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Software Assurance Tools: Web Application Security Scanner Functional Specification Version 1.0

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Abstract:

Software assurance tools are a fundamental resource for providing an assurance argument for today's software applications throughout the software development lifecycle (SDLC). Software requirements, design models, source code, and executable code are analyzed by tools in order to determine if an application is secure. This document specifies the functional behavior of one class of software assurance tool: the web application security scanner tool. Due to the widespread use of the World Wide Web and proliferation of web application vulnerabilities, application level web security and assurance requires major attention. This specification defines a minimum capability to help software professionals understand how a tool will meet their software assurance needs.

Keywords:

Homeland security; software assurance; software assurance tools; web application; web application security scanner; software vulnerability.

Errata to this version:

None

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1 Introduction

The NIST Software Assurance Metrics and Tool Evaluation (SAMATE) project provides a measure of confidence in the software tools used in software assurance evaluations. It provides software developers and purchasers with a means of deciding whether the tools in consideration for use should meet software assurance requirements. Through the development of functional specifications, test suites and tool metrics, the SAMATE project aims to better quantify the state of the art for all classes of software assurance tools.

Use of a tool or toolkit that complies with this specification does not guarantee the code will be free of weaknesses. It does however provide a tool user with knowledge that their tool solution covers some of the most prevalent and highly exploitable security vulnerabilities.

1.1 Purpose

This document constitutes a specification for a particular type of software assurance tool, which is referred to here as a web application security scanner.

A Web application security scanner is an automated program that examines web applications for potential security vulnerabilities [Fong and Okun]. In addition to searching for web application-specific vulnerabilities, the tools also look for software coding errors.

This document specifies basic functional requirements for web application security scanner tools used in evaluations of application layer software on the web. Production tools will have capabilities far beyond those indicated here. Many important attributes, like cost and ease of use, are not covered.

The purpose of the web application security scanner specification is to:

- define a minimum (mandatory) level of functionality in order for the purchaser and vendor to qualify the product,
- produce unambiguous clauses as to what is required in order to conform, and
- build consensus on tool functions and requirements toward the evaluation of software security assessment tools for behavior and effectiveness.

The minimum functionality described herein may be embedded in a larger tool with more functionality. The functionality could also be covered by several specialized tools.

The functional requirements are the basis for developing test suites to measure the effectiveness of web application security scanners. Accompanying documents detail test cases and methods to ascertain to what extent a tool meets these requirements.

1.2 Scope

This specification is limited to software tools that examine software applications which respond to dynamic web page requests over HyperText Transfer Protocol (HTTP) or other similar protocols. Web applications are designed to allow any user with a web browser and an Internet connection to interact with them in a platform independent way.

This document specifies minimum functionality only. Critical production tools will have capabilities far beyond those indicated here. Many important attributes, like compatibility with integrated development environments (IDEs) and ease of use, are not addressed. We focus on the ability of tools to detect vulnerabilities and do not consider other characteristics of the tool, such as protocols, parsers, methods, and authentication.

The following types of tools or functionality are outside the scope of this specification:

- Tools that scan other artifacts, like requirements documents, bytecode or binary code.
- Database scanners.
- Functionality that scans web services.
- Other types of system security tools, e.g., firewalls, anti-virus software, gateways, routers, switches, intrusion detection/protection systems.
- Functionality that checks infrastructure vulnerabilities, deployment, or configuration issues, such as running an obsolete version of a web server.

Source code security analysis tools are covered by another specification developed by SAMATE [NIST SP 500-268].

The misuse or proper use of a tool is outside the scope of this specification. The issues and challenges in engineering secure systems and their software are outside the scope of this specification.

It is assumed that this document, being a specification, only describes what functions should be (or must be) in the tool, and not how to implement these functions. Therefore, techniques, methods and algorithms for implementing certain functions are omitted here.

This specification is not a survey of tool functions and does not discuss how a tool handles variabilities and complexities in the web application.

1.3 Audience

The target audience for this specification includes users and evaluators of web application security scanners. It may also be useful to security professionals with an interest in web security, software assurance researchers, and developers of web application security scanners.

1.4 Technical Background

This section gives some technical background, defines terms we use in this specification, explains how concepts designated by those terms are related, and details some challenges in web application vulnerability assessment for security assurance.

Different authors may use the same term to refer to different concepts. For clarity we give our definitions. To begin, any event that is a violation of a particular system's explicit (or implicit) security policy is a *security failure*, or simply, failure. For example, if an unauthorized person gains "root" or "admin" privileges or if unauthorized people can read Social Security numbers through the World Wide Web, security has failed.

A *vulnerability* is a property of system security requirements, design, implementation, or operation that could be accidentally triggered or intentionally exploited and result in a security failure. (After [NIST SP 800-27]) In our model the source of any security failure is a latent vulnerability. If there is a failure, there must have been a vulnerability. A vulnerability is the result of one or more *weaknesses* in requirements, design, implementation, or operation.

An *exploit* is a piece of software or technique that takes advantage of a vulnerability to cause a failure. An *attack* is a specific application of an exploit [After AP-Glossary]. In other words, an attack is an action (or sequence of actions) that takes advantage of a vulnerability.

A *web application* is a software application executed by a web server, which responds to dynamic web page requests over HTTP [WASC-Glossary]. A web application is comprised of a collection of components, which reside on a web server and interact with databases or other sources of dynamic content. Using the infrastructure of the Internet, web applications allow service providers and clients to share and manipulate information in a platform-independent manner. A web application has a distributed n-tiered architecture. Typically, there is a client (web browser), a web server, an application server (or several application servers), and a persistence (database) server.

Since HTTP is a stateless protocol, web applications use separate mechanisms to maintain application state, or *context*, during a session. A *session* is a series of interactions between user and web application during a single visit to the web site. The context may be maintained via a GET or POST session, variables, cookies, and other methods.

A *web application security scanner* is an automated program designed to examine web applications for security vulnerabilities. In using the term vulnerability, we do not attempt to differentiate between the issues that cause critical, costly security failures (e.g., theft of credit card information) and those that do not (e.g., a buffer overflow that causes loss of personal preference information on a non-commercial site).

When a web application identifies a vulnerability, it reports one or more attacks. To allow the developers to verify and fix the vulnerability, an attack report must contain relevant information, including script location (e.g., http://foo.com/where/search.pl), input parameters (e.g., file=/etc/passwd), and context. This information is contained within the HTTP headers, so a tool may report the headers. Alternatively, a tool may report this information in a different format. Additionally, the output page can help the developer verify the vulnerability.

In order to provide different levels of access to different users, web applications employ various authentication mechanisms. Some functions of a web application may only be accessible to authenticated users; others may produce different output depending on the level of access of the user. A web application security scanner must be able to login, possibly with the help of the user, to an application. Once logged in, the scanner must be able to maintain the logged-in state and recognize when it was logged out.

Since it only takes one vulnerability to have a failure, the requirements have a tone of catching all vulnerabilities. Practical considerations require the *false positive rate* [Fleiss] to be acceptably low for the domain.

In addition, vulnerabilities within one type differ significantly in terms of difficulty of exploiting them and types of attacks that are effective against them. A web application security scanner may be able to find one SQL injection vulnerability, but fail to detect another. The reason is that web application developers implement different defense measures that make attacks more difficult. Annex B presents common defense mechanisms.

To save analysis time in later runs, some tools allow the user to *suppress* vulnerability instances so they are not reported again.

Modern web applications use various advanced client-side technologies. Ideally, a web application scanner must understand and support these technologies. At a minimum, it must recognize the presence of a technology that it does not (fully) support and alert the tool user that this may cause its vulnerability assessment to be incomplete.

1.5 Glossary of Terms

This glossary was added to provide context for terms used in this document. Many of the terms were copied from the web security glossary developed by the Web Application Security Consortium [WASC-glossary].

Name	Description
(Web) Application Server	A software server, typically using HTTP, which has the ability to execute dynamic web applications. Also known as middleware, this piece of software is normally installed on or near the web server where it can be called upon.
Authentication	The process of verifying the identity or location of a user, service or application. Authentication is performed using at least one of three mechanisms: “something you have”, “something you know” or “something you are”. The authenticating application may provide different services based on the location, access method, time of day, etc.
Authorization	The determination of what resources a user, service or application has permission to access. Accessible resources can be URLs, files, directories, servlets, databases, execution paths, etc.
Attack	An action (or sequence of actions) that takes advantage of a vulnerability.
Exploit	A technique or software code (often in the form of scripts) that takes advantage of a vulnerability or security weakness in a piece of target software.
False negative	Failure of a tool to report a vulnerability, when in fact there is one present.
False positive	Reporting of a vulnerability by a tool, where there is none.
Session	A series of interactions between a user and a web application during a single visit to the web site.
(Security) vulnerability	A property of system security requirements, design, implementation, or operation that could be accidentally triggered or intentionally exploited and result in a security failure.
Source code	A series of statements written in a human-readable computer programming language.
Universal Resource Locator (URL)	A standard way of specifying a location of an object, normally a web page, on the Internet.
Unvalidated input	User-supplied input data that has not been examined or filtered prior to use.
Unfiltered output	Application output that has not been filtered prior to being returned to the client.
Web application	A software application executed by a web server which responds to dynamic web page requests over HTTP.
Web application security scanner	An automated program that searches for software security vulnerabilities within web applications.
Weakness	A defect in a system that may (or may not) lead to a vulnerability.

2 Functional Requirements

In this section we first give a high-level description of the functional requirements for a web application security scanner, and then detail the requirements for mandatory and optional features.

2.1 High Level View

A web application security scanner(s) shall be able to (at a minimum):

- Identify specified types of vulnerabilities in a web application.
- For each vulnerability identified, generate a text report indicating an attack.
- Identify false positive results at an acceptably low rate.

Optionally a tool should:

- Produce a report compatible with other tools.
- Allow particular types of weaknesses to be suppressed by the user.
- Use standard names for weakness classes.

2.2 Requirements for Mandatory Features

In order to meet this baseline capability, a web application security scanner(s) must be able to accomplish the tasks described in the mandatory requirements listed below. The tool(s) shall:

WA-RM-1: Identify all of the types of vulnerabilities listed in Annex A.

WA-RM-2: Report an attack that demonstrates the vulnerability.

WA-RM-3: Specify the attack by providing script location, inputs, and context.

WA-RM-4: Identify the vulnerability with a name semantically equivalent to those in Annex A.

WA-RM-5: Be able to authenticate itself to the application and maintain logged-in state.

WA-RM-6: Have an acceptably low false positive rate.

2.3 Requirements for Optional Features

The following requirements apply to optional tool features. If the tool under test supports the applicable optional feature, then the requirement for that feature applies, and the tool can be tested against it. This means that a specific tool might optionally provide none, some or all of the features described by these requirements. Optionally, the tool(s) shall:

WA-RO-1: Find the appropriate vulnerabilities from Annex A when protected using the specified defense mechanisms listed in Annex B.

WA-RO-2: Not identify a vulnerability instance that has been suppressed.

WA-RO-3: Indicate remediation tasks.

WA-RO-4: Produce an eXtensible Markup Language (XML) formatted report.

WA-RO-5: Assign a severity rating to the vulnerabilities it identifies.

3 References

[AP-Glossary] Sean Barnum, Amit Sethi, *Attack Pattern Glossary*, in Build Security In.

[CWE] Common Weakness Enumeration, The MITRE Corporation, web site http://cwe.mitre.org/

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[Fong et. al] Elizabeth Fong, Romain Gaucher, Vadim Okun, Paul E. Black and Eric Dalci, *Building a Test Suite for Web Application Scanners*, Hawaii International Conference on System Sciences (HICSS'08), to appear.

[NIST SP 500-268] Paul E. Black, Michael Kass and Michael Koo, *Source Code Security Analysis Tool Functional Specification Version 1.0*, NIST Special Publication 500-268, May 2007.

[NIST SP 800-27] Engineering Principles for Information Technology Security (A Baseline for Achieving Security), NIST SP 800-27, Revision A, June 2004.
Available at http://csrc.nist.gov/publications/nistpubs/

[OWASP-TOP-10] OWASP Top 10: The Ten Most Critical Web Application Vulnerabilities, http://www.owasp.org/index.php/Top_10_2007

[PCI-DSS] Payment Card Industry (PCI) Data Security Standard, https://www.pcisecuritystandards.org/pdfs/pci_dss_v1-1.pdf

[WASC-Glossary] Web Application Security Consortium: Glossary, web site http://webappsec.org/projects/glossary/

[WASC-Threat] Web Application Security Consortium: Threat Classification, web site http://www.webappsec.org/projects/threat/

Annex A Web Application Vulnerabilities

The web application vulnerabilities in this table represent a “base set” of vulnerabilities that a web application security scanner must be able to identify if it supports the technology and languages in which the vulnerability exists. Criteria for selection of vulnerabilities include:

- Found in existing applications today.
- Recognized by tools today.
- Likelihood of exploit or attack is medium to high.

In devising the table, we used several taxonomies, including [OWASP-TOP-10], [CWE], and [WASC-Threat]. The table also provides a mapping, possibly incomplete, of the vulnerability names to Open Web Application Security Project (OWASP) Top Ten 2007, Common Weakness Enumeration (CWE), and the Payment Card Industry (PCI) Data Security Standard [PCI-DSS]. The mapping identifies related (not equivalent) terms.

Name	**Description**	**Related terms**	**OWASP Top Ten 2007**	**CWE ID**	**PCI DSS 1.1**
Cross Site Scripting (XSS)	A web application accepts user input (such as client-side scripts and hyperlinks to an attacker’s site) and displays it within its generated web pages without proper validation.	Reflected XSS, persistent (stored) XSS, DOM-based XSS	A1	79	X
SQL Injection	Unvalidated input is used in construction of an SQL statement.	Blind SQL injection	A2	89	X
OS Command Injection	Unvalidated input is used in an argument to a system operation execution function.		A2	78	X
XML Injection	Unvalidated input is inserted into an XML document.	XPath injection, XQuery injection	A2	91	X
HTTP Response Splitting	Unvalidated input is used in construction of HTTP response headers.	CRLF injection	A2	113, 93	X
Malicious File Inclusion	Unvalidated input is used in an argument to file or stream functions.	File inclusion, Remote code execution, Directory traversal	A3	98	

Insecure Direct Object Reference	Unvalidated input is used as a reference to an internal implementation object, such as a file, directory, or database key.	Parameter tampering, Cookie poisoning, Path manipulation	A4	233, 73, 472	X
Cross Site Request Forgery (CSRF)	An application authorizes requests based only on credentials that are automatically submitted by the browser. A CSRF attack forces a logged-in victim's browser to send a request to a vulnerable application, which then performs the chosen action on behalf of the victim, to the benefit of the attacker.	Session riding, One-click attacks, Hostile Linking	A5	352	
Information Leakage	Disclosure of sensitive information or the internal details of the application.	File and directory information leaks, System information leak.	A6	538, 200, 497	X
Improper Error Handling	Error message may display too much information that is useful in exploring a vulnerability.	Error message information leaks, Detailed error handling	A6	388, 209, 390	X
Weak Authentication and Session Management	Lack of proper protection of account credentials and session tokens through their lifecycle.		A7	287	X
Session Fixation	Authenticating a user without invalidating any existing session identifier. This gives an attacker the opportunity to steal authenticated sessions.		A7	384	X
Insecure Communication	Transmitting sensitive information (e.g., session tokens, credit card numbers or health records) without proper encryption (e.g., SSL).		A9		X
Unrestricted URL Access	Missing or insufficient access control for sensitive URLs and functions.	Predictable resource location, security by obscurity	A10	425	X

Annex B Defense Mechanisms

A tool must be able to identify vulnerabilities even when the application developer has implemented certain defense measures. This annex presents common defense mechanisms that can be implemented to make various attacks more difficult [Fong et. al]. The following table of defense mechanisms is not comprehensive. To be effective, these defense mechanisms must be implemented on the server side.

Defense Mechanism	**Description**	**Example**	**Affected vulnerabilities**
Typecasting	Convert the input string to specific type, such as integer, Boolean, or double.	(int)($_GET['var']) transforms "8<script>" into the integer 8	XSS, Injections, Cookie poisoning
Meta-character replacement	Encode characters from a blacklist	"<" is replaced with "<" for HTML documents, quotes replacement… For XSS, replace these characters: ', ", <, >, &, %, #	All technical vulnerabilities
Restrict input range	Restrict the range of integers, the type of an entry (only alphanumeric), length of a string, etc.	For HTML injection, use a regular expression such as: [a-zA-Z0-9_\s]+ to restrict the input to alphanumeric characters plus underscore and space. Use data binding for SQL queries (prepared statements), etc.	All technical vulnerabilities
Restricted user management	Use a restricted account for performing data manipulation, SQL queries, etc.	If user is not logged in, use a read-only SQL account that only allows commands like SELECT and EXECUTE; no UPDATE or INSERT allowed.	SQL Injection, OS Command Injection
Use of stronger function	Use a stronger function for performing a secure action	Use SHA-256 instead of SHA-1 or MD5, Salt the passwords, Secure cookies. Use HttpOnly cookies to prevent client-side script to read them.	Weak cryptographic functions, Insecure cookies
Token Validation	Use a unique token to verify the origin of the HTTP request	By adding a unique identifier (token) in the forms or in the HTTP header, the application must be able to verify the origin of the request	Cross-Site Request Forgery
Character encoding handling	Canonicalize resource names and other input that may contain encoded characters.	Sample attacks using encoding: XSS: The UTF-7 encoded string: "+ADw-script+AD4-	XSS, Injections, Cookie poisoning

		alert('XSS')+ADsAPA-/script+AD4-“ should be interpreted as “<script>alert(‘XSS’)</script>” SQL Injection: An injection technique that consists of replacing the strings to inject by a concatenation of characters	
Hide information	Hide information such as errors, Session ID, etc.		All vulnerabilities that can produce an informative output (SQL Injection, XSS, File Inclusion, etc.), Session Management