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C Source Code Auto Review Tool for Secure Programming of Indian Spacecraft Ground Software Elements, GEOSCHEMACS

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Abstract: ***Secure software development involves practicing secure programming constructs and standards. To enable the software is developed with secure programming standards, secure static analysis play major role in finding out the hidden vulnerabilities in the source code. Secure static analysis tools yield significant reduction in runtime failures of the software. GEOSCHEMACS (Geostationary Earth Orbit SpaceCraft HEalth Monitoring, Analysis and Control Software) is Indian Spacecrafts primary ground software element and developed mostly based on C programming language. The aim of this paper was to discuss the development of software for auto reviewing of C source code. The paper highlights the necessity of a customized & proprietary tool in complying against CERT (Computer Emergency Response Team) C secure coding standard and enhancing the secure software development of GEOSCHEMACS. It brings out the design and test results of the tool.***

Keywords: Secure Static Analysis, GEOSCHEMACS, Ground Software, C Source Code.

1. Introduction

Practicing secure coding constructs and standards is one of the most important aspects in secure software development. Many software security vulnerabilities were caused by insecure coding practices and also inherent problems of the language. Static analysis review for secure programming practices can always make the software development more secure. GEOSCHEMACS is a software system of over fifty major components and near to one million lines of source code of various technologies. C has been the primary programming language used in the development. Other many technologies such as X/Motif, OpenGL, Java, HTML, and JavaScript have been also rendered in realizing various packages.

To ensure the development of GEOSCHEMACS more secure and to minimize the scope of inherent software vulnerabilities, various practices are being added. Introduction of a static analysis tool for secure programming constructs of C language is one among them. Software possessing the capability of reviewing the source code against some secure coding standard has been thought. CERT of SEI (Software Engineering Institute) has been the major secure coding standard for C. As part of the research titled "Secure Software Development for Indian Spacecraft Ground Software, GEOSCHEMACS", a comprehensive and integrated capability of reviewing C source code for secure coding standard has been envisaged.

This paper was aimed at bringing the details of the tool developed for automatic reviewing of C source code against CERT secure coding standards. It has been arranged into introduction, background, the tool, methodology, testing, results and conclusion sections. Background tries to introduce the concepts on secure programming constructs, GEOSCHEMACS, CERT C secure coding standard, C secure static analysis tools. The necessity of in-house development of auto reviewing of C source code has been well discussed in the section of 'The Tool'. Design of the tool was explained in the next section. Testing and results of the tool were listed in the corresponding sections.

2. Background

2.1 Secure Programming Constructs

In general, guidelines for secure coding can be listed as [3][4]:
1. Minimum code size
2. Less complexity in code
3. Separation of data and program control
4. Consistent and standard coding style
5. Assumption of all inputs as hostile
6. Secure concern integration of library modules
7. Application of minimum possible privilege for the minimal amount of time for the minimal processes
8. No sensitive data in source code
9. Avoiding of insecure library routines
10. Proper error handling and failing securely
11. Secure use of standard compilers and extensions
12. Nondeterministic random number usage and strong cryptography
13. Proper handling of multithread and multi process related inter process communication and other complexities
14. Avoiding incorrect use of pointers and links
15. Exception handling and proper process synchronization

measures
16. Avoiding common logic errors with reference to input validation, compiler checks, type checking, static checking
17. Avoiding buffer overflows and race conditions scenario
18. Secure file operations
19. Secure storage and encryption
20. Ensuring that all input meets specification
21. Safe initialization and Data sanitization
22. Proper handling of strings and formatted output
23. Following and Coding as per security guidelines & standards
24. Coding for reuse and maintainability
25. Allocation of memory more cautiously

2.2 GEOSCHEMACS

It is a set of software packages based on client server distributed computing architecture and is the primary tool for Indian spacecraft health monitoring, analysis and control.

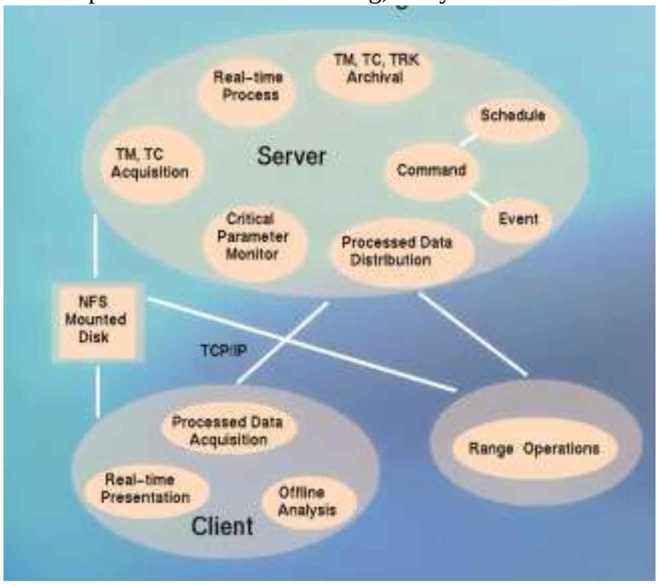


Figure 1: GEOSCHEMACS software architecture

2.3 CERT C Secure Coding Standard

The CERT C Secure Coding Standard [11] [12] provides rules and recommendations for secure coding in the C programming language. The goal of these rules and recommendations is to eliminate insecure coding practices and undefined behaviors that can lead to exploitable vulnerabilities [11] [12]. Coding practices are defined to be rules when all of the following conditions are met:
1. Violation of the coding practice will result in a security flaw that may result in an exploitable vulnerability.
2. There is an enumerable set of exceptional conditions (or no such conditions) in which violating the coding practice is necessary to ensure the correct behavior for the program.
3. Conformance to the coding practice can be verified.

Rules must be followed to claim compliance with this standard unless an exceptional condition exists. Compliance with recommendations is not necessary to claim compliance with this standard. The purpose of the secure coding standard is to promote software security [11] [12]. The secure coding standards proposed by CERT are based on documented standard language versions as defined by official or defacto standards organizations. Various categories that have been identified under this standard are related to Preprocessor (PRE), Declarations and initialization (DCL), Expressions (EXP), Integers (INT), Floating Point (FLP), Arrays (ARR), Characters and Strings (STR), Memory management (MEM), Formatted Input Output (FIO), Environment (ENV), Signals (SIG), Error-handling (ERR), Concurrency (CON), Miscellaneous (MSC) and POSIX (POS) [11][12].

2.4 C Secure Static Analysis Tools

Secure static analysis is the code reviewing technique for listing out the security vulnerabilities of the source. Since C is one of the legacy and prominent programming language having inherent problems, static analysis for secure programming constructs would always enhance the reliability of the software. Various open source static analysis tools such as RATS, ITS4, Flaw finder, Splint and many other commercial tools were used in reviewing the C source code.

Splint (Secure programming lint) is a tool for statistically checking C programs for security vulnerabilities and programming mistakes. Splint does many of the traditional lint checks including unused declarations, type mismatches, use before definition, unreachable code, ignored return values, execution paths with no return, likely infinite loops and fall through cases[13]. RATS (Rough Auditing Tool for Security) is a tool for scanning C, C++, Perl, PHP and Python source code and flagging common security related programming errors such as buffer overflows and TOCTOU (Time Of Check, Time Of Use) race conditions[14]. ITS4 (IT is Software Stupid Security Scanner) was developed for scanning vulnerabilities of C and C++ code [15][19]. Flaw finder is another open source static analysis tool which searches through C/C++ source code looking for potential security flaws [16].

3. The Tool

Usage of static analysis software for auto reviewing C source code has been one of the objectives towards secure GEOSCHEMACS. GEOSCHEMACS consists of major software components realized with C. To cover most of the legacy and upcoming C source code reviewed against certain secure coding standard, a suitable static analysis tool is required. C secure coding standard developed by CERT is most appropriate one for getting complied and reviewed against it.

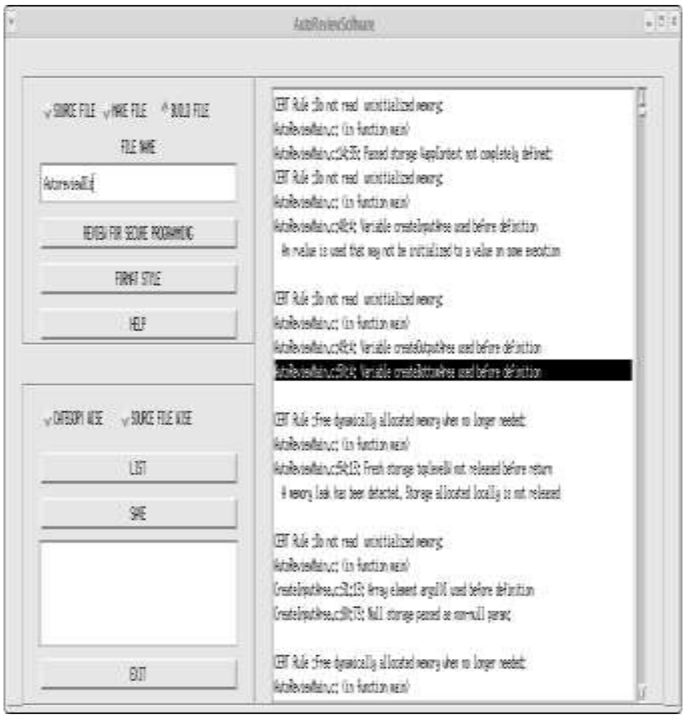
3.1 Why in-house developed software?

Many static analysis tools both of commercial and free categories are available for C source code analysis. Each of the tool has it’s own demerits. Open source C static secure vulnerability scanners such as Splint, ITS4, RATS, flaw finder were tested for the CERT C secure coding rules compliancy [1]. Test results show that Splint tool with around forty percent complied against secure coding rules has been the best among them with reference to different factors that have been considered in complying and reviewing the source code snippets of various embedded vulnerabilities [1].
The points favourable in selecting the option of in-house software for auto reviewing of C source code for CERT secure coding standard can be listed as:
1. No single open source security scanner could satisfy for CERT C secure coding standard rules [1]
2. In-house software would provide simple customization and user friendliness in giving a more permanent solution
3. No specific tool gives an integrated & comprehensive solution of C source code auto review

4. Too many ambiguities in finding / listing the vulnerabilities of the source by most of the tools in majority cases
5. Maintenance overhead of the open source tools
6. Economically not a good solution if a commercial tool is procured
7. An automatic review software for source code compliance to secure coding rules always saves time, helps in multiple times reviewing of the same source and enhances the software development process and the software quality[1]

3.2 Highlights of the auto review tool

1. GUI based software for auto reviewing of C source code.
2. Performs secure static analysis reviewing for the given source code file / make file / build file of the software.
3. Lists out all the vulnerabilities in source code with the corresponding suggestions for removing them
4. Reviews against CERT C secure coding standard.
5. Presents the listing of mistakes in designer friendly manner
6. Use of Splint open static analysis tool
7. Uses gcc compiler warnings and grep utility
8. Ensures the process of source code reviewing automated
9. Various software security vulnerabilities such as buffer overflows, invalidated input, race conditions, insecure file operations, access control problems etc… can be found out
10. Helps in building secure software



```
CERT Rule :Do not read uninitialized memory:
AutoReviewMain.c: (in function main)
AutoReviewMain.c:[illegible]: Passed storage AppContext not completely defined:
CERT Rule :Do not read uninitialized memory:
AutoReviewMain.c: (in function main)
AutoReviewMain.c:[illegible]: Variable createInputTree used before definition
  An rvalue is used that may not be initialized to a value on some execution

CERT Rule :Do not read uninitialized memory:
AutoReviewMain.c: (in function main)
AutoReviewMain.c:[illegible]: Variable createOutputTree used before definition
AutoReviewMain.c:[illegible]: Variable createBottomTree used before definition

CERT Rule :Free dynamically allocated memory when no longer needed:
AutoReviewMain.c: (in function main)
AutoReviewMain.c:[illegible]: Fresh storage toplevel[illegible] not released before return
  A memory leak has been detected. Storage allocated locally is not released

CERT Rule :Do not read uninitialized memory:
AutoReviewMain.c: (in function main)
CreateInputTree.c:[illegible]: Array element argv[0] used before definition
CreateInputTree.c:[illegible]: Null storage passed as non-null param:

CERT Rule :Free dynamically allocated memory when no longer needed:
AutoReviewMain.c: (in function main)
```

Figure 2: Main GUI of C source code auto review tool

This software system is for automatic code reviewing of any C source code against C secure programming standard (CERT C secure coding standard). It is based on X/Motif GUI and facilitates C source code of a make file or build file or single source file reviewed for CERT C secure coding rules.

4. Methodology

The criteria applied in designing the software for auto reviewing of C source code against CERT secure coding rules are
1. Usability
2. Maximum usage of the open source secure static tools
3. Minimum time of reviewing
4. Developer friendly presentation of the found out vulnerabilities
5. Minimum false positives
6. Targeting of zero false negatives
7. Possible Suggestions listed along with the flaws
8. Clear and unambiguous warnings listing with pointed line number, function and source file name
9. Ensuring of maximum extent source code compliance to CERT C secure coding standard
10. Facilitation of reviewing all the C source code of any software at a time

Different steps of the methodology are:
Step 1: Listing of all the secure coding rules against each category and for all the fifteen categories of CERT C secure coding standard [11][12].
Step 2: Identify probable patterns of messages or warnings listed by the tool Splint and the compiler gcc with –Wall flag for the violation of each secure coding rule under each category with source code snippets developed and stuffed with vulnerabilities for that secure coding rule.
Step 3: Apply the identified patterns or warnings of each secure coding rule to match the vulnerabilities / messages listed while reviewing the C source code of interest with Splint, gcc and 'grep' tools. List all the matched vulnerabilities with each one having the exact source code line and module of the corresponding source file, CERT secure coding rule that is being violated or to be complied.

Steps 1 and 2 are the presets for the step 3. Step 3 is actually the auto reviewing process against CERT C secure coding rules.

4.1 Algorithm

- Get input of either make file or build file of the software or any individual C source file. Ensure all the source files and include directory paths processed from the given input make or build file of the software.
- Check each and every source file is getting compiled. If any one source file could not be compiled, come out with appropriate error.
- Once all the source files are checked for compiling, apply splint tool for all these source files together. Every warning shall be checked for the match with reference to all CERT C secure coding standard rules corresponding listed patterns of step 2. If any pattern matches with the warning, display that vulnerability and with specific suggestions for removal.
- For each source of software, apply –Wall option with 'gcc' compiler to get the possible warnings. Resulting warnings shall be matched with the already listed patterns of gcc with the stuffed vulnerability source. If any message of the warning matches with the listed patterns, display the corresponding vulnerability and as well the possible remedy for the problem.
- Use 'UNO' tool [20] for checking the warnings related to array indexing error. UNO is any acronym for uninitialized variables, null-pointer dereferencing and out-of-bound array indexing [20].
- Use 'grep' tool for getting the unsolicited routines availability in the given C source. If any one of the unsolicited library routines used, display that vulnerability with the possible solution.

- Evaluate the source code verified against the insecure usage of signal handlers and signal processing. If any insecure programming issues with reference to signals were found, list them with the possible mitigation.

4.2 Implementation

As per the necessity, over 200 C source code applications stuffed with different vulnerabilities were collected. Each one of them attributes to violation of one of secure coding rules of one of the fifteen categories of CERT secure coding standard. These vulnerability stuffed source code snippets were reviewed with ‘splint’ tool and ‘gcc –Wall’. Patterns of the warning messages were gathered against each secure coding rule of every category of CERT C secure coding standard. Code snippets stuffed with array indexing vulnerabilities were analysed with ‘Uno’ tool also. Corresponding patterns of warning messages were taken for the usage of confirmation of array indexing related violations. ‘splint’, ‘gcc –Wall’ and ‘uno’ [20] were only considered [1] after testing all the open source static security vulnerability scanners mentioned in section 2.4. These three tools were included with reference to the capability of the tools in finding out the vulnerabilities of the C source code samples of stuffed vulnerabilities.

Table 1: Static analysis tools information

Tool name	*Version*
splint	3.1.0
uno	2.13
gcc -Wall	4.1.2

Table 2: Category wise C secure coding rules and vulnerability stuffed code samples

CERT C secure coding Category	*Number of C secure coding rules*	*Number of vulnerability stuffed code snippets*
Preprocessor	3	3
Declarations and initialization	8	19
Expressions	13	30
Integers	7	23
Floating Point	4	7
Arrays	6	18
Strings	6	17
Memory management	6	12
Formatted input output	13	21
Environment	5	8
Signals	4	6
Error handling	3	9
Concurrency	12	12
POSIX	17	17
Miscellaneous	7	8

As per the design and algorithm mentioned in section 4.1, software has been developed using C and X/Motif. The development operating system was RHEL (RedHat Enterprise Linux) 5.4 server version.

Properly indented and formatted source code would always help the secure static analysis or review. Source code beautified with certain indentation and formatting rules make the auto reviewing results understood easily & clearly. A feature of the nature of beautification of the source by the specified indenting & formatting rules has been included. Artistic Style (astyle) [17][18] is a free source code indenter, formatter and beautifier for C, C++, C# and Java programming languages. Artistic style software of 2.05 version (astyle 2.05) has been installed. The same has been used for beautifying the source code under review as per the developer’s optional selection.

Software was realized with a feature of interactive presentation of the found out vulnerabilities of the given C source code. Facility for reporting the summary to a file was also incorporated.

5. Testing and Results

Software has been realized by applying all types of testing at various levels including unit testing and as per the standard software process. Multiple source combinations such as individual C source file, individual C with X/Motif source, source code of the software through make file, source of the software through build file were reviewed for CERT C secure coding standard rules through this tool. Using this tool, various individual C source files and source files through make file or build file were beautified as per GEOSCHEMACS C source coding indentation, styling and formatting standards.

An instance of the result of automatic code review of an individual source file ‘CreateInputArea.c’ of this tool is as follows:

```
CERT Rule:Free dynamically allocated memory when no longer needed:
CreateInputArea.c: (in function reviewForBuildfile)
CreateInputArea.c:336:14: Fresh storage item not released before return
CreateInputArea.c:333:7: Fresh storage item created

CERT Rule :Do not read  uninitialized memory:
CreateInputArea.c: (in function reviewForBuildfile)
CreateInputArea.c:342:7: Buffer overflow possible with sprintf.  Recommend using snprintf instead: sprintf

CERT Rule :Guarantee that storage for strings has sufficient space for character data and the null terminator:
CreateInputArea.c: (in function reviewForBuildfile)
CreateInputArea.c:342:7: Buffer overflow possible with sprintf.  Recommend using snprintf instead: sprint

CERT Rule :Declare identifiers before using them:
CreateInputArea.c: (in function validateInputs)
CreateInputArea.c:476:13: Return value type int does not match declared type char

CERT Rule :Ensure that integer conversions do not result in lost or misinterpreted data:
CreateInputArea.c: (in function getSourceFilesFromBuildFile)
CreateInputArea.c:578:4: Assignment of int to char:
```

CERT rule: Instead of str(cpy/cat/cmp), use strn(cpy/cat/cmp with sufficient storage in dest. w.r.t the size of src + null char:
CreateInputArea.c:345:strcat(sysCmd, " -I");

Figure 3: Listed highlights for 'CreateInputArea.c' source file

For a build file (script for compiling multiple source files) of this auto review tool, called 'AutoreviewBld', some of the reported listings were as follows:

CERT Rule :Do not read uninitialized memory:
CreateInputArea.c: (in function reviewForMakefile)
CreateInputArea.c:221:34: Passed storage &noOfSrcDirs not completely defined:

CERT Rule :Do not read uninitialized memory:
ReportForMakeFile.c: (in function rptUnoForMakeFile)
ReportForMakeFile.c:234:7: Buffer overflow possible with sprintf. Recommend using snprintf instead: sprintf

CERT Rule :Guarantee that storage for strings has sufficient space for character data and the null terminator:
ReportForMakeFile.c: (in function rptUnoForMakeFile)
ReportForMakeFile.c:234:7: Buffer overflow possible with sprintf. Recommend using snprintf instead: sprintf

CERT Rule :Free dynamically allocated memory when no longer needed:
CreateInputArea.c: (in function reviewForMakefile)
CreateInputArea.c:294:14: Fresh storage item not released before return

CERT Rule :Ensure that integer conversions do not result in lost or misinterpreted data:
ReportForMakeFile.c: (in function rptFinalForSplintMakeFile)
ReportForMakeFile.c:551:68: Assignment of int to char: funcStrg = 1

Rule: Instead of str(cpy/cat/cmp), use strn(cpy/cat/cmp) with sufficient storage in dest. w.r.t the size of src + null char:
ReportForMakeFile.c:571:strcat(srcStr, tmpStr1);

Figure 4: Listed highlights for 'AutoreviewBld' build file

Through make file (makefile.tmacq) of the software which acquires spacecraft telemetry was reviewed with this tool. Few of the found out listed warnings are as follows:

CERT Rule :Guarantee that storage for strings has sufficient space for character data and the null terminator:
TmAcqLatest.c: (in function main)
TmAcqLatest.c:152:8: Buffer overflow possible with sprintf. Recommend using snprintf instead: sprint
CERT Rule :Do not read uninitialized memory:
TmAcqLatest.c: (in function main)
TmAcqLatest.c:244:8: Variable map_to_config used before definition. An rvalue is used that may not be initialized to a value on some execution

CERT Rule :Ensure that integer conversions do not result in lost or misinterpreted data:
TmAcqLatest.c: (in function main)
TmAcqLatest.c:293:8: Assignment of int to unsigned char:

CERT Rule :Do not read uninitialized memory:
TmAcqLatest.c: (in function main)
TmAcqLatest.c:300:26: Passed storage &err_i2 not completely defined:

CERT Rule :Ensure that integer conversions do not result in lost or misinterpreted data:
TmAcqLatest.c: (in function main)
TmAcqLatest.c:344:5: Assignment of int to char: TiuDataBreakL1[i] = 1

CERT Rule :Do not form or use out-of-bounds pointers or array subscripts:
TmAcqLatest.c: (in function main)
TmAcqLatest.c:534:44: Storage rfp[] may become null
TmAcqLatest.c: (in function write_into_port)

CERT Rule :Declare identifiers before using them:
TmAcqLatest.c: (in function map_to_config)
TmAcqLatest.c:802:10: Return value type int does not match declared type char:

CERT Rule :Ensure that control never reaches the end of a non-void function:
AcqEnvChk.c: In function 'AcqEnvChk'
AcqEnvChk.c:49: warning: control reaches end of non-void function

CERT Rule :Declare identifiers before using them:
AcqEvrTmacq.c: In function 'AcqEvrHand'
AcqEvrTmacq.c:40: warning: implicit declaration of function

CERT Rule :Declare identifiers before using them:
PostTypeOneFrame.c: In function 'postTypeOneFrame'
PostTypeOneFrame.c:233: warning: incompatible implicit declaration of built-in function 'exit'

Rule:Instead of str(cpy/cat/cmp), use strn(cpy/cat/cmp) with sufficient storage in dest. w.r.t the size of src + null char:
TmAcqLatest.c:756:strcpy (err_msg_c, "Invalid S/C id");

Figure 5: Listed highlights for 'makefile.tmacq' make file

Different combinations of testing results show that the purpose of the in-house developed tool for reviewing C source code against secure programming constructs as per CERT secure coding standard has been well met. The software has been put into usage for all the legacy software reviewing and also for the software being developed based on C language and X/Motif. However, the insecure programming related to concurrency was not handled in the present version of the software. Secure programming constructs with reference to concurrency and posix threads are yet to be incorporated in the tool.

6. Conclusions

The software for auto reviewing C source code against CERT secure coding standard rules was helpful in building secure software. Static analysis tool for secure programming constructs reviewing has been vital in removing vulnerabilities of the source code. An in-house tool based on X/Motif GUI for automatic review of the C source code of the given software with the corresponding input of make file or build file or source file has been developed. The tool was very much embedded into the secure software development of GEOSCHEMACS. The tool could give the developers to review the C source code and list the hidden vulnerabilities along with the possible suggestions. This software facilitates the developers to comply C code against the CERT C secure coding standard. It helped to have a better and most near estimation of the quality of C based software.

Since majority of the software components developed in C, GEOSCHEMACS software process can be enhanced with the inclusion of this auto review tool and for resulting secure software. The results were very encouraging since very low percentage of false positives and no false negatives. The induction of the tool would always cut the review and testing time sharply. It plays major role in building more confidence in the software. However, auto review of the C source code can't be a remedy for all the problems associated in the source. With an established software process and application of good coding standards, the tool can become most effective.

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