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Lee et al.

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(54) SOFTWARE VULNERABILITY ANALYSIS METHOD AND DEVICE

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(30) **Foreign Application Priority Data**

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(51) **Int. Cl.**
G06F 21/57 (2013.01)

(52) **U.S. Cl.**
CPC ***G06F 21/577*** (2013.01); *G06F 2221/033* (2013.01)

(58) **Field of Classification Search**
CPC G06F 21/577
See application file for complete search history.

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(57) **ABSTRACT**

The present disclosure includes: searching a code clone corresponding to a used source code from any analysis target source code; detecting a security sink and sensitive data of the security sink on the basis of patch information in the searched code clone; acquiring a source code which is from the user input point the a security sink by backwardly tracing the sensitive data detected in the analysis target source code; and verifying whether the searched code clone is a vulnerability in the analysis target source code by performing a concolic testing on the basis of a path from the input point to the security sink.

10 Claims, 11 Drawing Sheets

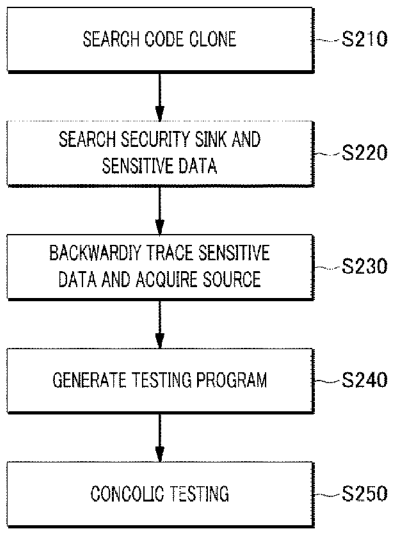

SEARCH CODE CLONE
S210
SEARCH SECURITY SINK AND SENSITIVE DATA
S220
BACKWARDlY TRACE SENSITIVE DATA AND ACQUIRE SOURCE
S230
GENERATE TESTING PROGRAM
S240
CONCOLIC TESTING
S250

FIG. 1

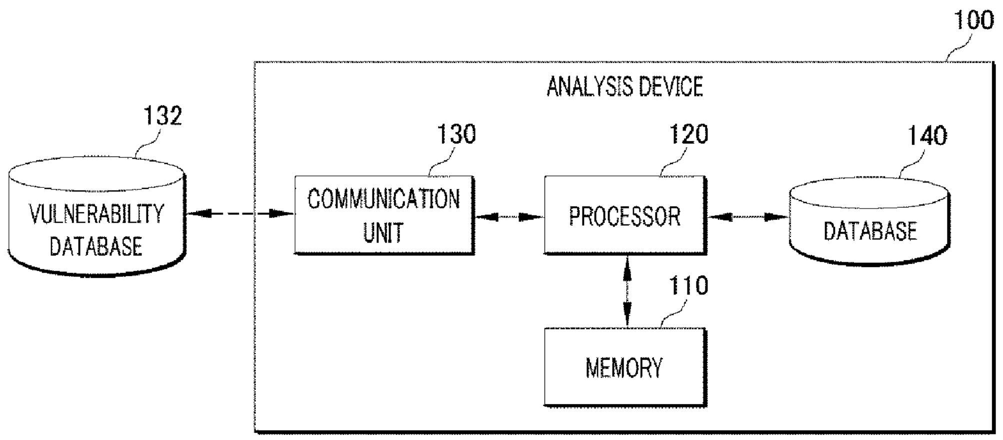

100
ANALYSIS DEVICE
132
VULNERABILITY DATABASE
130
COMMUNICATION UNIT
120
PROCESSOR
140
DATABASE
110
MEMORY

FIG. 2

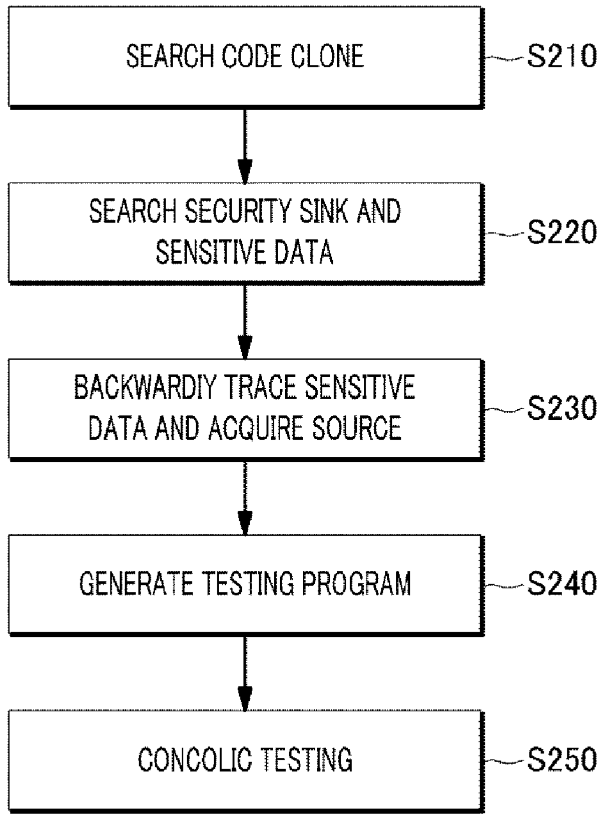

SEARCH CODE CLONE
S210
SEARCH SECURITY SINK AND SENSITIVE DATA
S220
BACKWARDIY TRACE SENSITIVE DATA AND ACQUIRE SOURCE
S230
GENERATE TESTING PROGRAM
S240
CONCOLIC TESTING
S250

FIG. 3

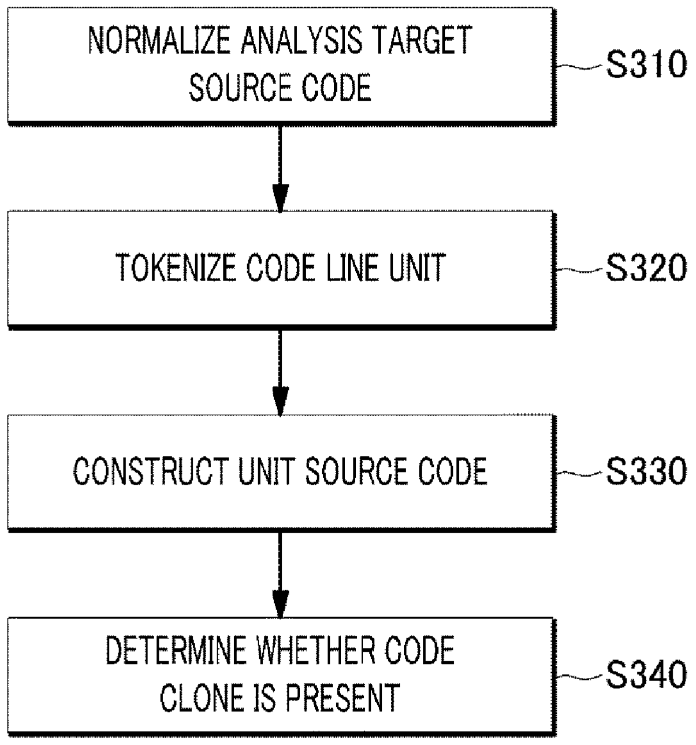

NORMALIZE ANALYSIS TARGET SOURCE CODE
S310
TOKENIZE CODE LINE UNIT
S320
CONSTRUCT UNIT SOURCE CODE
S330
DETERMINE WHETHER CODE CLONE IS PRESENT
S340

FIG. 4

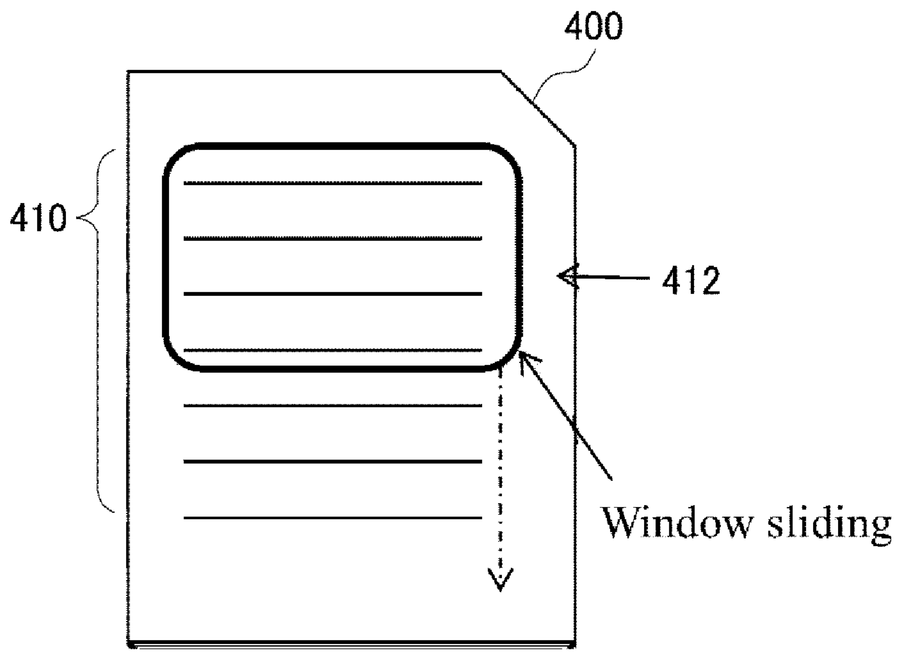


FIG. 5

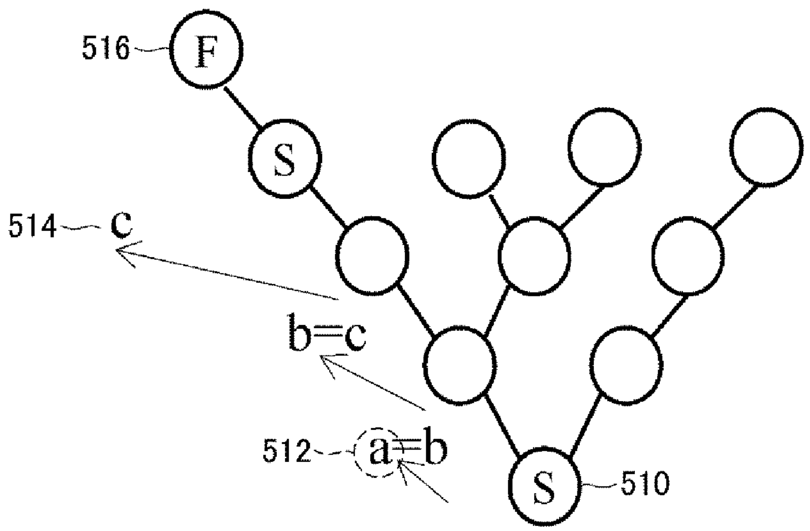
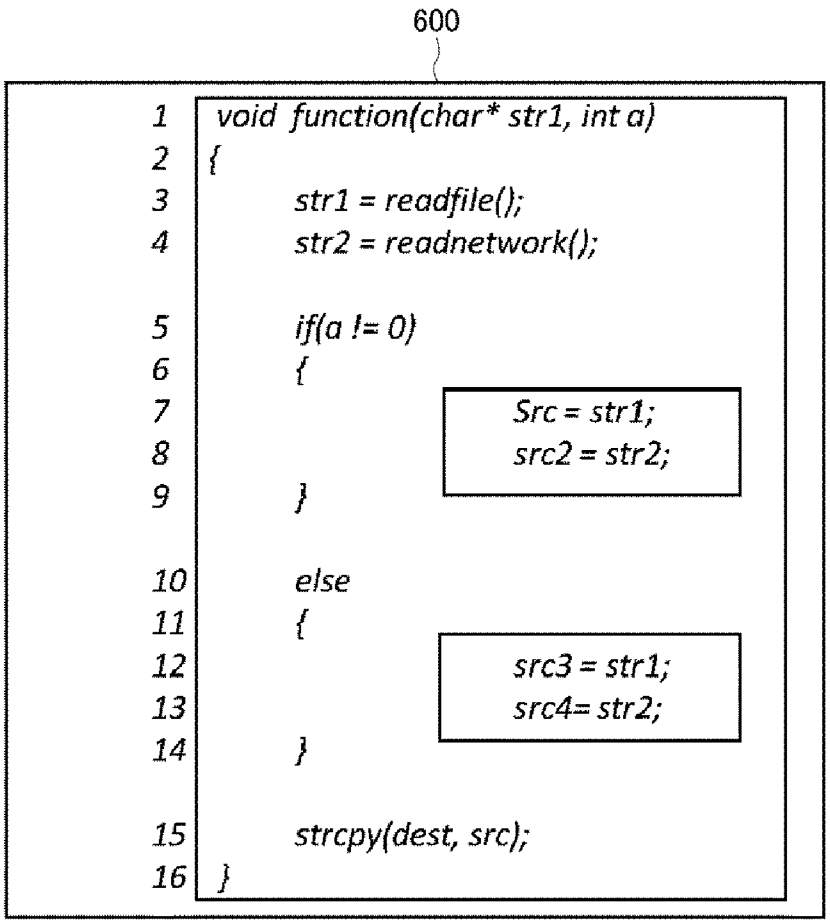


FIG. 6A



```
void  function(char* str1, int a)
{
        str1 = readfile();
        str2 = readnetwork();

        if(a != 0)
        {
                        Src = str1;
                        src2 = str2;
        }

        else
        {
                        src3 = str1;
                        src4= str2;
        }

        strcpy(dest, src);
 }
```

FIG. 6B

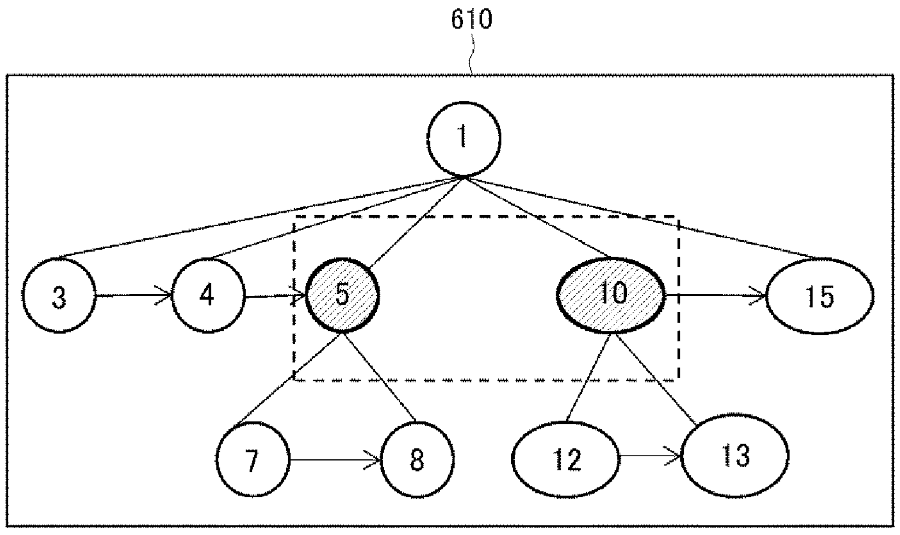
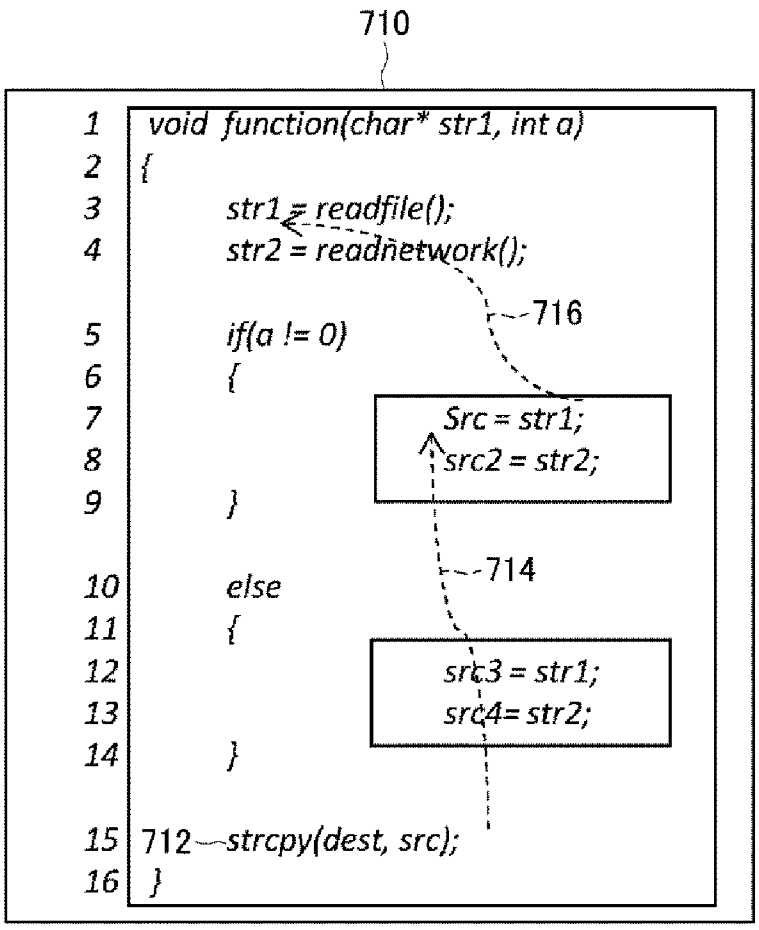


FIG. 7A



```
void  function(char* str1, int a)
{
        str1 = readfile();
        str2 = readnetwork();

        if(a != 0)
        {
                Src = str1;
                src2 = str2;
        }

        else
        {
                src3 = str1;
                src4= str2;
        }

        strcpy(dest, src);
}
```

FIG. 7B

720

```
Backward_Variable_Tracing(V, G){
                Ancestor = BackwardFindAncesotr(V,G);
                if(Ancestor IS NOT ROOT){
                    next_tracing_V = FindNextTracingVariable(Ancestor);
                    Backward_Variable_Tracing(next_tracing_V);
                }
                else{
                                Output(ROOT);
                }
}
BackwardFindAncestor(V,G){
   currentNode = getCurrentNode(V);
   while(1) {
         nextNode = BackwardTraverseCodeStructureGraph(currentNode,G);
         statement_case = CaseAnalyze(nextNode);
         switch(statement_case){
                         case 1:  return nextNode;
                         case 2:  return nextNode;
                         case 3:   return nextNode;
                         case 4:   return nextNode;
                         Default:
         }
         currentNode = nextNode;
    }
}
```

FIG. 8

SECURITY-SENSITIVE FUNCTION	SECURITY REQUIREMENT
strcpy(dst,src)	$dst.space > src.strlen$
strncpy(dst,src,n)	$(dst.space \geq n) \wedge (n \geq 0)$
strcat(dst,src)	$dst.space > dst.strln + src.strlen$
printf(format, ...)	$\#$ formats $= \#$ parameters-1

FIG. 9

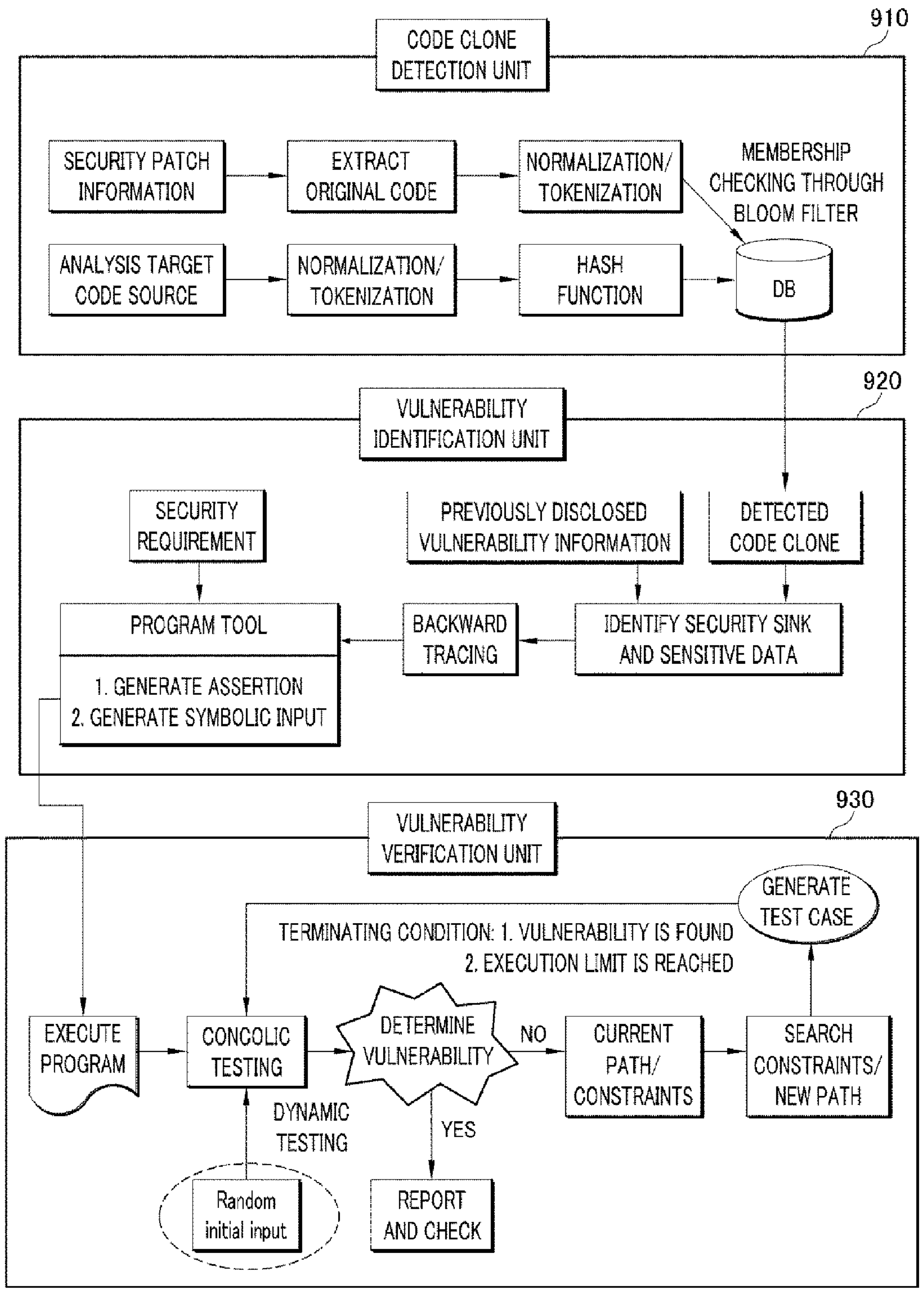

910
CODE CLONE DETECTION UNIT
SECURITY PATCH INFORMATION
EXTRACT ORIGINAL CODE
NORMALIZATION/ TOKENIZATION
MEMBERSHIP CHECKING THROUGH BLOOM FILTER
ANALYSIS TARGET CODE SOURCE
NORMALIZATION/ TOKENIZATION
HASH FUNCTION
DB
920
VULNERABILITY IDENTIFICATION UNIT
SECURITY REQUIREMENT
PREVIOUSLY DISCLOSED VULNERABILITY INFORMATION
DETECTED CODE CLONE
PROGRAM TOOL
1. GENERATE ASSERTION
2. GENERATE SYMBOLIC INPUT
BACKWARD TRACING
IDENTIFY SECURITY SINK AND SENSITIVE DATA
930
VULNERABILITY VERIFICATION UNIT
GENERATE TEST CASE
TERMINATING CONDITION: 1. VULNERABILITY IS FOUND
2. EXECUTION LIMIT IS REACHED
EXECUTE PROGRAM
CONCOLIC TESTING
DETERMINE VULNERABILITY
NO
CURRENT PATH/ CONSTRAINTS
SEARCH CONSTRAINTS/ NEW PATH
DYNAMIC TESTING
YES
Random initial input
REPORT AND CHECK

FIG. 10A

Target	CVE patches	Target src pool	# of files	# of reported code clones	Execution time
Src pool-1	CVE patch pool (2010-2014, for C code)	Ubuntu 14.04 OS distribution	259346	63	24812.5 sec (7 hours)
Src pool-2	CVE patch pool (2010-2014, for C code)	Httpd-2.2.23 to 2.4.6	7820	14	738.6 sec (12.31 min)
Src pool-3	CVE patch pool (2010-2014, for C code)	Rsyslog-5.8.13 to 8.2.1	1692	7	274.7 sec (4.57 min)

FIG. 10B

program	CVE patch	Location of the vulnerability
Cmake-2.8.12.2	CVE-2010-0405.patch	/Utilities/cmbzip2/decompress.c:381
Firefox-28.0+build2	CVE-2010-0405.patch	/modules/libbz2/src/decompress.c:381
Thunderbird-24.4.0+build1	CVE-2010-0405.patch	/plugins/pmrfc3164sd/pmrfc3164sd.c:381
rsyslog-7.4.4	CVE-2011-3200.patch	/plugins/pmrfc3164sd/pmrfc3164sd.c:272
gegl-0.2.0	CVE-2012-4433.patch	/operations/external/ppm-load.c:87
linux-3.13(Linux kernel)	CVE-2014-2581.patch	/net/ipv4/ping.c:250
httpd-2.4.7(Apache)	CVE-2011-3368.patch	/server/protocol.c:625

FIG. 10C

Version	# LOC	# of reported code clones	# of vulnerability found/verified	# of false positives
Httpd-2.2.23	350145	1	1	0
Httpd-2.2.24	350256	1	1	0
Httpd-2.3.6	209369	1	1	0
Httpd-2.3.8	210564	1	1	0
Httpd-2.3.11-beta	219427	1	1	0
Httpd-2.3.15-beta	226497	0	0	0
Httpd-2.4.1	223050	1	1	0
Httpd-2.4.2	223265	1	1	0
Httpd-2.4.3	223921	1	1	0
Httpd-2.4.4	226000	1	1	0
Httpd-2.4.6	233330	1	1	0

FIG. 10D

Version	# LOC	# of reported code clones	# of vulnerability found/verified	# of false positives
Rsyslog-5.8.13	78937	1	1	0
Rsyslog-5.10.0	78259	1	1	0
Rsyslog-5.10.1	77811	1	1	0
Rsyslog-6.6.0	92448	1	1	0
Rsyslog-7.4.0	105324	1	1	0
Rsyslog-7.6.3	111218	1	1	0
Rsyslog-8.2.1	112711	1	1	0

SOFTWARE VULNERABILITY ANALYSIS METHOD AND DEVICE

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit under 35 USC 119(a) of Korean Patent Application No. 10-2014-0190954 filed on Dec. 26, 2014, in the Korean Intellectual Property Office, the entire disclosures of which are incorporated herein by reference for all purposes.

BACKGROUND

Technical Field

The present disclosure relates to a software vulnerability analysis method and device.

Description of Related Art

According to a Symantec Internet Security Threat Report 2014, software vulnerability attacks are increasing every year. Particularly, 23 zero-day software vulnerabilities unknown before were newly discovered in 2013, which means a 61% increase over 2012. In Korea, attacks using software vulnerabilities are increasing day after day, and various attacks such as malicious code infections, DDoS attacks, personal information leakages, and the like have been reported.

Currently, in order to analyze and respond to software vulnerabilities, testing methods such as symbolic testing and fuzzy testing have been used. However, the conventional methods such as symbolic testing and fuzzy testing show poor performance in terms of analysis time and accuracy. Further, in order to use these methods, human resources with high level expertise and ample prior knowledge and practical experience are needed. Therefore, accessibility of these methods for analyzing software vulnerabilities is low.

Accordingly, under the current circumstances that a lot of new software is developed every day along with the growth of IT industry, a study on a method for increasing efficiency and accuracy in software vulnerability analysis and reducing time and resources required for the analysis is essential.

Meanwhile, Korean Patent Laid-open Publication No. 10-2014-0001951 (entitled "Intelligent code differencing using code clone detection) discloses systems and methods for intelligent code differencing employing code clone detection technology.

SUMMARY

The present disclosure provides a software vulnerability analysis method and device for analyzing software vulnerabilities after detecting a code clone. Notably, problems to be solved by the present disclosure are not limited to the above-described problems. There may be other problems to be solved by the present disclosure.

In some scenarios, the software vulnerability analysis method includes: searching a code clone corresponding to a used source code from any analysis target source code; detecting a security sink and sensitive data of the security sink on the basis of patch information in the searched code clone; acquiring a source code which is from the user input point to the security sink by backwardly tracing the sensitive data detected in the analysis target source code; and verifying whether the searched code clone is a vulnerability in the analysis target source code by performing a concolic testing on the basis of a path from the input point to the security sink.

In those or other scenarios, the software vulnerability analysis device includes: a memory in which a program for conducting vulnerability analysis on any analysis target source code is stored; and a processor configured to execute the program. Herein, when the program is executed, the processor searches a code clone corresponding to a used source code from the analysis target source code, detects a security sink and sensitive data of the security sink on the basis of patch information in the searched code clone, acquires a source code which is from the user input point to the security sink by backwardly tracing the sensitive data detected in the analysis target source code, and verifies whether the searched code clone is a vulnerability in the analysis target source code by performing a concolic testing on the basis of a path from the input point to the security sink.

According to any one of the above-described exemplary scenarios, a code clone corresponding to a used source code is searched from a large-scale analysis target source codes and the searched code clone is used for vulnerability analysis. Thus, it is possible to increase efficiency and rapidity in analyzing vulnerabilities of the large-scale target source code.

Further, according to the present disclosure, in order to acquire a source code corresponding to an input point which can be used by an attack, a backward tracing of a program path is performed on the basis of a security sink and sensitive data by using a code structure graph. Thus, it is possible to increase efficiency and accuracy in acquiring the source code which is from the input point to the security sink corresponding to the input point.

Furthermore, according to the present disclosure, a concolic testing is performed to the acquired input point which is from the user input point to the security sink to verify whether there is a vulnerability on the basis of security requirements. Thus, it is possible to determine whether the acquired source code is actually exploitable in an attack with high reliability. Therefore, as compared with the conventional static analysis methods, the present disclosure can reduce false positives. Further, the present disclosure can remove the restriction that the conventional concolic testing methods can be applied only to small-scale codes.

The foregoing summary is illustrative only and is not intended to be in any way limiting. In addition to the illustrative aspects, embodiments, and features described above, further aspects, embodiments, and features will become apparent by reference to the drawings and the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

In the detailed description that follows, embodiments are described as illustrations only since various changes and modifications will become apparent to those skilled in the art from the following detailed description. The use of the same reference numbers in different figures indicates similar or identical items.

FIG. **1** is a configuration view of a software vulnerability analysis device.

FIG. **2** is a flowchart showing a software vulnerability analysis method of an analysis device.

FIG. **3** is a flowchart showing a detailed process of searching a code clone illustrated in FIG. **2**.

FIG. **4** is a diagram provided to describe a unit source code.

FIG. **5** is a diagram provided to describe a backward tracing of a security sink and sensitive data.

FIG. **6**A and FIG. **6**B are diagrams provided to describe a code structure graph.

FIG. **7**A and FIG. **7**B are diagrams provided to describe an execution process of the code structure graph illustrated in FIG. **6**B.

FIG. **8** is a diagram provided to describe security requirements for generating a testing program.

FIG. **9** is a diagram illustrating a whole process of the software vulnerability analysis method proposed in the present disclosure.

FIGS. **10**A, **10**B, **10**C and **10**D are diagrams provided to describe a result of vulnerability analysis depend on the software vulnerability analysis method proposed in the present disclosure.

DETAILED DESCRIPTION

Hereinafter, embodiments of the present disclosure will be described in detail with reference to the accompanying drawings so that the present disclosure may be readily implemented by those skilled in the art. However, it is to be noted that the present disclosure is not limited to the embodiments but can be embodied in various other ways. In drawings, parts irrelevant to the description are omitted for the simplicity of explanation, and like reference numerals denote like parts through the whole document.

Through the whole document, the term "connected to" or "coupled to" that is used to designate a connection or coupling of one element to another element includes both a case that an element is "directly connected or coupled to" another element and a case that an element is "electronically connected or coupled to" another element via still another element. Further, it is to be understood that the term "comprises or includes" and/or "comprising or including" used in the document means that one or more other components, steps, operation and/or existence or addition of elements are not excluded in addition to the described components, steps, operation and/or elements unless context dictates otherwise and is not intended to preclude the possibility that one or more other features, numbers, steps, operations, components, parts, or combinations thereof may exist or may be added.

The following exemplary embodiments are provided only for understanding of the present disclosure but not intended to limit the right scope of the present disclosure. Therefore, the inventions that perform the same functions in the same scope as the present disclosure are also included in the right scope of the present invention.

A general software vulnerability analysis method is performed with respect to an overall flow of an analysis target source code. However, if the analysis target source code is large-scale software, it is difficult to understand the overall flow and there are a great number of cases for the analysis. Thus, it takes time and it is necessary to secure human resources with expertise.

However, a software vulnerability analysis method and device according to the present disclosure is a practical vulnerability analysis technique of priorly searching a portion (for example, a code clone) where vulnerabilities are actually highly likely to be generated rather than covering every portion of large-scale analysis target source codes and analyzing the searched portion by using vulnerability information previously disclosed.

Hereinafter, the software vulnerability analysis technique proposed in the present disclosure will be described in detail with reference to the accompanying drawings.

FIG. **1** is a configuration view of a software vulnerability analysis device **100**. The software vulnerability analysis device **100** may include a memory **110**, a processor **120**, a communication unit **130**, a vulnerability database **132**, a database **140**, and a display device **150**. However, the software vulnerability analysis device **100** illustrated in FIG. **1** is just an exemplary configuration of the present disclosure, and does not limit the present disclosure. That is the software vulnerability analysis device **100** may further include a user interface and thus may have a different configuration from that shown in FIG. **1**.

Further, the software vulnerability analysis device **100** may be implemented with various kinds of portable devices or computers. Herein, for example, the portable devices are wireless communication devices that ensure portability and mobility and may include all kinds of handheld-based wireless communication devices such as PCS (Personal Communication System), GSM (Global System for Mobile communications), PDC (Personal Digital Cellular), PHS (Personal Handyphone System), PDA (Personal Digital Assistant), IMT (International Mobile Telecommunication)-2000, CDMA (Code Division Multiple Access)-2000, W-CDMA (W-Code Division Multiple Access), WiBro (Wireless Broadband Internet) device, smart phone, and the like. Further, for example, the computers may include a notebook, a desktop, and a laptop, a tablet PC, and a slate PC equipped with a WEB browser.

The memory **110** illustrated in FIG. **1** may store a program (hereinafter, referred to as "vulnerability analysis program") for conducting vulnerability analysis on any analysis target source codes. The memory **110** stores the vulnerability analysis program therein. Further, the memory **110** may also store various programs in addition to the program. The memory **110** may be implemented with at least one of non-volatile memory such as cache, ROM (Read Only Memory), PROM (Programmable ROM), EPROM (Erasable Programmable ROM), EEPROM (Electrically Erasable Programmable ROM), and flash memory, volatile memory such as RAM (Random Access Memory), or a storage medium such as hard disk drive (HDD) and CD-ROM, but is not limited thereto.

The processor **120** may execute the vulnerability analysis program stored in the memory **110** and detect vulnerabilities from the vulnerability analysis program. While the processor **120** executes the vulnerability analysis program, the communication unit **130** may receive necessary information from the vulnerability database **132** and transfer the information to the processor **120**. Further, the communication unit **130** may communicate with external devices and other servers via a network.

The vulnerability database **132** may store source codes of an analysis target, original source code information before the analysis target is patched, patch information, and vulnerability information exploitable in an attack. Herein, the vulnerability database **132** may be an external database server connected to the software vulnerability analysis device **100** as illustrated in FIG. **1**, or may be a component of the software vulnerability analysis device **100** unlike the illustration in FIG. **1**.

The source codes of the analysis target may be source codes of the analysis target when being stored in the vulnerability database **132**. That is, if after the analysis target is patched, the source codes of the analysis target stored in the vulnerability database **132** may be source codes after the patch.

Original source codes of the analysis target refer to original source codes before analysis target source codes are patched. Herein, the original source codes of the analysis target may be stored in the vulnerability database **132** and directly provided to the processor **120** for vulnerability analysis. Further, codes of the analysis target may be extracted from an analysis target source code on the basis of patch history information stored in the vulnerability database **132**, and provided to the processor **120** for vulnerability analysis.

The patch information may include patch version information and patch history information. By way of example, the processor **120** may check whether the analysis target source codes are patched by using the patch version information and patch history information. In order to do so, the software vulnerability analysis device **100** may include a separate device configured to extract some information required for vulnerability analysis from the patch information, or a separate program used to extract some information required for vulnerability analysis from the stored patch information may be stored in the memory **110** and used by the processor **120** to extract some information required for vulnerability analysis from the patch information.

The vulnerability information may include already disclosed vulnerability information of the analysis target source codes. By way of example, the vulnerability information may be information used to compress and find a code clone having a vulnerability exploitable in an attack among detected code clones. The vulnerability information may be used as reference data for finding a source code of an input point of a security sink used by the processor **120** for detection of a security sink and sensitive data to be described later.

While the processor **120** searches a code clone, the database **140** may store a code clone searched through a bloom filter. Herein, the database **140** may store various other data required for code clone search in addition to the code clone. Further, the database **140** may be identical to the vulnerability database **132**. That is, the database **140** may store the source codes of the analysis target, code information before the analysis target is patched, patch information, and vulnerability information exploitable in an attack, which are stored in the vulnerability database **132**.

After the processor **120** generates a result of performing a concolic testing, the display device **150** may display the generated result of the concolic testing on a screen. Therefore, a user can see the concolic testing result (for example, false positive) as a result of code clone search through the display device **150**.

Hereinafter, a software vulnerability analysis method and the software vulnerability analysis device **100** will be described in detail with reference to FIG. **2** to FIG. **8**. FIG. **2** is a flowchart showing a software vulnerability analysis method of the software vulnerability analysis device **100**.

The analysis device **100** searches a code clone corresponding to a used source code from analysis target source codes (S**210**). Then, the analysis device **100** detects a security sink and sensitive data from the searched code clone (S**220**). The analysis device **100** acquires a source code corresponding to an input point by backwardly tracing the detected sensitive data (S**230**). The analysis device **100** generates a testing program on the basis of security requirements. Then, the analysis device **100** performs a concolic testing on the basis of the testing program (S**250**). To be specific, in order to detect a security sink and sensitive data (S**210**), the analysis device **100** searches a code clone corresponding to a used source code from any analysis target source codes.

In some scenarios, in order to detect a security sink and sensitive data, the analysis device **100** may directly compare analysis target source codes with original source codes of the analysis target source codes. Herein, the analysis target source codes and the original source codes of the analysis target source codes may be stored in the vulnerability database **132**.

According to those or other scenarios, in order to detect a security sink and sensitive data, the analysis device **100** may use original source does of an analysis target extracted using analysis target source codes and patch information. Herein, the analysis target source codes and the patch information may be provided from the vulnerability database **132**.

FIG. **3** is a flowchart showing a detailed process of searching a code clone illustrated in FIG. **2**. Referring to FIG. **3** in detail, in order to search a code clone (S**210**), the analysis device **100** may normalize the analysis target source code and a code of the analysis target (S**310**), tokenize the normalized source code (S**320**), construct a unit source code on the basis of the tokenized source code (S**330**), and determine a code clone using the unit source code (S**340**).

To be specific, firstly, the analysis device **100** may normalize the analysis target source codes and the original source codes of the analysis target (S**310**). By way of example, the analysis device **100** may normalize any analysis target source code by removing characters such as non-ASCII characters, redundant whitespaces, lower cases, and braces present in the analysis target source codes or original source codes of the analysis target. Then, the analysis device **100** may tokenize each of the normalized analysis target source codes and normalized original source codes into a line unit of source codes (S**310**). Then, the analysis device **100** may construct multiple unit source codes by grouping the tokenized analysis target source codes by a predetermined number of lines of source codes in sequence by a window sliding method (S**330**). By way of example, the analysis device **100** may construct multiple unit source codes by generating n-tokens on the basis of a window including n number of lines (tokens) and performing tokenization by overlapping a predetermined number of lines to slide the window.

FIG. **4** is a diagram provided to describe a unit source code. Referring to FIG. **4** in detail, the analysis device **100** may set a size of a single window in a tokenized token file **400** to a 4-token including four tokens. Further, the analysis device **100** may generate multiple unit source codes **412** formed of a 4-token by sliding the window while overlapping a previous window with each token.

That is, the analysis device **100** may generate x number of n-token unit source codes **412** by using window sliding including n number of tokens for a single window in a tokenized file $f(t_1, t_2, t_3, \ldots, t_l)$ generated by the tokenization (S**320**) and including l number of tokens in total. Herein, x, which is the number of the unit source codes **412**, may be represented by $x=l-n$ since the total length of the tokenized file is l and a length of the token included in the window is n. That is, the analysis device **100** may extract x number of n-token unit source codes from a file including l number of lines and construct a re-tokenized file $f(u_1, u_2, u_3, \ldots, u_x)$ with x number of unit sources in total.

Then, in order to determine a code clone, the analysis device **100** may determine a predetermined unit source code including the tokenized original source code among the multiple unit source codes as a unit source code including a code clone.

To be specific, the analysis device **100** may remove a line with a prefix "+" from the multiple unit source codes and add a line with a prefix "−" thereto. Further, the analysis device **100** may determine that if the multiple unit source codes from or to which a line is removed or added depending on a prefix are included in the tokenized analysis target original source codes, there is a code clone.

In other words, if a n-token file $f(u_1, u_2, u_3, \ldots, u_x)$ is present in a target source code pool and a predetermined unit source code f_v is present in the n-token file, the analysis device **100** may determine f_v as a code clone. Further, assuming that the unit source code f_v is one of unit source codes corresponding to $S=\{(u_1, u_2, u_3, \ldots, u_x\}$, in the case of $S_v \subseteq S$, the analysis device **100** may define that f_v is included in f.

Meanwhile, when comparing a large-scale analysis target source codes with a large-scale original source codes of the analysis target source codes, the analysis device **100** may use a bloom filter in order to quickly search a code clone. In this case, a hash function is generally used in the bloom filter.

The analysis device **100** may apply k number of independent hash functions (for example, $Hash(u_1)$, $Hash(u_2)$, . . . , $Hash(u_x)$) with a variable range of [1, m] on the n-token file of the analysis target source codes on the basis of the bloom filter. By way of example, in the case of a hash value h(x)=i, the analysis device **100** may set the i^{th} hashed bit value of a hashed bit vector to 1.

To detect a membership in the bloom filter, the analysis device **100** may apply k number of independent hash functions on a n-token data set. By way of example, the analysis device **100** may apply k number of hash functions on n-tokens from f_v.

Through the above-described process, the analysis device **100** may check whether all of bits relevant to a unit source code in the bloom filter are set to 1. In this case, if at least one of the hashed bits is 0, the analysis device **100** may determine that a code clone is not present.

The analysis device **100** determines whether a code clone is present in a unit source code (S**340**), ends the search for the code clone (S**210**), and searches a security sink and sensitive data (S**220**).

In order to search the security sink and the sensitive data (S**220**), the analysis device **100** may detect a security sink and all sensitive data relevant to the security sink on the basis of patch information within the searched code clone.

Herein, vulnerability information may be information received by the communication unit **130** of the analysis device **100** from the vulnerability database **132**. Further, the vulnerability information may include at least one of a source code already used for an attack of an attacker and a source code expected to be used for an attack of an attacker, and may be referred to for detecting the security sink and the sensitive data. In this case, the source code may include, for example, a function argument and function data.

Herein, the security sink may be a point where a function argument, which can be potentially used in a dangerous manner, is located in any analysis target source code. Further, the sensitive data refer to all relevant source code blocks including the security sink or all function arguments constituting the all relevant source code blocks.

By way of example, the security sink and the sensitive data may include function arguments and function data which can be used for memory copy, memory allocation, format string, and arithmetic operation.

To be specific, the security sink may be a point where a function argument used for memory copy is located in analysis target source codes. By way of example, a function used for memory copy may include strcpy and memcpy. This sensitive sink may cause serous security problems such as a buffer overflow when a relevant source code block (sensitive data) including the sensitive sink is maliciously used by an attacker.

Further, the security sink may be a point where a function argument used for memory allocation is located in analysis target source codes. By way of example, a function used for memory copy may include malloc and alloca. This sensitive sink may cause problems such as insufficient memory of a system when a source code block (sensitive data) including the point where the function argument for memory allocation is located is maliciously used by an attacker.

Furthermore, the security sink may be a point where a function argument used for format string is located in analysis target source codes. By way of example, a function used for format string may include printf and scanf. This sensitive sink may cause system control problems when a source code block (sensitive data) including the sensitive sink is maliciously used by an attacker.

Moreover, the security sink may be a point where a function argument used for arithmetic operation is located in analysis target source codes. By way of example, an argument used for arithmetic operation may an integer. This sensitive sink may cause integer overflow, integer underflow, or zero problems when a source code block (sensitive data) including the sensitive sink is maliciously used by an attacker.

In other words, in order to search the security sink and the sensitive data (S**220**), the analysis device **100** may detect a point (security sink) where a scour code function argument, which can be maliciously used by an attacker, is located and a source code block (sensitive data) including the function argument which can be maliciously used by an attacker.

Then, the analysis device **100** acquires a source (final function source) corresponding to an input point by backwardly tracing the sensitive data detected in the analysis target source code (S**230**).

A process for backward tracing sensitive data and acquiring a source code by the analysis device **100** will be described in detail with reference to FIG. **5** to FIG. **7**.

FIG. **5** is a diagram provided to describe a backward tracing of a security sink and sensitive data. Referring to FIG. **5**, the analysis device **100** may backwards trace an input point of a security sink by performing a backward tracing from a security sink "a" **510**. By way of example, the analysis device **100** may backwards trace a source code **516** corresponding to an input point "c" from the security sink "a" by performing a backward tracing of sensitive data "a" **510**→"b" **514**→"c" **514** in sequence.

The input point **516** may be a starting point of a final function relevant to the security sink and the sensitive data of the analysis target source code. Herein, the analysis device **100** may perform a backward tracing of the detected sensitive data by using a code structure graph (CSG) in order to acquire a source code corresponding to the input point **516**. The analysis device **100** may precedently define information about a source code execution sequence and information about parallel code blocks which are equivalent to each other but cannot be executed at the same time.

FIG. **6**A and FIG. **6**B are diagrams provided to describe a code structure graph. A sequence of executing a source code in any source code block **600** illustrated in FIG. **6**A can be seen from a code structure graph **610** illustrated in FIG. **6**B. As shown in FIG. **6**B, depend on the execution sequence of the source code **600** along a line No. for the source code illustrated in FIG. 6A, it can be seen that a first path is from "1"→"3"→"4"→"5"→"7" to "8" in sequence, a second path is from "1"→"10"→"12"→"13" to "15". Further, a line No. "5" and a line No. "10" may be parallel code blocks which cannot be executed at the same time. Therefore, a sequence of a backward tracing may be from "15"→"13"→"12"→"8"→"7"→"4"→"3" to "1".

FIG. 7A and FIG. 7B are diagrams provided to describe an execution process of the code structure graph illustrated in FIG. 6B. Referring to FIG. 7A in detail, an analysis target source code **710** shows a process for detecting an input point by performing a backward tracing of a source code block **714** including a high-level parameter relevant to a target to be actually copied in a source code and a source code block **716** including a second high-level parameter, from a security sink **712** using a string copy function argument.

Depend on a backward tracing code **720** performing such a backward tracing in FIG. 7B, the backward tracing code **720** uses a recursive function using a variable V indicative of a security sink and sensitive data and a code structure graph variable G. Further, the backward tracing code **720** repeatedly performs a process for finding a path (significant statement) for finding a source code of a final input point through a while loop.

Meanwhile, the analysis device **100** may generate a testing program for the path from the input point obtained through the process for backward tracing sensitive data and acquiring a source code (S**230**) and perform a concolic testing. In other words, the analysis device **100** performs a concolic testing on the basis of a path from an input point to a security sink and verifies whether a code clone searched by the concolic testing is included in a vulnerability in an analysis target source code.

In other words, the analysis device **100** may generate a testing program on the basis of a path expression of a source code path from the input point obtained by backwardly tracing the security sink and sensitive data in the detected code clone. Further, the analysis device **100** performs a concolic testing to the generated testing program through a dynamic testing in which a random initial input value is applied to each path.

By way of example, the analysis device **100** may extract a path from a security sink to a source code of an input point by inserting a probe. Herein, the path from the security sink to the input point may be a symbolic path formula. The symbolic path formula extracted as such enables determination whether a corresponding vulnerability is a vulnerability actually exploitable in an attack or a simple bug which causes a crash of a program.

Herein, the analysis device **100** may acquire a result of the concolic testing depend on a dynamic testing in which any initial value is input to the input point.

Further, the analysis device **100** may determine whether the result of the concolic testing satisfies a predefined security requirement to operate a statement of an analysis target source code as a significant operation command.

The security requirement may be relevant to at least one of predetermined security-sensitive function parameters, memory access, and integer arithmetic.

Herein, the security requirement may mean a condition which should be satisfied in a normal source code without a vulnerability. Therefore, the analysis device **100** may use the security requirement as a condition to determine whether the analysis target source code has a vulnerability.

FIG. **8** is a diagram provided to describe security requirements for generating a testing program. Referring to FIG. **8** in detail, requirements for the respective function parameters are shown.

By way of example, a security requirement for string copy functions (strcpy) **801** and (strncpy) **802** may be that a length of a string to be copied does not exceed a capacity of a buffer. A security requirement for a string manipulation function (strcat) **803** may be that a length of a string to be manipulated does not exceed a capacity of a buffer. A security requirement for a string output function (printf) **804** may be that a difference between the number of formats for a string and the number of parameters for a string format is uniformly 1.

The vulnerability analysis method and analysis device **100** described above make it possible to efficiently conduct vulnerability analysis high reliability.

Depend on any one of the above-described exemplary scenarios of the present disclosure, the vulnerability analysis method and analysis device **100** may search a code clone corresponding to a reused source code from a large-scale analysis target source codes and use the searched code clone for vulnerability analysis. Thus, the vulnerability analysis method and analysis device **100** can increase efficiency and rapidity in analyzing vulnerabilities of the large-scale analysis target source code.

Further, the vulnerability analysis method and analysis device **100** may perform a backward tracing of a program path on the basis of a security sink and sensitive data by using a code structure graph in order to acquire a source code corresponding to an input point which can be used by an attack. Thus, the vulnerability analysis method and analysis device **100** can increase efficiency and accuracy in acquiring the source code corresponding to the input point.

Furthermore, the vulnerability analysis method and analysis device **100** may perform a concolic testing to the acquired input point source code to verify whether there is a vulnerability on the basis of security requirements. Thus, the vulnerability analysis method and analysis device **100** can determine whether the input point source code is actually exploitable in an attack with high reliability.

Hereinafter, the analysis device **100** will be described more specifically with reference to an exemplary implemented configuration. However, it can be easily understood that the present disclosure is not limited thereto.

FIG. **9** is a diagram illustrating a whole process of the software vulnerability analysis method proposed in the present disclosure. The software vulnerability analysis device **100** may be implemented by the vulnerability analysis method as including a code clone detection unit **910**, a vulnerability identification unit **920**, and a vulnerability verification unit **930**.

The code clone detection unit **910** may detect a code clone by comparing a source code of an analysis target with an original source code of the analysis target. The original source code used herein may be directly provided from the vulnerability database **132** or extracted using patch information provided from the vulnerability database **132**.

Before detecting the code clone, the code clone detection unit **910** may perform a series of a normalization process and a tokenization process to each of the source code of the analysis target and the original source code of the analysis target.

The code clone detection unit **910** may reconstruct the normalized and tokenized source code of the analysis target into a hash function. Further, the code clone detection unit **910** may perform membership checking to the normalized and tokenized original source code through a bloom filter. Herein, the detected code clone may be stored in the separate database **140**.

The vulnerability identification unit **920** may perform a backward tracing by using vulnerability information stored in the vulnerability database **132** and provided to the analysis device **100** from the code clone detected by the code clone detection unit **910**. Further, the vulnerability identification unit **920** may acquire a source code corresponding to an input point on the basis of a security sink and sensitive data by performing the backward tracing.

Herein, the vulnerability identification unit **920** may backwards trace sensitive data detected by using a code structure graph. Further, the vulnerability identification unit **920** may acquire a path and sensitive data with respect to an input point obtained by performing the backward tracing.

The vulnerability verification unit **930** may verify whether the input point acquired by the vulnerability identification unit **920** is actually vulnerable. That is, the vulnerability verification unit **930** may perform a concolic testing to a path from the input point to the security sink and perform a dynamic testing applied with a random initial input. Herein, a security requirement may be used as a condition to determine whether there is a vulnerability.

As a result of the testing to the input point acquired by the vulnerability identification unit **920**, if it is determined that the input point has a vulnerability, the vulnerability verification unit **930** may report the vulnerability of the input point to a user through the display device **150** in the software vulnerability analysis device **100**. By way of example, the information reported to the user through the display device **150** may include used patch information, a list of detected code clones, the number of detected code clones, paths of detected code clones, and a false positive rate as a result of the concolic testing.

As a result of the testing to the input point, if it is determined that there is no vulnerability, the vulnerability verification unit **930** may repeat the testing until a terminating condition is satisfied. Herein, the terminating condition may include when a vulnerability is found from the input point or when a threshold determined by the user is reached. After the terminating condition is satisfied, if it is determined that the input point to which the testing is performed does not have a vulnerability, the vulnerability verification unit **930** may perform the testing to an input point determined as being next vulnerable.

FIG. **10**A to FIG. **10**D are diagrams provided to describe a result of vulnerability analysis depend on the software vulnerability analysis method proposed in the present disclosure. That is, FIG. **10**A to FIG. **10**D show types of information provided to a user through a display device in a software vulnerability analysis device.

FIG. **10**A is a diagram showing a detection result of a code clone. From FIG. **10**A, the user can see a program list ('target') to which vulnerability analysis is conducted, a patch list ('CVE patches') used for vulnerability detection, an analysis target source code pool ('target scr pool'), the number of files analyzed for vulnerability detection ('number of files'), the number of detected code clones ('number of reported code clones'), and time taken to detect a code clone ('execution time').

By way of example, detection result information may be provided in the form as shown in FIG. **10**B to the display device **150**. Referring to FIG. **10**B in detail, there is provided information about vulnerabilities actually exploitable in an attack among 63 code clones in 'Scr pool-1', which is a source code pool, from the program list to which vulnerability analysis is conducted. Further, information about each program list, a CVE patch in patch list of the program list, and a path in which each vulnerability is found can be seen from FIG. **10**B.

FIG. **10**C and FIG. **10**D are diagrams illustrating a result of a concolic testing applied with a backward tracing program and a dynamic testing. From FIG. **10**C and FIG. **10**D, the user can see a result of the concolic testing to a source code list of the analysis target to which vulnerability analysis is conducted. The user may check a false positive rate depend on whether the actually detected code clone actually has a vulnerability on the basis of the information provided herein.

The software vulnerability analysis method and analysis device **100** may search a code clone corresponding to a used source code from a large-scale analysis target source codes and use the searched code clone for vulnerability analysis. Thus, the vulnerability analysis method and analysis device **100** can increase efficiency and rapidity in analyzing vulnerabilities of the large-scale target source code.

Further, the software vulnerability analysis method and analysis device **100** may perform a backward tracing of a program path on the basis of a security sink and sensitive data by using a code structure graph in order to acquire a source code corresponding to an input point which can be used by an attack. Thus, the software vulnerability analysis method and analysis device **100** can increase efficiency and accuracy in acquiring the source code which is from the user input point to the security sink.

Furthermore, the software vulnerability analysis method and analysis device **100** may perform a concolic testing to the acquired input point which is from the user input point to the security sink to verify whether there is a vulnerability on the basis of security requirements. Thus, the software vulnerability analysis method and analysis device **100** can determine whether the acquired source code is actually exploitable in an attack with high reliability. Therefore, as compared with the conventional static analysis methods, the software vulnerability analysis method and analysis device **100** can reduce false positives. Further, the software vulnerability analysis method and analysis device **100** can remove the restriction that the conventional concolic testing methods can be applied only to small-scale codes.

The software vulnerability analysis method and analysis device **100** can be implemented in a storage medium including instruction codes executable by a computer or processor such as a program module executed by the computer or processor. A data structure in accordance with the illustrative configurations can be stored in the storage medium executable by the computer or processor. A computer readable medium can be any usable medium which can be accessed by the computer and includes all volatile/non-volatile and removable/non-removable media. Further, the computer readable medium may include all computer storage and communication media. The computer storage medium includes all volatile/non-volatile and removable/non-removable media embodied by a certain method or technology for storing information such as computer readable instruction code, a data structure, a program module or other data. The communication medium typically includes the computer readable instruction code, the data structure, the program module, or other data of a modulated data signal such as a carrier wave, or other transmission mechanism, and includes information transmission mediums.

The above description of the present disclosure is provided for the purpose of illustration, and it would be understood by those skilled in the art that various changes and modifications may be made without changing technical conception and essential features of the present disclosure. Thus, it is clear that the above-described embodiments are illustrative in all aspects and do not limit the present disclosure. For example, each component described to be of a single type can be implemented in a distributed manner. Likewise, components described to be distributed can be implemented in a combined manner.

The scope of the present disclosure is defined by the following claims rather than by the detailed description of the embodiment. It shall be understood that all modifications and embodiments conceived from the meaning and scope of the claims and their equivalents are included in the scope of the present disclosure.

We claim:

1. A software vulnerability analysis method in an analysis device, comprising:

searching a code clone corresponding to a used source code from any analysis target source code;

detecting a security sink and sensitive data of the security sink on the basis of patch information in the searched code clone after the searching;

acquiring a source code which is from a user input point to the security sink by backwardly tracing the sensitive data detected in the analysis target source code after the detecting; and

verifying whether the searched code clone is a vulnerability in the analysis target source code by performing a concolic testing on the basis of a path from the user input point to the security sink after the acquiring a source code;

wherein the searching a code clone comprises:

normalizing each of the analysis target source code and an original source code of the analysis target source code;

tokenizing the normalized analysis target source code and the normalized original source code into source code lines, respectively;

constructing multiple unit source codes by grouping the tokenized analysis target source code by a predetermined number of lines of source codes in sequence after the tokenizing; and

determining a predetermined unit source code including the tokenized original source code among the multiple unit source codes as a unit source code including the code clone after the constructing multiple unit source codes.

2. The software vulnerability analysis method of claim **1**, wherein the determining is performed using a bloom filter.

3. The software vulnerability analysis method of claim **1**, wherein the searching is performed by comparing the analysis target source code with an original source code of the analysis target source code.

4. The software vulnerability analysis method of claim **1**, wherein the searching is performed using the patch information.

5. The software vulnerability analysis method of claim **1**, wherein the acquiring a source code is performed by backwardly tracing the detected sensitive data on the basis of a code structure graph.

6. The software vulnerability analysis method of claim **1**, wherein the verifying comprises:

acquiring a result of the concolic testing by inputting any initial value to the input point; and

determining whether the result of the concolic testing acquired in the acquiring a result of the concolic testing satisfies a predefined security requirement to operate a statement of the analysis target source code as a significant operation command.

7. The software vulnerability analysis method of claim **6**, wherein the security requirement is relevant to at least one of predetermined function parameters, memory access, and integer arithmetic.

8. A software vulnerability analysis device comprising: a memory in which a program for conducting vulnerability analysis on any analysis target source code is stored; and a processor configured to execute the program, wherein when the program is executed, the processor searches a code clone corresponding to a used source code from the analysis target source code, detects a security sink and sensitive data of the security sink on the basis of patch information in the searched code clone, acquires a source code which is from a user input point to the security sink by backwardly tracing the sensitive data detected in the analysis target source code, and verifies whether the searched code clone is a vulnerability in the analysis target source code by performing a concolic testing on the basis of a path from the user input point to the security sink; wherein the processor searches the code clone by normalizing each of the analysis target source code and an original source code of the analysis target source code, tokenizing the normalized analysis target source code and the normalized original source code into source code lines, respectively, constructing multiple unit source codes by grouping the tokenized analysis target source code by a predetermined number of lines of source codes in sequence after the tokenizing; and determining a predetermined unit source code including the tokenized original source code among the multiple unit source codes as a unit source code including the code clone after the constructing multiple unit source codes.

9. The software vulnerability analysis device of claim **8**, wherein the processor searches the code clone using a bloom filter.

10. The software vulnerability analysis device of claim **8**, further comprising:

a display device,

wherein the processor displays a result of verifying whether the searched code clone is a vulnerability on the display device.

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