Impact assessment for vulnerabilities in open-source software libraries

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Software applications integrate more and more open-source software (OSS) to benefit from code reuse. As a drawback, each vulnerability discovered in bundled OSS potentially affects the application. Upon the disclosure of every new vulnerability, the application vendor has to decide whether it is exploitable in his particular usage context, hence, whether users require an urgent application patch containing a non-vulnerable version of the OSS. Current decision making is mostly based on high-level vulnerability descriptions and expert knowledge, thus, effort intense and error prone. This paper proposes a pragmatic approach to facilitate the impact assessment, describes a proof-of-concept for Java, and examines one example vulnerability as case study. The approach is independent from specific kinds of vulnerabilities or programming languages and can deliver immediate results.

1 Introduction

The adoption of open-source software (OSS) in the software industry has continued to grow over the past few years and many of today’s commercial products are shipped with a number of OSS libraries. Vulnerabilities of any of these OSS libraries can have considerable consequences on the security of the commercial product that bundles them. The relevance of this problem has been acknowledged by OWASP which included “A9-Using Components with Known Vulnerabilities” among the Top-10 security vulnerabilities in 2013 [1]. The disclosure in 2014 of vulnerabilities such as Heartbleed[1] and ShellShock[2] contributed even further to raise the awareness of the problem.

Despite the deceiving simplicity of the existing solutions (the most obvious being: update to a more recent, patched version), OSS libraries with known vulnerabilities are found to be used for some time after a fixed version has been issued [2]. Updating to a more recent, non-vulnerable version of a library represents a straightforward solution at development time. However, the problem can be considerably more difficult to handle when a vulnerable OSS library is part

[1] http://heartbleed.com/
[2] https://shellshocker.net/
of a system that has already been deployed and made available to its users. In the case of large enterprise systems that serve business-critical functions, any change (including updates) may cause system downtime and comes with the risk that new unforeseen issues arise. For this reason, software vendors need to carefully assess whether an application requires an urgent application patch to update an OSS library, or whether the update can be done as part of the application’s regular release cycle.

The key question that vendors have to answer is whether or not a given vulnerability, that was found in an OSS library used in one of their products, is indeed exploitable given the particular use that such a product makes of that library [3]. If the answer is positive, an application patch must be produced, and its installation needs to be triggered for all existing deployments of the application. If the answer is negative, the library update can be scheduled as part of the regular release cycle, without causing extra efforts related to urgent patch production by vendors and patch installation by users. The current practice of assessing the potential impact of a vulnerability in OSS is time-consuming and error-prone. Vulnerabilities are typically documented with short, high-level textual descriptions expressed in natural language; at the same time, the assessment demands considerable expert knowledge about the application-specific use of the library in question. Consequences of wrong assessments can be expensive: if the developer wrongly assesses that a given vulnerability is not exploitable, application users remain exposed to attackers. If she wrongly judges that it is exploitable, the effort of developing, testing, shipping, and deploying the patch to the customers’ systems is spent in vain.

This paper presents a pragmatic approach that contributes to simplify the decision making. We do so by automatically producing (whenever possible) concrete evidences supporting the case for urgent patching. More specifically we assess whether an application uses (portion of) a library for which a security fix has been issued in response to a vulnerability. The approach seamlessly integrates in the usual development workflow without requiring additional effort from developers and is independent of programming languages and vulnerability types.

The paper is organized as follows. Section 2 presents our approach and a generic architecture that supports it. Section 3 describes our prototypical implementation and its application to a case study. Section 4 outlines observations regarding the integration and quality of information stemming from different sources. Section 5 presents related literature. Section 7 concludes the paper.

2 Approach

Concept

In order to assess whether or not a given vulnerability in an OSS library is relevant for a particular application, we consider the corresponding security patch, i.e., the set of changes performed in the source code of the library in response to the vulnerability. Our approach is than based on the following pragmatic assumption:

(A1) Whenever an application that includes a library (known to be vulnerable) executes a fragment of the library that would be updated in a security patch, there exists a significant risk that the vulnerability can be exploited.

The underlying idea is that if programming constructs that would be changed by the patch are used, than the application is using code involved in the vulnerable part of the library. Therefore, we collect execution traces of applications, and compare those with changes that would be introduced by the security patches of known vulnerabilities in order to detect whether “critical” library code is executed. Figure 1 illustrates the approach graphically: The change-list $C_{ij}$ represents the set of all programming constructs of OSS component $i$ that were modified, added or deleted as part of the security patch for vulnerability $j$. Change-lists can be computed as soon as a security patch has been produced for a vulnerability. Patches can be assumed available at the time vulnerabilities become public in the case of responsible disclosure. The trace-list $T_a$ represents the set of all programming constructs, either part of application $a$ or any of its bundled libraries, that were executed at least once during the runtime of application $a$. The collection of traces can be done at many different times, starting from unit tests until the application is deployed for productive use.

The intersection $C_{ij} \cap T_a$ comprises all those programming constructs that are both subject to security patch $j$ and have been executed in the context of application $a$. Following assumption (A1), a non-empty intersection $C_{ij} \cap T_a$ indicates that a newly disclosed vulnerability is highly relevant, due to the risk of exploitability. An empty intersection, on the other hand,

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3 We use the language-agnostic term “programming construct” to refer to structural elements such as methods, constructors, functions and so on.
hand, may result from insufficient coverage, hence, it does not automatically render a vulnerability irrelevant. Coverage is described by the intersection of the sets $T_a \cap S_a$, where $S_a$ is the set of all programming constructs belonging to the application itself. The larger the intersection, the better the coverage, and the greater the confidence that constructs belonging to $C_{ij}$ cannot be reached.

Library versions can be disregarded, provided that the traces were collected before the release of a security patch and that all existing library versions are affected by the vulnerability. In other cases (in particular if traces are more recent than a patch, and if the corresponding constructs exist in both vulnerable and patched library version) one has to identify and compare the version of the library producing the trace with the ones affected by the vulnerability.

Our approach is not immune to reporting false-positives and false-negatives. False-positives occur if a vulnerability is not exploitable despite a non-empty intersection $C_{ij} \cap T_a$, which is due to the fact that exploitability can depend on many other conditions, e.g., the presence of sanitization techniques in the application or specific configuration settings. False-negatives occur if vulnerabilities are exploitable despite an empty intersection $C_{ij} \cap T_a$, which can result from insufficient coverage, a problem shared with many techniques relying on dynamic execution (as opposed to static analysis). The silver-lining is that the approach is entirely independent of programming languages or types of vulnerabilities and it can provide immediate results. Intuitively, we expect that developers are convinced to update a library when presented with a non-empty intersection $C_{ij} \cap T_a$, i.e., traces of programming constructs that are subject to a security patch. In any case, the information collected is valuable to simplify further analysis, complementing the high-level vulnerability description expressed in natural language in publicly available vulnerability databases, such as the National Vulnerability Database.

**Architecture.**

Figure 2 illustrates a generic architecture that supports our approach. Components depicted in white belong to the proposed solution and require an implementation, while components depicted in grey represent the solution’s environment. A specific implementation for Java and related tooling is described in Section 3.

The Assessment Engine on top is responsible for storing and aggregating the three sets of Figure 1. It also presents assessment results concerning the relevance of vulnerabilities to the security expert of the respective application.

The Patch Analyzer is triggered upon the publication of a new vulnerability for an open-source library. It interacts with the respective Versioning Control System (VCS), identifies all programming constructs changed to fix the vulnerability, and uploads their signatures to the central Assessment Engine. This change-list is built by comparing the vulnerable and patched revision of all relevant source code files of the library. The corresponding commit revisions can be obtained from the vulnerability database, searched in the commit log, or specified manually.

The Runtime Tracer collects execution traces of programming constructs, and uploads them to the central engine. This is achieved by injecting instrumentation code into all programming constructs of the application itself and all the bundled libraries. The instrumentation can be done dynamically, during the actual runtime, or statically, prior to the application’s deployment. The former can guarantee the tracing of all programming constructs used at runtime including, e.g., libraries included at runtime and parts of the runtime environment. Its major drawback is the impact on application startup, in particular if many contracts need to be loaded before the application becomes available to its users, as in the case of application containers. Static instrumentation does not impact the application startup time and can be used in cases where the runtime environment cannot be configured for dynamic instrumentation, e.g., in FaaS environments. However, it cannot guarantee the coverage of programming constructs used at runtime.

The Source Code Analyzer scans the source code of the application, identifies all its programming constructs and uploads their signatures as well as an application identifier to the central engine.

Note that the above-described components run at different points in time. Source Code Analyzer and Runtime Tracer are expected to run continuously during different phases of the application development lifecycle and their results are kept even after the release of the application to its customers. Once the Patch Analyzer is triggered, typically after the release of a patch for a vulnerable library, the assessment result is immediately available thanks to the comparison of the newly collected change-lists with the previously collected traces.
3 Proof-of-concept

This section describes our current implementation of the approach and the architecture presented in Section 2. We illustrate its application to CVE-2014-0050 as case study.

Implementation

The current prototype supports the assessment of vulnerabilities of Java components and is implemented by using technologies that can be seamlessly integrated in typical Java development and build environments based on Apache Maven.

The Assessment Engine is realized by means of a SAP Hana database where the change-list, trace-list and programming constructs are stored and manipulated. The results are accessible via a web frontend (see Figure 4).

The Patch Analyzer is implemented as a Java stand-alone application. It interacts with version control systems (VCS) (Git and Subversion in our current implementation) by means of the JGit and SVNKit Java libraries. Such libraries are used to retrieve the code for the patch and vulnerable revisions (i.e., the revision preceding the patched one). The ANTLR library is used for building the parse tree of the Java files to be compared in order to obtain the change-list.

The Runtime Tracer requires the injection of code into each programming construct of the application and its libraries. The instrumentation (both static and dynamic) is realized using Javassist. Dynamic instrumentation was found suitable for unit tests, executed by individual developers and during continuous integration. Static instrumentation is instead suited for integration and end-user acceptance tests performed on dedicated systems. In particular, if the application is deployed in application containers such as Apache Tomcat, static instrumentations allows to avoid the performance impact on startup time, which is caused by the significant number of classes loaded before the container and its application become available. Moreover, static instrumentation is also useful in case Java Runtime Environment (JRE) options cannot be accessed or changed to enable dynamic instrumentation, e.g., when using Platform as a Service (PaaS) offerings. In either cases, whenever the application is executed, the instrumentation code added is responsible for collecting and uploading traces to the

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4 http://eclipse.org/jgit/
5 http://svnkit.com/
6 http://www.antlr.org/
7 http://www.csg.ci.i.u-tokyo.ac.jp/~chiba/javassist/
central engine. Note that the collection and upload is only done upon the first invocation of the respective programming construct which significantly reduces the performance overhead. The limited impact on application performance has as goal to enable the trace collection during everyday testing activities.

The Source Code Analyzer is realized by means of a Maven plugin. As for the Patch Analyzer it uses the ANTLR library to parse the Java classes. The result is the collection of the signature of every programming construct belonging to the application itself. The Maven identifier (composed of group id, artifact id, and version) is used as identifier of the application to set the context for the analysis, i.e., it represents the application a to define the sets $S_a$ and $T_a$ of programming constructs and trace-list (see Figure 1).

**Case-study: CVE-2014-0050.**

The National Vulnerability Database (NVD) is a comprehensive, publicly available database for known vulnerabilities that are disclosed in a responsible manner, i.e., for which a patch has been made available at the time of the vulnerability publication. It also includes the information regarding affected products. In particular, the Common Vulnerabilities and Exposures (CVE) and Common Platform Enumeration (CPE) standards are used to identify the vulnerability and the affected products, respectively.

CVE-2014-0050 describes a vulnerability in Apache FileUpload as follows: “Multipart-Stream.java in Apache Commons FileUpload before 1.3.1, as used in Apache Tomcat, JBoss Web, and other products, allows remote attackers to cause a denial of service (infinite loop and CPU consumption) via a crafted Content-Type header that bypasses a loop’s intended exit conditions.”

Upon disclosure of the vulnerability, any developer using Apache FileUpload needs to judge whether her application is affected. Current practices require her to rely on the textual description for taking a decision. However, it is not straightforward to assess whether the Java class MultipartStream (referenced to in the description) is used in the scope of an application. In fact it may be used either directly (i.e., instantiated in the source code of the application) or indirectly within other classes of the libraries which are directly used.

The application used in our case study is a sample Web application, com.research.vulas:vlulas-testapp:0.1-SNAPSHOT, which performs various operations on compressed archives. Figure 3 shows assessment results for several vulnerabilities after the execution of both JUnit and integration tests of the Web application as well as the computation of change-lists. The first two vulnerabilities, including CVE-2014-0050, are marked as relevant because constructs part of the change-list (i.e., subject to the security patch) have been executed in its vulnerable version. CVE-2011-1498, CVE-2012-6153, and CVE-2014-3529 are marked as irrelevant since non-vulnerable releases of the respective libraries are used. For CVE-2014-3577 and CVE-2014-3574 the assessment result shows that the vulnerable release is used but no traces for the change-list were observed.

More in detail, the table at the bottom of Figure 3 shows the change-list $C_{ij}$ where $i$ is Apache FileUpload and $j$ the vulnerability CVE-2014-0050. In this case, the intersection $C_{ij} \cap T_a$ is not empty, but contains the constructor of the Java class MultipartStream. The exclamation mark in the “Traced” column highlights that its execution was observed at the time shown in the tooltip during application tests.

The Patch Analyzer computed the change-list using the URL of the VCS of Apache FileUpload and the revision number of the patch, which is provided by NVD in one of the references of CVE-2014-0050.

As the used programming construct in Figure 4 was modified as part of the patch (marked as MOD in the figure), it is present both in the vulnerable and patched version of the library. Moreover, the experiment was done for a rather old vulnerability, hence, the traces are more recent than the security patch itself. As a result, it is necessary to identify the version of the library in use, and compare it with the ones affected by the vulnerability.

This is preferably done by means of Maven identifiers and, if this is not possible, CPEs. In particular, we search the Maven Central repository (i.e., the default repository for dependency management with Maven) for the SHA-1 of the archive from which a class was loaded at runtime and, if a match is found, we obtain the version of the used library as well as the information about all existing versions.

The products affected by a vulnerability are identified by interacting with the VCS of the respective library. For that purpose, we analyze so-called tags, which are a common means for marking all those repository elements that constitute a given release.
Figure 3: Analysis overview for the sample application

— at least in case of the widely-used versioning control systems Apache Subversion and CVS. In more detail, we identify all tags applied prior to the security patch in question, and parse the Maven project files that existed at that time.

In case of VCS other than Apache Subversion and CVS, we resort to the NVD for establishing the affected versions of a given vulnerability. The NVD uses CPE names, mainly composed of the vendor, product and version information, to identify all affected products. In order to establish if the used library is affected by the CVE we check if its version is among those listed for the affected CPEs. In general, the use of CPE names is considered as a fallback only, since the matching of CPE vendor and product names to Maven identifiers is ambiguous (cf. Section 4).

Information about library releases is displayed in the upper table of Figure 4. It shows that the used library, i.e., apache commons_fileupload 1.2.2, is indeed affected by the vulnerability: there existed a corresponding tag that has been applied prior to the commit of the security fix. It also shows the latest, non-vulnerable release, i.e., apache commons_fileupload 1.3.1. By updating to the latest release, the risk of being vulnerable can be addressed.

Figure 4: Analysis details for CVE-2014-0050

As the web application of our case study runs within the Apache Tomcat application container, we opted for the static instrumentation in order to avoid the impact of dynamic instrumentation on the container’s initial startup time. The trace of the patched programming construct was collected by using integration tests on the interface for uploading files of the instrumented application. Intuitively, we perceive that unit and integration tests are complementary means for collecting traces. In particular, the focus of unit tests on the business logic of fine-granular components does not cover components involved in the application’s main I/O channels, many of which rely on OSS libraries, e.g., Apache FileUpload, HttpClient or Struts.

For CVE-2014-0050 an exploit exists as a Ruby script in the Exploit-DB, i.e., an archive of exploits for known vulnerabilities (http://www.exploit-db.com/exploits/31615/). By manually running it, we observed that assumption \((A1)\) of Section 2 holds in our case study, i.e., the vulnerability is exploitable in
the given application context even though only one programming construct belonging to the change-list has been executed.

Other than assessing vulnerabilities, the prototype offers two other views:

The first view shows all archives used by the application under analysis (cf. Figure 5), either because they have been declared using Maven or because they have been observed during application tests (i.e., classes where loaded from those archives). Archives whose SHA-1 is not known to the Maven Central are highlighted (commons-io-1.3.2.jar in the example), and so are archives that have not been declared but whose execution was observed during application tests. The former may indicate the use of a tampered archive, the latter bad development practice.

The second view displays the function coverage of application constructs as described in Section 2, aggregated on the level of Java packages (cf. Figure 6). Moreover, it shows the function coverage for archives used by the application, aggregated on archive level.

4 Data integration problems

Our approach requires the integration of information stemming from different sources, e.g., vulnerability databases, VCS for managing the code base of OSS, and public OSS repositories (e.g., Maven Central) in case of our Java prototype). During our experiments, we found that the integration is hindered by several problems, each one requiring ad-hoc, technology-specific solutions. Such problems hamper—in general—the automation of OSS vulnerability management.

Non-uniform reporting of products affected by a vulnerability.

The NVD uses the CPE standard for enumerating components affected by a vulnerability. In our experiments, we observed a non-uniform practice of assigning CPEs to vulnerabilities in OSS libraries. In some cases only the CPE of the respective library is mentioned. As an example, the affected components for CVE-2012-2098 are versions of Apache Commons Compress before 1.4.1.

cpe:/a:apache:commons-compress

In other cases also the CPEs of applications making use of the library are listed. This is the case for

11Algorithmic complexity vulnerability in the sorting algorithms in bzip2 compressing stream (BZip2CompressorOutputStream) in Apache Commons Compress before 1.4.1 allows remote attackers to cause a denial of service (CPU consumption) via a file with many repeating inputs.
CVE-2014-0050, whose affected components include not only Apache FileUpload,
cpe:/a:apache:commons_fileupload
but also several versions of Apache Tomcat,
cpe:/a:apache:tomcat
which is just one out of many applications using this library. As mentioned in the textual description of the CVE (cf. Section 3), JBoss Web, and other products are also affected, though, not listed as CPEs.

The above CPEs are written in the URI binding form. We made use of a subset of the supported fields, i.e., type a to denote an application, vendor apache, product commons-compress, commons_fileupload, and tomcat. It is important to notice that CPEs do not provide an immediate means to identify libraries.

**Vulnerability and dependency management make use of different naming schemes and nomenclatures.**

There exist many language-dependent technologies and nomenclatures for identifying libraries and managing dependencies at development and build time (e.g., Maven for Java), none of which maps straightforwardly to CPE. As an example consider the Apache HTTP Client library. Maven identifiers are of the form

```
GroupId=org.apache.httpcomponents
ArtifactId=httpclient
```

for each release as of 4.0. CVE-2012-6153 affects Apache Commons HttpClient before 4.2.3 and the CPEs listed as affected products are of the form

cpe:/a:apache:commons-httpclient

While a human can easily recognize the mapping, this is not the case for an automated solution. The problem is made even worse by the fact that Maven identifiers and CPEs may change for newer releases. As a matter of fact the syntax commons-httpclient that is used in the above CPE was also used as Maven group and artifact id for older releases (before 4.0).

Moreover, there exists no unambiguous, language-independent way for uniquely identifying libraries once they are bundled and installed as part of an application. Our prototype computes the SHA-1 of Java archives and performs a lookup in Maven central: an ad-hoc solution that fails if the bundled library has been compiled with a different compiler than the library available in the public repository.

**Vulnerabilities and VCS information of the respective security patch are not linked in a systematic and machine-readable fashion.**

The change-list computation requires as input the URLs of VCS and commit numbers. The Patch Analyzer of our prototype uses two strategies for discovering them: (i) pattern matching for identifying VCS information in CVE references and (ii) search for CVE identifiers in VCS commit logs. While successful in case of CVE-2014-0050 and many other vulnerabilities, they still represent ad-hoc solutions depending on the discipline of developers and the quality of CVE entries. In particular, both strategies are successful for CVE-2014-0050: (i) the VCS http://svn.apache.org/r1565143 is listed among the CVE references; (ii) the commit log for revision 1565143 contains the CVE identifier: Fix CVE-2014-0050. Specially crafted input can trigger a DoS if ... This prevents the DoS.

However in other cases different practices are used. As an example CVE-2012-2098 affecting Apache Commons Compress does not reference the VCS revision(s) fixing the vulnerability, nor the VCS commit log systematically references the CVE. In this example the revisions fixing the vulnerability are listed in a webpage of the Commons Compress project dedicated to security reports.

```http://commons.apache.org/proper/commons-compress/security.html```

**5 Related work**

With the increased adoption of open-source components in commercial products, the attention to the potential risks stemming from this practice has increased correspondingly. More specifically, the problem of evaluating the impact of vulnerabilities of open-source (and more generally, of third-party) components has attracted significant attention among researchers [4, 5] and practitioners [2, 12]. Several approaches tackle the problem of vulnerability impact assessment by examining the system statically, in order to determine a measure of risk, as in [6] where the authors consider the relation between the entry points of the subject system (the potential attack surface) and the attack target (the vulnerable code). Younis et. al [3], elaborating on that idea,
proposed a similar approach that also measures the ratio between damage potential and attack effort in order to estimate how motivated an attacker needs to be when targeting a particular point of the attack surface.

Our approach is complementary to these, in that our goal is to observe real executions of a system (as opposed to analyzing its structure and call graph) in order to determine whether actual executions were observed that touched a part of the code that is known to be vulnerable. Judging how likely is the exploitation of vulnerabilities that were not covered by concrete execution is not in the scope of this work (although we do plan to include that aspect in our future research).

Several tools have been proposed to help detect the use of vulnerable libraries, such as the OWASP Dependency-Check\(^\text{13}\) or the Victims Project\(^\text{14}\). Both support the check of whether a project depends on libraries for which there are any known, publicly disclosed, vulnerabilities. Similarly to ours, these tools are realized as Maven plugins to minimize the barrier to adoption. They differ from our approach because their goal is to identify whether a vulnerable library is included in a project, whereas we concentrate on detecting whether the vulnerable portion of the library can be actually executed as part of the container project, a question that is particularly relevant for released applications.

6 Future directions

Up to now, we have used the current implementation of our approach to a limited set of sample projects. The evaluation we could make was only preliminary, but the feedback we received from the early adopters of our tool (development units internal to our company) indicates clearly that the problem we are tackling is perceived as timely and extremely relevant in practice. That feedback also highlights the importance of several outstanding problems which demand further investigation. In this section we summarize the future directions of our research, which will be the topic of future works.

Accuracy of the analysis

One inherent limitation of our approach, as most existing approaches to vulnerability analysis, is that it is neither sound nor complete. In particular, the reliability of our assessment is heavily dependent on the coverage achieved through executions (e.g., obtained by testing) of the subject system and its libraries. This has two important consequences: one is related to the nature of the judgments that one can draw based on testing; the other is related to the problems that can arise when a test suite constructed for functional testing is used as the basis of a security assessment.

Obviously, when execution coverage is poor, it may happen that a vulnerability is not deemed relevant just because no observed path reached the vulnerable code. This says nothing about whether such path would be feasible in practice. Furthermore, even when relying on a well-written (functional) test suite that achieves high-coverage, there might still be corner cases – not considered in functional tests – that are potentially relevant from a security standpoint and that an attacker could exploit.

The first point can be addressed by using test suites that achieve good coverage and that therefore reduce the chances that obvious problematic execution paths go unnoticed.

Regarding the second point (which can also benefit from testing if the functional test suite is augmented with explicit tests for corner cases and negative tests), we feel it would be tackled more effectively by combining our current test-based approach with static analysis. By analysing the source code of the target program and its libraries, we could determine with some approximation (e.g., constructing the combined call graph), whether it is at all possible to reach vulnerable code from the application code.

In certain particular cases, this method could provide very strong evidence that the vulnerable code is unreachable, and as such it would complement nicely our test-based method with provides very strong evidence (a proof, indeed) in the complementary case, that is when vulnerable code is indeed reachable. This technique would still need to cope with some degree of approximation. A study of the interplay of test-based analysis and static analysis will also require to investigate which types of flow analysis are best suited to provide a good balance between reliability of the results and performance, especially when taking into account the the complexity of large real-world applications.

Scalability to large projects

While we do not have conclusive evidence nor quantitative figures to offer at this time, the performance...
observed in our preliminary tests is promising. We believe that the performance penalty that our tool imposes on the build process would acceptable in most practical cases. As a future work, we plan to conduct a systematic study of the performance of our tool, by using it in large commercial applications with complex build structure and hundreds of dependencies.

Experiments to validate the assumptions underlying our approach

The basic assumption on which this work is based (see Sec. 1) seems sensible based on what we observed in a limited set of sample projects both in the open-source and in industrial projects. However, its rigorous validation is a prerequisite for drawing more reliable conclusions about the quality of our approach. This validation will require examining a larger number of projects and compare the results of our analysis with the actual exploitability of vulnerable libraries in the context of those projects.

Tackling the data integration problems

Our approach heavily relies on data coming from an heterogeneous set of sources, which include vulnerability databases (such as the NVD) and source code repositories.

Based on our experience, we believe that, despite the growing attention that both researchers and practitioners dedicate to the topic of automated vulnerability management, the gap to be filled in is still quite large. A key problem that approaches like ours have to face is how to reliably relate CVE entries with the affected software products and the corresponding source code repository, down to the level of accurately matching vulnerability reports with the code changes that provide a fix for them.

This information is currently unavailable, and obtaining it proved to be extremely difficult.

We are currently adoption ad-hoc solutions to these problems. For example, we are manually constructing a curated list of widely used open-source projects and their respective code repositories. This approach has the obvious drawback of requiring manual effort both to build and maintain the list; furthermore the coverage is limited to a large but non-exhaustive set of projects. Similarly, we are using ad-hoc mechanisms to determine the correspondence between release numbers (as mentioned in CVEs) to commit identifiers in source code repositories.

As a future work, we will investigate ways to improve these solutions a we will study possible alternative methods.

Integrating continuous vulnerability assessment in continuous integration systems

Our approach, when considered as part of the overall software development lifecycle, has a very natural application in continuous build and integration systems. When included in such systems, our tool can collect traces on a regular basis and therefore can offer timely notifications when one or more of the used libraries are found to be affected by a vulnerability report.

At the time of writing, we are initiating the work to adapt our prototype to run as part of Jenkins builds. As a future work, we intend to complete this implementation and to evaluate it when used in large development projects (e.g., with over a hundred libraries).

7 Conclusion

This paper presented a pragmatic approach to answer one important and time-critical question: Does a vulnerability in bundled OSS libraries affect an application? Our approach helps to assess whether urgent patching is needed in response to a vulnerability. It is generic with regard to programming languages and types of vulnerabilities, and can be seamlessly integrated into industry-scale build and integration systems.

This paper presented both the conceptual approach and a concrete implementation as a tool, whose functionality was demonstrated using an illustrative example.

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