Abstract—With the popularity of open source library (re)use in both industrial and open source settings, ‘trust’ plays vital role in third-party library adoption. Trust involves the assumption of both functional and non-functional correctness. Even with the aid of dependency management build tools such as Maven and Gradle, research have still found a latency to trust the latest release of a library. In this paper, we investigate the trust of OSS libraries. Our study of 6,374 systems in Maven Super Repository suggests that 82% of systems are more trusting of adopting the latest library release to existing systems. We uncover the impact of maven on latent and trusted library adoptions.

I. INTRODUCTION

As software systems grow, so does its size and complexity. Known software engineering best practices suggest that we re-compose code into easy-to-understand and maintainable functional modules or libraries. With the emergence of large collections of software repositories over the Internet, now systems integrate popular Open Source Software (OSS) libraries like JUNIT and SPRING. The effect of heartbleed bug demonstrates OSS library widespread effect on everyday systems. Online collections of libraries together form super repositories like GitHub and the Maven Central Repository.

Well-known benefits of adopting libraries includes efficient development with credible assurance of quality. ‘Trust’ of a library plays an important role. Trust involves the assumption of a module’s functional and non-functional correctness. For instance, system maintainers need to trust the reliability of non-functional attributes such as security and stability of an adopted library.

Libraries, much like any software, are never perfect. Over time, release updates are sometimes necessary to address bugs or perform other maintenance activities such as refactoring. New features are added to expand functionality. Some updates become mandatory and is crucial patch vulnerabilities. However, sometimes updates break systems, causing incompatibility issues with shared system-wide resources. According to maven, ‘dependency management becomes crucial, especially with large-scale multi-modules software systems with tens of hundreds of modules’. The tracking and maintenance of libraries has come to be known as dependency management issues (colloquially termed as ‘dependency hell’). To handle dependency management issues, many system maintainers utilize build tools such as Maven and Gradle. These tools promote updates and the trust of latest available library releases in the super repository.

However, studies by Raemaekers et. al. and our previous work all report evidence of latency when updating to the latest release of a library. Incompatibilities, such as API breakages and technical rework needed to facilitate the new library may cause such delays. Other speculations involve the lack of awareness of a newer library release. Since trust has a human aspect, other various reasons may exist.

In this study, we investigate the impact of dependency management tools such as maven have on trusting a library. We coin the term ‘trusted adoption’ to when the latest release of a new library is adopted. Conversely, ‘latent adoption’ refers to when a maintainer does not adopt the latest library release.

The motivation is to investigate the latency of trust phenomena. We carried out an empirical study to evaluate trusted adoption of OSS libraries within the maven super repository. The following research questions guided our study:

1) How much ‘latent adoption’ exists? In RQ1, we empirically detect when a system does not adopt the latest release of a new library.
2) What is the current trend of maintainers trust? In RQ2, we investigate the trend over recent times to understand the current state of trust of OSS libraries.

We present a set of algorithms to classify initial and introduced library dependency types. Our results suggest that with the current tools and technology, latent adoption is still common. Maintainers, however, are more trusting when introducing new libraries into existing systems.

II. BACKGROUND AND MOTIVATION

A. Trust of a Library

We consider trust to play an important role when choosing and maintaining a third-party library. Trust intrinsically is a human trait, thus making it very difficult to ‘pin down’ to a

References:

- junit.org
- spring.io
- https://junit.org
- https://spring.io
- http://heartbleed.com/
- https://shellshocker.net/
- https://github.com/
- http://search.maven.org/
- http://www.gradle.org/
- http://gradle.com/
ASM updated from framework encountered incompatibility issues when Spring in many popular frameworks like H盏, A tiny and flexible java byte-code manipulation library used ASM resources. Take for example the java as their dependent libraries. A study by Raemaekers discovered that many libraries do not follow the SemVer schema, causing many breaking changes which could lead to latent adoptions.

The second type of trust is that the introduced library is not volatile towards the current system environment. This involves compatibility with other libraries or the shared-system resources. Take for example the java ASM library. ASM is a tiny and flexible java byte-code manipulation library used in many popular frameworks like HIBERNATE, SPRING, GLASSFISH, and DERBY SERVER. It is known for its fast execution speed due to its small size. The cost of keeping such a small size was that incompatibilities would occur whenever a new JDK compiler was released. The main issue occurred when systems adopted libraries that internally had different versions of ASM as they would break. For instance, systems that had adopted the DERBY server and SPRING framework encountered incompatibility issues when Spring updated from ASM5.x to ASM4.x. Eventually latter releases of ASM allowed for backward compatibility. This example illustrates the importance of the ASM library development team influence on trust adoption.

We refer to the third type of trust as loyalty for a certain version of a library based on experienced usage. For instance, in an informal interview, a developer replied that: ‘although it is an older version, I use JUnit5 as I am familiar with it. It is not a critical compile component of my system and suits my needs.’ This trust of a particular release promotes latent adoption.

Finally, a system maintainer may not trust the test maturity of latest version release. In informal interviews, we found that many maintainers are hesitant of the rigor of internal testing. They believe that undetected bugs that can only be uncover during in practical use may exist. In this case, maintainers search for most stable version (in many cases deemed as the popular) release.

III. SOFTWARE SYSTEMS AND LIBRARIES

We investigate the evolving relationship between systems and their dependent libraries. In this research we are only concerned with the adoption of new libraries. Updates to existing library dependencies are ignored. We used the model in Figure 1 to describe the necessary terminology.

A. Terminology and Definitions

- System and Library Releases. We conjecture that systems form a dependency relationship with a set of libraries. A release refers to an instance of a system or library. Let \( S_{\text{ver}} \) be the notation for a unique release of a software system and \( L_{\text{ver}} \) as libraries. In Figure 1, \( S_1, S_2, S_3, S_4 \) are different system releases of system S. \( A_1, A_2 \) are releases of library A and \( B_1, B_2, B_3, B_4 \) as library B releases. As depicted in Figure 1 all related releases are connected.

- Releases Ordering. Since releases have a temporal property, we can order releases by their release date. Thus, \( \text{pre}(S_{\text{ver}}) \) refers to a previous release while \( \text{suc}(S_{\text{ver}}) \) refers to successive releases of a system. Likewise for \( \text{pre}(L_{\text{ver}}) \) and \( \text{suc}(L_{\text{ver}}) \).

We use the notation \( > \) and \( < \) to represent the temporal ordering between all system and library releases. For instance, in Figure 1: \( B_4 > S_1 > B_3 \) describes the ordering between \( B_4, S_3 \) and \( B_3 \). We use the ordering

\[ A_1 \rightarrow A_2 \]
to identify particular releases. The initial release is used to describe an instance where no predecessor exists. (i.e. $\exists \text{pre}(S_{ver})$ or $\exists \text{pre}(L_{ver})$). For example, in Figure 1 releases $A_1$, $S_1$ and $B_1$ are initial releases. The latest release is such that no successive release exists (i.e. $\exists \text{suc}(S_{ver})$ or $\exists \text{suc}(L_{ver})$). In Figure 1 the latest releases are $A_2$, $S_4$ and $B_4$ respectively.

**Dependency Relations.** This refers to the dependency relationship that forms when a library is being adopted by a system. Suppose a system $S_x$ and library $L_y$, $\text{depends}(S_{ver}, L_{ver})$ describes the adoption of library $L_y$ into a system $S_x$. In Figure 1 for system $S$, $\text{depends}(S_1, A_1)$, $\text{depends}(S_2, A_2)$ $\text{depends}(S_3, A_2)$ and $\text{depends}(S_3, B_2)$ depicts how libraries $A$ and $B$ are adopted. As shown in Figure 1 dependency relations are the edges that exist between a system and library (i.e, edge between $A_1$ and $S_1$).

**Initial Dependency.** An initial dependency is all dependencies that exist at the initial system release. (i.e $\text{depends}(S_{ver}, L_{ver})$ where $\exists \text{pre}(S_{ver})$ conditions must be met). As depicted in Figure 1 $\text{depends}(S_1, A_1)$ is an initial dependency for system $S$.

**Introduced Dependency.** An introduced dependency refers to new dependencies introduce to an already existing system. (i.e $\text{depends}(S_{ver}, L_{ver})$ where $\exists \text{pre}(S_{ver})$ and $\ exists(S_{ver}, L_{ver})$ conditions must be met). In Figure 1 $\text{depends}(S_3, B_2)$ is an example of an introduced dependency.

**Trusted Dependency.** Trusted dependency is the adoption of the closest library release at a particular point in time. (i.e $\text{depends}(S_{ver}, L_{ver})$). One of the two conditions must be met 1) $L_{ver}$ is the latest version such that $\exists \text{suc}(L_{ver})$ and 2) If condition 1 is not true, (i.e, $\exists \text{pre}(L_{ver})$), then $\text{suc}(L_{ver})$ must be released after the system release $S_{ver}$ (i.e, $\text{suc}(L_{ver}) > S_{ver}$).

In Figure 1 taking $S_1$ as a reference point, the dependency $\text{depends}(S_3, B_2)$ is not an trusted dependency adoption. This is because $B_2$ is not the latest release. and the successor $B_3$ was released before $S_3$ ($B_3 < S_3$). The entrusted dependency would be $\text{depends}(S_3, B_3)$ as the successive release $B_4$ was released after $S_4$ ($B_4 > S_4$). Also, in Figure 1 $\text{depends}(S_3, A_2)$ is an trusted dependency as $A_2$ is the latest release of library $A$ (condition 1 is satisfied).

**B. Dependency Algorithms**

To determine a trusted dependency, we follow three steps as depicted in Figure 2. Suppose for a system $S$ and $n$ represents all of the system releases of $S$, we perform the following steps:

1) **Extract related dependency relations.** For all releases of $S$ (i.e, $S_1,...,S_n$), we extract all related dependency relations.
2) **Determine dependency relation.** In this step we distinguish if the dependency is either an initial or introduced dependency.
3) **Determine trusted dependency.** To determine a trusted introduced dependency, we check the conditions to satisfy a trusted dependency.

As shown in Figure 2 using the algorithm we classify into the interested dependencies. Formally each dependency is defined as follows:

**a) Initial Trusted Adoption (iniTA):** Trusted adoption of latest library release at initial conception of a system.

$$\text{iniTA}(S) = \{ \bigcup_{i \in n} \exists \text{depends}(S_i, L_x) | \exists \text{pre}(S_x) \land (\exists \text{suc}(L_x) \lor \text{if}(\exists \text{pre}(L_x)) \text{then}(\text{suc}(L_x) > S_i)) \}$$ (1)

**b) Initial Latent Adoption (iniLA):** Latent adoption at initial conception of a system.

$$\text{iniLA}(S) = \{ \bigcup_{i \in n} \exists \text{depends}(S_i, L_x) | \exists \text{pre}(S_x) \land (\exists \text{suc}(L_x) \land (\text{suc}(L_x) > S_i)) \}$$ (2)

**c) Introduced Trusted Adoption (introTA):** Trusted adoption of latest library release introduced to an existing system.

$$\text{introTA}(S) = \{ \bigcup_{i \in n} \exists \text{depends}(S_i, L_x) | \exists \text{pre}(L_x) \land (\exists \text{suc}(L_x) \lor \text{if}(\exists \text{suc}(L_x)) \text{then}(\text{suc}(L_x) > S_i)) \}$$ (3)

**d) Introduced Latent Adoption (introLA):** Latent adoption of library introduced to an existing system.

$$\text{introLA}(S) = \{ \bigcup_{i \in n} \exists \text{depends}(S_i, L_x) | \exists \text{pre}(L_x)$$

$$\land (\exists \text{suc}(L_x) \land (\text{suc}(L_x) > S_i)) \}$$ (4)

**IV. EMPIRICAL STUDY**

We implemented our trust dependency algorithms to study the ‘latent adoption’ phenomena between maven 2 repository libraries. The Maven Super Repository is the home to a large collection of software libraries that originate from the Java Virtual Machine (JVM) based languages such as Java, Scala and Clojure. Systems in the maven repository includes a Project Object Model file `POM.xml` that describes the project’s configuration meta-data —including its compile-time and run-time dependencies. We developed a tool to extract this dependency information from all versions of the POM-files in
TABLE I: Maven Super Repository

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Maven Dataset</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005-11-03 to 2013-11-24</td>
<td>188,951</td>
</tr>
<tr>
<td># Implicit Relations</td>
<td>11,195</td>
</tr>
<tr>
<td># of Systems</td>
<td>6,374</td>
</tr>
<tr>
<td># of Libraries</td>
<td>5,146</td>
</tr>
</tbody>
</table>

TABLE II: Dependency Classification Results

<table>
<thead>
<tr>
<th>Library</th>
<th># Dependencies</th>
<th># Dependencies (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>iniLA</td>
<td>4,192</td>
<td>20,372 (59.63%)</td>
</tr>
<tr>
<td>iniLA</td>
<td>848</td>
<td>13,791 (40.37%)</td>
</tr>
<tr>
<td>introTA</td>
<td>3,064</td>
<td>29,303 (81.16%)</td>
</tr>
<tr>
<td>introLA</td>
<td>823</td>
<td>6,543 (18.24%)</td>
</tr>
</tbody>
</table>

the repository (PomWalker16). Our implementation relies on version 3.1.1 of maven’s own maven-model project to parse each POM file and extract syntactic references to its dependencies.

POM files can either reference be explicit to a specific release version or be implicit. For instance, the syntax (<version>$library.version</version>) is used to import managed dependencies. For simplicity, we only used explicit release versions in our study. We implemented R scripts of the dependency algorithms. Using the extracted dependency information, we were then able to determine trusted dependencies. All scripts and tools are available as a replication package17.

V. RESULTS

Table II is a summary of the data collected by PomWalker. We extracted 188,951 dependency relations from the maven super repository. This consists of 6,374 systems using 5,146 libraries over 7 years. Table II refers to the extracted introduced and initial entrusted dependencies. In the case of initial dependencies, 59.63% of the detected dependencies trusted the latest release, while 40.37% did not adopt the latest release version. The results show a relatively smaller set of latent

TABLE III: Top 5 Initial Trusted Libraries

<table>
<thead>
<tr>
<th>Library</th>
<th># Dependencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>scala-library</td>
<td>710</td>
</tr>
<tr>
<td>junit</td>
<td>595</td>
</tr>
<tr>
<td>log4j</td>
<td>191</td>
</tr>
<tr>
<td>slf4j-api</td>
<td>178</td>
</tr>
<tr>
<td>commons-logging</td>
<td>169</td>
</tr>
</tbody>
</table>

TABLE IV: Top 5 Initial Latent Libraries

<table>
<thead>
<tr>
<th>Library</th>
<th># Dependencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>scala-library</td>
<td>1,468</td>
</tr>
<tr>
<td>junit</td>
<td>1,411</td>
</tr>
<tr>
<td>servlet-api</td>
<td>496</td>
</tr>
<tr>
<td>commons-logging</td>
<td>481</td>
</tr>
<tr>
<td>log4j</td>
<td>394</td>
</tr>
</tbody>
</table>

Fig. 3: A comparison of trust of initial dependencies over time in the Maven Super Repository.

Fig. 4: A comparison of trust of introduced dependencies over time in the Maven Super Repository.
adopted libraries (848) compared to their trusted counterparts (4,192). In the case of introduced libraries, 81.16% of the adopted libraries were latest releases. The results reveal a relatively smaller set of latent adopted libraries (823) that maintainers introduced into their systems.

The Top 5 libraries adopted at the conception of a system are shown in Table III (initial trust adoption) and Table IV (initial latent adoption). For introduced libraries, Table V (introduced trusted adoption) and Table VI (introduced latent adoption). Notice that popular libraries like SCALA-LIBRARY and JUNIT are apparent in all the dependency types. Both Figure 3 and Figure 4 depicts a cumulative number of initial and introduced library adoptions in the maven super repository from 2006 to 2014. Figure 3 shows a more steady trend between trusted and latent adoptions. On the other hand, in Figure 4 it is observed that when introducing new libraries, systems are more trusting of the latest releases.

VI. IMPLICATIONS OF RESULTS

Issues of updating libraries stems from the trust of releases. We did not study if these libraries eventually update these libraries, but a latent adoption may set a precedence of not updating libraries. The study shows a smaller subset of libraries may be responsible for latency in adoptions. Future work is towards identification and exploration of approaches to reduce latent adoptions. The study finds that trust adoptions are more apparent with introduced libraries. We speculate that introducing new libraries could indicate of adding new features to a system.

We are only beginning to understand the trust involved with OSS libraries. More study into trust of libraries will lead to better strategies to support component-based software. For example, how to ‘certify’ trust of a newly released release. Now we answer our research questions:

RQ1. How much ‘latent adoption’ exists?: The results show that the latent adoption exists, particularly at the initial conception of a system. Maintainers are less likely to adopt the latest releases at the beginning of project.

RQ2. What is the current trend of maintainers trust?: Figure 3 and Figure 4 suggests that maven libraries are becoming more inclined to adopt the latest releases when introducing new libraries (updating there existing systems).

VII. RELATED WORK

The trust of components is well-known in fields of Dependability and Secure Computing [7]. [8]. [9]. In this paper, we explore how trust of components can be realized with OSS libraries. Related work in Software Engineering are concerned with library API usage and popularity. Holmes et al. appeal to popularity as the main indicator to identify libraries of interest [10]. De Roover et al. explored library popularity in terms of source-level usage patterns [11]. Mileva et al. study popularity over time to identify the most commonly used library versions [12]. These studies to an extent, are evidence to update to the most popular as opposed to the latest release of a library. More recently, work by Teyton et al. [13] and Cossette et al. [14] have explored library migrations, particularly on candidate library replacements. Both studies provide additional insights behind latent library adoptions.

VIII. CONCLUSION AND FUTURE WORK

In this paper we explore the notion of trust when re(using) OSS libraries. Our results suggest that maintainers are becoming more trusting. Existing systems more inclined to adopt the latest releases to existing systems. The reasons for latent adoption are difficult to generalize. Related work reports lapses in updates and SemVer guidelines not being strictly enforced. Therefore, we believe that further investigation behind the reasons trust issues should be performed, such as maintainers satisfaction surveys on our current tools. We envision that future dependency management tools like maven should ensure OSS libraries are trustworthy, possibly resolving our dependency updating issues.

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REFERENCES