

Method for Partial Recovering Source Code of Telecommunication Devices for Vulnerability Search

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Abstract— The article describes a automated method for searching of low level and medium level vulnerabilities in machine code, which is based on its partial recovering. Vulnerability search is positioned in the field of telecommunication devices. Typical vulnerabilities in source code and algorithms for its search is given. There is forecast to develop methods and utilities in the near future.

Keywords— static analyzer, machine code, vulnerability, reverse-engineering, telecommunication devices

I. INTRODUCTION

Accidental and intentional errors that lead to vulnerabilities in software (hereinafter referred to as the SW) are one of the top challenges of the modern worlds that have taken the informatization path of development. Though the errors that have been made by hackers are seen less, they make the SW more unsafe, as long as such errors are the ultimate goal of the attackers. With view to the fact that critical information is usually shared via telecommunication devices, with the functional of such devices implemented with the help of the SW, the task of vulnerability search is one of the principal tasks of information security. This task is sophisticated and depends on an underdeveloped search methodology, which is defined via a set of methods used for such search. In this context, the efficiency of such methods is a function of purely practical application aspects, i.e. speed and complexity, and is now estimated as extremely unsatisfactory. Therefore, development of new and highly efficient methods for vulnerability search for telecommunication device SW is of theoretical (in terms of methodology) and, obviously, practical interest.

II. ANALYZING

In order to analyze available methods for SW vulnerability search, we would like to break such methods into the following groups by their application target.

Any methods that are applied exclusively to the SW source code fall into the first group and they are most abundant. Such methods are quite developed and are used very efficiently. A large base of typical source code vulnerabilities and methods for identification of such vulnerabilities has been collected. CppCheck, Lint and Cland may serve as implementation examples for the C/C++ code.

If the source code is not available, you will have to search for vulnerabilities using the final representation, i.e. machine code. Such methods form the second group and they usually rely on code disassembling and manual analysis by security experts (hereinafter referred to as the Expert). Individual implementations of such methods you may found in such products as Binary Static Analysis (SAST) by Veracode and Software Static Analysis Toolset by MALPAS. However, such methods have a different ultimate goal and may not be used as a comprehensive solution for the search of machine code vulnerabilities. However, a certain quantity of theoretical works, that are close to the solution of this problem still exists and is based on the use of the character programming [1].

It should be mentioned that the source code here means any code that must be compiled in a platform-dependent machine code for running such code – so called unmanaged code (e.g., C++, Pascal). A managed code (e.g. Java, C#) is an alternative and is compiled into an interim bytecode, which is then run on a virtual machine and is unambiguously converted into the source code. Availability and search for any vulnerabilities in the managed code are, obviously, a different task, which is less popular and more simple.

As long as a telecommunication device is usually supplied with the SW in the form of the machine code already installed on such device and one does not have any access to the source code, it seems so that the search for any vulnerabilities in the telecommunication device is done at the moment exclusively using manual techniques.

We should also mention a vast majority of telecommunication device models, modifications and SW versions leading to a tremendous number of various machine code images. And such machine code images may be of a rather big size – up to hundreds of megabytes. Also, it is obvious that each and every image must be analyzed "from scratch".

Thus and so, there is a critical task of search for vulnerabilities in the telecommunication device machine code in the above area of interest, and its solving efficiency is obviously not satisfactory. In this context, efficiency means a total number of vulnerabilities found in the machine code for a reasonable time, but not in the defined volume (i.e. vulnerability density). So, the manual technique would allow for identification of a larger number of vulnerabilities in small machine code volumes vs. any automated techniques.

However, application of such technique for any line of telecommunication device machine code will be so time-consuming in practice, even for a medium-sized volume, that the results will just not keep up with the release of new upgrades. Highly qualified Experts must also always be available for application of the manual technique, which is not always possible.

Design of a method and means of automated search for vulnerabilities in the machine code may be an obvious solution of the task, in which case involvement of human factor, especially highly qualified, will be minimized. Operational capability and vulnerability identification for large code volumes exactly for a small time at the expense of quality and density of the vulnerabilities found is the basic requirement to such method. However, the last factor is not critical, as long as you may always add any manual search methods, with the findings of the automated search simply facilitating such work.

The following available developments may be used as initial data for the task solution. First of all, as mentioned before, the development of methods for vulnerability search has allowed us to gather certain information about the vulnerabilities in the source code and search specifics. Second of all, the required vulnerability search may be implemented via conversion of the machine code of the device into the source code and application of the available search algorithms to such code. Therewith, any previous work of the authors [2] also touched this task directly, as long as it aimed at machine code algorithm recovery in the telecommunication device, which may be considered a partial source code recovery. Having combined such developments and with view to our goal, we hereby offer a solution of the task, which includes two major steps. We must systemize typical source code vulnerabilities and adapt such vulnerabilities to the machine code, i.e. select the vulnerabilities that may be found and identified in the machine code first. We must then develop a method for machine code vulnerability search (hereinafter referred to as the Method) based on the original recovery method for the algorithms and adapted vulnerabilities in the machine code. The Method offered is designed for searching two types of vulnerabilities, such as: low level vulnerabilities, e.g. errors in calculations, and partially medium level vulnerabilities, e.g. incorrect function algorithm operation, which is the most important peculiarity of this Method. In this case, the basic method of the authors [2] is suitable for full-sized search of medium level and high level vulnerabilities only; the last type corresponds to errors in the system architecture [3].

A. Adapted vulnerabilities in the machine code.

As long the vulnerability in the SW is basically an integral part of the SW contents (i.e. functional), any code presentation shape conversions may not affect vulnerability in any way, i.e. make it disappear or change significantly. Therefore, any source code vulnerability will be reflected in the machine code to some degree. However, due to any operations that reduce the program "structurization" (compilation,

assembling), the final presentation of the vulnerability may become "washed out", which may make it practically impossible to identify such vulnerability, even in cases of reversed engineering (disassembling, decompilation). Let us mark out the vulnerabilities that can be found in the source code, and are still integral in the machine code, which will be indicative of the potential ability of them being identified in the code. For this purpose there is a sufficient quantities of theoretical studies and practical implementations, for example, in the works [4] and [5].

1) Vulnerability – Dividing by 0: This vulnerability can be found in operations of dividing by 0, which should not occur in any correct programs at all. The reasons for such vulnerability may include missed check by zero value of denominators of expressions, and operational logic mistakes. Exclusion of division by zero will be called up as a result, which may lead to incorrect program exit. This vulnerability search algorithm is based on defining any possible variable value ranges, which are included in the expression with dividing and signalization of the possibility of the dominator equal to 0.

2) Vulnerability – Using a non-initialized variable: This vulnerability occurs during the first use of a variable that was not assigned any initial value. The reasons for such vulnerability may include any programmer's error, which usually includes missing initial value of the variable or assumption of such value equaling to 0 by default. As a result, the variable may take random values (so called 'garbage'), which will lead to incorrect calculations. The vulnerability search algorithm is based on determining locations of the initial variable assignment/use and signalization, if such use occurred before the assignment.

3) Vulnerability – Using a non-initialized variable: This vulnerability occurs due to no control over going out of the object stored in the buffer, which usually constitutes an array. Overwriting of the memory area, which is physically located out of the buffer (so-called buffer overflow), may occur and it may lead to writing off the contents of any other objects and change of the program code, or simply exclusion into the protected memory based on the record. The vulnerability search algorithm is based on detecting the buffer memory range, operation algorithms for the indexes of buffer objects, and possible values of such pointers, and signalization in case of index going out of the range [6].

4) Vulnerability – Handling incorrect memory pointers: This vulnerability can be found, while dereferencing of pointer containing incorrect memory paths. The reasons for such vulnerability may include errors in function operation algorithm or incorrect pointer initialization. Reading and writing using the pointer may be done on the area of the executed code as a result. Dereferencing of the 0x0th pointer is a special case. The vulnerability search algorithm is based on determining pointer values and dereference locations.

5) Vulnerability – Memory leaks: This vulnerability can be found in case of unlimited memory use. The reasons for such vulnerability may include missing required operations to free up the memory, in particular in case of cyclic execution. Memory shortage exclusion or write-off of the contents of used objects (due to incorrect stack handling) may occur as a result. Although such situation does not make the full-featured vulnerability, it may interrupt program operation in case of prolonged use, which typical just for the telecommunication device. Unfortunately, there is not any common vulnerability search algorithm available (as long as memory selection and freeing-up are phenomena that are defined exclusively within the program and program libraries). Nevertheless, manual algorithm set-up, such as obvious function and memory operation template determination will allow for identifying vulnerabilities of such type with the help of management flow graph analysis, including call-ups of such functions in the graph.

6) Vulnerability – Infinite loops and recursions: This vulnerability can be found in case of looping of function management flows or calling up the function as a result of incorrect program logics. Thus and so, the program may go, under certain circumstances, into a cycle that does not have any executable conditions for completion, or call up the same function indefinitely. This vulnerability can be identified by building complete management flow graphs and call-ups with further analysis of the conditions for simultaneous execution of their paths. It should be mentioned that the software of the telecommunication device often has an architecture, which consists of the single processing cycle for the incoming network packages, and such case must be processed separately.

7) Vulnerability – Unused code: This situation happens, if there are code areas in the programs with their instructions never to be run, and it corresponds to the destructured function algorithm structure. The reasons for such vulnerability may include errors in function algorithm operation, and a consequence of “rough” introduction of an alien code in the program. Although such situation does not make the full-featured vulnerability, it is indicative of an abnormality in the machine code, which is a potential vulnerability of the “bookmark” type.

B. Method for vulnerability search in the machine code.

As offered, the method for vulnerability search in the machine code must contain consecutive steps for source code recovery and vulnerability search using such code with the help of the existing algorithms. Although complete source code recovery (i.e. decompilation) is not practically possible, it may be recovered partially, which is a minimum requirement to search performance. Thus, for example, it is not crucially necessary to recover names of variables and points of return from the function in order to identify buffer overload vulnerability.

As mentioned before, a number of sub-tasks (algorithm recovery to be specific) were solved partially in the original method. Therefore, some steps of this method may be used in this Method. In particular, it is reasonable to use the IDA Pro product [7], which has the following functional. First of all, this product is a full-scale machine code disassemble for a large variety of processors. And second of all, this product performs a partial machine code recovery, as long as it divides memory areas into functions and data blocks, uses debugging information, if any in the machine code, and recognizes library functions by their signatures. It should be mentioned that crucial product specifics, such as interactivity and debugging capacity, may not be used for this Method in practice.

The rest of the Method relies on implementation of adapted machine code vulnerability search algorithms using the interim representation including output of any findings.

If we sum up the above, basic steps of the Method are:

1) Phase – Disassembling machine code: The machine code is converted to the assembler for disassembly and analysis. This step may be fully implemented based on the IDA Pro.

2) Phase – Recovering partially source code: The assembly code is disassembled, an internal program representation is built, necessary conversions are made, source code elements are assumed, and algorithms and other necessary information is recovered – this step and all further steps must be carried out using a specialized software application (hereinafter referred to as the Utility). It is obvious that SW analysis for a certain processor is not possible, unless its machine code is supported in the IDA Pro and FrontEnd of Utility (i.e. input parser) is available for its assembler. The basics code recovery is made using the IDA Pro immediately after the decompilation and it is reflected in the assembler, which is generated in Step 1. This step may be implemented in most part using algorithms based on the original machine code algorithm recovery method, as complemented by the algorithms gathering the information that is required for searching the adapted vulnerabilities. First of all, aliases must be supported, i.e. information about common code areas that are indicated by several different pointers or objects. Second of all, calculation of any possible value ranges, which are used in the object program, including pointers is required. Third of all, variable life time graphs must be plotted, including points of their first and last initialization / use.

3) Phase – Vulnerability search: Vulnerability search. Search for each of adapted vulnerabilities is made using the internal code presentation obtained. It is obvious that such presentation must not be a sophisticated text (usually used for SW development), but a set of specialized graphs, tables and structures determining program run. Such presentation will allow for more effective searching. Generalized search algorithms for each vulnerability have been provided earlier.

4) Phase – Gathering findings: Gathering findings. Machine code analysis findings are generated, i.e. information about the code (scope, number of functions), identified vulnerabilities or suspected locations of vulnerabilities etc. This processed SW code for the telecommunication device is especially characterized by its possible large size, various variations, and contents. Thus and so, this Method must be applicable multiple times with summarization of the findings obtained. Therefore, the presentation format of the vulnerabilities found must be suitable for program processing (i.e. its syntax must be strict) and for investigation by the Expert (i.e. human friendly). YAML [8] is a suitable presentation option for this task, which is characterized by such peculiarities as formalization and readability.

Diagram of Method steps and data used for such steps can be found in Figure 1.

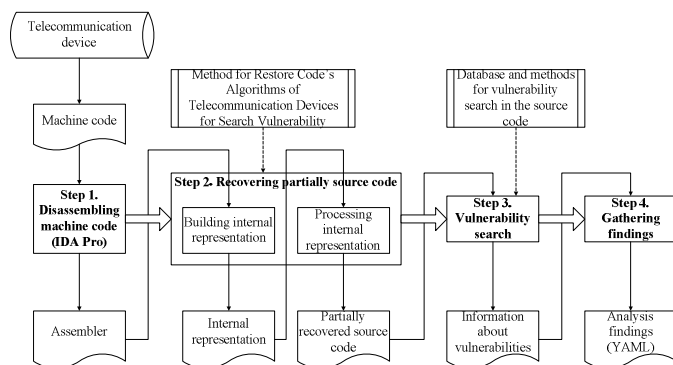


Figure 1. Method steps and used data

Note. The process of obtaining the telecommunication device firmware and reducing such firmware to the machine code is out of scope of this Method, as long as it is a separate and purely technical task that may be solved quite effectively.

III. EVALUATING THE METHOD

An imaginary experiment of application of individual steps of the offered Method on typical abstract machine codes, containing each of vulnerabilities in the original source code was done to study the specifics of such Method. We will get an unambiguous assembly code representation after the Step 1. This representation will also include vulnerabilities of all types, as long as IDA Pro converts binary processor instructions into text lines including operations unambiguously. The machine code does not usually include any debugging information, and, therefore, a partial code recovery in the Step 2 will be done without any source code meta information, such as function names and arguments. This does not appear to be rather significant; however, it may still affect the accuracy of our findings. To the contrary, machine code obfuscation could worsen recovery efficiency significantly, as long as it usually destroys the algorithm structure, albeit it is used quite rarely. Machine code optimization (source code compilation involving optimization options to be specific) is not applied to all SW types; in particular, it is not used often the telecommunication device. Various steganographic messages embedded in the executable

file, at this stage, will be lost; nevertheless, it is likely note rather than a disadvantage [9]. Efficiency of the Step 3 depends on the outcomes of the Step 2 completely, i.e. on the quality of the partially recovered source code. Therefore, assigning of some degree of reliability to the found vulnerabilities may be reasonable. This may prove useful for a semi-automatic application of the Method, i.e. including further analysis done by the Expert. Step 4 involves flow-by-flow output of vulnerability search findings in a special format and does not depend on the previous steps or analyzed machine code greatly. YAML does not have any application limitations. Therefore, any vulnerability details (if any) for each typical machine code will be gathered in one place and converted into the uniform base suitable for the manual analysis.

According to our imaginary experiment, application of the Method and its individual steps for vulnerability search in the telecommunication device machine code can be justified strictly and logically. The machine code for the processor supported by IDA Pro and Utility will be Method input, and a list of vulnerabilities in YAML will be Method output. Unsuitability for any obfuscated machine codes and average efficiency for any optimized code are among Method limitations.

IV. CONCLUSION

This methods aims at solving the most important task of machine code vulnerability search, which is critical specifically for the telecommunication device, as long as the SW of such device affects the security the information transferred. Application of the available developments in the area of vulnerability search by the source code as combined with the previous research of the authors [10] are the specifics of implementation of this method. Implementation of a software tool to operate the Method automatically and appropate such Method using existing telecommunication device SW will be the only next logical step and will allow to prove Method feasibility, in which case the theoretical value of the Method will be the development of the methodology of the highly popular machine code security area in terms of vulnerability search. Combination of the offered and previous original methods forms a methodological basis for search of vulnerabilities of all possible types in the machine code. Practical value of the Method is priceless, as long as identification of a vast number of machine code vulnerabilities for a tremendous number of existing telecommunication device firmware is foreseen upon automated application of such Method. Some of such vulnerabilities are still in action, which reduces significantly the overall security of information transferred via telecommunication networks.

ACKNOWLEDGMENT

In the end, we would like to express our gratitude to the Bonch-Bruевич Saint-Petersburg State University of Telecommunications for the possibility and support in development of the area of scientific studies, which was described in this and other articles.

The authors are thankful to their parents and Teachers for their craving for knowledge cultivated since their childhood and scientific achievements, which have been demonstrated multiple times using their own examples. First of all, to Evgeny Izrailov for development of source of H-beams for metrology and physical investigations. Second of all, to Vladimir Rosenberg for developing the special mathematical management support methodology.

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 2. M.V. Buinevich and others. Provision of organizational and technical support of stability of function and safety of general communications network./ Under the general editorship of S.M. Dotsenko.– Saint Petersburg: Publishing house SPbSUT, 2013.– 142 p.
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