

Multi-party Open Software and Services



Security, how we think it is

how it really is

how it should be

Secure Software Development in the Era of Fluid Multi-party Open Software and Services

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Assurance and certification in secure Multiparty Open Software and Services (Assure-MOSS) No single company does master its own national, in-house software. Software is mostly assembled from "the internet" and more than half come from Open Source Software repositories (some in Europe, most elsewhere). Security & privacy assur-

ance, verification and certification techniques designed for large, slow and controlled updates, must now cope with small, continuous changes in weeks, happening in sub-components and decided by third party developers one did not even know they existed. AssureMOSS proposes to switch from processbased to artefact-based security evaluation by supporting all phases of the continuous software lifecycle (Design, Develop, Deploy, Evaluate and back) and their artefacts (Models, Source code, Container images, Services). The key idea is to support mechanisms for lightweigth and scalable screenings applicable automatically to the entire population of software components by Machine intelligent identification of security issues, Sound analysis and verification of changes, Business insight by risk analysis and security evaluation. This approach supports fast-paced development of better software by a new notion: continuous (re)certification. The project will generate also benchmark datasets with thousands of vulnerabilities. AssureMOSS: Open Source Software: Designed Everywhere, Secured in Europe. More information at https://assuremoss.eu.



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Abstract-Pushed by market forces, software development has become fast-paced. As a consequence, modern development projects are assembled from 3rd-party components. Security & privacy assurance techniques once designed for large, controlled updates over months or years, must now cope with small, continuous changes taking place within a week, and happening in sub-components that are controlled by third-party developers one might not even know they existed. In this paper, we aim to provide an overview of the current software security approaches and evaluate their appropriateness in the face of the changed nature in software development. Software security assurance could benefit by switching from a process-based to an artefactbased approach. Further, security evaluation might need to be more incremental, automated and decentralized. We believe this can be achieved by supporting mechanisms for lightweight and scalable screenings that are applicable to the entire population of software components albeit there might be a price to pay.

Index Terms-software security, open source software, vision

I. SECURITY HEAD-SCRATCHERS

In the last decade, three major forces radically changed software development projects. First, the trends of DevOps as well as continuous integration and delivery have led to a fast-paced development with faster product changes [1], [2]. Second, the adoption of agile practices has lead to a democratised process where the development is carried out by self-organizing and cross-functional teams that have limited central oversight [3]. Third, after advocating the benefits of commercial off-the-shelf (COTS) and software reuse for years, we have finally come to the era of multi-stakeholder development and software ecosystems, where developers focus on differentiating features in their products and rely on 3rd parties for everything else (e.g. cloud deployment, use of open frameworks, and so on) [4]. We observe that the key issue is not that it is Free (albeit this is useful), but that it is in a state of constant changes and such changes are done by different people belonging to different organizations. To capture this phenomenon, we introduce the notion of Multi-party Open Software and Services – or MOSS¹– and to reflect the dual nature of modern software developer roles, we introduce the notion of MOSS Prosumer: to produce MOSS components, software developers not only develop their own code, but also consume the code from other projects. From a security perspective, the new situation, brings the two major challenges.

¹In this paper we are using the term MOSS *differently* from the software metrics domain, where it stands for Measure of Software Similarity [5]

Challenge 1 - Both internal and external sources of insecurity. Current software security techniques mostly focus on in-house development. The prevalence of the MOSS paradigm means that the root cause of software security problems is shifting from the development of homegrown software to the aggregation of 3rd party (external) components and libraries. And each actor in the ecosystem might have different security and privacy practices. Security is no longer an internal force. In CI/CD, on any given sprint (e.g., a two-week development cycle), MOSS prosumers pull in new FOSS libraries, the FOSS community produces security updates for those libraries, MOSS prosumers make decisions that impact the (security) architecture of the systems, new features (and their associated security bugs) are deployed to the customers, and so on. This challenges software developers to take additional responsibilities for proper security assessment, security integration, and security maintenance of third-party components. I.e., secure coding skills might not be enough.

Challenge 2 – From quality gates to continuous recertification. As the organisation of software development activities has morphed into a fluid, fast-paced, and democratized process, the traditional separation in specialized units (e.g., front-end developers, functional testers) that worked under the oversight of software architects and security experts is no longer adequate.

Rigid "security gates" that apply heavyweight security techniques (such as architecture risk analysis, code V&V) rely on the availability of stable artifacts at fixed points in the development process and assume the supervision of a few highly-skilled security specialists.

Such a centralized model needs to evolve to sustain fastpaced software development [6]:

"If the software security industry is going to make a meaningful impact, then everything has to be as easy as humanly possible for both the developers and users of software."

Hence, security assurance might greatly benefit from embedding into the development and operation pipeline in the form of lightweight, intelligent, fully- or semi-automated techniques that can be executed at scale to provide *screening tests* of security-relevant events (e.g., importing an open-source library that requires patching, deploying a container, etc.). These techniques enable an incremental (thus continuous) recertification of software and their outcome can guide the application of further, in-depth analysis that is more focused and may require expert intervention.

Scope of this paper — The above challenges are cross-cutting and span the entire development process. With reference to DevSecOps [7], we concentrate on the "Dev" part; due to space limitations, we leave out most *Ops*-related aspects, which we intend to cover in future work.

II. LIMITATIONS OF SECURITY ASSURANCE TECHNIQUES

We discuss the aspects of planning and designing a MOSS project, providing an implementation, and assessing its security with the intent of certification.

A. Secure design

Model-driven security. Several approaches exist to represent security concepts in design models, including architectural models [8]. Security-aware models are also used in model-driven approaches, e.g., to harden the models via model-to-model transformations and to generate secure implementations via model-to-code transformations [9].

Model detection from code. A general problem with the model-driven security approaches is that, often, there is no guarantee that the model corresponds to the code. Some approaches exist to check the compliance between the planned and implemented security mechanisms [10]. These approaches, however, hinge on the presence of an existing security-aware model, which is, in many situations, an unrealistic assumption. As an interesting alternative, securityaware models can be extracted directly from code [11]. However, only few works consider security issues and mostly focus on access control models [12]. Further, fully-automated techniques are notoriously plagued by low levels of precision and recall and produce results that are either not trustworthy or require substantial human checking. In this respect, semiautomated techniques might be more promising [13].

Model analysis. State of the practice techniques to assess security at model level are expert-based (e.g., STRIDE [14] and CORAS [15]. Some automated security analysis techniques have been suggested [16], [17]. However, the design flaws identified by such techniques are confined at the level of the design models: little support is provided to developers with respect to how to modify or refactor their code.

B. Analysis & correction of secure code

Vulnerability detection. Finding vulnerabilities in software projects is undoubtedly the core software security task. The classic vulnerability finders rely on either static [18] or dynamic analysis [19] to identify code locations that are likely to have a weakness. Current analysis tools are known to produce many false positive alerts [20], which makes them less attractive in practice [21]. The alternative for code analysis tools are usually referenced as "defect predictors" [22]. These techniques employ manually-devised heuristics or machinelearning approaches to construct a model of the source code and then use it to locate a bug or a vulnerability. However, such tools typically work on a file-level of granularity, hence, provide too generic results from practical perspective.

Automated corrections of security flaws. Automatic software repair techniques are proposed to fix bugs. One of the most popular approaches is generate-and-validate based [23], which first generates a list of candidate patches and verify them using a test suite. The design of repair techniques depends on several factors, such as the selection of modification points or repair operators. These factors strict the success of a technique to specific types of bugs; for example, MutRepair [24] tool is only effective on the bugs related to relational and logical operators while Kali [25] is preferred for the bugs that can be fixed by only removing code. Thus, designing a new repair approach requires analyzing the characteristics of bugs, which guide the development of the repair components.

C. Secure re-certification of code

Dependency studies. Several studies [26]–[28] argued that current dependency analysis methodologies are based on assumptions that are not valid in an industrial context. They may not distinguish dependency scopes [29] which may lead to reporting non-exploitable vulnerabilities or consider only direct dependencies [30] although security issues may be introduced through transitive dependencies [31].

Delta Evaluation and Re-certification for Code. Existing techniques for software security certification [32] make use of security standards and guidelines provided by certification authorities (e.g., the Common Criteria, NIST, ISO). The industrial need for a lightweight certification scheme is increasing. Yet, existing approaches [33], [34] require manual assessments and focus on assessing safety properties and trust in software systems. For instance, Dobbing et al. [35] published guidelines for certification of safety properties for COTS Real-Time Operating Systems. Apace with the rapid change in software development practices and changes in the market, source code modifications are often made on legacy, already certified (sub)systems. A fully-fledged re-certification of software security is therefore wasteful. Previous works aim to overcome the problem of high manual effort required to assess security for cloud services. Namely, Anisetti et al. [36] presented a certification scheme for the cloud, coupled with a semi-automatic certification process. However, to improve the automation of re-certification, reliable techniques for determining the impacted security from code changes and generating the required documentation for re-certification (i.e., delta evaluation) are needed.

III. SECURITY ASSURANCE FOR FLUID MOSS

Figure 1 shows a continuous and high-volume stream of security-relevant events that are generated both internally (because of own development) and externally (because of the dependencies to multi-parties). Below we provide an outline of the advancements over the state-of-the-art that are necessary in order to cope with these security events. As space is tyrant, we focus on continuous and incremental design and validation, integration and security assessment of software. The other Ops-

#	Security event	Туре	Current mitigation	Limitations in fluid MOSS	Research ideas
Continuously validated design					
E1.1	security/privacy design	internal	threat analysis of de-	due to continuously modified/challenged de-	develop techniques to continuously detect
	flaw introduced		sign model to dis-	sign decisions, the analysis results quickly	design-level security information in the code
			cover flaw	become obsolete	
E1.2	FOSS framework chosen	external	security requirements	due to the impossibility of central oversight,	connect security assumptions to code so that
			and policies to guide	developers' choices violate the security re-	
			selection	quirements, which might not even be known	to developers and experts
Continuous integration of secure code					
E2.1	Changed code introduced	internal	static or dynamic	time- and computationally-wise expensive,	lightweight checks that find the code
	new vulnerability		analysis tools	prone to FPs	changes introducing vulnerabilities
E2.2	FOSS dependency is vul-	external		security analysis is often postponed to the	machine learning could be used to analyse
	nerable		dependency analysis	pre-release stage (or even skipped)	patches and automatically generate fixes
E2.3	Dependency security flaw	external	tools	pre-release stage (or even skipped)	for vulnerable dependencies
	is fixed w/o advisory				
Incremental evaluation and continuous risk assessment					
E3.1	Upgrade of FOSS frame-	internal		entire application should be re-certified even	recertification technique should consider
	work is vulnerable		manual assessments	if a small part was changed	previously certified state and certify only the
			with check-lists		updated part
E3.2	Community project secure	external	with check lists	IT risk assessment standards do not provide	1
	coding deteriorated			quantitative measures	of the CI/CD pipeline is needed

TABLE I Security assurance for Fluid MOSS

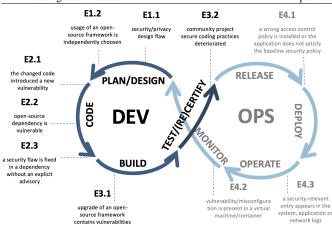


Fig. 1. Security events of the MOSS life cycle

related events, such as wrong access control policy, application violations of baseline security policies, misconfigurations and vulnerabilities present in a virtual machine or container are left to the next paper.

A. Continuous validation of design's security

Internal security events. The software architecture for the project can surface in a proactive way (explicit definition by an architect) or in an emergent way (implicit organization of the code). In both cases, the security tactics chosen by an organisation might introduce a security/privacy design flaw [E1.1] [37]. For instance, highly sensitive data, like user account data, might be stored in a database in clear-text (confidentiality threat), or there might be no way for the end user to delete their account (privacy threat).

External security events. MOSS prosumers might choose to use an open-source framework [E1.2]. However, such choice might jeopardize the integrity of the architecture from a security perspective. For instance, the framework might contain a configuration interface with default credentials that vastly extends the attack surface of the system.

Current approach. As mentioned, manual approaches, like model-based threat analysis, do not scale to the MOSS scenario. Although there exist automated model analysis approaches, few of them consider security properties and none link models and code. Hence, the validation of design from a security point of view is generally performed after the system is already deployed (e.g., penetration tests), and therefore, E1.1 and E1.2 could be discovered only at a later stage when their mitigation is costly and requires significant efforts.

Research directions in the era of fluid MOSS. Design artifacts are often abandoned to rust once the implementation work has started, because the code diverges over time from the planned design and this gap nullifies the value of the design models, e.g., for certification. Instead, the design models and their security validation could be incorporated into continuous integration process, by linking design to code. For this, techniques to detect design-level security information in the code should be developed [treatment for E1.1]. To enable the continuous synchronization of the model- and the code-level [treatment for E1.2], these techniques should receive feedback from the (security) experts and support the extraction of design models from the code base. Finally, there should be automated security checks to validate the design models vis-a-vis the intended security properties, e.g., the confidential management of critical information. These checks could be formulated as design-level security tests that can be continuously executed whenever the model of the application changes, e.g., when external components are pulled into the application.

B. Continuous integration of secure code

Internal security events. While implementing a new feature, developers might introduce a new vulnerability in an internally-developed module that needs to be identified and mitigated before the code is deployed [E2.1].

External security events. MOSS prosumers have pulled in an open source component to be used in the application under development. In turn, the open source component depends on additional (open source) components; its developers (or those of any of its dependencies) might release a new version that could contain vulnerabilities [E2.2]. Unfortunately, MOSS prosumers cannot expect to systematically receive information about security flaws in the 3rd party components of their projects [E2.3]: the practices for reporting vulnerabilities vary across projects and ecosystems, and it is well-known that only a minor part is represented in de-facto vulnerability databases such as the NVD [38], which also suffer from poor accuracy [39], [40]. This makes it difficult for applications that depend on those components to understand the impact of the vulnerability and to correctly determine and compare mitigation strategies (e.g., whether upgrading to a more recent, non-vulnerable version of the component is urgent, or if an application-level change could effectively mitigate the vulnerability at hand and make a potentially expensive version update unnecessary [41]).

Current approach. Many evaluation studies [42], [43] demonstrate that even industry-grade code analysis tools produce numerous false positive alerts when applied to real-world software projects. In many cases usage of such tools require significant human effort to adjusting the tool to work in the specific environment, while lightweight techniques that could work out-of-the-box are only starting to appear. For example, to find a vulnerability in the code of an application, developers have to use static or dynamic analysis tools [treatment of E2.1], that are expensive both time- and computationallywise, as well as known to generate numerous false positive alerts. Similarly, dependency analysis tools [treatment of E2.2, E2.3] are designed to be run together with code analysis tools. Hence, the code security analysis is often postponed to the prerelease stage (or even skipped altogether), which exponentially increases the cost of fixing discovered vulnerabilities [44].

Research directions in the era of fluid MOSS. In a CI/CD pipeline, unit testing of functionality is automatically performed whenever new code is committed. The outcomes of the unit tests determine whether the code can be integrated. A similar approach could be adapted to security assurance. Automated lightweight checks (leveraging machine learning, where appropriate) are key to identify the code changes that introduce security bugs and need to be reworked [treatment for E2.1]. We believe these checks are crucial to be considered as screening tests for vulnerabilities, since they are meant to be applied continuously, automatically, and *quickly*. Code changes should be analyzed automatically and characterized through features that can be efficiently extracted. Such features could include traditional code metrics (e.g., code complexity metrics) as well as properties defined on some abstract representation of the source code (e.g., models based on code tokens, on abstract syntax trees, on control-flow graphs, on data-flow graphs, or on other suitable graph-based representations).

Also, machine learning could facilitate extraction of vulnerability *repair rules* from the FOSS *security patches*. These rules can be automatically applied on commits that are found to introduce a vulnerability, particularly for code that is pulled in from external sources [treatment for E2.2]. Automatic repair might break the code functionality, which is hard to fix for external software, as the application developers are not necessarily familiar with that external code base. Therefore, there is a need for a verification process that selects the relevant test cases to check whether the corrections affected the intended behavior of the application or a MOSS component.

In this process, the machine learning algorithms must have the fundamental property of *explainability* (or *interpretability*) of the reason(s) why a particular vulnerability prediction has been made, or a vulnerability repair rule has been suggested. This feature will aid MOSS prosumers in making informed decisions as to whether or not to accept the change suggestion. However, this is not currently the case. At best ML algorithms suggest that a line of code might contribute with x% to vulnerabilities, at worst they suggest a file may contain a vulnerabilities. Either way that is not very actionable.

C. Incremental evaluation, certification and risk assessment

Internal security events. MOSS prosumers have adopted an open source framework and now they want to upgrade to a new version. The upgrade might contain vulnerabilities and could jeopardize the integrity of the application [E3.1]. Re-certifying the entire application every time such upgrades happen is unrealistic.

External security events. Considering the previous example, the community project developing a FOSS framework may lose traction (e.g., a key developer has left), so secure coding practices in the project deteriorate [E3.2]. The project manager should be able to assess this trend before the application becomes not sound.

Current approach. The automation of existing techniques for software evaluation and certification is limited, therefore, in practice, manual assessments with check-lists for entire software systems still prevail. These techniques suffer from a huge lack of reliability and repeatability due to the non-aligned indicators, over-simplified rating methods and lack of a mandate for certification (who, and according to which standards). Moreover, the necessity to certify an entire application even if only a small part was modified [E3.1] requires huge amount of expensive effort of security specialists. Additionally, currently no quantitative measures exist when we consider IT risk assessment standards. Hence, nowadays security techniques do not allow project managers to receive operational information about security coding practices of the project [E3.2].

Research directions in the era of fluid MOSS. To speed up the re-certification of a modified application, one may consider only the code commits that have happened in the application since the previous certification and verify that the changes are not breaking the existing security mechanisms [treatment for E3.1]. To capture early the weakening of security practices, there is a need to have a comprehensive set of risk indicators that cover most parts of the CI/CD pipeline [treatment for E3.2]. These indicators should be updated and analysed periodically (e.g., via time series) during a project life cycle.

IV. CONCLUSION

In this paper we have analysed the current state of software security approaches (with focus on software development) and evaluated whether they could efficiently cope with the security events of the MOSS era. We argue that software security techniques, once adjusted to the MOSS paradigm, will be beneficial in several ways:

- Project managers and security experts will be aware of the security implications made by the MOSS prosumers, e.g., when a FOSS component is used.
- Security experts will have an 'at a glance' overview of the security soundness of the project, e.g., by analyzing the (non-stale) architectural design or by looking at risk indicators that truly reflect the current snapshot.
- MOSS prosumers will get direct feedback about the security implications of their code commits, both at a feature level (introduction of code vulnerabilities) and at a project level (introduction of architectural flaws).

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