  | 2020   | Proprietary     | Forum | yes  | WUL, CLI | n/a  |
| TheHarvester 24           | 2011  | 3    | 2020   | GPLv2           | Forum | no   | CLI     | Python |
| Initial Access            |       |      |        |         |       |      |         |       |
| Aircrack-ng 25            | 2006  | 2    | 2020   | GPLv2          | Forum | no   | GUL, CLI | C, M4, C#, Shell, Python, Roff |
| GoPhish 26                | 2013  | 2    | 2020   | MIT            | GitHub| no   | WUL, CLI | Go, JavaScript |
| msf 27                    | 2014  | 2    | 2020   | Apache 2.0     | Forum | no   | GUL, CLI | C++ |
| Persistence               |       |      |        |         |       |      |         |       |
| C99 webshell 28           | 2005  | n/a  | n/a    | n/a          | n/a   | n/a  | CLI     | PHP |
| Reptile 29                | 2018  | 1    | 2020   | n/a          | n/a   | n/a  | CLI     | C, C++, Yacc, Perl, Shell |
| SharPerst 30              | 2019  | 1    | 2020   | Apache 2.0    | Forum | no   | CLI     | C#  |
| Privilege Escalation      |       |      |        |         |       |      |         |       |
| searchsploit 31           | 2014  | n/a  | 2020   | GPL-2.0       | Forum | no   | CLI     | C, Python, Ruby, Perl, PHP |
| msf 27                    | 2014  | 2    | 2020   | Apache 2.0    | Forum | yes  | GUL, CLI | C++ |
| Defense Evasion           |       |      |        |         |       |      |         |       |
| vein-evasion 32           | 2015  | 21   | 2016   | GPL-3.0       | Forum | no   | CLI     | Python, C, Shell, C++ |
| shelter 33                | 2014  | 14.7 | 2017   | special       | Forum | yes  | CLI     | n/a  |
| msf 27                    | 2014  | 2    | 2020   | Apache 2.0    | Forum | yes  | GUL, CLI | C++ |
| Credential Access         |       |      |        |         |       |      |         |       |
| LaZange 34                | 2015  | 3.6  | 2019   | LGPL-3.0      | Forum | no   | CLI     | Python |
|Responder 35               | 2014  | 7.5  | 2014   | GPL-3.0       | Forum | no   | CLI     | Python |
| Mimikatz 36               | 2007  | 0.5  | 2020   | CC-BY 4.0     | Forum | no   | CLI     | C    |
| msf 27                    | 2014  | 2    | 2020   | Apache 2.0    | Forum | no   | GUL, CLI | C++ |
| Discovery                 |       |      |        |         |       |      |         |       |
| linuxprivchecker 37       | 2015  | n/a  | 2020   | -            | Forum | no   | CLI     | Python |
| windows-privesc-check 38  | 2010  | n/a  | 2015   | GPL-2.0       | Forum | no   | CLI     | Python |
| Bloodhound 39             | 2016  | 7    | 2020   | GPL-3.0       | Forum | no   | CLI     | Python |
| Lateral Movement          |       |      |        |         |       |      |         |       |
| Mimikatz 35               | 2007  | 0.5  | 2020   | CC-BY 4.0     | Forum | no   | CLI     | C    |
| Rubeus 40                 | 2018  | n/a  | 2020   | BSD 3-clause  | Forum | no   | CLI     | C#  |
| msf 27                    | 2014  | 2    | 2020   | Apache 2.0    | Forum | yes  | GUL, CLI | C++ |
| Collection                |       |      |        |         |       |      |         |       |
| Veil-Pillage 41           | 2014  | n/a  | 2015   | GPL-3.0       | Forum | no   | CLI     | PowerShell, Python |
| msf 27                    | 2014  | 2    | 2020   | Apache 2.0    | Forum | yes  | GUL, CLI | C++ |
| Command and Control       |       |      |        |         |       |      |         |       |
| empire 42                 | 2015  | 4.33 | 2018\(1\) | BSD 3-clause | Forum | no   | CLI     | PowerShell, Python |
| msf 27                    | 2014  | 2    | 2020   | Apache 2.0    | Forum | yes  | GUL, CLI | C++ |
| Exfiltration              |       |      |        |         |       |      |         |       |
| DET 43                    | 2016  | n/a  | 2019   | MIT           | Forum | no   | CLI     | Python |
| Cloaked Factory 44         | 2018  | 4    | 2018   | MIT           | Forum | no   | GUL, CLI | Python |
| msf 27                    | 2014  | 2    | 2020   | Apache 2.0    | Forum | yes  | GUL, CLI | C++ |
| Impact                    |       |      |        |         |       |      |         |       |
| Veil-Pillage 41           | 2014  | n/a  | 2015   | GPL-3.0       | Forum | no   | CLI     | PowerShell, Python |
| msf 27                    | 2014  | 2    | 2020   | Apache 2.0    | Forum | yes  | GUL, CLI | C++ |